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Pattern Engineering for Customized Women Seamless Ballistic Protection Vest on 3D Virtual Mannequin ⋆

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Abstract

There has been a significant increase in the number of women involved in various security duties. However, they mostly wear men's ballistic vests with smaller sizes, which bring poor ballistic protection performance, less comfort, and negative psychological effects. In recent decades, considerable efforts have also been made to improve the overall performance of ballistic protective vest for women. However, a ballistic vest that properly adjusts the chest area for different morphologies to provide a good fit, comfort, and better ballistic protection is very important and in high demand. Our current research study introduces a new 2D-3D-2D pattern re-engineering design method and automatic pattern generation on the adaptive 3D virtual mannequin to develop the first and multi-layer pattern for a seamless women ballistic vest. The method mainly eliminates the inclusion of darts to achieve the required breast volume with better fit and most importantly satisfactory ballistic protection.

Keywords: 3D design process; Pattern Generation system; Women Ballistic Vest; Ballistic protection; Fit

1 Introduction

The ballistic vest is the most important piece of protective equipment for various individuals such as police officers, bodyguards and the civilian who are exposed to fragments of materials in the working place [1]. It usually consisted of a fabric carrier with a front and a back ballistic panel made of flexible material (textile) of a very strong fibre to absorb the impact energy. To date,

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many serious and potentially fatal injuries in confrontations, physical attacks, traffic accidents, and battlefield confrontation have been prevented by the wearing of body armour [2]. Nowadays, the involvement of female officers in law enforcement and similar fields is also increasing significantly worldwide [3, 4]. However, in recent decades, they have been exposed to a hostile environment due to the use of body armour designed for men. Aside from the physiological differences, women wearing body armour tailored for men have experienced problems with fit, comfort, and ballistic protection. Although significant efforts have been made to improve the performance of body armour for women in terms of ballistic protection, breathability, cost, fit and comfort for the wearer in response to customer requirements and experiences, the majority is still primarily aimed at male wearers [5]. Therefore, the well-fitting ballistic vest for women is in high demand. Currently, there are various body vest designs that are specifically used for female users after considering the differences between male and female body shapes [6, 7]. The main design techniques are still based on cut-and-sew, folding fabric and stretch-forming the traditional fabrics with their disadvantage. The cut-and-sew technique can shape the dome shape to accommodate the bust area, but damages the continuity of fibers in the fabric which in turn reduces the level of protection [8]. Fabric folding is another method of creating domes in women's ballistic vest, but it also affects comfort and mobility of the personnel, as the deformation of the body armour is strongly considered, causing the panel to be thicker near the armpit than in other areas. Even though overlapping seams are much stronger, the small ballistic projectiles can still penetrate them directly and cut the loop of threads between the seams. The design methods for female body armour are made even more difficult by the curvaceous body shape of women [2]. This indicates that still very important to design a front panel for female ballistic vests that hat considers the chest area with better impact performance, comfort, and fit for the different women morphology without the need of cutting, stitching, stretch folding or folding is very imperative. The most common method to avoid such problems of women's ballistic vest is molding. Developing the required shape of women ballistic vest by molding process not only provides reasonable comfort but also good ballistic protection [9]. Moreover, it is known that the ballistic vest for women should be molded to the required human body morphology to ensure the effectiveness of the ballistic protection. In the molding process, the textile material possesses and considered different molding properties such as surface shear angle, material thickness variation, indentation values and the corresponding mechanical damages [10, 11–13]. When designing women body armour panel using the moulding method, it is possible to create a seamless front by mimicking the chest area without the need for cut and stitch or other finishing methods. This ultimately provides better comfort, fit, and better ballistic protection than other design methods. However, improvement is still needed in both the panel design and the appropriate ballistic material with better protection and formability. Even though the structural and geometric complexity causes many difficulties in numerical modeling [14], several research shows that 3D interlock woven fabrics are promising materials to replace 2D structures in ballistic protection because they have low shear stiffness and extraordinary formability [15–18].

In the current research, the new 2D-3D-2D pattern generation methods were introduced on a 3D virtual adaptive bust mannequin with average bra size (90B) to develop the first layers and then the multi-layer patterns of women ballistic vest. This new pattern development system for ballistic vest could help to generate 2D pattern block for better fit and comfort with the projection of body contour measurement directly onto the projection grid. the projection of the body contour measurement directly to the projection grid.

