A FLEXIBLE OBJECT ORIENTATED DESIGN APPROACH FOR THE REALISATION OF ASSISTIVE TECHNOLOGY

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Abstract

This thesis contributes to a growing body of research conducted by the Interactive Systems Research Group (ISRG) at Nottingham Trent University within the fields of accessibility and accessible technologies. Core to this research is the exploration of how interactive technologies can be developed and applied as platforms for education, rehabilitation and social inclusion. To this end the group has been actively evolving the User Sensitive and Inclusive Design (USID) methodology for the design, development and evaluation of accessible software and related technologies. This thesis contributes to the further development of the USID method with a focus on its application for the design of assistive technology.

Video Games are increasingly being recognised as an important resource for the development and improvement of the quality of life of those with a disability and/or impairment. Creating universally accessible games and related technologies is however no simple feat. Review of literature quickly highlights that the predominant barrier to the adoption of console gaming and also video gaming in general, by those with a disability or impairment, is that of the human-machine hardware interface.

Drawing on both previous studies of the ISRG and the current innovations within the video gaming arena, this body of research aims to address four main objectives to:

1. Evaluate gaming interface controllers with regard to how well they support interaction for users with disabilities and impairments.
2. Investigate the paradigm of the Natural User Interface with regard to how well it can support the development of interaction for users with disabilities and impairments.
3. Enhance the practice of User Sensitive and Inclusive Design (USID) as conducted by the Interactive Systems Research Group for the development of accessible technology.
4. Examine the methods for involvement of users with disabilities in the design process and how this could be improved (using a product design approach).

The thesis demonstrates how each of the objectives has been achieved via the development of a complimentary approach to the practice of USID, Flexible Object Orientated Design. The validity of this approach is proven via the application of three design studies, each formulated to reflect the mapping of existent abilities and skills as a platform for the definition of input modality, and thus also the emerging philosophy of the Natural User Interface.

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Chapter 1: Introduction

Video Gaming and the Disabled

Video Games are increasingly being recognised as an important resource for the development and improvement of the quality of life of those with disability and/or impairment (Abbott, Brown, Evett, Standen & Wright, 2011; Rizzo A. A., 2008). As the awareness of this idea has grown, many themes of research have arisen to face the human interactional challenges presented by this new and exciting medium. By way of result, a wealth of research and literature has developed, indicating both the benefit and advantage of utilising games and gaming related technologies for education and rehabilitation (e.g. Standen, Cromby & Brown, 1998; Johannesson & Backlund, 2007; Deutsch, Borbely, Filler, Huhn & Guarrera-Bowlby, 2008; Rizzo, Reger, Gahm, Difede & Rothbaum, 2009; Brown, Standen, Evett & Battersby, 2010).

Creating universally accessible games and related technologies is however no simple feat, and until recently has simply not been on the agenda of many publishers and developers (see IGDA, 2004; Forrester Research Inc., 2004). Historically the video games industry had either not considered the significant role accessibility could play in market demographic expansion (see Boztepe, 2007; Kim & Mauborgne, 2005) or incorrectly determined, via use of tools such as cost benefit analysis, that the attention and investment in accessibility was not economically viable in terms of return (Forrester Research Inc., 2004). However as those playing video games have become increasingly diverse, market forces have driven game developers to make games more accessible.

Despite this subtle but growing shift, the impact of disability related demographics within the console gaming market is (unlike its counterpart the gaming market) still found to be extremely limited. This is despite overwhelming evidence that as society ages, an ever increasing volume of players will fall within the categories of disability and impairment (see Forrester Research Inc, 2004; European Commission, 2003; Eurostat, 2008). An analysis of literature quickly highlights that the predominant barrier to the adoption of console gaming and also video gaming in general, is that of the human-machine hardware interface (see Ellis, 2006; Iacopetti, Fanucci, Roncella, Giusti & Scebba, 2008).

All video games systems, be they games consoles or personal computers, have a primary interaction paradigm built around accompanying peripheral hardware. In terms of the personal computer, interface has been traditionally defined around the use of keyboard and mouse, whilst games consoles commonly use a joystick and button. For a long-time, accessible human interface technologies have been primarily nothing more than bridging solutions between the input paradigms dictated by the operating system and traditional modes of input for such platforms.[1] However as we approach a post desktop era we are also beginning to see a shift in the traditional paradigms for the human computer interface.

Current State of the Art

In his pioneering research that ultimately acts to define field of Ubiquitous Computing, Weiser describes a vision of our future infused with technologies (see Weiser M., The Computer for the Twenty-First Century, 1991; Weiser M., 1993). He details this infusion as a by-product of the age of distributed computing, and as a natural response to our increasing reliance on "interconnectedness" (Weiser & Brown, 1996). As we begin to into the post desktop era, the key aspect of Weiser's vision, and our relationships with technology, is becoming of greater importance. Within human computing interaction for example, focus is indeed beginning to shift to how computers can support human-to-human concerns (e.g. Abbott, Brown, Evett, Standen & Wright, 2011; Harper, Rodden, Rodgers & Sellen, 2008; BS EN ISO 9241-210:2010).

The transition to post desktop computing is changing the very definition of our personal and social environments and even the structure of our societies (see Forge, Blackman, Bohlin & Cave, 2009). However, such a shift is also ushering in new concerns of digital discrimination (see Vicente & Lopez, 2010; Hargittai, 2003). Just as technologies can amplify our abilities and potential, the same technologies can also act to impede and restrict us. As we become ever more interconnected there is a need to ensure the equal access to electronic information and services. This issue has become an important area of concern for persons with disabilities and or impairments, as quite often such demographics are determined as outlier groups within the target and application of digital products (see Goggin & Newell, 2007; Tomoko, 2003).

As an industry, video gaming has now become a prominent driver for technological advancement (see Kessler, 2011) and is found to be at the forefront of the transition to post desktop computing. By way of result the innovations within the field are acting to spearhead the transition towards new paradigms for human machine interaction, and are gaining popularity under the banner of the 'Natural User Interface.'

Research Background

This thesis contributes to a growing body of research conducted by the Interactive Systems Research Group (Nottingham Trent University) within the fields of accessibility and accessible technologies.

[1] In early works by Brown for example (Brown, Kerr, & Crosier, 1997) the researches state that the use of tablets failed in terms of drag and drop. This example demonstrates how a hardware interface was mapped directly to the existing interface paradigm.

Core to this research is the exploration of how interactive technologies can be developed and applied as platforms for education, rehabilitation and social inclusion. To this end, and since its formation in 1998, the group has been actively evolving the User Sensitive and Inclusive Design (USID) methodology for the design, development and evaluation of accessible software and related technology. This thesis contributes to the further development of the USID method with a focus on its application for the design of assistive technology. Whilst USID is a proven and effective methodology for the development of virtual and software based products and systems (e.g. Standen, Shopland & Brown, 2010; Brown D. , Shopland, Battersby, Tully & Richardson, 2009; Brown, Shopland & Lewis, 2005; Battersby, Kelly, Brown & Powell, 2002), weaknesses in this approach have been identified in respect to its performance when applied to the design of physical real world technology. Evidence of this can be found within ISRG publications under the themes of assistive technology (e.g. Lannen T., 2002; Ducat, 2002; Standen P., Brown, Anderton & Battersby, 2003; Brown D., Battersby, Standen & Anderton, 2005; Brown D. J., Battersby, Standen, Anderton & Harrison, 2011). These studies detail that the fact that despite the application of user-centric design practice the resulting developed hardware design solutions often fail to meet their performance expectations.

Over the last decade the ISRG have developed numerous assistive technologies whose application spans a wide range of target disabilities and impairments. These projects include:

1. The Lannen Joystick Study – Design of a two handed input peripheral for those with limited motor skills and intellectual disability.
2. The EPSRC Joystick Study – Design of a joystick type peripheral for those with limited motor skills and intellectual disability.
3. The Portland Switch Study – Design of a wireless assistive switch for those with severe physical disability and cognitive impairment.
4. The Virtual White Cane – Design of a system for interface within 3D virtual space for those with visual impairment.
5. The Nunchuk Switch – Design adaptation of contemporary gaming technology for the provision of switch-based interface for those with severe physical disability.
6. The Stroke Rehabilitation Glove – Design of a system to facilitate upper limb rehabilitation for survivors of stroke

With the exception of the Lannen Joystick Study (Lannen T., 2002) each set of studies has been conducted by a specialised multidisciplinary team, specifically assembled to guide the project's bespoke design and evaluation processes. Each member of this specialised multidisciplinary team has some specialised knowledge or expertise of the target demographic that can help in a unique way in the design process (e.g. The Department of Ageing and Rehabilitation, Nottingham University in Intellectual Disability and Evaluation Methods; The Portland College[2] in Physical Disability; The Oakfield School[3] in Intellectual Disability and Communication Techniques).

An analysis of these studies (the latter three of which are included within this thesis), has demonstrated the need for a supplementary and more "designerly" based approach be developed for the application of USID in a physical, real world technology context. The evaluation of design literature and the experience gained by the author in a design role within two of these studies (the EPSRC Joystick Study and the Portland Switch Study) resulted in the conclusion that within Human Computing Interaction user centred design is the design process, whereas within Industrial and Product Design user centred design is a tenet of the design process, and there are other tenets, materials, tools and principles that could also benefit the design process.

Assistive Technology & Design for All

The frame of reference for this research is the design of accessible and/or assistive technology. In a generic sense assistive technologies are those which increase, improve, or maintain the functional capabilities of those with disabilities and or impairments. There a numerous definitions for assistive technology, all of which cover a range of products and services. For the purpose of this research, the definition provided by the 108th Congress has been determined as being most appropriate:

> *"…any item, piece of equipment, or product system, whether acquired commercially, modified, or customized, that is used to increase, maintain, or improve functional capabilities of individuals with disabilities. 108th Congress, 2004"*

However, in the context of this research, additional definitions are needed to further define assistive technology specifically within the context of Information Communication Technologies (ICT) based products.

As a theme of research within the fields of Human Computing Interaction (HCI), information technology related assistive technology has developed as a complimentary approach to the philosophy of 'Design for All'. In this context 'Design for All' is the positive effort to apply principles, methods and tools to promote the ethos of 'Universal Design' in computer related technologies and services (Stephanidis, 2001).

[2] The Portland College is a national college for people with a wide range of disabilities.
[3] The Oakfield School are a local authority community school providing for pupils and students aged 3-19 with severe, profound and complex, physical and learning disabilities.

Newell & Gregor state that Design for All should not be perceived as an effort to foster a "*one size fits all*" design, but rather the adoption of user-centred practice to as a means of developing products that address the greatest range of human abilities, skills, requirements and preferences (Newell & Gregor, 2000). Ideally all products and services should be accessible to 100% of the population (Design for All or Universal Design), but this is not a realistic goal. This is due to factors such as diversity of user characteristics and personal and situational demands. Therefore a complementary approach is needed, and this is assistive technology.

Figure 1: Methods for "Reducing the Gap" between Human Abilities and the demand of Products (ICTSB Project Team, 2000)

In this context, accessible and/or assistive technology focuses on the development of special interfaces and devices that can bridge the gap (Figure 1) between demands from products, the environment and the users' abilities (ICTSB Project Team, 2000).

Research Objectives

Drawing on both previous studies of the ISRG and the current innovations within the video gaming field, this body of research has been constructed around four main objectives:

5. Evaluate gaming interface controllers with regard to how well they support interaction for users with disabilities and impairment.
6. Investigate the paradigm of the Natural User Interface with regard to how well it can support the development of interaction for users with disabilities and impairment.
7. Enhance the practice of User Sensitive and Inclusive Design as conducted by the Interactive Systems Research Group for the development of accessible technology.
8. Examine the methods for involvement of users with disabilities in the design process and how this could be improved (using a product design approach).

Each objective has been established in order to investigate the potential of contemporary video gaming systems as platforms for the distribution of materials created for both the development and improvement of "the" life experience for those with disability and or impairment.

Video gaming as an industry has evolved to be a driving force behind technological innovation (platforms, ubiquitous computing, interaction technologies, and affordability) and thus the way we interact with our environments, in a similar way that the Second World War drove scientific and technological innovation.

An Overview of the Thesis

The following section details a summary of the thesis.

Chapter One: Introduction

The thesis opens with an introduction detailing how video game technology is being applied as an important resource for the development and improvement of the quality of life of those with a disability and or impairment. The section demonstrates how this idea has grown; many areas of research have arisen to face the challenges presented by an ageing society and the opportunities afforded by this new and exciting medium to address these challenges.

The research of the Interactive Systems Research Group (ISRG, Nottingham Trent University), who are investigating the application of contemporary gaming technologies as platforms for the development of accessible technology is then reviewed. A summary of related work produced by the ISRG is presented and utilising these studies as points of reference, User Sensitive Inclusive Design (USID) is then introduced as a current and relevant design practice for the design and development of accessible technologies. .

Indication is made towards the current changes affecting the practice of human computing interaction; the employment of multidisciplinary approaches for the development of human-computer interface and the shift in the traditional paradigms for human-computer interface. The aims and objectives of the research are then introduced in respect to both the previous studies of the ISRG and this shift in paradigm. These aims and objectives are established to address the overarching issues of developing accessible technologies for those with disability and impairment and the enhancement of the design practice within the ISRG.

The chapter concludes with an overview of the thesis.

Chapter Two: Background/Literature

The investigation of literature commences with the classification of need for accessible and/or assistive technologies. To this end a growing volume of evidence is presented that we live in an ageing society with an accompanying increase in requirement for technology to be both accessible and assistive in nature. Such technologies should ensure the users' capabilities for independent living over an expanding time period, and also act to maintain and improve quality of life, integration and independence.

Research on videogames is reviewed in the light of both general and disabled gaming audiences. Review of these studies allows the description of the characteristics of video games that make them ideal educational and entertainment media for people with a disability and/or impairment. Video gaming is also identified as an important and widespread activity, both as a means of entertainment and for social interaction. Pockets of related research are then highlighted, which specifically focus on the development of assistive and/or accessible technology via application of user-centric methods. It is identified that assistive technology research and development spans many disciplines, however a core focus can be found within the fields of Human Computing Interaction and Industrial Design. A selected summary of assistive technology research is then presented with focus on the studies conducted by the ISRG. It is concluded that current ISRG practice is primarily focussed around the practice of user centred design.

Review of the principles of user-centred design is then presented to allow comparison of the structure of USID with that of equivalent design practices applied by others. The identification of variance and reported success and failure within these studies and approaches is then drawn to form a basis for determining both strengths and weakness within current design practices.

This knowledge is then used to formulate the basis for the enhancement of existing user sensitive design practices and as means of addressing the thesis' objectives.

The chapter then draws to a close with a discussion of the reviewed literature. Each area of investigation is summarised and the important issues are highlighted. A critical view of current practice is presented and using the holistic knowledge gained, the chapter concludes with the presentation of several research questions, each drafted to provide both guidance and structure needed to meet the objectives as outlined in chapter one.

Chapter Three: Methodology and Design Approach

Using the derived research questions as a basis, this chapter opens with a plan for fulfilling the research objectives. Utilising this plan this chapter describes the steps taken to enhance the practice of the USID methodology and provide the foundation for practical investigative studies.

First described is the modification to the practice of USID to reflect contemporary best practice in terms of both the practice of the design process and the activities of user participation within. To this end the design process is re-structured to reflect the adoption of guidance for the application of Human Centred Design (BS EN ISO 9241-210:2010) within the definition of practice as that described within BS EN ISO 7000:2008.

The chapter describes how observations made during literature review identified that the USID method applied by the ISRG had formulated its design activity around the definition of design practice as detailed within BS EN ISO 13407:1999. The result of which is that the application of the design process is heavily weighted towards design analysis and thus its application suffers in respect to the features of design synthesis such as iteration. To rectify this issue further guidance is drawn from standard BS EN ISO 9241-210:2010

It is highlighted that the human centred approach is not a standalone methodology. So far current focus has been applied to the elements of structure and principals of "human" rather than "user" centric design practice. However, as indicated by the questions derived from literature analysis there is also requirement for enhancement of design activity. To this end the following sections of this chapter outline suggested design activities under the following headings:

- Concept Generation Tools
- New Design Tools
- New Design Materials

Reference is made to the fact that the collation of the following tools and design materials is a result of the further investigation of contemporary design literature. As a collective these activities act to enhance the practice of USID via defining a supplementary design approach specifically tailored to the design of assistive products.

Coined as Flexible Object Orientated Design (FLOOD), the described approach empowers the practice of USID in a way that affords a synergetic focus of the holistic activities of design analysis and synthesis. This is achieved via an influx of flexible design strategy built around the core elements of user centric involvement currently practiced within USID and the definition of design practice as found within standards of best practice (e.g. BS ISO EN:7000-2:2008).

The chapter concludes with the definition of a suggested model for the application of FLOOD built around the adoption of a "middle-out" design approach.

Chapter Four: Applying FLOOD for Idea Generation

This chapter describes the initial application of the FLOOD model for the purpose of project idea generation. In order to validate the innovations of practice suggested within chapter 3, it is proposed that several design case studies should be implemented to test their validity within the overarching design process. However, before the innovations can be applied, the generation of project ideas is first needed to identify triggers for potential product and/or research development.

In order to address the research objectives the Nintendo Wii Controller is selected as a candidate for the initial investigation of the suggested design activity. The rationale for this selection is the reflection of current trends within the gaming technology arena and the growing interest with the device within assistive technology development communities as described within chapter 2.

Following the model described within chapter 3, the chapter describes the application of design analysis under the banner of Product Study. Focus is demonstrated on the features of analysis usually found lacking within assistive technology practice; namely:

- Determination of prior art
- Reflection of product lifecycle

This phase of analysis establishes that there are issues with the use of the Wii Controller as a licensed platform. Therefore in order for the continued application of the technology within this research to be viable, the device must be verified as a spring-board for concept creation and testing. To this end it is determined that there must be the ability to re-create the hardware and duplicate its functionality within legal constraints. This is achieved via the demonstration of the new design activities of Product Dissection and Benchmarking. The application of these new tools is used to also formulate the basis for the additional new activity of Design Replication.

Following the activities of Product Study and Design Replication it is concluded that the Wii Controller device is a viable platform for assistive technology development. This in itself reflects partial fulfilment of research objectives 1 & 2 (see Page 6).

The chapter continues with the generation of design ideas utilising the technologies of the Wii Controller as a springboard for concept creation. The techniques for idea generation are presented and attention is made to the application of activity via a multidisciplinary approach.

The chapter concludes with the presentation of the derived ideas to their respective stakeholders and target audiences.

Chapter Five: Applying FLOOD for the Iteration of Ideas

This chapter opens with a summary of the common themes identified for further development following the analysis of the design ideas developed within Chapter 4:

1. The Existing Wii Controller and Extensions
2. A Hub for Peripheral Enhancement
3. A Surface Free Interface
4. Gesture Recognition for the Physically Disabled
5. Sign Language Translator
6. Tremor Compensation for the Elderly and Physically Disabled
7. The Wii Controller as a Virtual Tool

In order to further verify both the design approach and the derived ideas, the chapter then presents the iteration of each idea's conceptual model via the application of design activities as described within Chapter 3.

The continuing development of the Wii Controller Interface Suite and its Peripheral Mapping Tool is introduced as an on-going developmental requirement required to achieve all of the design ideas. The function of the suite is to facilitate the connection and interface of the Nintendo Wii Controller and extension peripherals with the Windows Operating System.

The chapter draws to a close by determining that all of the derived ideas are feasible in terms of their potential for further development. The chapter then concludes with the identification of three design studies:

1. Design Study 1: The Virtual Cane Project
2. Design Study 2: The Nunchuk acting as an alternative assistive device
3. Design Study 3: A Wii based Rehabilitation Glove and Games for Stroke Rehabilitation.

By reflecting on the outcomes of the evaluation phases of these studies, the relative importance of paying due attention to the process of design synthesis, in comparison with an emphasis on primarily the design analysis process, is assessed.

Chapter Six: Design Study 1

This chapter demonstrates the first real application of the design model and practice defined within Chapter 3. Focus of presentation is applied to analysis of elements of the design process in respect to the definition of design problem in conjunction with the target demographic.

The objective of the study is the design of an intuitive interface for those with visual impairment, the realisation of which would allow those with visual impairment to navigate and interact within virtual spaces. Such an interface would demonstrate that the visually impaired demographic are a viable target for video gaming development, and demonstrate that with minimal adaptation, existing systems could be utilised.

Core to this goal, and trigger for this design concept, is the mapping of abilities and personal skill-sets as methods for input modality. In this context virtual space can be used to determine both traditional desktop paradigm, as well as those of 3D construct, such as simulated environments typically found within contemporary console gaming.

The product analysis of the Nintendo Wii Controller (Chapter 4) has identified that the device has great potential to be applied in ways which can be directly mapped to paradigms of real world interaction. Via the application of the human-centred design model, this work aims to verify the potential of the technology as a platform for (specifically in this case) visual impairment console gaming as well as a platform for rapid prototyping of assistive peripheral enhancement.

The study ends following the first build phase. This in order to demonstrate both the level of involvement of demographic targets within the activity required to achieve grounded human-centred design in respect to the framing of design problems and concept feasibility investigation.

The chapter concludes with a summary of the design study and the conclusions drawn.

Chapter Seven: Design Study 2

This chapter presents the further enhancement of design practice via the infusion of the derived design model and existing methods for USID evaluation. The previous application of the model (Chapter 6) demonstrated a focus towards the initial phases of design analysis with respect to both problem definition and initial concept feasibility. In contrast to the previous study (Chapter 6), where design synthesis focused on the iteration of design via development of an interface paradigm, this study demonstrates the adaptation of existing hardware and demonstrates application of the derived model and practice (Chapter 3) following the activities of feasibility investigation and development of a first stage prototype.

The design objective of this study is the realisation of a Wii Controller extension, that would enable those with severe physical disability and/or limited motor skills with the ability to interface with Wii Console based video games. The research objective of this study is to investigate the amalgamation of the current USID evaluation practice within the suggested human-centric design process, thus further informing the multidisciplinary approach towards design practice.

The chapter concludes with a summary of the design study and the conclusions drawn.

Chapter Eight: Design Study 3

This chapter demonstrates the third real application of the design model and practice defined within Chapter 3. Focus of presentation is applied to synthesis elements of the design process in respect to the iteration of the design via the activity of additive prototyping. As with both of the previous studies this activity is undertaken in conjunction with the target demographic.

The objective of this study is the development of a low cost home based system for stroke rehabilitation which would allow patients to practice the movements required for activities of daily living at the frequency required.

The two previous studies (Chapters 6 & 7) have demonstrated that the infusion of existent USID practice with the model and practice derived within Chapter 3 is an effective and efficient method for the development of assistive technology. This study aims to further these conclusions.

The study commences following the concept feasibility stage of the design process and closes following the development of the detailed design.

The chapter concludes with a summary of the design study and the conclusions drawn.

Chapter Nine: Discussion

This chapter presents a discussion around the conclusions drawn throughout this body of research. Comparison is made against the objectives of the research detailed in Chapter 1 and the questions derived in response to the objectives during the phase of literature review Chapter 2.

This chapter begins with a discussion of each of the design studies (Chapters 6-8) and the knowledge gained via practical application of from their holistic design activity. Performance of the design structure and suggested design activity as outlined within Chapter 3 is presented.

Next a comparison is made between the conclusions drawn and the overarching research objectives. In each instance the research is summarised and discussed.

Chapter 10: Conclusions

Following on from the previous chapter, this begins with a summary detailing how each of the research objectives has been achieved. The chapter then continues to demonstrate the innovations of this research by outlining the enhancements made to the practice of USID. This achieved by the presentation of each innovation and the rationale for its application against the five stage process for USID as defined by literature (Chapter 2, Page 28) as a basis for reflection.

The conclusions drawn in respect to the highlighted innovations of this research are seen to identify that the predominant weaknesses discovered in regards to the ISRG's practice of USID, can be seen to centre on the practical design elements of the methodology. Argument is made that the enhancement of design practice in each of the determined areas of weakness has resulted in a stronger and more efficient design method, however it is realised that more work is needed to fully realise the successful infusion of both the practices of design and evaluation.

The chapter then begins to draw to a close with the suggestions of potential topics for future research. It is suggested that further research is needed in order to unify the practice of human-centred design and the current USID evaluation practice. This body of research demonstrates that positive steps have been taken towards this end; however concentrated effort is needed to determine the most effective balance for design activity. It is also suggested that each of the designs developed during design studies be further iterated and evaluated.

The chapter then concludes with a summary of the conclusions drawn during the period of research.

Chapter 2: Background and Literature Review

The Need for Accessible Technologies

In 2003, the Microsoft Corporation commissioned a two phase report to understand both how accessible technology was being used and to investigate its future market potential (Forrester Research, 2004)[4]. The data collated determined that 57% (United States) of computer users are likely or very likely to benefit from the use of accessible technology, with future demand for such technology only projected to grow as society ages. This factor was also reflected by research conducted by the European Union (EU).

In the EU alone, the number of people who are elderly or disabled is estimated to be around 84 million, of which 50 million are in the age range of 15-64 and 34 million in the age range 65 and above. There is a large overlap between these two groups since disability is strongly related to age, with 70% of people with disabilities being aged 60 or over. By the year 2020 it is estimated that more than 25% of the European population will be aged over 65, a number that is estimated to rise rapidly in the coming years, the largest increase is expected in the oldest age groups (75 plus) where disability is most prevalent (Eurostat, 2008). The expanding proportion of elderly and disabled in the European population not only signifies the emergence of a gerontocracy, but also the importance of this issue.

The rise in the elderly population signifies an increasing requirement for technology to be assistive in nature. Such technologies would ensure capability for independent living over an expanding time period and act to maintain and improve quality of life, integration and independence. Since 2003 the objective of the European Commission Disability Strategy has been to make equal opportunities for disabled people a reality (European Commission, 2003). This was confirmed by the signing of the United Nations Convention on the Rights of Persons with Disabilities (Commission, 2005) in 2007. The EU Disability Action Plan 2003-2010 provides a means to implement this strategy by mainstreaming disability issues within all relevant EU policies.

Analysis of recent data confirms a strong correlation between disability and ageing (APPLICA, CESEP, & Alphametrics, 2007). It also demonstrates that disabled people continue to be disproportionately excluded from the labour market. Moreover, people with learning or intellectual disabilities are even less likely to be in work than those with physical disabilities. The exclusion of people with disabilities from the labour market is a serious concern from the perspective of equal opportunity. Furthermore there is a growing economic dimension to this problem: we are faced with a shrinking

[4] Information for the report was collated via a survey conducted by phone in the last quarter of 2003 and was completed by 3,428 computer users.

workforce resulting from this demographic change. In 2006 the Spring European Council highlighted the need to make the most of the untapped potential of many people excluded from the labour market and identified disabled people as one of the key priority groups (European Council, 2006). This together with the correlation between ageing and disability creates a strong demand for accessibility and accessible technology.

The Use of Video Games

Without any doubt, video gaming has become big business. According to leading market research conducted on behalf of the Entertainment Software Association (Ipsos MediaCT, 2011)[5] 72% of American households currently play computer or console games.

Figure 2: The NPD Group/Retail Tracking Service; Games Industry: Breakdown of players by age (Ipsos MediaCT, 2011)

Of this percentage 18% are under the age of 18 years of age, 53% are aged 18-49, and 29% 50 years plus. As can be seen from these statistics the individuals playing video games are becoming increasingly diverse. Today's video game players include not only the young but also their parents and grandparents.

[5] The study is the most in-depth and targeted survey of its kind, gathering data from almost 1,200 nationally representative households that have been identified as owning either or both a video game console or a personal computer used to run entertainment software.

The average gamer is 37 years old and has been playing video games for a period of approximately 12 years. Amongst most frequent gamers, males average 13 years of game playing, whilst female players average around 10 years.

Figure 3: The NPD Group/Retail Tracking Service; Games Industry: Total Consumer Spend (Ipsos MediaCT, 2011)

The gender balance of game-players is approaching a level of equilibrium with female game players now accounting for 48% of the gaming population. Women aged 18 or older represent a significantly greater portion of the game playing population (37%) than boys aged 17 or younger (13%). Of primary import is that in terms of physical content (at retail exclusively) console gaming dominates the video gaming market with a share of approximately 90% of total sales (Figure 3).

Video, Computer and Console Games

Historically the term Video Game was used to describe an electronic game that involves human interaction via an interface device or devices to generate feedback via a cathode ray tube display. As display technologies have progressed, the term is now used to encompass any type of display capable of displaying two or three dimensional imagery.

Computer Games and Console Games are divisions of Video Games that differ in terms of hardware needed for their playback. The term Computer Game refers to an electronic game that involves a player interacting with personal computer hardware connected to a video monitor. A Console Game refers to an electronic game that involves a player interacting with bespoke system hardware built for the purpose of running electronic games which can be displayed via a common television or equivalent display. It is important to understand the difference between these two “gaming platforms” as both have very different academic exposure in terms of disability and assistive technology. Often literature will detail Console Games as Video Games (primarily down to language differentiation) so diligence must be taken. In this research, use of Video describes the collective.

Disability and Video Gaming

Market research conducted behalf of PopCap Studios (Information Solutions Group, 2008)[6] details that more than one in five (20.5%) players of casual video games has a physical, mental or developmental disability. In this context casual games are games that can have any type of game-play, and fit into any gaming genre. They are typically distinguished by their simple rules and the lack of commitment and skill required to play them.

According to the data collated, tens of millions of disabled consumers have “gravitated” towards the casual video game genre as a source of relief or distraction from their infirmities, as well as a reported sense of accomplishment and/or belonging. Over three quarters of the more than 2,700 disabled consumers reported to have taken part in the study described their disabilities as "moderate" (54%) or "severe" (24%). The most common types of disabilities and medical conditions cited by respondents are described in Table 1. The majority (61%) of those survey respondents with a physical disability are age 50 or older, while slightly more than half (52%) of those with a developmental and/or learning disability are under 18 years of age.

Table 1: The most common types of disabilities within casual gaming (Information Solutions Group, 2008)

Physical Disability or Impairment	Mental Disability or Impairment	Developmental/Learning Disability or Impairment
Rheumatoid Arthritis or Osteoarthritis (14%)	Moderate or Severe Depression (41%)	ADD or ADHD (46%)
Fibromyalgia (11%)	Mental: Bipolar Disorder (16%)	Autism (15%)
Multiple Sclerosis (7%)	Anxiety Disorder (15%)	Dyslexia (11%)

The report details that those with developmental and/or learning disabilities reported learning (pattern recognition, spelling, and typing skills) far more often (61%) than those with disabilities which were mental (26%) or physical (23%).

When asked to pick their favourite categories of casual games, disabled gamers’ detail "puzzle" (84%), "word and trivia" (61%) and "arcade" (59%) as being the three most popular genres. The research found that only 26% of disabled casual gamers said they also play traditional, *"hard-core"* video games, reflective of those traditionally found on the console gaming platforms. Amongst these

[6] A total of 13,296 casual game players responded to the survey, with 2,728 respondents (20.5%) identifying themselves as "mildly" (22%), "moderately" (54%) or "severely" (24%) disabled. Of this number, 46% indicated that their primary disability was physical, 29% said it was mental, and 25% stated they had a developmental or learning disability. Over two thirds (69%) of disabled respondents were female, and a third (35%) of all respondents had another person assist them in taking the survey.

respondents, those with physical disabilities dropped to around 18%. Of all disabled gamers who also play hard-core games, 25% said they played hard-core games on a daily basis in comparison to 64% who play casual games daily.

Assistive Technology & Video Games

Prior to the commercial release of the Nintendo Wii games console in 2006, assistive technology related academic literature in regards to console gaming is found to be almost completely non-existent, a factor corroborated by the International Game Developers Association in their white paper, *Accessibility in Games: Motivations and Approaches* (IGDA, 2004). Prior academic literature can be found to always refer to video gaming within the computer gaming category. The premise for this fact is simple; at that time, console gaming was just not accessible enough, and academic development was impractical.

Since the release of the Wii however, inspired by new and innovative methods for interface, console gaming has begun to creep into academic research, and can be primarily found within rehabilitation and a supported educational context (see Flynn, Lange, Yeh & Rizzo, 2008; Abbott, Brown, Evett, Standen & Wright, 2011; Pearson & Bailey, 2007). There is also growing evidence of research which focuses on the use of console games by those with disability and impairment for gaming (e.g. Battersby, 2008; Iacopetti, Fanucci, Roncella, Giusti & Scebba, 2008; Evett, et al., 2011; Baihua, Clarke, Smith & Yates, 2011). However, and despite these examples, representation of console gaming within academic literature is still sparse[7].

With respect to the range of physical disabilities and impairment that can be experienced, the major barrier to interaction can be found in the predominant mode of console interface, the control-pad and its accompanying interaction schemas (see Ellis, 2006; Iacopetti, Fanucci, Roncella, Giusti & Scebba, 2008; Brown, Kerr, & Crosier, 1997. Typically, console game controllers are equipped a variety of inputs including push-buttons and joysticks, often which need to be operated at the same time. By way of result such hardware presents a real barrier to those with limited motor skills. This is also true for those with a cognitive impairment.

When considering people with visual impairments, console games are just not accessible due to their overwhelming dependence upon visual media. Even those with limited vision are excluded due to the resolution and picture quality of the display technologies. In contrast, a growing body of research can be found in respect to computer games and visual impairment (e.g. Westin, 2004; Lahav & Mioduser, 2005; Röber & Masuch, 2004; Röber & Masuch, 2011). As for auditory

[7] In this context academic literature refers to the field of assistive technology research and development.

impairment, console gaming suffers from the same accessibility issues that can be found within computer gaming. These include factors such as the absence of auditory cues and reduced immersion in reflection to environmental ambience (see IGDA, 2004; Forrester Research Inc, 2004).

Due to the restrictive nature of commercial console platform development, academic assistive technology and related research has predominantly opted for the personal computer as its targeted platform. It is unusual to see the successful adaptation and use of a games console platform for use by people with a disability and impairment, but much more usual to see the adaptation and use of the associated peripherals (Wii Controller etc.).

Gaming as State of the Art

Since its launch in 2006, the Nintendo Wii Console has continued to draw attention from the accessible technology development communities, due to the unique styles of game-play and interaction facilitated by its accompanying controllers. In contrast with typical controllers, the Wii Controller expands upon the paradigms for user-game interaction (button press and joystick movement, keyboard and mouse) by employing accelerometer and optical sensor technologies to afford motion sensing and pointing capabilities. As a result, fresh possibilities for interaction and human interface are enabled through use of physical movement and gesture.

The innovations of the video gaming arena such as the Nintendo Wii Controller are acting to spearhead a transition towards the next variant of human machine interaction, the Natural User Interface (see Greenfield, 2006; Buxton, CES 2010: NUI with Bill Buxton, 2010; Blake, 2010).

The Natural User Interface

As humans we constantly develop and invest in skills, innate and taught, during the function of everyday personal life experiences. However, in order for us to become a “power user” of a skill we must invest time to facilitate its development. Skills are unfortunately expensive to acquire, but once an investment has been made, we are gifted with the ability to reuse a skill and adapt it so that it can be applied to other tasks. The ability to draw upon senses and our investments in skill, as a means to define methods for input modality, is a powerful concept which has many advantages. Foremost is an immediate familiarity with methods for interface, intuitively gifting users of a system with the capability for performing basic interaction.

Buxton (2010) describes such interface as “natural”, detailing that an interface is natural if it “exploits skills that we have acquired through a lifetime of living in the world.” Blake (2010) furthers this definition by determining that an interface is natural if it is designed to utilise human behaviour for interacting directly with content. He states that by framing the definition of interface around natural human behaviours, we can talk about reusable patterns of behaviour derived from human-human and human-environment interaction, without implying that we should model an interface after specific interactions.

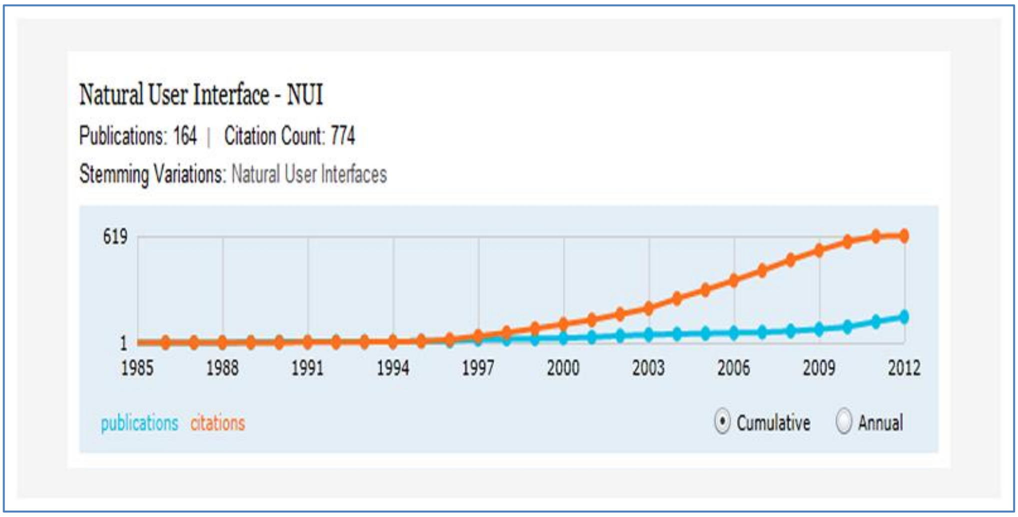


Figure 4: The Growth of NUI as an Academic Terminology (Microsoft, 2011)

While the idea itself is old (see Weiser & Brown, The Coming Age of Calm Technology, 1996), the technology to support Natural User Interfaces (NUI's) and the field of study around them is still in its infancy, and therefore the academic literature is sparse (see Figure 4; Buxton, 2010). Therefore, in order to gain a better understanding of the concept, original constructs of the field (specifically ubiquitous computing (see Greenfield, 2006) also need to be reflected upon.

Ubiquitous Computing & Calm Technology

In *Designing Calm Technology*, Weiser & Brown (1996) provide warning that whilst technological infusion has the great potential to improve and enhance our life experience, it also has the potential to impede and restrict us. In order to address this issue they describe the ethos of technologies that "en-calm" as a manifesto for our future relationships with technology.

Key to this concept is the embodiment of our periphery. In this context, our periphery is our connectedness to the world as defined by our senses and their capabilities, or as our personal boundary of perception made up of detail provided by our senses and experiences (see Weiser & Brown, 1996; Bakker, Hoven & Eggen, 2010; Pinheiro, 2010).

Figure 5: The centre and periphery of human perception as described by Pinheiro, 2010

By placing technologies within the periphery we are able to become attuned to them, allowing them to be selectively and subconsciously called upon to inform detail. This in turn affords us with an increased ability to attune to multisensory detail and thus, a greater level of knowledge to inform both response and our perceived "*locatedness*".

Our periphery provides us with an enormous volume of data, despite this fact however, we never become overburdened. This is because that as this data is within our periphery and we are attuned to it we are able centre on individual elements and bring them in and out of focus as required. In his research Pinheiro (2010) reflects on the idea of calm technologies and summaries the concept under the banner Ambient Information Systems stating:

> *"Many projects on this field are based on the enrichment of our peripheral attention, presenting information in such a way that it can be perceived without demanding effort, assisting in the intuitive understanding of a more complex situation."*

The embodiment of our periphery and an excellent visual representation of the concept as described by Pinheiro can be seen in Figure 5.

Pockets of Research

The following section outlines pockets of academic research that specifically focus on the development of assistive technology via the application of user-centric methods. Review of the literature indicates many isolated pockets of assistive technology research spanning across many disciplines. This can be considered as a reflection of the multi-disciplinary approach often described and applied for the development of assistive technology. The pockets of research presented highlight studies from across many disciplines including Human Computing Interaction, Industrial and Product Design, the Arts and Engineering:

1. The Interactive Systems Research Group (ISRG), Nottingham Trent University, and VIRART, University of Nottingham.
2. Universal Design at North Carolina State University.
3. Centre for Inclusive Design and Environmental Access Buffalo University.
4. University of Texas.
5. Department of Industrial and Systems Engineering, Virginia Tech.
6. Technology (HUSAT) Research Institute, Loughborough University.
7. Sensorama Lab Team Aalborg University.

Further focus is applied to the studies s of the ISRG as this thesis aims to expand upon and enhance the user-centric design practice conducted by the team. Following a full breakdown of the related research of the ISRG, a summary of studies from the other teams is also presented so that comparisons can be made, complementary approaches drawn, and any weakness of practice identified.

The Interactive Systems Research Group of Nottingham Trent University

Formed in 1998 and is a part of the Computing and Informatics Team at Nottingham Trent University. The Interactive Systems Research Group develops and evaluates virtual environments, serious games, location based services, and assistive technologies to promote the social inclusion of all EU citizens. They present in their collective research an evolving methodology for user-centric design practice.

The following summary of studies focuses on research conducted by the ISRG specifically for the development of Assistive Technology. This research builds upon earlier work conducted by the Virtual Reality Applications Research Team (VIRART) at the University of Nottingham.

During these early studies (e.g. Cromby, Standen & Brown, 1995; Brown, Kerr & Wilson, 1997; Brown, Kerr & Crosier, 1997; Brown, Neale, Cobb & Reynolds, 1999) it was highlighted that input peripherals restricted to two degrees of freedom provided the greatest utility for those with intellectual disability. Primary research focus was conducted for the use of joystick type peripherals, however indication was made that a joystick class peripheral was not the only effective means of providing user-computer interaction. For example, Brown et al (Brown, Kerr & Crosier, 1997) indicates use of a touch screen or mouse to be equally effective. However they also state that at that time touch screens suffered from hardware limitations, and failed in task scenarios involving drag and drop. They concluded that for the targeted demographic (those with intellectual disability), mice were more effective for drag and drop than touchscreens, whilst trackballs were found to be least effective. In terms of virtual environment interaction, navigation was found to be one of the most difficult tasks for users to undertake. Cobb (Cobb, Neale & Reynolds, 1998) showed that there are usability difficulties with the joystick and mouse, which were found to be the most suitable devices for people with learning disabilities to control virtual environment tasks.

Using the user-centric design method contained within these earlier studies as a foundation, Lannen enhanced the design practice within the ISRG via the introduction of contemporary design theories and tools (Lannen, Brown & Powell, 2000; Lannen T., 2002).

Lannen utilised concept selection matrices to map concepts against attributes drawn from a product specification (Terharr, Clausing & Eppinger, 1993; Hauser & Clausing, 1988), during the design of a Joystick type peripheral (Figure 6) for those with physical disabilities. This mapping was then used to rank the concepts in order of most effective in terms of user requirements. The specification itself was determined via a phase of User Requirement Analysis conducted in line with the UserFit framework (Poulson, Ashby & Richardson, 1996) developed by the Human Sciences and Advanced Technology (HUSAT) Research Institute, Loughborough University.

Figure 6: VR-1 Joystick (Lannen T. , 2002)

Core to the model for design practice presented by (Lannen T. , 2002) are the standards, BS EN ISO 13407:1999 *Human-centred design processes for interactive systems* and the associated ISO/TR 18529:2000 *Human-centred lifecycle process*. Lannen expanded on the traditional user-centric approach detailed within BS EN ISO 13407:1999 via the introduction of the additional phase of Technology Review and the elicitation of user requirements.

The design model as defined by Lannen with the addition of the Technology Review can be seen in Figure 7.

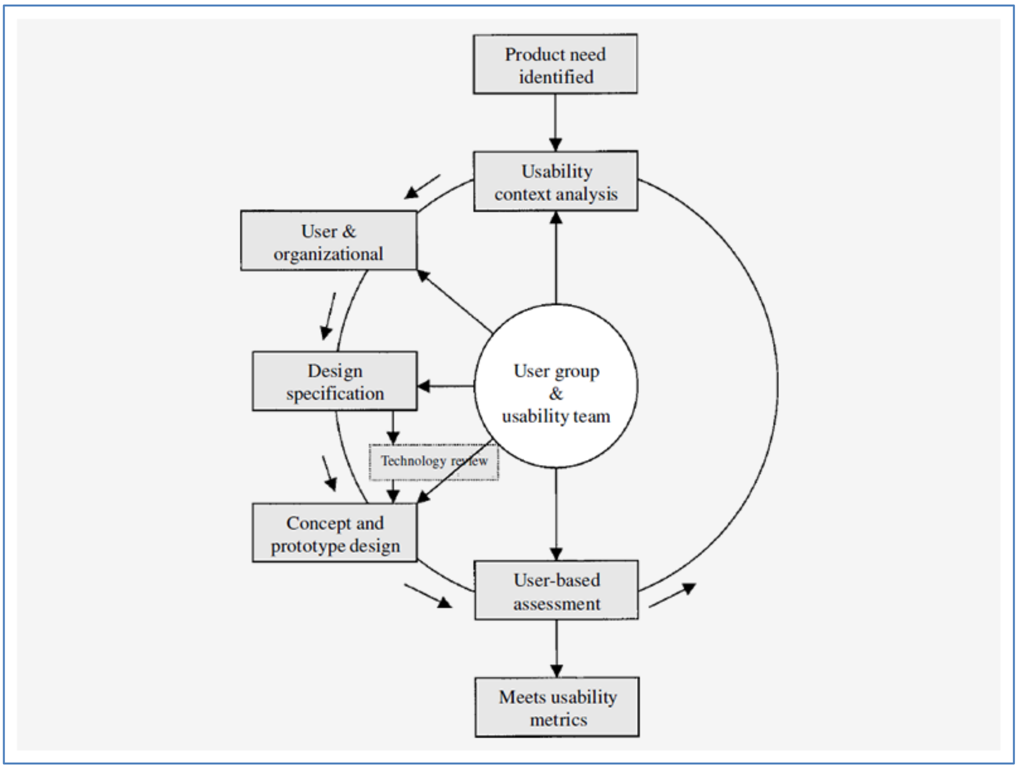


Figure 7: The user-centred design Process as described in (Lannen, 2002)

The study conducted Ducat (Ducat, 2002) evaluated the research conducted by Lannen via application of performance testing and analysis. Ducat indicated that whilst the methodology and iterative design process utilised by Lannen was sound, its implementation was however subjective. Ducat highlighted a need for more robust methods of data collection and evaluation to be established. The evaluation of the Lannen joystick prototype and design methodology was carried out via Product Analysis and a literature review respectively (see Smith, Ducat & Brown, 2008). Additionally an analysis of existing equivalent products was also conducted. This acted to expand upon the use of design theories within the development cycle.

During the evaluation the following conclusions were reached:

- Design and implementation in the Lannen study focused primarily on users' physical abilities, neglecting issues of ergonomics and cognitive ability.
- The Lannen prototype was impractical for ergonomic, environmental and economic reasons.
- Collection of data and evaluation methods need to be objective and robust.
- Product Analysis and implementation of design theories must be rigorous.

Using the Ducat outcomes as a basis for improving the application of the 5 stage user-centric process described by Lannen, an updated methodology was defined.

The EPSRC Joystick Study (EPSRC)

The ISRG continued to expand upon the infusion of contemporary design theory within the user-centric processes via development of another joystick peripheral, within a study funded by the Engineering and Physical Sciences Research Council (EPSRC).

At its core, the EPSRC Joystick study (Standen, Battersby & Lannen, 2002; Standen P. , Brown, Anderton & Battersby, 2003; Standen P. , Brown, Anderton & Battersby, 2004; Standen P. , Brown, Anderton & Battersby, 2006) adopted and adapted the iterative process defined by Lannen.

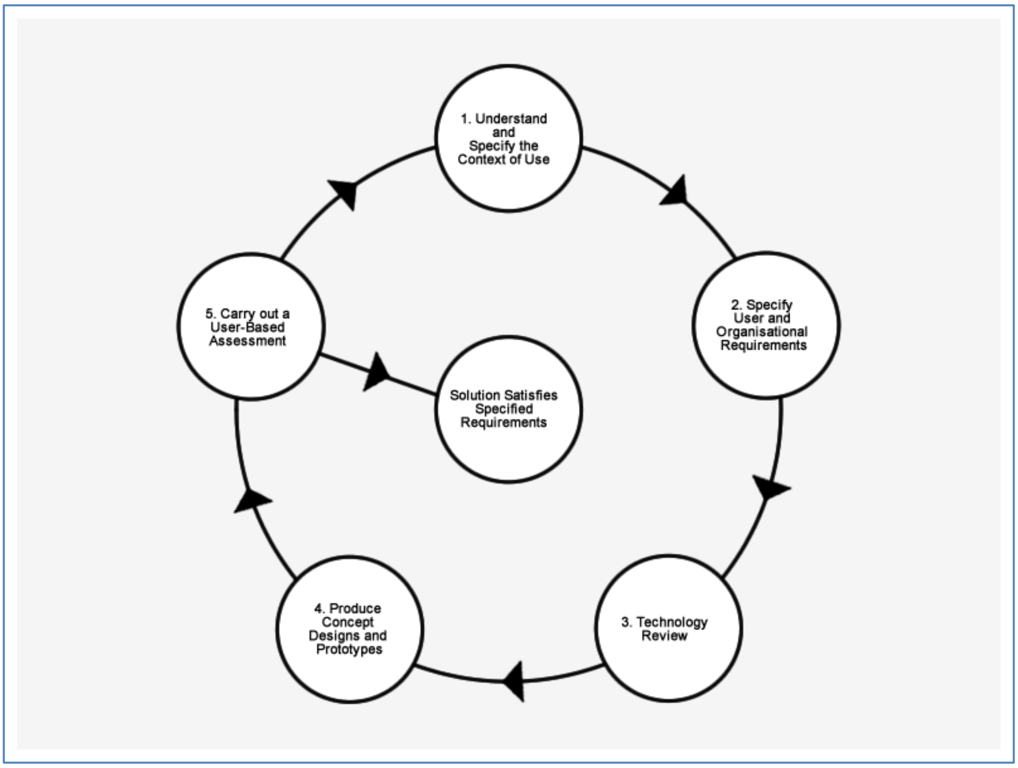


Figure 8: The User Sensitive Inclusive Design Model as described in Standen P., Brown, Anderton, & Battersby, 2006 & Brown, Battersby, Standen, Anderton & Harrison, 2011

The above image (Figure 8) depicts the flow of the user sensitive design model as described in Standen P. , Brown, Anderton & Battersby, 2006 and reiterated in Brown D. J., Battersby, Standen, Anderton & Harrison, 2011.

