Control of Vibration caused by Excessive Constraints on Human Body Deformation for Tailor-Made Undergarments

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ABSTRACT

In this paper, we propose a stable and natural deformation based on tensegric model with geometric constraints, which are for the surface line length and volume. This method is not only applicable for a free-form deformation, but also for simulating a human body shape constrained by tailor-made undergarments. However, these remains a problem of vibration witch occurs during calculation with excessive constraints. Here, we focus on a method to reduce this vibration and avoid unnatural results of deformation.

Keywords

women's shaping-undergarment, soft tissue deformation, tensegric modeling, FFD.

1. INTRODUCTION

A design of tailor-made undergarments requires not only a good outlook and paper patterns, but also an acceptable reforming result of customer's body. Therefore, it is important to customers to simulate the shaping results when they order.

Most shape deformation methods by FEM [10], anatomy-based, spring-mass system [11], and so on, predict more accurate results, but have difficulties for quick and easy computation by setting boundary conditions and for slower computational speeds.

Then, soft tissue deformation based on tensegric modeling was proposed as a real-time body shape simulation [13]. It works on a tensegric model - a sparser triangular mesh, which approximates the scanned body shape and has a mechanism of tensegrity to behave like a soft material.

The deformation of tensegric model is constrained by the constant volume and the length of specific lines lying on the model's surface, which correlates directly with the size of the undergarments. The body shape is modified according to the deformed tensegric model by using t-FFD (Free Form Deformation by using Triangular Mesh [4]).

However, there is a problem when the tensegric model is deformed with excessive constraints, such as the line length is set as improperly short. A vibration of the tensegric model sometimes occurs at calculating a balance between internal pseudo-forces and external constraining forces.

Our research objective is to propose a method to reduce this vibration and avoid unnatural results of deformation.

2. TENSEGRIC MODELING

Tensegrity is a neologism artificial word composed of "tense" and "integrity" used to represent architectural structures proposed by Buckminster Fuller. The structure is mainly classified into two kinds: The geodesic domes by B.Fuller [14], and the prestress structures by sculptor, K.Snelson [15], [13]. It is thought that various shapes of life forms have a tensegrity structure, such as deformation of cell-shape [16]. More complicated compositions of tensegrity are proposed by networking or accumulating tensegrity units of prestress structures [3], [6], but are not adequate to represent an arbitrary shape which approximates a body shape.

Our proposed system is achieved by employing a tensegric model [7], [5] with t-FFD. A tensegric model is used as a deformable object and a control mesh of t-FFD, witch is used to calculate a deformed body shape.

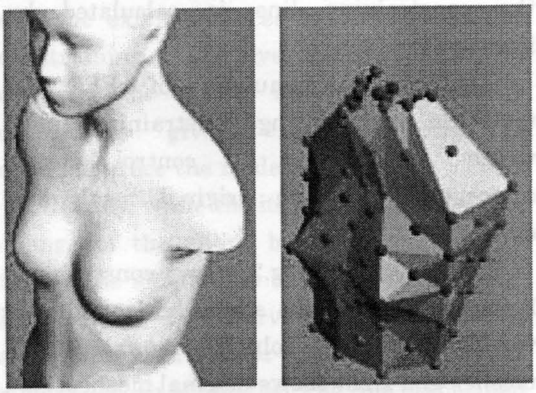
A tensegric structure is a combination of tensile parts and prestressed parts [3], [6] and maintains a whole shape by balancing the internal forces; tension and stress. In order to apply this tensegric model for soft tissue deformation, the structure is generated from an approximated body shape. Then, the model is deformed by constraints, such as fixing the locations of the parts on imposing external forces.

We employ a transformation method "t-FFD" [4] to deform a detailed shape according to the tensegric model. t-FFD is a kind of FFD[2], [9], and it needs an original mesh and a control mesh. When the control mesh is deformed, t-FFD calculates the modified original mesh. Our proposal system uses a body shape as the original mesh and an approximated body as the control mesh. If the control mesh is as much as similar to the original mesh, the deformation result reflects the change of the control mesh more properly. Then, the approximated body is generated using characteristic points detected from the detailed body shape.

