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MECHANICAL PERFORMANCE ASSESSMENT SYSTEM FOR ENDOTRACHEAL TUBE INTRODUCERS USING MOTION DETECTION AND OBJECT TRACKING

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ABSTRACT

Failure to secure the airway with an endotracheal tube in a timely manner on induction of anaesthesia can lead to serious complications, including death. Equipment design and selection can often contribute to procedure success or failure, although current equipment does not always provide optimum solutions. Most anaesthetists consider endotracheal tube introducers (bougies) essential equipment; however, there are many different types available, with little relative performance data to inform choice. To date, no performance assessment system exists that is capable of assessing the shape retention properties of bougies. This paper discusses the design development process of the Shape Retention Testing System (SRTS) that utilises motion detection, object tracking and image processing to assess the relative performance of bougie introducers.

KEYWORDS

Airway Management, Bougie, Difficult Airway, Image Processing, Motion Detection, Object Tracking

1. INTRODUCTION

Endotracheal intubation is fundamental to safe anaesthetic practice and the procedure continues to challenge experienced of anaesthetists. Serious consequences, including death and disability can occur (Cook et al, 2011). A UK national survey of major complications suggests improvements can be made in practice, design and choice of equipment (Cook et al, 2016). A bougie (also known as a bougie introducer) is one of the most common intubation aids used. Bougies are long, flexible, relatively narrow rods that have some intrinsic "shape memory". They are used when the view is limited, making direct placement of the endotracheal tube (ET tube) itself difficult. Bougies are manually manipulated to match the curve of the patient's airway and act as a physical guide over which the ET tube can be placed and the bougie removed.

If a bougie fails to retain its shape during use, it must be removed and reshaped. Limiting the number of reshaping processes required is vital for this time-critical procedure, therefore understanding the mechanical properties of bougies is desirable when designing new equipment and selecting it for use in practice. The Difficult Airway Society (2018) provides a comprehensive list of bougie introducers used in UK; however, these vary in diameter, length, tip design and material construction. Mushambi et al (2016) identified the re-usable Eschmann Tracheal Tube Introducer "Gum Elastic Bougie" (GEB) as the gold standard device.

Currently there is no standard testing equipment to accurately assess bougie performance, especially the shape retention properties. Siena et al, (2017) first proposed the construction of suitable testing equipment, including an analysis system for the assessment of the shape retention properties utilising vision based tracking.

Single use tracheal tube bougies/introducers are becoming more common due to their significantly lower price point compared to the GEB and the elimination of concerns over cleaning, disinfection and sterilisation. Mushambi et al (2016) suggests urgent further evaluation of the single use devices is required before they replace the GEB entirely. Specific device selection is often based on operator personal preference, availability of equipment within the NHS supply chain and hospital-designated suppliers.

Any new or existing device should conform to the UK's Difficult Airway Society's ADEPT principles (Pandit et al, 2011); however, many devices have not undergone any formal evaluation. An accurate, reliable testing system could inform device selection and usage decisions. Previous studies of the relative performance of bougie introducers suffer from several limitations including unreliability, inaccurate measurement, poor standardisation of applied pressures, calibration, accuracy of data acquisition equipment, repeatability of positional tracking and application of forces within desired angles and orientations. An objective, reliable system capable of assessing mechanical and physical properties of endotracheal tube introducers could overcome these limitations. We considered that the use of motion capture technologies to provide a repeatable and accurate method of measuring bougie motion and shape retention capabilities would be a reliable cost effective approach.

2. TESTING SYSTEM (SRTS)

The Shape Retention Testing System (SRTS) is a concept recently presented by the authors (Siena et al, 2017) as a method of analysing the shape retention characteristics of bougie introducers. This system utilises motion detection and object tracking in combination with image processing techniques for data acquisition and analysis. Annamaneni et al (2003), Hodzovic et al (2004a; 2004b) Jackson et al (2009), Janakiraman et al (2009) have previously completed studies to assess the uses, properties and risks associated with bougie-assisted intubation within simulated difficult intubations and considered factors such as the effect of tip pressures, placement considerations and comparative assessment between multiple use and single use bougies. However, many of these studies do not use standardised or even suitable testing techniques with the required accuracy to provide precise results. Using a motion detection and object tracking based system, in combination with image processing, the SRTS has been designed to overcome the above-mentioned issues.

