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Electronically controllable colour changing textile design

Dilusha Rajapakse, Nottingham Trent University, dilusha.dezoysarajapakse2012@my.ntu.ac.uk
Amanda Briggs-Goode, Nottingham Trent University, amanda.briggs-goode@ntu.ac.uk
Tilak Dias, Nottingham Trent University, tilak.dias@ntu.ac.uk

Abstract

Photochromic materials have often been categorised as a smart material as they could sense and change colour with reversibility from colourless to coloured once exposed to ultraviolet radiation. The aim of this ongoing research is to exploit the design potential of commercially available water based photochromic inks when applied onto textiles using a screen printing method. This research paper highlights the experimental design research conducted in order to design multi-colour change textile patterns and discusses an electronic activation method which could be used to activate dynamic photochromic colours. The results highlight the complex colour changing effects of photochromic inks and outline new variables which could be used to control the kinetic behaviour of photochromic prints.

Smart textiles; Colour changing design; Photochromics; Dynamic patterns; Printed textiles

Colour is recognised universally as a visual experience, a sensation of light that cannot be verified by other human senses; not by touch, taste, smell or hearing. The main use of colour is to add a visual property, and any changes in the colour of an object can be easily detected by an observer or by the use of colour measurement instruments (Bamfield & Hutchings, 2010). Gradual changes in surface colour could also become an extremely effective design feature as it has the potential to create pleasurable visual experiences. If these visual experiences occur repeatedly as a response to surrounding information and disappear without leaving any trace, they can be visually stimulating and aesthetically pleasing (Jakob, 2008).

Project background

Colouring textiles is a well-established industry and the recent research on textiles colouration has focused on improving dye uptake by textiles, producing new colours, improving process economics, enhancing environmental performance and improving the quality of colorants in terms of colour fastness in reacting to influences such as to light, washing and rubbing (Aldib, 2013). Most textiles are coloured using dyes or pigments providing a constant, predictable and reproducible colour that should last for the entire lifecycle of the textile product. Any variation in the colour of a coloured textile, for example when exposed to a change in temperature or to light, would normally be regarded as a defect (Christie, 2013). But the advancement in chemistry, fibres and electronic technology have opened up new opportunities for textile designers to develop dynamic textile surfaces where a textile surface transforms repeatedly from one surface appearance to several appearances as a response to surrounding information, and gradually returns back to its original expression (Worbin, 2010).

Using chromic materials is a niche material direction of achieving colour changing expressions on textile surfaces. According to Tang & Stylios (2006), chromic materials are often documented in relation to ‘smart materials’ as they sense and change colour in response to a range of external stimuli such as heat (thermochromism), light (photochromism), chemical reactions (chemichromism), moisture (solvation chromism), pH(ionochromism), pressure (pieorochromism) and electrical currents (electrochromism). These materials offer new opportunities for the emotional involvement of the end users due to their ability of modifying the surface colour and transparency which are the two most immediate visible aspects of objects (Ferrara & Bengisu, 2014). Thermochromics and photochromics have been used more often to experiment on textiles as both materials could be applied to textiles through screen printing processes and they can also be combined with traditional pigments to design dynamic visual characteristics on textile surfaces.

The focus of this ongoing research is on commercially available water based photochromic inks. This paper describes the design centered approach that has been carried out to exploit the creative potential of photochromic inks and demonstrate the controllable colour changing characteristics that can be achieved by integrating an electronic activation technology.

Photochromic materials

Photochromism is a chemical process where a compound undergoes a reversible change between two states having separate absorption spectra (Bamfield & Hutchings, 2010). This change occurs due to the influences of the Ultraviolet radiation. The forward colour change is facilitated by UV light and the change in the reverse direction occur either thermally when the UV source is removed (T-Type) or on irradiation with a different wavelength of light (P-type). The colour change in photochromism is generally colourless to coloured and the materials undergoing this change can be called as photochromic materials. Spirooxazines (SOs) are an extensively studied group of photochromic compound, which colourise to ultraviolet radiation, and rapidly fade back to colourless or transparent mode when the activating radiation is removed (Feczkó, Samu, Wenzel, Neral, & Voncina, 2013)

As suggested by Little (2008), the commercial awareness of photochromic materials were increased since 1960s due to the development of photochromic lenses, which darken in sunlight converting glasses to sunglasses. Dynamic optical properties of photochromic materials also offer wide range of other industrial applications such as security printing for cheques or document protection, optical data storage, optical switching devices, cosmetics and electrophoretic displays (Berkovic, Krongauz, & Weiss, 2000).

