The current issue and full text archive of this journal is available on Emerald Insight at:
www.emeraldinsight.com/0955-6222.htm

Three-dimensional garment pattern design using progressive mesh cutting algorithm

Yeonghoon Kang and Sungmin Kim
Department of Textiles Merchandising, and Fashion Design, Seoul National University, Seoul, The Republic of Korea

Received 21 August 2018
Revised 17 November 2018
Accepted 6 January 2019

Abstract

Purpose – The purpose of this paper is to develop the core module of computer-aided three-dimensional garment pattern design system.

Design/methodology/approach – A progressive mesh cutting algorithm and mesh reshaping algorithm have been developed to cut a single mesh into multiple patches. A flat projection algorithm has been developed to project 3D patches into 2D patterns.

Findings – The software developed in this study is expected to enable its users to design complex garment patterns without the in-depth knowledge of pattern design process.

Research limitations/implications – The mesh model used in this study was a fixed model. It will be extended to a deformable garment model that can be resized according to the underlying body model

Practical implications – The software developed in this study is expected to reduce the time required for time-consuming and trial-and-error-based pattern design process.

Social implications – Fashion designers will be able to design complex patterns by themselves and the dependence upon expert patterners could be reduced

Originality/value – The progressive mesh cutting algorithm developed in this study can cut a mesh model using arbitrary lines. The mesh reshaping algorithm can improve the mesh quality of divided patches to increase the numerical stability during subsequent pattern flattening process. The flip removal algorithm can effectively remove the partially flipped mesh elements.

Keywords Dart, Flat pattern projection, Garment pattern, Mesh cutting, Three-dimensional garment model

Paper type Research paper

1. Introduction

Information technology is being widely used for productivity improvement as well as quality management in various industrial fields. The garment industry, which has been considered as a labor-intensive one, is also evolving into a technology-oriented industry by introducing the information technology. In preparation for the so-called fourth industrial revolution, many research works have been made based on the information technology, such as computational geometry, artificial intelligence, Internet of Things, and so on. For many years, advanced countries such as the USA, Europe and Japan have been developing two-dimensional (2D) garment CAD systems. Since the 2000s, three-dimensional (3D) systems have been developed such as garment simulation and body measurement systems because 3D environment has become more and more important in garment design.

Until recently, garment pattern design process has been based on 2D methods, which is an inefficient process in which skilled pattern designers draw initial patterns based on their expertise and modify them by using a trial-and-error based method until the patterns fit well. Many studies have been made to solve this problem by using 3D pattern design process. Yang *et al.* (2011) tried to make prototype garment patterns based on 3D body scanning data. They cut the 3D garment model mesh into multiple pieces in three ways and developed them into 2D patterns. However, there was a limit that the mesh was cut only by a

This work was supported by the National Research Foundation of Korea (NRF) Grant funded by the Korean Government (MSIP) (NRF-2016R1A5A1938472).

© Emerald Publishing Limited
0955-6222
DOI 10.1108/IJCST-08-2018-0106

المنارة للاستشارات
www.

straight line defined by the feature points on the human body, rather by an arbitrary line. Wang *et al.* (2010) tried to make the patterns of a wetsuit by cutting a garment model into multiple 3D pieces and developing them into 2D patterns. Mitani (2005) proposed a mesh cutting method to design garments in 3D. However, the study did not include the pattern development process. Turkiyyah *et al.* (2011) conducted a research on mesh cutting for the interactive simulation of surgical operation, clothing design, clay sculpture and virtual reality applications. Zhang *et al.* (2016) proposed a new surface modeling method that cuts the mesh of a 3D body scan data into the shape of garment patterns and flattens them into 2D patterns. Yang and Zhang (2007) attempted to transform a 3D dress form model into 2D patterns for the mass customization of garments. Keckeisen *et al.* (2004) also tried to design garment pattern in 3D environment. Li and Lu (2014) proposed a new garment design method, which generates a new 3D garment model by cutting and combining the original garment model. However, there was a limitation that it was difficult to produce practical garment patterns because the method focused primarily on the visual modeling of a 3D garment. Zhang *et al.* (2018) tried to generate a garment model based on the 3D human body model. They cut the body model into the shape of a garment and developed it into flat patterns using an interactive user interface. Kulinska *et al.* (2016) developed a parametric garment design method using the virtual mannequins of the target population. They graded the neck and armhole lines in a 3D environment and thereby found the advantages of 3D parametric design. Hong *et al.* (2017) developed a virtual reality based apparel design process to produce customized clothing for people with scoliosis. A virtual human model and the 3D drape simulation technique were used to confirm the fit of the garment.

