Three Dimensional Apparel CAD System

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Abstract

We are developing a three dimensional (denoted 3D, hereafter) CAD system for garments to help the process of pattern making. This is a process to create a 3D form of a garment by designing a two dimensional (2D, hereafter) paper pattern that realizes the 3D form. The core of the system is a simulator that estimates the 3D form of a garment put on a body from its paper pattern (2D→3D process) and a developing program to obtain the 2D pattern that minimizes the energy required to deform it to the given 3D shape (3D→2D process). In both processes, the specific anisotropy of the mechanical properties of cloths is considered. In the 2D→3D process, the contact problem with body and geometrical nonlinearity are also taken into account. The preprocessor for the 2D→3D simulator is quite unique in that it converts an arbitrary 2D paper pattern into a 3D surface, considering the topological operation, 'sewing'. Both the 2D→ 3D process and the 3D→2D process are formulated as nonlinear energy-minimum problems, and they are solved by our original method in about 10 minutes with our workstations. Once the 3D form is obtained, the color pattern of a given cloth is mapped and displayed. As a consequence of the mechanical calculation, the distributions of the distortion and stress of the cloth are also visualized. Such information may contribute to the design of garments with consideration of physical attributes as well as visual beauty.

1. Introduction

The apparel industry is one of the fields where utilization of CAD systems dates back to the early age of computer graphics. However, still now, apparel CAD systems remain only for the treatment of 2D objects - paper patterns and color patterns of textiles, while CAD systems for other products can check the final results of designs by way of 3D views. This is mainly because of the gap between the 2D paper patterns and the 3D form of the garments. In fact, the mechanical analysis of a dress draping along a human body bears most of the difficult problems found in structure analysis, such as contact and friction with the body, large deformation non-linearity, and extreme anisotropy of materials. Although there has been some research conducted to analyze or simulate the formation of a 3D form of garments on the basis of material mechanics[1,2,14], these studies did not take the form of applicative general purpose systems. On the other hand, there are some apparel oriented graphic editors that allow local distortions of the picture imitating the 3D view. Once such distortions are defined by hand, then any pattern of cloth can be substituted into these places. In some cases, the 3D coordinates of an actual garment corresponding to the lattice points of a 2D cloth are measured, and pattern mapping onto a true 3D surface is realized[13]. Though such systems are effective for designing color patterns of clothes, they lend no aid for the design of the 3D form itself. Also we cannot forget to mention about the attractive studies which have presented the motions of cloth in wind[9,15]. Though, the ultimate goal must be the same (i.e. true dynamical simulation of the dress, body and the air), the present direction of these studies seems to be different from ours.

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Therefore, the system introduced here may be considered to be the first 3D apparel CAD system because it supports the mechanical analysis of draping from a 2D paper pattern to a 3D form, the development of a 3D surface to a 2D pattern, and the preprocessing which accepts arbitrary paper patterns for input. Although there is still a gap between our present system and commercial systems of the future, we are developing this system with the intention that it will be used by a wide variety of people. This is reflected in the fully automated preprocessor, where one need only to indicate the lines to be sewn together and the lines consisting of the waist or neck line, and our selection of robust methods all over the system, where no delicate regulation is required. But this does not mean that the true mechanics is sacrificed in this system. We rather believe that the fidelity to the natural process is a key for the clarity and easiness of such a system.

Due to the limitation of space, it is impossible to discuss the techniques used for the implementation of this system in detail. Several parts of the system including the formal mathematical expressions, have been published already[5,7,8,11]. However, we think that the concepts and structure of this system are more important than the implementation technique, and we believe that