Photochromic materials for smart textile design

According to Little (2008), there are comparatively few reports on the application of photochromic compounds on textiles but considerable research had been conducted on the dye chemistry, evaluation of the colouristic properties and colour measurement attributes. Little & Christie (2010a) conducted a series of research works to investigate the technical performance of the dynamic photochromic dyes on textile substrate. As a starting point for their technical investigation, they have established a colour measurement method which uses an appropriate UV irradiation source, and a traditional colour measurement system to evaluate the colouristic properties of photochromic textiles prepared by a screen printing process. By the use of this colour measurement technology, they have further explained the technical performance of the dye system including colour development and fading properties of the photochromic prints (Little & Christie, 2010b), assessment of the wash fastness and photo stability of photochromic prints (Little & Christie, 2011).

Also there have been some reports on investigations of dyeing methodologies of textile substrates using various photochromic dyes. For example, Aldib & Christie (2011) documented the possibilities of applying photochromic dyes as disperse dyes by exhaust dyeing onto polyester substrates. Furthermore, Billah, Christie, & Shamey (2008) also reported the direct application of photochromic dyes to polyester, nylon and acrylic by disperse dyeing method. Vikova (2011) argued the difficulty of accurately measuring the kinetic behaviour of photochromic pigments while Corns, Partington, & Towns (2009) discussed how photochromism has been exploited commercially and photochromic dyes might play a crucial role in future technologies.

The development of an ‘Information Curtain’ by Melin (2001) was an initial attempt to use photochromic materials to display information in a way that fits better with the environment, while taking advantage of the positive properties of textiles as an interior design material. The curtains were woven out of solar active threads which change colour reversibly from white to one out of seven colours once exposed to UV light. The colour change is effective for about 1 to 3 minutes depending on the intensity and time of exposure. During the weaving process, seven solar active colours were mixed in the warp and weft to create a number of colour mixtures and woven patterns. The woven curtain is white during night and transforms into a colourful striped pattern during the sun rise. The curtain also demonstrated the possibility of creating a dynamic pattern on a woven surface once exposed to artificial UV light. The projection of artificial UV light could be controlled via a computer. The exposure could be also controlled by mounting the UV source onto a motor controlled arm that could be directed towards different parts of the woven fabric surface, or simply projecting the UV light through a stencil design.

The research work conducted by Ledendal (2009) was focused on how the photochromic and thermochromic textiles could be utilized as an information bridge for isolated patients in a healthcare environment. The focus of the work has been to explore how the colour changing expressions could be used as an interface for subtle communication with patients. Under the design concept ‘The rhythm of the sun’, the photochromic textiles were used as a window screen. The colour change occurred depending on the intensity of the sun and that connected the patients with the environment indicating the time and the day.

Lauren Bowker, the founder of ‘Unseen’ combined science, technology and craft techniques to develop unique art pieces that change colour in response to the environment. These multi-sensory artifacts change colour dynamically when exposed to external environmental stimuli such as air, light and heat. Amy Winters and Japanese fashion house Anrealage pushed the boundaries of fashion designing by developing smart and interactive clothing with the use of printed photochromic patterns. They showcased garments printed with photochromic materials which create dynamic colour changing effects once exposed to UV light.

Current literature reveals some explanation for relatively limited textile design application of this smart material. Christie, Robertson, & Taylor (2012) suggested that the photochromic materials tend to degrade gradually when exposed to UV light, therefore the longevity of the final textile product is questionable. Another factor, which may have restricted exploitation, is the past usage of this material only for profit in high technological applications such as the already well-established ophthalmic industry, optical switching, data storage and biological applications (Christie, 2013). This may have created a psychological barrier for designers to explore more intelligent and creative use of this material in complex design systems. Limited material availability, and material cost may also have an impact on the restricted design experimentation of photochromic materials.

Electronically controllable colour change

One of the fundamental design problems for using photochromic material for the development of smart textile applications is the inability to control the activation and kinetic behaviour of photochromic colour changes on textile surfaces. As discussed in the previous section, the colour activation of the photochromic textiles is dependent on a UV source which could normally be the sun; this however is an unpredictable and uncontrollable activation source. Alternatively a UV bulb could be positioned externally to the textile surface and this method was also explored in previously completed design projects. It was evident that these activation methods have the effect of restricting the design possibilities and limit the potential to design creative and intelligent textile applications. However, the photochromic materials have the potential to be categorised as ‘active smart material’ when combined with an electronic system which could be used to control the integral functions of the materials (Robertson, 2011). Therefore identifying how to electronically supply regulated stimuli onto the printed photochromic surface, and to determine what type of variables could be used to control the electronic functions, were considered as key research questions for this study.

Since the photochromic colorants have not been developed specifically for the textile related applications, there was lack of documented technical knowledge on how to utilise screen printing as a method for exploiting the creative potential of photochromic inks on textiles. This presented a significant challenge and the researcher had to question his own design practice and to recognise new creative design processes in order to enhance the material understanding and to successfully apply multiple photochromic colours for the preparation of dynamic textile surfaces for electronic activation.