For example, Fig.1 shows an original mesh and a control mesh used in this research.

A mannequin is measured by a 3D scanner [1] and represented as a dense mesh (about 62,000 polygons), on an original mesh, shown in Fig.1 (a). The characteristic parts of the body, such as nipples or an under-bust (the area under the bust) are detected, and the parameters of their location and size are extracted.

Then, the geometry of a template polygon is changed to incorporate those parameters and is used as a control mesh of (120 polygons) of t-FFD, as shown in Fig.1 (b). Because the control mesh is not required to be a 2-manifold closed shell by t-FFD, it only covers the deformed part and its surroundings.



(a) (b)

Fig.1: Example of shape models.
(a) An original shape, (b) a control mesh.

3. CONSTRAINING LINE

A constraining line is used to represent a part of undergarments, which contacts to a body and behaves like a rubber band. A constraining line is defined as a constraint on the tensegric model to maintain its length as constraint as possible. The constraining line is polyline with some control points, witch correspond to the control points of the tensegric model. External forces, witch maintains constant length between each control point of the constraining line, are imposed to the tensegric model.

If there are no external forces given to the tensegric model, it is in a self-balancing status and does not change its shape. A natural length of the constraining line is given from the self-balancing tensegric model. The constraining line produces forces according to Hooke's law. When the natural length of the constraining line is changed to be short/long, each segment of the line produces a force to compress/extend its length. This works on the tensegric model as an external force to its control point. A new balancing status of the tensegric models with the constraining line is calculated by iterative manner.

Fig.2 shows a simulation of t-FFD and tensegric model using constraining lines, which constraint a control mesh corresponding to an original mesh like sphere.

Left column of Fig.2 shows constraining lines surrounding the shape horizontally or vertically. Middle column shows control meshes and right shows original meshes.

Middle row of Fig.2 shows initial length of constraint lines, top row shows the case of shorter length, and bottom shows of the longer case. This method with constraining lines is used to simulate body constriction by tailor-made undergarments.

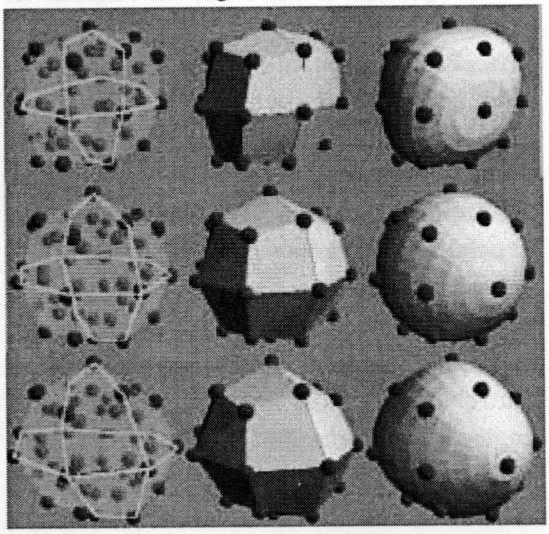


Fig.2: Constraining lines, control meshes, and original shapes.

4. VOLUMETRIC CONSTRAINT

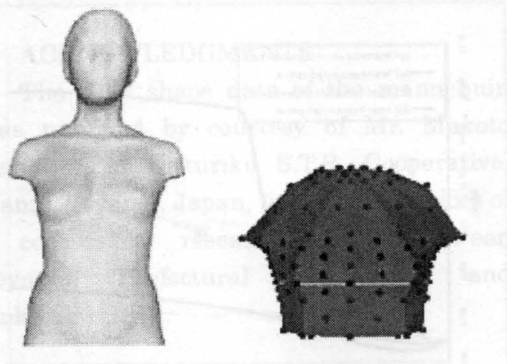
Because a soft tissue is assumed to be deformable and incompressible, the total volume of the deforming body needs to be constrained as unchanged [8]. However, the tensegric modeling does not have a constant volume property. So, we apply a pseudo external force to the tensegric model to maintain the volume of the control mesh during deformation. This volumetric forces are directed outward and act on each control point of the tensegric model as external forces, when the current volume is smaller than the initial volume, and vice versa. Instead of the body shape with a dense mesh, the control mesh is used for volume measurement to save computational cost. We use the control mesh properly fitted to the original shape and t-FFD generates similar deformation between the control and original meshes. Then, a volumetric difference ratio at deformation is thought to be almost same for the control mesh and original shape [13]. Hence, the volumetric constraint is possibly applicable to the control mesh instead of the body shape.

