

**3D Grading and Pattern Unwrapping Technique for Loose-fitting Shirt  
Part 1: Resizable Design Template**

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**ABSTRACT**

*This paper describes the Reverse Engineering (RE) and 3D modelling techniques used to develop a novel resizable design platform for use in virtual design; pattern flattening and automatic grading of men's upper-body outerwear. Advanced body scanning technology and RE technique are applied to extract a set of sectional curves. The extracted curves are further processed in a CAD software program and used for new surface generation by applying a 3D modelling technique to form a resizable design platform, which is intended to be used as a 3D drawing board for the creation of virtual shirts and for the execution of 3D grading and automatic pattern flattening. As far as can be ascertained, such a resizable design platform for combined virtual design, automatic pattern creation and 3D grading of men's shirt has not been previously demonstrated.*

*Keywords: Virtual shirt; resizable template; pattern flattening; 3D grading*

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**Introduction**

An emerging technique for clothing pattern creation is that of "3D to 2D pattern unwrapping" which means the automatic generation of 2D patterns by unwrapping or flattening the 3D design. Notable research has been carried out in this field in the last

decade (McCartney et al., 2000; Kim & Kang, 2002; Wang, Smith & Yuen, 2002; Wang, Wang & Yuen, 2002; Sayem, 2004; Petrak & Rogale, 2006; Petrak, Rogale & Mandekic-Botteri, 2006; Decaudin et al., 2006; Kim and Petrak, 2007; Fang & Ding, 2008; Fang, Ding & Huang, 2008 and Roedel, 2008). However this technology is

not equally advanced and sufficiently mature for both intimate wear and outerwear to be implemented in the industry at this point of time (Sayem, Kennon & Clarke, 2010 and 2012). A few clothing CAD systems such as *3D Interactive software* from TPC (Hong Kong) and *3D Runway* from OptiTex International (Israel) provide the capability to execute pattern unwrapping, but in a very limited context and only for close-fitting garments. No efficient solution is available for outerwear, which encompasses the major portion of clothing consumption worldwide. For example, it was 88% of total clothing consumption in the 27 member states of the European Union in 2007 and worth of € 260 billion (CBI, 2008).

Attempts to design virtual outerwear for the purposes of pattern flattening were made by Hinds and McCartney (2000), McCartney et al. (2000), Wang, Wang and Yuen (2002), Petrak and Rogale (2006), Petrak, Rogale and Mandekic-Botteri (2006), Kim and Park (2007), Yunchu and Weiyun (2007) and Siegmund et al. (2010). All of their works followed laborious routes to incorporate variable ease at different places between the virtual body and the garment panels for outerwear. None of their techniques consider ease distribution over the girth measurements as practically followed in the fashion industry during pattern creation for outerwear.

This paper presents a technique for developing a resizable design template that uses traditional size charts including ease distribution over the girth measurements for the purposes of 3D grading and pattern flattening of loose-fitting shirt.