The model details a five stage design process where the cycle of activities is repeated until the all the design criteria had been attained:

1. Understand and Specify the Context of Use
2. Specify User and Organisational Requirements
3. Technology Review
4. Produce Concept Designs and Prototypes
5. Carry out a User-Based Assessment

However, in order to address the issues identified by Ducat, additional design activities were adopted to enhance the application of the user-centric design practice. For instance, phases of peer review were introduced as a means to reduce subjectivity of the design practitioner. Similarly in order address experimenter subjectivity, in respect to the rating of scores of experimentee's performance, bespoke testing environments with facilities for automatic data capture were also introduced. The data provided by these environments also acted to complement data collected via methods established in earlier studies (Standen P. , Brown, Proctor & Horan, 2002) whilst also providing a means by which to calibrate this data.

In addition to addressing subjectivity, the study also acted to enhance user-centric practice by introducing tools to inform the design, aid in design creativity and production of prototypes. An extended Usability Context Analysis (UCA) was used to provide initial structure for both the evolving development cycle and collection of Baseline Performance Data (BPD). The application of UCA can be described as follows:

- User analysis: to describe physical, cognitive and perceptual abilities of the user group.
- Task analysis: to identify the major productive goals, which a user can achieve, using the product.
- Environment analysis: to describe the organizational, technical and physical factors of the environment in which the product will be used.

The BPD was then used to feed the development of any Potential Design Solutions (PDS). In order to increase the effectiveness of this process, the Technology Review (Lannen T. , 2002) was expanded to include the production of Parallel Product type Mood Boards (see Garner & McDonagh-Philp, 2001; Appendix D) to enhance not only background knowledge and reference resource for the designer, but also capability for expressing concepts and ideas with both design target demographics and other members of the multidisciplinary development team (e.g. evaluators, stakeholders and peer reviewers).

The introduction of Virtual Prototyping (Zorriassatine, Wykes, Parkin, & Gindy, 2003) into the design process provided a means of low resource rapid prototyping, thus speeding up the iterative design process. This enabled an increased volume of concept variants to be both developed and evaluated by the project team.

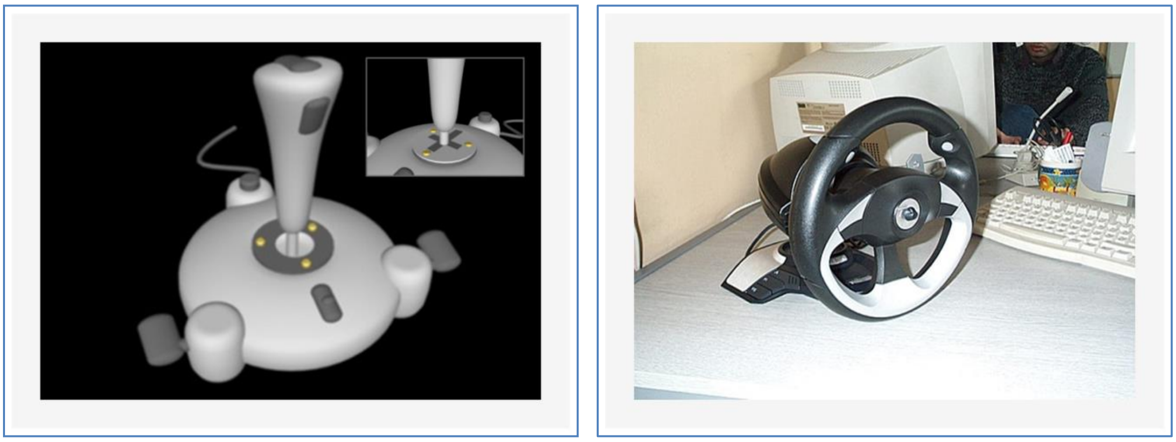


Figure 9: Examples of Virtual Prototype & Physical Prototype

Despite these enhancements to design practice, results from the study were reported as disappointing. The only clear cut outcome defined was that one of the derived concepts, a two handed device (Figure 9, right), was no better in terms of performance than the other design solutions.

Furthermore this solution was seen to perform much worse in terms of help required to use it when viewed in comparison with a contemporary joystick, such as that used within the BPD element of the study. This does however reinforce the conclusions described in Ducat (2002) in respect to the weakness of two handed joystick devices in terms of assistive technology.

A full listing of the results and breakdown of the data collected from this study can be found in Standen P. , Brown, Anderton, & Battersby, 2006.

The Portland Switch Study

Using experience gained during the EPSRC study for foundation, the ISRG once again continued to evolve their user-centric design method and practice via the development of a further new device, the Portland Partnership Assistive Switch (Brown D. J., Battersby, Standen, Anderton & Harrison, 2011; Brown D. , Battersby, Standen, & Anderton, 2005; Battersby, Brown, Standen, Anderton & Harrison, 2004).

Formed as part of the European Social Fund's Equal Initiative (EQUAL) the Portland Partnership aimed to produce innovative hardware and software solutions to be used alongside existing learning materials within the disabled adult learning domain. For a large percentage of learners under the Portland Partnership (those who experience limited physical mobility and control) digital interactivity through standard hardware was not possible. They had to rely on adaptations of existing assistive and/or adaptive technology to access learning software. By developing a new versatile piece of interface technology the partnership hoped to provide each learner with a more autonomous form of interactive learning. The ISRG's role within the partnership was to design and implement an assistive switch peripheral. It was concluded that design solutions would need to be adaptable to a wide range of physical disabilities and movements, making it particularly beneficial to those whose motor skills disabilities. The user-centric methodology evolved via the earlier related studies: Hall (1993), Brown, Kerr, & Crosier (1997), Lannen, Brown & Powell (2002) and Standen, Battersby & Lannen (2002) was once again adopted.

Driven by the experiences drawn from the EPSRC study, the design methodology was again evaluated in the manner demonstrated by Ducat (2002). The elements identified as having weaknesses were then addressed to improve the efficacy of the design practice. Primary foci included: communication of design solutions between the design team and the target demographic, design problem identification (Dubberly, 1995) and concept prototyping efficiency.

Unlike the earlier studies conducted by the ISRG, a technical specification was developed at the project initiation phase, in conjunction with the partnership. This was as a means of providing definition of problem, introducing a level of constraint and structure to the design. Surprisingly, despite the guidance supplied via sources such as the BS 7000 series of standards and BS EN ISO 13407:1999, a physical solution is often already defined before the design space is fully explored by the designer (for instance in the Portland Project the solution was already defined as a wireless switch for interaction before the design process began).

The Portland Partnership defined the form of the device to that of 'Switch', due to the high level of physical disability within the project's target user audience at the outset of the project. The technical and physical factors defined within the specification were used to form the basis of a project brief in line with contemporary design theory. The technical and physical factors defined were also used to provide basis for an Environmental Analysis, which complemented the Task and User Analyses, in turn forming basis for User Context Analysis (Step 1 of USID).

In order to enhance methods for communication, a modification of the existing storyboarding process, Participative Storyboarding (PS) was introduced (Battersby, Brown, Standen, Anderton, & Harrison, 2004). PS as a tool empowers the user-centric design process by placing users at the centre of a rapid prototyping development cycle that allows them to effect changes to the design, and in real time see the results of such actions, all without the need of a physical prototype. This rapid turnaround was determined by the team as an important factor for people with an intellectual disability, in order to maintain their interest and active involvement in the design process.

An enhanced investment in the Technology Review phase of study was also introduced in order to identify any existing and potentially adaptable technologies that would comply with the technical specification. To this end a survey of existing input and assistive and/or adaptive devices was used to identify devices, features and components that could inform both the design and any reusable components and technologies.

A within subjects design was again utilised to collect baseline performance data on existing devices, which could be compared in later analysis with new prototype devices, again to identify device performance enhancements. A positive outcome of the EPSRC study was the determination of software solutions for the process of data capture. As with the EPSRC study, data capture software was developed and presented using a gaming format as a means of engaging the user.

Distillation of design criteria to form the Design Specification Document was undertaken, utilising criteria evolved from the Parallel Products Review (reusability of existing design solutions and features), The User Team (interactive storyboards), the Usability Team (expert design storyboards), the Baseline Evaluation (identification of usability problems of existing switch devices with prototype VLE and learning software) and the User Context Analysis (design considerations from user, task and environment analyses).

Earlier work on the assessment of interface devices for people with a physical disability using VR (Brown, Kerr, & Crosier, Appropriate input devices for students with learning and motor skills difficulties, 1997) defined a list of key desirable features for any proposed input device. These key features were that any innovative device should be robust, modifiable, adjustable, reliable and affordable.

Figure 10: Example of Portland Switch Virtual Prototype

(Brown D. , Battersby, Standen, & Anderton, 2005)

Product Analysis was conducted and presented to the industrial partner TRAXSYS in conjunction with a draft of the Design Specification Document as a means of initial concept evaluation to ensure full compliance with the project specifications. Upon receiving feedback, concept prototypes were produced and presented to both the user and peer review teams.

The additional feedback provided via these prototypes resulted in the development of a final potential design solution which in turn led to the construction of a 3D CAD representation of the proposed solution (Figure 10). This conceptual design was evaluated via peer review using the project Usability Team. The conclusions of this evaluation were then further developed by TRAXSYS in conjunction with the designer as a means of providing engineering and experiential knowledge ensuring functional design feasibility.

This virtual prototype was then used to create physical representations via rapid prototyping techniques. These prototypes in turn were then fed into the user-sensitive design method. As before, evaluation was conducted by the Evaluation Researcher via performance study with a similar heterogeneous user group.

Figure 11: The Portland Switch with Wireless Adapter

An ideal outcome of this research would have been the identification of a design solution for as many people with physical and associated cognitive disabilities as possible; sadly this was not the case. Analysis of performance from the within subjects study identified the design solution developed by the ISRG as the second least favourite during testing.

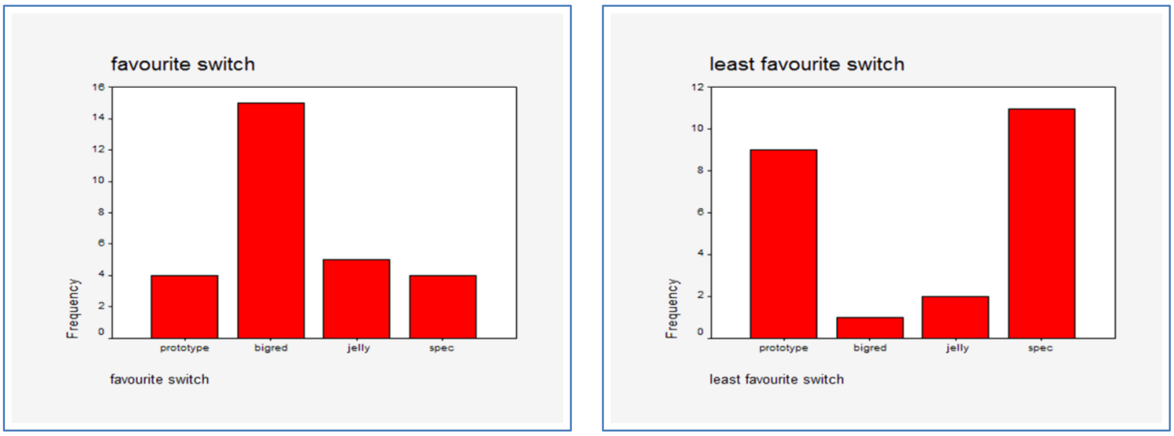


Figure 12: The Users Favourite & Least Favourite Switch

Despite user-centric influence throughout the design process the overall opinion of the device was disappointing (Figure 12). Rational provided by those responsible for evaluation was that, as with the EPSRC study, the targeted demographic represented a heterogeneous group who varied in abilities along many dimensions, for example, vision and hearing abilities, gross and fine motor abilities, cognitive abilities, understanding and use of language. The suggestion was re-affirmed that a more focused application study in terms of demographics should be conducted, thus further validating conclusions of similar literature, that a one device fits all solution is unlikely (Newell & Gregor, 2000).

On reflection it was felt that the prototype evaluated was not truly reflective of the design derived. Evidence is presented that during the phases of engineering and manufacture key elements of the design solution were modified to reflect the needs of rapid prototyping manufacture, engineering resource and also engineering experience. For instance the casing unit was designed to be clipped together; however the engineering partner implemented this as a screw mechanism with opposing threads which meant each time it was used it had a high chance of falling apart. The light circulatory, trigger mechanism and Bluetooth were also not implemented. This highlights both a need for production consideration within the design process and also a need for design practitioners to be able to justify and provide rationale their design decisions.

A full listing of the results and breakdown of the data collected from this study can be found in Brown D. J., Battersby, Standen, Anderton & Harrison (2005).

Universal Design at North Carolina State University

A team of researchers organised at the Centre for Universal Design at North Carolina State University have compiled seven principles that categorise aspects of Universal Design (Connell, et al., 1997) these seven principles are:

1. Equitable use
2. Flexibility in use
3. Simple and intuitive use
4. Perceptible information
5. Tolerance for error
6. Low physical effort
7. Size and space for approach and use.

For each principle, several guidelines have also been created. These principles have been well-received by designers in a range of disciplines. Further research effort has developed detailed and specific methods for both applying and evaluating the impact of these principles (Beecher & Paquet, 2005).

Centre for Inclusive Design and Environmental Access Buffalo University

Buffalo Universities Centre for Inclusive Design and Environmental Access (IDeA) are a group of researchers who actively focus on the area of Universal Design (Danford, 2003; Feathers, 2004; Langdon, Persad, & Clarkson, 2008; Steinfeld & Mullick, 1990). Although focused on architectural design, they have also undertaken research in the field universal design that extends to that of product design (Lenker, Narsarwanji, Paquet, & Feathers, 2008; Nasarwanji, Feathers, Lenker, & Paquet, 2008; Paquet, Lenker, Feathers, & Nasarwanji; Paquet, Nasarwanji, Lenker, & Feathers, 2008).

University of Cambridge

The University of Cambridge have developed a repeatable process for the application of inclusive design (Clarkson, Coleman, Keates, & Lebbon, 2003; Clarkson, Product experience, 2008; Clarkson, Langdon, Goodman-Dean, & Robinson, 2008; Waller, Landon, Cardoso, & Clarkson, 2008). Focus is applied to the modelling user groups, creating product assessment methods and extending the needs of inclusive design to modern product design processes.

Within their research, Keats et al (Keates, Clarkson, Harrison, & Robinson, 2000) proposes a seven-step approach for universal design, expanding the traditional three step approach described by Blessing (Blessing, 1995) and reiterated by Dubberly (1995):

- Define the problem
- Develop a solution
- Evaluate the solution

Via the introduction of user perception, cognition and motor function (Card, Moran, & Newell, 1983) to obtain inclusivity (Keates & Clarkson, 2003) within the seven-step approach as proposed by Keats et al, the first two levels parallel those of the Blessing's traditional design method, however step two is divided into three separate phases:

- Focus on the users’ perceptions of the product or how the physical layout affects user interaction.
- Focus on the users’ mental or cognitive interaction.
- Focus on user input or interaction

The primary focus of the Cambridge Group has been on modelling the user-centric differences between typical and functionally limited users, and the design challenges of accommodating the functionally limited user.

University of Texas

In a similar approach, research at Texas University focuses on the *"product and product user interplay aspects of universal design"* (McAdams & Kostovich, 2011; Nagel, Hutcheson, Stone, & McAdams, 2011; Moon & McAdams, 2010; Moon & McAdams, 2009).

Further studies s (McAdams & Kostovich, 2011) act to summarise the divisions described within the research conducted at Cambridge University, by detailing the requirements to complete a design within each of the aforementioned phases. That is, given that the designer knows that the disabled user has functional limitations, focus needs be applied to determine how the product must change in response to these limitations.

Department of Industrial and Systems Engineering, Virginia Tech

Researchers within the Department of Industrial and Systems Engineering, Virginia Tech describe development and use of the Needs Analysis and Requirements Acquisition Framework, to elicit and construct user requirements for the design of assistive technology (Smith Jackson, Nussbaum, & Mooney, 2003). They demonstrate application of an approach for universal design based upon four specific procedures, undertaken within a participatory and context based environment:

1. Elicit
2. Construct
3. Implement
4. Evaluate

They demonstrate application of the NARA framework to create an efficient procedure to capture requirements as means to improve accessibility before the design stages of development. Although the requirements are centred on users with disability and impairment, they describe the goal of NARA as determining product as usable by the entire consumer population. Studies (Ma, Wu, & Chang, 2007) detail the NARA method as an enhancement to practice under the banner of user-centred design.

Technology (HUSAT) Research Institute, Loughborough University

The Human Sciences and Advanced Technology (HUSAT) Research Institute, Loughborough University focuses on the usability of both mainstream and assistive technologies by people who are older or disabled (Colette & Bjorn, 1999; Abascal & Nicolle, 2000; Poulson, Ashby, & Richardson, 1996; Poulson & Richardson, 1998). HUSAT are the key drivers behind the UserFit methodology. UserFit is an established methodology, focused on the generation of usability specifications. Colette (1999) describes the methodology as:

> *"...a set of summary tools to collate, analyse, evaluate and develop information to build a specification, along with worked examples. "*

A key aspect of this methodology is that it forces design issues to be made explicit. It makes designers, especially those who work in multi-disciplinary teams, ask the right questions and justify and document any design assumptions or decisions they have made, either about the technology or its users (Poulson & Richardson, 1998).

Sensorama Lab Team Aalborg University

The Sensorama Lab team at Aalborg University, Esbjerg (Denmark) have demonstrated potential for use of aesthetic resonant environments as an effective medium for providing therapeutic exercises to encourage body awareness (Lewis-Brooks & Hasselblad, 2004). In addition, the team have also developed a conceptual model for the use of Soundscapes for home-internet based rehabilitation for stroke patients (Brooks, 2004). Studies (Herbelin, Ciger, & Brooks, 2008) also demonstrate an approach for taking existing software and hardware as a foundation for the cross-disciplinary user centred design of dedicated application for the provision of rehabilitation.

Identified Themes

The analysis of the research of these teams and further pockets of research detail a smorgasbord of terminology in respect to the activities and methods utilised for the creation of assistive technology products. In each instance however the common theme of user-centred design is apparent. Investigation of the principle is thus deemed vital in order to afford base knowledge for the comparison of the structure of USID and the equivalent practice applied by others. The identification of variance and reported success and failure within these works can then be used to form a basis for determining both strengths and weakness within the current practice. This information can then be used to formulate a basis for the enhancement of existing practice and as means of addressing the thesis's objectives.

To this end, it is also proposed that this knowledge can then be used to build a picture of how the fields of human computing interaction (specifically those related to accessible technologies) are evolving in respect of the apparent infusion of multidisciplinary practice as indicated within these bodies of research. A chronological review of both the aforementioned research and their respective research outputs reveals that over time the practice of user centred design has been increasingly influenced by the inclusion of designers in multidisciplinary teams and their influence on the design processes.

User-Centred Design (UCD)

Given its nature user-centred design as a field can be confusing to the uninitiated, comprising several sometimes conflicting approaches, each collated under the banner due to their individual involvement of user input, within the design process (Stolterman, 2008). These include human factors and ergonomics, participatory design (Greenbaum & Kyng, 1991; Schuler & Namioka, 1993; Sundblad, 2009), human-centred design processes (Beyer & Holtzblatt, 1998; BS EN ISO 13407:1999, 1999), usability measurements and inspections, i.e., usability engineering (ISO 9241-11, 1998); (Nielsen, 1993) and design for user experience (Norman D. A., 2003; Jordan, 2002). Furthermore, approaches such as user sensitive inclusive design (Brown, Standen, Evett, & Battersby, 2010; Newell & Gregor, 2000), user lead innovation (Von Hippel, 2005), worth centred design (Cockton, 2008) and usage-centred design (Constantine & Lockwood, 1999) are expanding the collection even further.

Donald Norman and Stephen Draper first introduced the term user-centred design in the title of their book User-Centred System Design: New Perspectives on Human-Computer Interaction (Norman & Draper, 1986). Within his seminal book: The Psychology of Everyday Things (POET) (Norman D. A., 1988), reprinted as the Design of Everyday Things (DOET) (Norman D. A., 2002), Norman defines user-centred design as a philosophy for design application by describing it as:

> *"A philosophy based on the needs and interests of the user, with an emphasis on making products usable and understandable.* (Norman D. A., 2002)*"*

This is a powerful definition as it determines active user involvement within the design cycle as a necessity, rather than as a component. By way of result, user-centred design can be characterised by a focus on designing for, and facilitating user influence in, the formulation and shape of product.

Since the advent of POET user-centred design has become the de-facto standard within the field of human-computing interaction for ensuring that the needs and interests of users are addressed. This status has been furthered, perhaps even driven, by a formalisation of the process in the standard (BS EN ISO 13407:1999, 1999) *Human-centred design processes for interactive systems*, its subsequent revision as BS EN ISO 9241-210:2010, and the associated ISO/TR 18529:2000 *Human-centred lifecycle process descriptions.* Earthy et al (2001), ascertain the publication of these standards as the maturing of user-centred design as discipline and as having obtained a level of recognition within the systems development community.

The User-Centred Design Model

In order to develop products that better meet the needs of their users, it is essential to enhance current design processes by incorporating techniques for usability and accessibility (Bevan, Design for Usability, 1999). As a philosophy, user-centred design can be characterised by a focus on designing for, and involving user influence in, the formulation and shape of a product (Norman D. A., 1988). As a standard, user-centred design can be determined as an approach to the design of interactive systems (BS EN ISO 13407:1999). Although focusing on computer systems, the principles of user-centred design are equally applicable to any interactive system used by humans (Bevan, Quality in use: Meeting user needs for quality, 1999).

It is commonplace within literature to define application of user-centred design as an iterative four stage process. Different terminologies are commonly used but fundamentally these four stages always involve the same kinds of activities, in which we: study, design, build and then evaluate. It is important to note however that as a process BS EN ISO 13407:1999 describes the user-centred design development cycle consisting of five stages. Before the phases of iteration can begin, an additional project planning stage must be completed. BS EN ISO 13407:1999 defines this initial stage as, *Plan the user-centred process.* The iterative nature of these activities as determined by Bevan is illustrated in Figure 13.

Figure 13: The interdependence of user-centred design activities

(Bevan, Design for Usability, 1999) & (BS EN ISO 13407:1999, 1999)

Maguire (1998) details the planning phase as the main cost of achieving the benefits of user-centred design. This is because to successfully employ user-centred design in practice, project planning must allow scope for iteration and for the incorporation of user feedback. Maguire also details the need for an enhanced requirement for effective communication between design team participants and for reconciling potential conflicts and trade-offs. Project managers will benefit from the additional creativity and ideas from an extended development team and skill base.

Standard BS EN ISO 13407:1999 defines the iteration phase of activities as:

1. ***Specify the context of use-*** *Identify the people who will use the product, what they will use it for, and under what conditions they will use it.*
2. ***Specify requirements-*** *Identify any business requirements or user goals that must be met for the product to be successful.*
3. ***Create design solutions-*** *This part of the process may be done in stages, building from a rough concept to a complete design.*
4. ***Evaluate designs-*** *The most important part of this process is that evaluation - ideally through usability testing with actual users - is as integral as quality testing is to good software development.*

Early in the design, user requirements will be at a high level whilst solutions and prototypes are likely to be low level. As design progresses, higher fidelity prototypes will be implemented and evaluated against more detailed requirements. The re-factoring of requirements within iteration of the cycle acts to specify the context in which a product will be used, and both the user and organisational constraints. Design solutions are then produced and then evaluated. The process ends and the product can be released once the derived requirements are achieved. Bevan (Bevan, Quality in use for all, 1999) describes the process as:

> *"...the sequence in which the activities are performed and the level of effort and detail that is appropriate varies depending on the design environment and the stage of the design process. (Bevan, 1999)"*

The Benefits of UCD

The primary difference of user-centred design from other design philosophies is that the practice tries to optimise the definition of product around how users can, want, or need to use the product, rather than forcing the user to change their behaviour to accommodate the product. This concept is of primary import and has been reported to have given rise to one of the most fundamental changes to occur in the fields of contemporary design, a shift of focus from form, to that of the human value and user experience:

> *"Design has shifted focus from giving form to objects and information to enabling user experiences, and from physical and cognitive human factors to the emotional, social and cultural contexts in which products and communications takes place.* (Boztepe, 2007)"

Without a doubt, involving users in design has been shown to lead to developing more usable satisfying designs (Buurman, 1997). The economic benefits of using user-centred design to improve "*quality in use*" (Bevan, Quality in use for all, 1999) have well been long understood (Bias & Mayhew, 1994; Keil & Carmel, 1995). Bevan also states that taking a user centred approach to design can reduce development times and rework for new versions, improve the productivity of users, and reduce training, documentation and support costs (International Standards for HCI and Usability, 2001). Brown and Mulley (1996) further this concept, demonstrating that user-centred design shortens overall development time and costs, by reducing the number of changes required in the latter stages of the design process. Studies by Vintner et al (1996) found that 60% of software defects arise from usability errors, while only 15% are related to functionality. The involvement of users in the design process is reported to lead to more effective, efficient and safer products and contributed to the acceptance and success of products (Preece, Rogers, & Sharp, 2002). Lannen et al (2002) describes usability as a crucial factor in the production of successful human computer interfaces and as central to the design process.

Norman suggests four basic principles of how a 'good' design should be:

- *Make it easy to determine what actions are possible at any moment.*
- *Make things visible, including the conceptual model of the system, the alternative actions, and the results of actions.*
- *Make it easy to evaluate the current state of the system.*
- *Follow natural mappings between intentions and the required actions; between actions and the resulting effect; and between the information that is visible and the interpretation of the system state.*

These principles place the user at the heart of the design process. However, the ways in which users' participation can vary; at one end of the scale involvement may be relatively light, users may be consulted about their needs, observed and participate in usability testing, whilst at the other end involvement can be intensive, with users participating throughout the design process as partners in the design activities (Abras, Maloney-Krichmar, & Preece, 2004).

The Barriers to UCD

A growing volume of literature has been identified demonstrating that user-centric design practice is often shunned in both an industry and academic settings, even by those who proclaim themselves as advocates of the process (see Mao, Vredenburg, W, & Carey, 2005). Confusingly, the rational for such opposition (factors such as: resource, time, and cost) often are the very arguments for adoption of such methods as previously discussed (see Bevan, 1999; Bevan, 2001). From this conflict within practice, we can conclude that something is missing and or drastically wrong with the process. In reality however the likelihood is probably much simpler; people/practitioners don't understand the concepts user-centred design and how to apply them correctly. This in itself can be seen as a reflection of the aforementioned need for the systemisation of the design method.

A large volume of studies categorically fail to mention the *"design"* approach used to generate design solutions and prototypes. The design information is often only reflected as the application of a "*design framework*" within a chosen "*design model*", this in itself is simply a reflection of the guidance provided within the standard (see BS EN ISO 13407:1999). Whilst this might just be semantics, the analysis of literature highlights a predominant focus toward need and method, for user-requirement analysis and the objective of quality, from the user's perspective, or to put it succinctly, the acquisition and verification of, and or via, usability (see Constantine & Lockwood, 1999; Spool, 2008).

Discussion of Findings

The following section summaries the knowledge gained during the process of literature review.

1. Need for accessible technology

Literature indicates that the future demand for accessible technology is only going to increase as society ages (Forrester Research, 2004). This is due to a strong correlation between disability and ageing (see APPLICA, CESEP & Alphametrics, 2007; Eurostat, 2008). Accessible technologies are seen as vital methods for ensuring the capability for independent living throughout an expanding period of life expectancy, and as a way to maintain and improve quality of life, integration and independence.

In the European Union, the exclusion of people with disabilities from the labour market is a serious concern from the perspective of equal opportunity. Furthermore, faced with a shrinking workforce as a result of transition towards gerontocracy, the European Union (EU) has highlighted a need to make the most of the untapped potential of those excluded from the labour market. To this end the EU has identified disabled people as a key priority group (European Council, 2006).

This together with the aforementioned correlation between ageing and disability creates a strong demand for accessibility and accessible technology and provides a definitive need for this research.

2. Disability & Video Gaming

There is a growing body of evidence that video gaming can contribute to the enhancement of quality of life for those with disability and/or impairment (e.g. Abbott, Brown, Evett, Standen, & Wright, 2011; Rizzo A. A., 2008). Furthermore, the literature details great potential benefits and advantages in applying games and gaming related technologies for the purposes of education and rehabilitation (e.g. Standen, Cromby, & Brown, 1998; Johannesson & Backlund, 2007; Deutsch, Borbely, Filler, Huhn, & Guarrera-Bowlby, 2008; Rizzo, Reger, Gahm, Difede, & Rothbaum, 2009; Brown, Standen, Evett, & Battersby, 2010; Cobb, Neale, & Reynolds, 1998; Brooks, 2004; Cobb, et al., 2010). However, despite this fact and a growing body of evidence console gaming platforms are found to be neglected as a medium for such applications (see IGDA, 2004; Forrester Research Inc, 2004).

3. Natural User Interface

Video gaming has been found to be at the forefront of a new field of research, the Natural User Interface (NUI). Evaluation of the ethos behind the emerging concept of NUI identifies a strong foundation of the field within that of Ubiquitous Computing (Greenfield, 2006). Core to this parent field are the works of Mark Weiser and the concept of Calm Technologies (Weiser & Brown, The Coming Age of Calm Technology, 1996). Combining the concept of designing for the periphery, with that of the Natural User Interface we can derive a powerful and innovative means for the application and development of interfaces.

As the interface is natural, we can use our investments in skill and our innate core abilities to gather, manipulate and act upon detail (Buxton, 2010). As this detail is located within our periphery, we are automatically attuned to it, and thus are able to bring selected elements to focus as required, whilst never becoming overburdened. It is hypothesised that this principal could be of vital import in respect to the development of functional and successful assistive technologies.

4. Pockets of Research

A variety of methods have been developed to support the design of assistive technology including usability testing, usability engineering, heuristic evaluation, discount evaluation and participatory design. Keinonen (2009) and many others (e.g. Beyer & Holtzblatt, 1998) describe user-centred design as the primary candidate for the role of determining the "*respect*" of user requirements and appreciation within the design process.

Since the advent of the initial description by Norman and the standard (BS EN ISO 13407:1999, 1999) derived from the research of Bevan (see Bevan, Design for Usability, 1999 & Bevan, Quality in use: Meeting user needs for quality, 1999) researchers have continued to evolve the user centred design paradigm and its application of use e.g. Lannen T (2002), Standen P. , Brown, Anderton & Battersby (2003), Keates, Clarkson, Harrison & Robinson (2000), McAdams & Kostovich (2011) and Brown D. J., Battersby, Standen, Anderton, & Harrison (2011). However, despite a large volume of research, it has been found that there is very little evidence of the systemisation of design method, both for the creation of design solutions and the resolution of design problems. There is a great call for such definition, especially from newcomers to the field (e.g. Chang, 2008) and from within the engineering and design communities (e.g. Gulliksen, et al., 2003; Spool, 2008; Stolterman, 2008; Keinonen, 2010).

5. User-Centred Design

The evaluation of design literature within the disciplines of Human Computing Interaction and Industrial Design indicates that overtime user-centred design has evolved to become a tenet of the design process (see Lidwell, Holden, & Butler, 2003; Thimbleby, 2008). Despite this fact however, many practitioners from the disciplines of HCI including those of ISRG seemingly apply both the notion of user-centred design, and sometimes even the model as described within BS EN ISO 13407:1999 as the design process itself. By way of result, activity has become naturally weighted towards the "analysis" aspects of practice. This is despite indication within the BS EN ISO 13407:1999 that the philosophy and activities of user-centric design should be conducted within the confines of established design practice.

With the re-issue of the standard as BS EN ISO 9241-210:2010 aspects of existing practice across the assistive technology development sector are now outdated. However, BS EN ISO 13407 can still be seen as a primary source of guidance within the majority of the evaluated assistive technology (specifically within the HCI disciplines) research and development literature. Whilst it is true that commentary within the re-issued standard highlights that the guidance contained has not changed substantially (BS EN ISO 9241-210:2010) there are a few vital caveats. For instance, the guidance now states that the elements of practice are now "required", thus reflecting the need for the improved structure of design practice to be established. Furthermore as the addition of a sixth principle: "*The design addresses the whole user experience*" can be seen to seriously impact on the philosophy of user-centred design, so too can the rebranding of the user to that of human.

Despite the suggestion of "subtle" change, the reality is that human-centred design now has an emphasis on the human side of human-computer interaction, and its affective results, rather than on the human performance aspects of usability which traditionally relates to the field of ergonomics (from which the standard was born). .

It has been found in some of the reviewed research, that the application of the model (Figure 13 and derived variants e.g. Figure 7) as described within BS EN ISO 13407:1999 and the works of Bevan (Bevan, Quality in use for all, 1999) is applied at face value. This has resulted in design practice weighing heavily in favour of the elements of "design analysis", where each of the phases of activity is applied in equal weight. In these instances, design can be determined to suffer from inadequate resource in respect to elements of "design synthesis" such as iteration, prototyping and build.

The evaluated literature of the ISRG indicates this issue to be especially prevalent within their conducted studies (e.g. Lannen T., 2002; Standen, Battersby & Lannen, 2002; Standen P., Brown, Anderton & Battersby, 2006). For example, the iteration presented within these studies (e.g. Standen P., Brown, Anderton, & Battersby, 2006; Battersby, Brown, Standen, Anderton, & Harrison, 2004) is found to be reflective only of design concept, and/or designs accompanying software solutions. In respect to the latter, the primary driver for such iteration is detailed as the enhancement of evaluation practice rather than to inform the design development. In respect to the former, there is evidence that attempt has been made to address this issue via the inclusion of methods to enhance prototyping efficiency (Battersby, Brown, Standen, Anderton, & Harrison, 2004) however there is still room for improvement. Whilst the inclusion of such practice can be seen to demonstrate an understanding the need for enhanced and effective communication as detailed by Maguire (1998), it can also be interpreted as a symptom of the design team attempting to retrofit iteration within the current USID design practice.

Utilising the works of the ISRG as a case in point (but not the sole culprit) more often than not there is little evidence of an evolving "physical" design repeatedly being placed in the hands of the users. The concept is notionally presented in theory; however literature repeatedly indicates such activity to be lacking in practice. Instead, use of low fidelity paper prototypes and/or virtual imagery is often presented to facilitate this role. Whilst this is both valid practice (see Buxton, 2007) and a valid means to involve users within the design and the collation of data (Lannen, 2002; Brown, Battersby, Standen & Anderton, 2005; Poulson, Ashby & Richardson, 1996), these works, and the justification of low fidelity prototyping, are representative of nonphysical software based products. Due to the nature of assistive technology, targeted audiences and the contexts of use, prototypes of a higher fidelity are required. The evolution of a design via sketching alone cannot be seen as a suitable implementation of the key principle of "user-centred design iteration". A design must be fully iterated and tested by stakeholders in real world contexts of use as much as possible.

The research analysed repeatedly indicates that the wealth of assistive technology design practice is focussed on the collation of context of use data and on evaluation activities. In effect, the practice of evaluation has become the activity of design practice. Whereas software has the ability to evolve, be duplicated and tested without great impact on design resource, in contrast an equivalent physical product, be it prototype or manufactured build, has to be produced each time from scratch. This impact is especially important in respect to both cost and time implications.

Research Questions

Utilising the knowledge gained several research questions have been formulated as means of addressing the overarching research objectives. In each instance a summary of the rationale behind each question is presented also reflecting the conclusions drawn via the investigation of literature.

Research Question 1

Rationale: There is a growing body of evidence that video gaming is a suitable medium for resources that aid in the enhancement and development of quality of life for those with a disability and or impairment. Furthermore, literature details promising benefits and advantages from utilising games and gaming related technologies for both education and rehabilitation. Despite this evidence however research also indicates that the console platforms of video gaming are neglected as a medium for such applications. Distribution of materials via console platforms could provide great benefits in terms of helping to tackle the high abandonment rates of assistive technologies and in terms of mainstream market penetration.

The primary barrier to the adoption of console based video gaming platforms by those with a disability or impairment are the control pad paradigms of interface (hardware and accompanying software schemas).

- RQ1: Are the current generations of console gaming platforms a viable platform for the delivery of accessible resources? Can the new modes of interaction made available via contemporary seventh generation hardware be utilised as means to afford access to those currently exiled by the gamepad paradigm of interface and its accompanying schemas for interaction?

Research Question 2

Rationale: It has been identified that the video gaming field is at the forefront of the Natural User Interface revolution and that its innovations are spearheading a transition towards new paradigms for human machine interaction. As these interfaces are "natural", it is hypothesized that we can use our investments in skill and our innate core abilities to gather, manipulate and act upon detail.

- RQ2: Can the concept of Natural User Interfaces be applied to the development of accessible technologies? Is it possible to apply the specialised investments in sense and skill of those with disabilities and/or impairments as methods for defining human-machine interface? If so, can such interfaces act to alleviate the traditional burdens of human-computer interaction for those people with physical, cognitive and/or sensory impairment?

Research Question 3

Rationale: Literature indicates that over the period of the last decade, a growing level of criticism and concern has been raised within the collective field of HCI in respect to the success of traditional user-centred design method (e.g. Constantine & Lockwood, 1999; Edwards, Bellotti, Dey, & Newman, 2003; Spool, 2008; Lai, Honda, & Yang, 2010). It has been argued that user-centred design and methods are not always useful for practitioners; that developed approaches are more often than not, too resource intensive, difficult to learn, difficult to apply, and most importantly do not lead to desired results when used in practice (see Vredenburg, Mao, Smith, & Carey, 2002; Mao, Vredenburg, W, & Carey, 2005; Stolterman, 2008). At the forefront of these criticisms is the repeated failure of assistive technologies to impact on the mainstream population and their high level of abandonment by those for which they were created (see Phillips & Zhao, 1993; Verza, Carvalho, Battaglia & Uccelli, 2006; Abbott, Brown, Evett, Standen & Wright, 2011). However such arguments seem non-apparent within the confines of human computing interaction driven disciplines of assistive technology research and development.

- RQ3: Is the application of current user-centred design practice truly an effective methodology for the development of assistive technology? Why is the application of user-centric methods repeatedly reported as successful despite the high level of abandonment by the target audiences for which they were created?

Research Question 4

Rationale: It has been found that in many of the reviewed studies that the model for user-centred design practice described within BS EN ISO 13407:1999 is often applied at face value to determine the structure of design activity. This has resulted in design practice, weighing heavily in favour of the elements of "design analysis". In these instances, design can be determined to suffer from inadequate resource in respect to elements of "design synthesis" such as iteration, prototyping and build.

- RQ4: Does the application of user-centred (or human) design impact on the weighting of design practice in terms of analysis verses synthesis? Is this division of balance important in respect to the development of accessible technologies? If so how can the practices of USID be enhanced as a means to alleviate and or rectify this issue?

A Plan for Achieving the Research Objectives

The plan for achieving the research objectives was derived with the following activities:

1. Restructure the application of USID using guidance from product design related literature (e.g. (Cross, Engineering design methods: strategies for product design - 4th Edition, 2008; Blessing, 1995; Dubberly, 1995; King & Sivaloganathan, 1999), examples of best practice for design integration within human-centric methods (e.g. Connell, et al., 1997; Newell & Gregor, 2000; Clarkson, 2008; McAdams & Kostovich, 2011) and standards for the application of design practice such as BS EN ISO 7000-2:2008.
2. Develop a model for the application of a human-centred design practice in accordance with guidance provided by BS EN ISO 9241-210:2010. The application of the model should aim to balance out the activities of design analysis and design synthesis.
3. Enhance the activity used to inform a design via adoption of contemporary tools and methods such as Product Dissection and Benchmarking (e.g. Wood, Jensen, Bezdek, & Otto, 2001; Lamancusa, Jorgensen, & Fridley, 1996).
4. Implement tools and methods to improve efficacy of design synthesis such as the inclusion of new design materials and use of rapid prototyping techniques.
5. Develop design tools and methods for the collation of data tailored to inform the design in relation to the philosophies of natural user interface and designing for the periphery.
6. Investigate the infusion of current USID evaluation activity within the developed practice.
7. Evaluate contemporary gaming interface controllers with regard to how well they support interaction for users with disabilities and impairments.
8. Evaluate contemporary gaming platforms with regard to how well they support interaction for users with disabilities and impairments.

The plan highlights the focus towards enhancement and restructure of USID practice. Not only is this reflective of questions derived during the process of literature investigation but also the experiences gained by the author as a designer within the EPSRC and Portland Switch studies.

The philosophy of NUI plays a vital role in this body of research and the concept of utilising gaming technology as potential platforms for assistive technology development.

Chapter 3: Methodology and Design Approach

The review of literature has resulted in the formation of several questions built around the needs and requirements of the research objectives as described in chapter one (Page 6). Using these questions as foundation, an 8 point plan (Page 46) for the achieving the research objectives has been derived. Utilising this plan, this chapter describes the steps taken to enhance the practice of the USID methodology and provide the foundation for practical investigative studies.

Re-Structure of the Design Process

The current practice of USID adopts an approach structured around the involvement of stakeholders within the design process. Whilst this is good practice, user involvement should be seen as a principle of the design process rather than the major driver for definition of practice. The true desired outcome for assistive technology design is the realisation of viable products that can bridge the gap (Figure 1) between demands from products; environment and user abilities (see Abbott, Brown, Evett, Standen, & Wright, 2011). The construct of design practice should reflect this. Whilst it is true that user involvement is crucial to achieving the design of successful products, care should be taken to ensure that design innovation and creativity design practice also play an equal role.

Figure 14: The design process at project level, BS EN ISO 7000-2:2008

Using the plan as an outline of work, it is determined that the USID method should be updated to reflect contemporary best practice in terms of both the structure of the design process and the activities of user participation within. To this end the design process is formulated to reflect the adoption of guidance for the application of Human Centred Design (BS EN ISO 9241-210:2010) within the process definition as that described within BS EN ISO 7000:2008. Figure 14 and the following point's detail an overview of the five phase design process as described in BS EN ISO 7000-2:2008:

- Phase 1 commences with the "trigger" which prompts the exploitation of an idea, and then goes on to investigate commercial viability and feasibility of the proposed project.
- Phase 2 establishes the overall product requirements, selects the preferred concept and generates the product specification.
- Phase 3 transforms the specification into a detailed design, while managing risks arising from innovative ideas or technology.
- Phase 4 moves the design into manufacture, and puts the product on sale.
- Phase 5 supports the product, and eventually considers withdrawal.

The verification and validation thread shown at the bottom of the diagram includes endorsing the design and approving continuation to the next phase. In this context a design can be determined fit to continue. This is a step has found lacking in the literature evaluated; where once the design process is initiated and an idea selected it is ultimately committed to. At a glance this is understandably a scary concept for many practitioners suggesting in reality that not all ideas are good ones, and sometimes even the best ideas can become unpractical in terms of resource, change in requirements and even expansion of knowledge. Therefore a design can, may, or even should be dropped. A scary prospect for many research teams!

However, rather than a design becoming "throw away", the indication here is rather that provision should be afforded to fully validate an idea or concept before allocating sizeable investment. Furthermore, both the design and design process should be implemented with provision for dealing with condition and edge cases[8]. Time should be allowed to formulate strategies for dealing with issues such as alternative needs, design error, user error, innovation and generic issues that can affect the design's ability to progress.

It is suggested that at each transition between the elements there are opportunities (but not solely) for the involvement of both multidisciplinary and user driven input within the practice.

[8] An edge case is a problem or situation that occurs only at an extreme (maximum or minimum) operating parameter. In engineering, the process of planning for and gracefully addressing edge cases can be a significant task, and one that may be overlooked or underestimated.

Adoption of a Human-Centred Approach

The practice of design is a problem solving process in which we analyse the problem and then synthesise a solution. What is also needed however is recognition that the elements of analysis and synthesis are interconnected; changing one variable in a design will affect other variables in that design and even other designs. The implication of which is that designers must not only consider particular elements of a design, but their relation to the design as a whole and their situation within the environment.

Observation has been made during literature review that both research of approaches and associated developed methods, such as the USID method applied by the ISRG have formulated activities around the definition of design practice as detailed within BS EN ISO 13407:1999. The result of which is that the application of the design process is heavily weighted towards design analysis and application suffers in respect to features such as design iteration.

Recognition of this fact (analysis driven practice and limited iteration) can be seen within the redefinition of the standard as BS EN ISO 9241-2010. A primary example of this is the revision of the model presented within the original standard (Figure 13) to that presented within the updated BS EN ISO 9241-2010, entitled the Interdependence of human-centred design activities (Figure 15).

Figure 15: Interdependence of human-centred design activities as described in (BS EN ISO 9241-210:2010, 2010)

Also of note is the rebranding of user centred design to that of human centred design and the enhanced indication of the iterative nature of design practice.

The standard describes 6 key principles that will ensure your design is human centred:

- The design is based upon an explicit understanding of users, tasks and environments.
- Users are involved throughout design and development.
- The design is driven and refined by user-centred evaluation.
- The process is iterative.
- The design addresses the whole user experience.
- The design team includes multidisciplinary skills and perspectives.

The exploration of each of these principles details the standard as an ideal manifesto for the development of assistive technologies in the context of developing practice:

1. The design is based upon an explicit understanding of users, tasks and environments:

   This principle is about understanding the design demographic targets' "context of use". A design team needs to understand the demographic target, understand what they want to do with the design and understand the environment in which the design will be used.

2. Users are involved throughout design and development:

   The purpose of this principle is to ensure design teams involve the designs demographic target audience in all design phases: not just by running a focus group at the start of design or by administering a survey at the end of design. The standard emphasises that user involvement needs to be "active": in other words, the design is not simply demonstrated to its target audience, rather that they should be engaged within the design. This can be achieved through field studies early in the design process and usability testing when an artefact (or Conceptual Model) becomes available. User involvement should be applied to the formulation of Conceptual Models grounding the design and multidisciplinary practice around user influence.

3. The design is driven and refined by user-centred evaluation:

   This point highlights that usability testing should be carried out throughout the design process. Prototypes of all fidelities should be placed within the hands of the target demographics. This includes, but is not limited to, preliminary designs such as paper prototypes. In the context of a physical product a design needs to be iterated by feedback. In reality a physical prototype in context is worth a thousand sketches and virtual mock-ups. This is especially important when dealing with those with disability and/or impairment and also those with limited knowledge and/or design experience. Physical prototyping makes an idea or concept real, and by way of result the detail collected via evaluation.

4. The process is iterative:

   This point is deeply interwoven with the previous one. The standard describes this principle unequivocally as: “The most appropriate design for an interactive system cannot typically be achieved without iteration.” The idea behind this principle is that it's extremely difficult, if not impossible, for members of the target demographic to explain what they need from a design.

   Therefore to determine what people need, you first have to show them something that they more than likely don't need, and then discover how to improve upon it. Furthermore this principle empowers the designer with the capacity for creativity. Just as it is unlikely for a demographic target to definitively define their wants and need, the same is true of the designer. A design must grow from requirements and exploration of design potentials with an ability to evolve which is paramount.

5. The design addresses the whole user experience:

   This principle was not mentioned in the previous incarnation of the standard (BS EN ISO 13407:1999). The likelihood is that it has been included in order to ensure that some people understand that usability isn't just about the maintenance factor of making things simple and easy to use, it’s about ensuring a good user experience:

   > *“...the concept of usability used in ISO 9241 is broader and, when interpreted from the perspective of the users' personal goals, can include the kind of perceptual and emotional aspects typically associated with user experience.”*

   To this end the standard defines usability as:

   > *“...extent to which a system, product or service can be used by specified users to achieve specified goals with effectiveness, efficiency and satisfaction in a specified context of use.”*

   It then hammers home the point by determining user experience as:

   > *“... person's perceptions and responses resulting from the use and/or anticipated use of a product, system or service...”*

6. The design team includes multidisciplinary skills and perspectives:

   The function of this principle is to ensure the application of a multidisciplinary approach is adopted within the application of the design process. The principle highlights that in order to approach human centred design properly a design team should consist of many influences. Human centric design requires a range of views and perspectives including, the voices of accessibility experts, end users and domain experts, as well as those of the designers.

The standard like its previous incarnation ISO 13407 does not prescribe a particular development methodology:

> *"The human-centred approach to design described in this part of ISO 9241 complements existing systems design approaches. It can be incorporated in approaches as diverse as object-oriented, waterfall and rapid application development."*

Though it may be obvious to some that the human centred approach is not a standalone methodology, literature indicates the need to reiterate the point.

