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A REVERSE APPROACH TO VIRTUAL SHIRT PROTOTYPING AND PATTERN CUTTING

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ABSTRACT

Traditional virtual clothing prototyping is achieved by wrapping 2D pattern pieces on virtual mannequins. This paper describes a reverse approach that develops 3D garments first and unwraps 2D pattern pieces out of them. To achieve this, a 3D drawing board for men's upper body outerwear was developed from bodyscan data by employing reverse engineering and geometric modelling techniques. The drawing platform was made scalable by integrating 12 size parameters that were found appropriate for loose-fitting shirt so that 3D grading in space can also be realised. This 3D platform can easily be used by fashion designers to develop virtual shirts by drawing simple lines and curves and by applying mesh generation tool, and to extract 2D pattern pieces automatically if an appropriate flattening engine is available within a 3D CAD environment. It has been found that a variety of shirt and jacket designs can be developed on this 3D platform. However, difficulties were faced with raglan sleeve and one-piece collar. This paper also describes the effects of technical parameters on mesh generation and pattern flattening processes.

Keywords: Virtual clothing, Pattern Cutting, Pattern Flattening

INTRODUCTION

The earliest records of clothing pattern illustration date from the pattern manuals published by a few eighteenth-century tailors (Aldrich 2007). Although computer graphics technology began to evolve in the middle of the 1950s and was already used in a wide range of industrial applications by the 1970s (Machover 1978), it was only in the 1980s when commercial computer aided design (CAD) systems for drafting and grading flat patterns were introduced into the clothing (Burke 2006). In recent years, three dimensional (3D) CAD systems for virtual clothing prototyping have started to become available on the market. These systems allow the wrapping of 2D pattern pieces onto a virtual mannequin to facilitate the evaluation of clothing fit, fabric drape and ultimate decision making (Sayem et al., 2010). Digital reverse engineering of clothing patterns, which means the extraction of flat pattern pieces from 3D virtual clothing, is an emerging concept in clothing technology. It has the potential to combine fashion design and pattern creation into a single step; but an efficient technique and a suitable CAD system for doing this is yet to be made readily available to the clothing industry. This paper describes the development of an anthropometric CAD technique for creating a resizable design platform for reverse engineering and 3D grading of men's outerwear.

Hinds et al. (1992) and Okabe et al. (1992) established the concept of creating clothing designs on virtual mannequin. McCartney et al. (2000), Kim and Kang (2002), Wang et al. (2002a, 2000b), Petrak and Rogale (2006), Petrak et al. (2006), Decaudin et al. (2006), Kim and Petrak (2007) and Fang et al. (2008a, 2008b) demonstrated various ways of extracting flat pattern pieces from 3D designs. Their work provides a particularly useful resource for software developers but will continue to be of little interest to end-users and designers until a suitable software package becomes available. Among the available clothing software packages, 3D Interactive software from TPC (HK) and the flattening tool of 3D Runway from OptiTex (USA) provide the capability to execute pattern unwrapping in a very limited context, mainly for close-fitting garments. The DesignConcept software from Lectra (France) is capable of executing 2D pattern unwrapping from 3D designs, but it is not intended by its supplier to focus on clothing product-development. Thus it is not currently supplied with any appropriate design platform for 3D clothing design.

One of the early methods of 2D sketch-based 3D design using a virtual human model and subsequent pattern flattening and also including a concept of 3D grading was presented by Wang et al. (2002a, 2002b). For 3D grading, they proposed to construct the same garment repeatedly on different-sized virtual models, which is a time-consuming and repetitive process. A more efficient alternative would be to convert the virtual model from one size to another after designing a garment only once. This approach requires the use of a virtual model which has been parameterised with the size data. A process of developing such a parametric model was proposed by Sayem (2004) but the model was only suitable for close-fitting garments. The research project 'AiF-1454 BG' from the German Federation of Industrial Research Associations which was concluded in 2007 also followed a similar approach for creating 3D designs of close-fitting garments on parametric virtual models and 2D pattern flattening (Roedel, 2008). However, close-fitting garments represent only less than 20% of our total clothing consumption as reported in the CBI Trade Statistics for Apparel (CBI, 2014). Techniques of developing loose-fitting virtual trousers and pattern unwrapping were demonstrated by Sayem et al. (2012), Tao and Bruniaux (2013) and Hlaing et al. (2013). Sayem et al. (2012) considered the ease distribution over the girth measurements as it is done traditionally in the pattern industry, however, Tao and Bruniaux (2013) and Hlaing et al. (2013) took a complicated route of ease distribution by defining several offset points on each girth. This paper demonstrates a combined technique of 3D design, 3D grading and extracting 2D patterns for men's loose-fitting shirts in a usable and practicable format for the clothing industry.

