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Study on Interactive Cloth Simulation Considering Airflow

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Abstract. We propose the interactive cloth simulation considering airflow. For this purpose, the implicit method and airflow model are introduced. Also, a computer mouse and a microphone are used as the interface of handling and airflow. As a result, we could simulate the behavior of cloth depending on handling and airflow on real time.

Keywords: cloth simulation, interactivity, airflow, real time

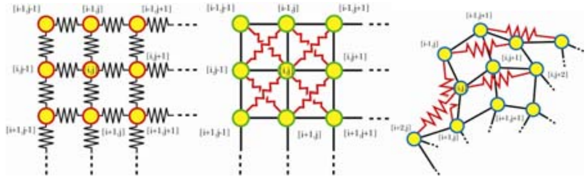
1. Introduction

Recently the social structures have shifted from the mass production and mass consumption society to the production of many models in small quantities that regards tastes and personalities for each individual. Multimedia technologies are expected to realize such a production system, and they are applied to various fields. In the apparel field, makers also require technologies to realize the on-demand production system that design and product for each individual, a computer simulation is expected to be one of the most important technologies. Up to now cloth simulators that are able to predict the shapes of garment from patters and human body shapes have developed, they are used for design, exhibitions, and so on [TER, 87] [CAR, 92] [PAS, 95] [IMA, 89] [IMA, 89] [BRE, 94] [HOU, 98] [JOH, 89] [LUC, 91] . However, almost all cloth simulators that predict the garment shapes based on preselected patterns and human body shapes are impossible to simulate the behavior of garment on real time according to ever-changing real world; for example, human's movement, airflow, and so on. In brief, they lack interactivity with real world. Therefore, in this paper we present the development of the cloth simulator that enables to interact with real world on real time. In this research, the most important thing is implementation of interactivity and real time processing for cloth simulation rather than the preciseness. Because the situation of exhibition including virtual catalogue requires the speed and interactivity rather than the accuracy of simulation. In particular, we propose the method to simulate the manipulation of cloth and the behavior of cloth in airflow.

2. THEORY

In this research, we introduce the simple mass-spring model as a cloth model because it is possible to calculate the cloth behavior in short time. In the implementation of interactivity and real time operation, it is more important rather than the precise representation of mechanical properties of cloth. Also we use the implicit method which is stable even large time steps as a numerical integration method in order to shorten calculation time.

2.1. Cloth model



a) stretching-compression model b) shearing model c) bending model

Fig.1 Structure of mass-spring model

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Spring-mass model consists of network of a lot of mass and spring, and it can represent mechanical properties of cloth by network structures of mass [XAV, 95]. Mechanical properties of cloth influence mainly stretching-compression, shearing, and bending. Fig.1 shows representations of each deformation.

2.2. Implicit method

We introduce the implicit method to shorten the calculation time and to stabilize the cloth simulation. With the implicit method, a stability of simulation is guaranteed at arbitrary time step dt in equation (1). The behaviors of mass point are represented by implicit Euler method as follows [DAV, 98].

$$\begin{aligned} \mathbf{v}^{n+1} &= \mathbf{v}^{n} + \left(\mathbf{I} - \frac{dt^2}{m}H\right)^{-1}\left(\mathbf{F}^{n} + H\mathbf{v}^{n}dt\right)\frac{dt}{m} \\ \mathbf{x}^{n+1} &= \mathbf{x}^{n} + \mathbf{v}^{n+i}dt \end{aligned} \tag{1}$$

F is force vector acting each mass point, **v** is velocity vector of each mass point, **x** is position vector of each mass point, m is mass of each mass point, dt is time step, n is mass point number, **I** is identity matrix, and H is matrix related to the cloth deformation. Matrix H is defined following depending on deformations.

