The application of parametric surface model in mould head design for brassieres

Long Wu

Apparel & Art Design College, Xi'an Polytechnic Universigy, Xi'an 710048, China

Kit-Lun Yick and Joanne Yip

Institute of Textiles and Clothing, The Hong Kong Polytechnic University, Hong Kong

Sun-Pui Ng

Hong Kong Community College, The Hong Kong Polytechnic University, Hong Kong

*Corresponding author's email: kit-lun.yick@polyu.edu.hk

Abstract

Purpose – The purpose of this paper is to establish a parametric surface model for characterizing the shape of mould head and moulded bra cups of various bra styles and cup sizes.

Design/methodology/approach – A parametric method for the design and grading of the master head cone is formulated. With this method, the new style of the mould head can be accurately and efficiently designed and/or graded into larger or smaller head sizes. In addition, parameterization based remeshing and a registration algorithm are used to characterize the 3D shapes of the convex surface of scanned mould heads. By using an example-based method, virtual master cones are constructed based on the 3D surfaces of the investigated bra cups after eliminating the style lines and size differences. Then, a new mould head design can be developed from the master cone by drawing the style lines in a virtual environment, different sizes can also be made by grading the wire frame model in a 3D manner. The present method developed from product-driven concept can provide a scientific and effective tool for the product development to support contemporary fashion trend.

Findings – Based on remeshing and a registration algorithm, the 3D shapes of the master head cones are characterized. The parametric method can be used for designing new styles and grading of mould heads, and evaluation of cup shape conformity. It also serves as a quantitative method for the evaluation of moulded bra cups and mould head design.

Practical implications – The proposed method not only provides useful information for the selection of suitable foam materials and the determination of suitable moulding conditions, but also shortens the design time. It will allow a rapid response to the continuous changing needs of the intimate apparel industry.

Originality/value – The results from this study will provide a scientific, practical and effective solution for intimate apparel manufacturers so that they can improve the development process of mould heads.

Keywords Moulding, Foam, Bra cup, Deformation
Paper type Research paper

1. Introduction

Among the various types of apparel, brassiere design requires a particularly lengthy process that demands design creativity, precision pattern making skills and a detailed knowledge of fabric (Hardaker and Fozzard, 1997). Mould head design is also a key process in producing brassieres. The process control parameters, such as the 3D shape characteristics of the mould heads, control of the moulding temperatures and dwell times, etc. determine the resultant shape and appearance of the final product. Conventionally, the moulded cup shape is visually inspected through a comparison with a plastic shot. The judgment of the quality and shape depends on the experience of the inspectors as seen in Figure 1. Geometric control of the mould head design is therefore a highly time-consuming process.

Figure 1. Foam cup sample is fitted into a corresponding plastic shot

The geometric feature and shape modification processes of developing new aluminum mould heads usually involve many “trial and errors”. Problems have further increased in the new century due to the complex style of the moulded cups (such as full coverage, demi, triangle, etc.), extreme range of cup sizes (from AA to F**)** and softness requirements of bras introduced into the market. Researchers continue to explore rapid prototyping, body scanning and other innovative product development technologies to improve this development process (Liao and Lee, 2010). As there has been limited studies to provide accurate and reliable guidelines for the mould head design process. It is crucial to develop a parametric optimization system for the mould head design. The proposed method not only provides useful information for the selection of suitable foam materials and the determination of suitable moulding conditions, but also shortens the design time. It will allow a rapid response to the continuous changing needs of the intimate apparel industry.

2. Literature review

2.1 Rapid prototyping technology

Recently, reverse engineering technology has been adopted to assist rapid prototyping, complex geometric measurements, shape evaluation, etc (Li et al., 2014; Sha, 2014; Varady, Martin, & Cox, 1997). In this research, by using a non-contact 3D digitizing apparatus, the surface coordinates of mould heads, cup samples and master cones can be accurately and quickly obtained. The key features of the surface will be constructed and revised from point clouds (Shimizu et al., 1992; Tam & Chan, 2007). On the basis of a parametric design programme for master cones of bra cups, the 3D shapes of the convex surface of scanned bra cups can be characterized (Yick, Ng, Zhou, Yu, & Chan, 2008). New styles of mould heads can also be accurately and efficiently designed and/or graded into different sizes.