2.1 Hardware: SRTS Construction

The SRTS utilises an Intel® RealSense™ SR300 camera to identify motion detection and object tracking. The SR300 is one of the smallest 3D depth and 2D camera modules currently available on the market utilising a short range, coded light 3D imaging system. The SR300 utilises depth sensing with a 1080p RGB camera, enabling users to complete tasks such as dynamic background segmentation, object tracking, facial recognition, gesture recognition, hand and finger tracking and augmented reality tasks (Intel® RealSense™, 2016). Figure 1 presents a 3D schematic diagram of the SRTS setup with key technical features highlighted:

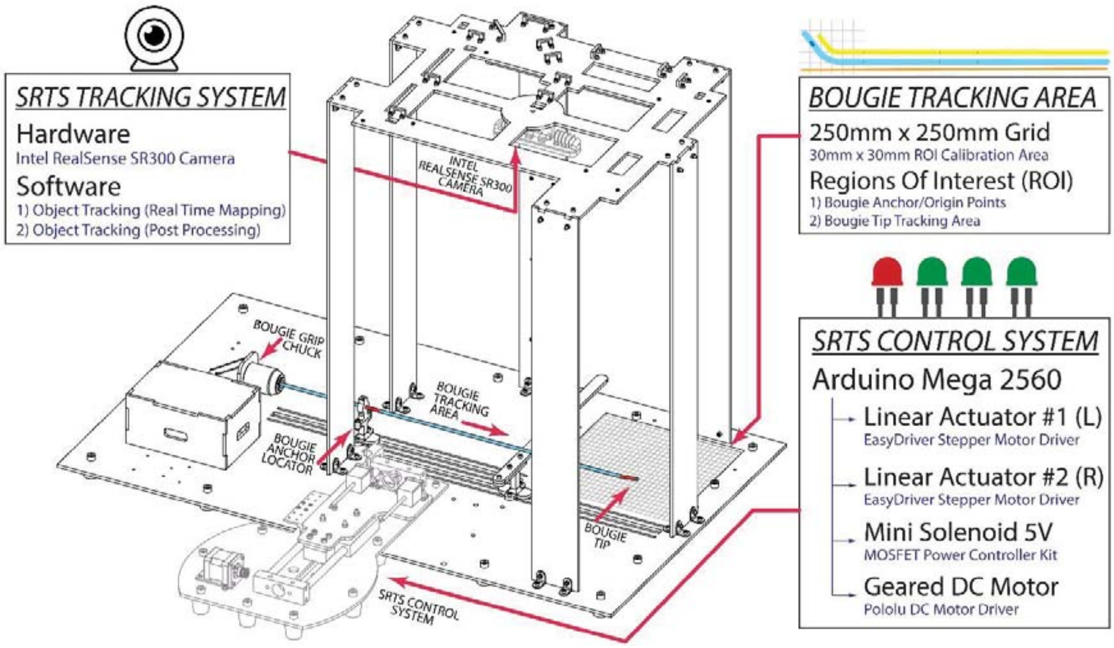

Figure 1. Shape Retention Testing System (SRTS) Setup

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2.2 System Control

The SRTS has been designed to function in three key stages. First, the STRS control system uses the linear actuator pushers to manipulate the shape of the bougie at one or more points to generate a curve similar to that of a patient's airway. Secondly, once in position, the SRTS tracking system, utilising object tracking (real time mapping), is activated and begins tracking, the linear actuator pusher system (LAPS) then retracts and the bougies shape retention is tracked; simultaneously a video recording of the movements is taken.