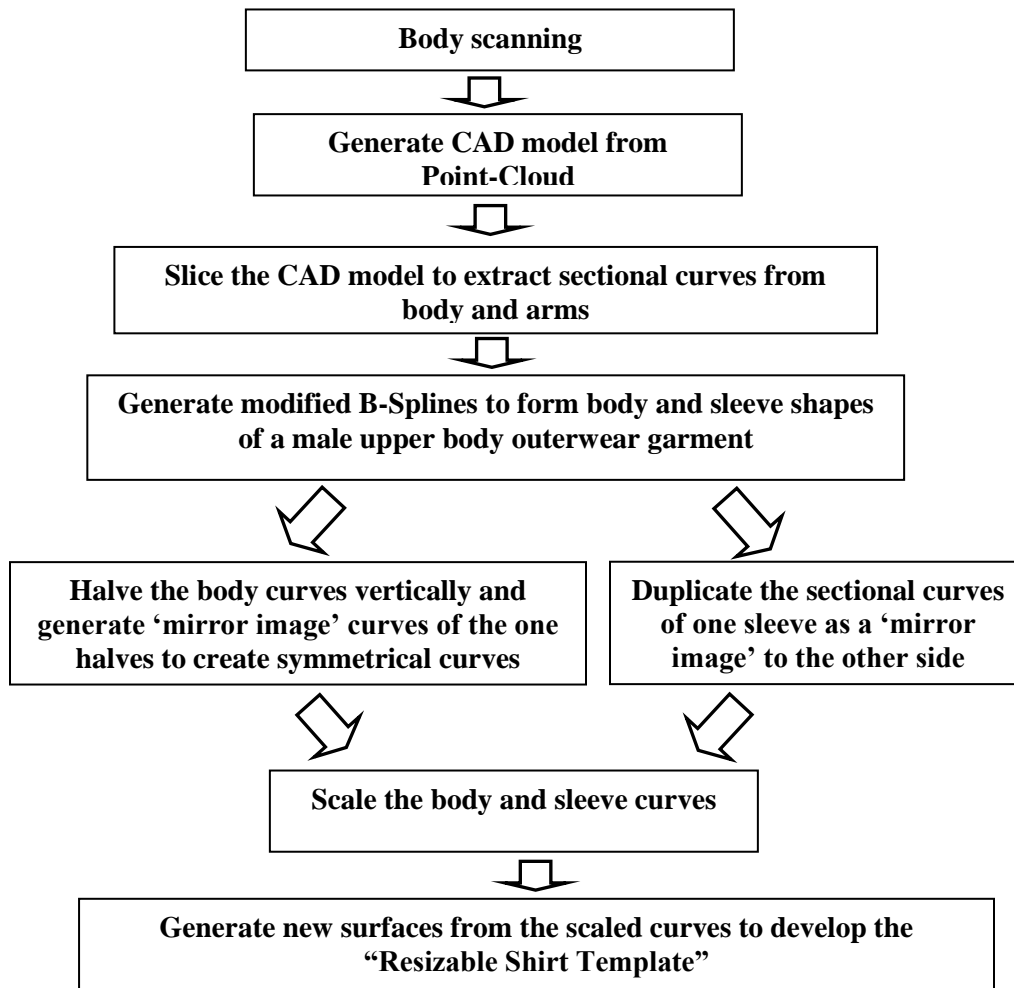
## Methodology

The proposed resizable design template was intended to be structured around a set of sectional curves, which are representative of the size parameters. These sectional curves are extracted from a virtual model constructed from a set of Point-Cloud data captured from a full-body scan of a mature male subject using NX16 body scanning system from [TC<sup>2</sup>] (Textile/Clothing Technology Corporation), USA. The process followed to develop a resizable shirt template is summarized in Figure 1 and explained in the following sections.

### *CAD Model from Point-Cloud*

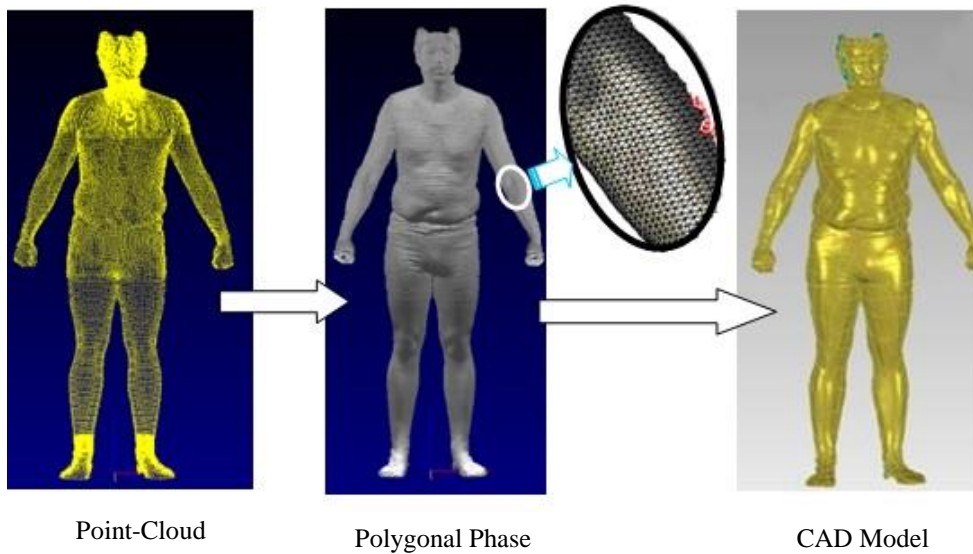
The raw scan data processed by the NX16 analytical software as a refined body model in “.rbd” file format was converted into a triangulated body model in “.obj” data format having approximately 110,000 triangles before importing into a reverse engineering (RE) software. Using an appropriate RE software, the triangulated body model was converted into a CAD model (Figure 2) having approximately 400,000 mesh triangles and this model was further used for extracting the sectional curves from it.

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**Figure 1. Workflow for Resizable Shirt Template**

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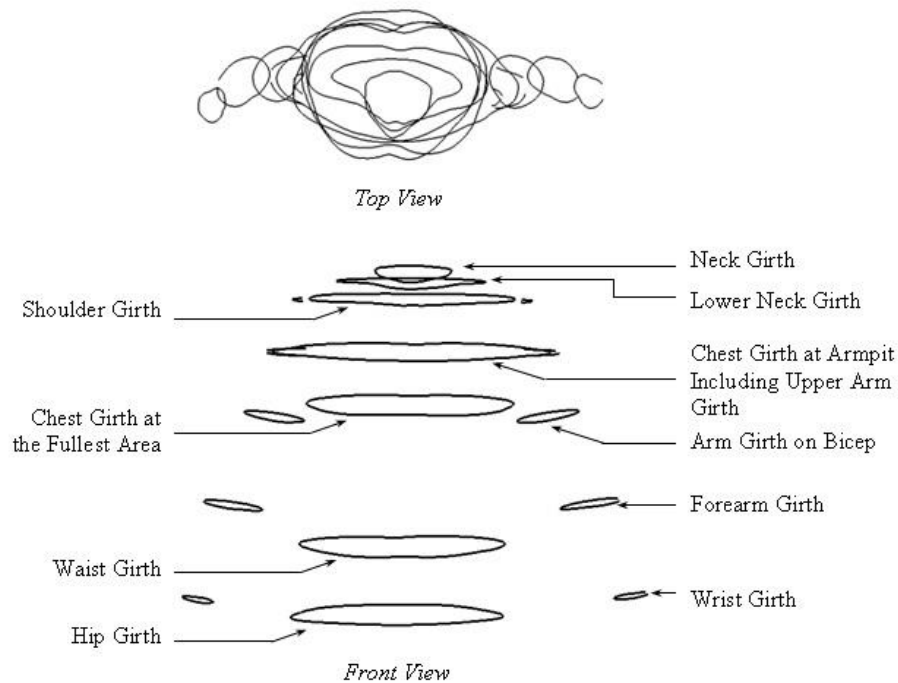
**Figure 2. Virtual Model of a Male Subject**

**Sectional Curve Extraction**

**i) Curves from torso**

Seven sectional curves namely neck girth, lower neck girth, shoulder girth, chest girt at armpit, chest girth at the fullest area, waist girth and hip girth were extracted from the

torso, as can be seen in Figure 3. The European Standard for size designation of clothes “EN 13402-1:2001” was consulted to identify the landmark positions of the four primary sectional curves representative of the neck girth, chest girth, waist girth and hip girth.