2.2 Mould head development process

The general process for mould head development included the following key steps. The mould head design starts with a standard cup shape. The designer and/or engineer then designs the mould head by means of a master cone profile, manually creates a plaster mould, and casts the aluminum units with male and female moulds. When developing the aluminum mould heads, their material properties were considered based on the foam properties, foam shrinkage, compression rate, etc. Computerized numerical control (CNC) systems may be adopted by large-sized bra cup moulding manufacturers. In bra cup moulding, a wide variety of flexible PU foams can be used for different styles and end-uses of the products with providing adequate support, comfort and hand feel. A pair of aluminum male and female moulds with a conformed shape, which is similar to the anatomy of the female breast, is designed and made according to the specified cup shape given by the customer (Yip & Ng, 2008). During the moulding process, the heated male mould stretches and compresses the originally flat foam sheets toward the female mould at a temperature over the softening point of the foam materials. A high temperature is used for about one minute to allow the heat to transmit through the foam sheets which are held in a space between the male and female moulds, so that the foam sheets are heat-set to the desired cup shape and thickness.

As a standard shape, the plastic master cone is used to compare against the shape of the moulded cup to assure 3D shape conformity of the moulded cup with the corresponding mould head design.When the moulded cup shape has been given approval, the pair of aluminum moulds, type of foam material and the optimal process parameters for bra cup moulding are then specified for mass production. Otherwise, the corresponding mould heads would be returned for further modifications.

3. Method

Scan data

Recently, reverse engineering technology has been adopted to realize rapid prototyping, complex foam cup geometric measurements, cup shape evaluation processes, etc. In this research, by using a non-contact 3D digitizing apparatus, the surface coordinates of the cup samples, master cones, and mould heads can be accurately and quickly obtained. The key features of the surface will be constructed and revised from point clouds (Tam & Chan, 2007). With this technique, new bra cups can be accurately and efficiently designed and/or graded into larger or smaller cup sizes.

To scan the 3D shape of bra cups, a 3D scanner is required. It is a device that analyzes a real-life object or environment to collect data on shape and possibly appearance (i.e. color). The collected data can then be used to construct digital 3D models. Many different technologies have been used to build these 3D scanning devices; each technology comes with its own limitations, advantages and costs. The collected 3D data is useful for a wide variety of applications. These devices are extensively used in industrial design, orthotics and prosthetics, reverse engineering and prototyping, quality control/inspection, documentation of cultural artifacts, etc (Bernard & Fischer, 2002; Kai, Meng, Ching, Teik, & Aung, 2000; Koller, Frischer, & Humphreys, 2009). There are a variety of technologies for digitally acquiring the shape of a 3D object which mainly includes digital photogrammetry, white light interferometry and 3D laser scanning.

Instrumentation

The equipment used in this research is a NextEngine desktop 3D laser scanner (NextEngine Inc., USA) mounted over a tripod. This scanner is based on multi-stripe laser triangulation (MLT): the device projects multiple laser-stripes and registers point positions with a charge coupled device (CCD) camera. The scanner comprises a compact box that is 22×28×9 cm in size, with twin arrays of four solid state lasers (red, 650 nm) and twin 3.0 megapixel complementary metal–oxide–semiconductor (CMOS) image sensors (Bradley, Chan, & Hayes, 2008).

Figure 2. NextEngine desktop 3D laser scanner

The NextEngine desktop 3D laser scanner (Figure 2) uses a proprietary platform, called Scan Studio, which runs on Windows OS. This software, although necessary for the acquisition, is not suitable for the alignment of the meshes of complex objects. The average distance between the scanner and the object surface needs to be approximately 45-50 cm in order to properly acquire the highest percentage of the scanned object (Yang, Cheng, & Chen, 2008).

4. Results

Prototype model

The application interface of the parametric design programme for master cones is shown in Figure 3. A standard master cone (prototype) could be modified and improved through related functions in the programme, which is actually more convenient and faster than the existing 3D software. In my research, the programme was further revised and the master cone was changed to a mould head template to facilitate the mould head design process.