2 Development of 3D Adaptive Bust Women Mannequin

In the development of the women seamless frontal panels, knowing the exact and good volumes of the bust are the first and very important step for a better fit and comfort. Moreover, the bra is also one of the most complex intimate garment for women that needs a very good shape to support and fit the complex 3D breast contour [19]. Developing a good bra design with an accurate bra sizing system plays an important role in developing of seamless ballistic women's vest. Moreover, bra design cannot be independent of the parameters of the woman's body and breasts. The shape, symmetry, size and spacing of women's breast may vary without any relation to the other body measurement [20]. Therefore, developing different cup sizes (adaptive bust) for the same women body sizes (90) using a 3D virtual mannequin is an essential step using 3D design approaches [21].

For this purpose, the design process for the development of breast volume was parametrized for upper and lower size using different values from the average bust size (90B), as shown in Fig. 1(a) and (b). For the implementation, we used a commercial software from Lectra called 3D design concept to numerically simulate the 3D mesh and pattern generation of multilayer women's soft body armour. Therefore, generating pattern design of the soft body armour directly on the specific 3D virtual adaptive mannequin was able give a very good result for both ballistic protection and fitness. The additional parameter values used for development of the different cups were obtained with different trials until the perfect alignment of the lower part of the breast (corresponding to the lower cup of the bra) with the different standard underwire of the bra was obtained. This then gives a good representation of the volumes of each cup size. Developing the required adjustable bust with the possible variation in cup size not only helps in designing a custom bra pattern but also in further integrating the appropriate bust volume into the women front piece for the proper and fitted design of a seamless ballistic vest for women.

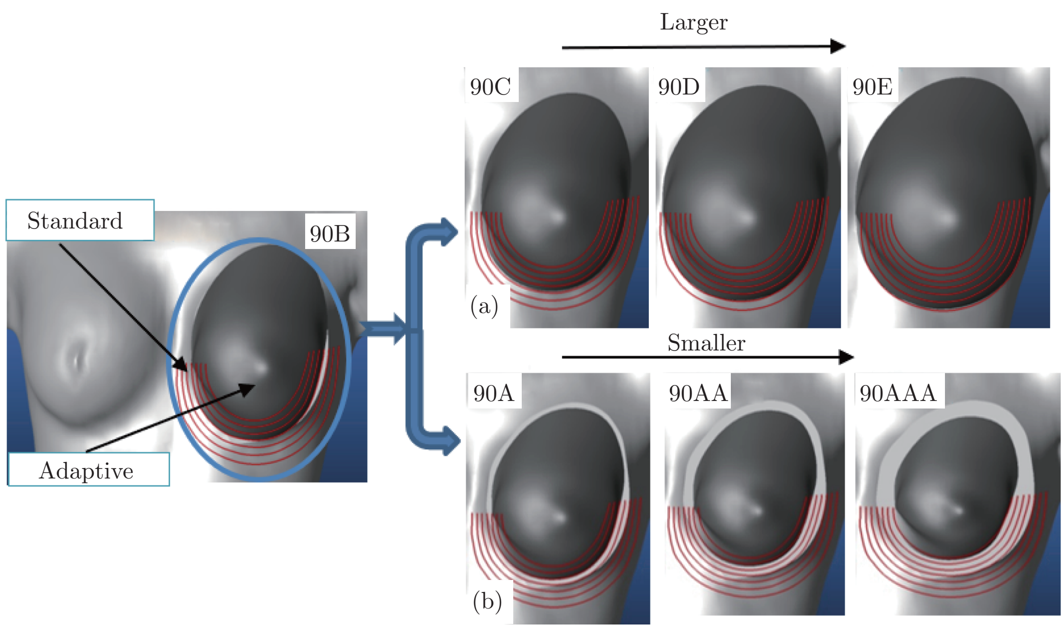

Fig. 1: (a) Various conceived adaptive bust for the upper sizes, (b) various conceived adaptive bust for the lower sizes

3 First Layer Pattern Developments of the Women Ballistic Vest

Based on the required volumes of the bust (90B) on the designed adaptive 3D virtual women mannequin with specified body size (90), the front part pattern associated with the bust could be developed. To develop the first layer (one layer) of the front seamless pattern from the selected adaptive 3D female virtual mannequin with specified bust size, a new process for reverse engineering (2D-3D-2D) the pattern was applied as shown in Fig. 2. The process involves developing of a basic mannequin directly on a virtual 3D model with 90B bust size using a reverse process (2D/3D/2D flattening method) which also helps to predict the deformation of the material between the 3D and 2D space. In this method, various strategic anthropometric feature points were first selected and marked on the 3D body contours to create the corresponding feature curves and reference markers lines as shown in Fig. 2(a). Then, as shown in Fig. 2(b) different horizontal and vertical meshes were created based on the different basic and detailed morphological contours of the body curves on the body to develop the base of the bodice. On it, the structure was created on a 3D surface that represents the basic bodice very close to the morphology of the front of the women body. Moreover, this criterion of proximity is very important from the point of view of ballistic protection the front part is shaped based on the contour of the body, which ultimately gives better blunt trauma resistance (BFS) than the panel that is not well adapted to the body. During pattern development, each vertical and horizontal grid in the 3D structure was extracted in its exact length and associated with another parameter based on its position with respect to the chest contour. All measurements are automatically taken according to the parameterization