MATERIALS AND EXPERIMENTAL METHODS

A) Development of Resizable 3D Shirt Template

Today's body scanning technology makes it possible to capture Point-Cloud data from the surface of a human body, and this may be processed using a suitable modelling software package to produce a realistic virtual model. Such a virtual model can serve as a '3D design platform' for close-fitting garments in a CAD system, but not for loose-fitting garments, unless it is subjected to further modification. In order to realise the required adaptation to obtain a resizable '3D design platform' for a loose-fitting men's shirt, a set of closed curves in the horizontal plane were extracted from a virtual mannequin generated from body scan data. These extracted curves were modified bearing in mind the geometrical structure of an outerwear garment and were then parameterised with size data in order to create a resizable design platform which will provide the basis of 3D grading. In next step, using appropriate 3D modelling procedures, a 3D structure was regenerated out of the modified and parameterised scaled curves. The resulting structure was suitable for use as an outerwear design platform. The process is summarised in Figure 1 and further described in the following sections.

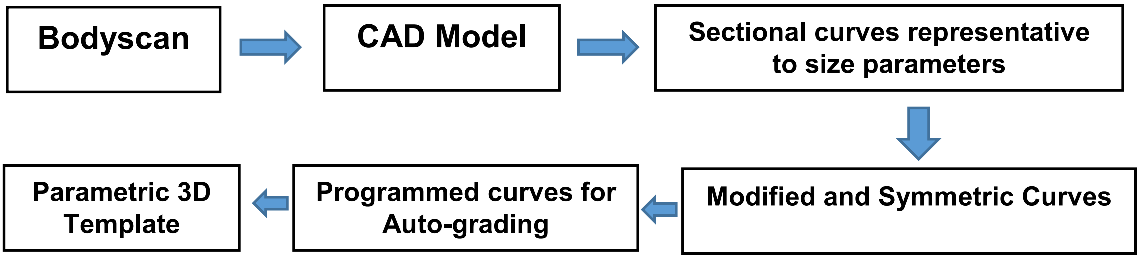

Figure 1: Work-flow for 3D Drawing Board for Virtual Men's Shirts

i) CAD Model from Point-Cloud Data: In order to capture the actual human anthropometry into the target 3D drawing board, an adult male subject was scanned by a [TC]² NX-16 body scanner and the scanned point-cloud data was used as the raw material for the next steps. It was then converted from point phase to polygonal phase using the proprietary NX16 software to obtain a body model in '.obj' format which features a surface network of adjacent triangles, created between every three data points. The body model was imported into a reverse engineering and modelling software "Geomagic Studio 11", which is capable of converting polygonal meshes into digital CAD models. A surface of Non-Uniform Rational B-splines (NURBS) was applied over the polygonal mesh and finally converted into a CAD model in '.igs' format, as shown in Figure 2.

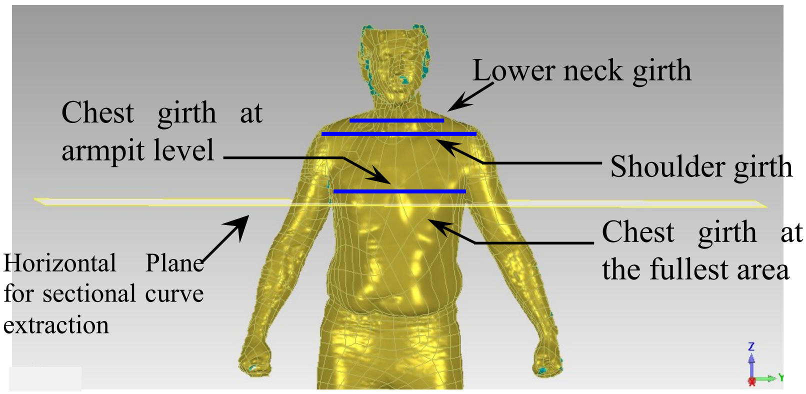

Figure 2 CAD Model and the Positions of Chest Girths, Shoulder Girth and Lower Neck Girth