The ongoing research work presented in this paper contributes to this approach. The next section of the paper reports on the two stages of design experimentation that has been carried out to exploit how dynamic photochromic patterns could be designed on textile surfaces and how an electronic control could be integrated into the activation of these dynamic surface expressions.

Designing dynamic photochromic patterns on textile surfaces

Water based photochromic inks which can be printed onto textiles are commercially available in various colours such as blue, yellow, red, purple etc. Once printed onto textiles, these inks can be activated by exposing them to UV radiation for 5 to 10 seconds. They would return back to the original colourless state when removed from the stimuli. This iterative experimental work initiated to explore how water based photochromic inks could be used to print finer motifs or patterns with complex decorative and colour changing effects. For this study, commercially available water based photochromic inks which supplied as a one part ink system with textile binder was experimented. Photochromic red, blue and yellow inks were selected to document the potential colour transition effects when exposed to UV light.

A complex print motif was designed for a screen printing experimentation. In order to avoid the colour separation process, the motif was converted into a single colour design.

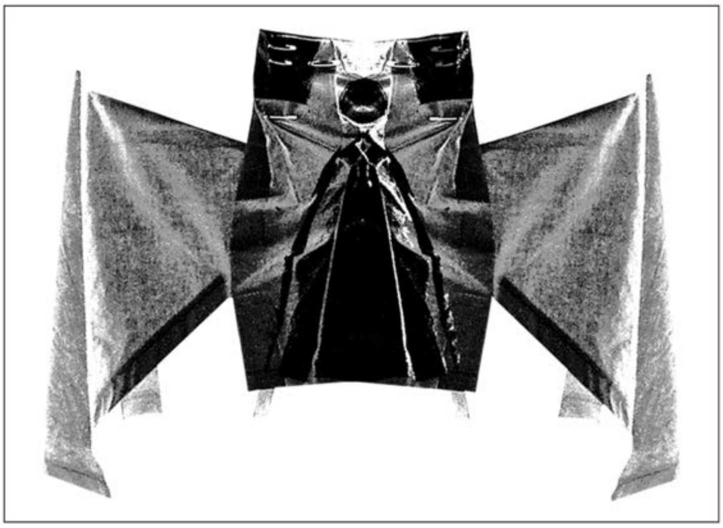


Figure 1: Selected motif with complex details. Designed by Dilusha Rajapakse

The cotton substrate provides the brightest photochromic visual appearance (Little & Christie, 2010b), therefore medium weight mercerized white cotton fabric was selected for the initial printing trials. A lightweight aluminium screen printing screen made of stretched polyester mesh (90T mesh count) was used to print the water based photochromic ink (red colour) onto the textile surface. The selected motif was printed onto a photopositive film with a laser digital printer. A consistent emulsion layer was applied to the mesh and the final screen was prepared by exposing the photopositive onto the mesh with a UV light box for 45 seconds. The print table was prepared with a backing cloth and the selected fabrics were pinned directly onto the backing cloth. After printing, the fabric samples were dried at 130 ˚C for 3 minutes. The printed samples were exposed to direct sunlight to capture the colour changing expressions and one of the selected visuals is shown in figure 2.

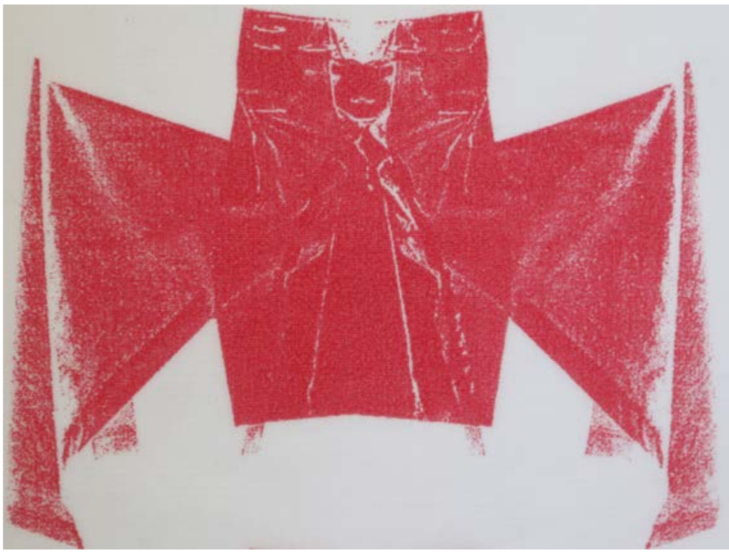


Figure 2: Initial screen printed sample

When the visual aesthetics of the printed samples (Figure 2) were compared with the original motif (Figure 1), it was evident that the finer details of the original motif have been lost due to screen printing. Since the primary aim of the screen printing experimentation was to print a dynamic colour changing effect with minimum photochromic colours, the importance of printing the design with finer details of the original motif was recognized. The visual quality of a screen printed sample is generally determined by many factors such as photo stencil, dot gain, mesh setting, substrate, emulsion thickness, print paste, and squeegee handling. As the fine details of the original motif consist of black and white colour tones, a halftone effect was applied to develop a new photo stencil for screen printing.