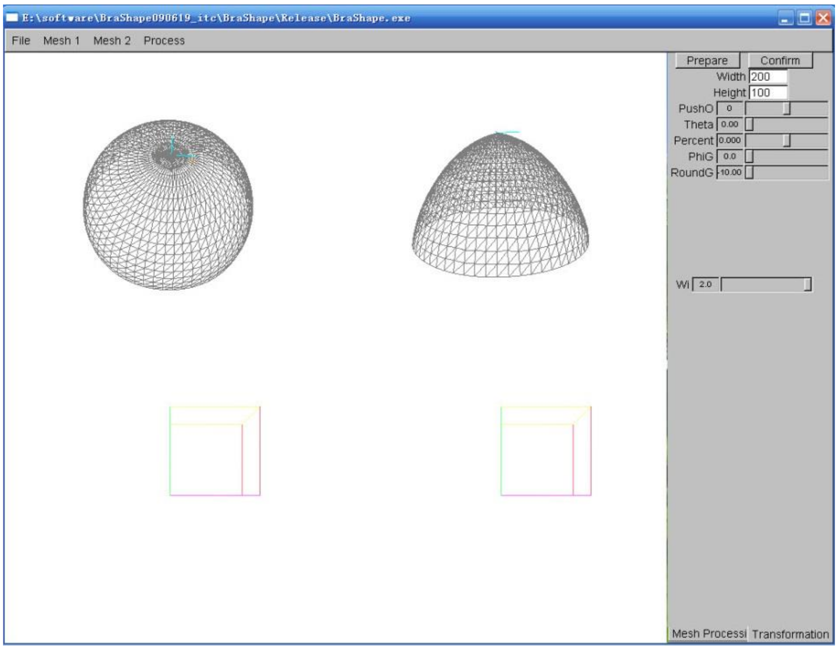


Figure 3. Application interface of a parametric programme for mould head design

In the mould head design field, there is great uncertainty as to whether a new mould head design will actually do what is desired, because new designs often have unexpected problems. A prototype is often used as part of the mould head design process to give designers or clients the ability to explore design alternatives and confirm style and size prior to starting the production of a new mould head. The entire parametric design of the mould head by the programme is based on its master cone.

In the programme, the storage of the mould head prototype information is found in an object (OBJ) file format. It is a common format which supports lines, polygons, surface and free-form curves, etc. The lines and surfaces are defined by their control points and additional information attached to the curve types. This file format can be used to store modified mould head designs and also can be directly exported into existing 3D software for further processing. As shown in Figure 3, a 3D model of a master cone is displayed in the form of a mesh structure, and can also be displayed in the form of a surface mode.

The surface of the mould head or bra cups could be obtained as cloud points by a 3D scanner. Then, triangular meshes will be randomly generated. However, different grid structures and mesh density distributions bring forth inconvenience in assignment and deviation calculations. The function of remeshing could reconstruct different grid structures of mould heads or bra cups without altering their 3D shapes, by using the mesh structure of the master cone as reference. Furthermore, the registration function is used to align two mesh structures to a certain reference point, which is easier for deviation inspection and shape conformity calculation.

Parametric design of master cone

The functions include style design, remeshing, registration and 3D grading etc. The style design function can generate a new master cone for the mould head in terms of the specified width and height based on the prototype. In addition, there is a parametric deformation function for designated parts on the master cone.

The width and depth must be input into the dialogs at the top right corner of the interface before the master cone file is opened. The width represents the diameter of the underside circle of the master cone, while depth refers to the vertical distance from the highest point to the bottom face as shown in Figure 4. In defining the width and depth of the master cone, a standard master cone (in a circular shape) is automatically generated.