So far current focus has been applied to the elements of structure and principles of "human" rather than "user" centric design practice. However, as indicated by the questions derived from literature analysis there is also requirement for enhancement of design activity. To address this issue the following sections of this chapter outlines suggested design activity which has been identified via literature investigation under the following headings:

- Concept Generation Tools
- New Design Tools
- New Design Materials

New Design Activities - Tools and Materials

The collation of the following tools and design materials is a result via the investigation of contemporary design literature.

Concept Generation Methods

In their research describing Flexible Design Strategies, King and Sivaloganathan (King & Sivaloganathan, Development of a Methodology for Concept Selection in Flexible Design Strategies, 1999) define Concept Selection as the Rubicon in the design process. They detail that it is vital the best initial concepts are selected, as these concepts determine the direction of the expression of a design idea. To this aim they perform a review of the most common concept creation methods used in contemporary design practice (see Table 2).

Table 2: A Summary of Concept Generation Methods as described by King & Sivaloganathan

	Brief description	Advantages	Disadvantages
Brainstorming method	An open group discussion with suggestion, discussion and agreement on ideas.	Can be done quickly and repeated.	Can lead to bias and intimidation of ideas.
'6-3-5' brainwriting method	A more controlled method of Brainstorming with each member adding to the others written ideas.	Can allow the communication of ideas without intimidation.	Can lead to frustration or boredom if not well managed.
Mind-mapping method	A group or individual way of breaking up ideas into a connected 'spider chart' map.	Can act as a good stimulus to other CSMs.	Can lead to a decomposition of the problem rather than solutions.
Sketch/model making method	A practical method of sketching and development to develop ideas.	Has a powerful graphical display and stimulation of other 'pictures'.	Can lead to early focusing on ideas and is time consuming.
Database search method	A formal method of accessing databases for key search terms.	Is not restricted by the knowledge or creativity of the group.	Limited to keywords and previously stored solutions.

Each of these tools is already common practice within the USID methodology, originally drawing guidance from works such as the UserFit handbook (Poulson, Ashby, & Richardson, 1996) and the research of Lannen (Lannen T. , 2002). Furthermore, practice has already been refined in order to facilitate effective communication in respect to the bespoke user group requirements (e.g. Battersby, Brown, Standen, Anderton, & Harrison, 2004; Brown D. , Battersby, Standen, & Anderton, 2005) and to reduce the subjectivity of design decisions (e.g. Ducat, 2002).

Via the analysis of these research studies it can be identified that the use of both sketch and model making is of prominent importance for the successful development of assistive hardware based products in reflection of disabled and impaired user requirements. This is because these techniques enable the most effective levels of communication.

Familiarity can be found between these disadvantages and the negative elements of design practice identified by Ducat (2002) and the conclusions drawn via literature (Page 42).

New Design Tools

Product Dissection

The dissection of a given product examines how the product works, the relationship between its parts and components and its functional and operational requirements. Through this practice, the vital features of a design and detailed execution of the design concept in order to meet product specifications can be identified, including elements of manufacturing and assembly (Lamancusa, Jorgensen, & Fridley, 1996).

Product Benchmarking

Benchmarking is a recognised technique for the identification of strengths and weaknesses. Its application typically consists of searching for examples of best practice and utilising them as a basis for both grading and improving performance. Thus in context, an existent design can then be built upon to obtain superior performance and product quality. The application of benchmarking across a range of products in a given situation means that market targeting can also be achieved, i.e. bottom through to top of range (see Lamancusa, Jorgensen, & Fridley, 1996; Fridley, Jorgensen, & Lamancusa, 1997; Wood, Jensen, Bezdek, & Otto, 2001).

Product Replication

Product Replication is effectively the duplication of existent products within constraints identified during the activity of product analysis, i.e. patent and copyright. The duplication of product in this manner provides:

- Reference for benchmarking by determining a viable "equal" product.
- Workable and practical platforms for the exercise of product re-design.
- Workable and practical platforms for the formation of conceptual models.
- Prototype materials that can be used to inform the design.
- Validation that a product can be used as a platform for concept creation and or testing.

Product Re-Design

When applied together, the activities of Product Dissection, Replication and Benchmarking afford a designer with hands on experience through the use of reverse engineering, which ultimately leads to the re-design of product built on an existent "benchmarked" solution.

This process affords an enhanced structure for the phases of Technology Review (Lannen T. , 2002) and offers an enhanced level of resource and knowledge that can be used to inform a design. Such exercises are also a proven method for instructing those new to the practice of design, the artefacts of design analysis and construct of design activities such as conceptual implementation and detailed design (see Wood, Jensen, Bezdek, & Otto, 2001; Lamancusa, Jorgensen, & Fridley, 1996; Fridley, Jorgensen, & Lamancusa, 1997). Therefore these activities can also be seen to aid in addressing the need for design related guidance as indicated by literature (e.g. Chang, 2008).

Product Study

When viewed as a collective, the activities of Product Study (dissection, benchmarking, replication and re-design) are in essence a “lite” application of the design process. The purpose of which is to identify current best practice and opportunities for design superiority across market segmentation.

Figure 16: Researching and analysing requirements as described in BS 7000-2:2008

As a tool the adoption of Product Study within the current USID phases of Technology Review provides formative structure to the process but also enhances design knowledge and resource that can be used to inform the design. To this end it is recommended that the analysis structure is also guided by the suggested model within BS 7000-2:2008 (Figure 16), and is adopted.

The SCAMPER Technique

SCAMPER is an acronym for an established design tool (see Ogot & Okudan-Kremer, 2004; Northey, 2005; Serrat, 2010) which is commonly used for generating concept ideas. It does this by promoting thoughts about how you could improve existing designs. Current SCAMPER practice is an evolution of the Checklist Method developed by Osborn (Osborn, 1963). Osborn's method used words and questions to trigger idea generation, reflecting the idea that creating something new is simply changing something that already exists. Michalko (Michalko, 1991, 2006) enhanced the practice by defining a fixed set of questions as the mnemonic of SCAMPER:

- Substitute – materials, components and so on
- Combine – mix and combine parts of other design or ideas
- Adapt – alter the design, change its function or the way it uses functions, use part of another idea and or element
- Magnify or Minify – reduce or increase the size of the whole design or elements of it, or change its shape
- Put to another use – determine if there is an alternative application for your design? Ask if it could have more than one function.
- Eliminate or Elaborate – remove and reduce parts, simplify to basics. (Ockham's razor, see (Lidwell, Holden, & Butler, 2003)).
- Rearrange or Reverse – turn the design inside out or upside down.

These headings provide a checklist for stimulating ideas for potential product modification. To apply SCAMPER, you first take an existing product or service. You then ask questions about the product, using the mnemonic as a guide. Finally, you look at all the answers to these questions to see if any stand out as viable for further exploration. In reflection of FLOOD, SCAMPER can be used as a both a springboard for idea generation and as a method to recursively iterate design concepts via application within each modular element of a design.

New Design Materials

Microcontroller Prototyping

A microcontroller is a small low powered computer on a chip. They contain a processor, memory and programmable input/output peripherals much like a general-purpose computer, however in a greatly reduced capacity. Microcontrollers are specifically designed for embedded application; that is a physical computing platform and is completely encapsulated by the device it controls such as general household appliances, mobile phones and or computer peripherals.

Microcontroller prototyping solutions, such as the Arduino and Netduino, are essentially printed circuit boards used to mechanically support and electrically connect external electronic components to the microcontroller via "breaking out" each of the controllers conductors to a terminal where they can be connected to for ease of use. They can be used to develop stand-alone interactive objects or can be connected to software on a desktop or tablet computer.

The use of such Microcontroller prototyping platforms as a basis for logically controlled electronic prototyping development can be determined as a strong tool for improving the design process by affording development capability for previously specialised electronic products.

Breakout Prototyping

Breakout boards are a printed circuit board, or PCB, used to mechanically support and electrically connect electronic components via "breaking out" each conductor to a terminal where they can be connected to for easy use. Commonly, the spacing between the terminals is implemented so that the boards can be fitted with terminal header pins and used in conjunction with both solder-less breadboards and strip-board for non-permanent prototyping as well as permanent installation.

Microcontroller Shields

Microcontroller Shields are boards that can be plugged on top of the microcontroller PCB extending its capabilities. In essence shields are enhanced all in one breakout solutions that share the same footprint as the microcontroller PCB and have been implemented to provide them with plug and play functionality. Simply, shields are plug-in electronic circuits that contain additional circuit elements to those found on breakout boards, the most basic example of which would be wiring.

Manufacturing Consideration

By utilising the new design materials of component breakouts and microcontrollers, design practice is empowered with the means for non-technologists to create and develop complex technology. Via new methods of technical exploration, a designer can rapidly prototype and realise electronic based technology that would have previously been impractical, if not impossible to achieve for such target audiences.

Despite these positive features however, and in reality, the reliability and endurance of such prototypes are far from adequate in terms of any real world implementation of our design. For example, as prototype design solutions, they are far too fragile to be presented to users for in depth testing. Furthermore, in some instances they would also be impractical to apply in the contexts of use envisaged. In a "product" related sense, such solutions are non-sufficient for numerous reasons. For example, in a manufacturing context, within their current state the prototypes can only be replicated by hand. Additionally, they would also suffer from limitations in respect to factors such as performance lifetime and miniaturisation (see SCAMPER tool).

What is needed is a formal way to document prototyping outcomes, and in turn methods to enable sharing of prototyping development within a multidisciplinary approach. Methods are needed to provide transition of the design/prototype to a stable, professionally produced (e.g. Printed Circuit Board, PCB) solution which is suitable for additional design tasks, such as user, and performance testing. Once a prototype is documented, the limitations of its breakout and/or breadboard construct become obsolete, as it can now be recreated from the documentation at any time by other designers and those responsible for manufacture. By combining such documentation with objectified source code (in the context of the microcontroller investigation), the complete blueprint for a design's electronic component manufacture is created.

Circuit Documentation Solution

Fortunately there are software solutions out there which have been created for just this task. However, much like the technologies for which they were created for, on the whole they are not very friendly for use by non-technical specialists. However, as Breakout and Arduino development is growing in prominence several software solutions are appearing that are developed with non-technologists in mind, and Fritzing is one such solution.

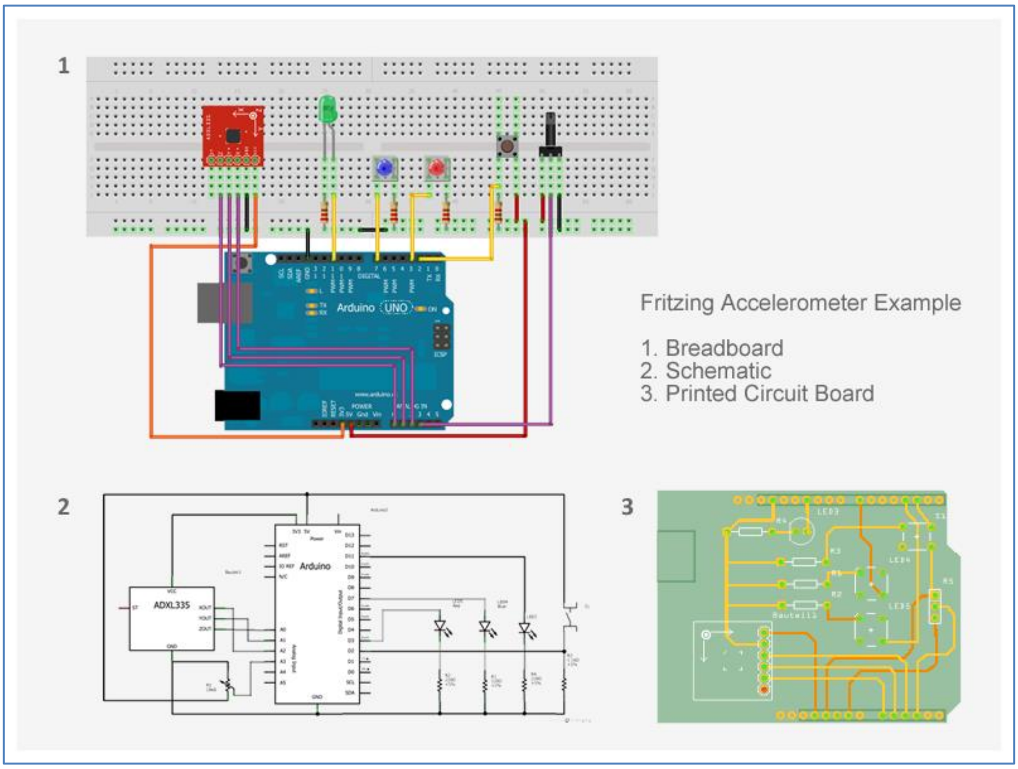


Figure 17: Example of Fritzing PCB Generation

Fritzing has been designed to lower the entry barrier for using electronics with artists and designers in mind; the software presents itself as intuitive and as hands-on as possible. Instead of starting with schematics, as most tools for engineers would do, the makers of Fritzing decided to allow a user to document their breadboard prototypes with a visual metaphor that mimics the real world prototyping situation. Once this is accomplished, the software allows the user to switch between a schematics view and a PCB view, where the initial breadboard circuit can be previewed as a PCB and exported for professional PCB production or self-manufacturing.

In order to create designs in a circuit board format all that is needed is to copy the real-world bread-board/breakout implementations via use of a GUI[9] (Figure 17, 1). Fritzing will then create a schematic view which can be modified in terms of layout for ease of reading (Figure 17, 2). Once either the breadboard or the schematic is completed, Fritzing can be used to automatically generate all the connections required for the PCB. Component layout can be modified by the designer to fit the bespoke requirements of the circuit, i.e. size of board and position of switches, etc. Using this method, a basic printed circuit board version of the entry level design (Figure 17, 3) can be created easily and efficiently without the need for extensive technical skills and knowledge.

Additive Printing

Additive Printing, more commonly known as 3D Printing, is a method of making physical and solid objects from a digital model. This is achieved by software slicing the model into layers and then successively printing out each layer one on top of another. Thanks to initiatives such as the RepRap community project (RepRap, 2004) 3D Printing has become both affordable and available to design practitioners, empowering design practice with capability for rapid production of physical prototypes. The amalgamation of this technology with the existent practice of Virtual Prototyping affords capability for prototypes to be efficiently realised and put into the hands of users in a cost effective manner.

[9] GUI – Graphical User Interface, in the context of Fritzing a graphically rich application that enables the build of electronic circuits via the drag, drop and manipulation of visual representations of electronic components.

Flexible Object Orientated Design

As a collective these activities act to enhance the practice of USID via defining a supplementary design approach specifically tailored to the design of assistive products. To this end each activity integrates to provide the rapid development of both physical and practical prototypes (in respect to the manufacture and detailed design phases) that can be iterated via both user and stakeholder feedback and the application in a real world context.

Coined as Flexible Object Orientated Design (FLOOD), this approach empowers the practice of USID in a way that affords a synergetic focus of the holistic activities of design analysis and synthesis. This is achieved via an influx of flexible design strategy built around the core elements of user centric involvement currently practiced within USID and the definition of design practice as found within standards of best practice (e.g. BS ISO EN:7000-2:2008).

Conceptual Modelling

At the heart of the FLOOD approach and central to its effort is the repeated application of conceptual modelling as a means to formulate design decisions based on a shared understanding. Design is a complex problem that when applied in a multidisciplinary approach often leaves practitioners confused in respect to the holistic view; in reality each practitioner only truly understands one small part of the problem, this in turn is usually reflected by their role and particular expertise. When implemented properly, the conceptual model should satisfy four fundamental objectives:

1. Enhance an individual's understanding of the representative design.
2. Facilitate efficient conveyance of design details between stakeholders.
3. Provide a point of reference for designers to extract design specifications.
4. Document the design for future reference and provide a means for collaboration.

Conceptual modelling plays an important role in the design cycle and when not fully developed, the execution of the activities of design practice may fail to be conducted correctly or even at all. This in turn impacts on both the design itself and the design process. An analysis of the literature in respect to research within this field indicates that these failures do occur (e.g. Brown D. J., Battersby, Standen, Anderton, & Harrison, 2011).

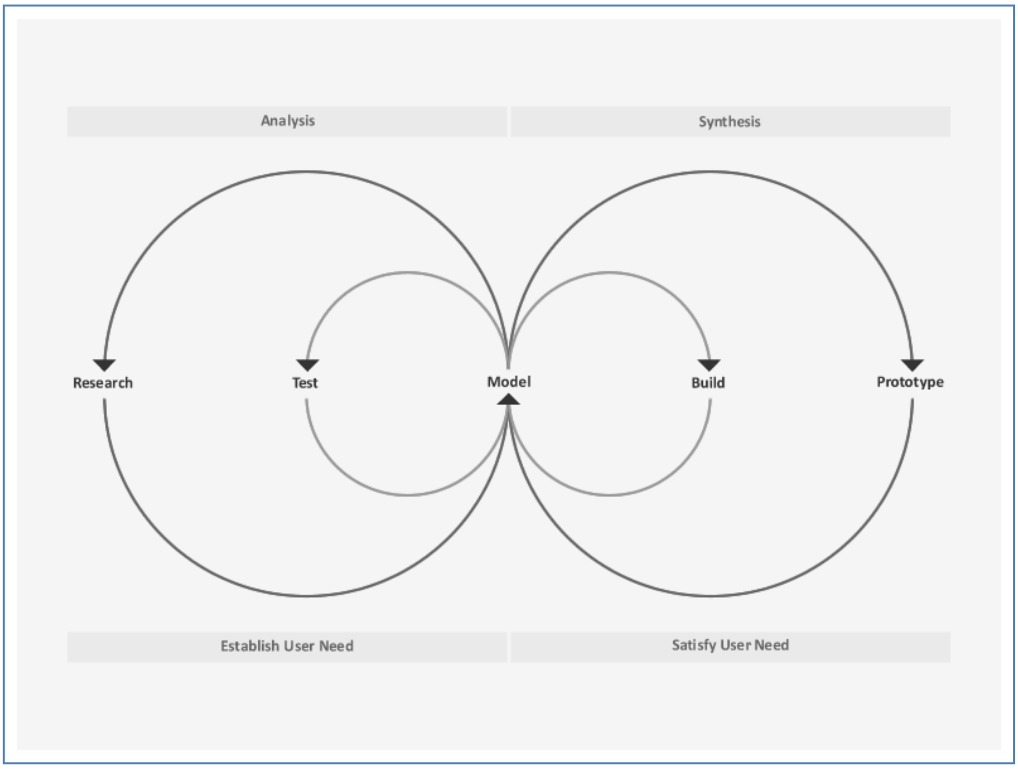


Figure 18: Flexible Object Orientated Design (FLOOD) Activity

FLOOD is a powerful design model that enables design practice with capability for future product concept creation, expansion, re-definition and adaptation. In effect, the design is empowered with the ability to evolve. This is important from the perspective of human centric design as such practice is often volatile in nature due to the nuances of people, a factor only exasperated when viewed in the contexts of disability and impairment. The FLOOD design model has been developed to describe a holistic view of the human centred design activity; detailing not only the iterative and interconnected nature of design practice, but also the key elements that act to define its structure (Figure 18).

By reflecting on the traditional goals of such models; description, prescription and explanation, the practical elements of design practice can also be determined. The model has been developed for multidisciplinary application. Central to this is iterative Conceptual Modelling via design stakeholders, such as practitioners, evaluators, advisers and target users. In contrast to typical UCD activity, models such as those shown within Figure 8 & Figure 15 adopt a ‘middle-out’ approach for design activity (see Crane, 2005). Crane describes the “middle-out” approach as one that enables the design to both address details quickly and address larger conceptual questions. By way of result detailed work springs from a logical foundation and results in a cohesive product.

In respect to this research the adoption of a ‘middle-out’ approach is on reflection a combination of the traditional strategies for design practice: top-down and bottom-up (see Cross, 2004). This empowers the process with the capability to begin with an existing conceptual model and then design other supplementary parts and/or adapt as required (see SCAMPER). In effect you analyse the design’s intent and via application of the described activity, develop the design via utilising existing components or the creation of new ones as required.

It is important to note that the model is only descriptive of design activity and not the structure of the design process. Guidance for the process is described within BS EN ISO 9241-410:2008 and illustrated within Figure 15.

Chapter 4: Appling FLOOD for Idea Generation

Using the research objectives (Page 6) and questions derived following the literature review (Page 46), several enhancements of the USID method have been suggested (Page 50). These include the introduction of new design tools, materials and methods for both the improvement of the structure and the synthesis of elements of design practice. A supplementary approach to the existing practice of USID methodology (FLOOD) has been proposed that facilitates the rapid production of physical and practical design prototypes which can be placed in the hands of users.

In order to validate these innovations of practice, it is proposed that several design case studies should be implemented to test the validity of such innovations within the overarching design process. However, before such innovations can be applied, the generation of project ideas is first needed to determine triggers for potential product and/or research development.

The advantages of this are as follows:

1. It allows the author to drive the initial application of the derived process in order to identify elements of best practice and weakness and formulate enhancements in real time before in-depth application within USID. Experience of the process was deemed to be required before any attempt was made to infuse the new practice with existent multidisciplinary activity. This in turn would ensure that the resource usage would be minimal in case the approach turned out to be non-viable. This in itself is reflective of guidance provided by literature, such as BS EN ISO 7000:2008 under the banner of 'feasibility investigation'.
2. If the application is successful, it would verify the new practice as a viable means for project generation. Generally the demonstrated application of design process as determined via literature commences via a design trigger. There is usually no indication toward the formulation of the "raw" project need behind the definition of a design project.
3. It allows for the research objective 1 to be fully addressed. This activity allows the investigation of gaming peripheral technologies as suitable assistive products and technologies. If proven viable, further research in the form of case studies can be utilised to further verify the concept of utilizing gaming technologies for the definition of assistive products providing evidence for its validity.
4. It allows for research objective 2 to be fully addressed. This activity allows for the investigation of the mapping of existent skill-sets and skill investments as means for defining input modalities. By utilising the concepts of NUI and designing for the periphery as a basis for concept generation, ideas can be formulated to test the hypothesis of using the principle of NUI for the definition of input modality and paradigms for interface.

In order to address the research objectives the Nintendo Wii Controller was selected as the primary candidate for the initial investigation and experimentation. The rationale for this was decision was reflection on current trends within the gaming technology arena and the growing interest with the device within assistive technology development communities.

Product Study: The Nintendo Wii Controller

The application of product studies greatly aid the acquisition of knowledge in terms of both competitive products and viable mainstream product definition. In essence a product study, or analysis, is itself a "lite" application of our design process. To this end the creative elements of our process are capped and focus is applied to the collation of "Product Analysis" design data as described within BS 7000-2:2008 (Figure 16).

Product Analysis

The Wii Controller is a motion sensing peripheral, designed and developed as the controller for Nintendo's 7th generation games console, the Nintendo Wii. Since its release in 2006 the Wii Controller has gone on to be one of the most sophisticated and widespread input devices in the world. Based on a handheld remote design the Wii Controller utilises a blend of optical sensor and inertial measurement technology to provide orientation and positional tracking capability.

Figure 19: The Nintendo Wii Controller and Nunchuk Extension, Nintendo.com

The Wii Controller (Figure 19) adopts a one-handed remote control based design, a significant contrast to the traditional two handed approach of the game-pad. The generally adopted rationale for this radical change in design was to make new methods for interaction offered by the device more intuitive. The familiarity of the remote control concept acts to emphasise the ergonomic fit of the device and rudimentary functionality can be determined almost immediately. The lack of shaped definitive features, such as grip, enables the device to be treated and held like a universal handle. This feature is powerful and when complimented by the Wii Controller's motion sensing capabilities enabling the device with many potential methods of interface.

In effect the motion of the device itself can be seen as one of the missing joysticks of the traditional game-pad paradigm of interface. This feature comes into its own when viewed in conjunction with one of the Wii Controllers most unique features; its capability for expansion. The Wii console's controller system is in reality a collection of component devices, which are adaptable to functional requirements and complexity designated by the application of game-play. Nintendo describe this feature of the Wii Controller as an expanding operating device and operating system (Urata, et al., 2010).[10]

The Wii Controller as a central component or module of this system provides only the raw components needed to facilitate rudimentary game-play, and system navigation. As a secondary function the device also acts as a hub for any additional interface required to compliment the functionality of the base unit. The advantage of this feature is that interface complexity can be swapped and changed to match the requirement of game-play. This in turn can also be achieved via software complement, hardware complement or a blend of both. This means that a variety of control schemas can be created, dependent upon context and ability, and those of best fit adopted by the consumer.

The body of the Wii Controller measures 148mm in length, 36.2mm in width with a depth of 30.8mm at its most prominent points. Weight is an important aspect of the Wii Controller's design. Unlike the traditional two handed support the Wii Controller predominately adopts a single handed approach in its default mode of operation. With the attachment of an extension device both hands are used however, and unlike the traditional joy-pad design, each hand is responsible for the support of a unique load.

The Wii Controller's design utilises a variety of textures to enhance its aesthetic, ergonomic and physical characteristics. The predominant feature of texture can be seen by the division between the

[10] Nintendo patent application originally filed 2008/12/219,851 issued as documented 2010

upper and lower casing sections of the unit. The upper section consists of a shiny glossy smooth finished surface that facilitates a minimal amount of traction, thus allowing the thumb to easily glide between buttons. This attribute is also present on the majority of buttons themselves facilitating enhanced transition during game-play.

In contrast the base section of the unit (approximately ¾ of the device) consists of a matt style finish that offers a higher level of adhesion. This feature is also apparent on the D-pad and B buttons where a finer element of control and grip is needed. The influence of texture can also be determined in definition of the shape of the unit. Both act to enhance the design's ergonomic characteristics.

Markings on the inside of the Wii Controller casing indicate that the predominant material used in the construction of the Wii Controller casing is Acrylonitrile Butadiene Styrene (ABS). Accompanying markings a1-4 and a2-1 are suggestive of ratios, however this cannot be confirmed. The most important mechanical properties of ABS are impact resistance and toughness. These qualities are reflective of the proportions of the component materials.

Interface with the Wii Controller

To ensure that the reuse of the Wii Controller is feasible without modification, investigation of the hardware is needed in respect of its capability for custom (non-Wii) system interface. The successful result of this would verify development of technology as practical and would also facilitate the development of "conceptual "(non-licensed) software. To this effect, it would be possible to validate the use of this hardware as a suitable distribution platform for our target audiences, and for the testing of related design ideas (non-Wii).

Bluetooth Connection

Interfacing the Wii Controller with a standard PC is an easy task. This is because the hardware uses Bluetooth to communicate with the Wii; therefore it can be connected to, and used by, practically any Bluetooth capable device. Pairing and connection is conducted via the standard methods provided by the operating system. Interface is achieved by setting the controller to discoverable mode by either utilising the Wii Controller's sync button or by pressing the Wii Controller's 1 and 2 buttons at the same time. Once in this mode (indicated by flashing LED's) the host's Bluetooth HID driver can query the Wii Controller.

Hardware Driver and API

Over the holistic period of the research several driver and API solutions were located and evaluated to assess their capability in providing the required protocols for communication between the hardware and the Windows family of operating systems. Windows was selected as the target platform as a direct result from analysing the environmental design data. Research continuously indicated that the Windows OS was the primary platform utilised by both users and the institutions which formulated both target demographics and stakeholder bodies.

Communicating with the Wii Controller

When this research work was conducted the use of Wii technology was highly innovative, and the alternative available solutions for interface were then extremely limited.

The GlovePIE API

The Glove Programmable Input Emulator (GlovePIE) acts a bridge between the Wii Controller device and Windows applications via use of custom scripts (Kenner, 2007). It was originally developed for the emulation of Joystick and Keyboard Input with the Essential Reality P5 Glove (Cyberworld Inc, 2007). In order to use GlovePIE as an effective means of communication with the Windows operating system several scripts had to be developed for mouse control, joystick emulation and keyboard mapping.

Table 3: Available Wii Controller Drivers and API's

Driver	About	Language
GlovePIE		Custom scripting
Managed Library for Nintendo's Wii Controller	Library includes source code and test harness samples	C# and VB
WiiYourself	Fully-featured Wii Controller native library.	C++
Wiiuse	Cross-platform C library	C

The construction of the GlovePIE software was limited to the mapping of input provided by the hardware to that of the traditional computing paradigms, i.e. keyboard and mouse. It was determined that this could be resolved by developing a socket communication link between the software and any potentially developed software for raw data access, however this would result in both complexity for the user in terms of set-up, but also utilisation of additional system resource that could impact on the limited hardware, as usually found within institutional use (e.g. The Portland College & The Shepherds School).

It was determined that an integrated API solution was needed which could be packaged within any developed software, and/or run silently in the background with minimal resource impact. Table 3 details a selection of Wii Controller drivers reviewed during the period of this research.

WiimoteLib

WiimoteLib is a .NET managed library for using a Nintendo Wii Controller and extension controllers from a .NET application (Peek, 2008). It is available through the Microsoft Developer Network Open Source project website, CodePlex .This library has been developed with the help of many different developers from around the world (including the author) to produce the best API for the Wii Controller available. The decision was made to use the .Net Managed Library for Nintendo's Wii Controller, WiimoteLib ((Peek, 2008) based on the following factors:

- It was (at the time) the most stable and feature complete API for the Wii Controller available.
- It had a solid and expansive user base and development community.
- It had compatibility with the .Net Framework and Windows OS:
    - Compatible with Microsoft's XNA Games Studio.
    - Compatible with Microsoft Robotics Studio (MSRS).
    - Compatible with Win-Forms and Windows Presentation Foundation (WPF).
    - Compatible with Microsoft Silverlight.

Authored as a dynamic link library, WiimoteLib can be packaged within.Net software frameworks and also run as a system service via these frameworks. With the development of the system interface via both GlovePIE and WiimoteLib respectively, it was determined that interfacing with the Wii Controller hardware was possible.

Determining Prior Art

The application of product analysis provides an opportunity to introduce a vital but often missed element to the design process, the investigation of prior art. Under the title*, Meeting standards and dealing with legal issues*, BS 7000-2:2008 indicates that investigation of prior art should be conducted as part of any researching and analysing requirements phase of the design process. It states that the investigation of prior art enables the identification of any patents and potential legal issues that might act to constrain the product development. Additionally, prior art or patents can provide details on viable methods for achieving or realising a product, if they are licensed or expired.

Existing applications (Patent) can be used to not only inform detail and insight into the "problem" as seen by others, but also be used as a basis to inspire creation of innovative methods for addressing the problem and product need.

In summary the investigation of prior art during both the product analysis and the encompassing design process, has two main important functions:

- Provision of technical information
    - Helps to determine how a product works.
    - Provides insight into a product’s definition.
- Provision of intellectual constraints
    - Identifies design limitations.
    - Provides basis for product viability.
    - Can protect against faux innovation.

It should be noted that in contrast to patent, prior art is any information that has been made available to the public in any form before a given date, which might be relevant to a patent's claims of originality. If the information is determined as prior art and not under the constraints of patent and/or copyright, then the information is viable for use. Interestingly, reference to this process has been found to be almost none existent in the reviewed literature on human computing interaction design; however, whilst it is true that this can be explained in regards of frequent suggestion of *“application of design within a derived and accepted model”,* the conclusion is that this is unlikely. On the rare occasions where mention of patent is featured it is only to indicate or claim ownership of innovation.

A large volume of patent documentation, in regards to the protected intellectual innovation of related Nintendo products has been identified e.g. Ohta (2008), Sato (2008), Koizumi, Hayakawa, Aoyagi, & Ishihara (2008), Okamura (2009), Sato, Yamashita, & Shimamura (2010), Sato, Ikeda, Ito, Kuroda, & Urata (2010), Urata, et al (2010), Ikeda, Kuroda, Urata, & Ito (2011) and Ikeda, Ito, Kuroda, Takeda, & Urata (2011).

Furthermore, the review of patent law within the gaming and related technology arenas, highlights these technologies as both a volatile and active arena in terms of both protected prior art and patent. A lack of prior art consideration can result in investment and development of innovation, which from the outset have no capable or viable means (until patent expiry or with licence and restriction) of mainstream realisation. In context, many academic investigations and their resulting assistive technology fail to be viable in terms of their potential for becoming a mainstream product. The recent trend of the adoption of Wii technologies is a prominent example of this. In these instances, the product’s impact is restricted to the confines of the design process, accompanying study and user self-implementation due to legal constraint.

Pursuit of Development Licensing

In reflection of prior art, Nintendo were contacted and informed of our intention to investigate the potential of the Wii Controller and Wii Console for the research and development of assistive technology. An Ideal outcome would have been the offer of aid and licensing permission to both further the investigation and develop the technology for the mutual benefit of both parties. The ability to utilise the console hardware as a platform for application would have proved invaluable as far as our target audience's and the platform's further definition were concerned. In essence, any developed solution would have had the capability of being able to be run by those that have ownership of the console.

Those with disabilities and impairments belong to an expanding demographic, and one which has been seen to far surpass the definition of *"core gamer",* thus facilitating a vast potential test-bed for solutions in their desired context of use. Nintendo, however, took the stance that any academic involvement would be a potential security risk in terms of intellectual property and declined both assistance and involvement in the research. With the advent of the Nintendo home developer program (WiiWare), Nintendo were again contacted in regard to potential research involvement, and/or licensing, for the development of hardware and software. Nintendo again declined, detailing that an academic environment is seen as a security risk and that any form of involvement would be very unlikely.

This factor does not affect our ability to prove that the console is viable as a platform for the distribution of assistive technologies, and also to prove whether or not gaming interface controllers can support interaction for those with disabilities and impairment. It does, however, impact on potential mainstreaming of any developed design that is tied to the technology of the Wii.

Reflection of Product Lifecycle

All products progress through four phases of existence: birth, growth, maturity and decline. Understanding the implications of each phase allows the detail of the design to be informed and affords provision for evolving requirements of a product to be addressed over its lifetime. The needs of a product change over the course of its life cycle and it is important to understand the dynamics of these changes in order to increase the lifespan, and thus the resulting impact of the product. Product lifespan is an important aspect to consider when determining materials and a key factor in the design.

In our studies we have identified that traditional games consoles have had on average a five to ten year lifecycle depending on vendor. Nintendo generally adopt a five to six year lifecycle for their products. Therefore we can assume that any design that we implement that utilises the technology of the Wii Controller may be limited to an equivalent period due to product availability.

Furthermore, in the context of the product lifecycle we must be aware that the industry often adopts strategies such as feature enhancement, and product iteration during the maturity phase of the lifecycle, as a means of addressing product retention. Therefore we can also assume that product availability could and would most likely be even shorter. This is an especially prevalent issue with the Wii Controller as the main software architectures used for interfacing the device with a PC are non-official, and therefore reliant upon the continued efforts of those who perform reverse engineering of the technology, and development of accompanying APIs. This in itself is extremely high risk, and potentially illegal.

Product Dissection & Benchmarking

It has been established that there are issues with the use of the Wii Controller as a licensed platform. Therefore in order for the continued application of the technology within this research to be viable, the device must be verified as a spring-board for concept creation and testing. To this end we must be able to re-create the hardware and duplicate its functionality within legal constraints. This can be achieved via the activities of both Product Dissection and Benchmarking.

Furthermore as discussed in Chapter 3 (Methodology and Design Approach, Page 50) the application of these activities allow us to examine the vital features of a design, and also how others have executed the design in order to meet product specification. This can be used as a basis for design innovation and to improve performance and quality.

The first stage in this task is to break down the device into both its operational functionality and component parts. There are many examples in literature which detail methods for undertaking this task and the benefit of doing so. For example, in the studies of King and Sivaloganathan (King & Sivaloganathan, 2008) the authors describe a systematic methodology to identify, describe and systematise the functions of a design for the development of flexible product, whilst the studies of McAdams & Kostovich (2011) present a product analysis framework via the combination of activity diagrams and functional models for the development of Universal Designs.

Both of these examples form a strong basis for the approach adopted here. In our approach however the initial breakdown was completed via a focus on the device’s component parts. This was achieved via deconstructing the device and using a blend of available literature (wiili.org, wiili.org, 2006) and component identification via part reference. Table 4 and Figure 20 describe the division of key elements that facilitate the function of the device and provide examples of the activities undertaken at this stage.

Table 4: The Key Elements that Facilitate the Function of the Wii Controller (Wii Controller)

Functional Elements of The Wii Controller		
Element	**Artefact**	**Description**
Encasement	Bodywork	ABS shell
Controller	Microcontroller	BCM2042
Memory	EEPROM	128kbit (= 16kB) EEPROM chip
Communication interface	Wireless/Bluetooth	BCM2042
Peripheral Input	Accelerometer	ADXL 330 Analog Devices
	Optical Sensor	PixArt, 8x subpixel analysis to provide a 1024x768 resolution for the tracked points
	Buttons	Standard membrane
Extension port	I2C Interface	Proprietary connector
Power source	Common battery	AA 1.5V will work with two AA 1.2V rechargeable
Feedback	Speaker	Piezoelectric
	LED's	4 * circuit mounted, colour blue
	Haptic Rumble motor	Offset motor equivalent to pager motor

From this simple breakdown all of the artefacts needed to replicate an equivalent device are defined. These were then used to draw a rudimentary specification for replication and were also fed into the design by analysis of the product. For example, via such analysis we outlined elements such as battery life, weight and form.

It is important to note however that is was not our intention to invest a large volume of resource in the replication of a technology if this process was not economically viable.

With this in mind we can rationalise the need for development of a fully featured solution and instead concentrate on the key areas that demonstrate the product's feasibility. For example, we can ignore the replication of the encasement and also the need for communication to be wireless.

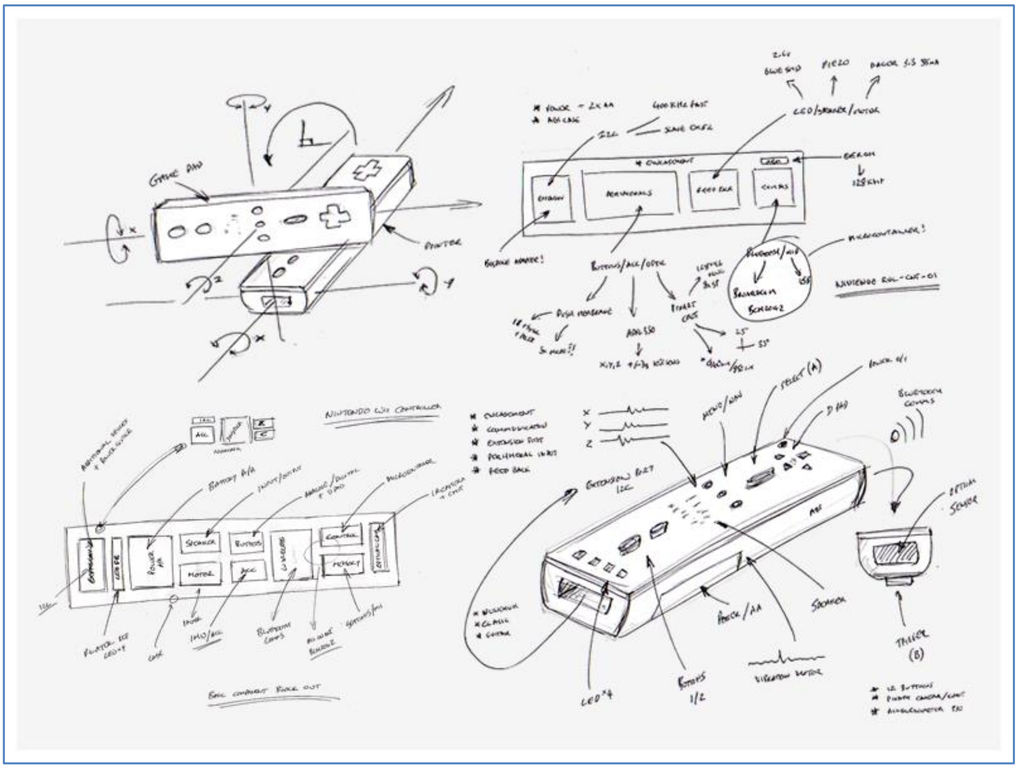


Figure 20: Sketches of the Component Breakdown of Wii Controller

The following sections summarise each of the areas of the technology identified for replication.

Encasement: The production of encasement at this phase is not critical for the demonstration of hardware replication. However, in order for our replication to be viable we must identify solutions that will comply with the original hardware as determined during our design analysis such as size and weight.

Communication: In terms of communication we can rationalise this requirement simply as the need for our device to be able to act as an open pipe that enables a two way transfer of data between the device and a host machine.

Extension Port: To facilitate the replication of the extension port, another communication pipe is also needed to allow transfer of data with "plug and play" peripherals such as those available for the Wii. This data must be able to also be packaged and utilised by the host.

Peripheral Input: In terms of peripheral input the key issue is the affordance of replication with motion sensing capability. The replication of button input can be determined to be feasible via a single instance, as long as we can verify that this capability can be expanded upon to reflect our derived requirements.

The optical sensor however is a special case, whilst it is true that we can include an equivalent camera solution to that found in the Wii Controller we must also reflect some of the findings of the product analysis. The investigation of related patent literature indicates that the potential use of a sensor bar and Wii Controller equivalent to an Optical Sensor for the purposes of providing yaw tracking and pointer functionality may cause infringement of protected intellectual property (see Ohta, 2008; Okamura, 2009). To resolve this issue reversing the system and utilising LED's mounted within the body of the replicated technology, infringement could be avoided (e.g. Bradski & Kaehle, 2008) and we can determine it as safe.

By utilising a system based camera, a higher degree of computer vision capability would be facilitated, in turn enabling:

- Object tracking
- Colour tracking
- Video streaming (RGB)

This is core to the functional expansion of the system that opens up further potential for the development of intuitive periphery enhancement. The application of such technologies is also viable as prior art (as aforementioned Bradski & Kaehle, 2008). It has become commonplace for desktop computers and personal laptops to be delivered with built in web cameras and for those without a large range of economically priced USB plug and play solutions are available. This means we can rule out the need for the implementation of a camera solution at this stage. Our task in this context becomes the implementation of visible tracking markers.

Feedback: In order to achieve feedback on replication we must at least be able to demonstrate independent and variable control of an output peripheral. In the case of the Wii controller the key peripheral is the force feedback motor. However, in order to demonstrate feature capability we should also include the control of LED's. Due to the unavailability of speaker communication in the current releases of the Wii Controller API's (e.g. Peek, 2008) it is rationalised that speaker communication can be left out at this stage. The control of both motor and LED's demonstrates an equivalent application in terms of auditory cues, such as a buzzer.

Product Replication

Using the functional outline of the Wii Controller as foundation, a technology review is next conducted in order to identify component parts for both the activities of re-design and replication prototyping. Many of the components have already been identified by the dissection process; however there is need to tie down further specialised components. Fortunately, the activities of product analysis and dissection can be reflected upon to provide specific component details; these can be used to identify breakout solutions for the technology, or at least equivalent implementation.

Concentrating on the accelerometer as an example, product analysis identified that the accelerometer within the Wii Controller is that of type ADXL 330, developed by Analog Devices. However this has now been superseded by the ADXL 335 (see Reflection of Product Lifecycle). Both solutions offer the same functionality, however the 335 is an improvement on the original solution.

Another factor that should be considered at this stage of design is cost. We should try and opt for the most affordable solutions for practical implementation, as at stage we are only trying to rudimentarily verify the capability to replicate the hardware. In respect to the application of re-design however, this consideration may also become important depending upon the market targeted (see Product Benchmarking). It is good practice to cover all bases and evaluate several "graded" potential solutions as demonstrated in Figure 21.

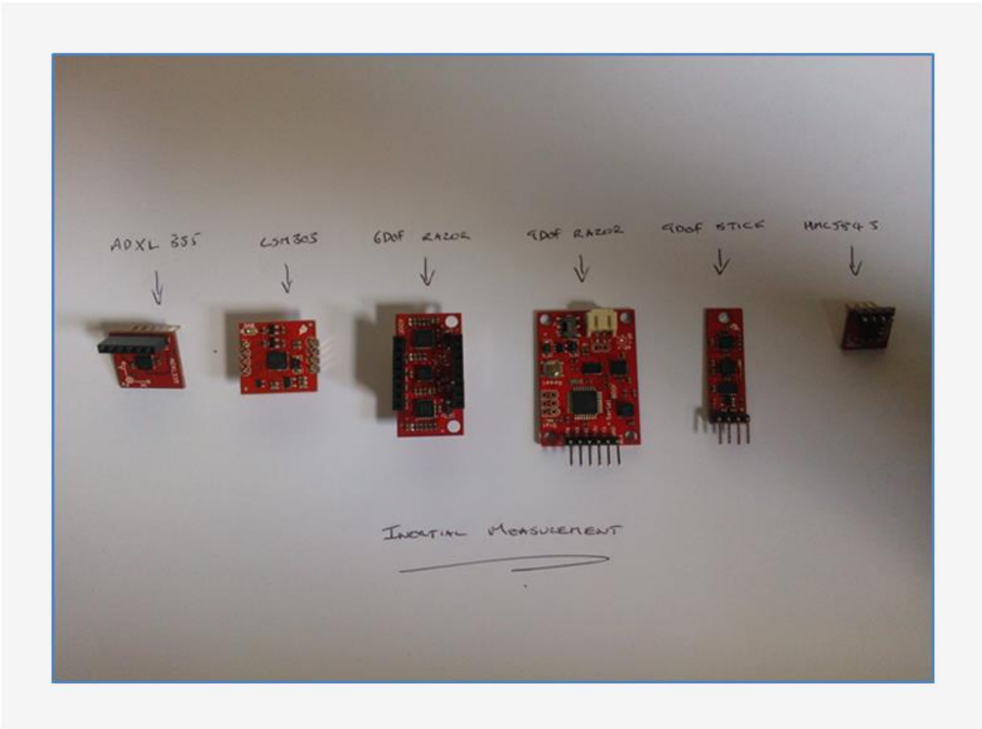


Figure 21: Example of Graded Solutions for the duplication of Accelerometer Functionality

Once complete and components are selected, physical implementation via breakout prototyping is conducted. Reference should be made to any patent and/or copyright limitations previously identified. Exact system replication would be an infringement of patent and/or copyright. In these instances, a bespoke and/or viable solution should hopefully be identified.

For example, in the context of the Wii Controller, in order for replication to be worthwhile, a new method for optical sensing needed identifying (see Peripheral Input). This was achieved by reversing the system so that the device utilised a camera to track Infrared beacons mounted on the device rather than the camera.

Microcontroller & Breakout Prototyping

In order for the replication of the device to be deemed feasible a simple implementation was constructed utilising the microcontroller and breakout design materials. Initial replication of the system was performed in a non-permanent manner utilising solder-less breadboards to connect each of the identified components to a microcontroller (see Figure 22, left). During this process each of the previously identified “graded” solutions (e.g. Figure 21) were also tested for suitability and performance. Following the successful production of several graded solutions in this manner, a permanent solution was developed via the production of a PCB utilising the Fritzing software (see Circuit Documentation Solution).

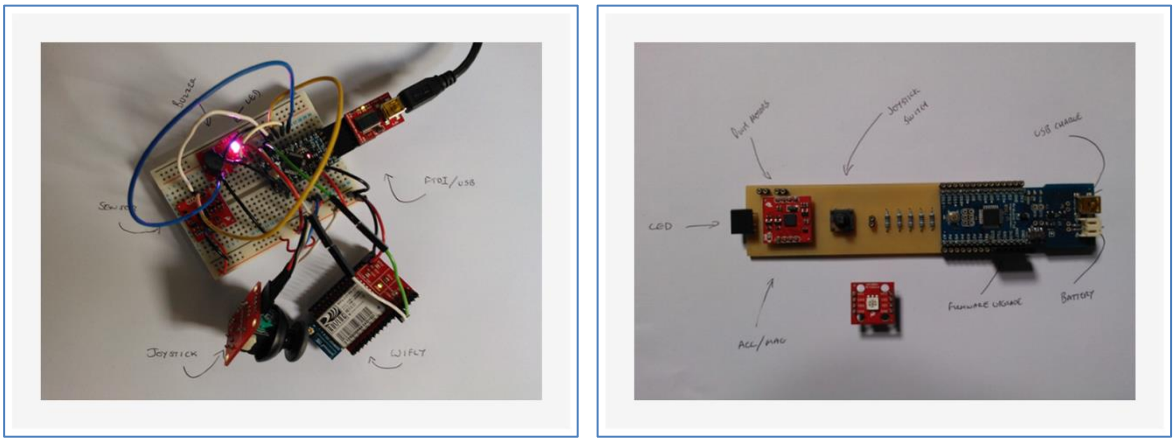


Figure 22: Replication of the Wii Controller via Microcontroller and Breakout

With the production of a PCB based prototype (Figure 22, right) that utilises a level of enhanced technology to that of the Wii Controller (e.g. capability for yaw, pitch and roll tracking) at the entry level (see Product Benchmarking), an implementation of a device has been created that exceeds the capabilities of the Wii Controller. The development of this solution acts to verify the use of the Wii Controller as a cost effective platform for the conceptual development of assistive interface solutions.