ii) Sectional Curve Extraction: As the 3D template or the drawing platform is intended to be used for 3D grading using size data-base, it is required to programme the template for auto-scaling up and down when an appropriate size data-base will be linked. This can only be realised if a set of sectional curves can be extracted from the CAD model and programmed with size parameters before re-building the 3D model out of them. A set of sectional curves at pre-determined horizontal displacements, as illustrated in Figure 3, was extracted from the digital body model using the "*curves by section*" command within the "Geomagic" software.

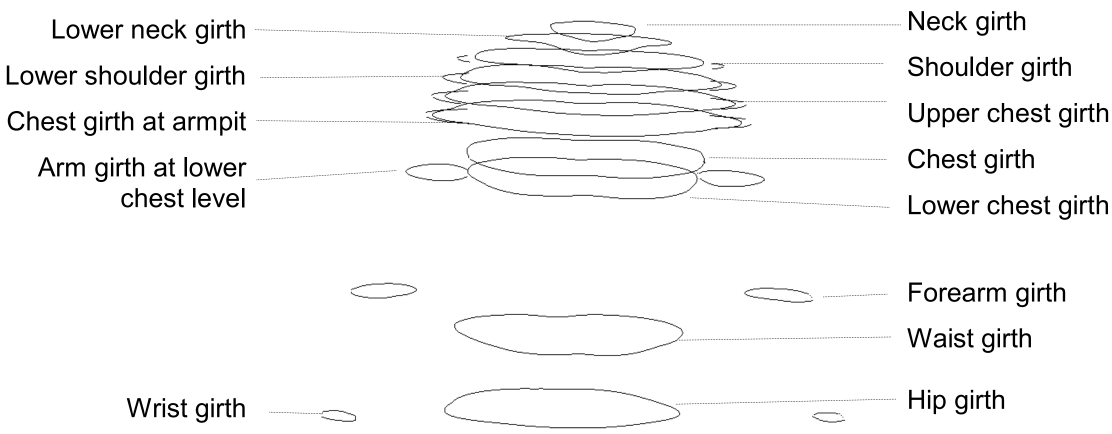

Figure 3: Sectional Curves Extracted from the Body Model

First the 'landmark' positions of the *neck girth, chest girth, waist girth* and *hip girth* were identified on the body model following the European standard EN 13402-1:2001. In addition to the four primary sectional curves, six secondary curves (three for the "neck to shoulder" area and three for the chest area) were found to be necessary to accurately reproduce the geometry of upper body garments. These girth measurements are not traditionally used as size parameters, because they do not correspond with easily identifiable anatomical landmarks. The shoulder girth curve was located at 1 cm below the crown of the shoulder on either side of the torso. The lower neck girth and lower shoulder girth were designated as being 3 cm above and below the shoulder girth respectively. Three secondary girth curves selected to rebuild the chest area were: the upper chest girth, taken as being 9 cm above the chest girth; the chest girth at the armpit, 6 cm above the chest girth; and the lower chest girth, 3 cm below the chest girth.

In order to develop the sleeves of the proposed 3D template, four curves, namely: the upper arm girth, the arm girth at lower chest level, the forearm girth and the wrist girth were used. Of these, only the wrist girth is sometimes used as a size parameter in traditional pattern cutting systems.