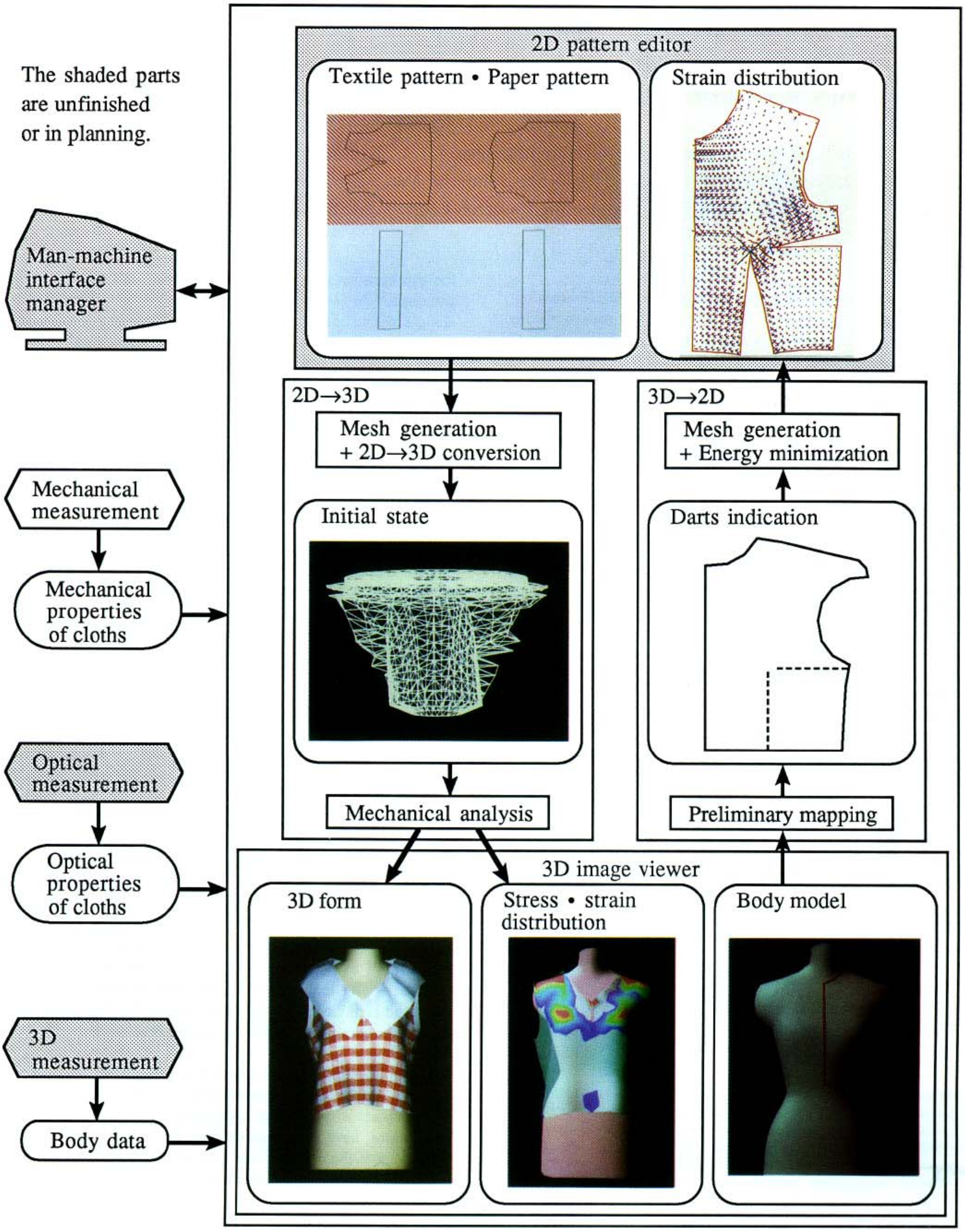

Figure 1 An outline of the 3D apparel CAD system

our system shows a basic framework for 3D apparel CAD. This means two things: First, this will provide a common ground or starting point for further discussions in this field. Second, the results of such discussions will be easily implemented and tested by refining or replacing some components of this system.

2. Overview of the system

An overview of the system including our future plan is shown in Fig.1. Though the textile editor and 2D pattern editor are expressed as different processes in the figure, it is only an expedient for explanation. As is observed in some programs for drawing, these two editors can be superimposed as two layers of a 2D graphic editor. Actually, our most important and urgent subject is to prepare an elegant and integrated interface between a user (designer) and our system. As a primitive form of such an interface, we have already developed a command procedure which provides the control of the execution of programs, file assignment and file management. But, with the ability of current graphic workstations, we can expect a much more comfortable and efficient work environment for designers. Especially, three graphic programs, textile color pattern editor, 2D paper pattern editor, and the 3D image viewer should be incorporated so as to reflect instantaneously the changes given in one view to others. That is, the cursors in the 2D view and 3D view should always point at the corresponding position of the cloth, and if one alters the color of a pixel of the cloth in the 2D view, it should be mapped to the 3D surface at the same moment, and vice versa.