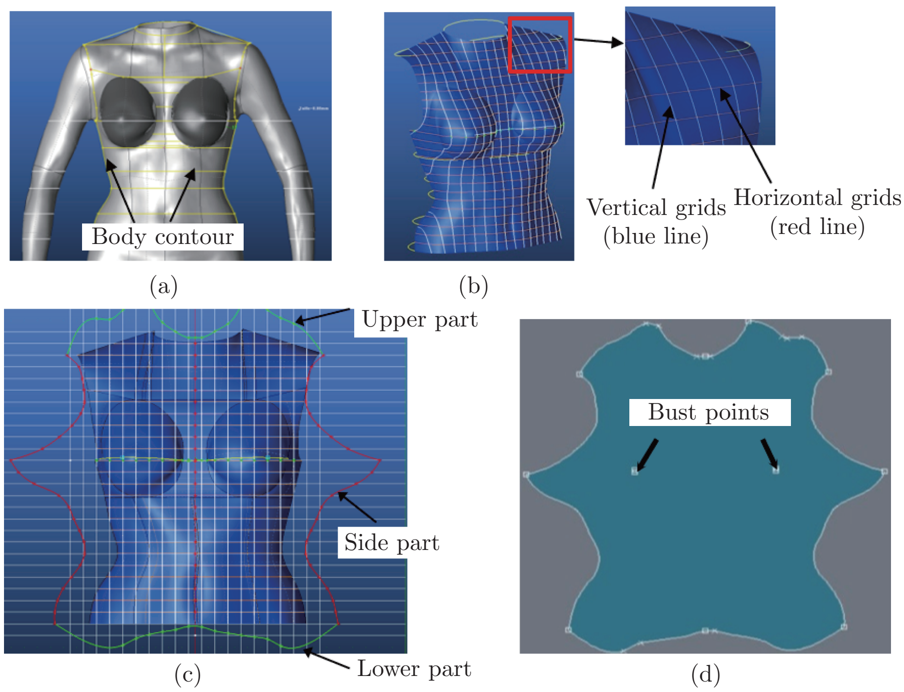

Fig. 2: (a) 3D virtual mannequin with (90B bust size) with the different reference point, (b) Developing 3D grid mesh in the 3D virtual mannequin, (c) Development of first layer frontwomen ballistic vest panel block pattern through 2D/3D/2D flattening process, (d) 2D pattern design for female seamless first layer panels

to develop the pattern blocks described previously. After obtaining the exact measurements of horizontal and vertical strands on the 3D body contour, it was projected onto the 2D grids to develop the basic block pattern shown in Fig. 2(c). To finalize the single-layer block pattern for the women's ballistic vest, the new 2D-3D-2D pattern flattening method was used to flatten the 3D surface of the block pattern. In this method, the outer frame of the block pattern was precisely defined by taking accurate horizontal and vertical measurement during flattening. Then, the female front was converted into the block pattern as shown in Fig. 2(d). using the software Modaris Lectra.

4 Multi-layer Soft Body Armour Panel Pattern Generations

The first step to create the patterns of the multilayer front panels of the ballistic vest for women through the 3D design process is to create the mesh surface on the surface of a virtual mannequin with zero value. This 3D surface mesh is essential and serves as a reference for the developments of the different surfaces, based on the corresponding thickness of the fabric layer. The surface mesh is generally the associated surface layer on the mannequin with boundary of the outer edge of the 3D body. To create the mesh surface, the first block pattern with fabric thickness values of zero was used. The appropriate 3D coordinate was critically described for creating the surface mesh to achieve good results. This surface mesh, formed directly on the 3D virtual woman mannequin, is later used as a reference to generate the patterns for different successive layers of the multilayer panel with defined fabric layer values by shifting outward. Our new multi-layered patterns for women's front parts were generated directly on the virtual 3D female mannequin using a new systematic 3D construction approach. This approach is possible due to the principle that if the soft body armour is designed following the contour shape of the body, not only good ballistic protection performance but also better fitness and comfort can be achieved. Here, we used Lectra's commercial software called 3D Design Concept to numerically simulate 3D mesh and pattern generation of multilayer soft body armour.

