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A Technique for Representing Cloth Shapes and Generating 3-Dimensional Knitting Shapes

Tatsushi FUNAHASHI, Masashi YAMADA, Hirohisa SEKI and Hidenori ITOH

Department of Artificial Intelligence and Computer Science, Nagoya Institute of Technology, Gokiso-cho, Showa-ku, Nagoya 466-8555, Japan

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Abstract. In this paper, a method of generating the three-dimensional knitting clothes shapes is described. First, a method of representation of the cloth is described. In this method, a cloth is represented by a mesh, which is a set of vertexes. Next, a method of generating the cloth shapes is described. The cloth covers three-dimensional objects. To generate the shapes, vertexes of the mesh are moved with considering spatial restriction of covered objects. At last, the usefulness of the proposed method is confirmed by execution examples.

1. Introduction

In general Virtual Reality systems, states of three-dimensional objects are represented in computers. The states are changed according to inputs from input devices, and the systems output new states. It is necessary for real-time I/O systems to apply high-speed processing to a large amount of data. Moreover, it is difficult to represent and process complicatedly structured three-dimensional objects efficiently.

In this paper, a method of generating three-dimensional knitting cloth shapes is described. This method generates shapes of cloth covering three-dimensional objects and pastes them with knitting patterns. It is necessary for generating the cloth shapes that spatial restrictions of covered objects are taken into consideration. Therefore, we present a three-dimensional shape generating method considering spatial restrictions of covered objects.

A cloth is represented by a mesh of $m \times n$ vertexes. In process of generating cloth shapes, vertexes are moved under spatial restrictions of covered objects and length of linkage between vertexes. In order to generate a form as soon as possible, this system only the conflict between the vertex composed the cloth form and covered objects.

Knitting patterns are generated by Itoh's method (ITOH *et al.*, 1996a, b). three-dimensional knitting pattern is obtained by pasting the generated shapes with the generated knitting pattern.

2. Representation of the Objects

2.1 Representation of the cloth

The cloth is represented by a mesh of $m \times n$ vertexes, which are arranged in three-dimensional space. A vertex $V_{i,j}$ is linked with $V_{i-1,j}$, $V_{i+1,j}$, $V_{i,j-1}$, and $V_{i,j+1}$. (Fig. 1).

Each linkage is given a length.

2.2 Representation of the covered objects

The covered object is presented by numerical formulas. In example of Fig. 9, one's elbow is composed of two cylinders and one sphere.

3. A Generating Method for the 3-Dimensional Cloth Shapes

3.1 Movement of vertexes

In this section, a movement of vertexes is defined. This movement is applied in order to generate the cloth shape covering three-dimensional objects.

The moving vector $v_{i,j\text{-move}}$ of a vertex $V_{i,j}$ is defined by Eq. (1).

$$v_{i,j-\text{move}} = \alpha \left\{ \sum_{(k,l)\in R} \frac{v_{i,j,k,l}}{\left|v_{i,j,k,l}\right|} \left(\frac{1}{1+e^{-\left(\left|v_{i,j,k,l}\right| - l_{i,j,k,l}\right)}} \left|v_{i,j,k,l}\right| - \beta l_{i,j,k,l} \right) + v_{\text{external}} \right\}, \tag{1}$$

where

- R is the set regrouping all couples (k,l) such as $V_{k,l}$ linked to $V_{i,j}$,
- $v_{i,j,k,l} = \overrightarrow{V_{i,j}V_{k,l}}$,
- $l_{i,j,k,l}$ is a given length of linkage between $V_{i,j}$ and $V_{k,l}$,
- α is a moving coefficient,

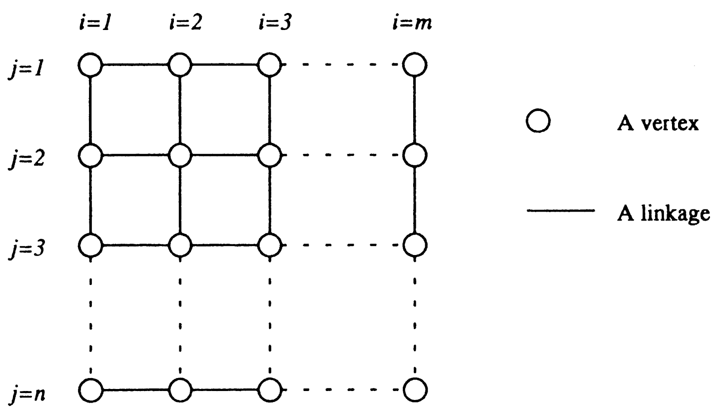


Fig. 1. Data structure of mesh representing the cloth.