In this study, a progressive mesh cutting algorithm has been developed to make garment patterns by cutting a 3D mesh model. Using this algorithm, a mesh model can be divided into multiple patches along arbitrary lines drawn on the mesh model. Then, the patches are projected as flat patterns. The outline of patterns can be saved as a drawing exchange format (DXF) file to be used in various garment CAD systems. A mesh reshaping algorithm has also developed to improve the quality of the divided mesh. Finally, a 2D pattern projection algorithm has been developed that can remove the partially flipped mesh elements during pattern flattening process.

It is expected that those who have little knowledge of garment pattern design will be able to design complex garment patterns using an intuitive user interface developed in this study. The time required for garment pattern production is also expected to be reduced.

2. Development of algorithms

2.1. Progressive mesh cutting algorithm

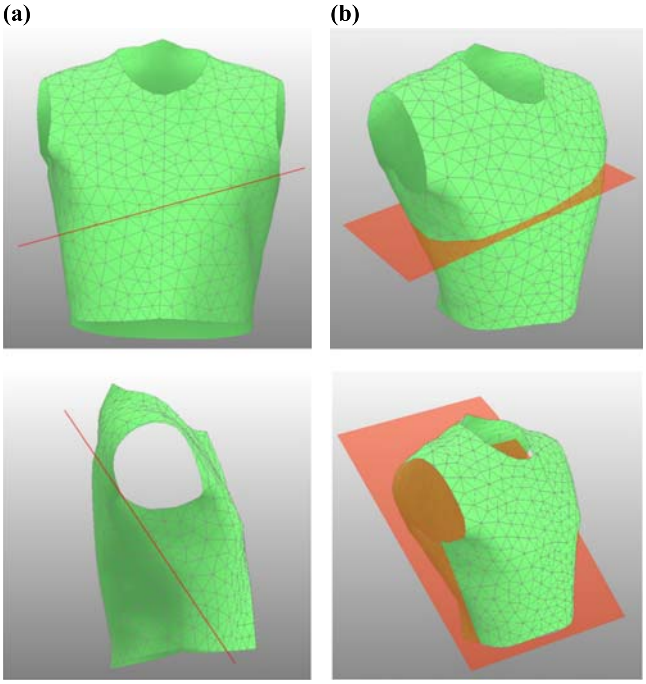
In this study, a mesh cutting algorithm has been developed that cuts a 3D mesh into several patches along arbitrary lines. It can be briefly explained as follows. When the user draws a straight line on the screen, as shown in Figure 1(a), a corresponding 3D plane can be defined from that line in consideration of the current point of view, as shown in Figure 1(b).

Once a plane is defined, the intersection points of that plane and each triangular element in a mesh can be determined, as shown in Figure 2(a). At this, the mesh structure needs to be reorganized as shown in Figure 2(b) because some triangular elements should be divided.

After the mesh is reorganized, it can be divided into two separate meshes by grouping the triangular elements with respect to the cutting plane. However, this algorithm can only be applied when the cutting line is straight and it cannot be applied when the line has multiple segments, as shown in Figure 3(a).

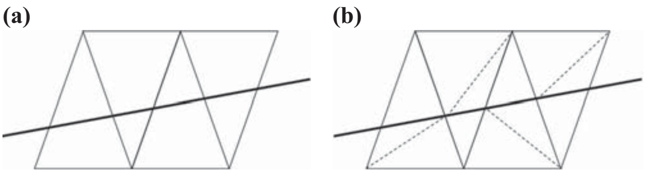
The reason is that it is impossible to determine whether or not a specific triangular element lies either on the left or on the right side of a cutting line when the cutting line consists in multiple segments. As shown in Figure 3(a), certain elements of the mesh can be on the left of one segment, while on the right of another segment at the same time. However, if the area to be

المنارة للاستشارات
www.



Notes: (a) 2D line in orthogonal view; (b) 3D surface in perspective view

Figure 1. Schematic diagram of cutting plane definition



Notes: (a) Location of intersection points; (b) triangular mesh reorganization

Figure 2. Mesh reorganization along cutting line

divided were defined as a polygon, as shown in Figure 3(b), the mesh could easily be divided by grouping the inside and outside elements with respect to that polygon. The schematic diagram of mesh division algorithm is shown in Figure 4. To group the elements, the user-drawn polygon is first subdivided into a coarse triangular mesh, as shown in Figure 4(c). Then, each element in the mesh is checked whether it lies inside of any of those mesh or not.