The Wii Controller as an Assistive Device

Following the activities of Product Study and Design Replication, it has been concluded that the device is a viable platform for assistive technology development. The important features of the Wii Controller which make it suitable for use as an assistive device are:

- The Wii Controller can be used to provide data needed to describe the 6 degrees of freedom required to orientate a body within 3D space.
- The Wii Controller provides capability for use as a 2D pointing device and can easily facilitate 2D mouse-like interaction.
- The Wii Controller has the facility to act as a wireless bridge between developed devices via use of its expansion port.
- The Wii Controller has the facility to provide auditory, visual and haptic feedback.
- The Wii Controller is an expandable solution that can be extended to meet the criteria of both user needs and game-play complexity.
- The technology can be duplicated within legal constraints.
- The technology can be applied without the need for direct modification. Where such modification is needed this can be achieved via the use of extension peripherals.

There are however limitations in regards to the application of Wii technology in respect to both copyright licensing constraints, and this factor should be constantly kept in mind.

Generation of Design Ideas

Given the proven capability of the Wii Controller as both an assistive device and as a springboard for concept creation, several open ended brainstorming (

Table 2), and design sketching (Figure 23) sessions were conducted with the device in order to generate ideas (see Buxton, 2007; Cross, Engineering design methods: strategies for product design - 4th Edition, 2008). To this end, the Wii Controller was used as a physical prop for idea generation.

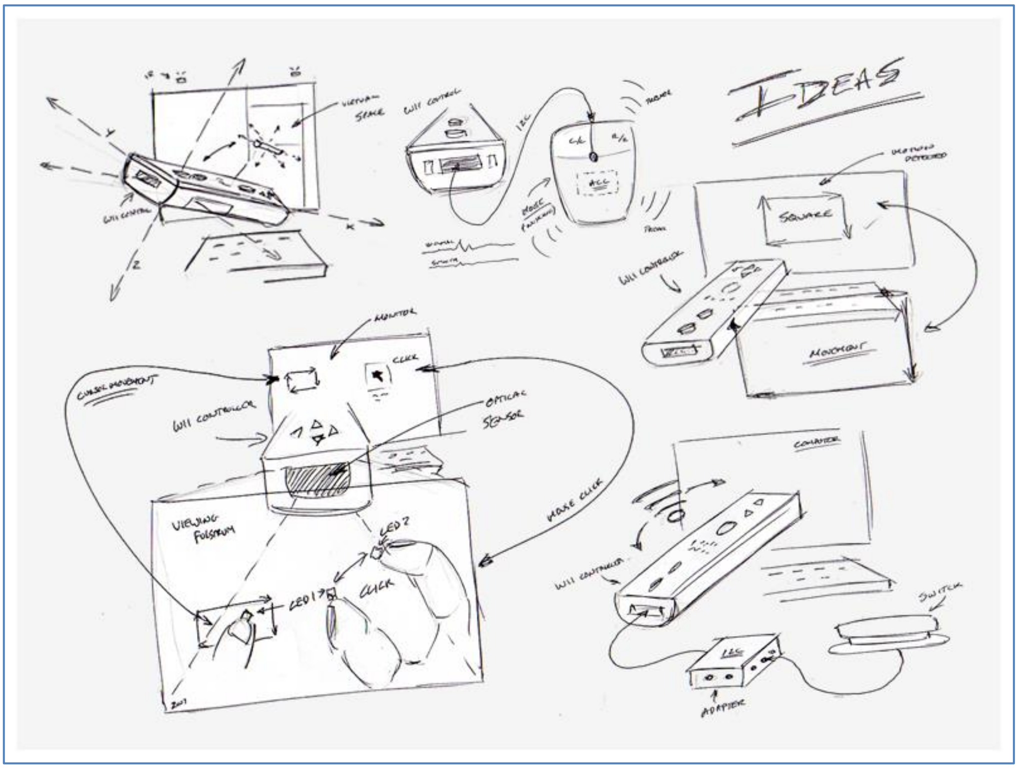


Figure 23: Examples of Generated Design Sketches

This exercise was initially conducted by the design team (as a springboard for idea generation) and then repeated in conjunction with co-designers with visual impairments, special educational needs teachers, and health psychologists. Each of these groups contributed to the activities of concept generation. In each instance, exercises were informal and the only guidance, material and input can be detailed as follows:

- A Wii Controller with Nunchuk and Classic Controller extensions.
- The title of the specific target demographic.
- The title of the specific aim – development of an accessible technology.
- Conclusions drawn from the product study phase.

The aims of these sessions were threefold:

1. To identify potential skills developed by users that could be adapted and/or reused for providing a means of input modality. For example, the current assistive technologies which people apply in an everyday context, and the skills which people with disabilities and impairments have developed to communicate and interact in their everyday lives.
2. To investigate the potential ways in which the Wii Controller could be used to facilitate interface.
3. To identify the barriers that those with disability and impairment face in the context of their information technology use.

The data and concepts collated in the sessions (e.g. notes, mind-maps and sketches) were then further developed via literature analysis and (where relevant) comparison with earlier research. Figure 24 shows an example of one of the outputs from a session conducted with a visually impaired user focussing on the subject of assistive technologies.

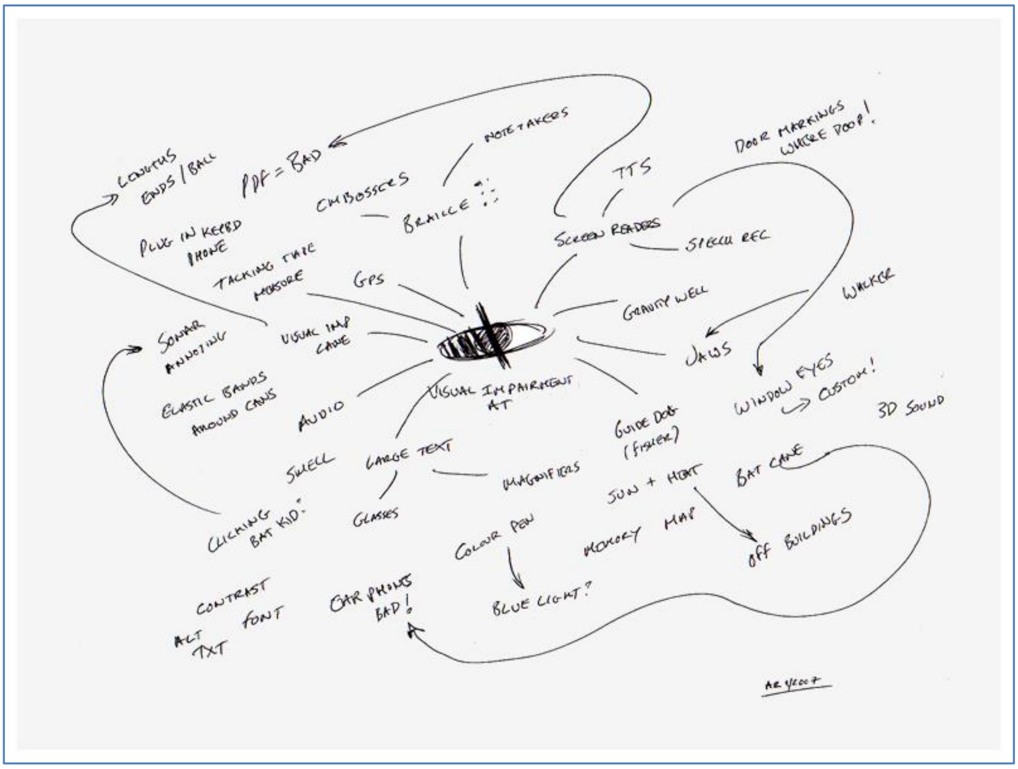


Figure 24: Example of Visual Impairment Brainstorming Session

In each instance a basic model was then created detailing the potential idea. A basic summary of each was then presented for informal evaluation by the project supervisory team and third party multidisciplinary specialists within field (e.g. The Department of Ageing and Rehabilitation, Nottingham University; The Portland College; The Shepherds School).

Table 5: Breakdown & Summaries of Initial Ideas

Concept or Idea	User type	Modified Controller	Generic Notes	Outline of further works and Investigations needed
Existing Controller and Extensions	All	No	▪ Demonstrates use of console viable ▪ Multimodal input – pc and or console ▪ Platform for development of ideas with related peripheral technologies ▪ Test platform for ideas ▪ Springboard for idea generation	▪ Software solution needed for pc development and console concept testing. ▪ Licence needed for console development. ▪ Hardware replicated within constraint ▪ Hardware Improved via re-design ▪ Related literature investigation
Surface Free Interface	All	Y/N see notes	▪ Device used in reverse ▪ Use of optical sensor peripheral only – wireless extension possible? ▪ Nui concept.	▪ Hardware replicated within constraint - bespoke solution for tracking ▪ Related literature investigation
Hub for Custom Peripheral Enhancements	All	Custom extension I2C	▪ Could be targeted to provide a bridge for existing technologies such as switches. ▪ Nui concept	▪ Extension replication required. ▪ Related literature investigation
Gesture recognition for the physically disabled	Physically disabled Elderly	No	▪ Motions could be trained by the user for bespoke and tailored input. ▪ If manipulation of the device is impractical then a custom extension could be developed. ▪ Developed system could be used to compliment other ideas. ▪ Could be done via Controller or Extension	▪ Hardware replicated within constraint ▪ Hardware Improved via re-design ▪ Extension replication required. ▪ Concept testing viable via existing hardware ▪ Software solution needed – hardware ▪ Related literature investigation
Tremor compensation for the elderly and physically disabled	Physically disabled Elderly	Custom extension	▪ The accelerometer technology could be used in a mouse to provide data for damping	▪ Related literature investigation ▪ Software solution needed – hardware
Tool within 3D Environments	All	No	▪ The Wii Controller can be held as a handle and mapped to a tool within a virtual environment. ▪ Feedback could be provided by vibration of the motor. ▪ Nui concept	▪ Software solution needed – driver ▪ Software solution needed – environment ▪ Related literature investigation

The ideas and points of interest selected for further investigation at this stage were then summarised as detailed in Table 5. In each instance the idea is detailed in conjunction with an outline of suggested further work for others involved within the selection process. A basic model was then created detailing the potential of each idea and a summary then presented for informal evaluation by the project supervisory team and third party multidisciplinary specialists within field (e.g. The Department of Ageing and Rehabilitation, Nottingham University; The Portland College; The Shepherds School).

Chapter 5: Applying FLOOD for the Iteration of Ideas

Given the simple definitions of design ideas (presented in chapter 4) which can be viewed as initial individual conceptual models, common themes for further development were identified:

1. Further literature investigation to identify detail on user characteristics and related technologies.
2. A software solution to facilitate the development of Wii Controller based technology. The solution would effectively act as a driver for the hardware enabling all concepts to communicate with the Windows operating systems. The driver would allow all concept ideas and modes for interaction to be tested. These can then also be applied to console distribution when licensing issues are resolved. If licensing is not viable then the device can be utilised unmodified via the Windows operating system.
3. Product dissection and replication is needed for extension peripherals in order to validate them as viable platforms for concept generation and testing. The replication of the technology would determine that disability and/or impairment bespoke interfaces could be developed that utilise the technology of the Wii Controller.

In order to apply this approach each idea was then iterated (to varying degrees) via research, prototyping, evaluation and building. Following these iterations new conceptual models were formed and evaluated by the design team and related stakeholders, i.e. users, specialists within field, etc.

Idea 1: The Existing Wii Controller & Extensions

In contrast with typical controllers, the Wii Controller expands upon the traditional paradigms for user-game interaction (button press and joystick movement) by employing accelerometer and optical sensor technologies to provide motion sensing capability. As a result, fresh possibilities for interaction and human interface are enabled through use of physical movement and gesture. The volume of physical data made available by the device allows for feature expansion through use of software solutions to interpret and affect system input.

Facility to train an individual device in turn opens up the possibility of truly adaptable design solutions to be conceptualized and created. The activity of Product Study has identified that if designs and schemas for interface are produced for those with disability and/or impairments utilising an unmodified unit, then with license, these solutions would be viable for distribution via the Wii Console platform. To facilitate the development of all conceptual solutions it has been determined that implementation of an advanced driver software solution (Windows) is required.

Such software would enable the Wii Controller to be utilised as is (an un-modified unit), for the purpose of human-machine interaction. This would demonstrate that any concept developed that utilised the technology in an un-modified form would be viable for video game console distribution, given developmental licence. In addition, such implementation would also prove the application of the technology as also potentially viable for computer game-based interface within legal constraints.

The Wii Controller Interface Suite

The Wii Controller Interface Suite (Wiici) is an ever evolving collection of tools developed to facilitate the connection and interface of Nintendo Wii Controller and Extension peripherals (official and devised variants), with the Windows family of operating systems.

Over the period of this research, five applications and four dynamic link libraries have been developed that enables access to all aspects of the devices technologies. Wiici is a result of extensive investigative study and evaluation of each aspect of the technologies offered by the Nintendo Wii Controller and its capability for the development of Assistive Human Interface Devices (AHID's).

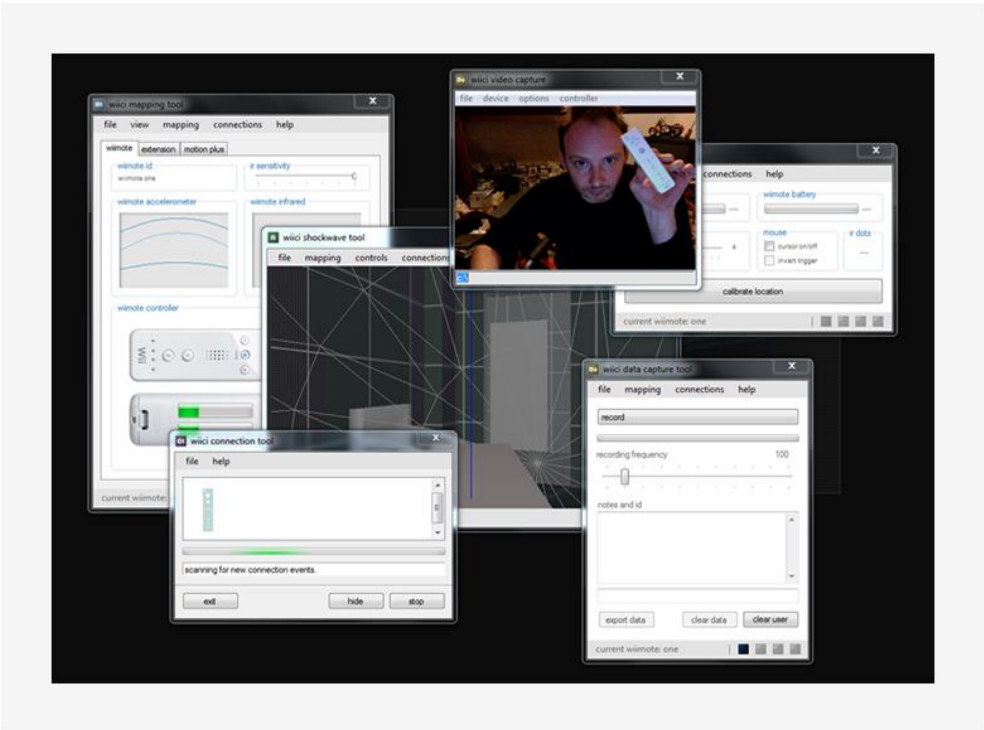


Figure 25: The Wii Controller Interface Suite (Wiici)

The obvious starting point for validating that the Wii Controller and its accompanying extensions can be employed as an assistive technology is the evaluation of the device itself. This has been already been achieved via the phase of product analysis. The identification and development of software solutions to enable two way communication with the device (e.g. GlovePIE & WiimoteLib), and access to the data it provides, verifies the hardware as a viable platform for concept development.

The capability to be able to duplicate and improve upon the hardware, via rapid prototyping methods such as breakout construction, also establishes the device as a viable platform for conceiving, testing and evaluating ideas in respect to alternative modes of interface, as afforded by the Wii Controllers peripheral technologies.

To this end, throughout the holistic period of this research, the development and refinement of software solutions to facilitate effective and multipurpose application of the Wii Controller was conducted as a continual process; reflecting changes in requirement, developments within the field and developments of other selected concepts. The evolution of the software in response to this activity acted to formulate a range of software solutions coined the ‘Wii Controller Interface Suite’. A full listing of the software can be found in Appendix C.

The Peripheral Mapping Tool

Utilizing Brian Peek's (2008) Managed Library for Nintendo's Wiimote as its heart, the Wiici Peripheral Mapper, aka Mapping Tool (Wiici-Mt), is a functional windows-based application written in C#, which provides facility for keyboard, mouse and joystick mapping/emulation.

Wiici-Mt not only provides the facility for the Wii Controller to be mapped to the windows operating system, but also the primary accompanying extensions, such as the Wii Classic Controller and Wii Nunchuk. Mapping functionality is facilitated via the use of several panels, each of which enable a user to configure each of the Wii Controller's physical inputs to any desired keyboard, mouse or joystick input combination. In effect this enables the Wii Controller to be seen by the system as any of the highlighted devices, limited only by the volume of inputs available from the device.

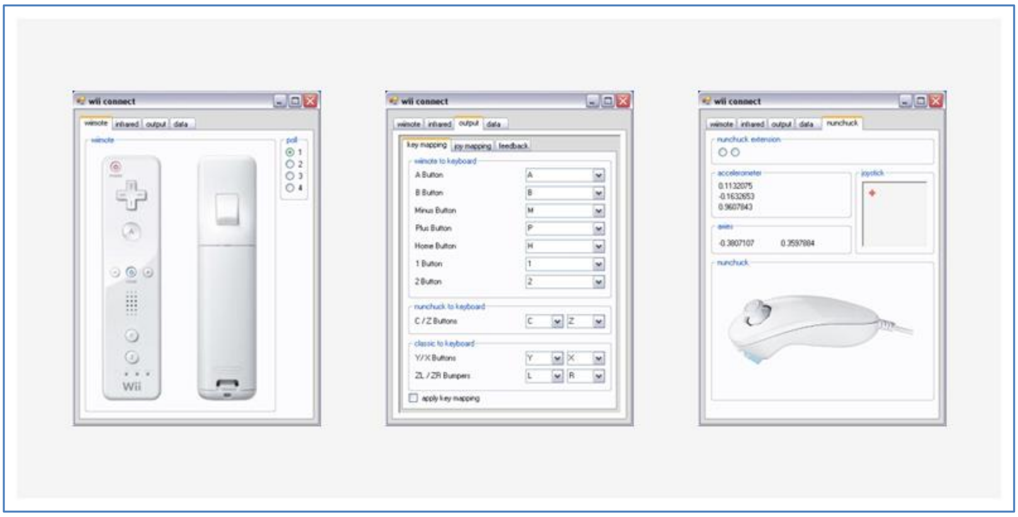


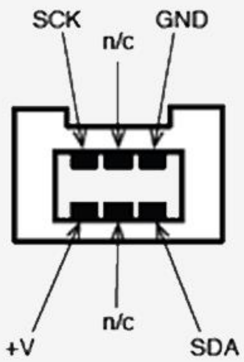
Figure 26: The Wiici-Mt Application Interface

Customizable feedback is provided by the feedback mapping panel, enabling a user to set flags which in turn allow the system to operate any of the Wii Controllers feedback mechanisms, such as the rumble feature.

Idea 2: A Hub for Peripheral Enhancement

The Wii Controller features an I2C expansion port at its base. This allows the connection of auxiliary controllers to augment the input capabilities of this device. As the port is I2C, any extension that plugs into the port can work with I2C capable microcontrollers such as those of the Arduino and or Netduino prototyping platforms. Investigation of Wii Controller related literature and the activities of product dissection have identified all the required elements needed to both replicate the Nunchuk peripheral, and also afford the capability for its stand-alone implementation.

As the extension port adopts the standard I2C protocols, the detail of both communication byte structure and definition of the extension connector wiring (wiili.org, Nunchuk, 2007) makes it is an easy task to interface the Nunchuk extension with an Arduino microcontroller.



Byte	Description	Values of sample Nunchuk
1	X-axis value of the analog stick	Min(Full Left):0x1E / Medium(Center):0x7E / Max(Full Right):0xE1
2	Y-axis value of the analog stick	Min(Full Down):0x1D / Medium(Center):0x7B / Max(Full Right):0xDF
3	X-axis acceleration value	Min(at 1G):0x48 / Medium(at 1G):0x7D / Max(at 1G):0xB0
4	Y-axis acceleration value	Min(at 1G):0x46 / Medium(at 1G):0x7A / Max(at 1G):0xAF
5	Z-axis acceleration value	Min(at 1G):0x4A / Medium(at 1G):0x7E / Max(at 1G):0xB1
6	Button state (Bits 0/1) / acceleration LSB	Bit 0: "Z"-Button (0 = pressed, 1 = released) / Bit 1: "C" button (0 = pressed, 1 = released) / Bits 2-3: X acceleration LSB / Bits 4-5: Y acceleration LSB / Bits 6-7: Z acceleration LSB

Figure 27: Nunchuk Extension Protocol and Wiring (wiili.org, Nunchuk, 2007)

Literature also indicates several applications within the Wii Controller home-development communities that demonstrate both the replication and bespoke realisation of extension hardware, including investigating the use of Wii Controller's extensions as interface devices in their own right, and resulting in the development of the WiiChuck adapter (Kurt, 2008).

The adapter is a small PCB that enables connection of extensions to microcontroller development boards such as the Arduino and Netduino. As the extension connectors for the Wii Controller are proprietary, the adapter facilitates use without the need to cut the jack off in order to gain access to the wires needed for connection.

Figure 28: The WiiChuck Adapter (Kurt, 2008)

Successful application of the extensions in this manner further emphasises the viability of custom device development in respect to the personal computer interface.

Additionally, Zhao (Zhao, 2009) has developed a C based library that can be used to make extensions with AVR Microcontrollers such as that of the Arduino. The library gives the microcontroller the ability to act as, and be seen as, a Wii Controller. At the time of investigation only the Nunchuk and Classic Controller extensions were supported. However, over the period of this research the capabilities of the library have been grown to include the: Guitar Hero 3 controller, Guitar Hero World Tour Guitar Controller, and Guitar Hero World Tour Drum Controller.

The library has two parts: the I2C slave device and Wii Controller protocol handling. It can be used with a compiler compliant with C language high level code, and creates a binary that can be programmed onto an AVR chip such as those found on Arduino microcontrollers. The ability to be able to use the Arduino platform for development demonstrates that the development of custom extensions is feasible. In effect, current assistive technologies, e.g. assistive switches, can be interfaced with the Wii Controller. Therefore custom solutions can feasibly be developed for the Wii Console. As the devices would be in effect clones of existent peripherals (such as the Nunchuk), input could be mapped directly to that of existing games. Furthermore, in respect to personal computer use the Wii Controller can effectively be used to facilitate wireless connection and a power source if required.

Figure 29: The Wii Controller Ten Key (Kako, 2007)

In respect to bespoke device creation, E. Kako (Kako, 2007) has demonstrated successful interface of a custom numeric keypad peripheral extension, via the use of the Wii Nunchuk I2C communication protocol and a custom built interface using a PHILIPS PCA9539 I2C Bus.[11]

[11] The PCA9539; PCA9539R is a 24-pin CMOS device that provides 16 bits of General Purpose parallel Input / Output (GPIO) expansion with interrupt and reset forI2C-bus/SMBus applications and was developed to enhance the NXP Semiconductors family of I2C-bus I / O expanders. I / O expanders provide a simple solution when additional I / O is needed for ACPI power switches, sensors, push buttons, LEDs, fans, etc.

Figure 30: The Ten Key Circuit

Kako details the methods and circuitry (Figure 30) used for custom extension development, but reports that the performance of the device is very slow and sometimes fails to be recognised. The reported performance and reliability of the Kako method can be seen as demonstrating concept feasible but is also in need of improvement. All of these reports demonstrate that the development of custom extensions are practical. This can be seen to address aspects of the thesis research objectives; via determining the potential for console technology adaptation for those with disability and impairment.

In order to determine the use of Nintendo technology as a springboard for equivalent product design we need to duplicate the technology of a Wii Controller extension as basis for a non-Wii Console related assistive product.

Dissection and Replication of Nunchuk

As with the Wii Controller replication exercise; the functionality of the Nunchuk was first broken down into its component parts (Table 6).

Table 6: Functional Elements of Nunchuk Extension

Functional Elements of the Wii Controller Nunchuk Extension		
Element	**Artefact**	**Description**
Encasement	Bodywork	ABS shell
Communication interface	Wireless/Bluetooth via Wii Controller	BCM2042
Peripheral Input	Accelerometer	ADXL 330 Analog Devices
	Buttons	Standard membrane * 2
	Joystick	Standard 2 axis pot joystick
Extension Jack	I2C Interface	Proprietary connector
Power source	Power provided via Wii Controller	3v3 Line will run at 5v

Once again, this step provides an outline of the device's peripherals and components and parts needed for Nunchuk replication. A .Net Micro Framework microcontroller (Netduino) was chosen as the platform for initial device replication; however the same activity could also be carried out just as easily via the Arduino or equivalent microcontroller. Using the component details as a basis for functional requirements, potential breakout components were then resourced and investigated.

This process identified a microcontroller shield, the Sparkfun Joystick Shield (Sparkfun, Joystick Shield Kit, 2009) as a prime candidate for prototyping Nunchuk equivalent hardware. Designed for the Arduino, the Joystick Shield kit contains all the parts needed to enable the Microcontroller with rudimentary game-pad/control-pad functionality. The shield sits on top of the Microcontroller and equips it with five momentary push buttons and a two-axis thumb-joystick. This in effect results in input functionality capacity equivalent to that of a sixth generation console controller or half functional capability of a seventh generation console games controller.

Each of the momentary push buttons are connected to the microcontroller's digital pins 2-6; when pressed they will pull the pin low (utilizing the internal pull-ups of the microcontroller). Vertical movement of the joystick will produce a proportional analog voltage on analog pin 0; likewise, horizontal movement of the joystick can be tracked on analog pin 1.

The previous Wii Controller replication exercise had already determined the facility for duplicating the Accelerometer functionality of the Nunchuk. This solution was added to the shield construction via use of a bread board. Additionally the Wireless solution developed for Wii Controller replication was also included.

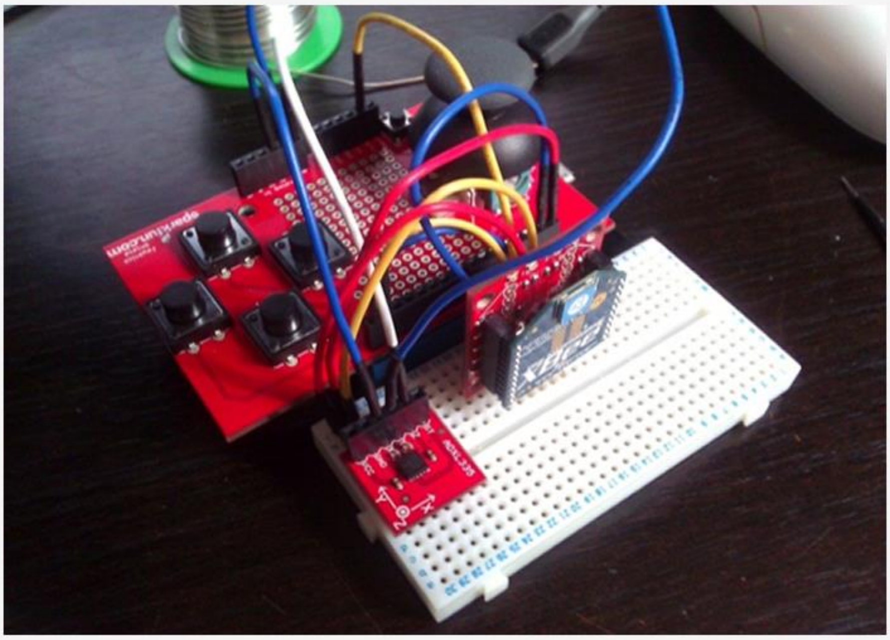


Figure 31: Nunchuk Prototype One

The resulting prototype device can be seen to have extended capability to that of the Nunchuk. The enhanced features include 3 additional buttons, wireless serial communication that can be used in conjunction with a computer directly, or through an intermediary.

The provision of a microcontroller also enables the device with facility for further feature expansion and capability for software updates during the product life-cycle. In effect the device itself also can become a hub for expansion equivalent to that of the Wii Controller.

The replication of the hardware via Microcontroller and Breakout Prototyping has demonstrated that, as with the Wii Controller, extension peripherals are viable as platforms for idea generation, product iteration and product re-design. By utilising the existing Nunchuk as a benchmarked solution, the application of product re-design has resulted in an enhanced version of the device that can be seen to improve on the original device by adding wireless capability and additional input capabilities. This could also be further enhanced via the exchange of the accelerometer for a superior inertial measurement unit such as those identified within the Wii Controller replication exercise (Page 78).

Idea 3: A Surface Free Interface

The Wii Controller features an optical sensor situated at the front end of the device. The sensor is an infrared camera manufactured by PixArt (see WiiBrew, 2007; PixArt, 2006). The camera is connected to an integrated image analysis chip that can identify up to four individual Infrared light sources and report their position, approximate size and level of intensity. The light sources are provided in the form of two clusters of Infrared LED's situated at opposite ends of a stationary bar. The image sensor sees the light as two bright dots separated by a known distance. Triangulation is used to calculate the distance between the bar and the Wii Controller. In addition, the rotation of the Wii Controller with respect to the ground can also be calculated from the relative angle of the two dots of light on the image sensor (Ohta, 2011).

Using patent literature as a basis (e.g. Ohta, 2011) it was conceived that the current system implementation could be reversed (see Battersby S., 2007; Battersby S., 2008) and a viable solution developed that uses movable infrared light sources instead of the Wii static sensor bar. As a result the optical sensor of the device could be utilised as a cheap and available camera for infrared tracking applications. In order to evaluate this idea, two movable Infrared light sources were prototyped using standard infrared LED's. Called Finger-Mice, a name derived from their initial functionality, the individual light sources consisted of an infrared LED and used a button battery to provide power (Figure 32). A Velcro strap was used so that the light sources could be attached to the finger. In order to test the concept, the Wiici Software was modified so that the light sources could be used to drive multiple (mouse) pointer functionality.

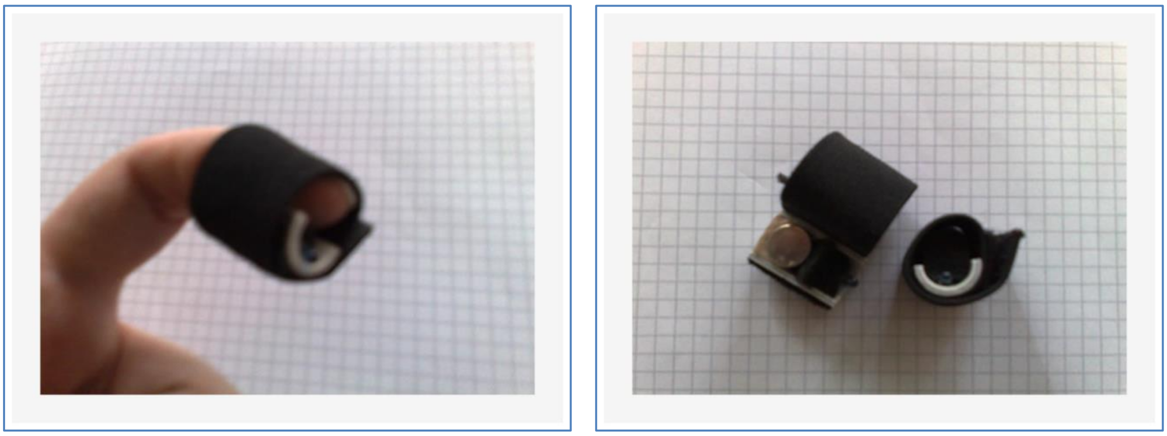


Figure 32: Finger Mice Prototypes

Functionality was tested by "slaving" the (computer mouse) cursor to the median point of infrared light via a custom script in GlovePIE. The distance between the two points was used to activate a left click. The success of these investigations suggested that the concept of finger point tracking via the Wii Controller as means for system interface was feasible. However the caveat at this time was that the system had to utilise additionally developed multi point software to facilitate the use of more than one cursor. Further investigation of Wii Controller related research identified a similar application of the finger tracking concept, however in a reflective form.

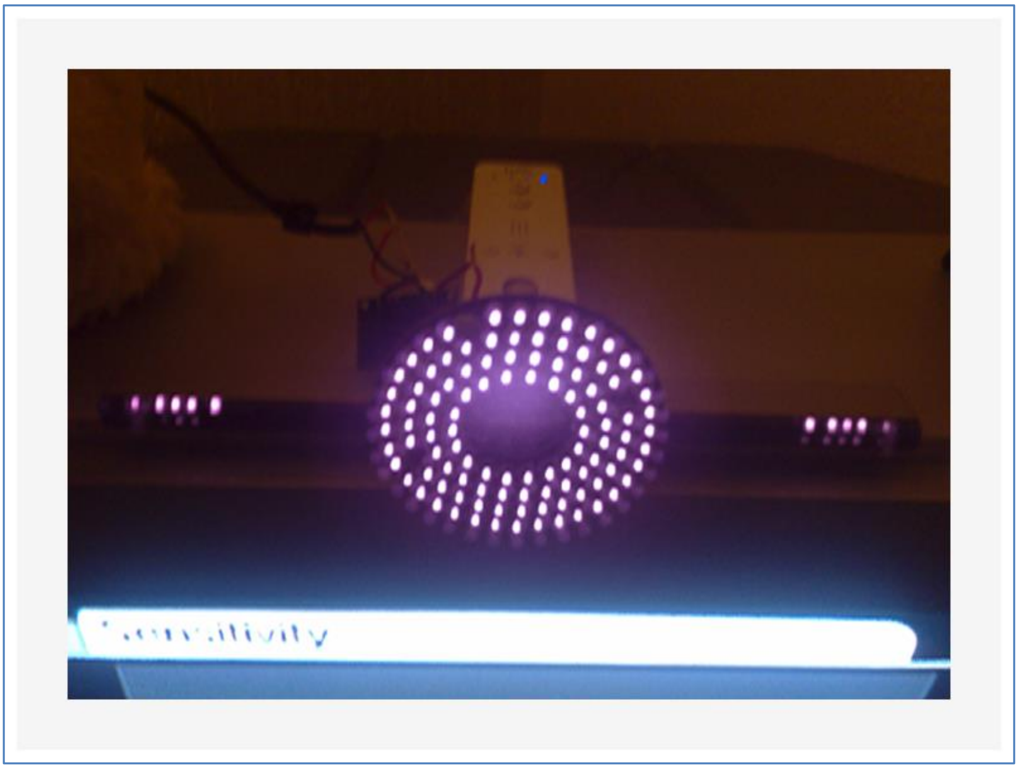


Figure 33: Evaluation of the Reflective System described by Lee (Lee, 2007, 2008)

The research of Jonny Chung Lee (Lee J., 2008) extended the original concept by utilising reflective surfaces to provide sources of infrared light that the system could use to determine finger-tip location. Initial testing of this concept via the recreation of Lee's experiment revealed that the use of reflective materials is very unreliable in normal ambient lighting conditions. Furthermore, the limitation of the device's optical sensor package being able to track only four individual points of infrared light simultaneously introduces a restriction in respect to the development of multi-touch applications.

Experiment of point tracking performance

A simple experiment was constructed utilising the developing Wiici-Mt application, a Wii Controller and four powered LED's. The aim of the experiment was to investigate how the optical sensor reacted and performed in conditions when the visibility of the infrared was interrupted.

Varying combinations of zero to four light sources were illuminated in front of the Wii Controller (Figure 34). Performance was logged for continuity of detected light source and the corresponding ID issued to the light source via the application. The results of the experiment indicated that the Wii

Controller is unable to maintain the adequate tracking of point ID if more than two light sources are lost at any one time. This variance is an indication that in order for successful and precise tracking capability some form of software, and/or hardware solution, also needs to be developed to provide the successful determination of point ID.

In order to clarify that this was not a behaviour caused by the structure of the WiimoteLib API the experiment was repeated utilising a simple GlovePIE script. Similar results to those described determined that this performance is related to the filtering conducted by the Wii Controller's optical sensor's integrated multi-object tracking (MOT) engine. Despite these factors, and since these initial investigations, many others have gone on to develop this concept.

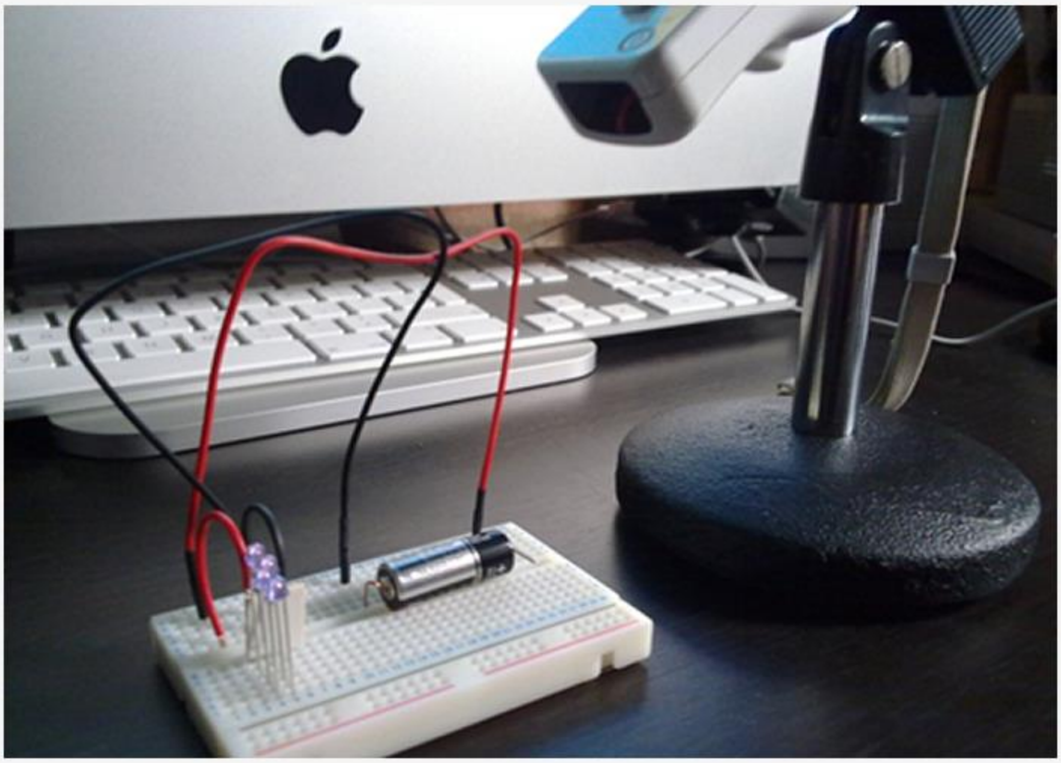


Figure 34: Wii Controller Illumination Experiment

The initial investigation into the development of a surface free interface utilising Wii technology has identified several issues with the utilisation of the device's optical sensing technology. Foremost is the performance of the technology with regards to ambient lighting conditions. Following the evaluation of the developments of Lee (2008), focus has returned to the original Finger Mice concept as this has been proven to be more reliable. Initial results proved encouraging, however it was identified that further work needed to be undertaken to improve resolution and functionality within well-lit surroundings. The capability of using the Wii Controller as a surface free interface has suggested numerous applications. Further brainstorming of this concept suggested two potential applications for those with disability and/or impairments:

- *A Stroke Rehabilitation Exercise Tool* - It is suggested that a user is tasked with drawing objects within free space. Facility to draw in this manner results in the capability for a full range of upper body exercises to be developed. For example, to create a 3D object such as a tetrahedron, four points at varying depths must be achieved. This naturally results in the use of a full range of arm movements. In addition, gesture recognition could also be used by physiotherapists to define a bespoke suite of exercises, thus enabling a tailor-made course for patients.
- *A Sign Language Translation Tool* - Using the surface free application in conjunction with gesture recognition, a software solution could be trained by a user to recognise a suite of hand movements. Repetition of defined motions by the user could be used to trigger corresponding auditory output in the form of pre-recorded speech. A practical implementation of this is that of a sign language translator. This application was conceived by reflecting on the use of sign language, and would demonstrate the re-use of existent real world investments in skill.

Following the presentation of both of these concept ideas to their respective stakeholders and the project supervision team, a decision was made to treat each idea as an additional concept. To this end further research in respect to the Sign Language Translation concept is now described. The Stroke Rehabilitation concept is fully described in Chapter 8.

Idea 4: Gesture recognition for the Physically Disabled

Review of research has highlighted several studies that utilise the technology of the Wii Controller as a means for providing trainable gestures as a means of providing interface.

In a Wii Controller driven context, researchers (Schlomer & Poppinga, 2008) from the University of Oldenburg have developed Wiigee, an accelerometer-based gesture recognition library specifically for use with the Wii Controller. Developed in java for cross-platform compatibility, Wiigee allows you to define and recognize your own, freely trained gestures. Researchers (Rehm, Bee, & André, 2008) from the University of Augsburg have also developed a Wii Controller driven gesture recognition library.

WiiGLE provides an environment to record gestures, calculate features, train classifiers, and uses the Wii Controller for online gesture recognition. Again the functionality of the library is based on accelerometer data. Developed in the .Net Framework, WiiGLE features a Programming API that allows integrating your own features and classifiers. An investigation was conducted with the WiiGLE library to determine whether its functionality could be added to the developing Wiici-Mt application.

Successful use of the WiiGLE library to train and recognise a custom set of gestures was seen to verify the concept as feasible. However, all of the discovered Wii Controller driven gesture applications relied on only input from the hardware's accelerometer.

Figure 35: The Wiimote Gesture Learning Environment (Rehm, Bee, & André, 2008)

The library was chosen as a potential platform for further development as it was developed in the .Net framework and was based around Brian Peek's WiimoteLib, and was considered as the best platform to provide compatibility with the developing Wiici-Mt application.

Idea 5: Sign Language Translator

Investigation on this theme has revealed a wealth of literature related to this concept. In summary there are two primary methods used for sign language translation. In terms of broad categorisation these are: visually or mechanically. Both methods need to measure a person's hand movements and both have their own benefits and limitations. However, the majority of the reviewed research opts for the visual method.

Figure 36: Animated Sign Language Translation System

Japanese researchers at NHK Science & Technology Research laboratories are developing an animated sign language translation system that automatically converts strings of Japanese words into gestures. The goal is to improve sign language broadcasts for Deaf viewers, especially in the case of disaster or breaking news (Kennedy & Osuga, 2011).

Kendal Lowrey of Carnegie Mellon University has developed a glove that is able to translate the alphabet and 10 words from American Sign Language into American English (Lowrey, 2010). The glove utilises a combination of accelerometer and flex sensor inputs connected to an Arduino microcontroller.

Figure 37: The Sign Language Translator Glove

When viewed in conjunction with the investigation of gesture recognition capabilities of the Wii Controller, and the ability to create custom extensions, it can be determined that an equivalent system can be delivered using the Wii Controller as a platform for development.

Investigation during the product analysis phase of this research had identified the components used in the development of the Lowrey glove as alternative solutions to those of the official hardware, and that rudimentary implementation of similar systems has already been developed. The expansion of these systems to utilise gesture recognition as an additional means of input is deemed as feasible.

Idea 6: Tremor Compensation for the Elderly and Physically Disabled

Investigations using force feedback technology to assist motion-impaired computer users (Hwang, Langdon, Keates, & Clarkson, 2001) indicate that implementation of force feedback as non-directional viscous damping has a beneficial effect for some users, improving time taken to reach a designated target by up to 50%. In reflection of the concept idea it was conceived that there were three potential methods of interface that could be adapted to facilitate the dampening and or accountancy for tremor.

- Using the Wii Controller as a pointing device for cursor control and using software filters for damping.
- Construction of a custom extension that uses accelerometer values for damping and detection of outlier data.
- Construction of a new device that uses accelerometer values for damping and detection of outlier data.

Practical experimentation with the Wii Controller has demonstrated that both accelerometer data for the Wii Controller and Nunchuk can be obtained without much complexity. Driven by the concept idea, comparison of the Nunchuk with a standard computer mouse reveals many similarities between the two in terms of available input capability: two button input, and analog XY axis. In order to further verify this concept a simple mock-up was constructed utilising an ADXL 335 Accelerometer as discovered during the product study phase of investigation.

Idea 7: The Wii Controller as a Virtual Tool

The Wii Controller's ability to describe a body within 3D space means that it can be used like any tool with a handle. This idea was inspired by the mapping of the device in this manner within contemporary Nintendo Wii video games. For example, within the game Zack & Wiki (Capcom, 2008) the Wii Controller is mapped to numerous real world tools and their application such as a saw (Figure 38), a hammer and even a flute.

Figure 38: Zack & Wiki - Mapping the Wii Controller as a Tool (Capcom, 2008)

Brainstorming of this concept identified potential for the device to be used in this manner to replicate many real world interactions. Although proven via the implementation within gaming, investigation was performed to see if this functionality could be duplicated. The rationale for this was that if such capability was available, the concept would provide a strong basis for further idea generation and capability for the mapping of bespoke user requirements. Research could then be conducted in order to see how real world paradigms for interaction could be applied as modes for computer interaction.

Building on the developing software system interface, implementation of a virtual environment was conducted via use of the Adobe Director (Di) 3D framework (Adobe, 2007). The Di framework contains a 3D development environment which is made available as an Active X component. This allows it to be embedded within a windows form application, equivalent to those used within the then current implementation of the Wiici software. As a result, the concept could be tested quickly.

A mechanism was developed to allow for communication between Di Framework and WiimoteLib via external event calls, utilizing the existing capabilities of both frameworks. With Wii Controller data made available to the Di movie the next stage of implementation was to map movement of the Wii Controller to that of a virtual counterpart.

The counterpart was developed within Autodesk's 3D Studio Max application (Autodesk, 3D Studio Max, 2007) and consisted of a rectangular block defined with the physical dimensions of a Wii Controller. The block's pivot point was set to be equivalent to the location of pivot when held in the human hand. This meant that the physical rotation of the Wii Controller would be more accurately represented by the counterpart.

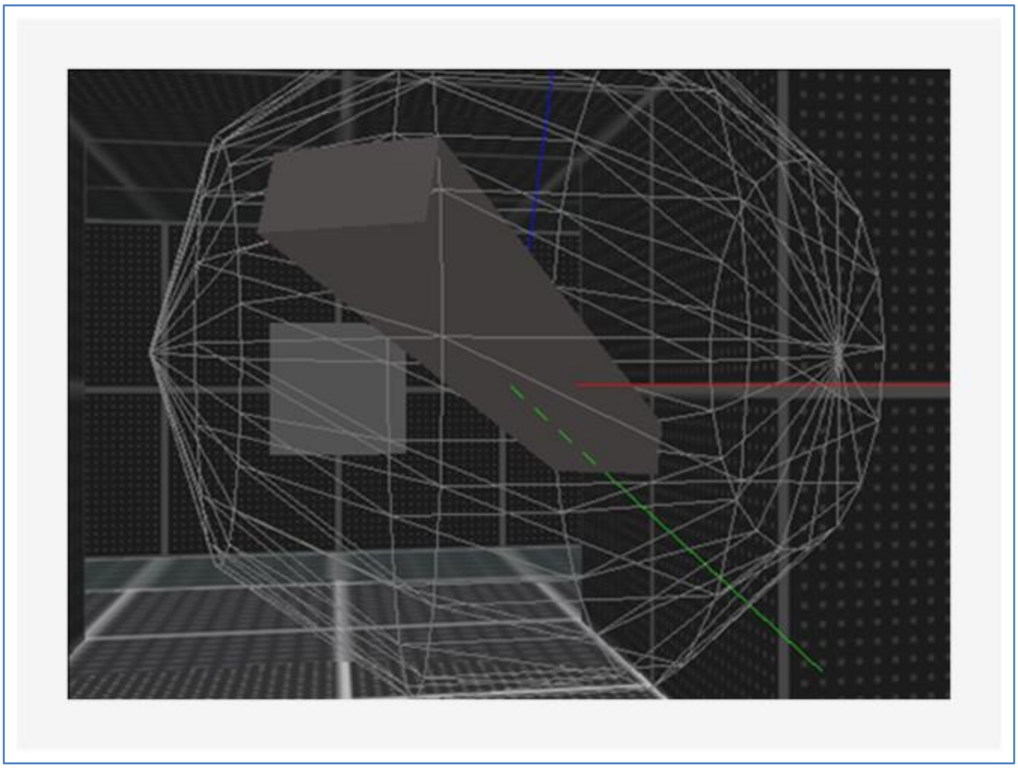


Figure 39: The Wii Controller as a Virtual Tool

With the successful slaving of motion complete, the functional scenario was deemed fulfilled and the basic functional requirements needed to validate further application of the concept were deemed verified and feasible.

Idea Selection & Conclusions

In this chapter the continuing development of the Wii Controller Interface Suite and Peripheral Mapping Tool has been described, facilitating the connection and interface of the Nintendo Wii Controller and extension peripherals with the Windows Operating System.

The replication of the Wii Controller using Arduino technology has provided a platform with extended functionality that facilitates ideas generation, and product iteration and redesign, and allows the research questions posed in Chapter 2 to be addressed. These include whether gaming platforms and peripherals are suitable for the delivery of accessible assistive technologies, and whether the new modes of interaction they offer can be exploited by people physical, sensory and cognitive impairments? Designing systems which are sensitive to, and exploit, the skills and communicational modalities these user groups already possess is also important.