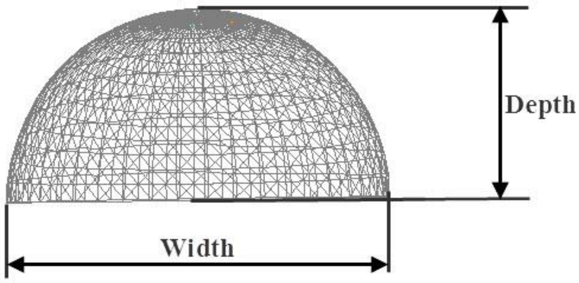


Figure 4. Schematic diagram of the width and depth of master cone

Figure 5 shows three different prototypes of the master cone in which their depths are set at 50, 75 and 100 mm, respectively, and all have a standard diameter of 200 mm.

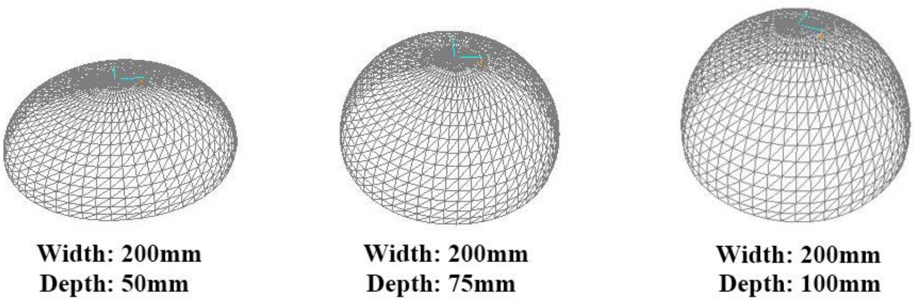


Figure 5. Master cones with three different depths

To change the shape of the master cone, a number of regulating parameters can be adopted. These include:

PushO：mainly used to adjust the diameter of the master cone. As shown in Figure 6, the values of PushO can be set at -1, 0, 1, respectively. When PushO is set at “-1”, it means only the upper region of the cone will be adjusted while the value “1” means only the lower part. The value “0” indicates that both two parts will be simultaneously adjusted.

Percent: represents the adjustment percentage in which the scope is limited by ±10%. Parameters PushO and Theta can be adjusted by the mould head designer so as to change the standard circular master cone to an oval shape.