As shown in Figure 5, a plane intersects a triangular element in a mesh in four modes. A triangle can be subdivided up to four triangles.

Especially for mode 2, two different cases can be assumed, as shown in Figure 6. In this case, triangles with too acute angle can cause numerical instability in 2D pattern projection process, which will be discussed later. Therefore, a triangle should be divided so as to minimize the standard deviation of the angles of all the resulting subdivided triangles.

Figure 7 shows the schematic diagram of progressive mesh cutting process.

www.

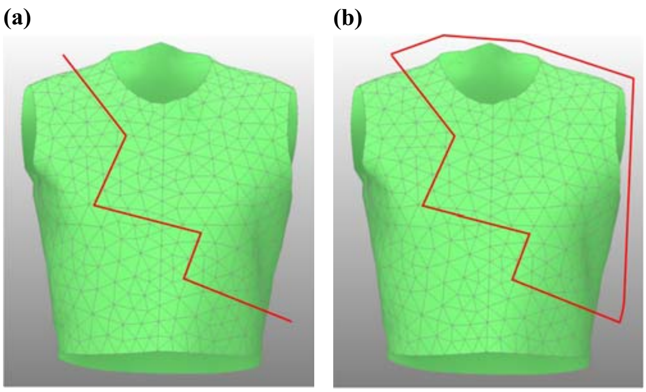


Figure 3.
Definition of complex cutting line

Notes: (a) Polyline representation; (b) polygon representation

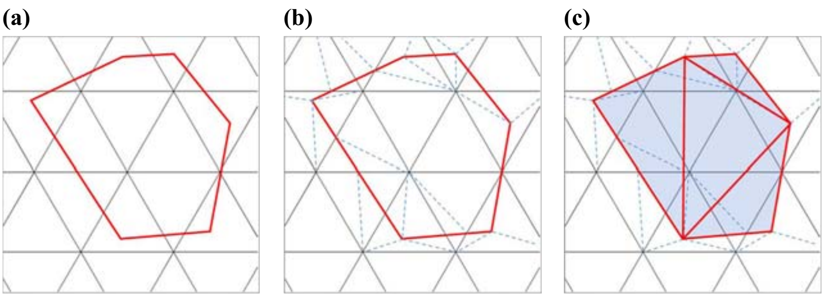


Figure 4.
Schematic diagram of mesh division

Notes: (a) Polygonal region definition; (b) mesh reconstruction; (c) grouping of triangular elements with respect to the polygon

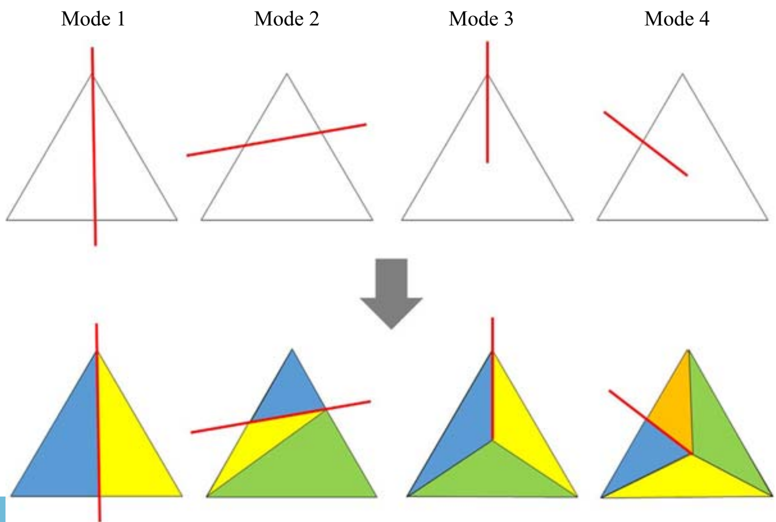


Figure 5.
Schematic diagram of triangular element subdivision

المنارة للاستشارات

www.