The design ideas generated and shown as feasible in this chapter using this newly created platform acted as a rich resource for the Interactive Systems Research Group. The most promising were further developed and evaluated within large scale research projects, or where there was already a context in which to test these ideas. These were:

4. Design Study 1: The Virtual Cane Project
5. Design Study 2: The Nunchuk acting as an alternative assistive device
6. Design Study 3: A Wii based Rehabilitation Glove and Games for Stroke Rehabilitation.

Finally, by reflecting on the outcomes of the evaluation phases of these studies, the relative importance of paying due attention to the process of design synthesis in comparison with an emphasis on primarily the design analysis process can be assessed.

Chapter 6: Design Study One (DS1)

This study was conducted by a multidisciplinary design team consisting of members from the Interactive Systems Research Group (Nottingham Trent University). The author's responsibility within the study was the design, implementation and evaluation testing of both the developed hardware and accompanying software solutions.

The study demonstrates the first real world application of the derived design model. Focus of discussion is applied to the analysis elements of the design process and concludes following the first build phase. This is in order to demonstrate the level of involvement of demographic targets within the activity required to achieve grounded human-centred design in respect to the framing of design problem and concept feasibility investigation. The activity of feasibility investigation provides basis for verifying further investment in the design and affords provision for the collation of data in terms of initial user requirements analysis and context of use (see BS ISO EN:7000-2:2008).

Original literature describing the study produced in partnership with the author can be found in the appendix section of this thesis and via the following references Evett, Battersby, Ridley & Brown (2009), Evett, Brown, Battersby, Ridley & Smith (2008), Battersby (2008) and Battersby (2007).

DS1 Research Objective

The objective of this research is the design of an intuitive interface for those with visual impairment, the realisation of which would allow those with visual impairment to navigate and interact within virtual spaces. Such an interface would demonstrate that the visually impaired demographic are a viable target for video gaming development, and demonstrate that with minimal adaptation, existing systems could be utilised.

Core to this goal, and trigger for this design concept, is the mapping of abilities and personal skill-sets as methods for input modality. In this context virtual space can be used to determine both a traditional desktop paradigm, as well as those of a 3D construct, such as simulated environments typically found within contemporary console gaming.

The product analysis of the Nintendo Wii Controller has identified that the device has great potential to be applied in ways which can be directly mapped to paradigms of real world interaction. Via the application of the human-centred design model, this work aims to verify the potential of the technology as a platform for (specifically in this case) visual impairment console gaming as well as a platform for rapid prototyping of assistive peripheral enhancement.

DS1 Research Rationale

The application of the investments in skill that we make to perform the activities of everyday living experience, as potential methods for input modality, has many advantages. Foremost is an immediate familiarity with methods for interface, intuitively gifting users of the system with capability for basic interaction. Designed activity can be practiced in a manner akin to that of real world interaction. This is true for both for the visually impaired and mainstream demographics.

In terms of the individual with visual impairment, such provisions would act to empower them and enable active participation in new forms of social interaction and experience. This is of vital import in terms of future inclusion and is only exacerbated as our personal environments become ever more ubiquitous and our personal experiences ever more virtual.

DS1 Background Literature

People who are blind tend to adopt sequential, route-based strategies for moving around the world (Golledge, Klatzky, & Loomis, 1996). Common strategies take the self as the main frame of reference, but those who perform better in navigational tasks use more spatial, allocentric map-based strategies (Hill, Rieser, Hill, & Hill, 1993). It is reported that training in such strategies can improve performance (see Cummins & Rieser, 2008; Simonnet, Guinard, & Tisseau, 2006).

Virtual Environments have great potential, both for allowing people who are blind to explore new spaces, reducing their reliance on guides, and aiding development of more efficient spatial maps and strategies. Importantly, Lahav & Mioduser (Lahav & Mioduser, 2005; Lahav & Mioduser, 2008) have demonstrated that, when exploring virtual spaces, people who are blind use more and different strategies than when exploring real physical spaces, and develop relatively accurate spatial representations of them.

The application of Product Study and Concept Verification exercises has identified that the Wii Controller allows a user to interact with a system via movement and pointing. In addition, visual, auditory and haptic feedback is also available. Product Analysis has determined that using the Wii Controller for the development of Assistive Technology has many advantages, not least that it is mainstream, easily available and relatively cheap. This is in full compliance with the guidelines for the development of assistive technology as outlined by Brown et al (Brown, Kerr, & Crosier, 1997).

However despite these advantages the use of Wii Controller also suffers from several constraints, such as: design copyright, technology patent and non-standards compliance. This research however would determine whether without hardware adaptation the Nintendo Wii Console would be a suitable platform for commercial application visual impairment games.

DS1 Design Analysis

In order to expand on existing data produced within the idea verification phase, the prototype developed for idea verification was used as a point of reference for human centric investigation and definition of the design problem. This is so the key aspects of design requirement are formed from the perspective of the target demographic.

Investigation was conducted in the form of an informal interview session between the designer and individual members of the target group. It is important to constrain user involvement at this initial phase of design. Guidance provided by both literature (e.g. BS ISO EN:7000-2:2008; Nielsen, 1993) and the experience drawn from previous projects (e.g. The EPSRC study & the Portland Switch study) indicate that the investment of resource and development of idea before the concept has been deemed feasible is unsound. Reference should also be made that in accordance with the literature, the quality of data is of greater import than that of quantity (Lai J. , Honda, Yang, & Noyce, 2010).

Definition of a Base Statement

A base statement is a good way of fixing the design task at hand to a concrete and achievable goal. In essence a base statement is, in its rawest form, the definition of the problem identified. The process is started by asking the demographic targets just what it was that they found most difficult to do on a personal computer and whether they had any experience of video gaming. Responses indicated that the visually impaired demographic are in fact quite well catered for in terms of everyday computer interaction, this is not to say that things are by any means perfect however. Rather, the majority of responses detailed information such as weaknesses in accessibility compliance, compatibility with existing assistive technologies like as screen readers and other such related issues.

Conclusions were drawn that over-time as a demographic the visually impaired have attuned quite well to everyday personal computer use. When asked whether this was also reflective of console gaming, the general response was that of very little or no experience. Using these answers as a base point for determining project need, investigation continued to formulate an overview of the issue.

Overview of Design Need

Virtual environments provide those with visual impairment with many barriers, some of which are similar to those that they find in the real world. In these cases however, they are emphasised to a much higher degree as the real world provides additional detail that can be used to compensate for a lack of visual information. Virtual environments in contrast don't provide any such additional detail. It's true that quite often virtual environments give feedback such as audio cues to actions such as movement; however, there is no way for the visually impaired player to determine if they are in collision with an object during such movement or whether such movement will result in them performing a fatal action such as walking off a cliff. This lack of definition also carries over to basic interactions, such as the collection of an item or the pushing of a button. More often than not the indication of location of such objects within virtual space relies upon the fact that virtual reality is a visual medium. In order to improve the usability of the space it is commonplace to find further visual message framing such as a heads up display as a means to indicate a raft of additional detail such as status indication, instruction and objective. This is especially prominent within a gaming context.

Finally, traditional assistive technologies used by the demographic are more often than not incompatible with such environments and or spaces forcing a user to adopt unfamiliar methods for interaction and control. However this is only reflective of the computer game division of video games.

Mapping the Periphery

The development of our periphery mapping is really the beginning of this creative design process. As a design tool it provides an in depth understanding and point of reference of how those for whom we are designing perceive and interact with the world. A good periphery map includes detail of factors such as: environmental variance, response to change and personal feeling. Additionally it also describes the potential areas of skill and sense invested in by the targeted demographic.

In order to map the periphery we first need to examine at a base level how our target demographic perceives their environment and facilitate the basic interactions of their living experiences. A key point here is to try and identify the many ways that people interact in normal everyday scenarios, such as watching television, preparing food, going to the shops etc. as well as more specific and related tasks such as using a computer. More often than not it is the former that will afford the greatest cues which can be used to map the periphery. In essence, as a design tool, the periphery map aids the designer by providing a basis for asking demographic targets the questions we need to, in order to inform our design. This was achieved by holding a series of interviews with the targets and asking them to identify how they achieve some of the tasks defined. It is important to constantly reflect against the overview definition.

Additionally investigation was tailored to find out what existing assistive technologies were already used by the targeted demographic. It is important to note that peripheral enhancements do not have to be ubiquitous computing devices and or electronic devices. The investigations determined several existing technologies which may be potentially useful platforms for the development of periphery enhancement:

- The Braille Language
- The Visual Impairment Cane
- Guide Dogs
- GPS Personal Navigation Systems
- Screen Readers
- Personal identifiers e.g. elastic bands around tins

For each technology a periphery mapping was developed in conjunction with the targeted demographics.

Examining the Periphery

In order not to confuse things the following description uses as an example the application of the Wii Controller technology and the concept eventually chosen as the targeted periphery enhancement, a visual impairment cane.

> *As a periphery enhancement the cane provides a user with an increased perception of their environment in many ways. The most immediate and obvious being indication of future potential of obstacles and hazards that may appear within our environment, however when viewed in terms of the periphery the cane also provides an operator with much more detail than this.*
>
> *Consider the following, movement across the ground affords additional information such as texture via subtle nuances in vibration; this is further enhanced via the sound transition across particular materials. Over time a DT naturally develops a database of such peripheral cues allowing for the identification of the construct of their environment. Visually non impaired users do the same by also collecting cues from the periphery*.

So far the example detailed only reflects the device in use; however in terms of the periphery there is much more going on, in fact the device or cane in this context is only one part or enhancement of the system.

> *At the same time both auditory and touch senses provide cues that indicate it is raining, this is furthered by the subtle reduction in friction the cane makes as it is moved across the surface of travel, in conjunction with sound subtly dampened whilst also complimented by the swish made by the movement that experience indicates to be water.*
>
> *A slight change in balance indicates the possibility of an incline, however the canes balance in the hand during a concurrent sweep remains similar, a lack of additional pressure on both the fingers and palm indicates that in fact we are just on a bump in the road, differing volumes of pressure on the ball, arch and heel of the foot clarify this fact. This is furthered by our innate proprioceptive functions that tell us our foot is in fact parallel to the other just slightly raised in height.*
>
> *Sound from the sweep and our corresponding movements subtly reverberates impacting on dullness located in the surrounding ambience suggesting there is an object to the left, a feeling of reflected warmth and humidity is also emanating from the same position confirming the presence. The volume of the dullness within the overall ambience determined by a mix of sound and light indicates the object to be large; as we move subtle changes the quality and frequency of the dullness indicate a change in density and material of the object, experience indicates this material transition to be from brick to glass…*

There is a lot going on here. First of all from the description we can see that with experience the demographic targets build up mappings of information that empower them with the ability to determine not only their "*locatedness*" within, but also the constructs of their environment.

An additional aspect of the mapping not covered so far is that the periphery also communicates to the environment informing other entities within the environment of detail. In the case of a visual impairment cane this could be that the operator has some form of visual impairment. In the real world this is achieved via the white colouring of the cane, the addition of a red band would also indicate hearing impairment.

Summary of Design Problem

In order to collate and define the design problem the following steps were conducted:

1. Definition of a base statement
2. Outline of an overview of our need
3. Conduction of Literature analysis
4. Conduction of Perception investigation
5. Development of a periphery map

It is important to determine a solid frame of reference. By doing so you are afforded with a rudimentary outline and structural basis for the design. More importantly you are able to provide detail to others as to the nature of what the design will actually encompass.

In relation to the design model this frame of reference is the first iteration of our conceptual model. When viewed as a whole the output from each of these 5 activities acts to achieve the four principles of conceptual modelling as detailed in the definition of the design model (Page 63). In order to collate the design problem, all the stages of the model have been applied to a varying degree, as have the principles as outlined in standard BS EN ISO 9241-210.

The application of activity has shown that whilst the entire model is involved, there is greater concentration on the analysis activities during the initial use of the design process. Despite this fact there is still evidence of a symbiotic need for design synthesis in order to complete the phase of analysis as means to iterate and formulate the design idea.

DS1 Design Synthesis

Conclusions from the product study have identified that the Wii Controller is a viable platform for the development of assistive technology in two ways:

1. The development of natural user interface schemas for Wii Console interface.
2. The rapid prototyping and testing of design concepts that utilize equivalent peripheral technologies.

To this end, the decision was made that prior to the design idea being proved feasible, the existent technology of the Wii Controller should be used for the activity of feasibility investigation. Further rationale is that the activities of Product Dissection and Product Benchmarking have already proven viable the capability for the implementation of an equivalent and/or superior device (within legal constraint). These decisions act to limit the volume of resource applied to a design before it is proven viable (see BS ISO EN:7000-2:2008) and also enable the rapid prototyping and development of the design idea.

DS1 Prototype One – Fixed Compass Direction

The Nunchuk thumb-joystick was used to direct motion in eight directions at each 45 degree point. The Nunchuk was used to determine direction with respect to self. That is, whatever direction the thumb-joystick was held in, when the Z button was pressed motion would be in that direction. The aim was to provide an on the spot point of self-reference. It was determined that as with a person turning, the thumb-joystick would be turned (providing reference) and forward motion would proceed in that direction when the *“motion”* button (Nunchuk Z) was pressed.

Force feedback rumble varied according to the distance (determined via ray-casting[12] from point of reference of the virtual Wii Controller) from an object, with a constant rumble triggered on collision. Pressing a button (Nunchuk C) produced spoken distance and object name. However, there was no external frame of reference with respect to the environment which resulted in the user being disoriented.

DS1 Prototype Two – Wii Controller Only with Software Cues

In this iteration of design the Nunchuk was removed because the added complexity appeared to outweigh any benefits. Iteration one needed additional environmental cues in order to orient the user within the space. It was determined that cues such as footsteps, rumble on approach (pulsing to indicate distance), rumble on collision (constant), sonar and auditory signposts could be developed as means to facilitate this requirement. The feedback developed for this iteration was rumble (constant) on collision, and sonar, whereby frequency of beeps indicated distance.

As with the previous configurations, pressing a button produced spoken distance (Wii Controller button 1) and object name (Wii Controller button 2). In addition, on entering a virtual space, a description of the space is available via a button press (Wii Controller button Home). In order to turn, the Wii Controller was rolled to the left or the right. A beep indicated turning mode, and every beep indicated a 15 degree turn. The left and right beeps were different to make them identifiable.

Movement was provided by a button press on the Wii Controller (Button A), inducing movement in the last facing direction. Because of the positions of the various buttons on the Wii Controller, it proved difficult to control; additionally, button presses tended to move the Wii Controller, producing positional confusion. The Nunchuk was therefore re-introduced in iteration three.

DS1 Prototype Three – Turning via Nunchuk Accelerometer

In this final iteration, left and right turning was achieved by rolling the Nunchuk to the left and to the right, producing a 15 degree turn. As before, left and right step sounds provided turning feedback, which proved easy to interpret.

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[12] **Ray casting** is the use of ray-surface intersection tests to solve a variety of problems in computer graphics. It enables spatial selections of objects in a scene by providing users a virtual beam as a visual cue extending from devices such as a baton or glove extending and intersecting with objects in the environment. (Wikipedia, 2011)

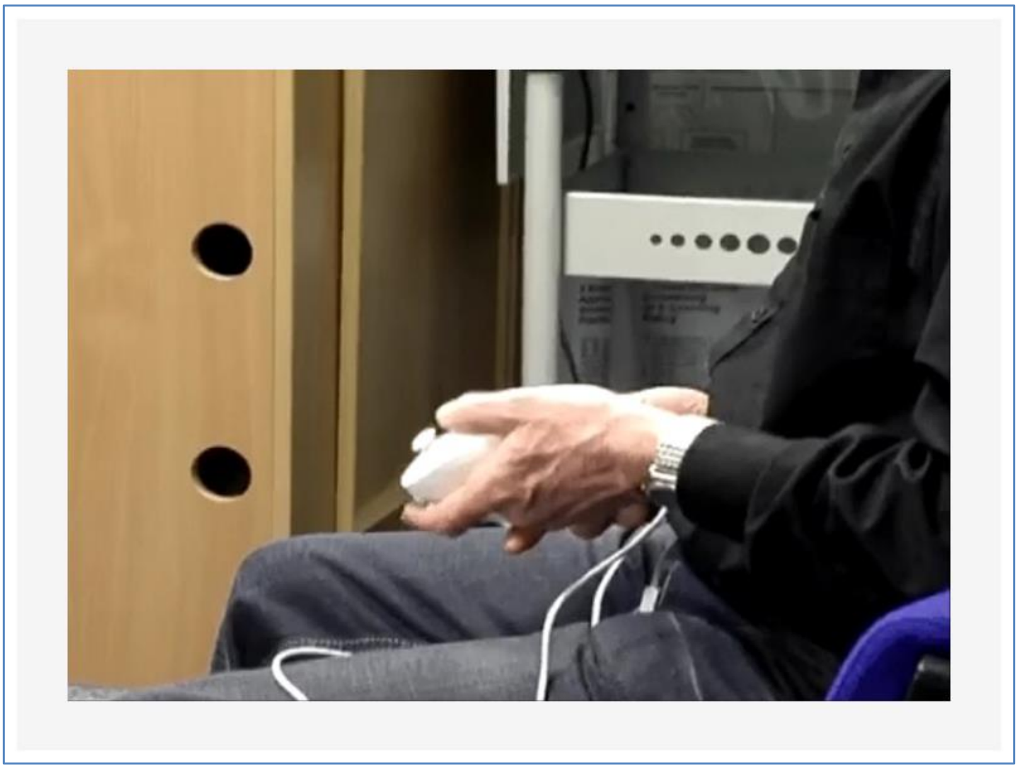


Figure 40: Testing of the Turning via Nunchuk Accelerometer Prototype

Motion forwards and backwards was initiated by tilting the Nunchuk forwards or backwards. The Wii Controller was used for scanning the space. Audio cues were used for indicating different types of objects and their distance. Different tones of beep were used to indicate furniture, walls, doors, and floors. Indication that a user was out of the scanning plane was provided in the form of a constant rumble. The rate of the beeps increased as any object was approached. There was a constant rumble on collision. Participants were told when they had passed from one space to another (for the last participant this was implemented as a whooshing sound on transition).

As with the previous configurations, pressing a button produced spoken distance and object name. This configuration separated motion (controlled by one hand with the Nunchuk) and scanning (controlled by the other hand with the Wii Controller), and was considered to be a clearer arrangement.

DS1 Design Evaluation

Having arrived at the system design of iteration three, and following rudimentary testing of the configuration with members of the demographic representative team, it was determined that the iteration was stable enough for more in depth human-centric assessment. The results of which would be used to verify and or rebuke the idea with respect to feasibility of concept.

Environment

Two virtual spaces were modelled that reflected the traditional T and radial arm mazes. It was perceived that by utilising these maze paradigms, different system conditions could be investigated, and experiments developed to evaluate the effect of the system in regards to factors such as learning and memory.

Literature indicates that the expansion of the T maze to include multiple T mazes can be used to identify the generation of cognitive maps during subject explorations (Tolman & Honzik, 1930). It was conceived that from this basic design, functionality of the system could be determined and empirical evidence produced to demonstrate success or failure of the awareness of the user via factors such as: location, navigation ability and orientation.

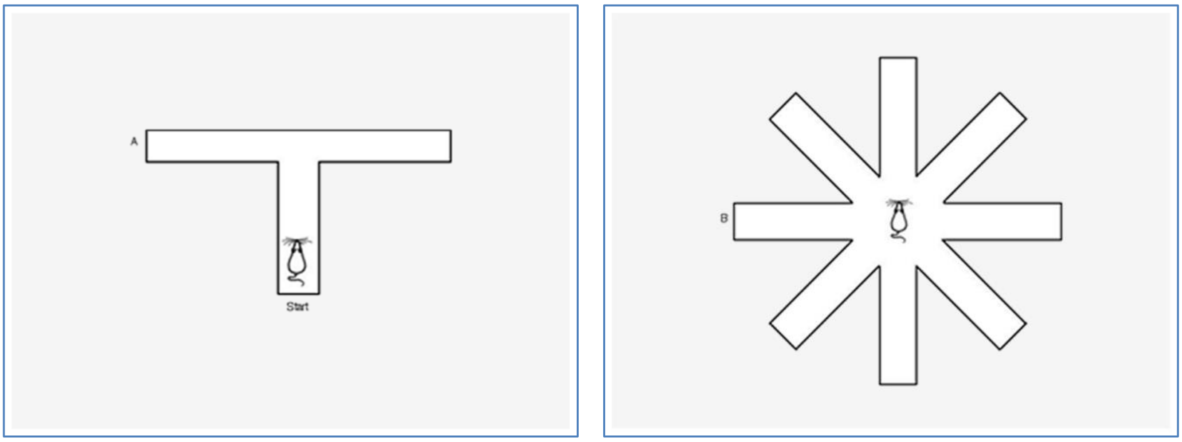


Figure 41: The T (left) and Radial Maze (right)

Furthermore it was envisaged that such a system could also be used to determine and evaluate proximity cues and artefacts which could be embedded within a virtual space to enhance the system from a software perspective. However following presentation of the virtual spaces and the construct of the suggested test scenarios to the demographic representatives of each group, reference was made to "*Rats in a maze*" and the testing method rebuked.

Another virtual space was then created for testing the system. Following the feedback from the demographic targets, it was decided to advance the system to a stage more representative of final product and context of use.

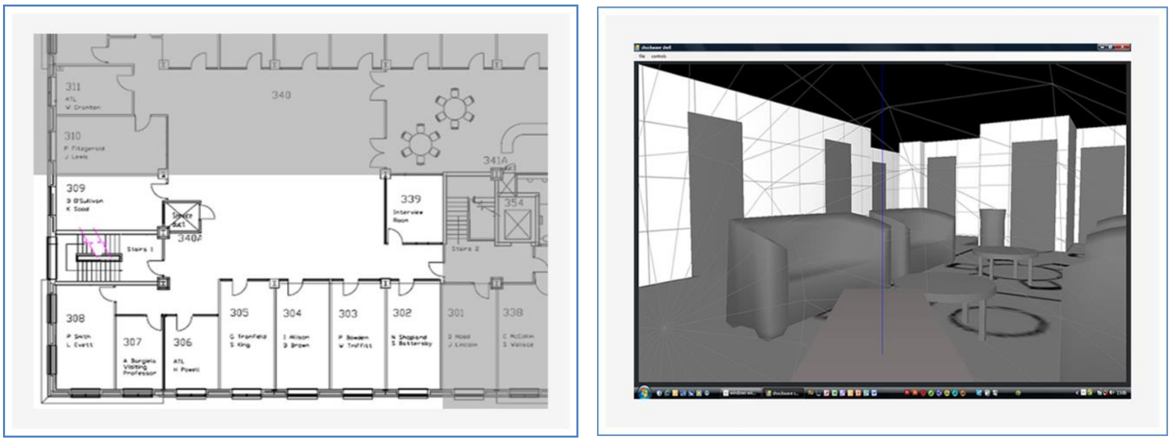


Figure 42: CIB Floor plan and corresponding Virtual Environment

To this end, the developed virtual space is a re-creation of part of the third floor of the Nottingham Trent University (NTU) Computing and Informatics Building (Figure 42).

This area was chosen for a variety of reasons as outlined below:

- It is easily available.
- It is a real functional space.
- It contains an open plan area with a number of obstacles of different types within it.
- It contains numerous potential areas for navigation and numerous potential navigation and perspective tasks.
- It is irregular, the level of complexity encouraging development of spatial awareness and navigational skill.

Testing of the software with the target demographic determined that whilst the existing software solution (Wiici-Mt) was both functional and accessible, the overall complexity could be reduced via the construct of a dedicated solution. Rationale for this was that a lot of the features of Wiici-Mt (Page 86) were not needed, and the direct mapping of controls would make setup and general operation simpler. To this end an additional application (The Wiici Shockwave Tool, Wiici-St) was developed. The tool isolated the required functionality needed to implement the virtual cane concept.

During user testing of the software iteration it was also identified that the current virtual environment was not suitable for those with low vision due to the textures used. This was resolved by re-texturing the environment using both a darker colour scheme and more prominent contrast between obstacles (e.g. furniture and the walls). Iteration of the software was conducted in conjunction with regular testing and feedback from users, thus ensuring that the system was practical in terms of visuals and compatible with current typical assistive technologies (e.g. screen readers).

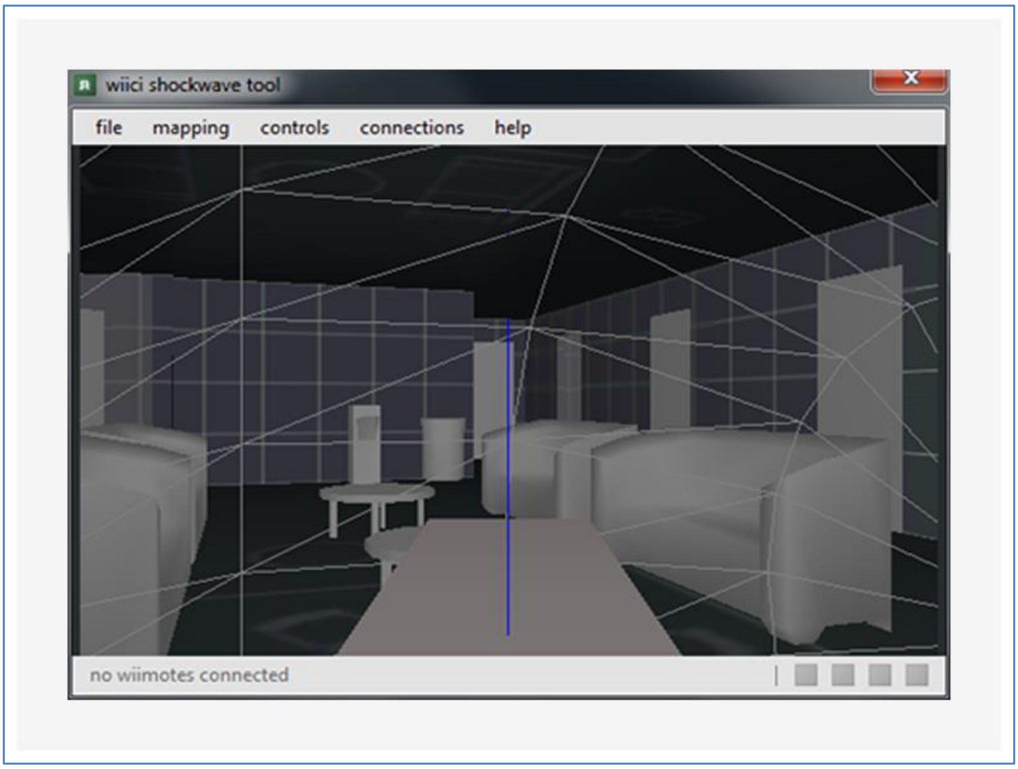


Figure 43: The Wiici Shockwave Tool and Updated Environment

Following verification of acceptability by the demographic representatives the system was deemed ready for human-centric feasibility evaluation.

Participants

Three members of the visually impaired demographic were selected to take part in the concept feasibility evaluation exercise. They were selected to cover as great a variety of the target demographic as possible and range from the partially sighted to the fully blind. Additional consideration was also made to each participant's normal methods for everyday environmental navigation with a criterion that each must have some experience and familiarity with use of a visual impairment cane.

Participant A

Participant A is fifty two years old and has Hallerman-Streiffe syndrome. His eyes were not formed properly at birth and he has no functional vision. He was blind until about the age of two, when he had surgery to restore his sight. After the surgery he had functional sight; his distance vision was fine but close up he could not read without the use of a lens, or recognise faces. He could however move around and navigate without difficulty. His sight began to deteriorate in his late thirties and by the age of forty two had no remaining vision.

Around this time he received basic training in the use of the visual impairment cane. He reported that the training involved methods for holding the cane and methods for using the cane such as sweeping and turning, identifying landmarks, and the use of inner and outer shorelines. He also details that there was also some discussion of using additional sensory detail such as smells and sounds. In terms of navigation, the training focused on egocentric and route strategies. Beyond this it seems that people develop their own strategies, and all three subjects reported doing so. Independent travelling in new spaces is very difficult; in such cases, a trainer will guide the person in at least the first instance. This is also true when dogs are used.

Of the three people who took part in this evaluation, Participant A is the most familiar with the space being used. While he often visits certain parts of it, other parts he knows very little, if at all. Participant A is also a member of the aforementioned demographic advisory team.

Participant B

Participant B is a twenty seven year old female who is partially sighted, although she could be registered blind if she requested it. Currently she has minimal vision in her left eye, which is only apparent when her right eye is shut and or obscured. In her right eye she has tunnel vision, with a section missing on the nasal side, and blind spots. She was very short sighted, with some retinal damage, up until 9 years ago when she suffered several bouts of optic neuritis. Her vision is currently stable but likely to get worse. She received basic cane training, similar to that of Participant A, when her vision first deteriorated. She is familiar with a very limited part of the area being used in this study.

Participant C

Participant C is a thirty eight year old male, who suffers from retinitis pigmentosa. His sight had been deteriorating from the age of about ten and he suffered from being very short sighted up until the age of seventeen, when he was registered blind. When registered blind he also received the basic cane training as detailed. He has had a guide dog for the last three years; however at work he has a full time support worker and so is often guided. Participant C has not visited the evaluation area before.

Procedure

At the start of each session, participants were asked their age, their sight history, the mobility training they had received, and how they generally got about. Participants were then taken into room 302 (see Figure 42, left), which was designated the training room in the virtual space.

Participant A had been in this room often and in the room (339) opposite. Both he and participant B were aware of the short corridor leading from the door from the stairs, to the rest of the space. Participant A has visited two other offices down the side of the space, and had sat on one of the sofas. This was the limit of his knowledge. Participant C had been guided to an office at the end of the line of offices on two or three occasions, and this was the limit of her knowledge. Participant C had the short entrance corridor described to him for orientation.

Each participant was told that they were to use the Wii Controller to explore a virtual representation of the open area, and were informed that it contained some items of furniture and other items. They were also informed that the space was edged by numbered offices and other doors. They were instructed in the use of the systems controls and the feedback they should expect, which were also demonstrated. They were asked to explore room 302 to get used to the controls and to ask any questions. They were given feedback on their use of the controls and the height of the infrared bar was adjusted to suit the comfortable holding of the controllers.

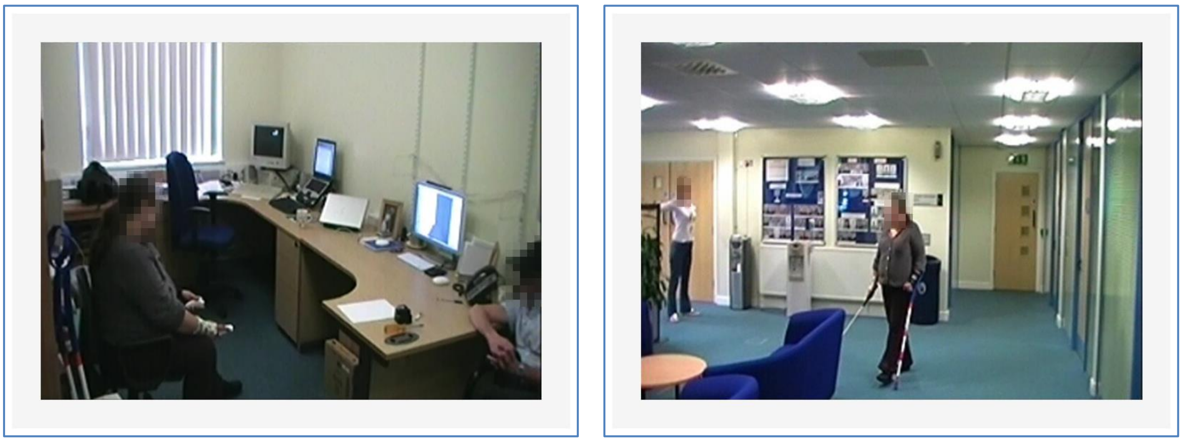


Figure 44: Exploring the Virtual and Real World Environments

Once they seemed familiar with the controls they were asked to find the door and exit 302 (this was the only door they could pass through), and then to explore the open space for as long as they liked. During their exploration, further feedback on their use of the controls was given, and, in the case of participants B and C, they were given tasks to complete (e.g., “there are some tables, try and find them”) to ensure they had explored all of the space. Once they had explored the space to their satisfaction they were asked to return to room 302.

They were then asked to describe the space. The participants were then asked to go out into the real space with their canes. Participants A and B were told there was an object on table 2 and were asked to find it and take it to the fire door. Participant C was not very successful in exploring the virtual space so he was taken to the top of the open space, asked to find the tables and from there the fire door. All participants were then asked some questions about the ease of use of the system and their views of it.

DS1 Results

Both participants A and E managed to explore the whole of the space, find all the objects in it and most of the doors. When asked to describe the space they gave a fairly accurate description of it, its shape and the positions of the objects in it. When asked to find the object and take it to the fire door, they both did so directly and with confidence. They found the controls a bit challenging but also talked about the space in spatial terms and thought it would be a good way for people who are blind to learn to navigate new spaces. Participant B, when asked to find the tables in the VE said “let me picture it”, thought about it and then found them.

Participant C struggled to explore the space. Although he seemed to understand the controls and the feedback, he often went out of plane and collided with objects. In these cases he made little attempt to either get back in plane or out of collision. After a short while he was reminded what the feedback was telling him and what to do about it. He did manage to visit most of the space, but mainly by luck and prompting rather than by making a systematic effort to do so. He could not describe the space apart from saying he knew there was a space, he had no idea of the shape, he knew there were sofas, tables and bins but not where they were. He was not asked to find the object but taken into the space and asked where the tables were, which he found quite easily, and from there to go to the fire door. He went to it almost directly. While he had found the exploration difficult and did not seem to have much idea of the space, he did not have any trouble finding objects in the real space. His residual vision helped him find the tables, because the tables are light coloured and under a skylight, but this would not have helped him find the fire door from the tables.

Participants A and B had some difficulty turning. Often they did not roll the Nunchuk far enough to effect a turn, and they over-rolled it when returning to centre. However, they both liked the correspondence between the movement of the device and movement effected in the VE. Participant B had the same problem, and reported the controls as difficult. However, he was also reluctant to move the Wii Controller at all.

DS1 Discussion

Overall, the results of the evaluation were positive. Participants A and B enjoyed using the system, appeared to develop clear spatial maps of the space, and were able to successfully navigate in a space which was largely new to them. Participant C was not so successful, but did seem to have some idea of layout. Participants A and B both use computers regularly. Participant C does use computers but described himself as a technophobe. He is often guided. Participant A often travels independently. Participant B is generally independent. Participant A is obviously familiar with the controls. Participants B and C had both used the Wii game system previously. Participants A and B were tested first and picked up the controls very quickly. Both these people are frequent and confident computer users. It is often noted in the literature that there is a wide range of strategies and navigational abilities used in spatial tasks amongst people who are blind (e.g., Hill, Rieser, Hill, & Hill, 1993). It was clear from the evaluation that training for Participant C needed to be taken more slowly, and this may well be the case for other people.

Following the assessment of the Wii Remote Virtual Cane (WRVC) it became apparent that the concept of mapping existent demographic abilities and skill is sound. This study has demonstrated that when mapping an interaction within virtual space, preserving an inhabitant's personal orientation is paramount in order to overcome the barriers and synthetic nature of immersion. Other researchers have also stressed the importance of spatial synchronisation between real and virtual worlds (Viciana-Abad et al, 2010). This paradigm is expanded further by Lombard (1997) who defines presence as the occurrence of an inhabitant of virtual space forgetting that their perceptions are mediated by technology.

The Wii Controller is restricted in its ability to perform such tasks. This is primarily due to the limitation of yaw tracking being reliant upon provision of infrared markers. In a desktop usage scenario, this artefact greatly impacts on the performance of the system as environmental context acts to restrict the Wii Remote optical sensor s field of view, a result of the distances involved.

This factor is also exacerbated by the cane paradigm itself. In order for the Wii Controller to be able to simulate cane use, the sensor bar has to be positioned below the desk line. During use of the system it became apparent that users require the facility to be able to scan the environment with the virtual cane in a non-traditional manner, in order to fully create a picture of the environment. Sometimes the Wii Controller needs to be raised, causing the connection with the infrared markers to be lost. In this context, button mapping and activation can also be an issue as a result of the device’s ergonomic construction (design symmetry so the device can be used as a control pad).

In order to adequately operate the D-pad or buttons “1” and “2” functionality the device has to be shifted in the hand so that the finite control aspects can be effectively operated. The resulting positioning of the device becomes more vertical or dipped respectively, when conducted naturally. More often than not, this results in a break in the line of sight between the infrared Camera and the infrared emitting sensor bar. This occurrence has been especially prevalent with assessment participant A.

DS1 Conclusions

This design study can be seen to partly fulfil all of the objective aims of this research.

Objective 1 has been addressed via the analysis and application of seventh generation gaming technologies to provide a design solution that enables those with visual impairments access to virtual space. The application of the technology of the Nintendo Wii Controller in this manner demonstrates that via the provision of engineered software solutions such devices are a viable means for interface in respect to this target demographic.

Objective 2 has been realised, and demonstrated by the empowerment of blind users to be able to successfully navigate virtual space. By mapping the paradigm of real world assistive-cane use to the navigation and interaction requirements of virtual space the principles of NUI have been demonstrated as a viable means of defining input modality.

Objective 3 has been realised via the application of the innovations of practice derived within Chapter 3 for the creation of a successful assistive technology solution.

Objective 4 has been addressed via the application of the innovations of practice derived within Chapter 3 in respect to user involvement within the design process. This study demonstrates that the gradual involvement of both stakeholders and demographic targets within the design is an effective means for design concept development without the need for large scale evaluation based resource upfront. Via the grounding of the design in respect to the users perspective of the problem immediate data can be derived that acts to better inform the design.

Despite the positive outcomes however, the critical evaluation of the Wii Controller Virtual Cane concept highlights that there is much need for improvement before such a system could be deemed suitable for marketable release and/or in depth user-centric evaluation. The negative aspects of the system which have been identified are primarily reflective of typical desktop usage and the limitations of the hardware in respect to its capabilities for yaw tracking.

In order to rectify these issues it is concluded that further iteration of the design is needed to enhance system performance. The re-design of the Wii Controller is seen as a perfect starting point for the continuation of this research. This is reflective of both the activities of Product Benchmarking and Product Re-Design.

It can be determined however that the issues related to desktop use (vision of the Infrared sensor bar) would not be as prominent within traditional usage. This is because of the increased zone of activity (i.e. sofa to TV). Further research is needed to verify that this is the case.

Chapter 7: Design Study Two (DS2)

This study was conducted by a multidisciplinary design team consisting of members from the Interactive Systems Research Group (Nottingham Trent University) in conjunction with specialists from the Division of Rehabilitation and Ageing, Nottingham University and the Portland College.

The study demonstrates the further enhancement of design practice via the infusion of the derived design model and existing methods for USID evaluation. The previous application of the model (DS1) demonstrated a focus towards the initial phases of design analysis in respect to both problem definition and initial concept feasibility. Design synthesis focused on the iteration of design via development of an interface paradigm. In contrast this study demonstrates the adaptation of existing hardware and demonstrates application of the model following the activities of feasibility investigation and development of a first stage prototype.

Original literature describing the study produced in conjunction with the author can be found in the appendix section of this thesis and via the following reference: Standen, Camm, Battersby, Brown, & Harrison, 2011. Foundation for the study can be found via Battersby (2008) and Battersby (2007).

The author's primary responsibility within the study was the design and implementation of both the developed hardware and accompanying software solution.

DS2 Research Objective

The design objective of this study is the realisation of a Wii Controller extension, that would enable those with severe physical disability and or limited motor skills with the ability to interface with Wii Console based video games. Whilst it is likely that the complexity and speed required for interface would make it nearly impossible for certain members of this demographic to successfully play some games, there are others (both users and games) which would become viable. Furthermore this research would also determine the Wii Console as a suitable platform (given licence) for specialised software and games production.

The research objective of this study is to investigate the amalgamation of the current USID evaluation practice within the suggested human-centric design process, thus further informing the multidisciplinary approach towards design practice. This study aims to identify areas of friction between the activities of design analysis and design synthesis identified during the investigation of literature.

DS2 Research Proposal

The Nunchuk is the primary extension for the Wii Remote. Once connected to the Wii Remote, the Nunchuk gives the device additional functionality, such as those required for complex navigational tasks within virtual spaces; however research has demonstrated that the Nunchuk itself is a potential platform for the development of accessible technologies. The Nunchuk has multiple peripherals that provide it with many potential avenues for recursive concept development. Unlike the Wii Remote Controller however, the Nunchuk cannot function as an independent device.

The peripheral technologies of the Nunchuk can be detailed as follows:

- A triple axis accelerometer
- A thumb joystick
- 2 momentary membrane switches

The Nunchuk is easily operable by the thumb and forefinger and the analysis of user requirements in previous study (Brown D. , Battersby, Standen, & Anderton, 2005) suggests that the Nunchuk could be easier to use than a standard game controller. Concept creation has identified that data obtained from the contained accelerometer could be used to provide means for tremor compensation, a distinct advantage for those within the severely physically disabled demographic, many of whom experience tremor as a result of cerebral palsy or other neurological problems acquired at birth.

DS2 Proposal Rational

Custom made alternative devices for those with special needs can be expensive and the low unit turnover makes the prospect unattractive to potential manufacturers. An alternative low cost solution is to exploit and modify contemporary gaming technologies for use as control devices. Such an interface would also demonstrate that divisions of the physically disabled demographic are a viable target for video gaming development. The device would demonstrate that with minimal adaptation and or creation of a bespoke extension, the existing system could be utilised.

Current research has indicated that the Wii Remote and or equivalent technologies can be used as expandable hubs for multifaceted Assistive Technology solutions. The advantage of such systems is that a blend of both technologies can be tailored to fit the individual requirements of members of large and heterogeneous user demographic. Idea generation exercises have determined that not only is the Wii Remote an optimal platform for the creation and evaluation of such solutions but also their implementation.

DS2 Background Literature

A full and informative breakdown of the related background literature for this study can be located via Appendix A. The study is also fully documented in the aforementioned original works and within the detailed previous studies conducted by the ISRG during literature review (The EPSRC Joystick (Page 27) & The Portland Switch (Page 30)). The following is a brief summary to provide an outline of the topic that laid basis for these works.

Virtual environments have been shown to be effective in facilitating the acquisition of living skills e.g. shopping (Standen, Cromby, & Brown, 1998). Furthermore, the three-dimensional nature of virtual environments allows for the creation of ecologically valid settings to promote activities such as decision making and social interaction, which people with intellectual disabilities usually have limited opportunity to practice (Standen & Ip, 2002). Video game based solutions can also provide engaging activity for people who are frequently under-occupied and denied real world opportunities (Standen, Lannen, & Brown, 2002).

DS2 Design Analysis

This case study follows on from the works detailed in the Portland Switch study. As such, the product requirements with respect to user demographic data can be determined as detailed within that body of research (see Battersby, Brown, Standen, Anderton, & Harrison, 2004; Brown D., Battersby, Standen, & Anderton, 2005). In effect these works are a further design iteration. Additional design detail collated via the phases of product study and DS1 are also used to formulate the basis of the design analysis e.g. patent consideration, materials, lifecycle etc. However there are several elements of analysis which needed to be addressed separately, in order to reflect the bespoke requirements of the study which are detailed as follows:

1. Functionality of the Design

Utilising the Portland Switch study as a basis for the definition of rudimentary product requirement, the functionality of the design can be determined as follows:

- Provision of Scanning
- Provision of Selection

The Portland Project also provides a rudimentary technical specification that outlines the desired aspects of a design solution:

- The device should be Wireless
- The device should be compatible with existing hardware (Discover switch, Joy Box, standard USB PC etc.) or better than this hardware in terms of functionality
- The device should be compatible with existing software and also any materials produced by the Portland Partnership.
- The device should potentially be used as an assessment device (in terms of being adjustable in specification (surfaces, mounting etc.))
- The device should be flexible in terms of physical attachments
- The device should be accompanied by a system which allows for the base unit to be moved within a specified range (45 cm)
- The device should be capable of adhering to the technical specifications as advised by the technical group of the Partnership.

From the outset it was decided that several aspects of the Portland specification were outside the remit of the study. This is due to specification items targeting both bespoke project requirements and existent switch based solutions.

2. Environmental Consideration

Testing of the solution was defined to be undertaken within the participants' common learning environment so that participant performance in the study would be reflective of environmental influence and distraction of the context of use for which the device is intended. However this can be interpreted as a limitation in some respects, as use of the system can only be seen to reflect usage within a supported learning environment.

It was determined that to fully facilitate evaluation this would need to be extended to the home environment, however this was determined as out of the remit and constraints of this body of research and at this stage.

3. Consideration of Inclusive Design

During the Portland Switch study, the USID methodology was applied to the design of a wireless switch for use with a virtual learning environment (VLE). The switch based device was required to provide the typical scanning and selection functionality.

Rationales for the poor performance of the switch during its evaluation were:

- That further cycles in the design process were needed after the applied quantitative evaluation.
- Changes to the design by the engineering members of the development team.
- A lack of adequate design iteration due to available resource in the period before the application of quantitative evaluation.

As with the Portland Switch Study (Page 30) a within subjects design was once again implemented to compare performance data on computer-based tasks, using a design solution and each participant's familiar device.

4. Testing Strategy

Instead of using a game based system for the collation and evaluation of data, at the request of the design team (the author) an alternative solution was sourced. The evaluation of the User-centric assessment conducted within previous studies had highlighted weakness in respect to the collection of informative design data, specifically data detailing device performance and product function.

Consultation with assistive technology specialists in regards to the methods for appropriate device selection (during the collation of data for design analysis), identified the Single Switch Performance Test (Liffick, Romich, & Hill, 2005) as a prime candidate for data acquisition.

Figure 50: Example of the SSPT in Action

The Single Switch Performance Test (SSPT) is software to facilitate measurement of the ability to activate a single switch. The SSPT software measures the average time required to activate or release the switch (following visual and/or audio prompts) and also can measure the speed of repetitive activations. A breakdown of the tests is provided in Table 7.

Table 7: Single Switch Performance Tests and Activities

Performance Test	Activity
Activation	A participant is required to click the switch as soon as the screen changed colour
Release	A participant required to press and hold the switch down and release the switch as soon as possible when the screen transitions to another colour.

The Activation and Release Tests generate data on the mean, fastest and slowest response times in seconds. Following the suggestion of the use of the SSPT by the design team, the Evaluation team constructed a collection of tests to conduct evaluation of design solutions. The following constraints were determined:

- Maximum hold time for the Release Test was set at 3 and 5 seconds.
- The Repetition Test required the participant to press the switch five times in succession as quickly as possible and generated data on time taken to test completion in seconds.

For each of the tests, lower scores indicate shorter reaction times i.e. faster switch press or release times.

DS2 Design Synthesis

During the period of the project, three designs were developed and prototyped. However due to resource constrains only the first was evaluated. Despite this fact the objectives of the study can be seen to have been met, and the iteration of design is still presented.

DS2 Prototype 1 – The Modified Nunchuk

The modified Nunchuk was initially created as a throw away prototype, developed specifically to validate the idea that an existing Wii Controller could be used as an expandable hub for hosting assistive technology solutions (for both console and computer use). Surprisingly however, the device (Figure 45) performed much better than expected and proved itself as a viable solution for assistive input for those with physical and cognitive disability.

Figure 45: The Modified Nunchuk

The construct of this initial design drew from the documented outcomes and experiences of the Portland Switch study (see Battersby, Brown, Standen, Anderton, & Harrison, 2004; Brown D. , Battersby, Standen, & Anderton, 2005) and guidance informing the constraint of available inputs (see Brown, Kerr, & Crosier, 1997). The device was fashioned by removing the joystick from a standard Nunchuk. The prototype therefore only offers two buttons and accelerometer functionality. The adaptation of a standard Nunchuk in this manner enabled quick turnaround of a prototype capable for testing both the expandable/hub interface and tremor compensation concepts.

DS2 Prototype 2 – The Wii Switch Adapter

The activities of Product Dissection and the investigation of Wii related research literature have identified viable means for producing Wii Controller extensions. Furthermore the initial positive performance of the Modified Nunchuk indicated Wiici-Mt as a robust platform for device development. Wiici-Mt utilises the Wii Controller as a wireless bridge between the device and a host system such as a personal computer and or games console.

In order to further evaluate the concept of utilising Wii Controller technology as an expandable platform for interface solution development, it was decided to revisit the Portland Switch design solution and evaluate how the application of Wii technology and the emerging theme of expandable solutions would affect design outcome.