Fig.3 and Fig.4 show an example of body deformation for tailor-made undergarments with a single constraining line across the bust. Constraining line becomes approximately 3% shorter, and the volumetric error is maintained less than 0.1%.

Fig.3 (a) is a human body model, which is measured by a 3D digitizer from a real human. This model has about 65,000 polygons.

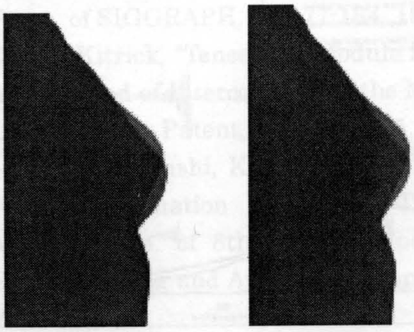
Fig.3 (b) shows a control mesh and control points of tensegric model generated from the human body model. The control mesh is an approximated human body with 168 polygons. The control points are partially fixed not to deform the body except the bust. The constraining line is set between full bust and under bust on the control mesh, shown as white line in Fig.4 (b).

Fig.4 shows deformation results of the human body shown in Fig.3. Fig.4 (a) shows the side views comparing of busts before and after deformation. It shows the bust moving upward as the result of constriction of the constraining lines. Fig.4 (b) shows the comparison of applying volumetric constraint with not applying. It shows that a constraining line suppresses the bust without a volumetric constraint.



(a) (b)

Fig.3: Measured human body and control mesh. (a) Original mesh measured from a real human body, (b) control mesh and control points.



(a) (b)

Fig.4: Side view of original mesh before/after the deformation.

5. CONTROL OF VIBRATION CAUSED BY EXSESSIVE CONSTRAINTS

The calculation of the tensegric model works on iteration. In one turn of iteration, each component part of the tensegric model is moved to a locally balancing position among other parts and external forces. After calculating about the entire parts, the volume and the line lengths are measured and the external forces are refreshed. The constraining lines give external forces to constrict the model, and, the volumetric constraints gives external forces to expand/reduce the model.

Usually, while the iteration advances, the change of the shape becomes smaller and finally the shape gets to a new static state. However, it is observed that the model sometimes vibrates or diverges, especially when a length of constraining line is specified too small with excessive constraints. On the other hand, the vibration does not occur, if the volumetric constraint is not applied

Here, it seems that the vibration is caused by conflicts of volumetric and line length constraints, and volumetric forces to maintain the shape volume are required to control properly. Conventionally, the volumetric force is calculated from difference between the initial volume and the volume measured in the previous turn of iteration. If the forces by volumetric constraints and constraining lines are applied in the similar direction in one turn, these constraints work as over-shot and the forces direct reversely in the next turn, like flip-flopping. And, in the first turn after applying an external force, the internal forces of the tensegric model becomes relatively large to cause an over-shot for local balancing. This causes a vibration or divergence of the model.

Based on these analyses, we propose an

adaptive method to control the volumetric forces according to the changing ratio of the volume. That is, when the ratio is larger, the volumetric forces become smaller, vice versa. This effect works similarly to the dumping factor of the mass-spring system [11].

However, our dumping mechanism is only applied to the critical forces and does not harm to the convergence speed of calculation.

6. EXAMPLE

Here, we compare the two methods to control the volumetric constraints; conventional and adaptive methods. Fig.5 shows human body models and control meshes. Fig.5 (a) is a mannequin measured by a 3D digitizer, and (b) is a real human.