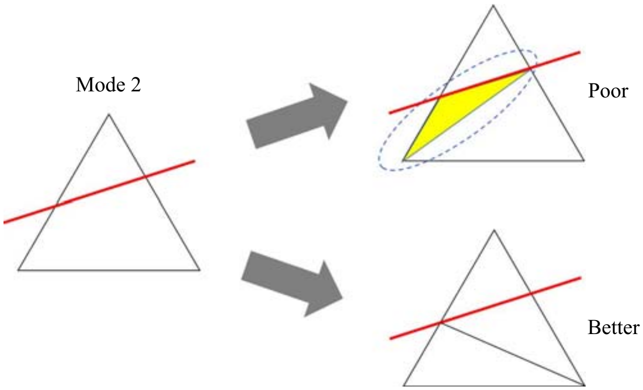


Figure 6. Subdivision of triangular element for mesh quality improvement

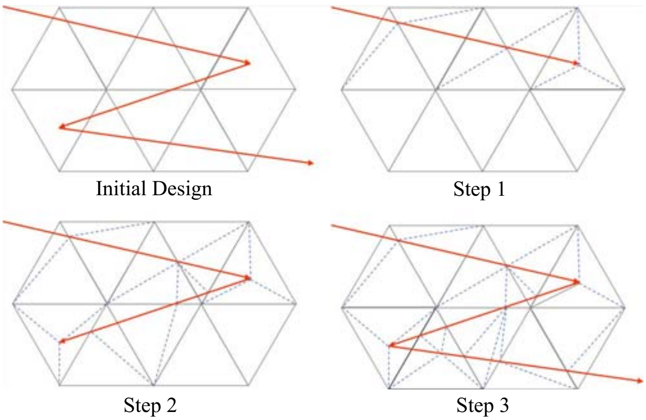


Figure 7. Schematic diagram of progressive mesh cutting process

If a divided patch were not a developable surface, an additional cut line, in other words, a dart would be required to flatten the patch. A dart line can be defined as a line segment with one end being outside of a patch while the other being inside. Then the mesh is divided and reorganized along the dart line by the same process as described earlier.

2.2. Mesh reshaping

As shown in Figure 8, some undesirable acute elements may be produced during the cutting process. In this case, it is necessary to remove those elements as many as possible since they may cause numerical instability in the subsequent pattern flattening process.

This is done in two steps. The first step is to merge the adjacent points on the cut line together, as shown in Figure 9(a). If three points A, B and C on the cut line satisfy the condition of Equation (1), an acute triangular element can be removed by combining point B with the nearest point either A or C:

$$|\angle BAC - 180| \leqslant C_1,$$

$$\overline{AB} \leqslant C_2 \text{ or } \overline{BC} \leqslant C_2, \quad (1)$$

where C_1, angle tolerance and C_2, minimum edge length.

www.

The second step is to remove elements with any corner angle smaller than the predetermined threshold value. As shown in Figure 9(b), a poorly shaped triangular element can be removed by merging the points together that make up the shortest side of that element.

2.3. Flat pattern projection

In order for the divided patch to be flattened, it must first be projected onto the two-dimensional plane. This can be done by finding the intersection point between a plane and the line passing through each point on the patch and a projection center, as shown in Figure 10. At this time, the shape of the projected patch is usually distorted, and in some cases, overlapped triangular elements may occur.

Ignoring the overlapped elements, a 3D patch and its 2D counterpart can have the identical shape by repeating the calculation described in Equation (2) over all the triangular elements in the patch:

$$l = |\overline{e_{3D}} - \overline{e_{2D}}|,$$

$$d = 1 - \frac{\tan^{-1} l}{\pi}, \quad \vec{v} = \overrightarrow{p_0 p_1},$$

$$\overrightarrow{p_0} = \overrightarrow{p_0} + \vec{v} \times d, \quad \overrightarrow{p_1} = \overrightarrow{p_1} - \vec{v} \times d, \tag{2}$$

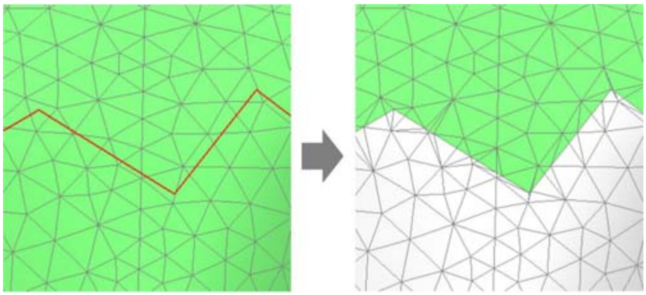
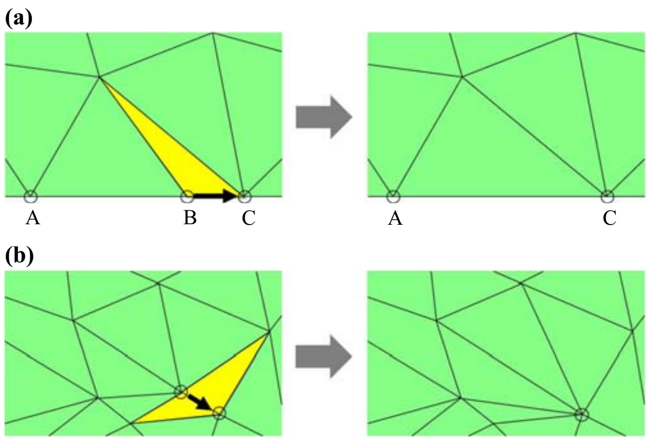