Finally, once the video recording is completed, the post processing data analysis software is utilised to analyse device performance. There are multiple components to the SRTS that overcome many of the limitations discussed. The LED lighting system creates a standardised lighting environment when used in combination with the blackout hood that encompasses the testing systems support frame; this ensures ambient room lighting is minimised. The mechanical chuck grips the bougie and works in combination with the bend location anchor that can be adjusted based on the bougie being assessed. The linear actuator pusher system (LAPS) is controlled by an Arduino Mega 2560 and utilises several motor drivers and power control modules. Control parameters have been programmed within the code to ensure commands can be altered based on the required input parameters, but also an automatic reset command is utilised to ensure the system has a calibrated home position.

The SRTS has been designed with the capability to alter testing parameters, creating a repeatable testing system adaptable for variable equipment assessment. The camera system provides accurate camera/video tracking with a fixed frame rate and appropriate field of view (FOV) to track the bougies bend angles, tip movements, speed of movement and shape retention within pre-defined regions of interest (ROI) (Figure 2). Accurate camera tracking data, captured in combination with interchangeable angle measurement grids, allows the assessment of data over clinically relevant ranges both pre and post processing.

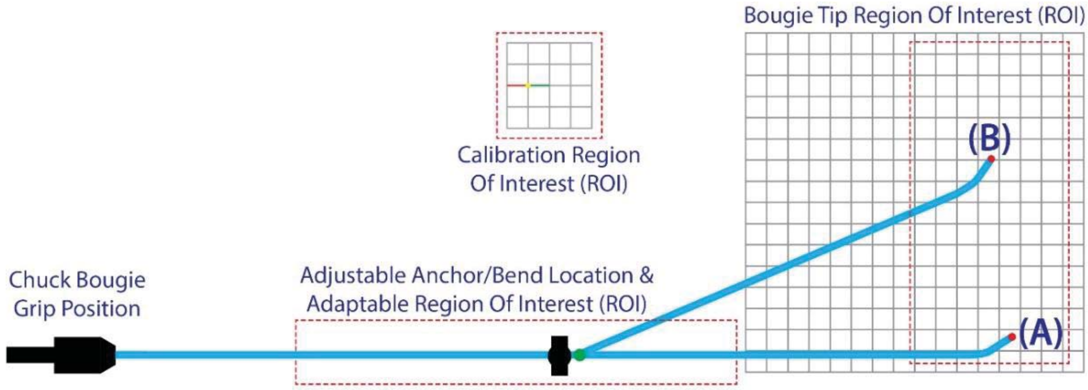

Figure 2. Bougie Tracking Regions of Interest (ROI)

2.3 Software: Motion Detection, Object Tracking and Image Processing

The SRTS uses two software packages to assess the shape retention properties of bougie introducers. The Real Time Mapping Software (RTMS), which has been adapted from an open source object tracking C# program that utilises a live camera video feed to assess the colour and size of objects (Gupta, 2013). This program is used for motion detection and object colour tracking to plot/map the bougie tip movements. The RTMS identifies coloured objects and tracks their positional movement. The X and Y co-ordinate data is captured and plotted onto a position-tracking map as the object is moved providing a mapped image.

The Object Tracking Post Processing Software (OTPPS) analyses a recorded video of the bougie introducer movements to determine the starting angle (degrees), change in angle (degrees), the distance moved (mm) and the speed of movement recorded in millimetres per second (mm/s). The OTPPS tracks over a set number of frames tracking the anchor/origin location and the tip of the bougie, both of which are defined by coloured markers. Data points are then monitored and captured during bougie manipulation (Figure 2b) as the bougie attempts to return to its original shape (Figure 2a). The OTPPS software requires a number of input parameters in order to function correctly. Initially, it is imperative to identify the key colours within the image that we wish to identify as our targets; each target also has a Region of Interest (ROI) defined (Figure 2). The ROI instructs the software the location to search for the given target colour. This not only reduces the area that the system will need to search, thereby speeding up the process, but will also reduce the chance of any object outside of our search area being identified by the camera and being incorrectly tracked by the system. The OTPPS software breaks down the video into individual video frames, extracting the pixel data from each frame, isolating the pixels of our given target colour and creating a digitised array representation of the image that the computer can now search (Figure 3). Pixels are extracted from the source image and are converted into a digitised map Figure 3 (Left). Figure 3 (Right) shows a 4x4 extract of an image, showing the converted digitised version with target colours turned into numerical values.