The visualization of various mechanical properties of garments such as the distribution of normal stress (which is equal to the body contact pressure) must be especially useful for the design of underclothes and sportswear. In the future, provided with a more precise mechanical model for human bodies and a 3D measurement system, this ability of our system may contribute to furnish all clothing with a perfect fit of custom-tailoring.

In Fig.2, we show the position of our system in the whole process of the design and production of garments. It should be noted that both textile design and apparel design can be parallelly or synchronously processed by our system, though, traditionally, they are thought to be in serial relation. There is a special implication in the connection between our system and the manufacturing process of clothes. Our data structure for paper patterns contains the description of how the parts of a dress are sewn together and how the dress is to be put on the body. The fact that our CAD system can simulate the formation of the final shape of a dress, assures that the information given by this data structure is sufficient to indicate how the parts should be assembled and sewn in apparel CAM or an automated sewing system.

The old version of our system was written by FORTRAN and we utilized CORE for 3D views and PLOT10 for 2D views. The present version utilizes PHIGS or IDEAS for both 3D and 2D views. Now we are rewriting the whole program in C or C++ for the explicit treatment of the data structures, easy interface with advanced graphic libraries, and convenience for use at workstations.

The requirement for our system for the memory is very humble. The most demanding step is the mechanical analysis, but it requires no more than 3M bytes for the structure, including up to 4000 triangles (6000 variables). The most time consuming step (that is, of course, the mechanical analysis) is finished within 10 minutes for typical structures containing 1500 triangles by floating point calculation oriented workstations. We suppose that this is not an unbearable time for designers because the corresponding conventional process to sew up a prototype dress needs one day or more.

3. Preprocessor - conversion from 2D to 3D

Making a system that accepts various inputs is completely different from writing down a program that calculates a special problem. This preprocessor for mechanical analysis is the main source of the difference from other studies simulating cloths. In addition to the usual mesh generation, our preprocessor has a

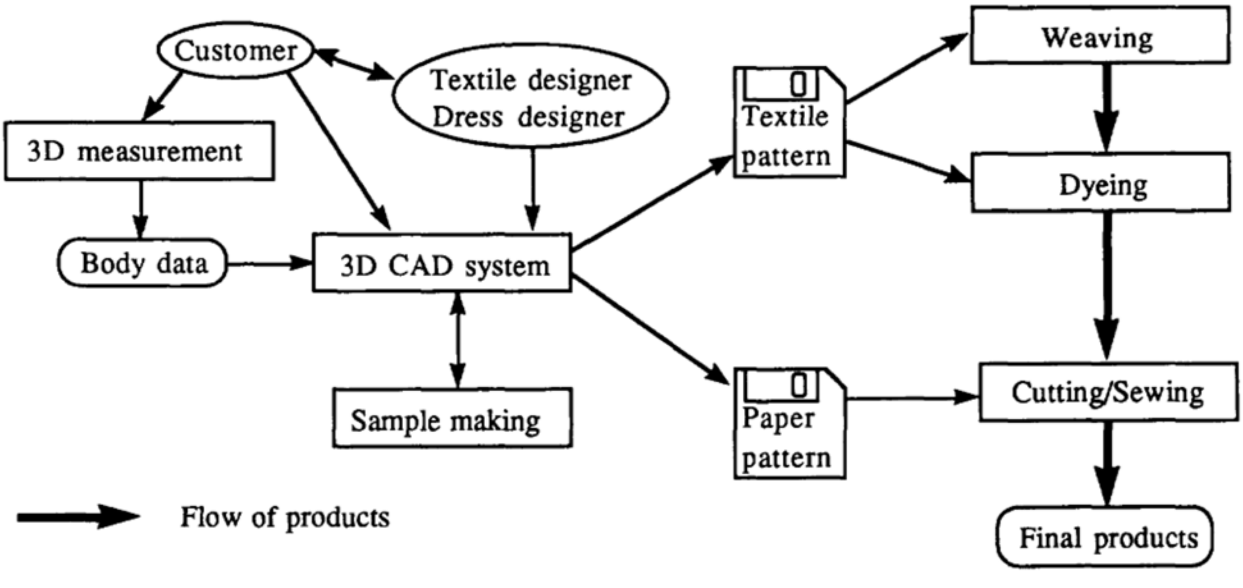

Figure 2 The position of the 3D CAD system in apparel industry in the future.

remarkable function to convert a 2D paper pattern into a 3D structure, which may be characteristic to 3D apparel CAD systems.