Figure 8.
Examples of acute triangular elements along cut line



Notes: (a) Boundary elements; (b) internal elements

Figure 9.
Schematic diagram of mesh reshaping

المنارة للاستشارات
www.

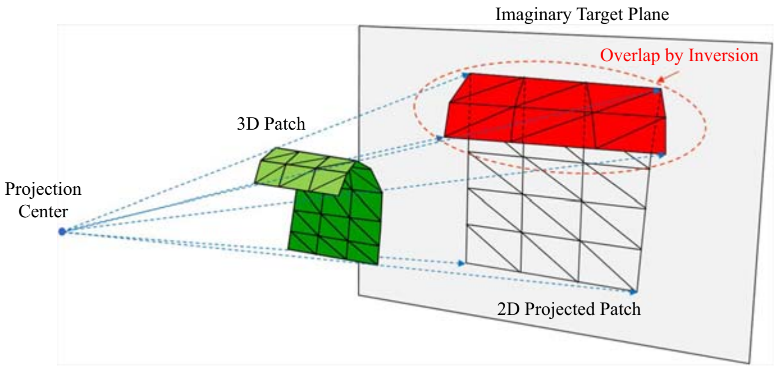


Figure 10. Schematic diagram of 3-D to 2-D initial projection

where, e_{3D} = an edge in 3D patch, e_{2D} = an edge in projected 2D patch, p_0, p_1 = two end points of e_{2D}.

This is an algorithm that moves both end points of a 2D edge in consideration of the length difference d of each edge between 3D and 2D patches. In the case of a large length difference, sudden large movement of points may make the whole system unstable. For this reason, the movement of each point needs to be properly damped by using the arc tangent function, as shown in Equation (2).

However, flipped triangle elements mentioned above cannot be corrected by this process and it is necessary to correct the flipped triangle during the flattening process.

Assuming the three vertices of A, B and C of a projected triangular element A, B and C, their 3D cross product can be obtained by using Equation (3). The sign of the z component of the cross product of a correct element and that of a flipped element are opposite to each other. This makes it easy to determine whether an element is flipped or not:

$$A' = (A_x, A_y, 0),\ \ B' = (B_x, B_y, 0), C' = (C_x, C_y, 0),$$

$$\vec{v_1} = \overrightarrow{B'A'},\ \vec{v_2} = \overrightarrow{B'C'},$$

$$\vec{p} = \vec{v_1} \times \vec{v_2}, \tag{3}$$

where A', B', C' = 3D coordinate of each point.

$\vec{p}$ = 3D cross product of $\vec{v_1}$ and $\vec{v_2}$.

The flipped element correction process is shown in Figure 11. First, find a flipped triangle that shares any edge with a non-flipped triangle. Then flip that triangle with respect to the shared edge. At this time, other flipped triangles related with that triangle may also be corrected. Finally, all the flipped elements can be corrected by repeating this process.

3. Results and discussion

3.1. Overview of system

The overview of the system developed in this study is shown in Figure 12. The software was developed using Embarcadero C++ Builder 2010.

3.2. Progressive mesh cutting

An example of progressive mesh cutting process applied to a bodice model is shown in Figure 13. In this process, a single bodice model was divided into multiple patches. When a patch is selected, it becomes the active patch and highlighted in green. When a cut line is drawn on the screen, the active patch is divided into two patches along that line.

المنارة للاستشارات
www.