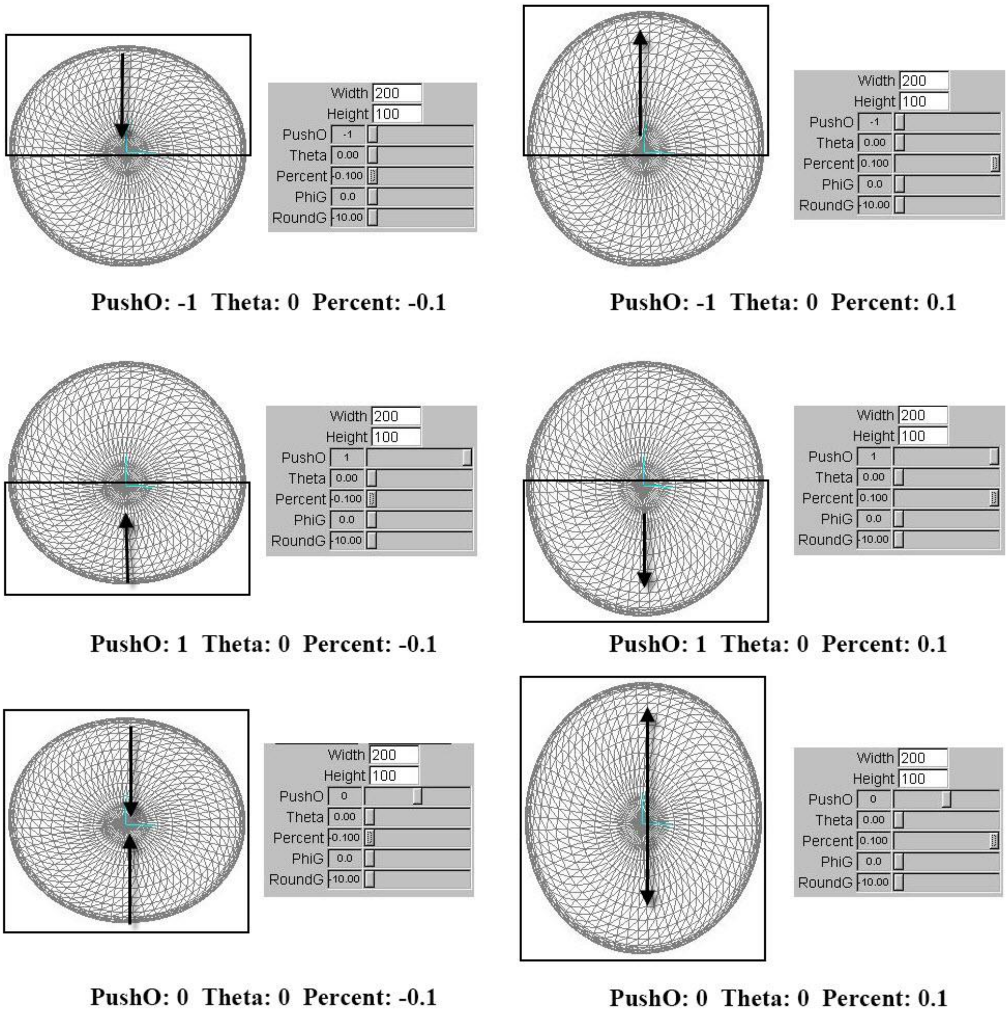
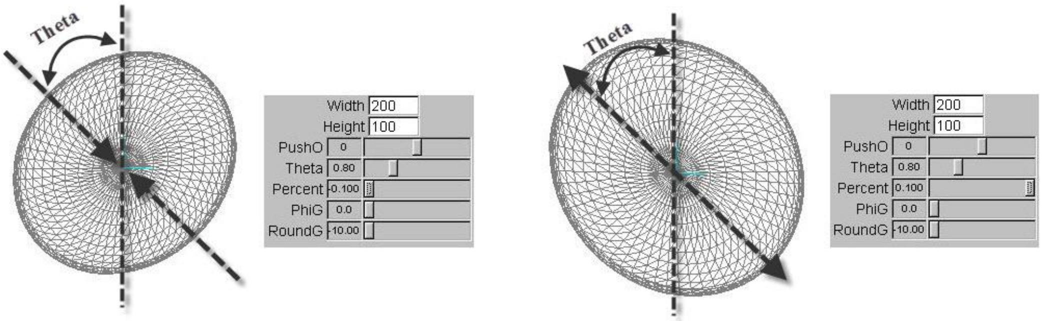


Figure 6. Shape modification of master cone by using PushO and Percent parameters

Theta: indicates the radian between the direction to be adjusted and the north-south axis, see Figure 7. The designer can therefore manipulate the master cone into different angles, which ranges from 0 to π (180°).



PushO: 0 Theta: 0.8 Percent: -0.1 **PushO: 0 Theta: 0.8 Percent: 0.1**

Figure 7. Shape modification of master cone by adjusting Theta parameter

PhiG： defines the radian of the reserved area with the vertical axis from the side, see Figure 8. The radian ranges between 0 and 1.6 (90°) within which the mesh structure in the reserved sector area cannot be modified.

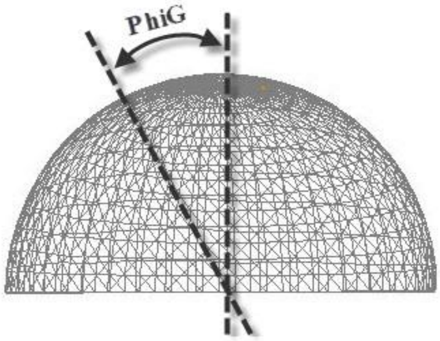


Figure 8. Schematic diagram of the PhiG parameter for modification of master cone

RoundG: means the round grade which modifies the curvature along the outside surface of the mesh structure except for the reserved sector region defined by the PhiG parameter. Figure 9 shows the shape modification of the master cone with RoundG from -10 to 10.