**Figure 3. The Extracted Sectional Curves**

The measurements of waist girth and hip girth are not directly used in the traditional pattern cutting system for men's shirts (Aldrich 1990). However, the position of the waist line is important for shaping and tailoring the middle part of the body of shirts and jackets (Aldrich 1990). The waist girth curve was selected in this work with the aim of maintaining an option to produce a tailored silhouette of men's shirts on the proposed design template; and the hip girth curve was selected as its lower end contour.

In addition to the four primary sectional curves, three secondary curves (two for the "neck to shoulder" area and one 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. As a result, no available standard describes their positions on the torso. For rebuilding the "neck to shoulder" area, two secondary girth curves, namely the lower neck girth and the shoulder girth were incorporated. The shoulder girth curve was located at approximately 1 cm below the crown of the shoulder on either side of the torso. The lower neck girth is designated as being 3 cm above the shoulder girth. To rebuild the geometry of the chest area, a second girth measurement at the fullest chest area was selected.

#### *ii) Curves from arm*

In order to develop the sleeves of the proposed 3D template, four curves, namely: the upper arm girth, the arm girth on bicep, 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 (Aldrich, 1990). The other measurements do not correspond to easily-defined anatomical landmarks; they do not lend themselves to repeatable manual measurement. Consequently, no size standard describes the

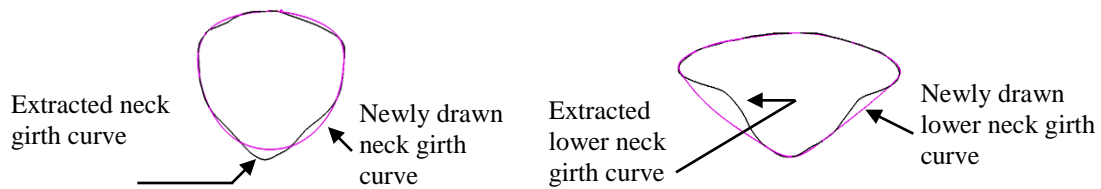
position of the arm girth measurements. However, with the availability of body scan data, it is possible to specify and take advantage of non-standard anatomical measurements, as they can offer useful secondary measurements. The forearm girth was located on the fullest area below the elbow, and the upper arm girth on bicep was located at approximately 5 cm above the elbow joint. Later, an additional curve, termed here as "curve TS", was extracted from the shoulder curve to define the upper edge of the each sleeve, as can be seen in the Figure 5.

#### *Modified Curves Generation*

The sectional curves, which are stored as an IGES data format, were imported into an advanced 3D CAD software package. 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, they were found to be broken in some places due to limitations of the scanning and modelling processes. Using the curve drawing tool of the CAD system, continuous B-spline curves were generated from each of the sectional curves by removing the irregularities in the extracted curves such as concave areas due to the natural geometry of the human body (for example the spinal cord line at the back of the torso) and by taking the geometry of men's upper body outerwear into account.

While drawing the modified neck girth, the protruding parts at the front due to the laryngeal prominence were avoided as well as the concave segments both at the front and back which were smoothed out. The lateral concave segments of the lower neck girth curve were also smoothed out in the newly drawn modified curve. These modified curves are illustrated in Figure 4. Similarly modified curves for the chest girth at the fullest area, waist girth and hip girth are drawn.

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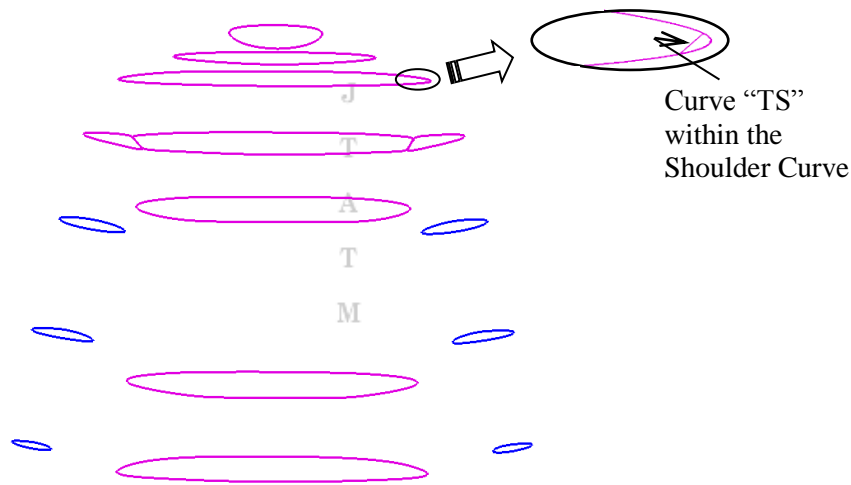
**Figure 4. Modified Neck Girth and Lower Neck Girth Curves Generation**

***Symmetrical Curves Generation***

The human body is not a symmetrical object, so the curves that are derived from it inevitably lack symmetry. Even the newly drawn modified curves inherit visible asymmetry from their parent curves. However, mass-produced clothing is expected to have a symmetrical structure if intentional asymmetry has not deliberately 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, and one set of halves (the left halves) are mirror-duplicated

to the right side, and each of the left halves were joined with its respective mirrored curves to form completely closed and continuous curves. This generates fully symmetrical body curves (see Figure 5). These symmetrical curves were further used in the subsequent steps of the process.

In order to ensure the symmetry of the proposed 3D design template, the modified sleeve curves from the left side are mirrored to build the respective curves for the other side, hence creating symmetrical curves for the right and left sleeves (Figure 5).