Stretching-Compression deformation

$$H = k\begin{bmatrix} -2 & 1 & 0 & 1 & 0 & 0 & 0 & 0 & 0 \\ 1 & -3 & 1 & 0 & 1 & 0 & 0 & 0 & 0 \\ 0 & 1 & -2 & 0 & 0 & 1 & 0 & 0 & 0 \\ 1 & 0 & 0 & -3 & 1 & 0 & 1 & 0 & 0 \\ 0 & 1 & 0 & 1 & -4 & 1 & 0 & 1 & 0 \\ 0 & 0 & 1 & 0 & 1 & -3 & 0 & 0 & 1 \\ 0 & 0 & 0 & 1 & 0 & 0 & -2 & 1 & 0 \\ 0 & 0 & 0 & 0 & 1 & 0 & 1 & -3 & 1 \\ 0 & 0 & 0 & 0 & 0 & 1 & 0 & 1 & -2 \end{bmatrix} \tag{2}$$

Shearing deformation

$$H = k\begin{bmatrix} -1 & 0 & 0 & 0 & 1 & 0 & 0 & 0 & 0 \\ 0 & -2 & 0 & 1 & 0 & 1 & 0 & 0 & 0 \\ 0 & 0 & -1 & 0 & 1 & 0 & 0 & 0 & 0 \\ 0 & 1 & 0 & -2 & 0 & 0 & 0 & 1 & 0 \\ 1 & 0 & 1 & 0 & -4 & 0 & 1 & 0 & 1 \\ 0 & 1 & 0 & 0 & 0 & -2 & 0 & 1 & 0 \\ 0 & 0 & 0 & 0 & 1 & 0 & -1 & 0 & 0 \\ 0 & 0 & 0 & 1 & 0 & 1 & 0 & -2 & 0 \\ 0 & 0 & 0 & 0 & 1 & 0 & 0 & 0 & -1 \end{bmatrix} \tag{3}$$

Bending deformation

$$H = k\begin{bmatrix} -1 & 0 & 1 & 0 & \cdots & 0 & \cdots & 0 & 0 & 0 & 0 \\ 0 & -2 & 0 & 1 & \cdots & 0 & \cdots & 0 & 0 & 0 & 0 \\ 1 & 0 & -3 & 0 & \cdots & 1 & \cdots & 0 & 0 & 0 & 0 \\ 0 & 1 & 0 & -2 & \cdots & 0 & \cdots & 0 & 0 & 0 & 0 \\ \vdots & \vdots & \vdots & \vdots & \ddots & \vdots & \iddots & \vdots & \vdots & \vdots & \vdots \\ 0 & 0 & 1 & 0 & \cdots & -4 & \cdots & 0 & 1 & 0 & 0 \\ \vdots & \vdots & \vdots & \vdots & \iddots & \vdots & \ddots & \vdots & \vdots & \vdots & \vdots \\ 0 & 0 & 0 & 0 & \cdots & 0 & \cdots & -2 & 0 & 1 & 0 \\ 0 & 0 & 0 & 0 & \cdots & 1 & \cdots & 0 & -3 & 0 & 1 \\ 0 & 0 & 0 & 0 & \cdots & 0 & \cdots & 1 & 0 & -2 & 0 \\ 0 & 0 & 0 & 0 & \cdots & 0 & \cdots & 0 & 1 & 0 & -1 \end{bmatrix} \tag{4}$$

Here k is the coefficient of spring. By using equation (2), (3), (4), we can predict each stretching - compression force, shearing force, and bending force. And by substituting each force for equation (1), each velocity vector and position vector are calculated.

2.3 Airflow model

We should develop the airflow model to represent the behavior of airflow in the simulation. Behaviors of fluid including airflow are modeled by Navier Stokes equation. If fluid is incompressible and the density of fluid is constant, Navier Stokes equation is the following.

$$\frac{\partial \mathbf{u}}{\partial t} = -(\mathbf{u} \cdot \nabla)\mathbf{u} - \frac{1}{\rho}\nabla \mathbf{p} + \nu \nabla^2 \mathbf{u} + \mathbf{F}$$
$$\nabla \cdot \mathbf{u} = 0 \quad (5)$$

Here ρ is the density of fluid, v is coefficient of viscosity, **u** is the velocity vector, t is time, **p** is the pressure of fluid, and **F** is the force. In order to calculate equation (5) on real time, we introduce the stable fluid method [JOS, 99].

3. USER INTERFACE

In order to input the force and airflow to cloth simulation, we use a computer mouse and a microphone as an interface between real world and virtual world. The implementation of use interface is the following.