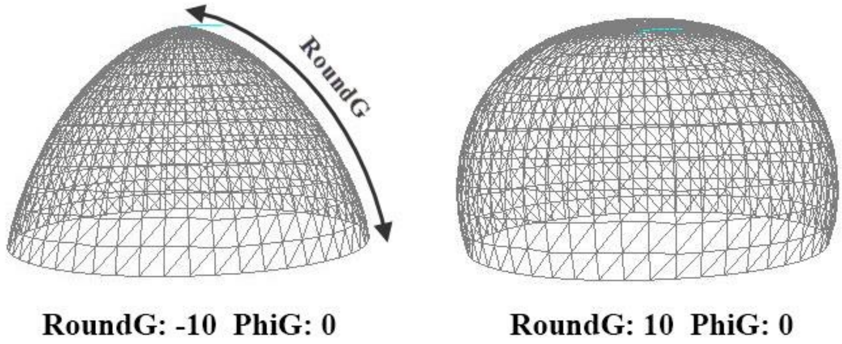


Figure 9. Shape modification of master cone with adjustments of RoundG when PhiG=0

Example-based design of cone shapes

By using an example-based algorithm, designers can merge the features of two different cone shapes in terms of various weightings. The example-based method aims to provide a tool for designers to produce new master cones with the aid of known samples. If each existing sample represents a typical modification in the design of a master cone, the new master cone can be conveniently modified by adjusting the corresponding weightings. An example is shown in Figure 10. Suppose S_1 is a push-up master cone and S_2 is a plunge style, respectively. Based on the original master cones of S_1 and S_2 , new master cones (S_3, S_4, S_5) are generated by using different weightings as shown below.

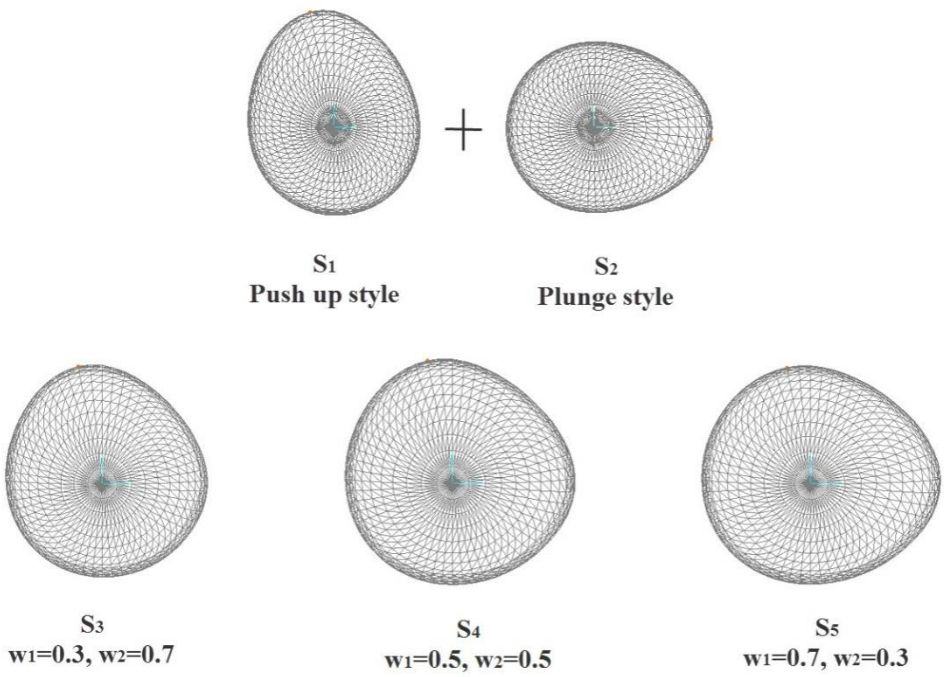


Figure 10. New master cones (*S_3, S_4, and S_5*) are generated by using different weightings of S_1 and S_2

As virtual master cones can be constructed based on 3D surfaces, designers need not modify the master cone and manually cut along the style lines for desired product design and the development process. The features of typical master cones could be created and normalized to a specific width and height by scaling. Modifications can also be made by adjusting the loading weight of each sample by using the following Equation (1), which is:

$$S = \sum_{i=1}^{n} w_i S_i \qquad (1)$$

where S_i is the style of a typical example, w_i is the weighting of S_i and $\sum_i w_i = 1$. A larger w_i produces a master cone that is more similar to S_i.