First, we input the 2D shape of each piece of a paper pattern as a collection of curved lines, assign the lines to be sewn together, and mark the lines which are to be put at some characteristic position of the human body (e.g., waist line). Precisely, this is a task of the 2D paper pattern editor.

Then the computer generates a triangular mesh on each piece, considering that the lines to be sewn together should be divided with the same proportion along each arc length, even though they have mutually different shapes and lengths. We call this mesh in the 2D plane the P-mesh. Next, the topological structure of the 3D garment (S-mesh) is obtained by unifying the edges and vertices of the P-mesh indicated to be sewn together. The correspondence between the triangles of the S-mesh and those of the P-mesh is one to one, while an edge or a vertex of the S-mesh may correspond to two or more elements of the P-mesh. At this point, the 3D coordinates of the vertices of the S-mesh are left open. The data structures for the P-mesh and S-mesh are designed to satisfy the definition of the two dimensional sim-plicial complex, and this facilitates the utilization of the concepts and results of elemental topology.

The last step is to fill in the 3D coordinates of the vertices of the S-mesh with appropriate values, providing a good initial state for the mechanical analysis. Let us take an example as in the case of a skirt. First, the vertices on the lines that are designated to be put at the waist line (we denote these vertices as the 0th layer vertices) are given the 3D coordinates along the waist line of the human body model. Then, each vertex adjacent to the $(i\text{-}1)$th layer vertices in the S-mesh is classified to be the ith layer, and they receive 3D coordinates $(k_i x, k_i y, z\text{-}a_i)$, where x, y and z are the average of the coordinates of adjacent vertices in the $(i\text{-}1)$th layer, and k_i and a_i are determined by the standard mesh size and the numbers of vertices in the $(i\text{-}1)$th and ith layers. We regard this step as an analog of the process to put a dress on a human body. As the standard characteristic portions of the human body for this step, we selected the neck line, arm holes, waist line (for skirts) and crotch-waist lines (for pants).

4. Mechanical analysis

The mechanical elements considered in the present version of our system are expressed by the following energy terms:

$$E = E_{au} + E_{av} + E_{sh} + E_{bu} + E_{bv} + E_{tw} + E_g + E_p ,$$

where E_{au} and E_{av} are elongation energies, E_{sh} is the shearing energy, E_{bu} and E_{bv} are bending energies, E_{tw} is the twisting energy, E_g is the gravitational energy and E_p is the energy of a potential function of which the value is 0 at the outside of the body and Kd^2 inside the body, where d is the distance from the surface of the body and K is an appropriate large value. Note that the deformation energy terms E_{au}, E_{av}, E_{sh}, E_{bu}, E_{bv} and E_{tw} should be calculated by referring to the original position of each triangle in the P-mesh, because the directions of the warp (u-axis) and weft (v-axis) in the 2D pattern determine the anisotropic properties of each triangular element in the S-mesh. The term E_p is known as the penalty function for the violation of the boundary condition. From the viewpoint of treating the human body as a deformable object, the penalty function method is not an expedience, but is the first order approximation, while a completely hard surface corresponds only to the 0th order approximation.

We do not take into account the mutual interference of each part of cloth, because it requires a large amount of calculation[4]. So, it sometimes happens that two different parts of cloth penetrate each other, causing a destructive effect for the 3D view. Presently, the appearance is covered by shifting one part upward, but we recognize that this is not the true resolution, and we are determined to take up this problem in the near future.