**Figure 5. Symmetrical Body and Sleeve Curves**

***Waist and Hip Curves Selection***

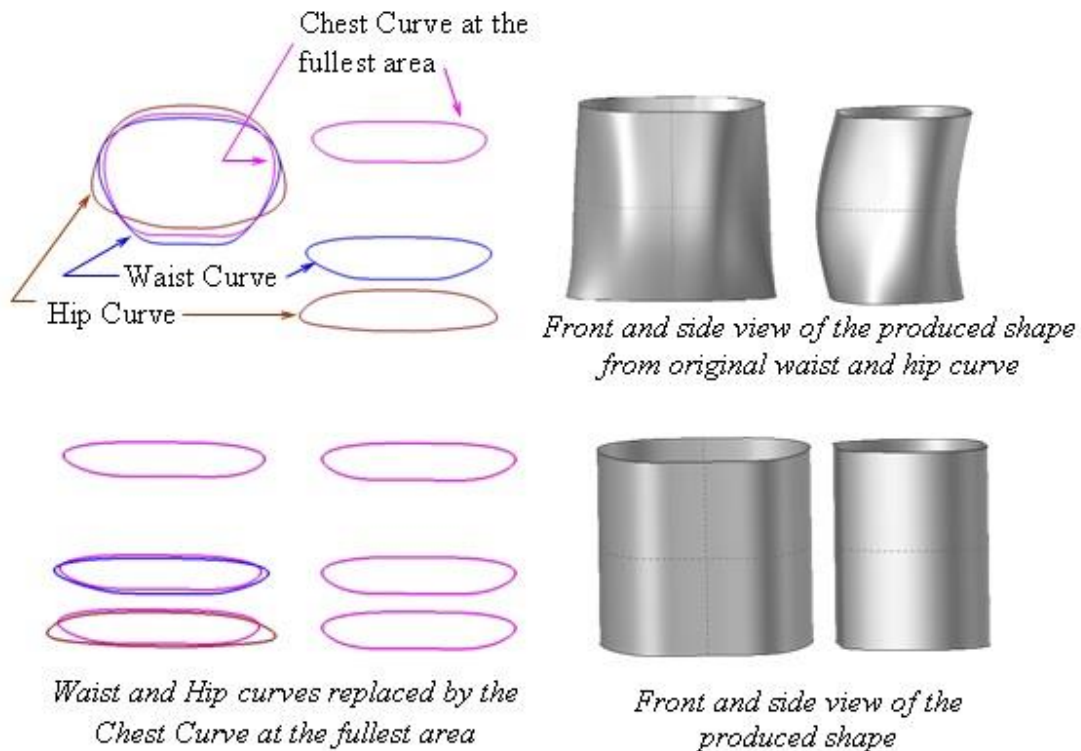
Before scaling the curves to ensure the resizeability of the proposed shirt template, these symmetrical curves were first tested by

generating a surface out of them. The surface generation process is further discussed in a later section. The qualitative ability of the body curves to form appropriate geometry of a men’s shirt is

dealt here. A close review of the curves representing the chest girth at the fullest area, waist girth and hip girth; reveals significant differences in their shape and depth. They do not produce a good body shape to represent as a standard shirt geometry, as can be seen in Figure 6. The resultant shape from these three curves has a

convex outline at the front and a concave outline at the back, when seen from the sides. To address this problem, the waist curve and hip curve were replaced by duplicated copies of the chest curve. Because they utilize the same curve geometry, they form a uniform body shape as can be seen in Figure 6.

**Figure 6. Curve Replacement and the produced Shape**



For the scaling and final surface generation processes, the duplicated copies of the chest curve were used instead of the waist and hip curves and they will be hereafter described as waist and hip curves due to the locations in which they are used.

### **The Scaling Process**

The scaling process forms the basis of automatic 3D grading for the parametric 3D shirt template which can be used for the creation of a virtual shirt and for the extraction of 2D pattern pieces using a flattening technique. The scaling procedure

involves the creation of two length parameters for each curve, selection of a scaling point for each curve and inputting one or more scaling factors for each curve. As a part of the scaling process, all of the modified and symmetrical body and sleeve curves are first defined as length parameters. Similarly, for each of the curves, an additional parameter is defined to facilitate the acceptance of external values from a size table for the purpose of resizing or grading. Designations of the length parameters are summarized in Tables 1 and 2. To make the scaling process functional it is necessary to link the set of second length parameters with

external size databases for importation of necessary values whenever required.

**Table 1 List of Parameters and Scaling Factors for Body Curves**

	Names of The Curves	Parameter Designation for Existing Length (A)	Parameter Designation for External Values from Size Table (A')	Scaling Factor (A'/A)
1	Neck Girth	Ng	Ng_ST	Ng_ST/Ng
2	Lower Neck Girth	LNg	LNg_ST	LNg_ST/LNg
3	Shoulder Girth	Sg	Sg_ST	Sg_ST/Sg
4	Chest Girth at Armpit	Cg_ap	Cg_ap_ST	Cg_ap_ST/Cg_ap
5	Chest Girth at the Fullest Area	Cg	Cg_ST	Cg_ST/Cg
6	Waist Girth	Wg	Wg_ST	Wg_ST/Wg
7	Hip Girth	Hg	Hg_ST	Hg_ST/Hg
8	Centre Length (Shirt Length)	CL	CL_ST	CL_ST/CL

**Table 2 Lists of Parameters and Scaling Factors for Sleeve Curves**

	Names of The Curves	Parameter Designation for Existing Length (A)	Parameter Designation for External Values from Size Table (A')	Scaling Factor (A'/A)
1	Curve "TS"	Ts	Ts_ST	Ts_ST /Ts
2	Upper Arm Girth	UAg	UAg_ST	UAg_ST /UAg
3	Arm Girth at Bicep	Ag_b	Ag_b_ST	Ag_b_ST /Ag_b
4	Forearm Girth	Fag	FAg_ST	FAg_ST /Fag
5	Wrist Girth	Wrg	Wrg_ST	Wrg_ST /Wrg
6	Sleeve Length	SL	SL_ST	SL_ST/SL

The scaling factors for each of the curves are defined as A'/A as can be seen in Tables 1 and 2, where:

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

A = the existing circumferential value of that girth curve.