- β is a repulsion coefficient,
- v_{external} is input of an external force.

v_{external} represents an external force. For example, gravitation, force of the wind and so on. The moving coefficient α affects the amount of movement at once. If α is too large, interferences between vertexes result and the cloth shape does not become stable. If α is too small, it takes long time to become stable. The repulsion coefficient β affects repulsion between vertexes. If β is zero, repulsion is not affected.

Figure 2 shows correlation between $|v_{i,j,k,l}|$ and $v_{i,j,k,l}$ ingredient in $v_{i,j\text{–move}}$. The horizontal axis is $|v_{i,j,k,l}|$. The vertical axis is the $v_{i,j,k,l}$ ingredient of $v_{i,j\text{–move}}$, provided $\alpha = 1$, $\beta = 0.5$, $l_{i,j,k,l} = 5$, $v_{\text{external}} = 0$. When $|v_{i,j,k,l}|$ is less than 5, a repulsion is generated between $V_{i,j}$ and $V_{k,l}$.

3.2 An algorithm of generating cloth shapes covering 3-dimensional objects

Here, an algorithm of generating cloth shapes is presented. This algorithm takes account of spatial restrictions of covered objects while the system iterates movement of vertexes, and then generates a cloth shape.

This algorithm is as follows.

1) User set initial state.
   - Arrange mesh in the three-dimensional space.
   - Select fixed vertexes among the mesh.
   - Arrange covered objects in the three-dimensional space.
2) User change of environment.
   - Transfers optional vertex to optional position.
   - Move or transform optional covered object.
3) The system calculates $v_{i,j\text{–move}}$.
4) The system move vertexes except fixed vertexes by $v_{i,j\text{–move}}$. If a vertex will be in

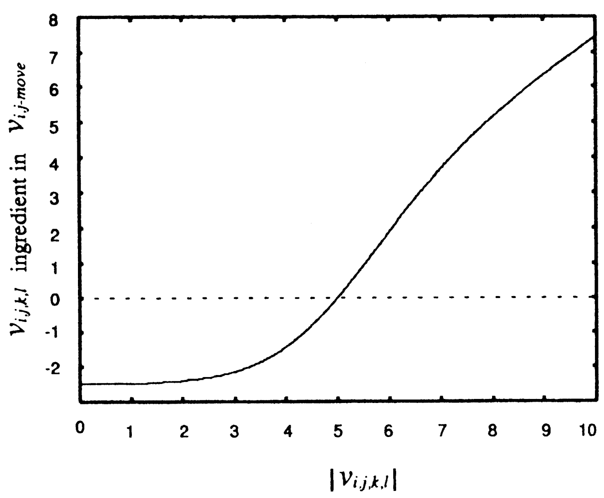


Fig. 2. Correlation between $|v_{i,j,k,l}|$ and $v_{i,j,k,l}$ ingredient in $v_{i,j\text{–move}}$.

the covered object, move the vertex to the nearest outer point of the object.

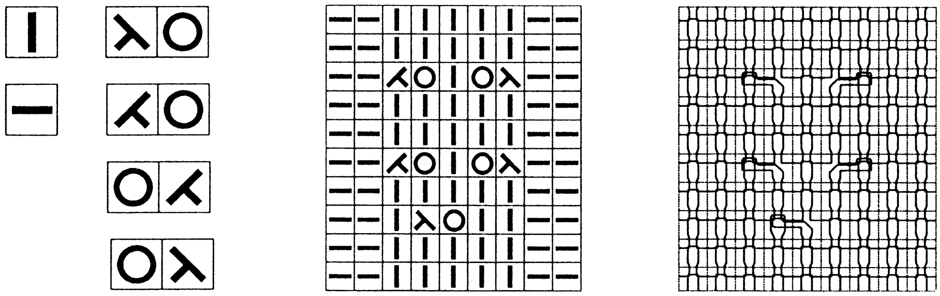
5) The system iterate step 3) until every vertex becomes stable. “vertex $v_{i,j}$ becomes stable” means that a length of $v_{i,j\text{–move}}$ is almost zero.