Our method for finding the minimum point of the energy function highly contributed to the development of this system, with its robustness, efficiency and compactness by means of both the program size and data memory area. It can be classified as a mutant of the steepest descent method, but, since we control the size of the step in each variable independently, the total vector of one step is no more directed to the gradient of the energy function. The spirit of the step control is very simple. One step is tried to the decreasing direction of the energy. If the value of the partial derivative of energy by that variable does not widely change, one can proceed more boldly, i.e. with a larger step. If the value of the partial derivative widely changes (for example, the sign changes), then one should reduce the scale of the step the next time. Though it is not mathematically proven for general cases, many experiments showed that this method never loses control and it ends in a certain minimum solution. Moreover, we tested this method with many classical sample functions known to be difficult to attain the minimum, and its robustness and efficiency were well confirmed.

5. Development from 3D to 2D

It is natural to think that it would be quicker and more straightforward to make a 2D pattern directly from a 3D form by developing or flattening it. However, with more consideration, it is noticed that the process to flatten a curved surface to a plane is different from the process to force a pattern on a plane to take the form of the given curved surface, and the real process to make a dress from an undeformed cloth is equivalent to the latter. So, we solved a sort of inverse problem to obtain a 2D pattern that will take the given 3D form after its spontaneous deformation, as follows.

Although there are some trials[3], it is not easy to define and edit a curved 3D surface of a human body or a garment with standard I/O devices of present graphic workstations. Therefore, we project the domain of the 3D surface with a preliminary mapping Φ, in order to obtain an initial shape of the 2D pattern. Here, we use a very simple Φ that maps a point on the body expressed as (r,θ,z) by the cylindrical coordinate system to a point $(r_0\theta, z)$ by the two dimensional Cartesian coordinate system, where r_0 = 10cm. Then we define some darts in the initial 2D pattern and generate a P-mesh on it. Next, we operate the inverse map of Φ to the vertices of the P-mesh to obtain the S-mesh. This time, we consider the energy E required to deform the P-mesh to the S-mesh as a function of the 2D coordinates of the vertices of the P-mesh, and the minimization problem of E is solved by the same method for the 2D →3D simulation. Since E_p is independent from the uv coordinates of vertices, it is omitted in the minimization. We also neglect E_{bu}, E_{bv}, E_{bv}, E_{tw} and E_g since the changes of these terms are higher order functions of the infinitesimal deformation of the S-mesh. As a result, the final shape of the 2D pattern and the distribution of the