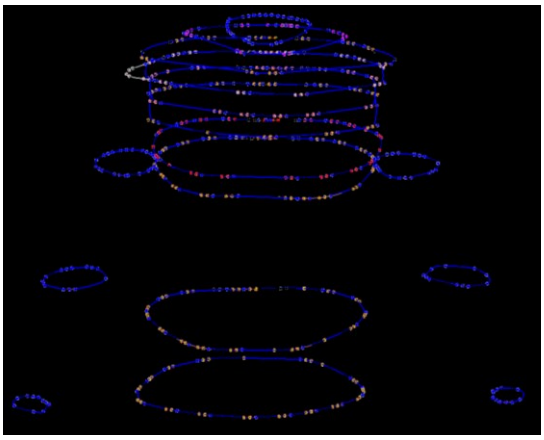

Figure 4a: Drawing B-spline Curves on the Sectional Curves

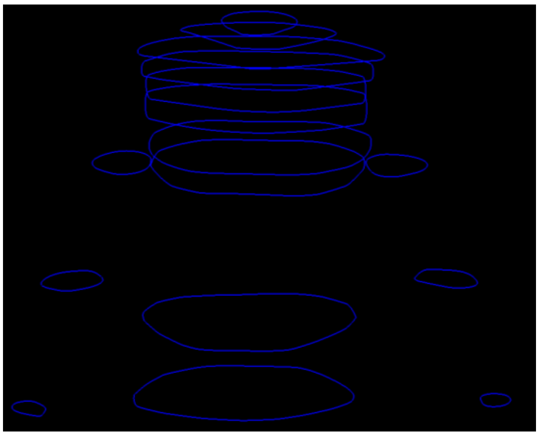

Figure 4b: Drawn B-spline Curves

iii) Modified B-spline Curve Generation: The sectional curves in '.igs' data format were imported into "DesignConcept TexTech (DCTT) V4R1c1" which is a CAD software suite with tools for surface regeneration, digital drawing and for flattening 3D surfaces into 2D. Naturally, these curves represent the surface geometry of a scanned subject, but do not necessarily provide a satisfactory shape for the surface geometry of an outerwear garment. Furthermore, these were found to be broken in some places due to limitations of the scanning and modelling processes.

For the body section, using the curve drawing tool of the CAD system, closed B-spline curves were generated from each of the sectional curves, as demonstrated in Figure 4, by avoiding the protruding parts (for example in the neck girth and lower neck girth due to the laryngeal prominence) and by smoothing out the concave segments at the front and back of the torso. For the lower shoulder girth, the upper chest girth and the chest girth at the armpit; modified curves are drawn without considering the arm sections which lie on either side of each extracted chest curve. For the waist girth and hip girth, efforts were made to achieve an elliptical shape as closely as possible, by controlling the interpolation points of the drawn B-spline closed curves to resemble the lower shaping of classical outerwear garments. The human body is not a symmetrical object, so the curves that are derived from it inevitably lack symmetry. However, mass-produced clothing is expected to have a symmetrical structure if intentional asymmetry is not introduced by designers. This required the curves to be modified to meet the purpose. The body curves were split into two halves based on a vertical plane. The individual halves of the body curves were duplicated as a 'mirror image' to generate fully symmetrical body curves. These symmetrical curves were used in the subsequent steps of the process.

For sleeves, during the processing of the scan data to form a triangulated surface mesh, the arms became merged with the upper body part of the model as can be seen in Figure 3. To address this problem, the upper arm girths had to be separated from the larger central section from which the modified chest girth at armpit level was drawn. This procedure is illustrated in Figure 5.

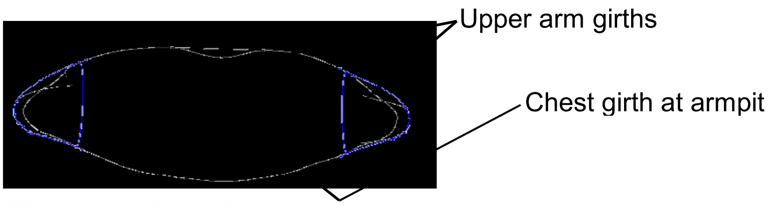

Figure 5: Drawing upper arm girth

Small sections from the furthest ends of both sides of the shoulder girth curve were separated as two closed curves to define the upper part of each arm/sleeve, hereafter mentioned as 'Tip of Sleeve'. Modified closed curves for the arm girths at the lower chest level, the forearm girth and the wrist girths were drawn following a similar technique as was used to create the body curves shown in Figure 4. In order to ensure symmetry of the proposed 3D design platform, the arm curves from one side were copied and used in 'mirror image' to build the other side, hence creating symmetrical curves for the right and left sleeves.

iv) Programming for 3D Grading: The scaling process involved selecting anchor points for each of the curves from which they would enlarge or diminish themselves; it also required the incorporation into the software of a scaling factor, so that the programme would be able to determine the extent of the enlargement and diminution of each curve during grading. The middle point of the lines joining the front and back part of each curve were selected as scaling points for all the body girth curves. Similar scaling points were used for the arm girths at the lower chest level, the forearm girth and the wrist girths. In next step, the lengths of the closed curves were first set as parameters in order to scale them. A scaling factor of A'/A, where:

A' = the value of a desired size of girth curve; and
A = the existing circumferential value of that girth curve;

was formulated as a parameter for each of the curves in the set. The value of the desired size for each curve equates to the size measurement for a particular type of clothing. All curves except the hip curve and wrist curve were scaled on the horizontal plane. The hip curve required to be scaled in horizontal plane to ensure the change in girth measurement and also in vertical plane to ensure the change in shirt length as described in Sayem et al. (2014). This required top include shirt length as an additional parameter. Similarly, the wrist curve was scale din horizontal plane and vertical plane taking sleeve length as an additional parameter.

At the end of the scaling process, using the appropriate “Excel Link” command from within the DCTT software, an option for importing given values from an external database was programmed for all scaled curves except the *lower neck girth*, the *lower shoulder girth*, the *upper chest girth* and the curves representing the upper tips of the sleeves, to facilitate 3D grading. For these four curves the following relationships, which are calculated based on the size ratio of the modified curves achieved, had been programmed:

Lower neck girth = 1.65 x Neck girth;
Lower shoulder girth = 1.2 x Shoulder girth;
Upper chest girth = 0.99 x Chest girth at armpit level;
Tip of sleeve = Shoulder girth / 21.2.

Hence, these four curves will follow these pre-determined relationships in every case of resizing the “3D design platform”. Finally, the target 3D template was scaled with 12 size parameters, namely, neck girth, shoulder girt, chest girth at armpit, chest girth at the fullest area, waist girth, hip girth, upper arm girth, arm girth on bicep, forearm girth, wrist girth, shirt length and sleeve length. Appropriate size data based from shirt sizes 37, 38, 39, 40, 41, 42, 43, 44 and 45 were developed in excel sheets for the purpose of automatic grading.

v) Generation of 3D Template as Drawing Platform: A new surface was developed by combining all the scaled curves, employing the *“curve to curve”* matching and *parametric synchronisation* options within the 3D modelling function of the DCTT software, as illustrated in Figure 6. The newly-generated surfaces for the body and sleeves form the desired “3D design platform” on which the virtual cloth will be created, and on which 3D grading may be performed.

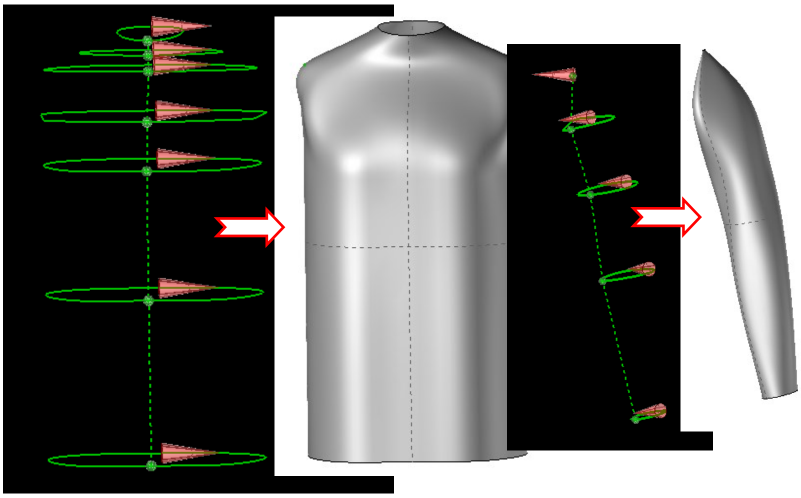

Figure 6 New Surface Generation out of Scaled Body and Sleeve Curves

B) Testing the 3D Shirt Temple

Once the 3D template was ready, its functionality was tested by drawing shirt outlines and by generating virtual shirt by using the relevant mesh generation tools. Once a drawing has been completed, an area of triangulated mesh is created on the template using the *"create region"* tool within the DCTT software, as may be seen in Figure 7. Similarly, it was tested with different shirt and jacket designs. The resizability of the shirt template was checked by varying the values of different size parameters individually and collectively using external size charts. The changes in the size and position of the scaled curves and the corresponding shape of the body and sleeves were observed. Variable combinations of technical parameters namely link-length and vertex angle were tried during clothing design to examine their effects of mesh generation and pattern flattening.