6) Return to 2) or end.

4. A Transformation Technique from Stitch Symbols to Knitting Patterns

We have already proposed a method of generating knitting patterns from stitch symbols (ITOH *et al.*, 1996a, b). The stitch symbols (Fig. 3(a)) are defined by JIS (Japanese Industrial Standards), which shows a basic stitch pattern.

This method, first, generates an initial string diagram (Fig. 3(c)) from a pattern knitting diagram, where the pattern knitting diagram is a combination of stitch symbols (Fig. 3(b)). In this process, the string diagram database as Fig. 4 is used. Stitch symbols are replaced with corresponding string diagrams by referring the string diagram database.



(a) Stitch symbols

(b) A pattern knitting diagram

(c) An initial string diagram

Fig. 3. Stitch symbols, a pattern knitting diagram and an initial string diagram.

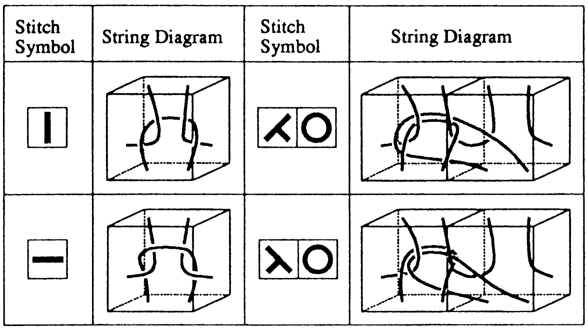


Fig. 4. An example of stitch pattern database.

This method, next, generates a knitting pattern from the initial string diagram. In this process, cross points (where two strings cross) in the initial string diagram are moved by tension of string. When cross points are moved, topology of string diagram does not change. For minimizing the number of crossings and the total string length, the system iterates *Reidemeister movements* (KAUFFMAN, 1987a) as shown in Fig. 5.

An generating example is shown in Fig. 6. Figure 6(b) is a knitting pattern generated from the pattern knitting diagram (Fig. 6(a)).

5. A Method for Pasting the Cloth Shapes with Knitting Pattern

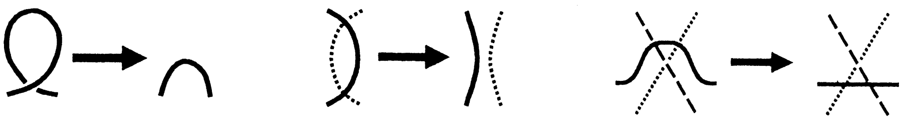
Three-dimensional knitting cloth shapes are generated by pasting the three-dimensional cloth shapes with knitting patterns. This process is shown in the following steps 1), 2), 3) and 4) (Fig. 7).

1) The knitting pattern is partitioned into $(m-1) \times (n-1)$.

2) The square, which is formed from $V_{i,j}$, $V_{i+1,j}$, $V_{i+1,j}$, and $V_{i+1,j+1}$, is corresponded to each partitioned knitting pattern.

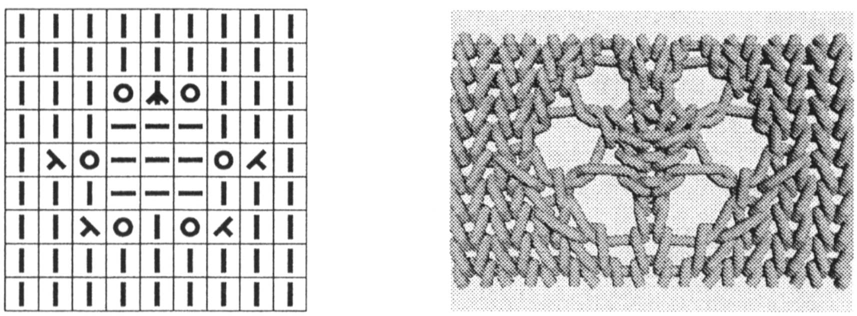
3) Each partitioned knitting pattern transforms into the same shape of the corresponding square.

4) Pasting the corresponding square with each transformed knitting pattern.



(a) (b) (c)

Fig. 5. Reidemeister movements.



