A Survey on Simulation of Virtual Surgery Soft Tissue Force Feedback Algorithm

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Abstract. Virtual surgery simulation system is a typical application of virtual reality technology in the medical field. Firstly, in order to select a suitable way for real-time deformation and force feedback algorithm, after compared several classical numerical integration algorithm, we select the mid-point method as the deformation algorithm in this paper. The feedback force calculation is based on a spring-damper model. The total amount of the form variables of all virtual mass-spring in the system is the surface deformation of an object; the total amount of the forces of all virtual mass-spring equals to the contact force of the object surface. The algorithm is simple in the deformation process. It can also well meet the requirements of real-time interactive systems. Finally, a good virtual surgery simulation system must be able to give the operator with experience of synchronization of visual and tactile in the process of interaction. In this experimental system, we use OpenGL 3d graphics standard to draw and render visual model, at the same time, use Open Haptic packages to give haptic rendering. The PHANTOM force feedback device is used as a real-time interactive device. Finally, the simulation results verify the effectiveness of the system.

Keywords: virtual surgery, spring - particle model, Soft tissue deformation, force feedback.

1. Introduction

With the rapid development of modem science and technology, the computer application field are becoming wider and wider. Virtual surgery is an application of virtual reality in modern medicine. It can present real reappearance of the operation for user by vision and force feedback. It is very useful in surgeon training, surgery prediction and image guided surgery.

Nowadays most data used in virtual surgery systems are medical data collected by Medical appliances such as CT, MRI, PET and type-B ultrasonic, or the Virtual Human Data. The models reconstructed by the data perform well in accuracy and color, but it is very hard for the users to use these models in real-time surgery systems. To solve the real-time problem, simplifying the models is proved to be an efficient method, but the reduction process would also remove some key details on soft tissue and degrades performance in virtual surgery systems. With the purpose of performing in real-time, it is common in virtual surgery systems to simulate soft tissue with linear elastic models. However, soft tissues are rendered with obvious viscoelasticity when large deformations happen. Linear elastic models are not applicable in such settings. Nowadays, in research of soft tissue simulation in virtual surgery, the main contradiction is between similarity and real time.

This paper is based on the spring-mass the soft tissue model of virtual particle method, and the model describes the deformation process of its dynamic model of dynamic equations. In terms of force feedback which is based on spring - damper model, it combines the topics proposed model topology, and gives the corresponding force feedback algorithm. To create a real sense of immersion, we use Visual C + +10.0 development environment combined with OpenGL 3D graphics standard for rendering visually, and a PHANTOM haptic interaction device and its accompanying OpenHaptic force feedback application software packages to create tactile experience. Finally, by building own virtual surgical simulation platform, the research of this topic has been verified.

2. SOFT TISSUE MODELING

2.1Create s soft tissue model

When drawing a regular hexagon surface topology model, we must first analyze the most primitive structure of the regular hexagon model. Clearly, the smallest regular hexagon surface structure is a triangular face, and then gradually approaching surface decomposition method on the basis of triangular faces. Specific procedures for the cam face decomposition are expressed as follows: Make a vector constituting the vertices of the original triangle be the smallest structure: A, B, and C. The higher the degree of approximation of the model, the greater the need to carry out decomposition stages, where the series is set number of decomposition, which is the most primitive graphics aliquot of times. If num = 0, the initial three vertices directly videos triangle. If num = 1, we will have to halving, take the midpoint of the initial three sides of the triangle faces D, E and F. And so, ultimately the original triangle will be broken down into regular hexagonal surface structure. Its graphical representation is shown in Figure 2-1.

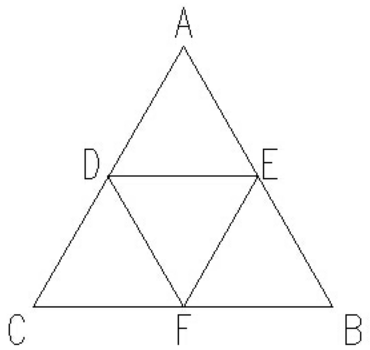


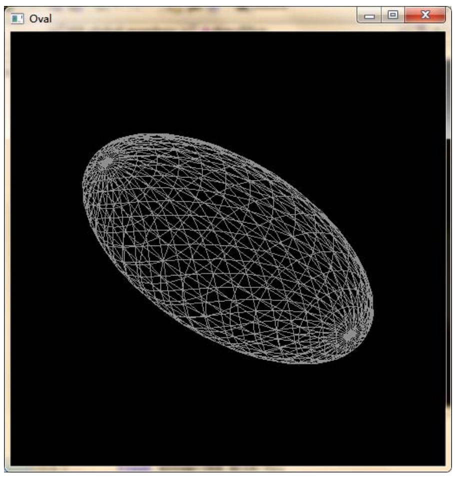
Fig2-1 Triangular decomposition method demonstrated.