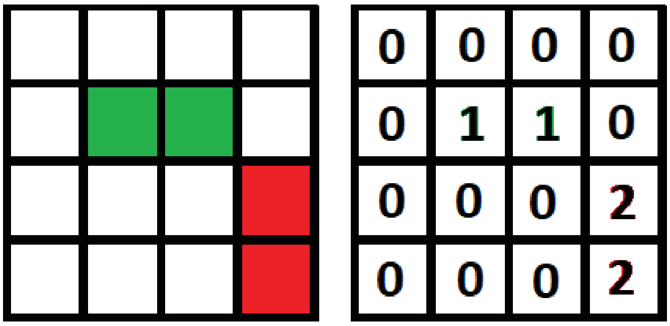

Figure 3. Original image in pixels. (Left) Digitised map of the pixel image (Right)

Once the system has this array of data, it now isolates the centre of the required object and use this point as the coordinates for any measurements collected. Two targets were required to be tracked to calculate the required angle and speed of the bougie tip movement. The first target is located at the base of the bougie where it will be shaped; this is a fixed anchor point which will not move during testing. The second is the tip of the bougie (Figure 2(a)); this is the part of the bougie that will move and will be tracked (Figure 2(b)).

As the video runs at a fixed frame per second (FPS) rate, it is therefore possible to calculate an exact timestamp for each frame and set of coordinates. Using this data, it is possible to calculate the movement of the target points between two specified timestamps. By calculating the angle between the anchor and the bougie tip for each of the two frames and subtracting the first angle from the second, the amount of rotation that has occurred within the specified timeframe is calculated. An important part of the measurement calculation is to define the scale of the camera image, to convert the pixel coordinates into measurements of distance (mm). To do this, a grid system is utilised with a fixed sized grid width of 10mm. An ROI is setup for this grid and requests the camera to find the location of the grid. Once the camera system locates the first line in the grid, it scans to the right-hand edge of the line and then scans across to the start of the next line. The distance between the two points gives the number of pixels per 10mm, which is then divided by 10 to give pixels per 1mm. This can now be used when converting from pixels into mm's. To calculate the distance moved, the bougie tip start frame is subtracted from the bougie tip end frame; this defines the distance in pixels between the two points. By dividing this new value by the number of pixels per mm it is possible to discover the number of millimetres moved by the bougie tip between the start frame and the end frame.

The analysis of video frames is a processor intensive task. As a result, this image-processing task was optimised within the program to allow the processing of video frames in parallel, thereby utilising all of the cores available on the computer/workstation. The main thread of the program controls the file access to the video file and extracts frames as and when they are needed. Once extracted, the image from the frame is passed into a parallel thread, which then proceeds to process the image and extract the required coordinates and data.

Once complete, the thread returns the result to the main thread, which then collates the data into a single data set and writes the output video frame into the output video file. Using this framework, the program is capable of running any number of threads, this is easily modified within the program code to increase or decrease the threads as needed. During testing, the program was set to use eight threads to best utilise all the available cores on our test computer/workstation.

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3. CONCLUSION

Utilising object detection and tracking in combination with image processing has ensured that the development of the Shape Retention Testing System (SRTS) has been possible. Developing the SRTS has demonstrated that an accurate, repeatable and reliable testing system can be manufactured to provide anaesthetists and the medical device industry with a testing system capable of providing data to inform device selection and usage decisions. The data collected by the developed SRTS will be utilised to provide evidence for device selection and purchase decisions. In addition, the data collected can also be used to provide evidence to professional societies and academics to inform their guidelines for best practice; this in turn could place the device manufacturers under pressure to conform to a strict device performance criteria. Using object detection and tracking, the SRTS has demonstrated its capability to standardise and monitor many elements not previously considered in studies conducted and published within academic case studies and equipment assessment literature. The SRTS can also be adapted for paediatric equipment assessment in the future. The SRTS will now be used to assess the performance of the extensive bougie introducer range available for purchase within the UK.

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