(a) An input pattern-knitting diagram (b) An execution example

Fig. 6. A generating example of knitting pattern.

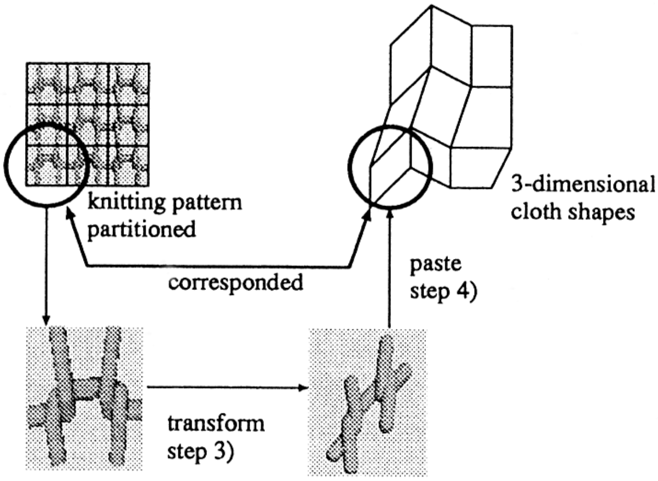


Fig. 7. Process of generating a 3-dimensional knitting cloth shape.

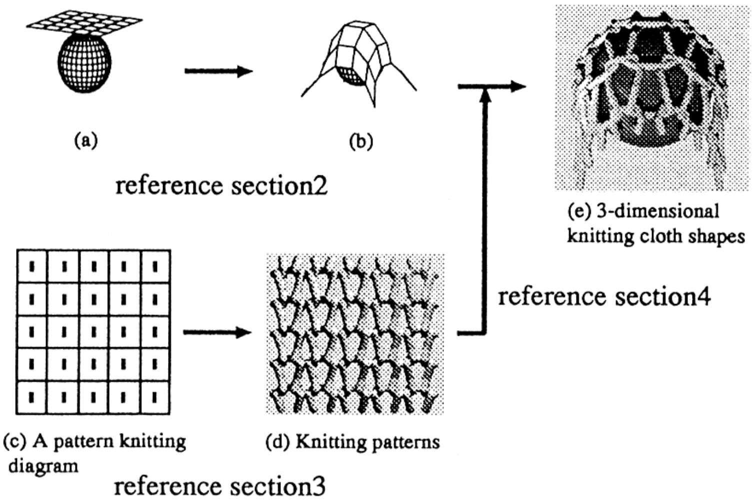


Fig. 8. A completed the 3-dimensional knitting cloth shape generating system.

6. 3-Dimensional Knitting Cloth Shape Generating System

In this section, three-dimensional knitting cloth shape generating system is described. Figure 8 illustrates the scheme of the system.

First, the system generates a three-dimensional cloth shape by using the method described Sec. 3. In this method, A mesh and a covered object are arranged in three-dimensional space such as Fig. 8(a). Some vertexes of the mesh are selected and moved to any position by user and they are fixed. Then, the other vertexes of the mesh are moved by Eq. (1) until the shape becomes stable. In Fig. 8(b), four corner vertexes were selected and moved to under and fixed. Then, the other vertexes are moved by Eq. (1) until the shape becames stable.

Next, the system generates a knitting pattern from stitch symbols by using the method described Sec. 4. Figure 8(d) shows a generated knitting pattern from stitch symbols of Fig. 8(c).

Finally, the system pastes the three-dimensional cloth shapes which the generated knitting patterns by using the method described Sec. 5 and generates a three-dimensional knitting cloth shape such as Fig. 8(e).

7. Examples

In Fig. 9, the elbow is simulated. The mesh has 50×20 vertexes. A vertex $V_{i,j}$ is linked with $V_{i-1,j}$, $V_{i+1,j}$, $V_{i,j-1}$ and $V_{i,j+1}$. In addition, $V_{i,1}$ is linked with $V_{i,20}$. The mesh form is a cylinder in the initial state. The covered objects are two cylinders and one sphere, they