The value of the desired size for each curve equates to the size measurement for a particular type of clothing.

The subsequent step involves selecting scaling points for each of the curves from which they enlarge or diminish themselves; it was also necessary to incorporate into the software a scaling factor, so that the program would be able to determine the extent of the enlargement and diminution of each curve during resizing and grading. To implement this process within the CAD system in use, the scaling options include



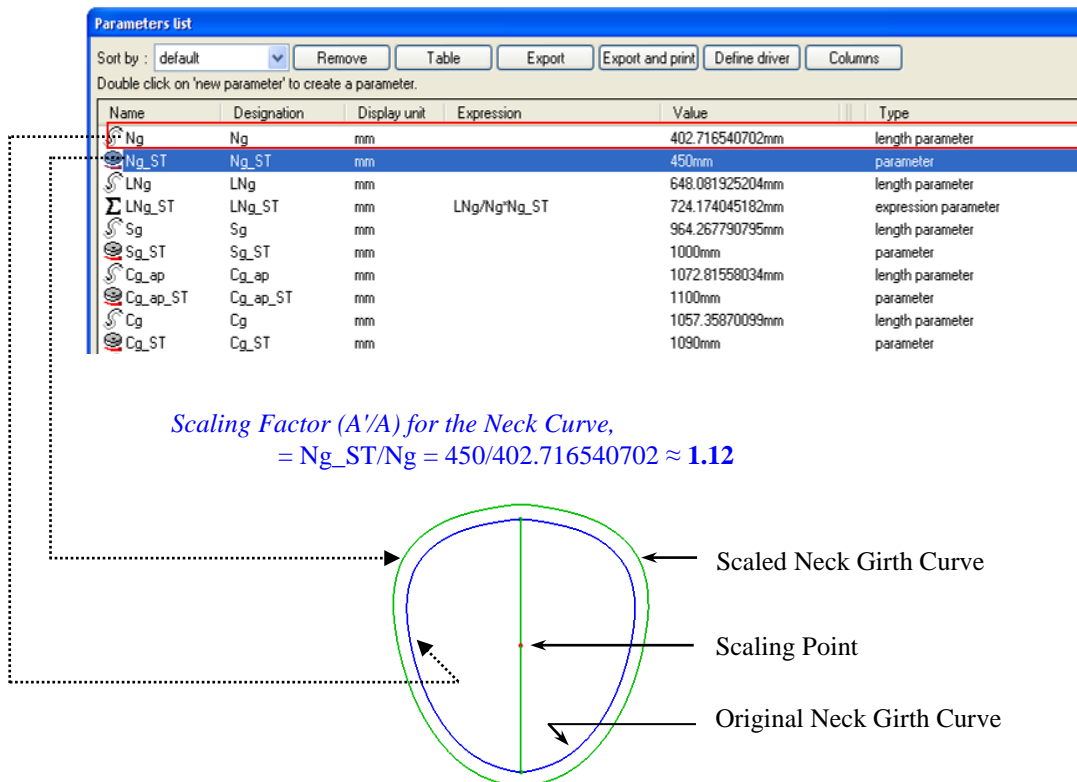
“scaling from point” and/or “scaling with three factors”.

**i) Scaling the Body Curves**

For the purpose of scaling, the body curves were divided into two groups: a) shirt length-independent curves (neck, lower neck, shoulder, chest and waist curves), and b) length-dependent curves (hip curve). As clothing size tables are developed within the standard height groups (Aldrich 1990), it is assumed that the neck, lower neck, shoulder, chest and waist curves, which are not dependent on the shirt length, require scaling only in the horizontal plane. However, for the hip curve, it is also necessary to scale in the vertical plane to ensure that the change in shirt length is executed as per designers’ and customers’ requirements.

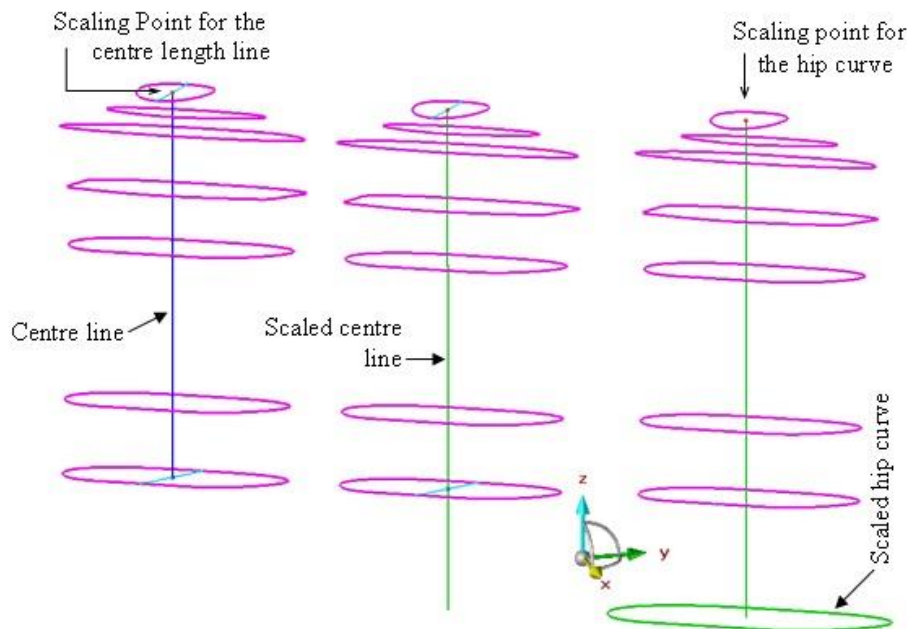
The middle point of the lines joining the front and back part of each curve, as can be seen in Figure 7, were selected as scaling points for all the body girth curves except the hip curve. Designations of two