Therefore, generating the pattern design of soft body armour directly on the specific 3D virtual adaptive mannequin could achieve a very good result in terms of protection, fitness and comfort. The 3D design process for generating patterns of multilayer soft body armour starts with designing a suitable block pattern for the specific size of the first layer close to the body. Therefore, the previously developed block patterns were used. The first step was to generate the surface mesh on the associated 3D virtual mannequin. This first surface mesh was generated and defined in a plane parallel to the virtual 3D front of the mannequin with thickness values of the layer of zero (near-body).

The thickness of the successive layers has been coded in the 3D design software which helps to move the mesh of the next successive layer in all directions with proper coordination, as shown in Fig. 3. Moreover, thanks to the 3D design software, the value of the gradation for each of the measurement points is numerically counted automatically to attain each successive layer mesh based on the input values (thickness of the fabric layer). Consequently, depending on the spacing in each successive layer, at the defined coordinate points, the values are shifted to generate the next layer mesh. The developed mesh for the block surface of soft body armour can then be fed to the flattening operation to generate the corresponding 2D pattern. The generation of the flattened 2D pattern also strictly follows the principle of classical 2D pattern design knowledge. The different successive flattened block patterns for the panel are shown in Fig. 4(c).

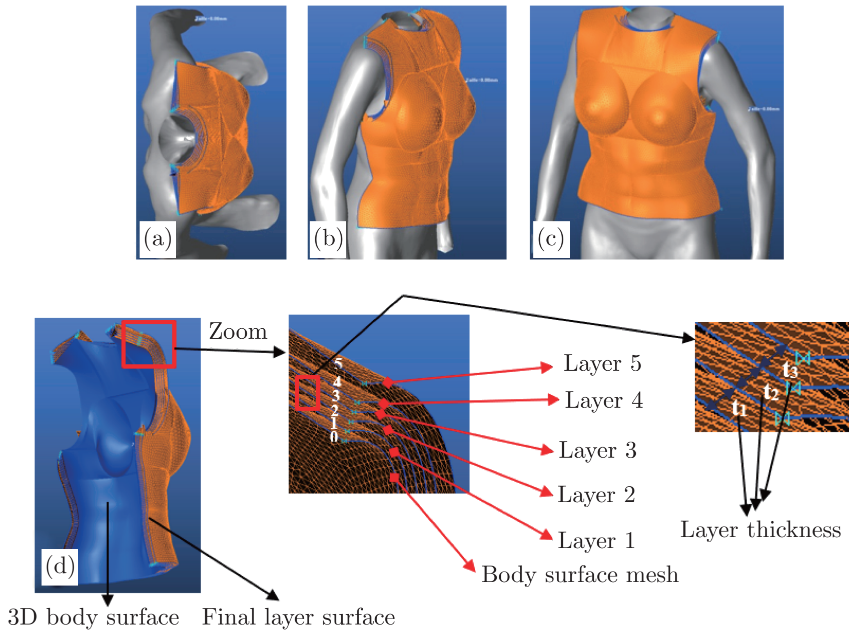

Fig. 3: Developed multi-layers frontal seamless female soft body armour panel mesh on the virtual adaptive female body surface (a) top view, (b) side view, (c) Front view, and (d) multi-layer panels with its thickness of the corresponding mesh (t_1, t_2, t_3, $\cdots$, t_n)

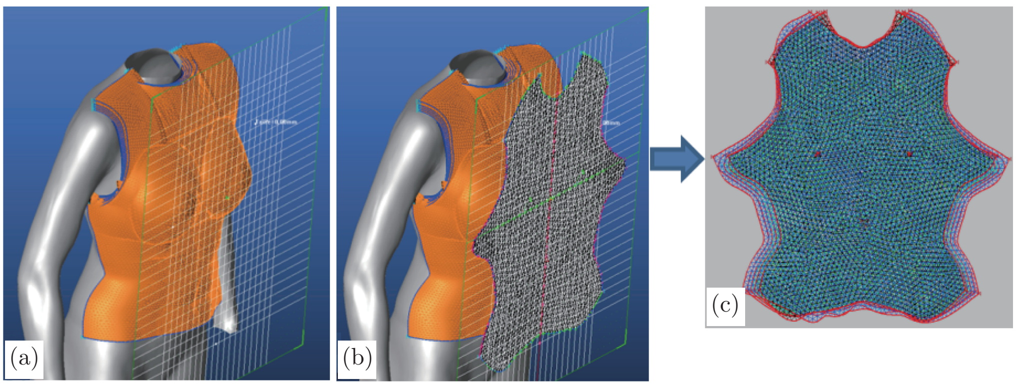

Fig. 4: Multi-layer Pattern flattening (a) Projection grids, (b) pattern block projection for multi-layer through flattening, (c) Flattened multi-layer soft body armour panel pattern