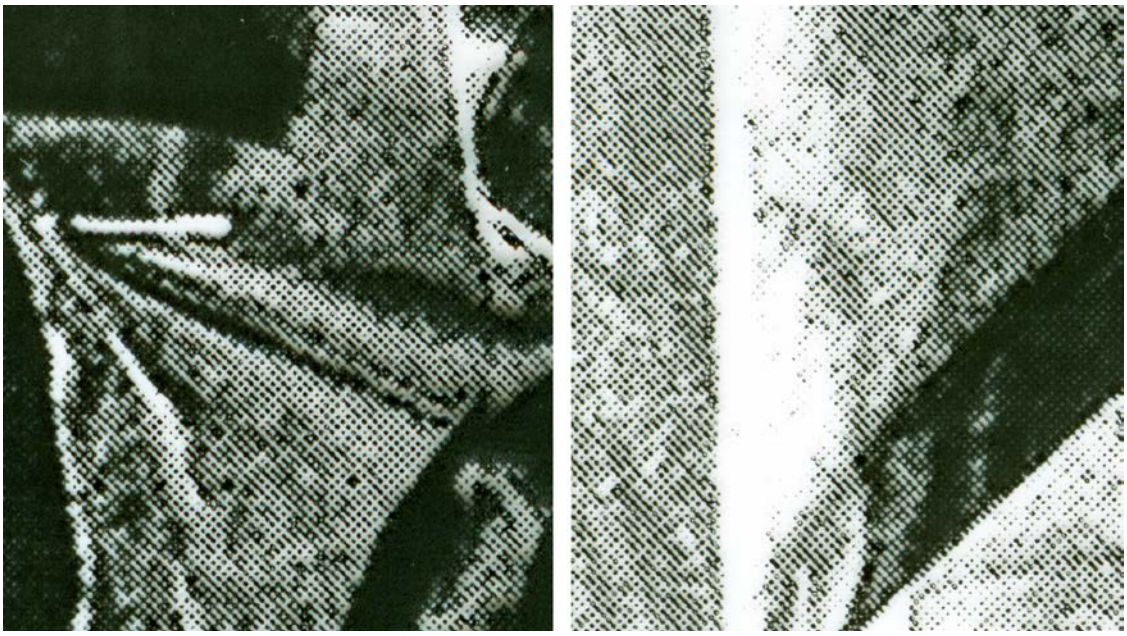


Figure 3: Photo stencil with halftone effect

The halftone screen effect was developed to be able to achieve the tonal effects of the original images. This process breaks the colour tones of a detailed picture into small dots of varying sizes and densities (Figure 3). The size of the dot depends on the grey scale intensity of the image and the number of dot lines per inch (LPI). For example a 45 LPI halftone screen has 45 dot lines (vertical and horizontal) per inch. Therefore the higher the LPI number is, the smaller is the dot size. The correct LPI value to use is defined by the mesh count, viewing distance and the detail one wants to produce on textile surfaces. As there is no clear mathematical formula that can be used to select the right LPI value for a design, it was necessary to experiment with several LPI values with the original artwork. As such, photopositive outputs were developed for different LPI halftones. Final screens were developed by exposing the photopositive to 90T mesh for 45 seconds. By keeping the substrate, photochromic ink paste, and mesh count the same, new screen printing trials were conducted and the results were photographed after 5 seconds of direct UV exposure.

Sample 1	Halftone setting
LPI Value	115
LPI dot angle	45˚

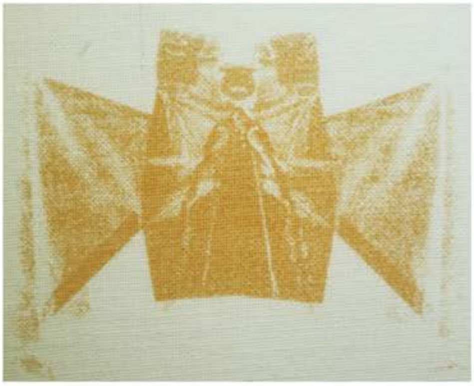
Sample 2	Halftone setting
LPI Value	57
LPI dot angle	45˚

Sample 3	Halftone setting
LPI Value	10
LPI dot angle	45˚

Figure 4: Experimenting with different halftone settings

When printed with water based photochromic ink paste, the 115 LPI halftone effect produced the precise details and subtle colour shades of the original motif. Compared to 115 LPI print, both 57 LPI and 10 LPI prints could not achieve the finer decorations of the motif but the design and the colour changing visual characteristics could be clearly visible at normal viewing distance. By considering the results of these preliminary screen printing experiments, it was decided to carry out further trials by mixing two different photochromic colours.