Fig.6 shows the height of the nipples during the iterative calculations. The graph lines (a1) and (b1) represent the results of the conventional method for mannequin and real human models, respectively, and (a2) and (b2) are about the adaptive method. For both of models, the vibrations are reduced by the adoptive method and the converging values become stable and bigger than the conventional method.

Fig.7 shows the error of the volumes during the iteration. The line symbols are same meanings with Fig.6. The adoptive method makes no vibrations and produces significantly smaller error than the conventional one. The real body (b2) gives a bigger error in the initial stage of the iteration. This is thought to be caused by the imbalance of the control mesh, which is produced from asymmetric locations of the characteristic points.

According to these results, an adoptive control of volumetric forces are effective to reduce vibrations.

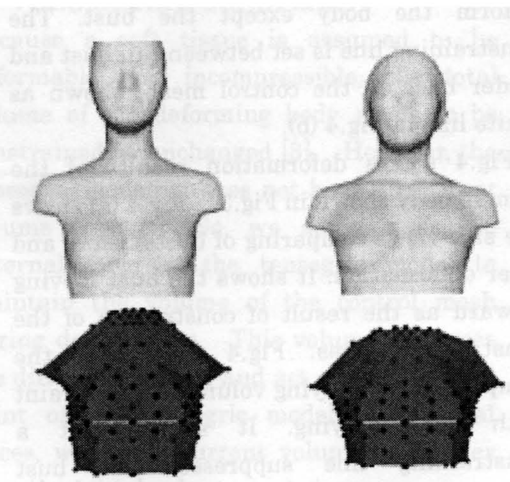


Fig.5: Original meshes and control meshes.

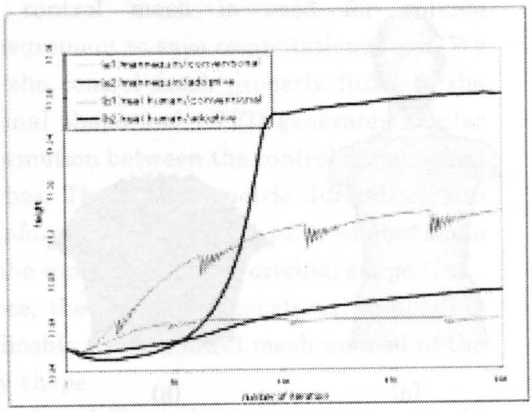


Fig.6: Height of nipples and iteration.

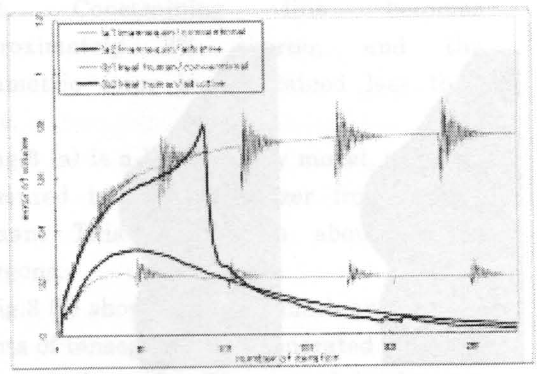


Fig.7: Volumetric error and iteration.

7. CONCLUSIONS

We proposed an adaptive method to control volumetric forces for human body deformation. It reduces the vibration during iterative calculations with excessive constraints for both data of a mannequin and a real human body.

In this paper, the deformation is applied only around a bust. For future extensions to a waist and buttocks for shaping-undergarments, our proposal method is thought to be applicable. Because adaptive control is not specific for the bust, but more general to use changing ratio of the volumes.

8. ACKNOWLEDGMENTS

The body shape data of the mannequin was provided by courtesy of Mr. Makoto Kanatani of Hokuriku S.T.R. Cooperative, Nanto, Toyama, Japan, under the auspices of a cooperative research project between Toyama Prefectural University and Hokuriku S.T.R.

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