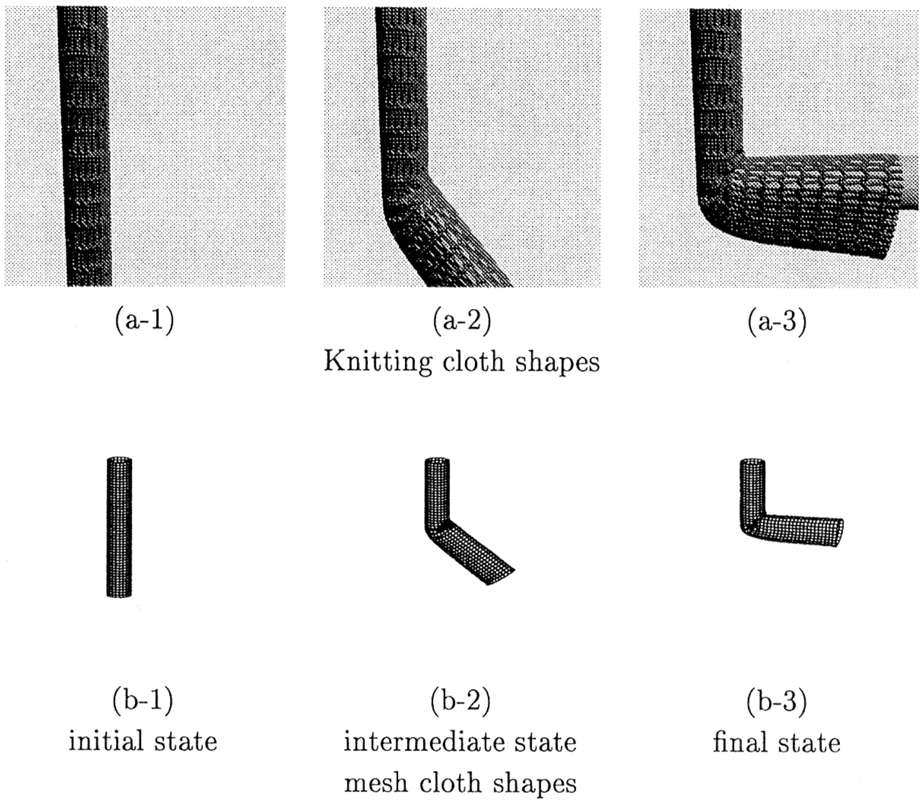


Fig. 9. An example (simulate the elbow).

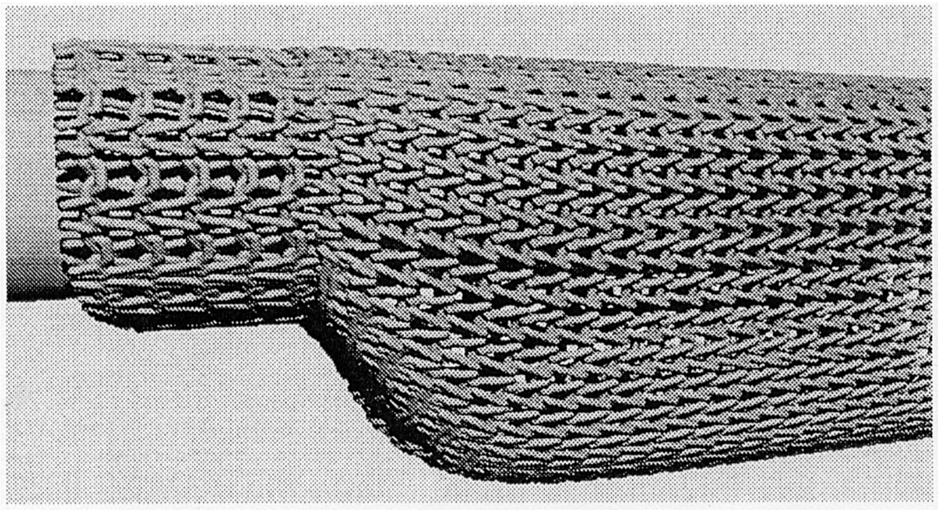


Fig. 10. An example (simulate the sleeve).

means the upper arm and the forearm. At change of environment a cylinder, that means the forearm, is raised little by little. In this example, parameters are $\alpha = 0.1$, $\beta = 0.5$, $l_{i,j,k,l} = 5$ and v_{external} is zero vector.