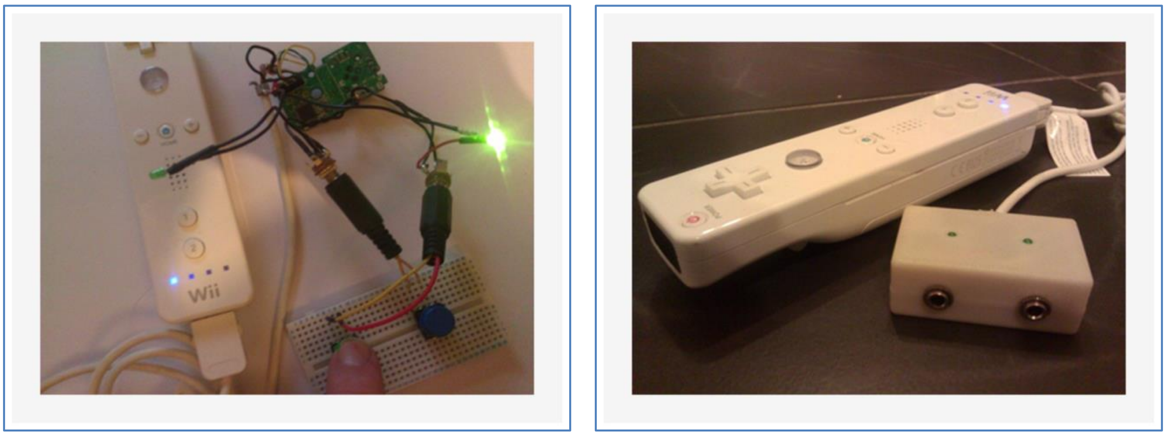


Figure 46: The Nunchuk Switch Adapter - First and Final Prototypes

Functional evaluation was conducted via the comparison of the extension's performance with a standard interface for Assistive Switches, the Joy-box, and the Single Switch Performance Test. Each of the SSPT component tests were conducted 3 times for each of the interfaces. In each case an AbleNet JellyBean switch was used. The results from the test indicated that the two devices were comparable. This reflects the results obtained via the evaluation team in respect to the modified Nunchuk.

DS2 Prototype 3 – The Wii Switch

The positive results of the modified Nunchuk performance indicate that the Wiici-Mt driver and the Wii Controller used in conjunction provide a sound platform and basis for device development. In order to further evaluate the concept of utilising such technologies as an expandable platform for interface solution development, it was decided to revisit the Portland Switch design solution and evaluate how the application of Wii technology and the emerging expandable solution theme would compare and affect the outcome of the design solution.

Figure 47: Wii Switch Iteration 1, Foreground & Background

Switch Iteration 1

Utilising the Portland Switch design (Figure 10) as a basis, design iteration one acts to implement rudimentary switch functionality and "Wii" aesthetic. The reflection of the Wii related mood-boards (Appendix D) and the aesthetics analysis conducted during the activity of Wii Controller Product Analysis (Page 67) were used to define the initial of styling of the design.

Reflection of the Portland Switch was also taken into consideration and the following key aspects were determined for the designs aesthetic:

- Symmetry
- Balance
- Smoothness
- Solidness
- Clean
- Simple

Several concepts were created (see Figure 47: Wii Switch Iteration 1, Foreground & Background) utilising the Autodesk Inventor CAD package (Autodesk, 2009). Comparison with the aesthetic key aspects was then used to refine and select the design. Next a switch mount was designed that facilitates the support of several differing switches. This was added to the existing CAD model and a prototype was printed for purpose of facilitating rudimentary practical testing. Testing determined use of the Sparkfun TSA12110 Tactile Switch (Sparkfun, 2010). Rationale for this decision includes: Sound of click, Feel of click, robustness, sturdiness and package size.

The application of in house functional testing of the existent design solution identified several performance and function related issues including:

- Tendency to miss fire if light pressure was applied to the edge of the dome
- Unit Rigidity and a lack of perceived strength.
- Quality of finish
- A lack of provision for permanent fixture.

Despite these limitations the switch was found to be functional and determined aesthetically physically reflective of Wii influenced styling.

Switch Iteration 2

Design iteration 2 acts to improve the robustness and performance of the switch. In order to address these issues, iterative design sketching exercises were conducted in conjunction with real-time CAD modelling. In order to increase the robustness of the design it was determined that a support ring be added to the dome cap. The addition of the support enhances the design by performing two functions:

- Increasing the impact strength and rigidity of the dome, a reflection of user application.
- Provision of a platform for supporting and attaching the dome base.

Additionally the base of the device was made solid to increase the lower weight of the unit. The use of weight in this manner helps enhance the perceived affordance of the device. The extra weight also acts to increase motion resistance of the unit when the device is use and not mounted.

It was conceived however that such an increase in material could potentially act to severely increase the production cost of each unit. With this in mind it was surmised that an additional ring could be cut out of the base and the cavity filled with a weight and then covered with an equivalent ring as used on the dome cap. In order to verify this design artefact it was determined that user-centric performance testing is required in conjunction with anthropometric review to determine optimal weight. The three mounting holes have been extended to pass completely through the base of the unit. This provision enables the switch to be mounted on a mounting plate so that it can be fixed either temporally or permanently (via addition of three nuts hidden inside the unit) to a surface, such as a wheelchair desk.

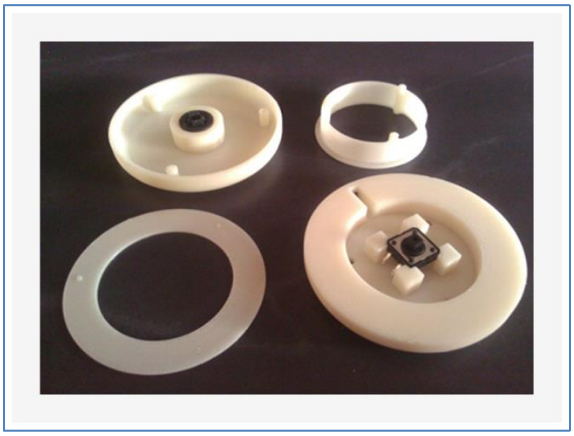


Figure 48: Wii Switch Design Iteration Two Parts (left) and Assembled Unit (right)

In response to this modification, design of a mounting plate was then also conducted. The plate was fitted with three hardware bolts that can be used to marry with the mounting holes on the switch base. In order to reflect existing switch mountings and thus environmental context of use the equivalent guide holes and dimensions found on the Able Net range of switches (described by the college as the primary switches in use) were also added to the plate.

Functional evaluation was conducted via the performance comparison of the prototype and the AbleNet Jellybean Switch via use of the SSPT (see Figure 49). Each switch was connected to a PC via the Wii Nunchuk Switch Adapter, thus reflecting the desired context of use. The results from the test indicated that the two devices are comparable. However what was not apparent from this data was that there is a slightly greater degree of trigger force required to activate the prototype.

Figure 49: The Wii Switch, a Jellybean Switch and the WiiChuk Adapter

Figure 49 shows the completed switch and adapter unit in use. In this instance the Wii Controller acts as a wireless bridge between the hardware and the personal computer.

DS2 Evaluation

Participants

23 volunteers, between 17 and 21 with a mean age of 19.17 years, were recruited from students attending a specialist college for people with intellectual and physical disabilities. Potential participants were identified by a lecturer from the college who is on the research team and the Occupational Therapist at the college. Inclusion criteria were as determined by the Evaluation team were:

- Ability to use a switch that could be interfaced with a computer.
- Adequate visual ability to see a computer screen.
- Sufficient hearing to perceive audio feedback from the tests

13 of the 23 participants were male and 10 were female. 12 of the participants were in the Personal Development and Communication (PDC) level at the college, for learners with the most severe intellectual and physical disabilities.

Assessment of Ability

Cognitive ability was assessed using the British Picture Vocabulary Test (BPVS; Dunn et al, 1997). British Picture Vocabulary Test (BPVS). Physical ability was determined via Subtests of the Quick Neurological Screening Test (QNST; Mutti et al, 1998). Full details of the tests conducted by the evaluation team and their results can be are represented in Appendix A. Cerebral palsy was determined as the most common diagnosis (83%). The remainder of participants suffered from other conditions affecting their motor control.

Control Devices

Each participant used the customised Nunchuk with the thumb-joystick removed and their usual (familiar) device as detailed in Table 8.

Table 8: Familiar Devices

Device Name	Number of Users
Rollerball	9
Mouse	12
Big Keys Keyboard	1
Wobble Stick	1

Outcome measures

Primary outcome measure was the participants' performance on SSPT; however the evaluation researcher also noted the following additional outcomes:

- Number of erroneous clicks or releases.
- Problems participants had using the Nunchuk.
- How participants held the Nunchuk

Procedure

Participants were ranked according to their ability scores and these ranks were used to group participants into matched pairs. The two groups differed in the order that they used the two devices in the testing. Each participant had two test sessions, each lasting between 15 and 25 minutes.

Prior to testing, participants completed the SSPT once using the Nunchuk, to familiarize them with the SSPT followed by the new device. In the following sessions, the participant used the Nunchuk in one session and their familiar device in the other. If they were able, the participants completed three trials of all three exercises of the SSPT, as means to generate a better sample of their individual performance. At the advice and request of the design team (author) photographs were taken to demonstrate how each participant held the Nunchuk.

DS2 Results

A full breakdown of the results collated within this study can be found in Standen, Camm, Battersby, Brown & Harrison (2011) The following section details a summary of the results collated by the evaluation members of the multidisciplinary team in order to demonstrate the infusion of both design and evaluation practice undertaken within this body of work and the overarching and evolving multidisciplinary approach.

The summary highlights areas of detail that are deemed to inform the design. Furthermore the summary only describes investigation of the first design iteration, the Nunchuk Switch. This limitation is of vital import and is further addressed within the discussion section of this study.

Results Summary

Not all of the participants successfully completed each of the individual tests. This was particularly poignant in regards to the release test. This was reported by the evaluation team as either a lack of ability to apply prolonged pressure to the switch, or because the participant did not appear to understand the practical requirements of the test. An examination of the way participants chose to hold and activate the Nunchuk switch indicated that this was related to whether they obtained a better level of performance than with their familiar device.

Photographs of the way participants held the Nunchuk were independently categorized by two experts into one of three categories as detailed in Table 9 and described visually in Figure 50.

Table 9: A Breakdown of the Categorisation of Device Manipulation

Category	Number of Participants
Standard	11
Backward and or Arched	5
Requiring Assistance	7

In the activation test and repetition test, 55% and 64% respectively of participants who improved were using the Nunchuk with a standard grip. When proportions of participants using the standard grip were compared between the two groups, the difference between them was not significant.

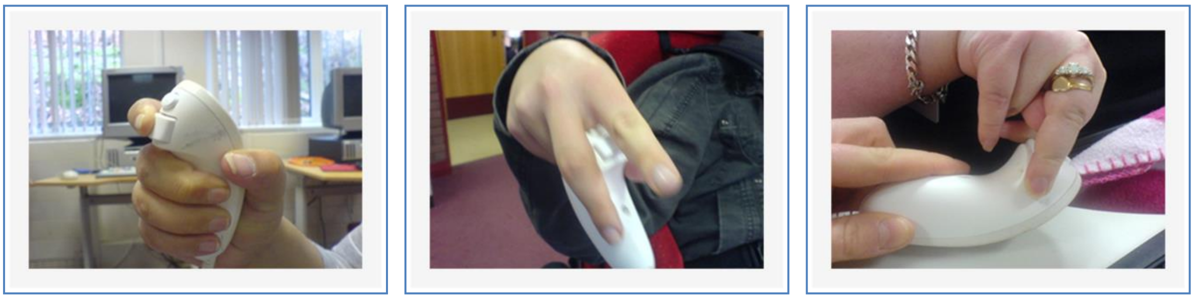


Figure 50: Standard, Backward or Arched and Requiring Assistance

Finally, problems experienced by participants during testing are displayed in Table 10. The most common problem was that some participants (30%) were unable to hold the Nunchuk unassisted.

Table 10: Problems experienced by participants when operating the Nunchuk

problem using the Nunchuk	Frequency	(%)
needed assistance to hold	7	30
difficulty applying adequate pressure to switch	5	22
pressing “C” button instead of “Z”	2	9
fingers slipping off of button	3	13
unable to apply prolonged pressure to the switch	6	26

This study found no overall differences between participants’ performance with the Nunchuk and their familiar device for the functions tested in the Single Switch Performance Test (SSPT).

The only exception was in the release test with maximum hold of 5 seconds. In this scenario, participants performed significantly better with their familiar device than with the Nunchuk. So it could be concluded that the switch function of the Nunchuk performs just as well as people’s familiar devices. However, group analysis disguised the fact that almost half of the participants demonstrated better performance using the Nunchuk. This is a very surprising result and in many respects in direct conflict with the results from the Portland Switch study.

Those who demonstrated better performance were no different in chronological age, reading age or upper limb ability. However there is some suggestion that being able to hold the Nunchuk in the way it was designed is related to being able to achieve better performance with it. It was surmised that this is probably a direct reflection of the ergonomic definition (shaping) of the design.

The problems experienced by participants in using the Nunchuk indicates need for adaptation to the shape of unit to reflect the handling capabilities of the unit in reference to the three identified grasp types (see Figure 50). 26% of the participants were unable to apply prolonged pressure to the Nunchuk switch. This suggests requirement for design improvement and further investigation in respect to positioning of the switch and sensitivity of trigger. This data also suggests that standard video game controller membrane switches are applicable for just fewer than 75% of the participants tested.

DS2 Discussion

The first practical attempt at the infusion of the derived structure and model for design activity with that of current USID evaluation practice has highlighted several interesting points for discussion. Of primary import is that the described evaluation practice could not keep up with the new methods for design iteration. Whilst it is true that activity began at a stage where a conceptual model had already been formed, and thus a volume of design analysis already conducted. This is reflective of previous examples of ISRG design practice. For example, the Portland Switch study also began in a similar manner, with the provision of the technical specification. Whilst it is true that activities of evaluation such as those detailed (i.e. gathering of baseline performance data, in-depth user characteristics) could have been conducted in tandem with the activities of design analysis.

The experience of this study suggests that within previous works, the creative aspects of design practice were held up by those of evaluation; furthermore the detail obtained via the evaluation is predominantly of a non-informative nature further adding counter-productive complexity. This provides support to some of the literature that observes that the practice of User-centred design impacts on the efficacy and speed of design practice. However the study also indicates the merits of user-centric practice (see Mao, Vredenburg, W, & Carey, 2005). The productive elements of the data collated were vital to informing design decisions such as those that lead to usability improvement of the accompanying driver software and also the physical aspect of the Wii Switch (e.g. ease of holding and mounting capability).

In previous studies it is apparent that much of the design resource is spent on the development of motivational accompanying software utilised to obtain data primarily for evaluation, rather than the iteration and development of the actual assistive product.

This study has described the application of a large amount of additional design resource before investigation commenced. The study managed to:

- Verify the Wii Controller as an extendable hub for Assistive Solutions
- Verify the Wii Controller as a communication device
- Verify the Wiici Mapping Tool as a functional and viable software solution for Wii hardware accessible technologies
- Always meant to be a throw away solution however

The primary outcome of this application of Design Study however is the demonstration of infusion between both the approach to design practice via the design and evaluation members of the multidisciplinary team respectively, the suggested new design application structure formulated around the model definition within BS: 7000 and the existent evaluation heavy user-centric method design construct.

An advantage of this study was the application of the Single Switch Performance Test for functional data collection. The SSPT is straightforward, easy to administer and involves the range of functions required of a switch. These factors can be seen to facilitate the efficient provision of data to aspects of product function and also usage requirement, aspects found to be previously lacking in the design cycle.

In this context it is important to remember that this case study is representative of investigating the feasibility of design concept not the definition of a final product, this is in turn a reflection of the resource allocated for study in terms of design. As iteration to the design is undertaken the evaluation of concept should be enhanced to include further analysis and the expansion of requirement, more reflective of every day context of use.

At such an early stage in the development cycle a large expenditure of resource in terms of product evaluation is unwise, as indicated by literature and verified during the period of investigative study. The rationale for this is provision of early verification of rudimentary concept functionality and the inclusion and infusion of user-centric influence with a minimal impact on resource.

DS2 Conclusions

Despite the limitations discussed, this study was able to demonstrate that the Wii Controller could effectively be used as a central module unit for the development of assistive solutions. Additionally the study was able to demonstrate the efficacy of the switch function of the modified Nunchuk for some people with intellectual and upper limb motor disabilities. In some respects this can be seen as a direct conflict with the results and conclusions drawn within the Portland Switch study and more research is needed to determine why such a contrasting device (in comparison to familiar device) determined such amicable results.

However, in the context of product feasibility the study has verified the raw functionality needed for iteration of the device. Evaluation of the functional requirements of the system in respect of the user-centric evaluation has identified that a rationalisation of the system would be advantageous. Additionally the performance comparison between the devices and the Nunchuk solution highlights the efficacy of the Wiici-Mt as a bridge for Wii Controller to desktop communication.

Future studies could investigate whether the type of grip a user employs can predict whether or not a person will have better performance with the Nunchuk or even whether encouraging users to hold the Nunchuk a certain way improves its performance. Finally, evaluation of the Nunchuk provision for navigation (thumb-joystick and accelerometer) should also be conducted in order to evaluate the device's full potential as a control device for people with intellectual and physical disabilities.

Chapter 8: Design Study Three (DS3)

This study was conducted by a multidisciplinary design team consisting of members from the Interactive Systems Research Group (Nottingham Trent University) in conjunction with specialists from the Division of Rehabilitation and Ageing, Nottingham University.

Original literature describing the study produced in conjunction with the author can be found in the appendix section of this thesis and via the following references: Standen P. J., et al (2010), (Standen P., et al (2010), Standen, et al (2010). Foundational works for the design and development of the study can be found via Battersby (2008) and Battersby (2007).

The author's responsibility within the study was the design and implementation of both the developed hardware and accompanying software solutions.

DS3 Research Objectives

Given the fact that most current stroke rehabilitation systems employ relatively sophisticated or expensive hardware and software, one question of paramount clinical importance is whether the benefits obtained from these systems can be achieved with less sophisticated affordable systems.

The objective of this study is the development of a low cost home based system for stroke rehabilitation which would allow patients to practice the movements required for activities of daily living at the frequency required to promote recovery of functional movement.

Previous studies (The Virtual Cane & the Nunchuk Switch) have demonstrated the infusion of existent user-centric design practice with the application of product study and the evolving product design focused model for development of Assistive Technology. The successful implementation of this study can be seen to:

- Further verify the concept of expandable hubs for multifaceted AT solutions.
- Further demonstrate the infusion of existent user-centric design practice with the application of product study and the evolving product design focused model.
- Demonstrate the recursive nature of design practice in a practical context.

DS3 Research Proposal

A systematic review of studies conducted by Nottingham University's Stroke rehabilitation team found a significant improvement in upper limb motor function recovery within stroke survivors that were able to utilise robot-assisted therapy (see Standen P. J., et al., 2010), however such systems are expensive, require technical support and are hospital or laboratory based.

A proposed solution (Battersby S. , 2008) is the development of a low cost rehabilitation glove using the capacity of the Optical Sensor on the Nintendo Wii Controller to pick up the signal from four diodes placed at the patient's fingertips. This compensates for the inability of previous low cost solutions to track fine motor movement.

The expansion of typical Virtual Environment application areas such as computer gaming, simulation based training and academic research to include provision for those recovering from stroke has many potential benefits. In terms of the individual, such provision would act to empower and enable active participation in new forms of rehabilitation and exercise. Furthermore, stroke survivors with continuing impairment in their upper limb often find it difficult to access the early intensive, task specific practice that research has shown is necessary for motor recovery.

Although the commercially available gaming platforms lack in dedicated stroke rehabilitation software, hardware and performance metrics they often provide other equally important advantages such as mass acceptability, easily perceived feedback and most importantly affordability for unrestricted home use.

DS3 Research Foundation

Following on from the project proposal phase (Battersby S., 2008); a feasibility study for the design concept was then undertaken by a third party (Barker, 2009). In his works, Barker conducted an evaluation of available technologies in line with established USID methodology. Inspired by the works of Lee (Lee J. , 2008), Barker determined that a system based on that described by Battersby (Battersby S. , 2008) was the optimal way to proceed.

In his rationale for the use of the Nintendo Wii Technology Barker states:

> *"The decision to implement the Wii Controller into this system over any other device was paramount to this projects success. The versatility of the Wii Controller means it has lots of potential for other applications as well. With the current implementation in this project, the ability to have multiple object tracking gives a very engaging and intuitive way of interacting with a game environment. Barker, 2009"*

This is in contrast to the conclusions drawn within the existing body of research, which have determined several potential issues in regards to factors such as ambient lighting condition and the robustness of diode tracking capability. Despite these differences however, Barker's works acted to verify the feasibility of the design concept and further research was defined in accordance.

DS3 Design Analysis

This case study follows on from the works of Barker (2009). As such, the product requirements in respect to user demographic data can be determined as detailed within that body of research. In effect these works are reflective of the proposed model for design practice following the phase of feasibility investigation. Design detail collated via the phases of product study and the works of Barker are used to formulate the basis of the design analysis e.g. patent consideration, materials, lifecycle etc. However following the evaluation of the study conducted by Barker, several elements of analysis were identified that needed investigating and/or to be re-addressed:

1. Design Functionality

Following on from the works of Barker (2009) a description of the typical user demographics was determined as described by Standen (Standen P. , et al., 2010). The design solution developed by Barker Figure 51 consisted of four light emitting diodes (LED) sown into the fingertips of a glove. Inspired by the works of Lee (Lee J. , 2008) and research conducted at Reading University (Murgia, Wolff, Sharkey, & Clark, 2008) Barker developed a system that utilised two Wii Controllers and algorithms developed by Iocchi & Konolige (1998) to triangulate the positioning of each of the diodes in three dimensional spaces.

Figure 51: The Barker Glove & Lights Out Game (Barker, 2009)

The decision to use 4 diodes per glove was based on the limitations of the Wii Controller's optical sensor. In order to combat the issue of finger identification, Barker determined that the position of the ring finger is predictable from the position of the fingers either side in most movements, the four diodes were placed on the remaining fingers and the thumb. Reflection of these works determined the functionality of the design as:

- Replication of hand within virtual space
- Definition of finger placement via infrared beacon

In addition to the production of the prototype glove system Barker also constructed a rudimentary software implementation that demonstrated use of the glove in a gaming context.

2. Environmental Consideration

The project brief provided by the evaluation team (Nottingham University) in response to the works of Barker, described the context of use for the application of developed hardware would be reflective of a typical home desktop environment. With this in mind consideration had to be taken into account of variance in factors such as available space and ambient lighting and (issues that had already been raised as points of concern). Hardware was to be provided and installed by the evaluation team (Nottingham University), thus determining provision of the clinical setup of equipment.

3. Anthropometric Consideration

The demographic requirements of the project aims and the context of device use determined two areas for consideration in terms of anthropometric requirement:

- Hand size anthropometrics
- Desk environment anthropometrics

In order to facilitate these requirements data was collated (BS EN 420:2003+A1:2009; BS ISO 13999-1:1999) to determine the best fit for hand sizes. As with the Virtual Cane and Nunchuk Switch studies, the standards (BS EN 527-1:2000; BS EN ISO 9241-410:2008) were used to define the maximum area of product usage in terms of desktop provision. Desktop provision is only reflective of the environmental consideration of computer games. In respect to console games these limitations do not apply and reflection is made towards display optimal viewing distances (see HDHES, 2006), for example affording a distance of approximately 1.2M – 4M for a 32 inch television.

4. Inclusive Design

Following the successful application of user-centric involvement within the development of the Virtual Cane, and the enhancement of this process via the Nunchuk Switch, a multidisciplinary team was formed to handle each of the specialised elements of the design and evaluation process. Utilising the aforementioned studies as foundation, focus is applied to the further infusion of design and evaluation practice within the evolving design methodology. The previous studies have respectively demonstrated focus on the analysis and synthesis divisions of the design process. The objective of this study in respect to the thesis objectives is to demonstrate the activity of iteration within the derived design practice.

Once again reference was made to the following points:

- The investigation of the Wii Controller as a hub for custom peripheral communication determined that the development of custom peripherals is feasible.
- The evaluation of existing Wii Controller extensions has identified the Nunchuk peripheral as the optimal platform for the rapid development of extension solutions, due to the peripheral capabilities (e.g. accelerometer) and the volume of inputs available (2 buttons and thumb-joystick).
- Reflection of patent limitations infers that if the concept is successful that further development will be needed in order to make the device viable.

Primary points of interest as described by the evaluation team included:

- A Desktop scenario of use.
- Definitive use of Wii Technologies for solution.
- Requirement for a non-traditional glove solution.

Evaluation of the works by Barker highlighted unforeseen limitation in the system in terms of the environmental consideration. This limitation was identified via application of simple trigonometry in reflection of the definition of the desktop user space as determined via anthropometrical consideration in the aforementioned standards. The impact of this outcome was that the software solution as developed by Barker can be seen to be non-viable within the desired context of use.

DS3 Design Synthesis

The development of the design commenced with the evaluation of technical product data collected during the Product Study. Furthermore reference was also made to feedback and requirements that had been concluded by the evaluation team (Nottingham University) following the aforementioned feasibility study by Barker. Utilising these works as a foundation an initial conceptual model defined in the form of a design specification and refined concept idea which utilised the technology of the Wii Nunchuk as a basis. The model was presented to the project stakeholders and following acceptance design iteration began in the form of prototyping via modification of existent third party Wii hardware.

Prototype One (The IRA-USB-R1)

The investigation and replication of the Wii Console's peripheral hardware has determined that the Wii Nunchuk extension is an excellent base platform for the development of assistive solutions. Utilising the described works as a basis, a prototype was constructed to determine whether a wireless version of the technology could be for the development of further design solutions.

Figure 52: Prototype One, Wireless Communication and the IRA-USB-R1 Glove

In order to facilitate use of wireless third party (non-Nintendo) hardware solutions within the current implementation of WiimoteLib, modification was needed in order for the library to recognise the devices. This was easily achieved and several commercial wireless hardware solution id's were added to the library's codebase. Figure 52 shows both the glove iteration and accompanying software solution.

Prototype Two (The IRA-USB-R2)

Following the successful implementation of design iteration one a second version of the glove was produced which again utilised a wireless Nunchuk to form provision for the base circuitry requirement. In this iteration however, following testing and feedback provided via the evaluation team, the fingertips were swapped for a more robust and adaptable solution.

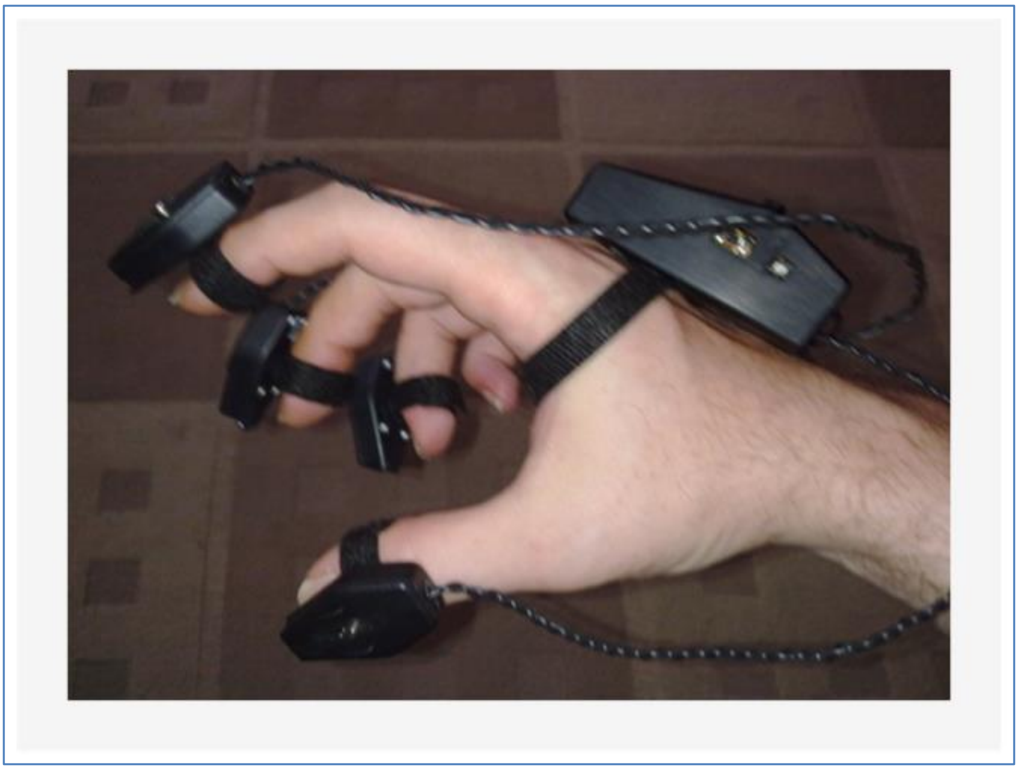


Figure 53: Prototype Two, the IRA-USB-R2 Glove

The shaping of the fingertips to a point was seen to improve the ergonomics of the design by reducing the potential for fingertip "*clashing*" when the glove was in use. However the additional bulk on the back of the unit and the balance of the unit on the strap that holds it to the hand detail a reduction in usability.

The following list details some of the key features of the IRA-USB-R2 glove:

- Inclusion of an accelerometer for gesture and user performance logging.
- Inclusion of two buttons for the provision of additional input capability.
- Inclusion of mini joystick for the provision of additional input capability.
    - Operable as computer mouse when used in conjunction with button mappings via Wiici-Mt.
- Robust and resilient ABS casing.
- Customisable finger attachments to facilitate use by those with different hand sizes.
- Improved LED fingertip mounting.
- Changeable finger loop attachments - hygienic requirement.

By utilising the Nunchuk as basis for the development of the design solution, provision was gifted for the device to also function as a mouse (assuming adequate motor capability of the secondary limb). This artefact of the design means that once the glove had been donned by a user, capability is afforded to navigate the Windows interface if needed. In comparison, design iteration one and the glove by Barker both required that once donned, removal was then required in order to operate the operating system. However, this can be seen to also be in conflict with the presented literature in that additional operability has been added to the design (e.g. Brown, Kerr & Crosier, 1997; Ellis, 2006; Iacopetti, Fanucci, Roncella, Giusti & Scebba, 2008).

Following the development of iteration IRA-USB-R2 the glove was determined as functionally sound and as suitable for initial user-centric evaluation. In accordance with the evolving design model as outlined in the Virtual Cane and Nunchuk Switch studies. It was observed however that additional iteration was needed to reduce the issues introduced with the encasing of the circuitry.

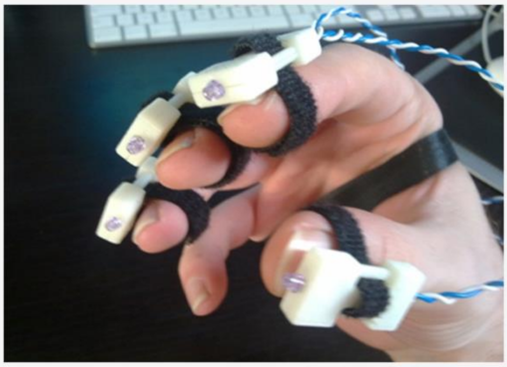
Prototype Three (AB Wii Glove 1)

At this stage however the continued development and application of design was undertaken by a third party within the ISRG (Burton, et al., 2011). At this time stakeholder based feedback and in-house testing of the IRA-USB-R1 and IRA-USB-R2 prototypes resulted in the decision to remove all Nunchuk equivalent functionality. The rationale for this decision included:

- Fear of IP and Patent Infringements.
- Reduction of bulk and weight.
- Reduction in costing for the overall design

Utilising the IRA-USB-R1 prototype and the Barker Glove prototype as a basis for development, a new prototype was fashioned that utilised two CR2032 batteries as a power source (Figure 54, left).

However, the design was flawed with respect to the specified requirement of the LED's (as large a field of view as possible); the power requirements of the system resulted in a performance life of just 15 minutes. The removal of the accelerometer from the system also resulted in an additional impact in regards to the accompanying software implementation.



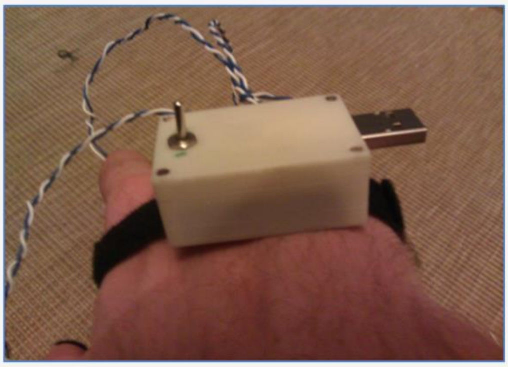


Figure 54: Prototypes Three & Four, the AB Wii Glove 1 (left) and the AB Wii Glove 2 (right)

Evaluation of the works of Barker determined that the current system was not robust enough in regards to finger identification tracking. In order to resolve this issue data from the accelerometer was used to improve the performance of the system. By gifting provision of real world physical data in respect to hand orientation, the use of the accelerometer acted to compliment the system by providing a definitive means for identifying rotation as well as enhanced finger positioning filtering. This advantage was lost with the accelerometers removal.

Software Iteration 1

The removal of the accelerometer required that a system be developed that allowed for the tracking of rotation by use of the diodes alone. An algorithm was developed that utilised "line of best fit" regression as a means of determining hand rotation (treating the diode x and y positions as though they were points on a graph). Evaluation of the works by Barker and the resulting investigation into the potential methods for finger tracking by the author, had already ruled out the use of this method as a means of identifying hand rotation.

The rationale for this was that the system was limited and open to abuse e.g. provision for the manipulation of rotation value via movement of a singular point. This factor can only be seen to be exacerbated when viewed in the context of use (positioning around a circumference) and further still in reflection of the motor control and capabilities of the target demographic.

Prototype Four (The AB Wii Glove 2)

Following on from the development and testing of iteration AB Wii Glove 1, a new version of the glove was designed that offered recharge capability and a greater life performance. In order to increase the life performance of the device new LED's were sourced that required less power to operate. The downside to this was that the capability field of view was also greatly reduced. In order to rectify this issue infrared diffusers were sourced and added to the fingertips. Furthermore, the fingertips were also reshaped to reflect the design of those in iteration IRA-USB-R2 as means of reducing clashing during operational use.

Following on from the decision to reduce bulk and weight via the removal of the accelerometer, the new solution was unfortunately twice the size and twice the weight of the original design solution. This is reflective a lack of adherence to the information gained during previous iteration and lack of adequate research and technical investigation. Needless to say, this iteration (Figure 54, right) performed poorly and received negative feedback during stakeholder evaluation on grounds of ergonomic implementation and lack of adhesion to requirement specifications.

Prototype Five (The AB Wii Glove 3)

Following on from the feedback provided in regards to iterations AB Wii Glove 1 and AB Wii Glove 2, the design was readdressed in order to reflect the following key areas of concern:

- A reduction in size and bulk.
- Increased performance life.
- Ergonomic viability.

Conclusions drawn from the feedback provided by the usability team led to the refactoring of the design. The primary changes between AB Wii Glove 2 and AB Wii Glove 3 can be summarised as:

- The swapping of USB charging connection from male to female.
- A reduction in overall size as a reflection of the above.

Following completion the device was submitted to the evaluation team for testing. Initial results were in terms of performance were good. However, further testing by the usability evaluation team identified that the solution soon lost the ability to maintain power. This factor in conjunction with the still limited ergonomic capacity of the device meant further design iteration was needed.

Software Iteration 2 (WiiciTrackLib)

At this stage of development the design implementation was handed back over to the author. Primary concern was the impact of the removal of the accelerometer from the system. Although this was seen by the project team to simplify the gloves design, this move in fact negatively impacted on the design greatly. In addition to further hardware iteration, iteration was also needed in terms of software in order to fully facilitate the change of design concept. Additional requirements had also been introduced in terms of the environmental context of use. Following infield investigation by the evaluation team it was determined that the defined fixed desktop scenario was not reflective of the real world context of use.

By way of result the clinical and fixed setup required to facilitate finger tracking by the Iocchi (1998) algorithm was no longer viable. The combination of these two factors meant that a full revision of the code-base created for the finger tracking functionality was required. The resolution at this time was to create a separate library that could be used in conjunction with WiimoteLib to facilitate finger tracking.

WiiciTrackLib

Inspired by the works of researchers Nebulusless (2008) and Ghannoum (2008) the Wii Controller Interface Suite Tracking Library (WiiciTrackLib) was developed by the author. The library performs ray intersection calculations to approximate the position of infrared points within 3D space.

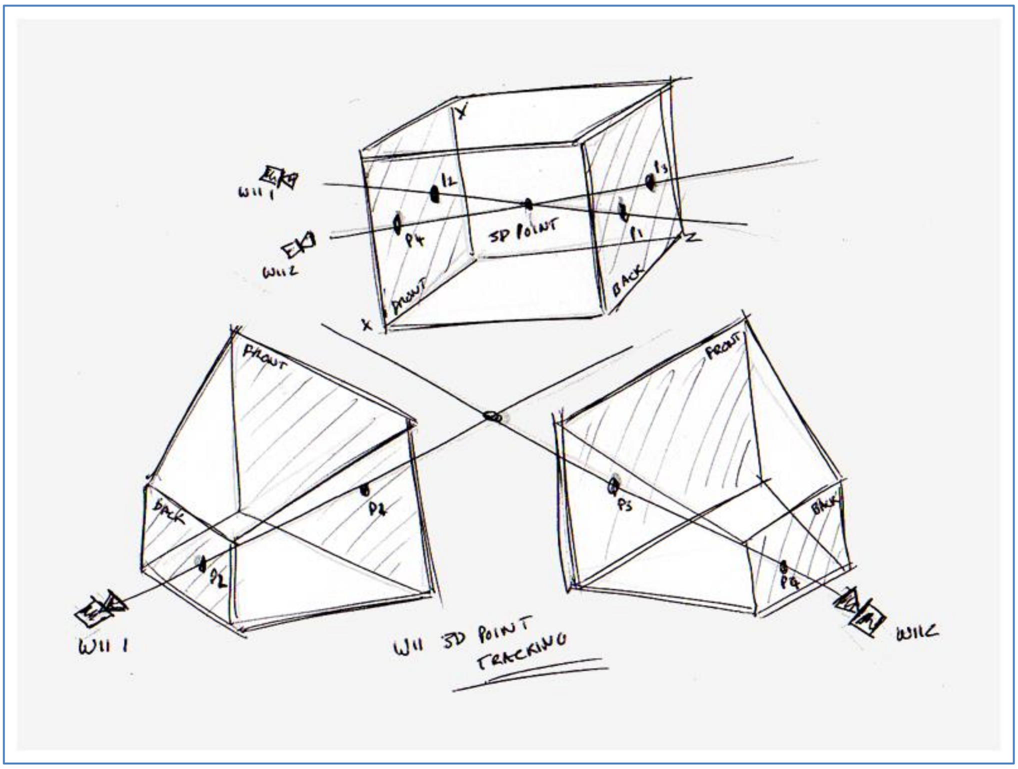


Figure 55: Design Sketches of the Point Tracking System

During calibration two planes are defined which represent the front and back faces of a cube in 3D space. Planar Homography is then used to find the correspondence between the Wii Controller(s) camera pixels and the defined cube, by utilizing a similar method as demonstrated by Johnny Lee (Lee J. , 2007) within his white-board application (Fernandez & Peek, 2009).

Once both planes have been defined, they can then be used to determine the start and end points of a viewing ray from the Wii Controller(s) to the infrared source via the intersection of each plane:

- Ray One: P1 -> P2 (Front Left Point -> Back Left Point)
- Ray Two: P3 ->P4 (Front Right Point -> Back Right Point)

With these two rays, an intersection calculation is performed to determine the location of the point in 3D space. The library has been implemented to be environmentally sensitive so that robust and accurate tracking performance can be achieved without the need for *"clinical"* preparation and calibration. This was achieved by catering for common issues such as physical measuring inaccuracies, errors and distortion.

Prototype Six (IRO-USB-R4)

Following the re development of the Wii Controller finger tracking software solution it was decided that a full redesign of the glove was needed undertaking in line with the design model. Evaluation of the feedback provided by both infield user-centric testing and feedback provided by the evaluation team has determined the following key points for re-design:

- Universal finger attachment
- Capability to replace component parts
- Reduction in size
- USB rechargeable
- Robust and enhanced performance
- Fast charge times
- Improved ergonomics
- Reduction in weight

Following the application of design sketching and brainstorming for the generation of glove ideas, several concept solutions were demonstrated to the evaluation team in conjunction with exemplar prototypes (e.g. Figure 56, left). Feedback was provided by the team in the form of the selection of design options. Work then commenced on the development of a new Virtual Prototype which could be quickly be realised via Additive Printing. In addition to the design of the device's encasement, focus was also applied to the revision of component circuitry. This was completed via the sourcing of component breakout solutions that reflected the key points for re-design.

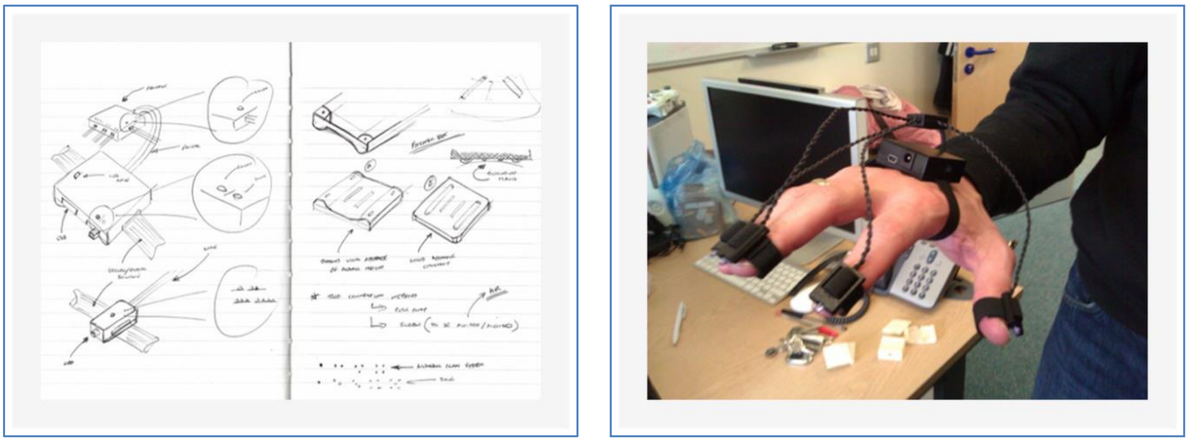


Figure 56: Example of design sketches and physical IRO-USB-R4 Glove

This process was enhanced via the inclusion of a further technological review in respect to power-supply and recharge capability. As a result of this process a breakout solution was identified for the provision of recharge requirement. The developed glove IRO-USB-R4 can be seen in Figure 56 (right). Key features of the glove as determined by user-centric development and evaluation are:

- Infrared sources (pendants) are interchangeable allowing for numerous variants to be attached to the power source.
- If a LED fails the pendant can be changed and use and/or testing can continue.
- Fast 100mah/280mah USB rechargeable power source.
- Recharge indicator LED.
- Ambidextrous pendant design for left or right handed individuals.
- Compact lightweight fingertip mountings, especially designed to be customizable to a user's individual anthropometric requirements.
- Compact lightweight body mounting, designed to facilitate a user's individual anthropometric requirements.
- Pendant infrared source operational control (on/off switch).
- Lightweight and compact.
- Solid and robust performance, up to 1hour 40min constant use. It will last longer but this is the optimal usage period.

Whilst the power capabilities of the device have proved to be more than satisfactory, feedback from infield user-centric testing identified that the pendant aspect of the design to be unreliable and prone to breakage. Furthermore, the connection of the pendant to the base unit (facilitating capability for part replacement) has been found difficult to use. Over time it has been discovered that the fingertip connections are prone to fail due to the repetition of putting on and removing the glove. Natural tendency is to pull on the wires in order to aid in putting the glove on, thus eventually resulting in the breakage of LED to wire connections. This factor is also related to the aforementioned pendant failure.

Prototype Seven (IRO-USB-R5)

The optimisation of the design, in respect to feedback provided during the holistic period of this research has resulted in the development of final design iteration.

Figure 57: Prototype Seven, the IRO-USB-R5 Glove

The IRO-USB-R5 is the accumulation of all the glove related performance data thorough each of the design iterations. Features of the glove include:

- Approximately 25% size reduction to that of the IRO-USB-R4.
- Approximately 30 minutes charge time.
- 2 hours performance lifetime (1 hour full brightness tested).
- Removable fingertips – facilitating infield fitting and prevention of wire-pull damage.
- External charging indicator LED.
- External power status LED – enabling a user to determine that the glove is on.
- Robust clip casing.
- Snap fit elastic fingertip straps.
- Wii aesthetic body and casing design.

The final point in this list demonstrates the definition and adherence of the glove's design to the specification conclusions drawn within the period of the product study.

DS3 Discussion

At the time of this report the IRO-USB-R5 is currently undergoing the user-centric phase of performance evaluation. In house testing has determined the iteration as a reliable and robust design solution; however unfortunately this cannot be fully verified until the completion of infield performance testing. The designed solution is currently being evaluated using a two group randomised control trial to compare the glove with usual care. Sixty patients with a minimum age of 18 are currently carrying out the intervention trial.

Participants all have a confirmed diagnosis of their first stroke, and are no longer receiving any other rehabilitation therapy, however they still have residual upper limb dysfunction. Participants have been randomly allocated to either an intervention group or the control group. Participants within the intervention group have the virtual glove in their homes for a period of up to 10 weeks. In order to achieve the recommended exposure time of 60 hours (Kwakkel et al, 2004), participants have been advised to use the system for 20 minutes 3 times a day for 10 weeks. An additional period of 10 hours has been included in order to cater for any missed days and or sessions during this time.

DS3 Conclusions

The suggested design activities have been successfully employed for the development of an assistive solution for the rehabilitation of stroke survivors. The resulting "infrared Glove" interface device and its accompanying games can be used to track the position of a "real world" hand and map its movement to that of a virtual counterpart. The application of gaming technology in this manner can be seen to verify that console technologies can be utilised for motivational stroke rehabilitation. This research demonstrates that such technologies can be reproduced and/or enhanced further still to produce novel hardware solutions that improve upon the current system and remove environmental limitations (ambient lighting) and licensing constraint. The development of this concept has demonstrated the application of not only the enhanced iteration capabilities of the FLOOD model, but also robustness of design activities in respect to prototyping method.

Randomised Control Trial

The designed solution is now being evaluated using a two group randomised control trial to compare the glove with usual care. Sixty patients with a minimum age of 18 are currently being evaluated by the evaluation team. Participants all have confirmed diagnosis of their first stroke, and are no longer receiving any other rehabilitation therapy, however still have residual upper limb dysfunction. Participants have been randomly allocated to either an intervention group or the control group. Participants within the intervention group have the virtual glove in their homes for a period of 10 weeks. In order to achieve the recommended exposure time of 60 hours (Kwakkel et al, 2004), participants have been advised to use the system for 20 minutes 3 times a day for 10 weeks. An additional period of 10 hours has been included in order to cater for any missed days and or sessions during this time.

Chapter 9: Discussion

The following chapter details the conclusions drawn in this body of research. The objectives of the research, and the questions derived in response to the objectives during the phase of literature review, are addressed.

Summary of Design Study Outcomes

The following section summarises the design outcomes as determined during the practical application of activities within this research.

Summary of outcomes for the Virtual Cane

This design study can be seen to partly fulfil all of the objective aims of this research (see Page 122).

The study demonstrates the first real world application of the derived design model. Focus is applied to the analysis elements of the design process, and concludes following the first build phase. The application of human-centric investigation in a design study format has demonstrated that via the application of product design driven method, the initial definition of assistive solutions can be determined and verified without the need for user group demographic involvement.

The Wii Remote Virtual Cane as a design solution has demonstrated the empowerment of blind users by enabling the successful navigation of virtual space. The successful application of the investments in skill that we make to perform the activities of everyday living, as potential methods for input modality, has demonstrated that the philosophy of NUI is a powerful means of defining both input modality, and designed activity that can be practiced in a manner akin to that of real world interaction.

Summary of outcomes for the Nunchuk Switch

The design objective of this study was the realisation of a Wii Controller extension, that would enable those with severe physical disability and/or limited motor skills with the ability to interface with Wii Console based video games. This study was able to demonstrate that the Wii Controller could effectively be used as a central module unit for the development of assistive solutions. Additionally the study was able to demonstrate the efficacy of the switch function of the modified Nunchuk for some people with intellectual and upper limb motor disabilities.

The primary outcome of this study however is the demonstration of the infusion of both the approach to design practice via the design and evaluation members of the multidisciplinary team respectively, the suggested new design application structure formulated around the model definition within BS: 7000, and the existent evaluation heavy user-centric design method.

Summary of outcomes for the Wii Glove

The suggested design activity has been successfully employed for the development of an assistive solution for the rehabilitation of stroke survivors. The resulting "Infrared Glove" interface device and its accompanying software solution can be used to track the position of a "real world" hand and map its movement to that of a virtual counterpart. The application of gaming technology in this manner can be seen to verify that console technologies can be utilised for motivational stroke rehabilitation.

The development of this concept has demonstrated the application of not only the enhanced iteration capabilities of the FLOOD model, but also robustness of design activities in respect to prototyping method.

Overall discussion of outcomes

Following the evidence for success of the design method provided by these studies it is suggested that the proposed design activity is a viable and effective means for improving the efficacy of the practice of USID. Furthermore, the successful application of the philosophy of NUI has provided evidence that it is a viable and effective means for the definition of input modality. These points are further elaborated upon in the following section via the comparison of the research outcomes with the overarching research objectives.

Comparison with Research Objectives

The following section details how each of the design objectives have been met during the period of this research. In each instance a summary of the research is presented to provide both context and insight into the research conducted in order to fulfil the research objectives.