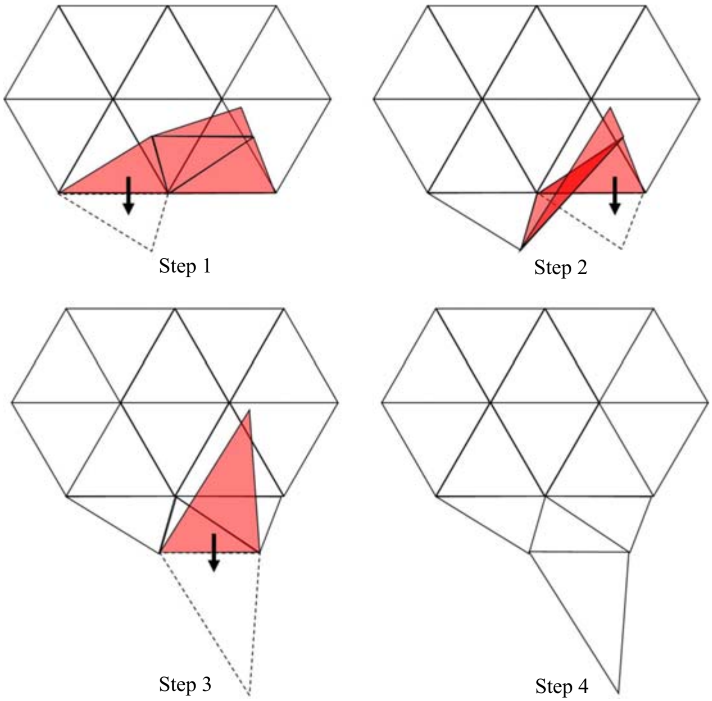


Figure 11.
Schematic diagram of flipped element correction process

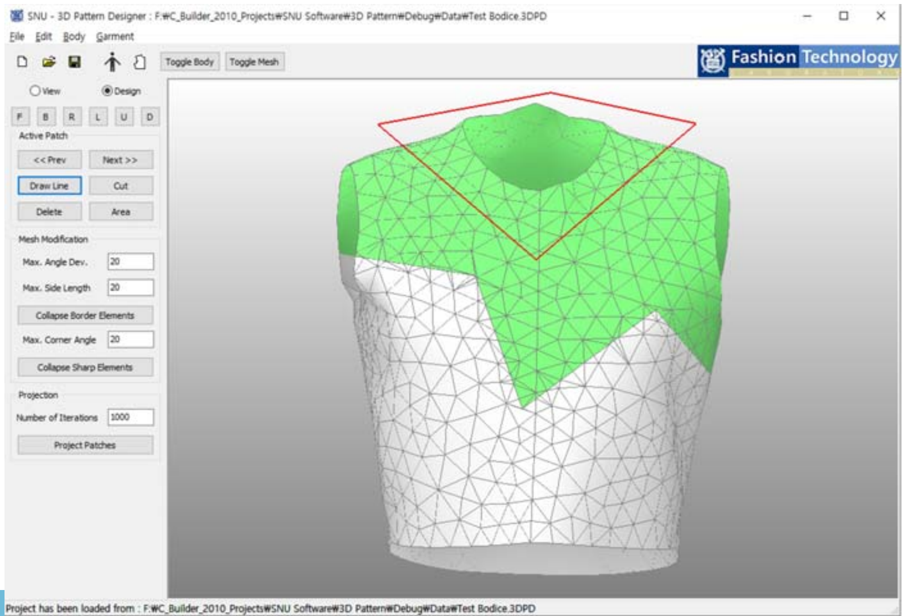


Figure 12.
Overview of 3D pattern design system

المنارة للاستشارات
www.