The potential to achieve multiple colour changing effects for a single halftone print layer was also experimented by mixing a conventional static colour pigment into a photochromic ink paste. Further experimental work revealed that it was also possible to create more complex effects by layering different photochromic colours with varied LPI settings; i.e. modifying the halftone dot shape and the halftone dot angle. Some of these colour changing patterns were photographed under a UV light source and can be seen in figure 5 and figure 6.

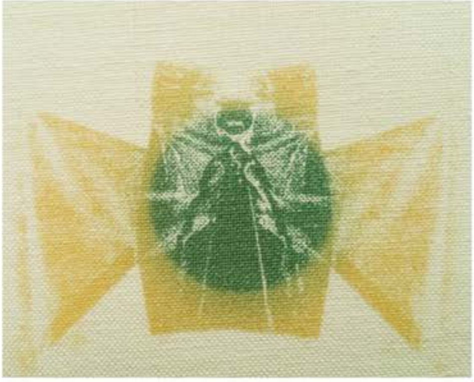


Sample description

Printed with a mixture of static yellow pigment and photochromic blue ink.

Photographed before UV exposure.

LPI Value	115
LPI dot angle	45°

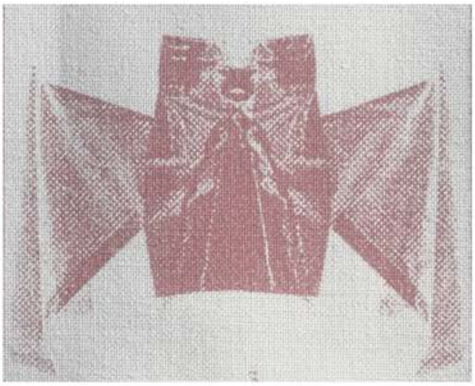


Sample description

Printed with a mixture of static yellow pigment and photochromic blue ink.

Photographed after 5 seconds of UV exposure.

LPI Value	115
LPI dot angle	45°



Sample description

Printed with a mixture of photochromic blue and photochromic red inks.

Photographed after 5 seconds of direct UV exposure.

LPI Value	115
LPI dot angle	45°

Sample description

Layering two different photochromic colours in different halftone settings.

Photographed after 5 seconds of direct UV exposure.

LPI Value	115 (Red)	57 (Blue)
LPI dot angle	45° (Red)	15° (Blue)

Figure 5: Complex colour changing effects

6a: Printed surface before UV exposure

6b: Multiple colour change effect after UV exposure

Figure 6: Multiple and complex colour changing effects

As highlighted in the previous section of this paper, the activation of smart photochromic pigment was determined by incidental UV light. The common method of activating a printed photochromic textile would be to expose the textile surface directly to a UV light source. A new concept of electronically activating a printed photochromic textile was explored by supplying regulated stimuli from the reverse side of the textile surface. The following experimentation was conducted to understand the potential of using commercially available UV emitting Surface Mount Light Emitting Diodes (SMD LED) as a source which could be used to activate a printed photochromic colour on textile surfaces. These small devices offer a greater UV radiation with a much larger beam angle and most importantly, they could be soldered flat against a printed circuit board.