3.1. Manipulating cloth model by computer mouse

We can't manipulate the cloth model directly. However, we can manipulate the cloth model by a computer mouse. In the simulation, by clicking a computer mouse on the cloth model, we can add the force to the mass point of cloth model. The mass point added the force is decided by the coordinate of mouse pointer and the coordinate of mass point of cloth model as shown in Fig.2. First of all, **m** that is position vector between the coordinate of mouse pointer **Ppoint** and the coordinate of camera in the virtual world **Pcamera** is calculated, and the crossing point **Pcross** between vector **m** and cloth model is calculated. If the crossing point **Pcross** doesn't exist, the force isn't added to the cloth model. If the crossing point exists, the mass point nearest the crossing point **Pcross** is added the force by a computer mouse. In the simulation, the strength of force is constant, and the direction of force is the same as the direction of vector **m**.

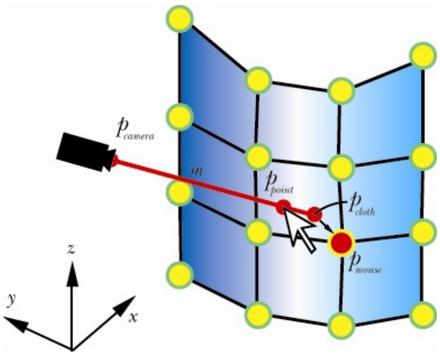


Fig.2 Detection of mass point added force by mouse pointer

3.2. Input airflow by microphone

In order to input the airflow on real world as velocity vectors on the virtual boundary faces, we need to acquire the airflow velocity on real world. Generally, the strength of airflow tends to be proportional to the loudness of airflow. Therefore, we use a microphone to acquire the loudness of airflow. Also, in order to acquire the direction of airflow, we put some microphones perpendicularly as shown in Fig.3. This method is not precise, but it is very easy to realize virtual world considering airflow. In the simulation, by analogue-digital conversion of sound on real time from each microphone, loudness of sound are added as airflow to virtual world.

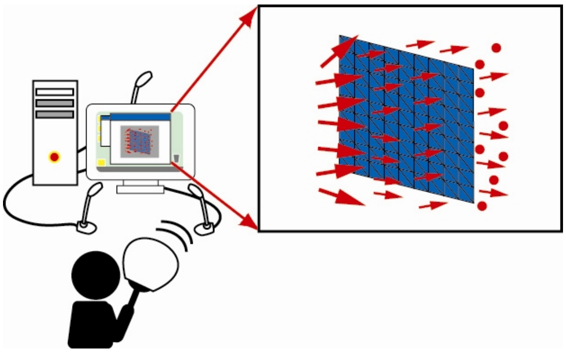


Fig.3 Input airflow by microphones

3.3. Air resistance force

Air resistance force of cloth model should be developed in order to calculate the force added to cloth model by airflow field. Air resistance force **Fw** is calculated from relative velocity between mass point and airflow [BRE, 94]. Air resistance force is following.

$$\mathbf{F}_w = C_1 l^2 (\mathbf{n} \cdot \mathbf{U})\mathbf{U} \tag{6}$$

Here, C_1 is the constant related to the air resistant force and material, l is the distance of each mass point, **n** is the normal vector of triangle as shown in Fig.4, and **U** is the relative velocity between mass point and airflow.

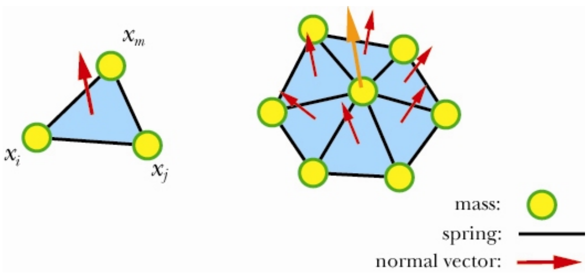


Fig.4 Calculation of air resistant force

4. SIMULATION

4.1. Simulation of manipulating cloth model

In order to verify the behaviour of cloth model and the interactivity, we carried out the simulation as shown in Fig.5. The cloth model is placed in the three dimensional space where the gravity is defined on the vertical direction, and it is fixed at the upper corners. Table1 shows simulation parameters, and Fig.6 shows the flowchart of this simulation. In the simulation, the force is added according to a movement of computer mouse.