5 Validations of the Pattern Panels Model

The developed ballistic vest panels for women were developed using the specially adapted punching bench with the specific open die and the bust-die punch shape on the produced multi-layer 3D warp interlock fabrics. After moulding, the ballistic vest with frontal panel was draped on the mannequin with similar body and bust size (90B) for visual observation and validation. Fig. 5 shows the Aexperimental dome-moulding process and panel testing in the fabrication of seamless ballistic vest with multiple layers on the front panel.

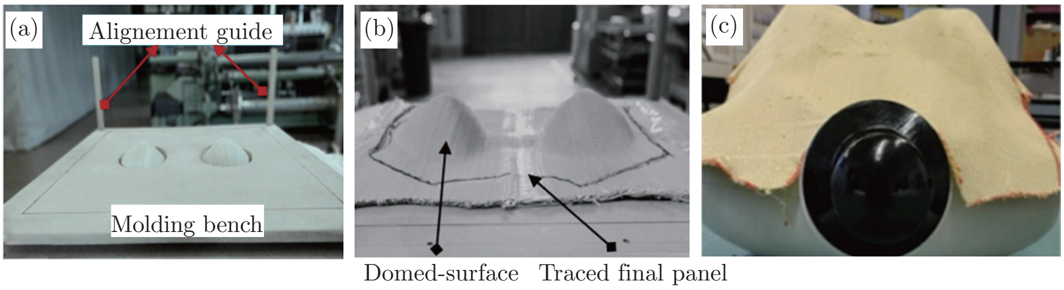

Fig. 5: Dome-formation processes of female frontal soft body armour (a) Molding bench set-up, (b) Zoom area for domed- surface for right and left bust, and (c) final domed-shape frontal panel

During fabrication, it is very important to note and accurately indicate the two breast points on each layer of fabric so that they are properly aligned with the punch to obtain better fabric indentation values in all directions to obtain a good final ballistic vest for women, as shown in Fig. 5(a) & (b). Moreover, during the forming process, it is found that the application of proper pressure is very critical and should be applied while fixing the fabric layer between the upper holder and the lower open die to avoid various defects of the fabric layer such as wrinkling, buckling, high shear on the final panels. After the dome forming process, in addition to using 3D interlock fabrics that are easy to shape, applying a small amount of fixing liquid to the curved breast surface helps to achieve an even more stable shape. The different successive plate layers (the 1st, 2nd, 3rd, $\cdots$, nth layer) initially had different pattern sizes based on the corresponding thickness of the fabric layers. However, after the moulding process, the different panel layer boundary lines (contour) should be aligned together on the same line position to achieve effective ballistic performance and better fitness and comfort for the wearer. The alignment of the two different consecutive panel layers on the boundary line (waist contour) was demonstrated by separating one corner of the upper panel layer and one half of the lower panel layer for verification. The developed ballistic vest for women was also draped on a mannequin with the same body size for observation and further analysis, as shown in Fig. 5(c). With this design and fabrication process, a pattern generation method can be developed, which is also very promising for developing women's ballistic vests that are form-fitting, without darts or rigid inserts, such as Shield@ materials. The layers in the vest do not need to be cut during construction, much like a man's vest. With some tweaks to the dome forming process, it is also possible to evolve it and achieve an even better product.

6 Conclusions

In this paper, 3D systematic design approaches were applied to the designed 3D virtual adaptive mannequin for women to generate a pattern for the first and subsequent layers of the multilayer seamless ballistic vest for women. The study uses the block pattern of single layer ballistic vest as a base developed by reverse (2D-3D-2D flattening) design method. The method mainly considers the thickness of the fabric in each successive layer of the ballistic vest panel to shift the pattern. The parameterization was developed on the database of 3D construction process for automatic shifting and generation of mesh of each outer layer on the virtual 3D adaptive female mannequin. This is done based on the position of the base layer (zero value) and the thickness of the layer (mesh). The different mesh layers developed on the virtual 3D adaptive female mannequin were then flattened for the front of each successive layer to create a multilayer pattern design. Although the modelling and simulation of the mesh approximated the shape of the virtual mannequin body, the front panel of the soft ballistic vest for women should be experimentally tested to verify and prove the function of the system.

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