Mould head grading

The 3D grading function is similar to the scaling dimension in garment design. Due to the bra features, the magnitude of the extension and contraction on different parts can be varied. The programme could conduct 3D grading by using a medium standard prototype in terms of certain grading rules. A range of different-sized mould heads can be finished in design in a short amount of time.

The peak shape around the bust point is essential for defining the mould head shape and the specific mould head design starts from a master cone. Therefore, the master cone is used as a prototype, which is constructed by extending the curves from a wire frame representation of the mould head specimen. Since the mould head specimen is the top part of the master cone, the entire master cone surface is generated by extending the curves on the surface of the mould head specimen, see Figure 11.

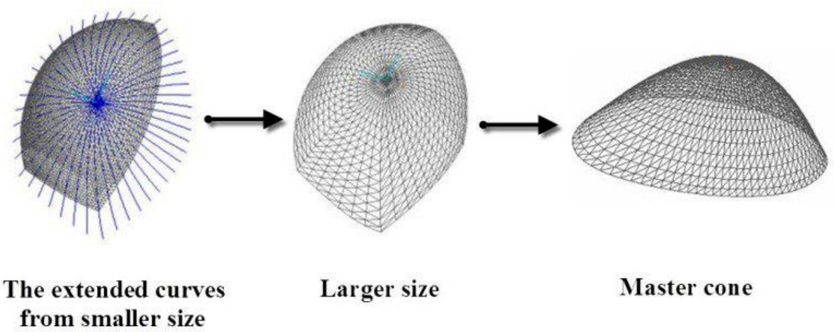


Figure 11. Backward production of master cone

Calculation of shape conformity

The 3D outer surfaces of moulded bra cups are firstly scanned and compared against a plastic shot. The highest bust point for the plastic shot is first defined. To measure the deviation of the corresponding points on the scanned cup surface, the parameterized-based remeshing and registration algorithm (PRRA) method is used to characterize the 3D shapes of the convex surface on the scanned bra cup (Yick et al., 2008). The initial bra cup images with missing data after scanning are mended by reverse engineering software for curvature smoothing. Irregular triangular faces from cloud points when producing the surface are also rectified so as to generate a completed cup surface. The outer surfaces of the plastic shot and the bra cup are aligned and their 3D shape deviations are then calculated. In this process, the plastic shot is used as the reference mesh, the bra cup surface is converted to the structure of the reference mesh by rigid transformation, whereas the corresponding vertices are matched around the bust point (Su, Cao, Shi, & Liu, 2006). The 3D geometrical data files would be the output for carrying out the subsequent processes. To produce a fitting surface for comparison, the following steps are carried out, see Figure 12.

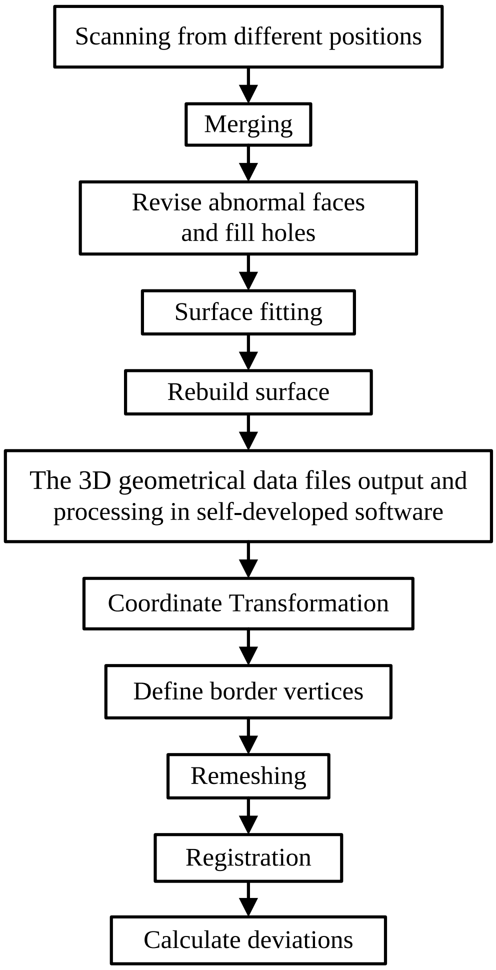


Figure 12. Processes of calculating deviations between plastic shot and bra cups

For calculating shape conformity, remeshing and registration between the bra cups and master cone are first carried out with the parameterized-based remeshing and registration algorithm method. After scanning the 3D shape geometry of the plastic shot and the bra cups produced under different processing conditions, their fitting surfaces can be rebuilt based on the original 3D surfaces and then output into reverse engineering software through an OBJ file format.