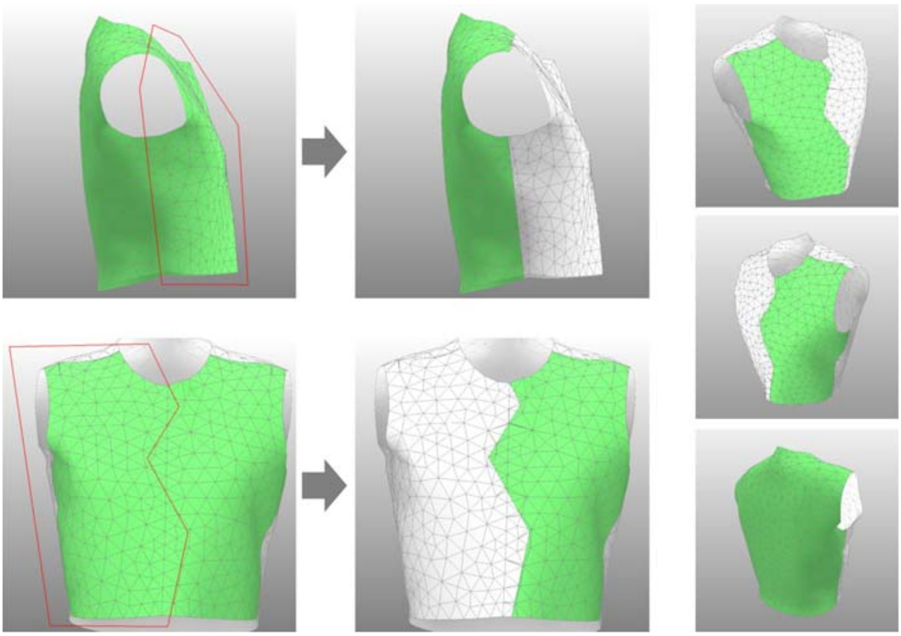


Figure 13. Examples of progressive mesh cutting

3.3. Mesh reshaping

When the mesh is cut, there are inevitably sharp shapes in the newly created triangular elements. In this case, it is necessary to reduce the pointed triangle because it can invoke numerical instability during the flattening process.

Figure 14 shows the result of mesh reshaping process. The shape of each element was modified as uniform as possible by removing poorly shaped triangular elements formed along the cut line or inside the mesh.

3.4. Flat pattern projection

An example of flat pattern projection is shown in Figure 15. The strain that occurs during the flattening process is shown in colors. The color becomes red if an element was extended and becomes blue if it was shrunk.

The outline of a patch can be determined by finding and connecting the edges that belong to only one element as shown in Figure 16. First, one of those edges is selected as the starting edge. Then, find the next edge, of which the starting point is the end point of previous edge. A closed path can be completed by repeating this process until the first edge is revisited. The outline can be saved as a DXF file so that it can be used in other CAD systems.

4. Conclusion

In this study, a pattern design system has been developed that can enable its users to design garment patterns in 3D environment using an intuitive user interface. Users can cut a garment model into multiple patches by drawing arbitrary lines on the model while observing it from various angles. A robust progressive mesh cutting algorithm has been developed to divide the mesh using arbitrary lines instead of straight lines. Poorly shaped triangular elements produced during mesh cutting process were removed by the mesh reshaping algorithm. Patches were projected into flat patterns by using an algorithm that can effectively remove the partially flipped triangular elements occurred in the projected

المنارة للاستشارات

www.