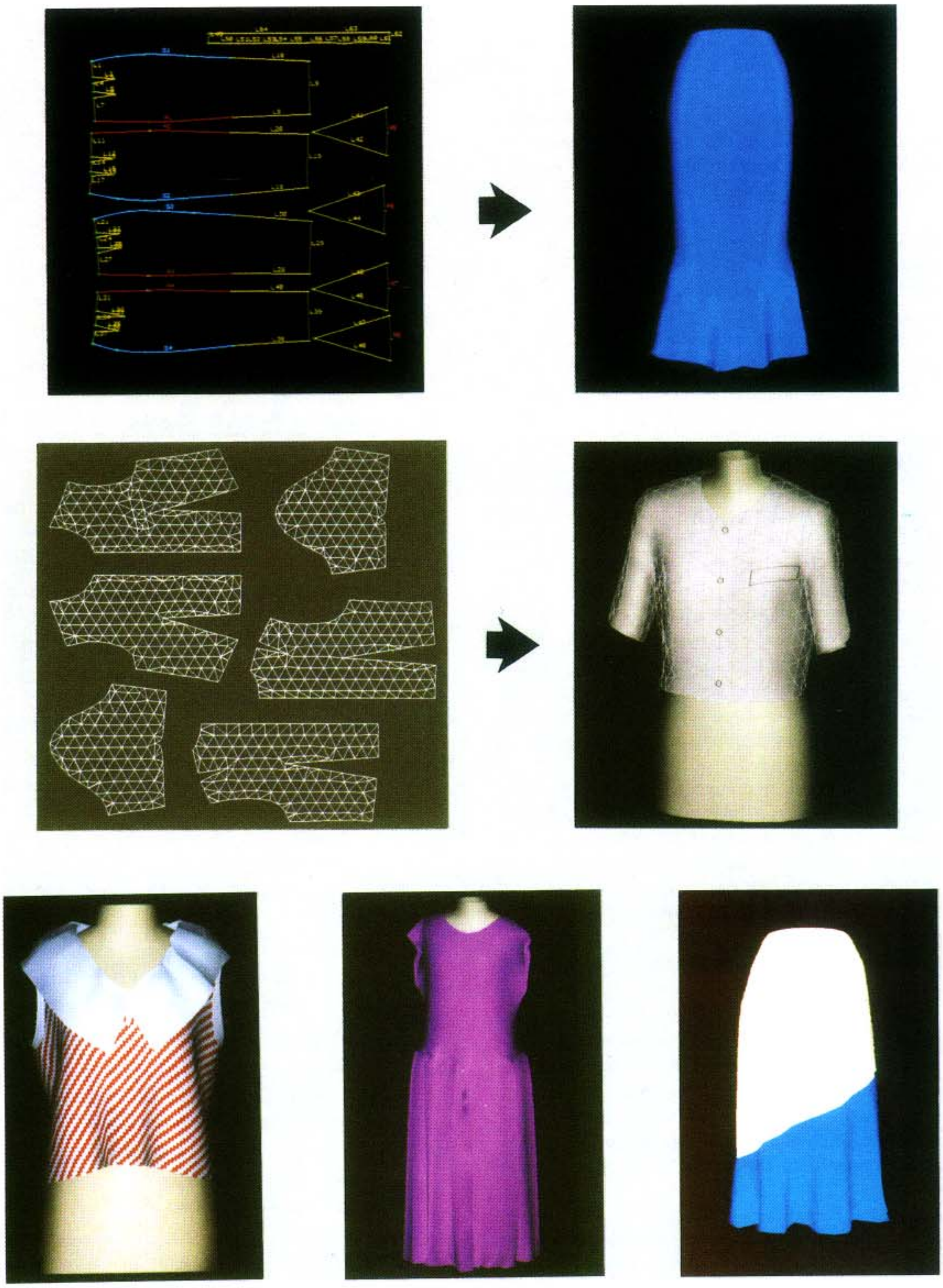

Figure 3 Examples of simulated garments and their paper patterns

residual strain that could not removed by the darts are displayed.

There is no guarantee that the developed 2D pattern will take the very indicated 3D form because the cloth is no more constrained on the indicated surface in the natural draping process. In other words, there are 3D forms that can never be realized by draping. Therefore, the developed pattern should be checked by the 2D→3D simulator, and it should be modified until a satisfactory 3D drape form is obtained.

6. Further results and future problems

Some experiments were made to check the agreement between the real material and the results of the calculations[6]. The differences of the draped shapes were no more than 3% of the length of the cloth in the standard experiments using rectangular specimens and less in the experiments using actual skirts. Considering that displacement of specimens by deformation is very large and that some percentages of variance in the mechanical properties of a given cloth are usual, the agreement is satisfying. The results of the measurement of the contact pressure were more striking. We observed that even the smallest sensor embedded in the contacting object caused a concentration of pressure, and the total stress always exceeded the weight of the specimen. On the other hand, the total stress and the weight agreed precisely in our simulation[10].

The mechanical parameters of fabrics used in our system were measured by KES, a fabric measuring system developed by S. Kawabata. But when compared with hard materials like metals, our knowledge about the mechanical properties of cloths is still very incomplete and there are many problems in deducing mechanical parameters for our simulation from the results of measurements.

Although they are not considered much in our present system, the optical surface character and 'matière' of cloths are very diverse, and they are important factors in the appearance of garments. There are some trials to model and visualize the touch of cloths[16,17], but recognizing the variety from velvet to gossamer and from silk to leather, we realize that this is still a vast area to be explored.

Precise and quick measurement of a 3D form of an object is very important in obtaining human body shapes and comparing the forms of actual garments with computed ones. At present, our model for the human body is based on a dress dummy measured by a contact type 3D digitizer. But in the future, the measurement of a customer's body in various postures or even in motion may be required. In response to such a request, we are now engaged in the research of a 3D measurement system based on color pattern recognition and multi-TV camera stereoscopy[20].

Our system may have more applications. Paper is another highly deformable 2D material widely used to produce 3D forms and we have a special concern in simulating paper crafts or *origami*, a highly geometrical traditional art of Japan. Our system may be interesting from the viewpoint of computational topology. As sewing and draping accompany large deformations, the mesh structures and their operations defined in our system should be firmly based on topology. In turn, our system can help the visualization of topological operations since it can simulate the widely used rubber film model in topology.

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