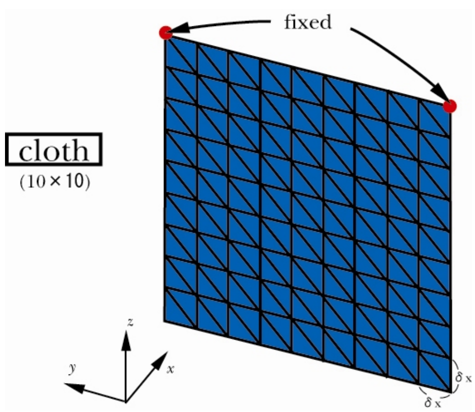


Fig.5 condition of cloth model simulation

Table 1 parameteres of cloth model

Number of mass point	Warp	10
	Weft	10
Mass [g]	0.5	
Spring constant	0.7	
Time step [s]	0.3	
Distance between mass points [cm]	1.0	

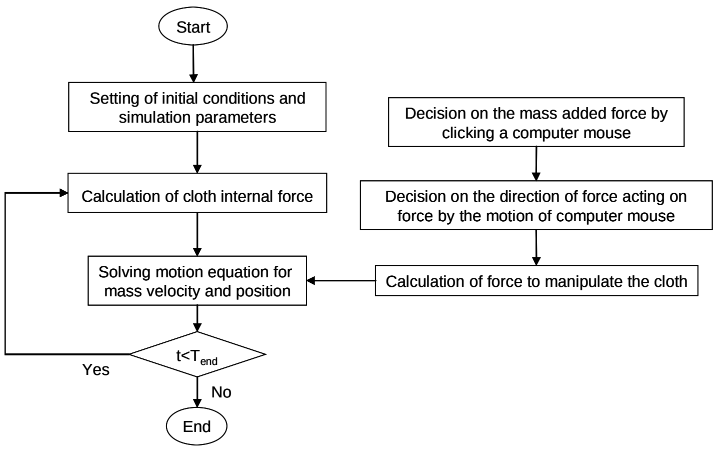


Fig.6 Flowchart of manipulation simulation

4.2. Simulation of cloth behavior in the airflow field

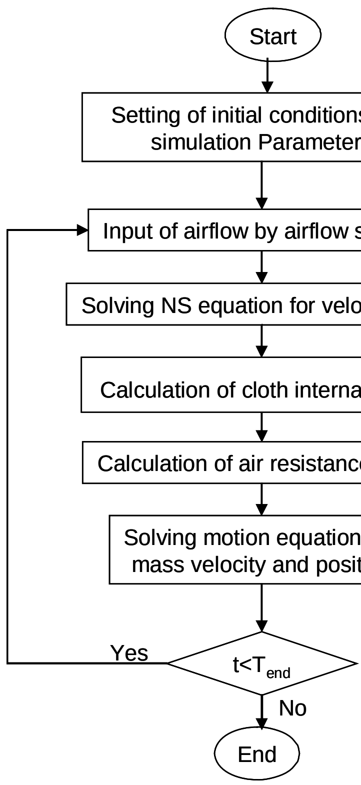


Fig.7 Flowchart of airflow simulation

In order to verify the behavior of cloth model in airflow field, we carried out simulation as shown in Fig.3. The placement of cloth model is the same as the simulation manipulating the cloth. Table 2 shows parameters of airflow model. In this simulation, the airflow is assumed to be incompressible. The initial condition of airflow field is that the velocity is zero. Also, as to the boundary conditions, we assume that the horizontal component of the velocity is zero on the vertical boundary faces, while the vertical component of the velocity is zero on the horizontal boundary faces. In the simulation, airflow is sent in front of cloth model through microphones. Fig.7 shows the flowchart of this simulation. First, the airflow in the real world is measured by microphones. Then, it is input as a velocity on the boundary face in the virtual world. Here, we assume that the input velocity is always perpendicular to the boundary faces. After that, the velocity field is calculated, and the cloth behavior in this velocity field is simulated.