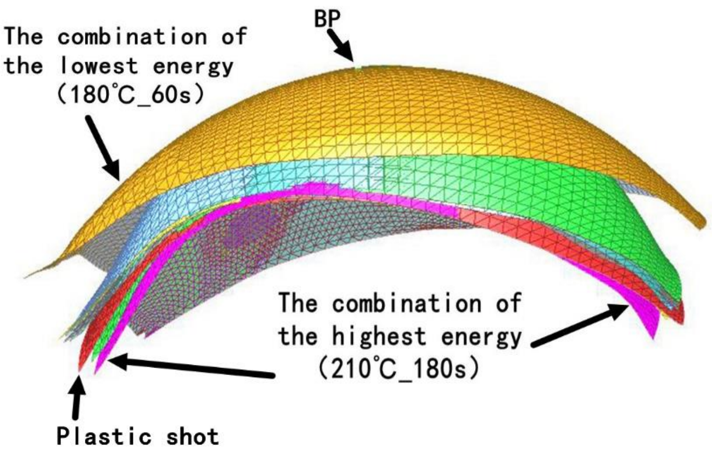


Figure 13. Profiles of moulded foam cups under the different combinations of energies

As shown in Figure 13, profiles of moulded foam cups under the different combinations of energies are aligned to the bust point through coordinate transformation. When the moulding temperature is lower with the shorter dwell time, viz., the combination of lower energy absorption, the shape conformity between moulded cup and plastic shot will be greater; when the temperature is higher with longer time, the shape conformity will be also greater.
The rigid transformation is computed by matching the corresponding vertices around the bra cup peak. By aligning the highest point (bust point) of the plastic shot that of the moulded cups, the coordinate differences of the same points between the two 3D surfaces can be quantified. According to industrial practices, the degree of shape conformity (*T*) between the moulded cups and the plastic shot at the cup peak region is evaluated by calculating the percentage of deviation at the corresponding points by using Equation (2).

$$T_{\mathrm{tip}} = \frac{f_1(0 < D \le 1)}{\sum_{i=1}^{10} f_i\left[(i-1) < D \le i\right]} \times 100\% \qquad (2)$$

$$(i \in N)\text{, and } D = \left|Deviation(X_j - M_j)\right|, \quad (j \in R)$$

where T_{tip} is the percentage of frequency f_1 (which have deviations that are less than 1 mm) out of the total frequency within a surface area that cover a three centimeter radius from the cup peak. M_j is an arbitrary coordinate on the plastic shot and X_j is the corresponding coordinate on the moulded cup. The function Deviation (*j*) is used to calculate the absolute deviations between the plastic shot and moulded cup.

5. Discussion and conclusion

The style design function in a parametric design programme has been used to primarily solve the problems with style parameters, including style and size modification. This programme makes it easy to overcome these difficulties. In this study, an example-based method for designing mould heads or bra cups is presented. Based on the sample input by any existing sample, a master cone can be developed for a new style in any mould head design. The proposed wire frame based method provides a unique presentation of mould heads that facilitates the process of foam cup grading as well as its design and development processes. On the basis of the parameterization based remesh and registration algorithm method, it is possible to register the scanned bra cups, and shape conformity can also be evaluated and effectively quantified. The optimal moulding conditions for particular types of foam materials can also be easily determined. The current process of development shortens at least three or four cycle times of design and analysis compared with traditonal method. This not only facilitates the control of the bra cup moulding process and communication amongst different sectors of the intimate apparel industry, but also moves towards more sustainable production process for fast fashion trend in intimate apparel industry.

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