In Fig. 10, the sleeve is simulated. The mesh has 30×20 vertexes. A vertex $V_{i,j}$ is linked with $V_{i-1,j}$, $V_{i+1,j}$, $V_{i,j-1}$ and $V_{i,j+1}$. In addition, $V_{i,1}$ is linked with $V_{i,20}$. The mesh form is a cylinder in the initial state. The covered object is a cylinder that means the forearm. v_{external} is down force that means gravitation. Given length of linkage at the cuff is shorter than other place. In this example, parameters are $\alpha = 0.1$, $\beta = 0.5$, $l_{i,j,k,l} = 2$ at a cuff, $l_{i,j,k,l} = 5$ at other place and $v_{\text{external}} = (0,0,0.2)$.

8. Evaluation

8.1 Correlation between moving coefficient α and processing time

Figure 11 shows correlation between moving coefficient α and processing time. If α is large, the processing time is short. However, if α is too large (in this example $\alpha = 0.18$), interference between vertexes result and the three-dimensional shapes does not become stable. In this case generated forms are shown in Fig. 12.

8.2 Effect of repulsion coefficient β

Figure 13 shows two generated knitting patterns. The left side and right side patterns are generated under $\beta = 0.0$ and $\beta = 0.5$ respectively.

When $\beta = 0.5$, the knitting pattern has loose. However when $\beta = 0.0$, the knitting pattern has no loose. Table 1 shows total length of string constituting knit and its ratio to the total length of initial state. It's obvious that knitting pattern shrinks, when $\beta = 0.0$.

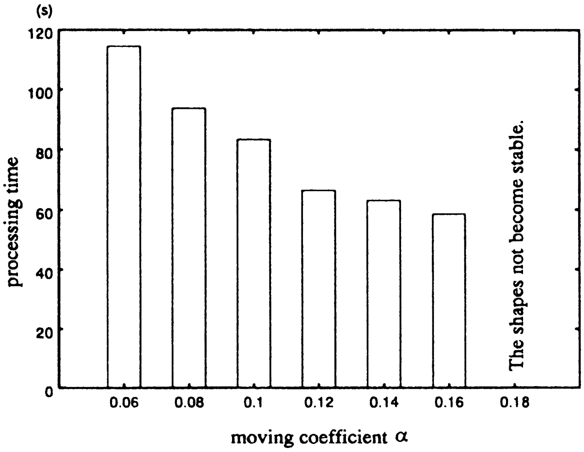


Fig. 11. Correlation between moving coefficient α and of processing time.

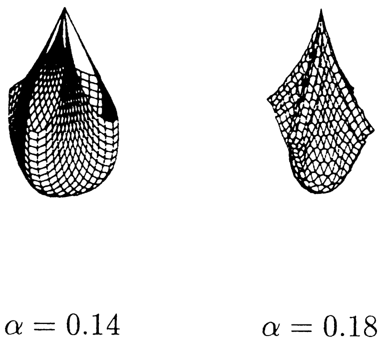


Fig. 12. Comparison between α = 0.14 and α = 0.18.

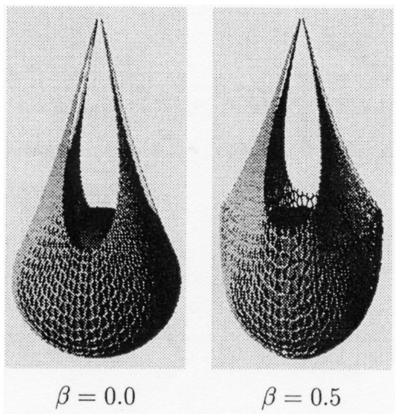


Fig. 13. Comparison between β = 0.0 and β = 0.5.

Table 1. The total string length and ratio to the length of initial state.

	Initial state	β = 0.0	β = 0.5
Total length	15954	14337	16557
Change ratio	100%	89.9%	103.8%

9. Conclusion

In this paper, we propose a method of generating knitting cloth shapes. In this method, the cloth shape is represented by a mesh and vertexes in the mesh moved under spatial restrictions of covered objects. In addition, repulsion of between vertexes is utilized to prevent shrinking the shape. The generated shapes are pasted with knitting pattern generated from stitch symbols.

In order to generate a form as soon as possible, this system only the conflict between the vertex composed the cloth form and covered objects. Therefore this system can generate an impossible form in real world.

In a future work, we will examine a method of generating loose of the inside bend of his elbow.

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