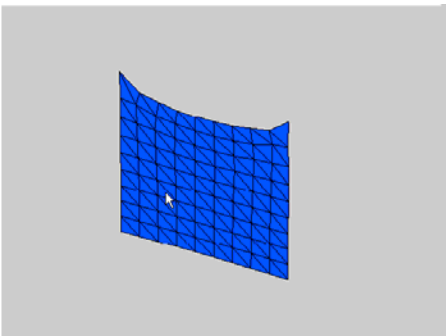
Table 2 parameteres of airflow model

Number of grid	10 x 10 x 10
C_1	-0.03
Viscosity coefficient	10

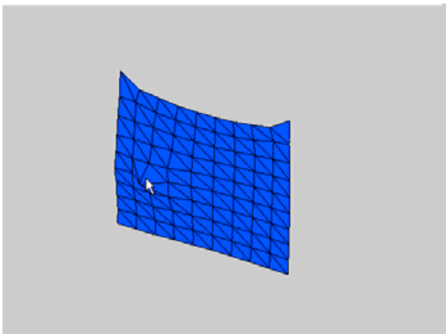
5. RESULT

5.1. Simulation of manipulating cloth model

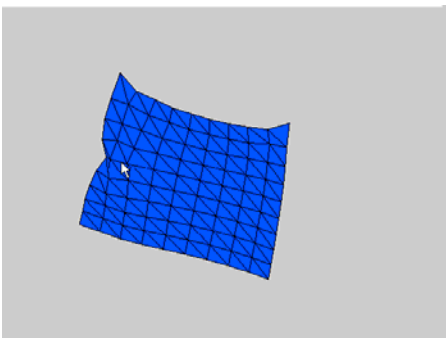
Fig.8 shows the result of simulation of manipulating cloth model. In this figure, the mark in white is a mouse pointer, and the force is added on the position of mouse pointer. Once the left button of a computer mouse is clicked, the manipulation point is decided. (Once the right button is clicked, the manipulation point is released.) Under this condition, a mouse pointer is moved by users, so that the force is added on the manipulation point. The direction of force is decided according to the direction that a mouse pointer is moved. However, the strength of added force can't adjust, because we use a computer mouse as interface. Therefore, as a next step, we plan to use other input device such as a joystick in order to adjust the strength of added force. As a result of the simulation, it has been confirmed that we can manipulate the cloth model by a computer mouse on real time. Also, wherever the force is added, the behaviour of cloth model has been stable.



(a) 0 [s]



(b) 1.0 [s]



(c) 3.0 [s]

Fig.8 Result of manipulating cloth model

5.2. Simulation of cloth behavior in the airflow field

Fig.9 shows the result of the cloth simulation in the airflow field. In this figure, the arrows in red are the velocity vector of airflow. At the initial state, the cloth is stationary as shown in fig.9 (a). Then, the wind is input through the microphone, so that the airflow field has varied as shown in fig.9 (b). After that, due to airflow field, the cloth is added air resistance force, so that the cloth has deformed as shown in fig.9 (c), (d), (e). In a short time, due to the diffusion of airflow, the velocity of airflow has decreased as shown in fig.9 (f), (g). Finally, the cloth has been stationary such as the initial state as shown in fig.9 (h). Consequently, we have realized the simulation of behavior in airflow field on real time. Also, it has been confirmed that this simulation can be carried out with the manipulation simulation in real time. However, in this case, if the number of mass point increases, time lag has occurred in the simulation.