parameters for each of the body curves are listed in Table 1. The body curves, with the exception of the hip curve, are scaled only in the horizontal plane (i.e.  $\pm X$  and  $\pm Y$  axis) with a single factor for each of the curves. For the neck curve, for example, Ng represents its original length which was 402.72 mm; and Ng\_ST represents the value for resizing it, which would be input through an Excel size table. If the value of Ng\_ST was 450mm, for example, the scaling factor (A'/A) would be 450/402.72 (=1.12). Using the appropriate scaling tool from the 3D CAD system in use, the neck curve would be scaled from the pre-determined point, shown in Figure 7, with a factor of Ng\_ST/Ng, which was in this case 1.12. However, the value of the scaling factor is variable depending on the value of Ng\_ST from the size tables. Similarly all of the body curves except the hip curve are scaled with their respective factors as expressed in Table 1.



The hip curve defines the lower end contour of the proposed shirt template. As the length of the men's shirt can vary with the size change or within the same size depending on the design, the position of the scaled hip curve should vary in the vertical plane (i.e. according to the change in shirt length). In order to relate the hip curve with the shirt length, the shirt length is first defined as a

vertical line from the center of the neck to the hip curve, as shown in Figure 8, and scaled with a factor ( $A'/A$ ) of  $CL\_ST/CL$  as described in Table 1. The hip curve is then scaled from the upper end point of the scaled center length line as shown in Figure 8 and with the factor  $CL\_ST/CL$  for the  $\pm Z$  direction and with the factor  $Hg\_ST/Hg$  for the  $\pm X$  and  $\pm Y$  directions.



**Figure 8. Scaling the Hip Curve**

The lower neck curve is essentially used to reproduce the “neck to shoulder” geometry appropriately. However, this is not a standard measurement location from the clothing manufacturing point of view. To reduce the number of parameters in the size table, this girth measurement is not considered as a direct size parameter for the proposed shirt template. Rather it is linked to the neck girth using the following expression:

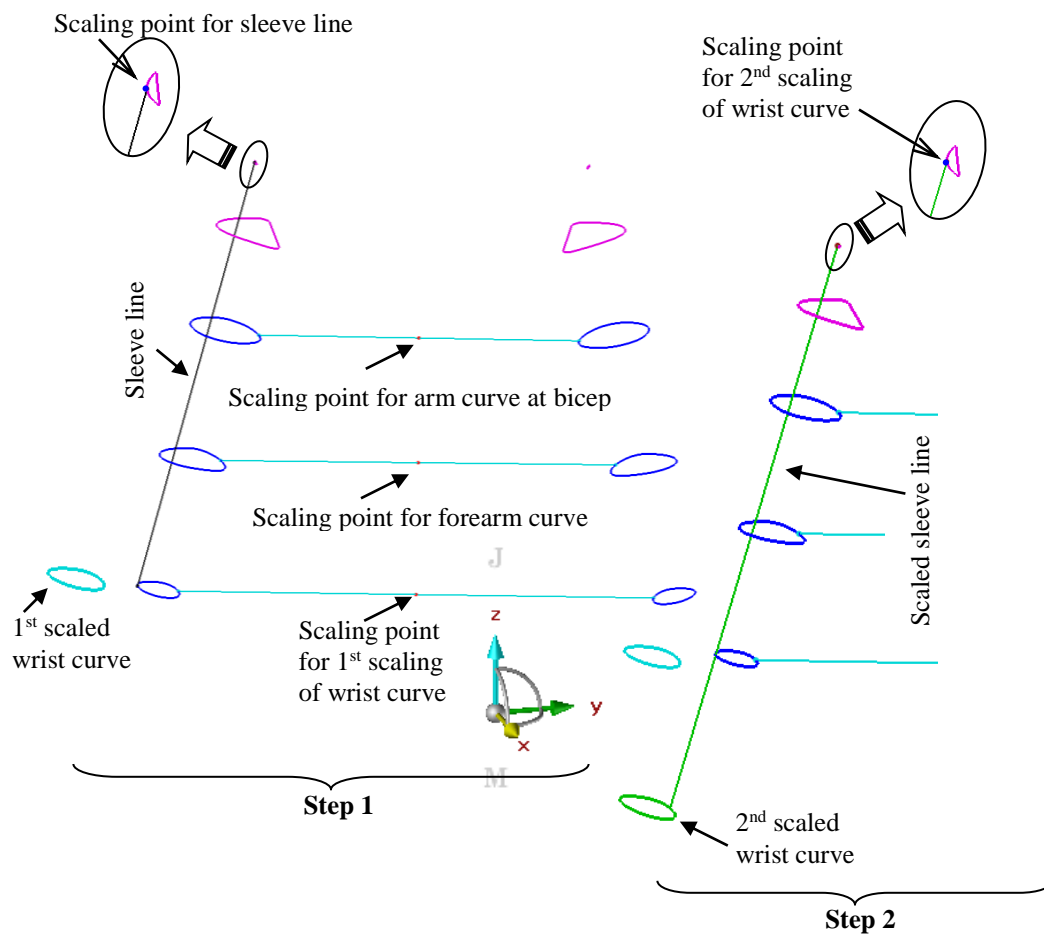
$$LNg\_ST = Ng\_ST \times LNg/Ng$$

So the system will calculate the value of  $LNg\_ST$  (the value of the lower neck girth used for resizing the template) based on the value of  $Ng\_ST$  (the value of the neck girth from the size table) as a factor of  $LNg/Ng$  (the ratio of the original length of the lower neck girth to the original length of the neck girth). As a result the size change of the lower neck girth will always be dependent on the size change of the neck girth.