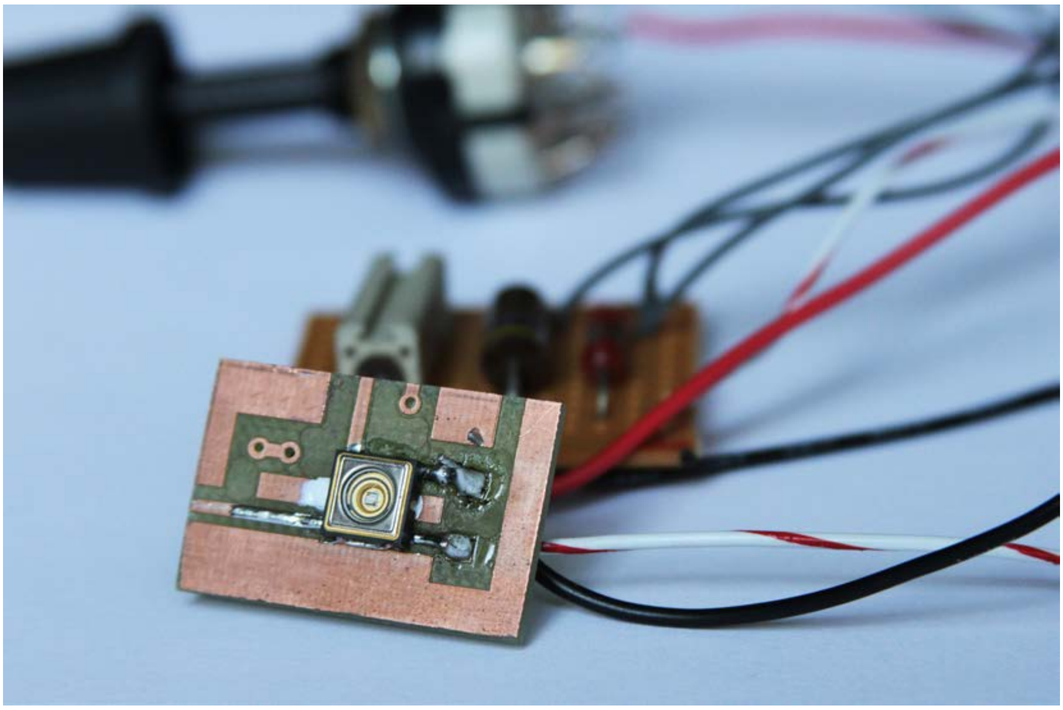


Figure 7: UV emitting Surface Mount Light Emitting Diodes

Electronic activation for printed photochromic patterns

Within the framework of this research, a LED device which can emit a peak wavelength of 380nm to 390nm (UV-A) was used. Fine copper wires were soldered onto SMD UV LED chip according to the manufacturer's recommended conditions. The soldered LED was then mounted onto a white board. Both ends of the conductive thread were connected to laboratory DC power supply and applied controllable voltage to activate the LED chip. The laboratory DC power supply also offered flexibility to input a variable power at different time intervals. The fabric printed with water based photochromic ink was attached onto a white board placed in front of the UV LED chip (Figure 8). Under various voltage values, the UV LED chip was activated and the photochromic fabric surface was exposed to the UV chip for 9 seconds. On the 10th second, the LED chip was switched off and the activation area of the fabric surface was photographed (Figure 9, image1). On the 30th second (20 seconds after image 1), the active colour area of the fabric was photographed again (Figure 9, Image 2) and this process was continued for the rest of the voltages. During the experiment, the distance between the fabric surface and the LED chip was also adjusted with the use of an adjustable milling machine base, equipped with a measurable X, Y axis. The images were analysed in figure 9. The results demonstrated how the power supply (voltage) and the distance between the fabric surface and the LED chip could have an impact on the activation characteristics of the printed photochromic textiles.