1. Evaluate gaming interface controllers with regard to how well they support interaction for users with disabilities and impairment.

Gaming interface controllers have been identified as the primary barrier in terms of the adoption of console gaming for those with physical disability and impairment (see Ellis, 2006; Iacopetti, Fanucci, Roncella, Giusti,& Scebba, 2008; Brown, Kerr, & Crosier, 1997). Typically, console game controllers are equipped with a large variety of inputs including push-buttons and joysticks, which generally need to be operated concurrently. By way of result, gaming hardware presents a real barrier to those with limited motor skills. This is also true for those with intellectual impairment who suffer in terms of an inability to efficiently process information, often becoming overwhelmed by the germane load required to operate these devices effectively. In both instances this factor is only compounded by the accompanying traditional control schemas of gaming interfaces, i.e. combinational camera and navigation control needed for many 3D computer games. In contrast, for those with visually and hearing impairments, gaming interface controllers are found not to be the primary barriers for exclusion.

In respect to those with Visual impairment, console games (primarily 3D) are inaccessible due to their overwhelming dependence upon visuals and the schemas needed to facilitate navigation and interaction (see Forrester Research, 2004; IGDA, 2004). For example, the navigation of 3D space without visual indication results in a lack of any location reference. Other researchers have also stressed the importance of spatial synchronisation between real and virtual worlds (Viciana-Abad et al, 2010 and Folds, 2011). This paradigm is expanded further by Lombard (1997), who defines presence as the occurrence of an inhabitant of virtual space forgetting that their perceptions are mediated by technology. Those with limited vision are also excluded due to factors such as resolution and picture quality of display technologies. This factor is further exasperated by the styles of graphics user interfaces commonly adopted in games for elements such a health and score, etc. Often such graphics float over the top of the 3D environment which makes it very hard for those with limited vision to distinguish between the GUI and the environment itself. This issue is further compounded by factors such as contrast and colour utilised for their design. There are various existing assistive technologies developed to alleviate these issues, however such technologies are only currently available for personal computer platforms (e.g. screen-readers & visual display optimisation tools). In this case, more often than not, they have been found to be non-compatible with 3D game technologies (e.g. rendering engines).

In respect to auditory disability and/or impairment, console gaming can be seen to suffer from the same accessibility issues as found within computer gaming. These include factors such as the absence of auditory cues and reduced immersion in reflection due to environmental ambience (see (IGDA, 2004); (Forrester Research Inc, 2004)).

Utilising this knowledge as a foundation, the following questions were developed that target the core requirements of the objective:

- Are the current generations of console gaming platforms a viable platform for the delivery of accessible resources?
- Can the new modes of interaction made available via contemporary seventh generation hardware be utilised as means to afford access to those currently excluded by the gamepad paradigm of interface and its accompanying schemas for interaction?

These questions were investigated via the formulation of three case studies, each of which acted to research contemporary seventh generation games controller technologies and apply the technology for the design and development of assistive products. In order to define these studies the suggested tools and activities derived via the analysis of both previous studies conducted by the ISRG and related literature investigation were utilised for the generation of potential design ideas. This activity validates the derived model both as a viable means for concept generation (see Chapter 4, Page 66), but also as a method for performing the initial verification of design ideas (see Chapter 5, Page 85).

The technology of the Nintendo Wii was selected as a platform for focused investigation, as at the time of this research it was the prominent example of gaming interface technology which implemented the philosophy of NUI and innovative modes for gaming interface, in turn reflecting elements of the fourth objective of this research. Since this research was conducted, both Sony and Microsoft have also released equivalent hardware in the forms of the PlayStation Move and the Microsoft Kinect respectively. Investigation of these technologies in an equivalent manner is suggested as future works to further verify the findings of this research.

The outcomes from these studies act to verify that both current and future iterations of console platforms that adopt a NUI approach (hardware & software) for the definition of interface paradigm are suitable for the distribution of accessible resources. The development of both customisable hardware and software solutions for a range of disability and impairments demonstrates that not only are consoles a viable platform for universally accessible gaming and distribution of accessible resources, but these technologies are also a viable means of generating and evaluating conceptual interface ideas which affords access to those currently excluded by the gamepad paradigm of interface.

The primary example of this concept is DS1 (Page 106), where this research has proved this concept via enabling those with visual impairment to successfully navigate 3D virtual space and use these to create accurate spatial mental models. In addition the outcomes from DS2 and DS3 both demonstrate that existing gaming technology can also be enhanced and/or expanded to provide access for those with both physical and/or intellectual impairments.

2. Investigate the paradigm of the Natural User Interface with regard to how well it can support the development of interaction for users with disabilities and impairment.

Analysis of literature and current technological trends indicate that the video gaming arena is at the forefront of the Natural User Interface revolution. The innovations found within the field are spearheading the shift towards new paradigms for human machine interaction. Within this research, the investigation of literature surrounding this concept identified the philosophy of designing for the periphery as a manifesto for development of NUI solutions. As such interfaces are “natural” it is determined that we can use our investments in skill and our innate core abilities to gather, manipulate and act upon detail. As this detail is located within our periphery, we are automatically attuned to it and thus are able to bring selected/required elements into focus as required.

Utilising these hypotheses as a foundation, the following questions were developed that target the core requirements of the objective:

- Can this concept be applied to the development of accessible technologies?
- Is it possible to apply the specialised investments in sense and skill of those deemed disabled and/or impaired as method and means for defining human-machine interface?
- If so can such interfaces act to alleviate the traditional burdens of human-computer interaction for those people with physical, cognitive and sensory impairment?

Through the application of the design activity and model derived to meet the 3rd objective of this research, three design case studies have demonstrated that the principles of the NUI are a strong and effective philosophy for the development of assistive technology.

Via the infusion of the principle of designing for the periphery, with that of the Natural User Interface, it has been found that we can derive a powerful and innovative means for the creation, development and realisation of interfaces. As the interface is natural, we can use our investments in skill and our innate core abilities to gather, manipulate and act upon detail. As this detail is located within our periphery, we are automatically attuned to it, and thus are able to bring selected elements to focus as required, whilst never becoming overburdened.

The application of contemporary gaming technology (the Nintendo Wii Controller) as physical real world metaphor, and an accompanying representation of a virtual tool in 3D space demonstrated in practice that the mapping of investments in real world skill against input modality is an effective method for defining input modality. By mapping the familiar paradigm of cane use this research has demonstrated the concept of periphery enhancement for those with visual impairments proving that the reuse of invested skill is a viable and powerful means of determining paradigms for interface. This is also furthered via the outcomes of DS2 that demonstrates the reuse of skill investment in terms of assistive switch use. The developed solution within DS3 further demonstrates the use of the concept of NUI for the rehabilitation of stroke survivors.

What is needed now is further investigation of this objective in regards to the application of multimodal interface. Throughout this research suggestion has been made that derived solutions should be expandable in nature. In order to achieve this goal it is hypothesised that further research be conducted that tests this concept.

3. Enhance the practice of User Sensitive and Inclusive Design as conducted by the Interactive Systems Research Group for the development of accessible technology.

The evaluation of literature produced by the ISRG with respect to the development of assistive technology demonstrated a wealth of research focused on the design and realisation of assistive technology products. These research studies identified that over a period of a decade the team had evolved their design practice from one which was user-centred to one which is user-sensitive in nature.

At the heart of these studies can be found the philosophy of user-centred design as determined via the field of Human Computing Interaction. As experience of assistive technology based design practice has grown however, evidence can be found of an influx of contemporary design theory. Core to this influx is the adoption of a multidisciplinary approach to the practice of design and evaluation activities. In comparison to equivalent bodies of assistive technology design related research, the ISRG can be found to report that despite these positive steps, more often than not design solutions were found to perform below expectation. This honest reporting of outcomes highlighted weakness within current practice of the design of assistive technology. The comparison of these findings with those as reported in the literature (e.g. high levels of assistive technology abandonment) indicated that the application of UCD may not be the most effective form of design practice.

Utilising the knowledge gained via the analysis of both UCD related literature and the current practice of the ISRG as a foundation, the following questions were developed that target the core requirements of the objective:

- Is the application of current user-centred design practice truly an effective methodology for the development of assistive technology?
- Why is the application of user-centric method repeatedly reported as successful despite high levels of abandonment by the target audiences for which they were created?

In addition, further questions were also derived following the analysis of literature:

- Does the application of user-centred (or human) design impact on the weighting of design practice in terms of analysis verses synthesis?
- Is this division of balance important in respect to the development of accessible technologies?
- If so, how can the practices of USID be enhanced as mean to alleviate and/or rectify this issue?

The application of user-centric investigation in the format of the three design studies has demonstrated that via a "product" design driven method, the initial definition of assistive solutions can be determined and verified with appropriate balance between target users and designers (see DS1 and DS2). This is an important outcome and should not be confused with stating that heavy user-centric evaluation is not required in the development of assistive products, but rather that the application of, and structure of the design method is of equal if not greater importance in terms of resource allocation during the creation, development and detailed activities of the design process than that of the evaluation process.

The rationale for this is that evaluation practice is often confused with user testing during design development. If such human-centric testing is carried out throughout the design process across an increased volume of design iteration it can be determined that the eventual evaluation of the product would effectively be a minimal task. This in turn should not be confused with the need and requirement for in depth evaluation practice. However, these should be conducted within context and are found to be reflective of additional research aims such as the feasibility evaluation of at home rehabilitation (DS3).

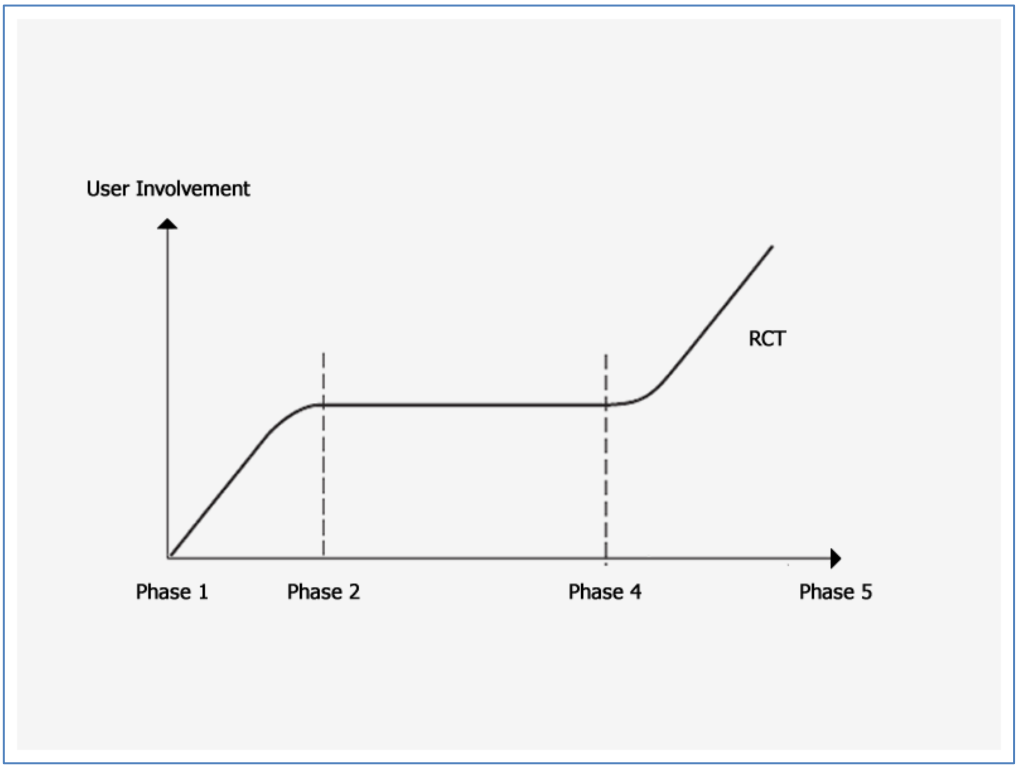


Figure 58: Suggested User Involvement within the Design Process

Argument is made that in-depth evaluation such as Randomised Control Trial (RCT) and/or Within Subjects Design (WSD) are performed at a stage following the creation of detailed designs. This would act to verify the design before the phase of manufacture, and ensure that artefacts and issues resulting from an incomplete design are resolved. Evidence for this can be found within the feedback provided through the development of the infrared Glove during DS3. Users are involved in all phases, and their involvement increases throughout the phases.

A key point to be identified here is that in comparison to many related studies, those of the ISRG are generally conducted at a scale that exceeds many of the other academic studies analysed. This factor is identified as a potential reason behind the reported failure rates of design solutions in comparison with other studies within field. In effect, many of the studies identified can be seen to focus on the development of bespoke solutions targeting an isolated section of the targeted demographic (i.e. those involved within the study). Therefore the design can be reported as successful; however it is only successful in respect to these users (see Constantine & Lockwood, 1999).

Via the comparison of varying levels of user involvement over three design studies it has been established that demographic target involvement is of paramount importance at the concept definition and early iterative phases of the product development lifecycle. This is critical to ensure the grounding of the design in respect to user requirements.

The current USID practice has been found to overburden the design with data that more often than not is gathered to support the eventual activity of a design's evaluation rather than to inform the design detail. The comparison of DS2 and DS3 with previous studies conducted by the ISRG, such as the Portland Switch and EPSRC studies, identifies that this activity impacts on the design process. Specifically the gathering of Baseline Performance Data (BPD) can hold up, restrict creative and overwhelm design activity.

This research concludes that a phase of additional analysis should be conducted during the initial period of the design process specifically tailored to the collation of design informative data. An example of this in practice was demonstrated during DS1 (The Virtual Cane). The collation of BPD can be run in conjunction with this process and or completed separately. This is demonstrated via the isolated activity of DS2. In this instance the data obtained in respect to environment and functional requirements were utilised to formulate a raw design solution. The original purpose of this solution was to be utilised as a throw away prototype which could be used to obtain real world application data from the perspective of the target audience in respect to guidance provided via standard BS EN ISO 9241-210:2010. However due to the volume of effort needed to collate BPD, even in the limited capacity demonstrated during DS2, further iteration and testing of concept prototypes in the hands of the users was deemed not possible due to resource constraints.

Further investigation is needed to determine the most effective infusion of design and evaluation practice, however it is identified that activities such as that of BPD and in-depth evaluation should not conducted until the design/project concept has been verified as feasible as means to avoid unnecessary expenditure of resources. Failure to do so ultimately acts to commit to the design/project even if it is not viable and is bad practice. This guidance is in accordance with that as found within BS ISO EN:7000-2:2008.

Human-centric design is good design practice, and in contradiction with some literature (see Mao, Vredenburg, W, & Carey, 2005; Constantine & Lockwood, 1999), this study determines that human-centric involvement is an important driver for the influence and inform of design.

Analysis of literature indicates that many of the major issues in relation to the practice of UCD result from a misunderstanding of the principle demonstrated via its application of as the method of practice rather than as a design tenet. In order to counteract this malpractice a new representation of design activity was developed that has been specifically designed to reflect design activities across disciplines. Furthermore, the restructuring and guidance provided for the application of design activities provides a strong basis for the development of assistive products. The conclusions and research results from both DS1 and DS2, act to verify that this practice is an effective means of applying design activity. The successful reported outcomes in both instances provide evidence that via the application of human-centric design principles within an overarching product design driven methodology, assistive technology can be developed that has potential for mainstream penetration.

However it should be noted that further work is needed to fully justify and clarify these findings. In each instance the design can be seen as ready for a level of enhanced evaluation study in a manner equivalent to that described within the Portland Switch and EPSRC studies conducted by the ISRG. In effect, each of the presented studies is only reflective of a full iteration of the human-centric design model. In each instance the design can be seen at the stage where initial design detail has been developed, prior to the production of manufacturing prototypes.

By way of result this research indicates an expansive investment in design practice that is quite often neglected in the reporting of assistive device development and concept generation, a factor found to be often reported as an issue within literature.

Therefore this research can be said to highlight a greater need for design resources for effective development of viable assistive products. In order to verify such stringent claims further investigation is needed into the integration of product design driven practice, with that of the traditional application approach of evaluation driven practice, which is currently commonplace within the assistive technology development sector.

It is hypothesised that the determination of correct balance between these two approaches would greatly enhance the product development lifecycle.

4. Examine the methods for involvement of users with disabilities in the design process and how this could be improved (using a product design approach).

Many of the facets of this research objective have already been addressed via the definition of how the research has achieved objective 3. For example, as already highlighted the application of human-centric design studies has demonstrated that via a “product” design driven method, the initial definition of assistive solutions can be determined and verified without the need for overwhelming target demographic involvement (see DS1 and DS2). Furthermore, through the application of design studies it has been established that demographic target user involvement is of paramount importance at the concept definition and early iterative phases of the product development lifecycle. This is critical to ensure the grounding of the design in respect to user requirements.

In reflection of these findings suggestion has been made in regards to the volume of user participation in the design process (see Figure 58). Furthermore, suggestion has also been made that there are a need for additional activities of design analysis that act to greater inform the design rather than provide data for the design's evaluation.

To this end new methods for the collation of design informative data have been defined and their implementation and capabilities tested during application within design studies (see DS1 Design Analysis, Page 108).

In addition to these steps the inclusion of new tools and materials and further design activities (e.g. Additive Prototyping and Breakout Prototyping) has formulated a basis for enhancing the level of current user involvement within the design process by facilitating capability for user involvement during development of high fidelity prototypes. The evaluation of literature produced by the ISRG in respect to the development of assistive technology demonstrated a wealth of research focused on the involvement of users within the design process. However, the literature was found to indicate that the involvement of users within the design process was limited to the activities of low-fidelity prototyping (e.g. Paper Prototyping and Story Boarding). By way of result the practice of USID was found limited in respect to the volume of its "physical" design iteration, or more specifically, applying the iterations of the design in the both hands of users and in the environmental contexts of use.

In order to rectify these issues the new design activities of Additive Printing and Breakout Prototyping not only affords provision for the an enhanced volume of (rapid) design iteration but also a higher level of involvement of the target users within their production. The interactive storyboarding process developed during the Portland Switch study which started with an explanation of the storyboarding process using 3D based CAD has been enhanced via the introduction of real-time 3D developmental sketching, and also by the 3D printing of the developed sketches. In summary, the enhancements to the virtual prototyping method enable continuous testing of products throughout the design's development cycle. Acceptance of the virtual and physical prototypes leads to the construction of a final physical design solution which can then be tested with users in the same manner as conducted for the collation of Baseline Performance Data.

Chapter 10: Conclusions

Through the use of summary and discussion the last chapter has identified that each of the objectives of this research as outlined in Chapter 1 (Page 6) have been achieved. In summary the research objectives have been achieved with the following primary conclusions:

1. Evaluate gaming interface controllers with regard to how well they support interaction for users with disabilities and impairments.

   Seventh generation gaming technologies have been identified as strong and reliable platforms for the development of assistive technology.

2. Investigate the paradigm of the Natural User Interface with regard to how well it can support the development of interaction for users with disabilities and impairments.

   The philosophies of both NUI and designing for the periphery have been identified as being an excellent means for determining both modes for interface paradigms and definition of input modality.

3. Enhance the practice of User Sensitive and Inclusive Design as conducted by the Interactive Systems Research Group for the development of assistive technology.

   Via the evaluation of literature weaknesses in practice have been identified in respect to the USID method practiced by the ISRG. Utilising this knowledge as a basis for improvement the practice of USID has been enhanced via a complimentary approach developed specifically for the design of ICT based assistive products.

4. Examine the methods for involvement of users with disabilities in the design process and how this could be improved (using a product design approach).

   New design activities have been introduced within practice that acts to enhance the involvement of users within the design and iteration of products. Suggestion has been made in respect to the phased introduction of user involvement within the design process. Guidance has been adopted that determines the practice of design to be human centred in nature.

Innovation of Research

A high level of innovation has been demonstrated during the period of this research. Core to this innovation is the further enhancement of the USID method practiced by the ISRG, itself based on the user-centric design model as originally outlined by Lannen (2002), to one that can be defined as human-centred in nature. This has improved practice by affording a more balanced application of the elements of design synthesis and design analysis.

The application of new design tools and materials has identified a new complimentary approach to USID for the development of assistive products; the Flexible Object Orientated Design Model. Following on from the practice outlined during the literature review phase of this research further advances to both design methodology and practice have been introduced and demonstrated in practice (Chapters 6-8).

The following section acts to outline the further enhancement of practice and process in respect to the innovations as detailed within this research. This is achieved by using the five stage process for USID application as defined by literature (see Figure 8) as a basis for describing the innovation:

1. Mapping of Existent Skill and Ability:

The mapping of existent abilities and skill as a platform for the definition of input modality has been proven to be a viable concept. This new and exciting approach to the development of assistive technology solutions has formulated the construction of a method where technology can be developed to facilitate interaction as a prosthesis rather than solution.

Rationale: Enhances both the collation of informative design data and the concept creation phases of the development cycle (Steps 1, 2 & 4).

2. Introduction of New Tools and Materials:

The inclusion of Product Replication via the use of Breakout and Microcontroller components enables enhanced and rapid investigation of concept solution technologies. The nature of these materials enables the concurrent development of bespoke system circuitry (if required in a design solution) and verification of concept ideas in a relatively cost effective and reproducible means. As such replication of product acts to verify the use of a developing concept, and reflects the requirements of potential manufacture and future realisation of the product. If a product is identified as restricted (e.g., subject to intellectual property constraints) in its capacity for solution development, then the replication of product provides a basis for unhindered further development when conducted in conjunction with further design process enhancements such as Patent and Technology Review.

Additionally, the component decomposition of the technology of the existing product acts as a platform for the application of Design Replication, Concept Creation and thus gifts provision and inspiration for further works (see Product Benchmarking).

Rationale: Further strengthens step 4 by enhancing the viability of the product in terms of its mainstream application. Further strengthens step 1-3 by providing a basis for further work. Further strengthens step 4-5 by strengthening the evidence for design viability. Further enhances steps 4 by facilitating for rapid production of technical prototypes.

3. Introduction of Product Study as a framework for Design Analysis

The application Product Study acts to provide structure for the activities of Design Analysis and Technology Review. In the context of this research, current related gaming peripheral products and technologies were reviewed in two forms:

- Equivalent technology and Products
- Existing technology and Products

To this end the current application of Technology Review as described by Lannen (20002) was expanded upon to provide an in-depth knowledge of products which were not only similar, but also equivalent, in function.

By drawing upon guidance provided by standards for the structure of Design Analysis (see Figure 16) additional headings for analysis are identified that have found to be often lacking in current practice:

- Investigation of Prior Art
- Reflection of Product Lifecycle

Rationale: The investigation of prior art during both the product analysis and the encompassing design process, has two main important functions:

- Provision of technical information
    - Helps to determine how a product works.
    - Provides insight into a product's definition.
- Provision of intellectual constraints
    - Identifies design limitations.
    - Provides basis for product viability.
    - Can protect against faux innovation.

This in effect ensures that designs are viable in terms of their potential for becoming a mainstream product. This research indicates that often an assistive product's impact is restricted to the confines of the design process, accompanying study and user home-brew communities due to legal constraints. Therefore the investigation of prior art strengthens steps 2-4.

Reflection of Product Lifecycle enforces acknowledgement that all products progress through four phases of existence: birth, growth, maturity and decline.

Rationale: Understanding the implications of each phase allows the detail of the design to be informed and affords provision for evolving requirements of a product to be addressed over its lifetime. This in turn acts to strengthen steps 2 & 4.

The use of Product Study for the evaluation of equivalent technology solutions has the following outcomes:

- A product knowledge base.
- Focus point to suggest possible design iterations and reusability of existing solutions and features.
- A Platform for the activities of Product Dissection and Benchmarking.
- A Platform for Concept Creation

Rationale: Improves upon works of Ducat and Lannen via focused use of Product Design technique and Investigation drawn from contemporary design theory and thus strengthens Step 3 & 4.

4. Enhancement of Prototyping Process

Given the experience of earlier investigations, a USID methodology was adopted for the underlying structure of the Design Studies. Similar in nature to that used within the Portland Study an enhanced user participation design method was included as a means of providing a greater level of understanding between the stakeholders, users and designer. The interactive storyboarding process developed during the Portland Study, which started with an explanation of the storyboarding process using 3D based CAD, was enhanced via the introduction of real-time 3D developmental sketching and also finally 3D printing of the developed sketches.

This resulted in a rapid turnaround of product prototypes that could be both physically handled and used by all members of the multi-disciplinary development team and also the respective client groups. Over time the application of the method in context acts to reinforce the understanding of the realisation of the process of design sketching to physical artefact.

This process greatly enhances the capabilities for design iteration that is paramount to the application of human-centric design. By being able to place evolving solutions in context improves the quality of the design feedback and reduces the chance of design related risks such as those resulting via innovation, etc.

Rationale: Further strengthens step 4, by increasing effective design participation of the target user audience in using Design Requirements - arising from steps 1 and 2 - to produce Conceptual Designs and Prototypes. Additionally this process also acts to further enhance the validity of the design in respect to the implementation phase of the product development cycle and the acceptance and defence of design decisions during the engineering and evaluation assessment processes.

In addition to the realisation of the physical prototype, provision is also gifted for the application of performance simulation. However this was not implemented during this research and further investigation is suggested under the future works section.

5. Restructuring of Design Practice

The current practice of USID adopts an approach structured around the involvement of stakeholders within the design process. Whilst this is good practice, this research identifies that user involvement should be seen as a principle of the design process rather than the major driver for definition of practice. Whilst it is true that user involvement is crucial to achieving the design of successful products, care should be taken to ensure that design innovation and creative design practice also play an equal role. To this end the design practice that is described that reflects the adoption of guidance for the application of Human Centred Design (BS EN ISO 9241-210:2010) within the process definition as that described within BS EN ISO 7000:2008.

Rationale: strengthens the holistic design process by providing structure and guidance for the practice of design. The adoption of the structure as described within BS EN ISO 7000-2:2008 acts to determine a basis for design activity which in turn affords balance to the elements of design analysis and design synthesis. In addition, the adoption of practice as defined within BS EN ISO 9241-210:2010 can be seen to provide a manefesto for design practice that is human-centred rather than user-centric in nature.

Conclusions Drawn from Innovation

As can be seen by these summaries primary research focus has automatically drifted towards the design aspects of the assistive product development lifecycle. The conclusions drawn from this are that the predominant weaknesses identified during the period of study can be seen to centre on the practical design elements of the applied USID methodology. This is extended via the reflection on literature that indicates a strong and empirical basis for the development of evaluation practice and the respective influence of user involvement in the processes. However the literature often fails to adeptly define the infusion of such practice within the context of the product development lifecycle.

The enhancement of design practice at each of the determined areas of weakness has thus resulted in a stronger and more efficient design method, however it is realised that much more work is needed to fully realise the successful infusion of both design application and evaluation practice.

Focus should be applied to further develop the relationship between these two (sometimes opposing) approaches. This move would go a long way in addressing many of the issues that this research has found as core barriers to the development and acceptance of assistive products.

Future Works

Throughout this thesis suggestions have been made for additional research to be conducted to both further verify the findings of this research and further to enhance practice. For example, a great deal more research and investigation is needed in order to unify the practice of human-centred design and current USID evaluation practices.

This body of research demonstrates that positive steps have been taken towards this end; however concentrated effort is needed to determine the most effective balance for design activities. A primary example of this is the staging of both design informative analysis and collation of Baseline Performance Data. In addition to the resolution of these expected teething problems it is suggested that each of the prototypes developed during this body of research are further iterated and evaluated.

The Virtual Cane

The artefacts of the Virtual Cane study (DS1) have been identified as very promising and future work has already commenced in regards to the further development of this concept. It is hypothesised that this advanced Wii Controller equivalent device addresses the primary issues as described within the conclusions of DS1 (Page 122).

Furthermore, suggestion is also made for the replication of the design solution utilising contemporary mobile technology as the cane intermediary. The ability to describe both human form and intermediaries (e.g., the cane itself) within virtual space is seen to empower an inhabitant of that space with capabilities for exploration, manipulation and affect, further akin to that of real world experience.

Further investigation is needed to determine whether such activity acts to promote the development of allocentric map based navigational strategies which are more powerful and flexible than the egocentric route strategies often used by people with visual impairments in the real world.

The Wii Switch

The next phase of research in regards to this study would be to perform an evaluation of the additional design solutions that were developed and not tested. Additionally, it is recommended that further iteration of the adapter solution be conducted that utilises none Wii hardware solutions. This would enable a more generic device be designed which could be applied across platform. Furthermore, it is also suggested that the additional features as defined and not implemented within the original Portland Study also be implemented (e.g. LED's and auditory feedback).

The Infrared Tracking Glove

The positive feedback received during the development and initial testing of this design solution has identified this body of work worthy of further investigation. It is suggested that the design be further iterated to reflect the original design solution which contained an accelerometer for the capture of inertial measurement data. Furthermore, by converting the design to a Microcontroller-based solution, provision would be afforded for the inclusion of additional sensors for performance enhancement and/or haptic feedback.

Summary of Conclusions

The primary conclusions drawn and research outcomes arising from this research can be summarised as follows:

- The development of multiple software solutions for the purpose of facilitation, evaluation and development of assistive products.
- The development of multiple hardware solutions for the purpose of facilitation, evaluation and development of assistive products.
- The development and enhancement of the design and development methodology for the design, development, evaluation and production of assistive products.
- The development and enhancement of the design and development practice for the design, development, evaluation and production of assistive products.
- The identification of a new and innovative platform for the development of assistive products as systems for intuitive interface.
- Verification of seventh generation gaming technologies as suitable platforms for the development of assistive products.
- Verification of seventh generation gaming technologies as suitable platforms for the delivery of accessible resources, e.g. learning materials and rehabilitation solutions.
- Identification of new design materials as platforms for the research and development of assistive products.

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A FLEXIBLE OBJECT ORIENTATED DESIGN APPROACH FOR THE REALISATION OF ASSISTIVE TECHNOLOGY

APPENDICES

STEVEN BATTERSBY

A thesis submitted in partial fulfilment of the

Requirements of Nottingham Trent University

For the degree of Doctor of Philosophy

February 2013

Table of Contents

Appendix A: Authored Literature

This appendix presents all of the literature research related to this thesis which has been published in conjunction with the author. The original texts cannot be included due to copyright and intellectual property constraints.

Background Literature

This section outlines the background literature published in relation to the presented research. Many of these works are referenced during the review of literature, however in this appendix is provided for ease of reference.

Journal Publications

Battersby, S., Brown, D., Standen, P., Anderton, N., & Harrison, M. (2004). Design, development and manufacture of novel assistive and adaptive technology devices. *Proceedings of the Fifth International Conference on Disability, Virtual Reality and Associated Technologies*, (pp. 283-290). Oxford.

Brown, D., Standen, P., Evett, L., & Battersby, S. (2010). Designing Serious Games for People with Dual Diagnosis: Learning Disabilities and Sensory Impairments. In P. Zemliansky, & D. Wilcox, *Design and Implementation of Educational Games: Theoretical and Practical Perspectives* (pp. 424-439). IGI Global.

Standen, P., Brown, D., Anderton, N., & Battersby, S. (2003). The development of control devices for virtual environments for use by people with intellectual disabilities. *10th International Conference of Human Computer Interaction*, (pp. 897-901).

Standen, P., Brown, D., Anderton, N., & Battersby, S. (2004). Problems with control devices experienced by people with intellectual disabilities using virtual environments: a systematic evaluation. *Fifth International Conference on Disability, Virtual Reality and Associated Technologies,* (pp. 299-304). Oxford: ICDVRAT/Reading University.

Conference and Other Publications

Battersby, S., Brown, D., Standen, P., Anderton, N., & Harrison, M. (2004). Design, development and manufacture of novel assistive and adaptive technology devices. *Proceedings of the Fifth International Conference on Disability, Virtual Reality and Associated Technologies*, (pp. 283-290). Oxford.

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Standen, P., Brown, D., Anderton, N., & Battersby, S. (2003). The development of control devices for virtual environments for use by people with intellectual disabilities. *10th International Conference of Human Computer Interaction*, (pp. 897-901).

Standen, P., Brown, D., Anderton, N., & Battersby, S. (2004). Problems with control devices experienced by people with intellectual disabilities using virtual environments: a systematic evaluation. *Fifth International Conference on Disability, Virtual Reality and Associated Technologies,* (pp. 299-304). Oxford: ICDVRAT/Reading University.

Original Literature

This section outlines the original literature published in relation to the presented research. Many of these works are referenced during the review of literature, however in this appendix is provided for ease of reference.

Journal Publications

Burton, A., Liu, H., Battersby, S., Brown, D., Sherkat, N., Standen, P., et al. (2011). The Use of Motion Tracking Technologies in Serious Games to Enhance Rehabilitation in Stroke Patients. *International Journal of Game-Based Learning*, 60-73.

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Standen, P., Camm, C., Battersby, S., Brown, D., & Harrison, M. (2011). An evaluation of the Wii Nunchuk as an alternative assistive device for people with intellectual and physical disabilities using switch controlled software. *Computers and Education*, 2-10.

Conference and Other Publications

Battersby, S. (2007). Serious Games and the Wii. *BCS SGAI AI-2007 Serious Games Workshop.* Cambridge.

Battersby, S. (2008). *The Nintendo Wii controller as an adaptive assistive device – a technical report.* Middlesbrough: HEA ICS Supporting Disabled Students through Games Workshop.

Evett, L., Brown, D., Battersby, S., Ridley, A., & Smith, P. (2008). Accessible virtual environments for people who are blind – creating an intelligent virtual cane using the Nintendo Wii controller. *7th ICDVRAT with ArtAbilitation* (pp. 271-278). Maia, Portugal: ICDVRAT/University of Reading.

Standen, P. J., Brown, D. J., Battersby, S., Walker, M., Connell, L., & Richardson, A. (2010). Study to evaluate a low cost virtual reality system for home based rehabilitation of the upper limb following stroke. *8th Intl Conf. on Disability, Virtual Reality and Assoc. Technologies* (pp. 139-146). Valparaíso, Chile: ICDVRAT/Reading University.

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Appendix B: Example Sketches

This appendix presents all the examples of design sketches which have been presented within the thesis. In each instance the included sketch details both its original figure reference and page location. These versions have been included for easier reading and enhanced reference.

Outline of Sketch Content

The following list details all the sketches contained within this appendix:

1. Example of a Brainstorming Sketch for Visual Impairment Assistive Technologies

2. Sketches of the Component Breakdown of the Wii Controller

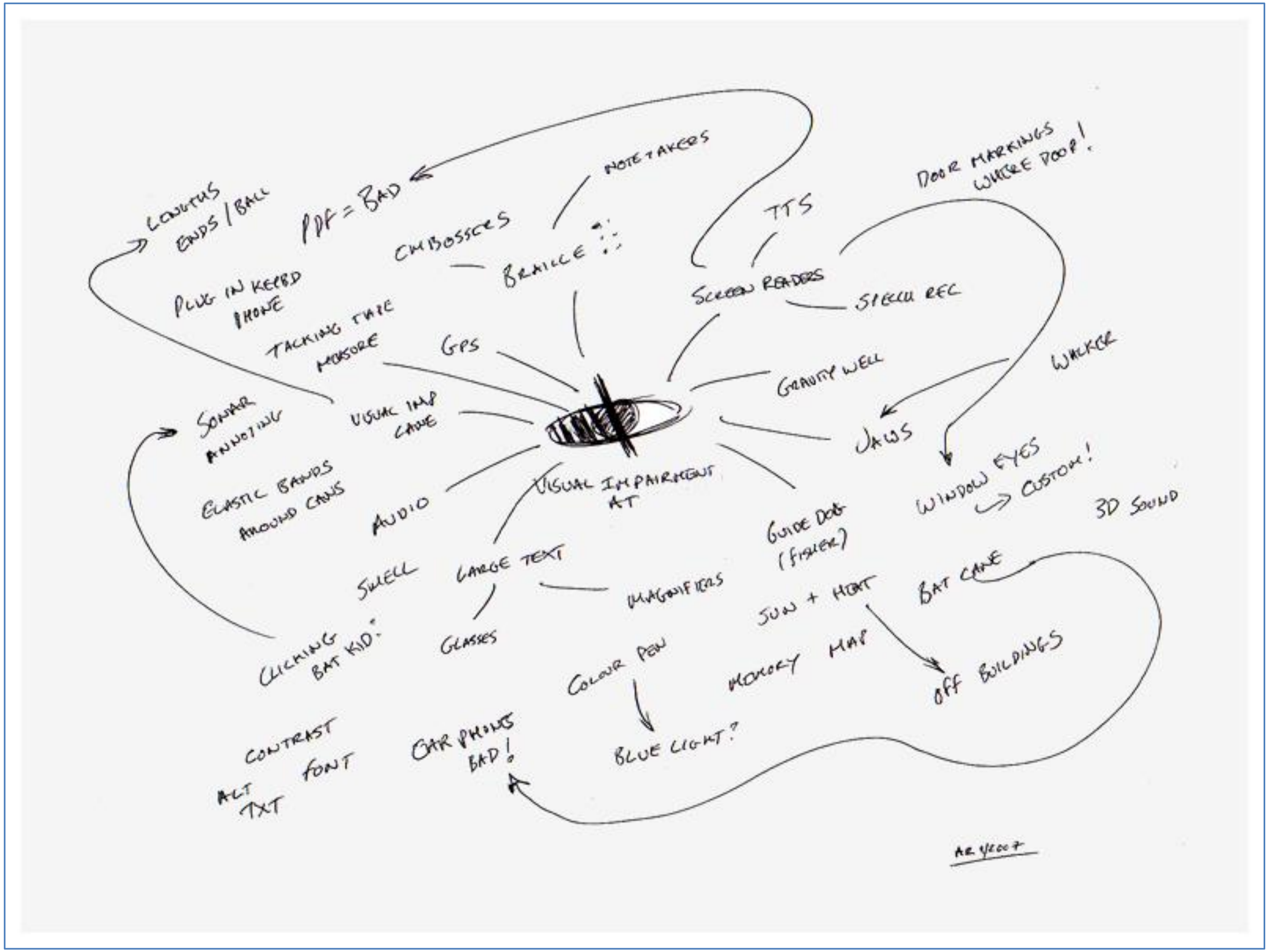
    a. A Breakdown of the Wii Controller
    b. Wii Controller Orientations
    c. Wii Controller Technologies Breakdown
    d. Basic Component Block-out of the Wii Controller

3. Examples of Generated Design Sketches

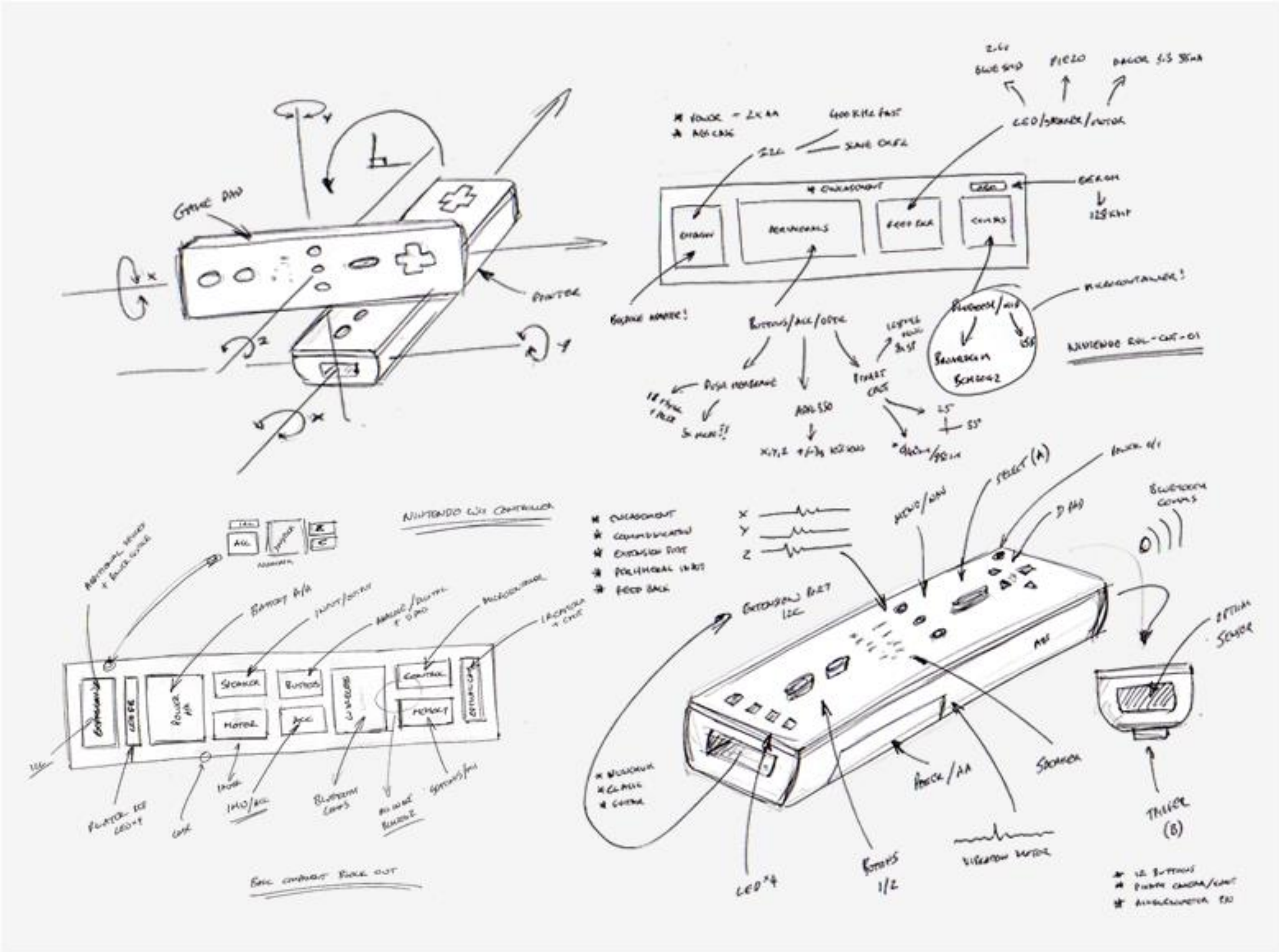
    a. A Surface Free Interface
    b. Gesture Recognition for the Physically Disabled
    c. Tremor Compensation for the Elderly and Physically Disabled
    d. A Physical Metaphor for Virtual Spaces

4. Development Sketch for WiiciTrackLib

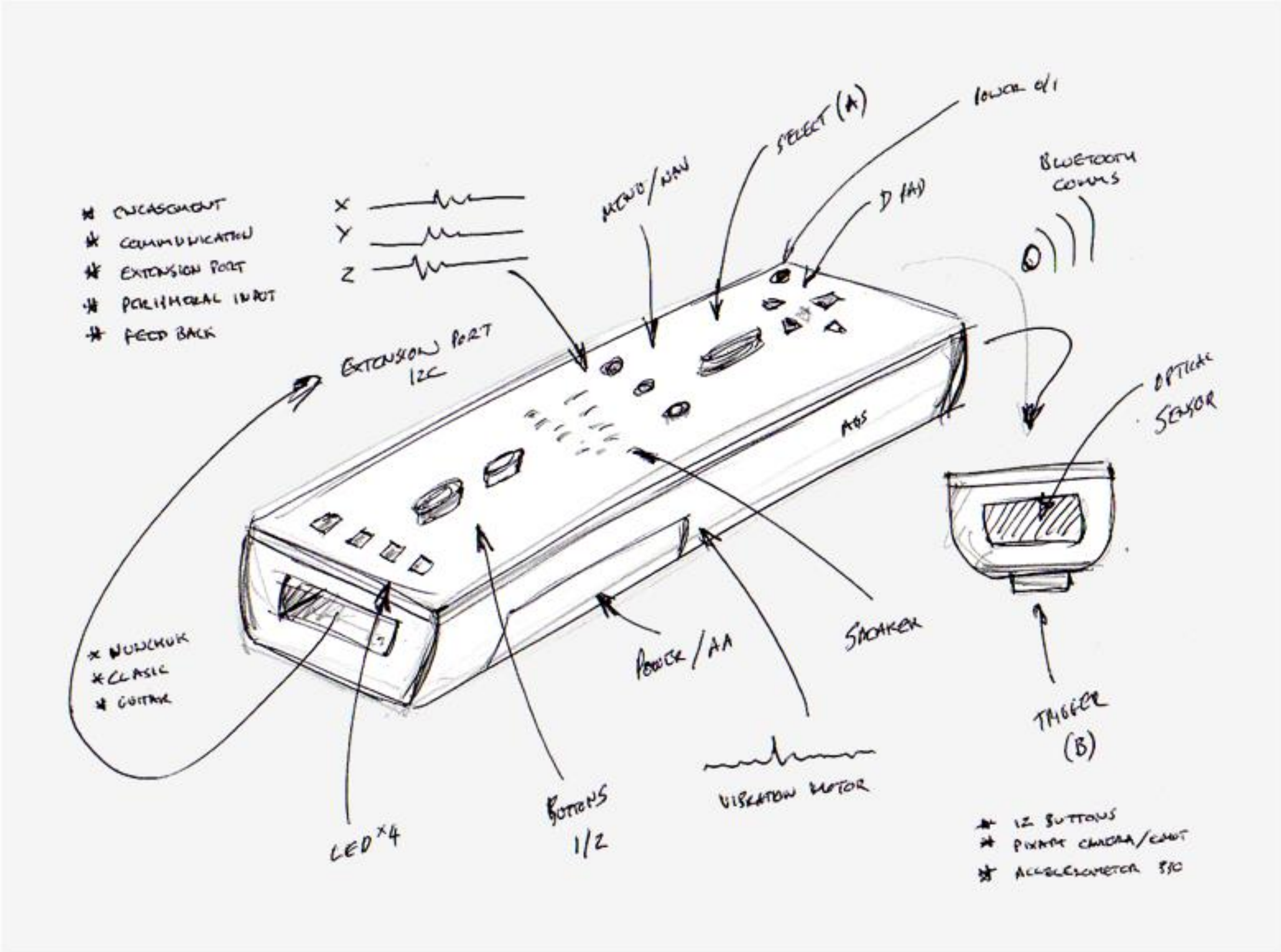
5. Development Sketches for the Infrared Glove



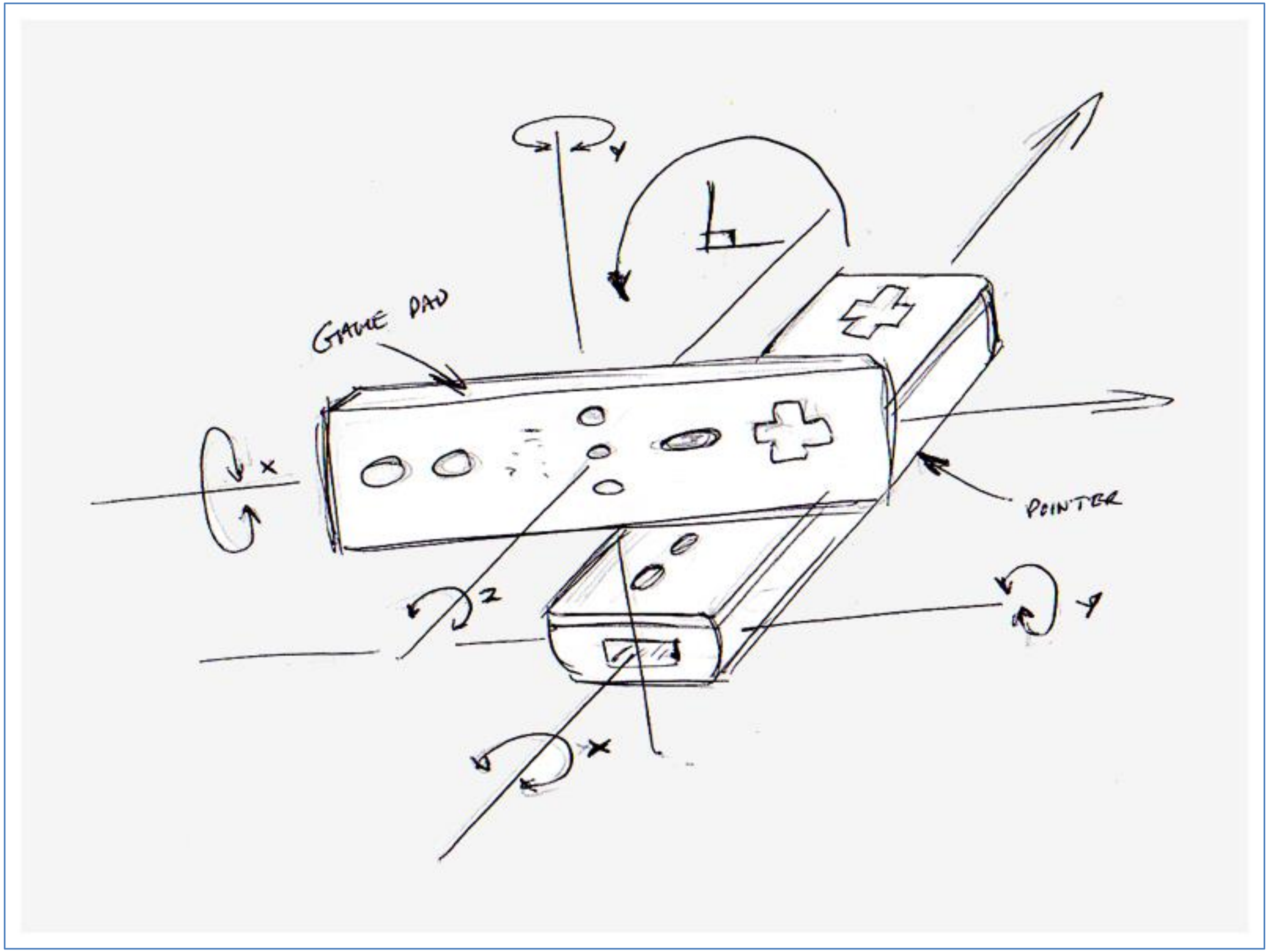
1. Example of a Brainstorming Sketch for Visual Impairment Assistive Technologies (Page 82, Figure 24)