**ii) Scaling the Sleeve Curves**

Similarly to the body curves, the sleeves curves are also divided into two categories, denoted as: a) sleeve length-independent curves (curve “TS”, upper arm, arm girth at bicep, forearm curve); and b) sleeve length-dependent curves (the wrist curve). Designations of two parameters for each of the sleeve curves are listed in Table 2. For the upper arm curve and for the curve “TS” representing the upper edge of the sleeve, the middle points of the halving lines joining

the front and back parts of the chest girth at the armpit level and the shoulder girth curves respectively. The curve “TS” and the upper arm curve were scaled on the horizontal plane based on the factors described in Table 2. Similarly, the curves representing arm girth at the bicep and the forearm girth were scaled on the horizontal plane, but the scaling points were taken as the middle points of the lines joining the curves from the left and right sleeves, as can be seen in Figure 9.



**Figure 9 Scaling of the Wrist Girth Curve**

To ensure that the change in sleeve length corresponds with the change in clothing size or design, the wrist curve was scaled along both the horizontal and vertical planes. The procedure was completed in two steps, which are illustrated in Figure 9. Initially,

the wrist curve was scaled in the horizontal plane from the middle point of the line joining the left and right wrist curves. The newly scaled wrist curve was scaled again in the vertical plane, based on using the end point of the scaled sleeve line as a scaling

point, as can be seen at the left side of Figure 9. The twice-scaled wrist curve (the second scaled in Figure 9 was finally used in the surface generation process described in the next section. As a result, the scaled wrist curve changes its size based on the change of its value in the size table and also changes its position based on the change in sleeve length in the size table.

Similarly to the creation of the lower neck curve described in previous section, the curve “TS” does not represent a standard measurement location from the clothing manufacturing point of view. To reduce the number of parameters in the size table, it is linked to the shoulder girth using the following expression:

$$Ts\_ST = Ts/Sg \times Sg\_ST$$

So the system will calculate the value of Ts\_ST based on the values of the parameters Ts, Sg and Sg\_ST, where the value of Sg\_ST will be input from size tables and the values of Ts and Sg are presented to the system as length parameters.

### ***Developing Size Databases for 3D Grading***

A database of sizes from 37 to 45 for men’s shirts has been developed using the MS Excel spreadsheet program, as detailed in Table 3. The values for neck girth, chest girths, waist girth, hip girth and wrist girth were taken from the standard body measurements for mature figures of standard males described by Aldrich (1990) in the second edition of the book “Metric Pattern Cutting for Menswear”. The values for the shoulder girth, upper arm girth, arm girth at the bicep and forearm girth are not available in any traditional size tables. For the shoulder girth, upper arm girth, arm girth at the bicep and forearm girth, the measurements extracted from the scan data, which have been used throughout this work, were selected for use in the size table as the measurement for size 42, because the

subject from which the scan data were generated and from which the subsequent body model was developed, had a chest measurement and a waist measurement close to that described by Aldrich (1990) for this size.

The size table was split into sub-databases for individual sizes with appropriate ease allowances. A minimum functional ease of 7.5 cm for the chest area was selected following the findings of Moll and Wright (1972) and a design ease of 8.5 cm was selected to make a total ease of 16 cm which corresponds to the suggested ease around the chest (without a seam allowance) for easy-fitting men’s tee shirts and knitwear, by Aldrich (1990).

When creating a straight side-seam silhouette for a man’s shirt, sufficient ease allowances for the waist girth and hip girth were selected to keep the final measurements equal across the chest area. Although no circumferential expansion takes place in the arms as it does for the chest and waist areas due to the breathing mechanism, sufficient functional ease is required in the sleeves to allow for unhampered arm movement. The size parameters with ease allowances for size 42 are included in Table 4. The same ease allowances have been included for other sizes, namely 37, 38, 39, 40, 41, 43, 44 and 45 for this work. However, it has to be noted that the size databases and values of ease for each measurement point may be altered in the databases to meet the designers’ and customers’ requirements. Once all the size tables with ease allowances had been prepared in Excel spreadsheets, they were programmed, by assigning parameter designations to the corresponding cells containing size parameters, to be linked with the 3D grading process using the “Excel link” facility within the 3D CAD software suite used in this research so that they can be imported, as required, to support automatic grading.