Using the flattening tool provided by the software used, the front part, back part and the sleeves for size 38 were flattened into 2D pattern pieces as may be seen in Figure 8. A 1 cm seam allowance was added to the pattern pieces before printing them. A physical prototype of an easy-fitting tee-shirt was prepared using 100% cotton single jersey knit fabric of 180 g/m^2 based on the printed pattern pieces.

RESULTS

i) Virtual Clothing Generation

It was found that the newly-created design platform can function as a 3D drawing board which allows sketching and development of virtual clothing on its surface. As the template is a model of the upper body surface to which operational levels of ease have been appended, drawing on the template effectively defines the 3D outlines of an appropriately sized garment. Tee-shirts with regular and raglan sleeves could have been designed on it with no problem. For dress shirts, standard straight collar and 2-pieces collar could easily be designed on this. Even it was found possible to design suit Jacket on it. However, it is not possible to develop a one-piece shirt collar on the shirt template, as any overlapping surface cannot be flattened into a single 2D component using the existing flattening tools.

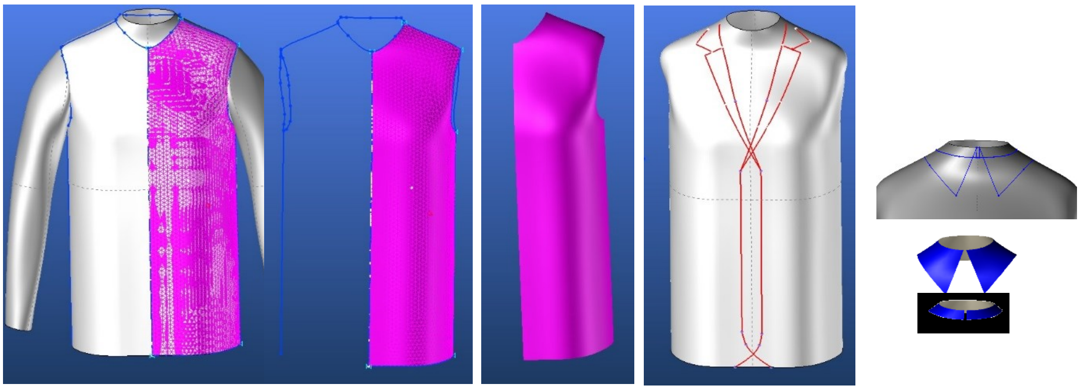

Figure 7 Examples of Different Designs developed on the 3D Shirt Template

However, as the sleeves were created as separate parts of the 3D shirt template, a design limitation was found prevailing in it. For example, the raglan sleeve design could still be visualised on the shirt template but could not be flattened as a single pattern piece as can be seen in Figure 9. A modified shirt template with sleeves merged with body parts may be developed to address this problem. If the sleeves can be seamlessly merged with the body of the shirt template, it will not be a problem to develop a raglan sleeve on it and subsequently flatten it into 2D.

ii) Grading in 3D

The virtual garments using this technology are found resizable, by incorporating values from the appropriate size databases developed previously. Hence, this facility provides an opportunity for successfully executing 3D grading. After drawing the virtual shirt, the garment may also have its size varied by changing the size of the design platform. It has been found that size parameters can be changed individually or in group. The process requires to design a virtual garment only once on the platform and then conversion from one size to another is carried out through simple excel-linking of pre-developed size database.

iii) Pattern Flattening and Physical Prototype

Using a flattening tool, it is possible to extract flat pattern pieces from the virtual clothing designed on the shirt template. When a half of the front shirt panel was flattened into 2D, it was found that the centre front line was curved inside the chest area as can be seen in the Figure 8. However, this problem can easily be overcome by flattening a complete front panel and then dividing it into 2D halves using 2D cut tool. The physical prototype made based on the flattened pattern pieces also exhibited acceptable fit when tried by live model.