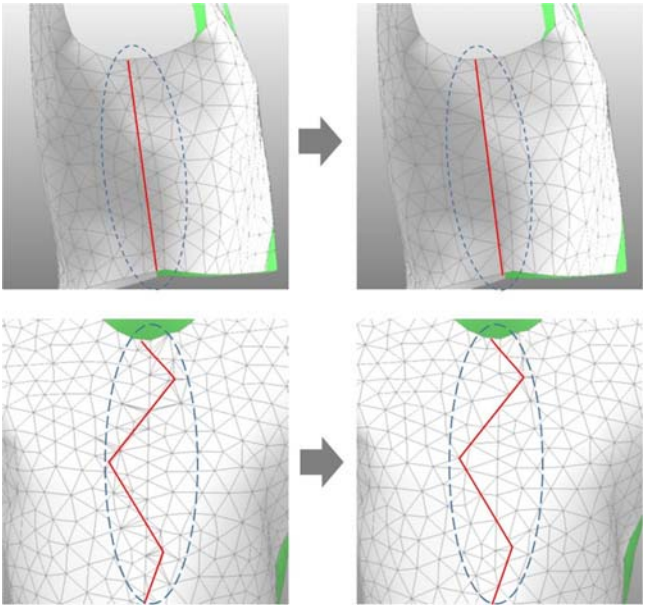


Figure 14.
Examples of mesh reshaping

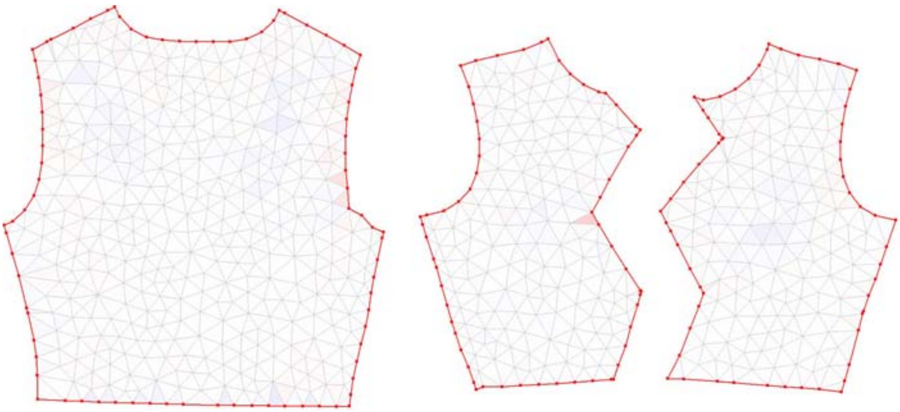


Figure 15.
Examples of projected patches

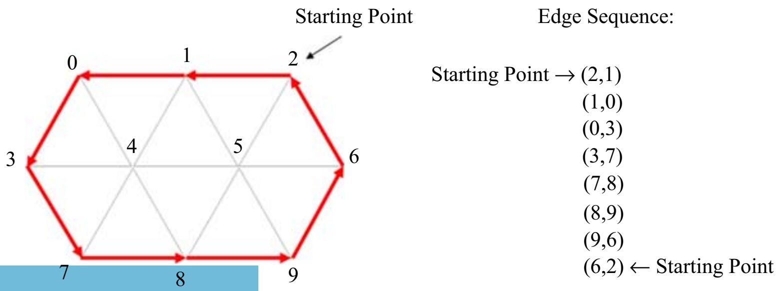


Figure 16.
Schematic diagram of patch outline extraction

المنارة للاستشارات
www.

patches during the projection process. The outlines of the flattened patches were extracted and saved as a DXF file to be further used in other CAD systems. Using the system developed in this study, it is expected that even those who do not have the in-depth knowledge of pattern design will be able to make complex garment patterns. The time required for garment pattern production is also expected to be reduced.

References

Hong, Y., Bruniaux, P., Zeng, X., Liu, K., Chen, Y. and Dong, M. (2017), "Virtual reality-based collaborative design method for designing customized garment for disabled people with scoliosis", *International Journal of Clothing Science and Technology*, Vol. 29 No. 2, pp. 226-237.

Keckeisen, M., Feurer, M. and Wacker, M. (2004), "Tailor tools for interactive design of clothing in virtual environments", *Proceedings ACM Symposium on Virtual Reality Software and Technology*, pp. 182-185.

Kulinska, M., Bruniaux, P., Ainamo, A., Zeng, X. and Chen, Y. (2016), "Virtual mannequins and garment parametrization", *Proceedings of the 12th International FLINS Conference Uncertainty Modelling in Knowledge Engineering and Decision Making*, pp. 984-989.

Li, J. and Lu, G. (2014), "Modeling 3D garments by examples", *Computer-Aided Design*, Vol. 49, pp. 28-41, available at: www.sciencedirect.com/science/article/pii/S0010448513002418

Mitani, J. (2005), "A simple-to-implement method for cutting a mesh model by a hand-drawn stroke", Proceedings 2nd Eurographics Workshop Sketch-Based Interfaces and Modeling, ACM Press, Dublin, August 28.

Turkiyyah, G.M., Karam, W.B., Ajami, Z. and Nasri, A. (2011), "Mesh cutting during real-time physical simulation", *Computer-Aided Design*, Vol. 43 No. 7, pp. 809-819.

Wang, C., Zhang, Y. and Sheung, H. (2010), "From designing products to fabricating them from planar materials", *IEEE Computer Graphics and Applications*, Vol. 30 No. 6, pp. 74-85.

Yang, Y. and Zhang, W. (2007), "Prototype garment pattern flattening based on individual 3D virtual dummy", *International Journal of Clothing Science and Technology*, Vol. 19 No. 5, pp. 334-348.

Yang, Y., Zou, F., Li, Z., Ji, X. and Chen, M. (2011), "Development of a prototype pattern based on the 3D surface flattening method for MTM garment production", *Fibers and Textiles in Eastern Europe*, Vol. 19 No. 5, pp. 107-111.

Zhang, D., Liu, Y., Wang, J. and Li, J. (2018), "An integrated method of 3D garment design", *The Journal of the Textile Institute*, pp. 1-11.

Zhang, Y., Wang, C.C. and Ramani, K. (2016), "Optimal fitting of strain-controlled flattenable mesh surfaces", *The International Journal of Advanced Manufacturing Technology*, Vol. 87 Nos 9-12, pp. 2873-2887, available at: https://link.springer.com/article/10.1007/s00170-016-8669-2

Corresponding author
Sungmin Kim can be contacted at: sungmin0922@snu.ac.kr

For instructions on how to order reprints of this article, please visit our website:
www.emeraldgrouppublishing.com/licensing/reprints.htm
Or contact us for further details: **permissions@emeraldinsight.com**

المنارة للاستشارات

www.

Reproduced with permission of copyright owner. Further reproduction prohibited without permission.

www.