Figure 8: Electronically activating photochromic prints

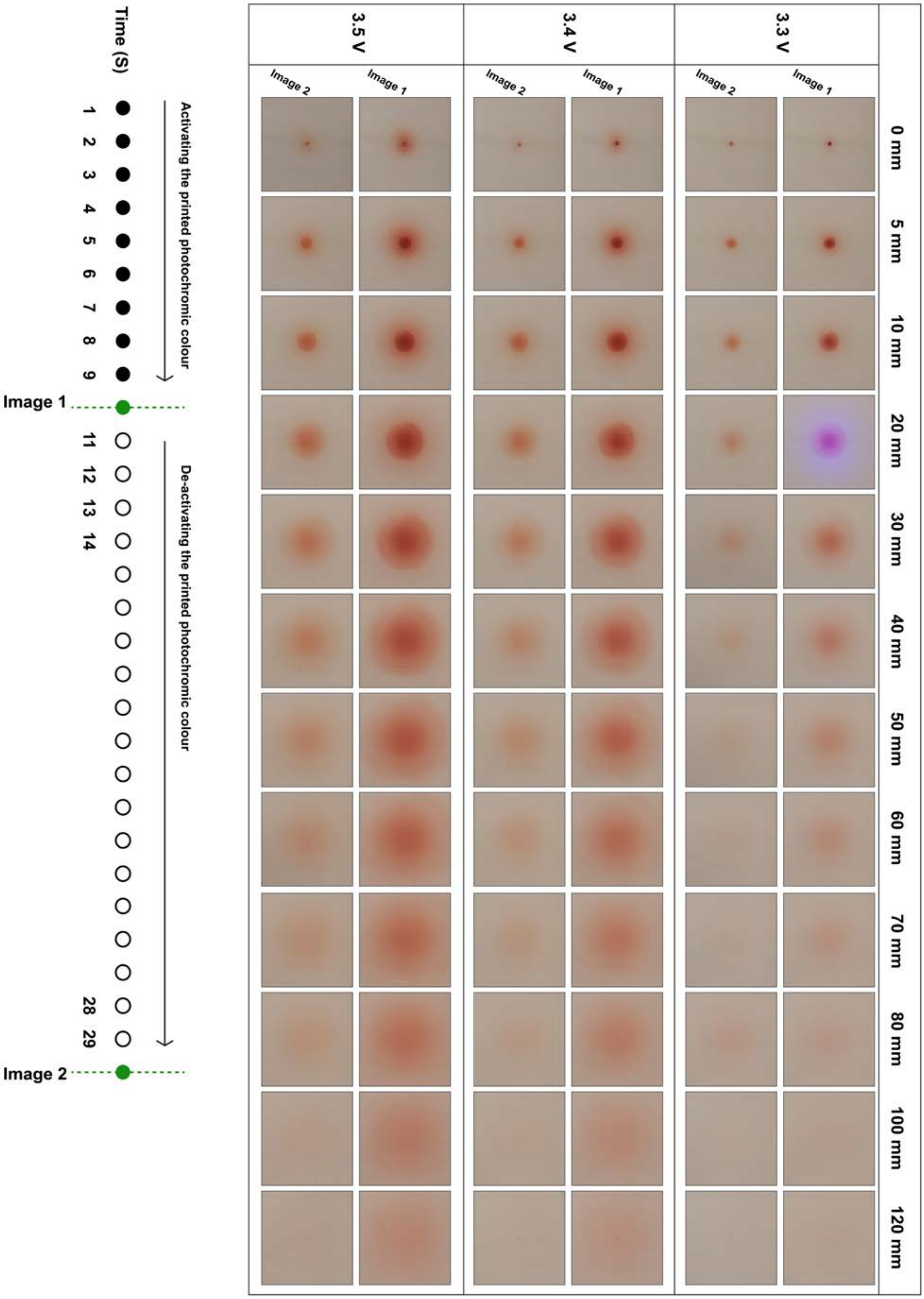


Figure 9: Identifying new variables for electronic activation

It was recognised that the forward voltage of 3.3V was required to turn on the LED chip and approximately 3 seconds of LED activation could trigger a visible photochromic colour change on mercerized white cotton fabric. A range of voltages generated different colour changing effects. When the input voltage increased, the photochromic print activated with a bright and wider colour spot and it took a much longer time to transform into its original colourless state. With different input voltages and 9 seconds of LED activation time, the distance between the LED surface and the textile was adjusted to further investigate the visual effect. It was visible that to fully activate a considerable area (8 cm x 8 cm) of the printed surface, the fabric needed to be placed at least 3 cm away from the LED surface.

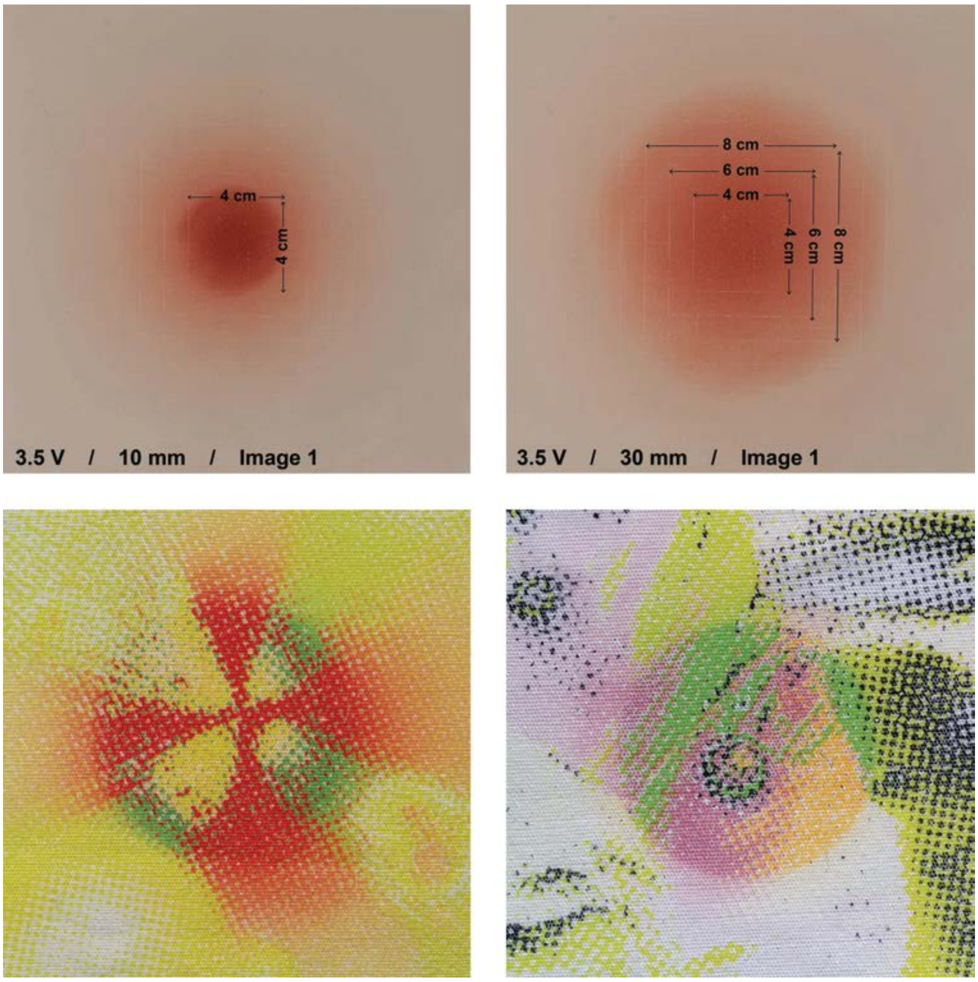


Figure 10: Colour change effect when activated from the reverse side of the printed surface