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**Table 3 Size Table for Men's Tee-Shirt**

	Size Parameter	Measurements for Men's Shirts (without ease) in cm (neck size as size designation)								
		37	38	39	40	41	42	43	44	45
1	Neck Girth	37	38	39	40	41	42	43	44	45
2	Shoulder Girth	87	89	91	93	95	97	99	101	103
3	Chest girth at armpit	88	92	96	100	104	108	112	116	120
4	Chest girth at the fullest area	88	92	96	100	104	108	112	116	120
5	Waist girth	74	78	82	86	90	98	102	106	110
6	Hip girth	92	96	100	104	108	114	118	122	126
7	Upper arm girth	30	31	32	33	34	35	36	37	38
8	Arm girth on bicep	29.5	30.5	31.5	32.5	33.5	34.5	35.5	36.5	37.5
9	Forearm girth	27	28	29	30	31	32	33	34	35
10	Wrist girth	22	22.5	22.5	23	23	23.5	23.5	24	24
11	Shirt Length	76	78	80	81	81	82	82	82	82
12	Long Sleeve Length	87	88	88	89	89	90	90	90	90

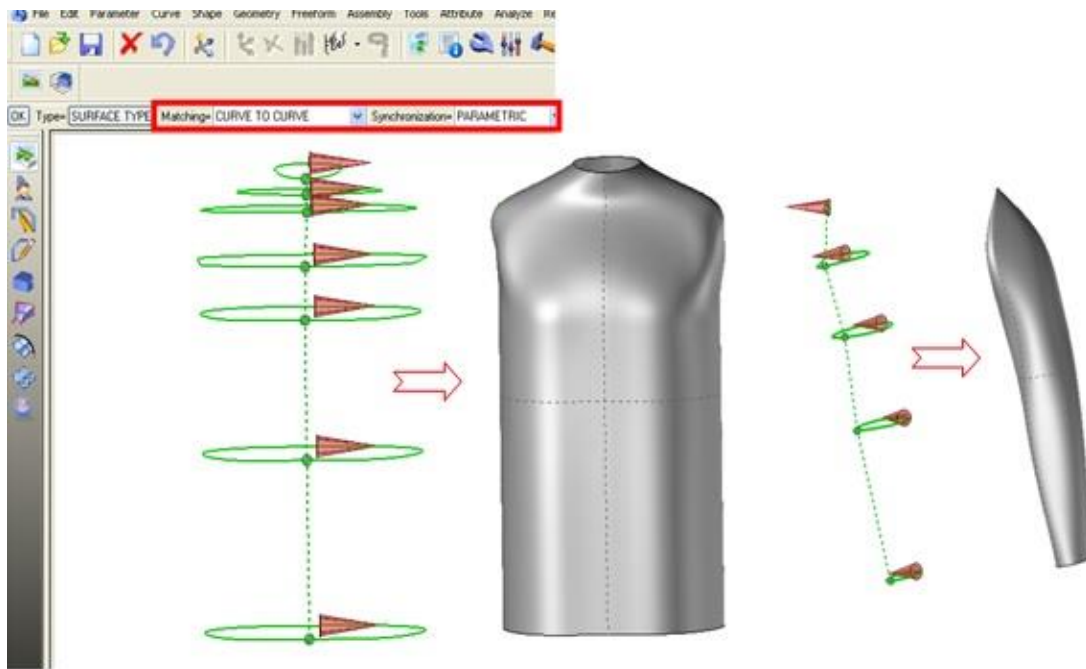
**Table 4 Size Parameters with Ease Allowance for Size 42**

Size Parameter	Measurement without ease (cm)	Functional Ease (cm)	Design Ease (cm)	Clothing measurement (cm)
Neck Girth	42	0	0	42
Shoulder Girth	97	0	1	98
Chest girth at armpit	108	7.5	8.5	124
Chest girth at the fullest area	108	7.5	8.5	124
Waist girth	98	7.5	18.5	124
Hip girth	114	0	10	124
Upper arm girth	34	T	0	41
Arm girth on bicep	33	A	0	39.5
Forearm girth	30.5	T	0	35
Wrist girth	23.5	T	0	25.5
Shirt Length	82	M	-	82
Long Sleeve Length	90	-	-	90

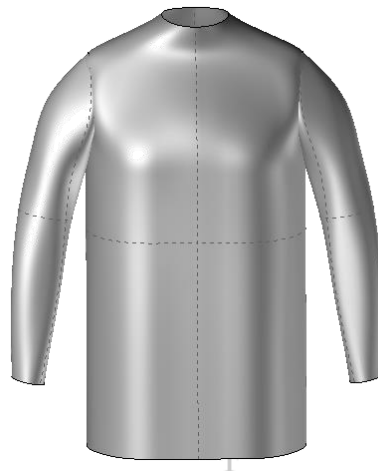
**Surface Generation to form the 3D Shirt Template**

Once all the body and sleeve curves have been scaled, a geometric modelling technique was applied to generate a new surface out of them, employing the *curve matching* and *parametric synchronization* options available within the 3D modelling

function of the 3D CAD software in use, as illustrated in Figure 10. The newly-generated surfaces for the body and sleeves form the desired shirt template as 3D design platform for virtual clothing creation, pattern flattening and automatic grading in 3D as can be seen in the Figure 11.



**Figure 10. New Surface Generation out of Scaled Body and Sleeve Curves**



**Figure 11. The Resizable Shirt Template**

### Conclusions

In this part of the research, a process of developing a 3D shirt template by applying reverse engineering and geometric modelling techniques, and a novel scaling process to make it ready for use in 3D grading have been demonstrated. Its application in virtual design and automatic pattern flattening are described in part 2 of this paper. This shirt template is intended to be used as a 3D drawing board for fashion designers to create a virtual shirt directly in

the 3D environment. The template is scaled with 12 size parameters (7 for body and 5 for sleeves) represented by construction curves. The scaling process forms the basis of the parametric 3D shirt template which can be used to facilitate automatic 3D grading. The value of the size parameters i.e. the length of the scaled curves can be altered individually or in group (representing the arm, or the torso for instance) and this procedure may be invoked whenever it is deemed to be necessary, by the designer or by a pattern technician.

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