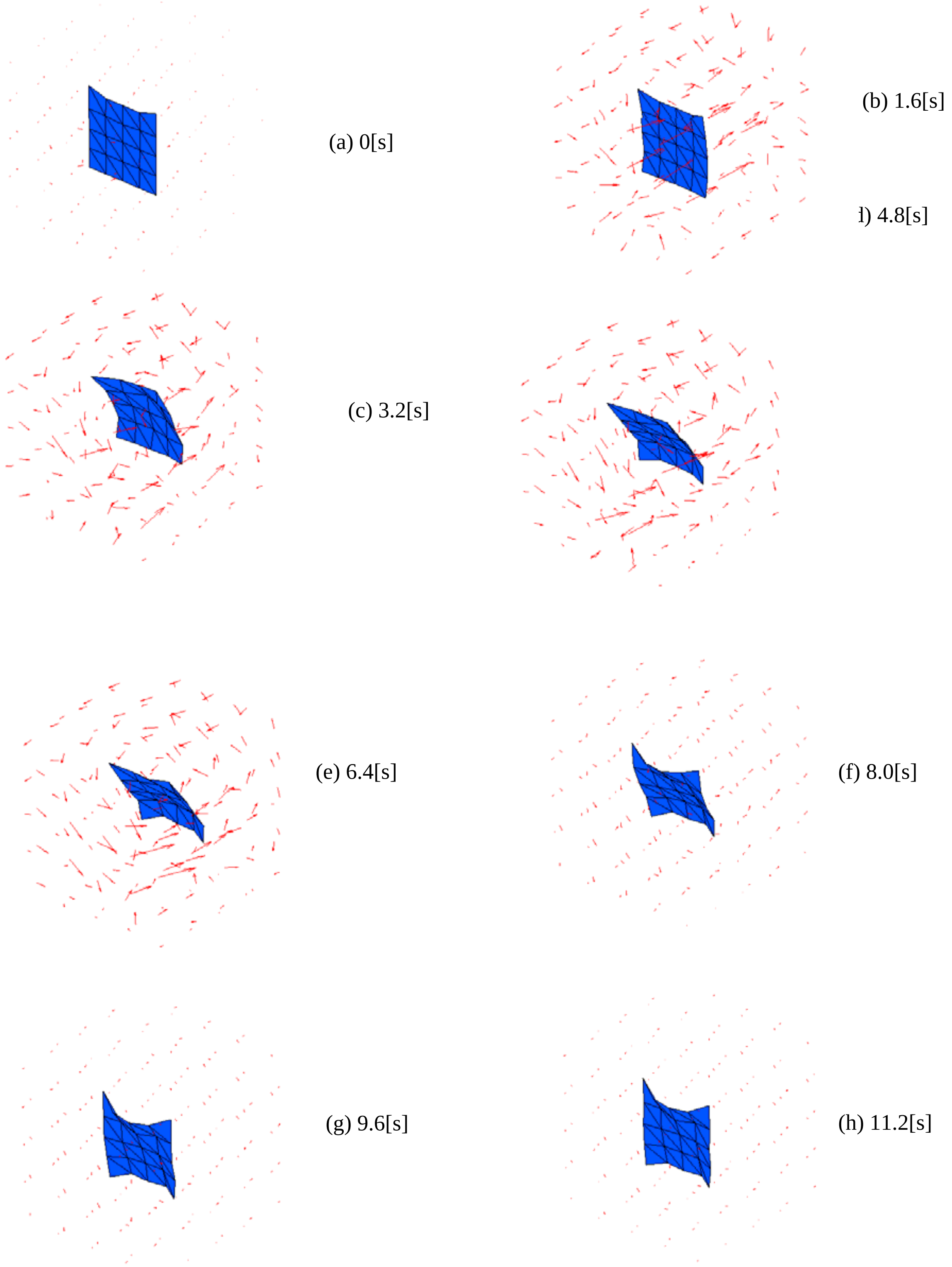


Fig.9 Behavior of cloth in airflow field

5.3. Problem and solution

As a result of simulation, it has been confirmed that the behaviour of cloth in air flow field is able to be represented by using the implicit method and Navier Stokes equation. However, the simulated results have not been close to the actual behaviour very well. In order to represent the actual smooth behaviour, we should carry out the increase of number of mass point for cloth model, the consideration of nonlinear properties of cloth, and so on. But if we use more precise models in the simulation, it is expected that the simulation couldn't be carried out on real time. For the solution of the problem, the development of hardware that specialize this simulation will be effective, but it may not be realistic in a respect of expense. Also, in order to input air flow, we used a microphone in this simulation. Needless to say, the sound of airflow isn't airflow itself. Therefore, airflow sensors should be used for the precise simulation. And in this simulation, the cloth model is added by airflow, but calculations of airflow velocity have not considered the cloth model, that is to say, the behaviour of airflow is same whether in the case of cloth model exists in the apace or not. Therefore, the interaction between cloth model and airflow model should be considered in the simulation.

6. CONCLUSION

We have developed the cloth model that is implemented the interactivity and real time processing. As a result of the simulations, the calculation has been stable in any case. However, because we used a small number of the mass point, the cloth behaviour hasn't been close to the actual behaviour very well. To my opinion, for the clothing design, the accuracy of simulation is important, but in the case of marketing, for example, consumers want to confirm the appearance and behaviour of clothing instantly, the speed of simulations is very important. The important thing is selection in different way depending on the situation. In the simulations that are required precise results, more precise cloth model such as particle model or continuum should be used for cloth simulations. On the other hand, in the situations that are required quick simulation, our proposed model will be an effective tool.

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