This research data also demonstrates that the UV LED can excite a circular area on the printed photochromic surface. This occurs due to the in-built radiation angle of the LED chip. The circular measurement could also be used to predict the amount of SMD UV LEDs required to activate a certain printed area of a textile display or how the SMD UV LEDs should be positioned on a circuit board and placed within a textile artifact to electronically activate and control the dynamic visual characteristics. For example, when UV LEDs are positioned as a grid pattern and placed behind the printed photochromic fabrics display, the LEDs can provide accurate and regulated activation stimuli to the specified areas of the printed fabric surface. The LED grid pattern could be programmed to a specified activation sequence circuit enabling the fabric surface to visualize an unpredictable yet controllable colour changing effect. Depending on the input power and the time of LED activation, variations of colour change effects could be visualized on the textile surface.

The experiment results also revealed that the absorption characteristics of the textile substrate could have a significant impact on the activated photochromic colour strength, especially when attempting to activate the print from the reverse side of the textile surface. Further experimental work needs to be conducted with other textile substrates, in order to understand these variables and their contribution to the dynamic visual characteristics of photochromic prints.

Summary and conclusion

The focus of this research paper is to discuss the design potential of commercially available water based photochromic textile inks for the development of smart textile surfaces. As an application method, screen printing was used to apply the water based inks onto textile surfaces to explore the potential visual characteristics. The experimental screen printing work had led to an increased understanding of the technical parameters, and the possibility of achieving dynamic and multiple colour change effects with finer decorations. It was identified that one of the major barriers for using photochromic textiles as a smart material for design application was the inability to electronically activate and control the dynamic colour changing effects. A preliminary work has been conducted to electronically activate a printed photochromic textile surface by the use of a Surface Mounted UV Emitting LED device. A basic circuit display was used to understand the potential of the UV LED and to monitor the key variables that are associated with activating a photochromic textile sample. Moreover the function and the placement of the SMD UV LED could also be used to control the kinetic behaviour and activation position of the photochromic surface. This demonstrates the feasibility of positioning the external stimuli within textile artifacts for the development of dynamic photochromic textile applications.

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Author Biographies

Dilusha Rajapakse

Dilusha Rajapakse is a recipient of the Nottingham Trent University Vice Chancellor's Scholarship award and his ongoing practice based PhD project investigate the aesthetics and technologies of colour changing textiles. This project is adopting multi-disciplinary experimental research methods to test the fusion of textile design practices and emerging technologies in order to develop surfaces equipped with responsive colour changing aesthetics. This project highlights the potential visual characteristics of smart materials once applied through textile printing techniques and demonstrates how dynamic expressions could be electronically activated and control on textile medium. Dilusha has successfully completed a Master's Degree in Digital Fashion at London College of Fashion, University of the Arts London and a Bachelor's Degree in Fashion Design and Product Development at University of Moratuwa, Sri Lanka.

Dr. Amanda Briggs-Goode

Dr. Amanda Briggs-Goode received her PhD in Digital Textile Design in 1997 and has since this time been working in this field as an academic as both a lecturer and researcher. Having led the course Textile Design for five years she has recently become head of department for Fashion, Textiles and Knitwear and published a text book 'Printed Textile Design' in 2013 with notable publishers Laurence Kings as well as in 2011 an edited publication on Textile Design with Woodhead Publishing. Her research work has covered a number of textile related disciplines; printed textile design, lace and the Nottingham Trent University archive and smart textiles. Her work and collaboration with researchers into new technologies led to work with stretch sensors and creative practice and now through the internet of sort things project to use textile practice and material to consider person centered design and the therapeutic impact of both making and the products themselves.

Prof. Tilak Dias

Tilak Dias is the Professor of Knitting at Nottingham Trent University. He is the founder and the leader of the Advanced Textiles Research Group in the School of Arts and Design at Nottingham Trent University. Professor Dias has a background in electronics, textiles and electronic textiles and a track record in exploiting his research. The main focus of his current work is in the area of electronic textiles where the objective is to embed integrated circuit chips within the fibre of yarns. Professor Dias is also working with the military in the development of active camouflage and prosthetic limb interfaces. Other projects have been electronic textiles for the automotive industry, electrically heated gloves, textile sensors for stroke rehabilitation and textile electrodes for ECG measurements.