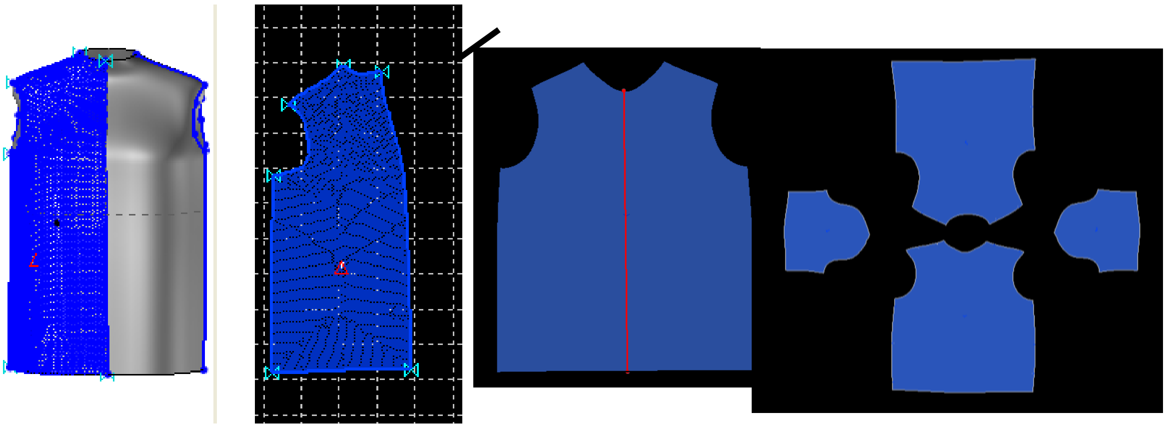

Figure 8 2D Design and Flattened Pattern Pieces

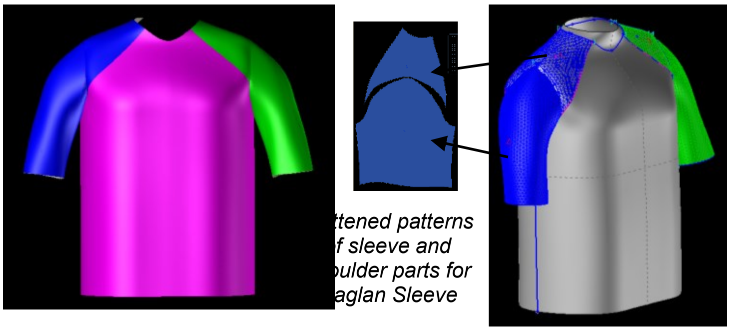

Figure 9 Visualisation of Raglan Sleeve and Flattened Patterns

iv) Effect of Technical Parameters

It has been found that link-length significantly affected the meshing quality and time. The bigger the link-length selected for a mesh structure, the smaller the mesh surface area and the higher the meshing and flattening speeds. However, a commensurate deterioration in the quality of the pattern pieces is also experienced. Any link-length below 5 mm is technically not feasible for computers offering conventional level of processing capability. The optimum link-length has been found to be between 10 mm and 15 mm. It has also been found that the vertex angle does not influence the surface quality of the generated mesh, but affect the segmentation around the boundary line. For clothing pattern generation, a vertex angle between 120° and 160° was found useful.

v) Combining Fashion Illustration and Pattern Creation

Within the environment of 3D CAD system in use, it is possible to render a virtual shirt developed on this design platform with different graphical surfaces, as is shown in Figure 10. This facilitates fashion illustration in a 3D format. As 2D pattern pieces can be extracted directly from virtual clothing by utilising the flattening mechanism, no additional effort in respect of pattern drafting is necessary. However, it has been found that multi-layer fabrics could not be visualised properly using the existing capability of the CAD system used in this work.

Figure 10 Physical Prototype and Illustrations

CONCLUSIONS

A technique for applying digital reverse engineering to derive flat pattern pieces for men's upper body outerwear based on a resizable 3D design platform had been demonstrated within the extent of this research work. The resizable 3D platform, which can work as a 3D drawing board for designers, was developed using a set of body-scanned data and by following a novel technique within an available 3D CAD system. This platform has been scaled with twelve size parameters and may thus be converted from one size to another using the size databases developed to facilitate the 3D grading. Using the resizable design platform, it was found possible to combine the fashion design and pattern creation into a single step. The virtual clothing drawn on it changed its size with the size change of the design platform, which ensures automatic 3D grading. Integrating such a resizable design platform into 3D CAD systems will have significant implications for the fashion industries.

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