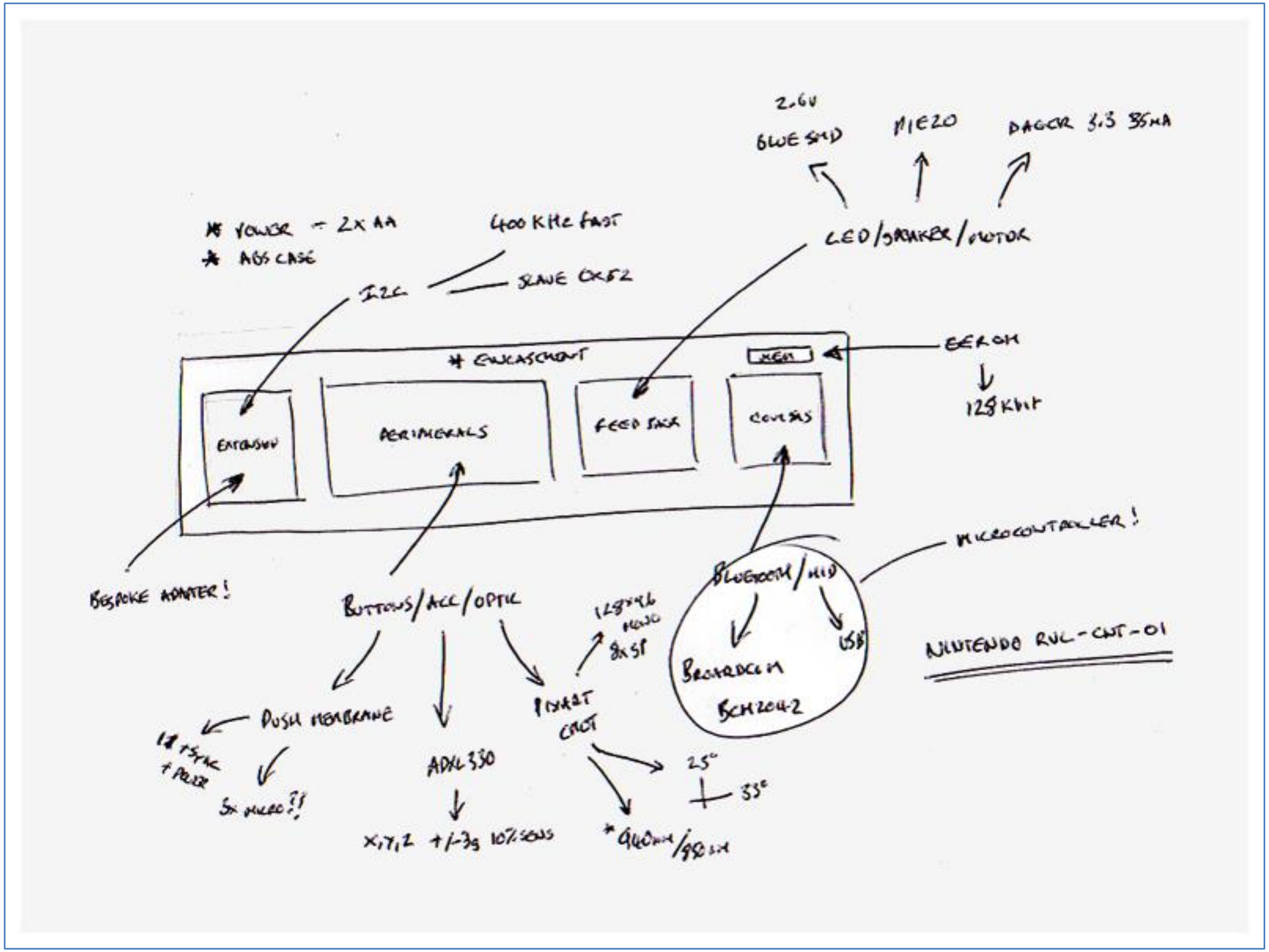
2. Sketches of the Component Breakdown of the Wii Controller (Page 76, Figure 20)



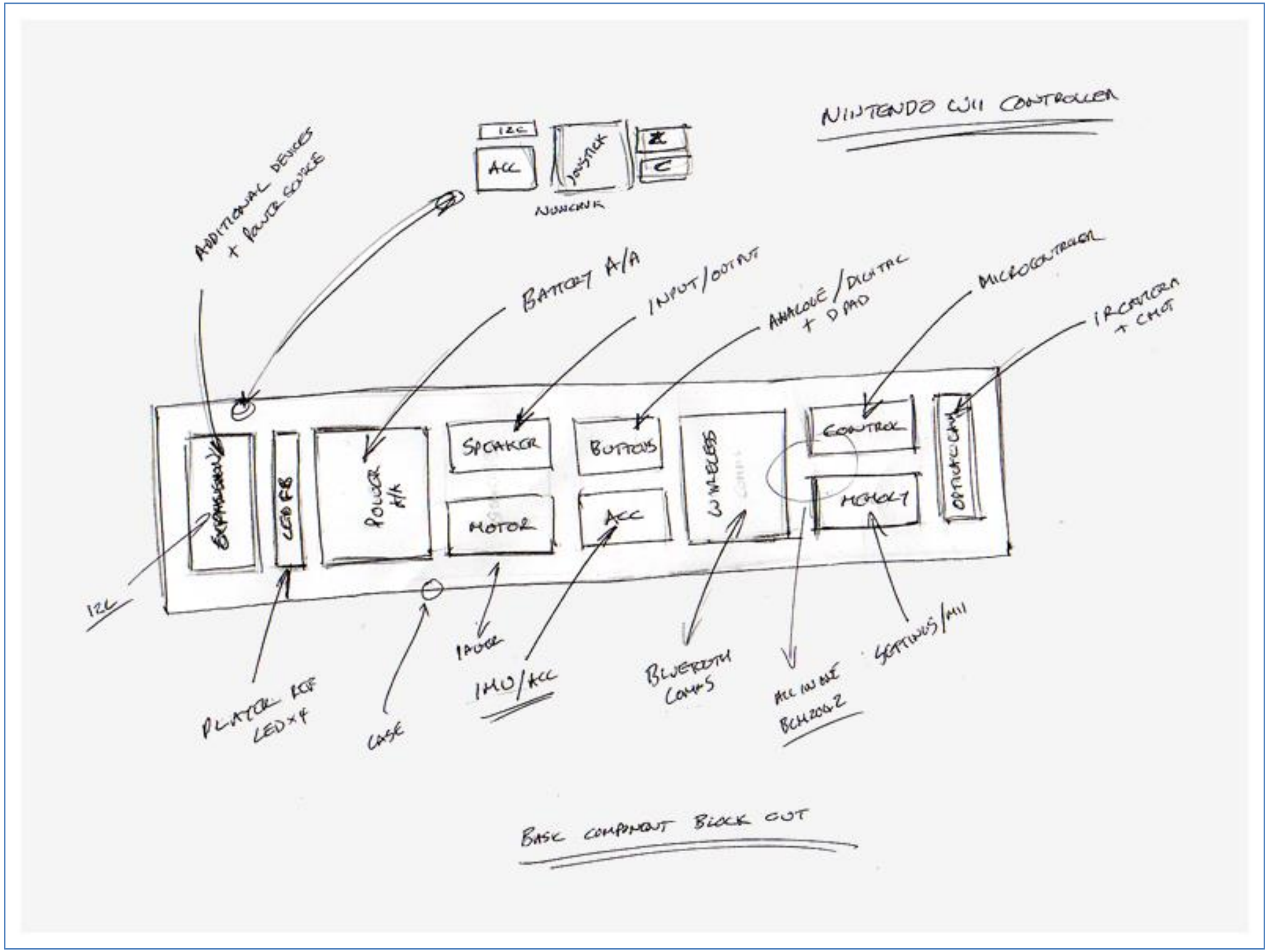
3. A Breakdown of the Wii Controller (Page 76, Figure 20)



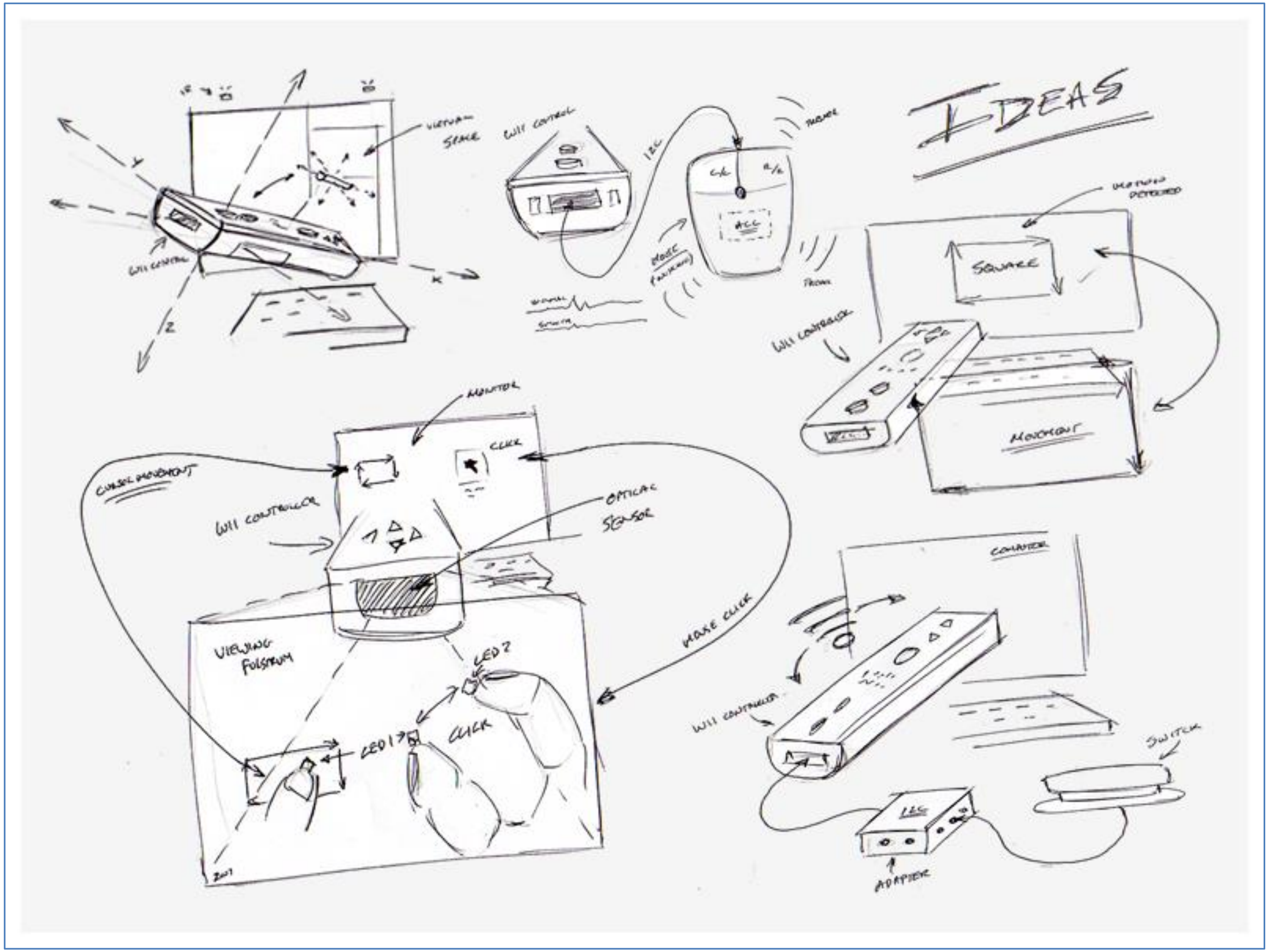
4. Wii Controller Orientations (Page 76, Figure 20)



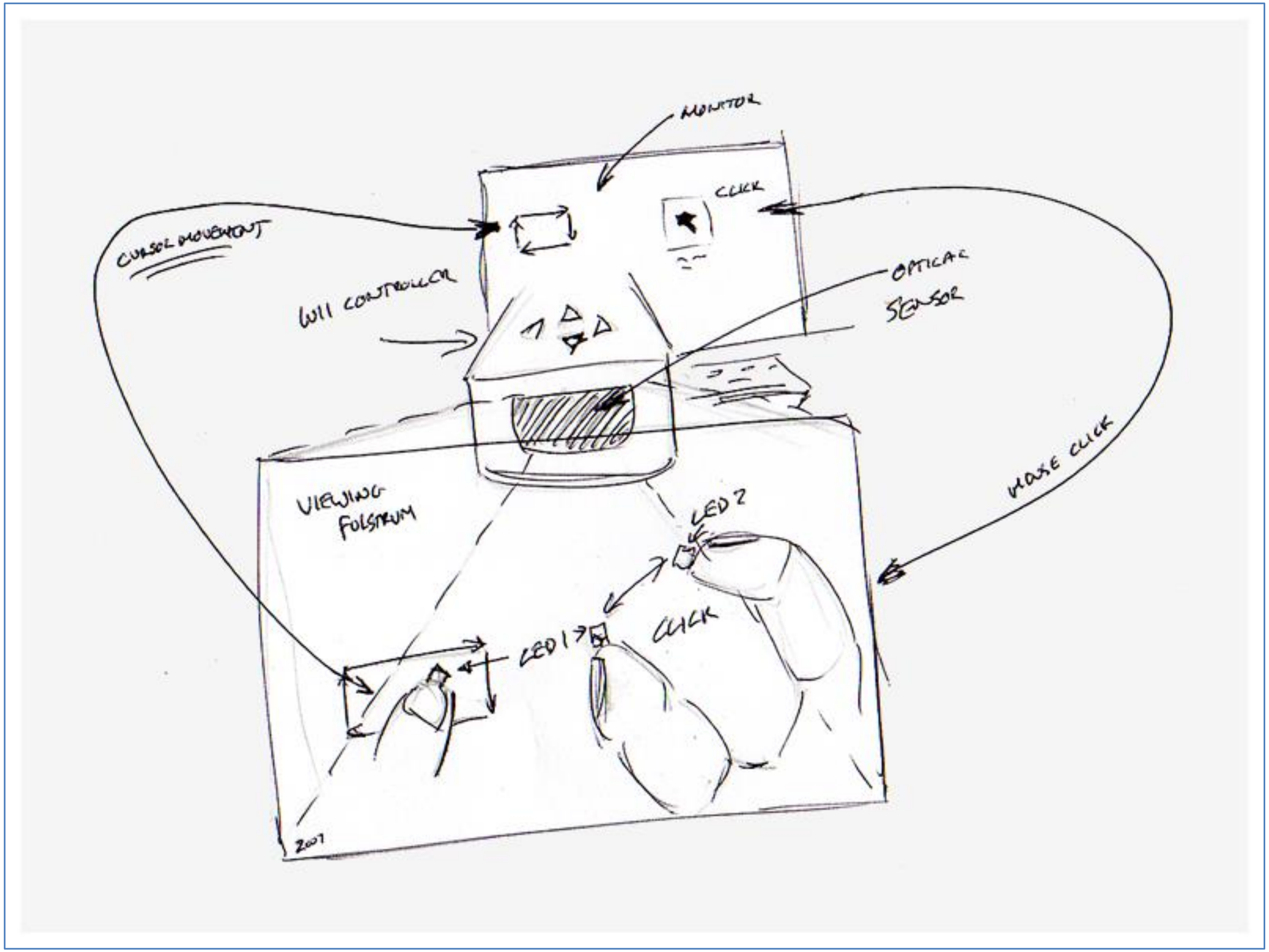
5. Wii Controller Technologies Breakdown (Page 76, Figure 20)



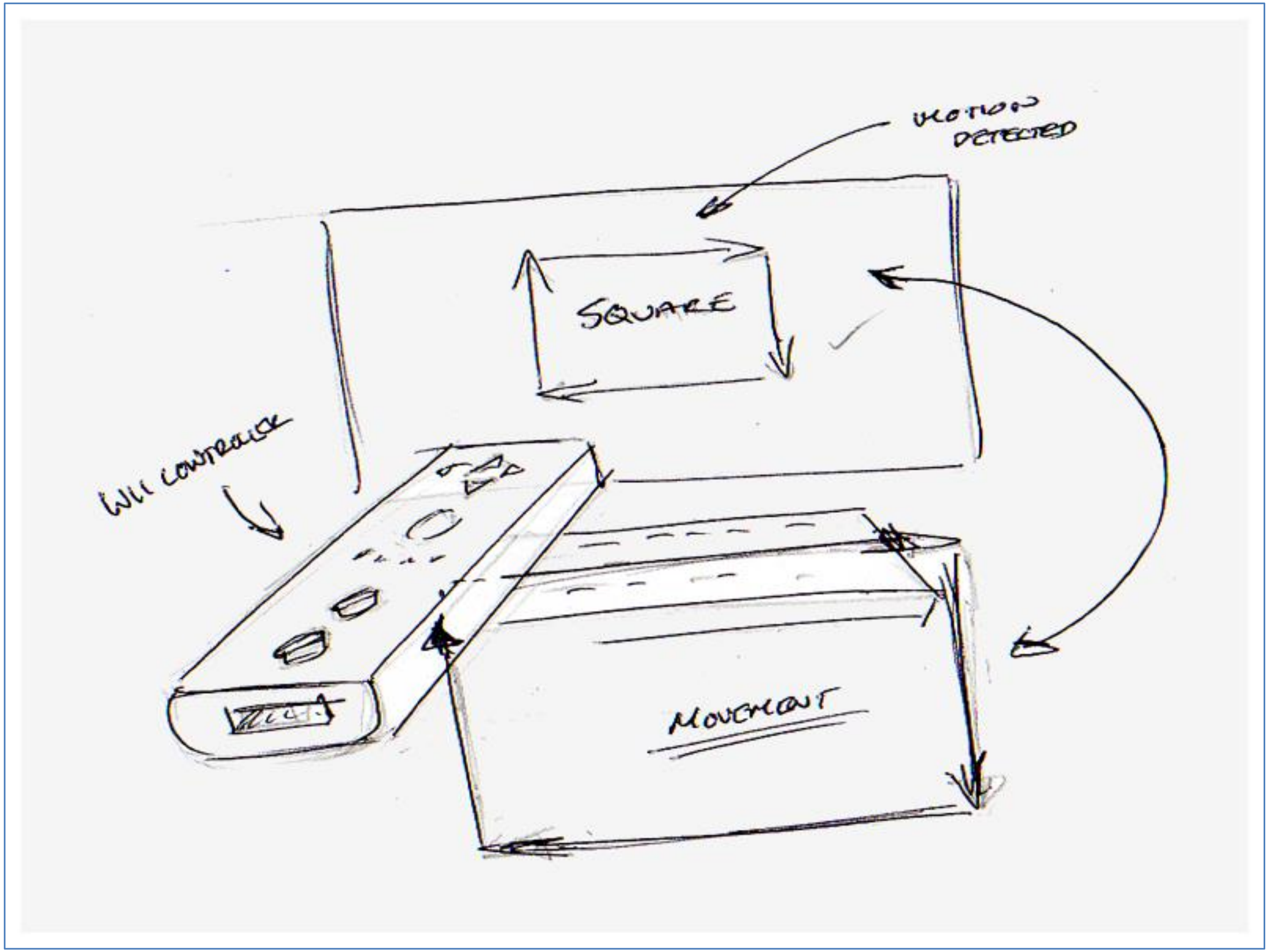
6. Basic Component Block-out of the Wii Controller (Page 76, Figure 20)



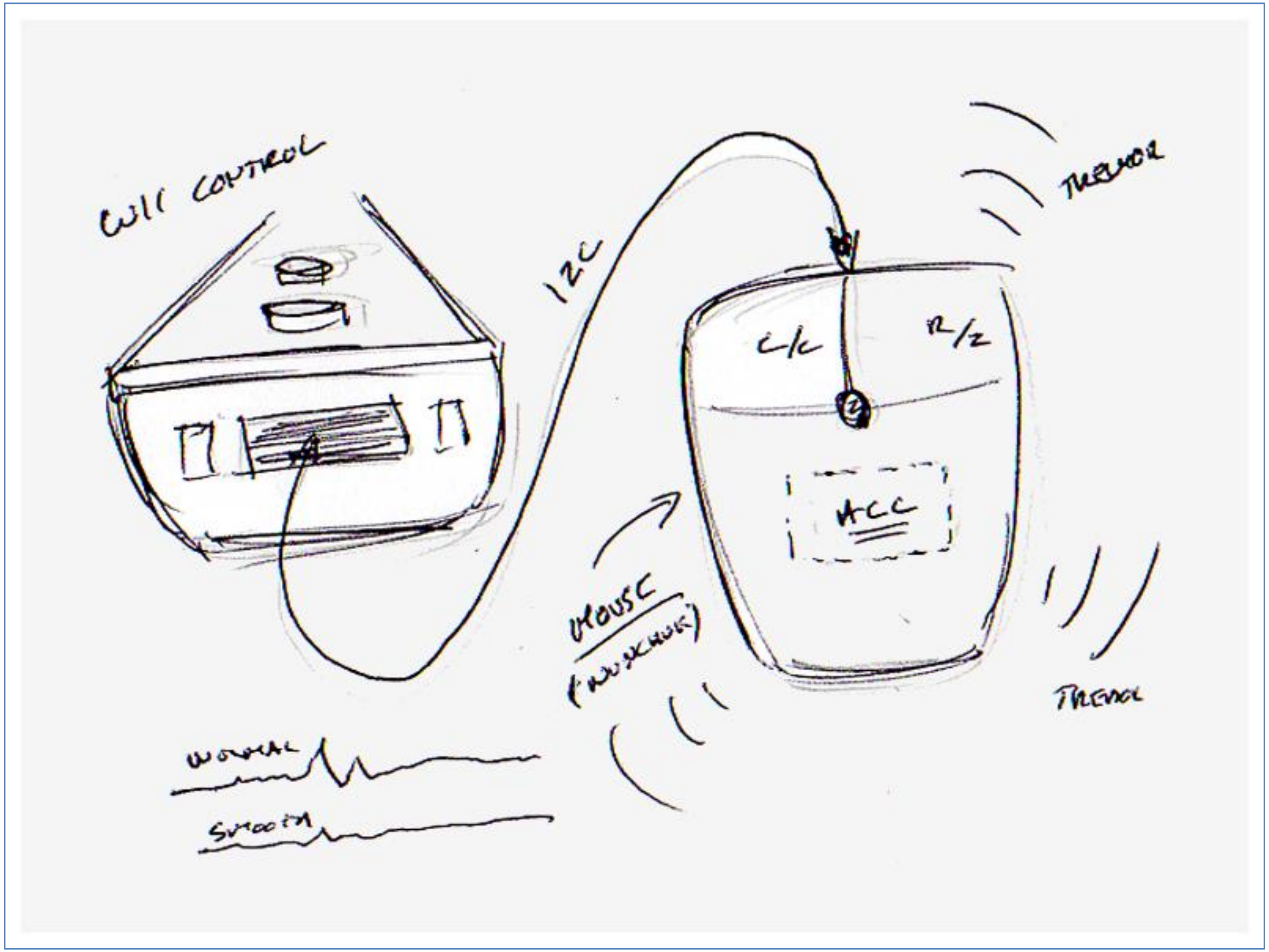
7. Examples of Generated Design Sketches (Page 81, Figure 23)



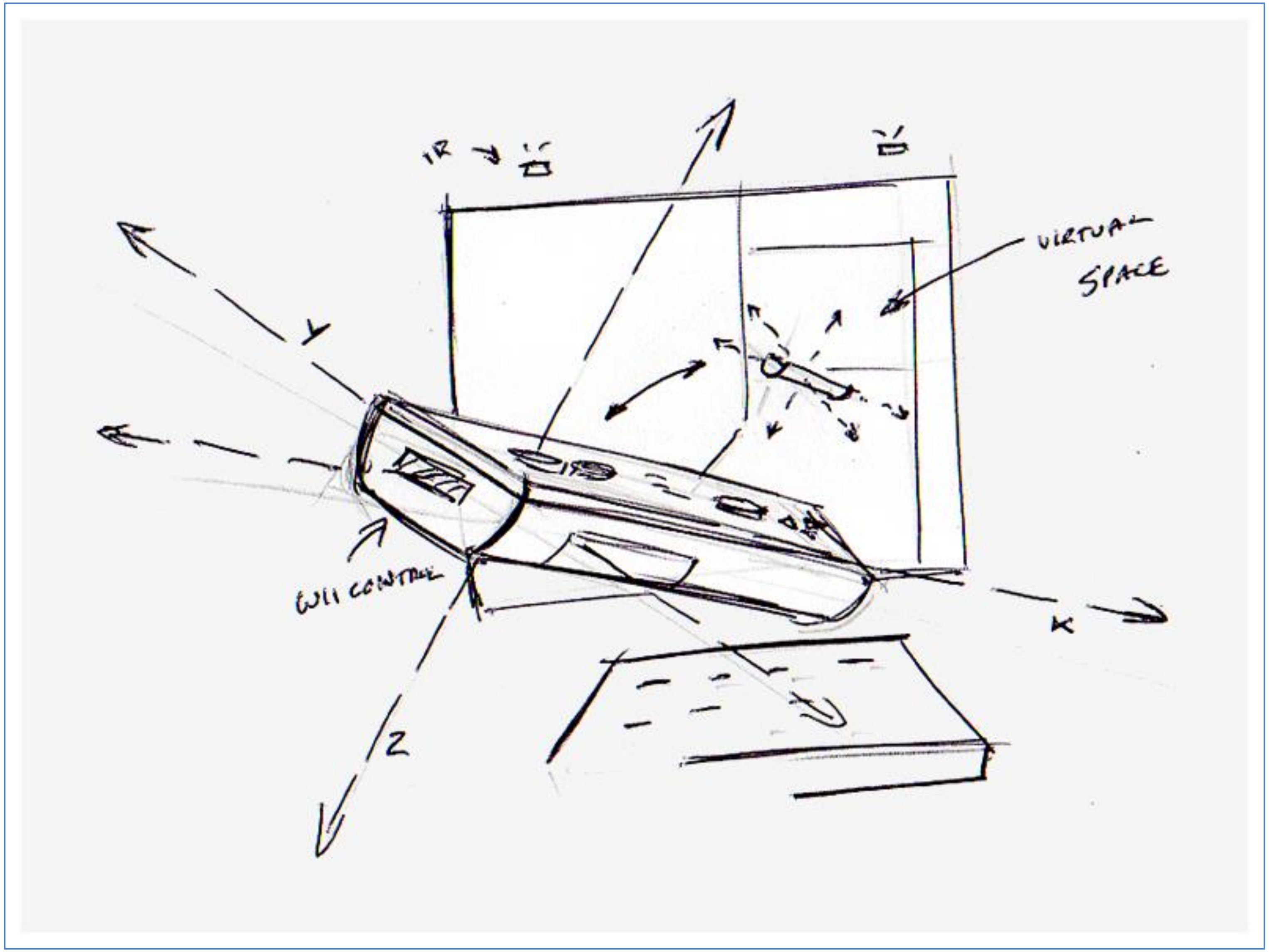
8. A Surface Free Interface (Page 81, Figure 23)



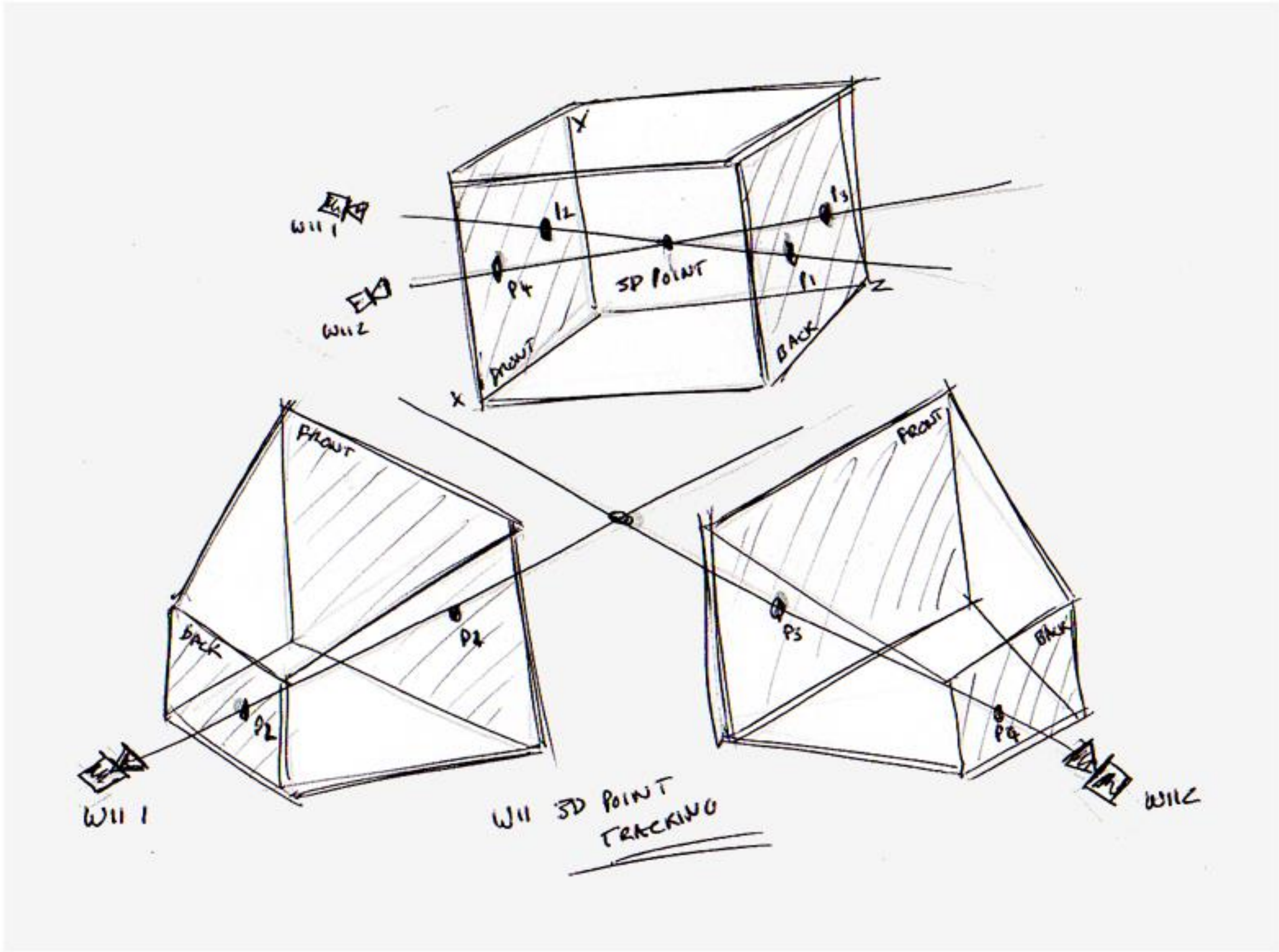
9. Gesture Recognition for the Physically Disabled (Page 81, Figure 23)



10. Tremor Compensation for the Elderly and Physically Disabled (Page 81, Figure 23)



11. A Physical Metaphor for Virtual Spaces (Page 81, Figure 23)



12. Development Sketch for WiiciTrackLib (Page 153, Figure 55)

Appendix C: Artefacts of Research

During the period of this research many product artefacts were conceptualised, realised and evaluated. This appendix identifies the key artefacts of the research in terms of both hardware and software.

Software

Several software solutions were conceptualised, developed, realised and evaluated. The following list details the primary software developed:

The Wii Controller Interface Suite software applications:

- Peripheral Mapping Tool
- Data Capture Tool
- Shockwave Tool
- Bluetooth Connection Wizard
- Video Capture Tool
- The Whiteboard

The Wii Controller Interface Suite software libraries

- WiiciTrackLib
- WiiciToothLib
- WiimoteLibBB

Imagery of the developed software can be seen in Figure 2.

Hardware

Several hardware design solutions were also conceptualised, developed, realised and evaluated. The following list details the primary hardware developed:

- The Wii Glove - IRO-USB-R5
- The Wii Switch
- The Nunchuk Adapter
- The Replicated Wiimote
- The Replicated Nunchuk

Imagery of the developed hardware can be seen in Figure 1.

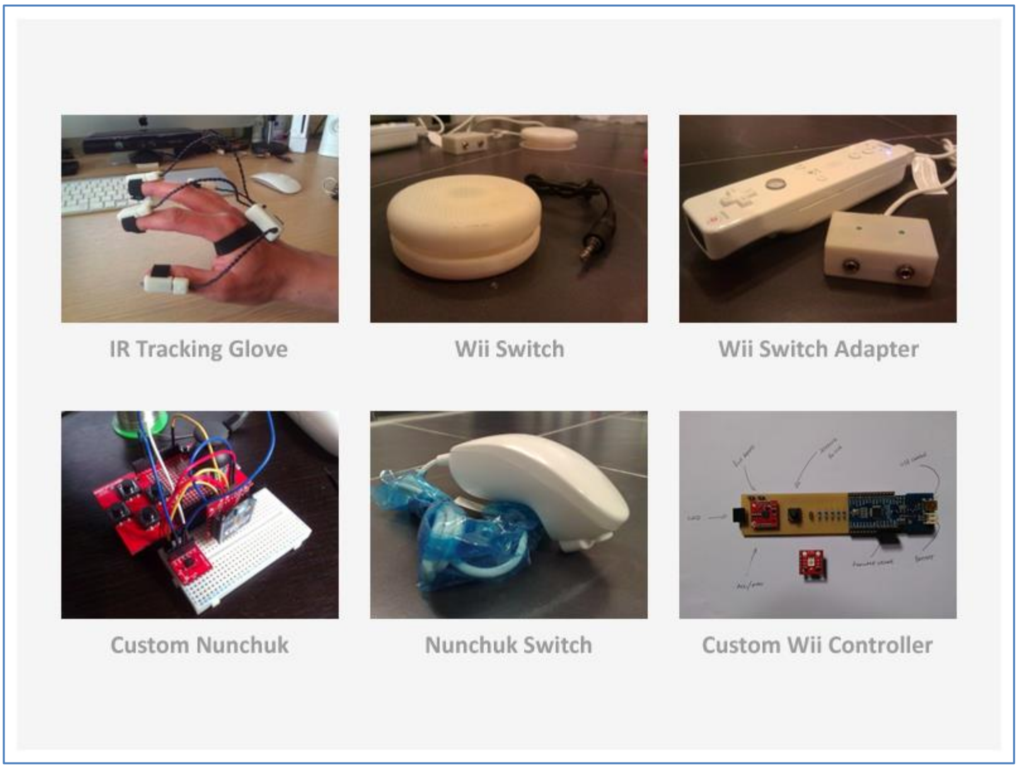


Figure 1: Hardware developed during the period of research

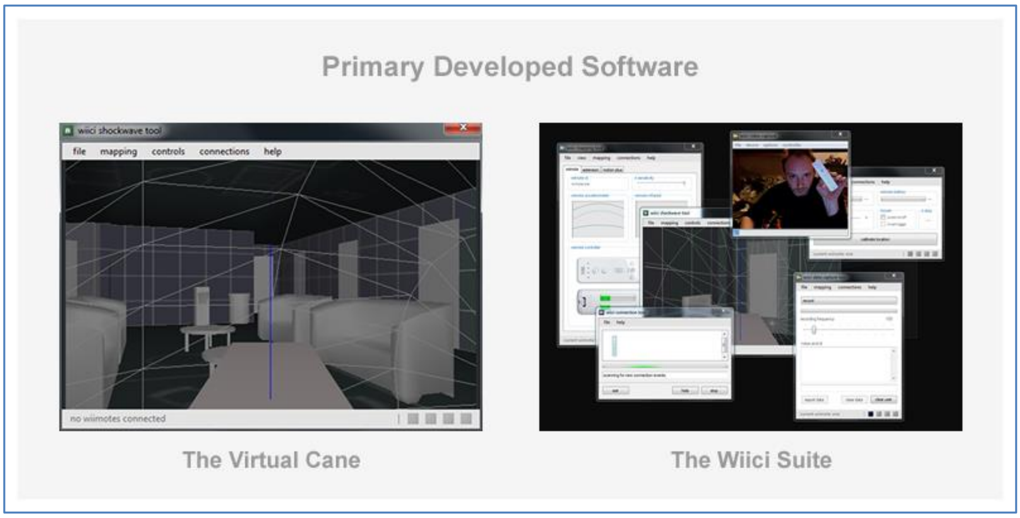


Figure 2: Primary Software developed during research

Appendix D: Example Mood Boards

This appendix presents selected examples of the mood boards developed within design studies detailed within the thesis.

Appendix Contents

The following lists details the contents of this appendix.

1. Wii Product Board
2. Xbox 360 Product Board
3. Related Product Board


Wii
Wii
Wii
Wii
HOME
1
2
VOLUME
MUTE


XBOX 360
XBOX 360
XBOX 360
XBOX 360


EXPANSYS
lenovo
NeuroSky
touch
iPad
FREESPACE

Appendix E: Wii Controller Charts

This appendix contains the charts developed during the Product Study and Wii Controller Design Analysis activities. These charts were used to identify the strengths and weaknesses of the device thus providing both rationale and basis for the activity of Product Re-Design.

Appendix Contents

The following lists details the contents of this appendix.

1. Video Game Input Device Comparison
2. Chart of Wii Remote Strengths
3. Chart of Wii Remote Weaknesses
4. Strength and Weaknesses Comparisons

[1] Product	Function	Power	Communication	Input	Output	Ergonomics
Wii Remote	Menu navigation Pointer driven cursor button select Motion driven game-play Finite control – good Peripheral system hub Text entry – point and click Text entry – scan and select Ability to function as a control pad Ability to be housed in external apparatus to match context of use.	2 AA Battery Third-party recharging solution	Bluetooth custom implementation		Game-play on screen feedback Force feedback motor Low quality audio 4 * Micro LED blue	Both handedness Forced grip style Single handed Hand held
Wii Remote and Nunchuk	Menu navigation Pointer driven cursor button select Joystick driven cursor button select 3D environment exploration – dynamic camera Motion driven game-play Finite control – good Text entry – point and click Text entry – scan and select	2 AA Battery Third-party recharging solution Shared power	Bluetooth custom implementation		Game-play on screen feedback Force feedback motor Low quality audio	Both handedness Forced grip style – Wii Remote Natural grip style - Extension Two handed Hand held
PS3 Dual Shock	Menu navigation Button driven cursor button select Joystick driven cursor button select 3D environment exploration – dynamic camera Subtle Motion driven game-play Finite control – good Text entry – scan and select	Built in charging solution via USB	Bluetooth Wired – USB custom implementation		Game-play on screen feedback 2 *Force feedback motor 4 * Micro LED red	Symmetrical positioning of thumb joystick s Forced grip style Two handed Hand held
Xbox 360	Menu navigation Joystick driven cursor button select 3D environment exploration – dynamic camera Finite control – good Text entry – scan and select	2 AA Battery Official recharging solution	Wireless Wired -USB		Game-play on screen feedback Force feedback motor 4 * Micro LED green	Ergonomic positioning of thumb joystick s Natural grip style Two handed Hand held
**[2]						
Keyboard and Mouse	Menu navigation Pointer driven cursor button select 3D environment exploration – dynamic camera Finite control – good Text entry – hardware Text entry – scan and select	Variable power predominantly AA battery for Mouse and/or Keyboard if wireless predominantly USB port for Mouse and/or Keyboard if wired	Wireless and Wired Standards compliant		Game-play on screen feedback Device dependant Force feedback variants available	Two handed – Independent Single handed – mouse Two handed – keyboard Two handed – combo Desk mounted
Joystick	Menu navigation Driven cursor button select 3D environment exploration – fixed camera Finite control – poor on standard units Text entry – scan and select	Variable power predominantly AA battery if wireless USB if wired	Wireless and Wired and Bluetooth Standards compliant		Device dependant Force feedback variants available	Single handed for primary use Two handed for additional axis control if available Desk mounted

Video Game Input Device Comparison

[1] Above is a simplified version of the strengths and weaknesses comparison conducted during the analysis phase of the product study. Additional factors such as Aesthetics, Manufacturing, Cost and were also evaluated and taken into account. With the exception of Cost all additional variables were found to be equivalent (e.g. all use injection moulded ABS for body construction) for the primary artefacts of investigation (video game input devices). Cost is an exception due to the Wii Controller and Nunchuk combination being retailed as two separate devices in effect doubling the unit value.

[2] Keyboard and Mouse and Joystick have been included to demonstrate that a full range of devices had been taken into account during the product study, and as a reflection of continuance of previous works. Whilst is accepted that the evaluation of these devices is good practice for the collation of baseline data for the purposes of evaluation, at this stage of investigation it was determined that focus should be applied to the evaluation and investigation of the primary thesis concept, use of mapping skill-set and ability as means for input modality. The in-depth investigation of these input solutions was deemed a duplication of resource and works already conducted within the overarching research. See chapter-Portland Study and EPSRC Study.

<table>
<tr><th>Function</th><th>Materials</th><th>Ergonomics</th><th>Aesthetics</th><th>Manufacturing</th><th>Cost</th></tr>
<tr>
<td rowspan="3">The device is expandable to match the complexity requirements of game-play.

The device acts as a central module providing both power and communication facility for additional modules that expand upon the capability of the unit.

The pointer functionality of the device enables selection without the need to scan through multiple options.

The pointer functionality offers finite selection and targeting of objects.

The Wii Remote allows for an expanded variance in input mappings for game-play interaction.

The device is wireless allowing for expanded areas of interaction and game-play.

The device facilitates capability for new and intuitive methods of interaction via use of motion sensing technologies.

The device offers capability for back catalogue compatibility.</td>
<td rowspan="3">The device and its respective extensions utilise materials that are predominantly recyclable.

Hardware has been selected to prevent the average user from gaining access to the electrical components.

External connections are made of materials that are resistive to environmental corrosion.

The materials chosen allow for the production of complex structures at low cost.

The outer materials chosen are resistant to impact and offer a high level or robustness and protection of the internal components.

Materials have been chosen that allow for a variety of textures to be facilitated.</td>
<td>The device has been design so that is can be used equally by both types of handedness.

The dimensions of the device have been selected to represent best fit to an overwhelming variance of population reflecting good use of anthropometrics.</td>
<td>The Wii Remote uses a high degree of visual techniques to ensure correct usage application.

The controls of the device are easy to identify.

Multimodal feedback can be used to enhance game-play and indication of required interaction.</td>
<td rowspan="3">The design of the unit and selection of the materials enables it to be mass produced.

A minimal amount of manual input is needed to manufacture and assemble the device.</td>
<td rowspan="3">The abundance of technology contained within the Wii Remote makes the device a cost effective solution for experimentation.

The physical shaping of the device means that tooling costs are not amplified by the complexity of design.

Predominant use of plastics within mass production context keeps the overall production costs down.

Additional cost has been passed on to the consumer via the lack of recharge capability</td>
</tr>
<tr><td colspan="2">The use of texture, shape and symmetrical layout acts to enhance both the ergonomics and aesthetical appeal of the device. Use of good design has acted to ensure that both ergonomics and aesthetics complement each other effectively.</td></tr>
<tr>
<td>The devise is lighter than traditional wireless controllers facilitating use in a single hand.

The device can be used one in one hand.

The user is not restricted to the central and joined hand positioning found in contemporary game-pad design.</td>
<td>The branding and design of the system is appealing to many different demographics due to its simplicity and un obtrusive nature.

The overall style chosen for the device is one which suggests expense and reliability.

Selection of colour and trimming act to distinguish the brand from equivalent competition.</td>
</tr>
</table>

Chart of Wii Remote Strengths

Function	Materials	Ergonomics	Aesthetics	Manufacturing	Cost
As a solo artefact the Wii Remote is not equipped with the required input complexity for the un-aided navigation and exploration of 3D space. For full interaction that utilise all the input capabilities of the device the user is required to maintain a stance of play where the optic sensor is in full view of the bar. There is a strong reliance on software solutions to both compliment and determine the paradigms for interaction. For some interaction methods an expanded area is needed. The lack of a built in recharge solution means that the device has to be opened by a user in order to replace the power source. Whilst facilitating novel and exciting schemes for interaction the unit fails in comparison to traditional joy-pad designs for traditional game-play interaction. New interface skills have to be developed by the user in order to perform equivalent interaction in some game-play scenarios.	The materials used for the various extension cables cannot be cleaned easily. The unit's base texture collects dirt at a higher rate than that of the top resulting in emphasis of degradation. There is an environmental impact resulting from the production of the materials required. The electronic component artefacts of the device means that it cannot be disposed of via refuse collection. Use of bespoke circuitry and uncommon fixing hardware result in difficulties in reflection of home based repair.	Over time due to the forced position of grip discomfort can form during the wrist game-play. The multi function design of pointer and pad has resulted in the operation of buttons conflicting with the operation of sensor functionality in some game-play scenarios. The shaping of the body means that in energetic game-play it can quite easily escape the grip of the user. A player is forced to hold a trigger position for prolonged periods. This results in levels of discomfort within the index finger during repetitive use. The device can become heavy over prolonged periods of use. This is more prominent than with other controllers which disperse load over two limbs. In sit down and play scenarios the extension cables can interfere with both comfort and game-play.	The lack of contrast between the iconic indication of button function and the base units colour reduces functionality for those with visual impairment. The primary use of white can result in early visual degradation of the design. Although subtle the use of red and blue clashes. The unit's base texture collects dirt at a higher rate than that of the top resulting in emphasis of degradation. This is also apparent on the Nunchuk thumb joystick and the connector cable.	Due to the complexity of the design an initial outlay in revenue is needed to facilitate tooling.	Additional cost is required in order to meet requirements of the full Nintendo software catalogue. To facilitate the requirements equivalent interface as offered by peripherals from the same generation of consoles additional peripherals need to be purchased. Additional cost has been passed on to the consumer via the lack of recharge capability.

Chart of Wii Remote Weaknesses

Function	Materials	Ergonomics	Aesthetics	Manufacturing	Cost
The Wii Remote cannot be seen as a solo device and in reality fails in comparison to other generation equivalent input devices in terms of functional application. The Wii Remote is in effect an expandable design solution that enables configuration to reflect the complexities required in game-play. To be more specific the Wii Remote is a platform for interface. The primary functionality of the Wii Remote is to facilitate navigation interaction of the console interface. The secondary functionalities of the device are: • To provide communication and power capabilities for expandable solutions for interaction. • Provide means for novel interaction in new game-play genres. • Facilitate the basic requirements of backward compatibility in terms of the Nintendo software catalogue. • Attract new gamers to the marketplace. In order to facilitate these functional requirements, compromise has had to be made across several aspects of the units design.	Materials have been chosen to ensure the durability and performance of the device. Materials have also been chosen to ensure the mass production capability of the device. The materials allow for a variety of ergonomic considerations such as shape and texture to be facilitated. The materials are reliable in a variety of conditions such as temperature variation and atmospheric moisture. The composition of the device makes it capable of withstanding accidental spillages and minor immersion in water. The ratios of the ABS compound and custom mounting and fit of the circuitry components ensure that the device is capable of withstanding accidental knocks during a game-play context. A large percentage of the device can be recycled.	Overall there is an abundant level of detail that supports a high level of ergonomic influence in the units design. Despite this factor however several compromises have been made to facilitate the multi functionality of the controller, specifically the ability to also function as a joy-pad. Prolonged use is an issue as the device is shaped to manipulate the desired form of grip and application. This is countered primarily via use of software solutions inferring periods of play. The device can be equally used by both dominant hand types and this is a key feature in the overall design. This is a great advantage when viewed in comparison with other same generation console input devices. The application of ergonomics is more prevalent in the design of the accompanying extension peripherals. Ergonomics is the devices weakest aspect.	On initial inspection the aesthetics of the device are good. However over time degradation becomes apparent due to the material composition. There is definitive evidence of branding identity. The device and its accompanying extensions can easily be identified from counterpart solutions. The aesthetics have been kept simple and symmetrical to facilitate multiple demographic appeal and functional requirement of the device. Influence can be found in reference to a full range of sensory consideration. At purchase the device is stylish and indicates an emotional response of expense and quality. The aesthetics consideration span from the hardware to the software implementation.	The device is capable of manufacture with a minimal amount of manual labour requirement. The majority of the body components are produced using injection moulding. Component costs have been reduced via use of an all in one solution for Bluetooth communication and peripheral interface. Component costs have been reduced via use of software solutions to facilitate high performance of interaction.	The device once tooling has been developed is fairly cheap to mass produce. The main issue of cost is at the hand of the consumer who is forced into the purchase of multiple peripherals to facilitate full device capability. Additional cost has been passed on to the user via the lack of recharge capability. This reduces cost production but also increases environmental impact and consumer expense.

Chart of Wii Remote Strength and Weaknesses Comparisons