2.2Visual rendering of soft tissue model

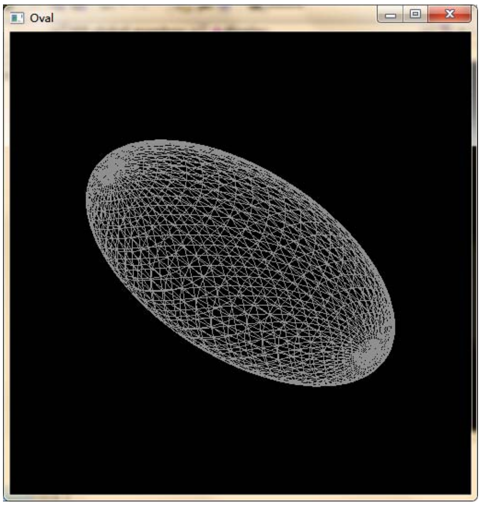
Surface model and soft tissue ellipse model based on regular hexagon were drawn by using OpenGL; this section is mainly on the sphere model of visual rendering process. In this paper, the model only made some basic rendering. For each pixel, using a color made a monotonous color made rendering.

Finally, the effect of rendering the sphere of soft tissue in Figure 2-2 shows a different picture which shows the qualitative comparison chart points around the human sphere model rendering. In the following, (a) is a prime soft tissue around 256 points for the rendering model, (b) is to increase the quality points (quality points to1024) rendering soft tissue model.

As we can see from the renderings, the more decomposition stages , the more quality points, the model rendering more smooth and delicate, the stronger the sense of reality. However, the decomposition level is bound to a large amount of calculation increases, which will affect the final real-time interaction.



a) The particle numbers the 256 spheres of soft tissue contrast diagram.



b) The particle numbers the 1024 spheres of soft tissue contrast diagram.

Fig2-2 Apply colors to a drawing before and after contrast figure sphere model.

2.3Soft tissue model rendering on force Sense

Force feedback technology is actually a kind of virtual reality technology; it will be in a virtual environment reaction manifested by mechanical equipment. In this paper, the interaction between changes in virtual surgical instruments of the virtual environment and soft tissue into a tactile feel real force interaction device.

Add springs in the previous section geometry created in - attributes particle model, you constructed a physical model of virtual soft tissue. Each vertex in the geometry punishable spring - mass model of the particle, the particle was connected between springs -damper connected. During the interaction, virtual surgical instruments acted on the particle of the model, the particle occurs under the force of deformation, deformation process produces a virtual body spring. What is shown in Figure 2-3. Calculation of the force feedback is implemented based on this physical model.

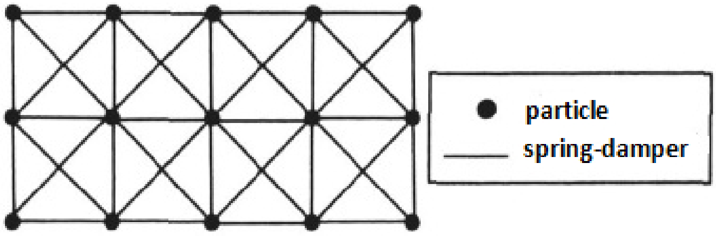


Fig2-3 Soft tissue physical model

The current virtual surgery simulation system, mostly used to calculate the force feedback spring - damper model, its force normal to the surface is used to calculate. In this way the calculation is simple, refresh frequency reproduction force sense in 1 KHz or more. PHANTOM force feedback device also uses this model. Spring - damper model is a classic structure simulation of viscoelastic tissues and organs, maintaining the elasticity of the spring system, damper simulation made the system have gradually stable viscosity. Surgical instrument with a virtual model of the role of the soft tissues, resulted in a difference in the role of the puncture depth of the model surface point, the force feedback model is calculated by the difference in depth of the magnitude of the force feedback. To calculate the feedback force involved in the two key location information, damper force feedback model was shown in Figure 2-4 Spring-based. A surgical instrument is a virtual terminal (Haptic Interface Point, HIP) location, another is the surface contact point contacts with end of the virtual operation instruments and soft tissue of the (Surface Contact Point, SCP) position. Control force feedback devices and The virtual soft tissue surface in the process of interaction, when the end of the force feedback device, namely Virtual surgical instruments vertices without access to human tissue surface, a virtual hand The surface of the equipment operation vertex position and actual position of contact point coincidence; When virtual hand Equipment operation vertex in contact with the human tissue surface, a virtual surgical instruments vertices Surface contact point location for its actual location in the corresponding human tissue on the surface of the cast the shadow.

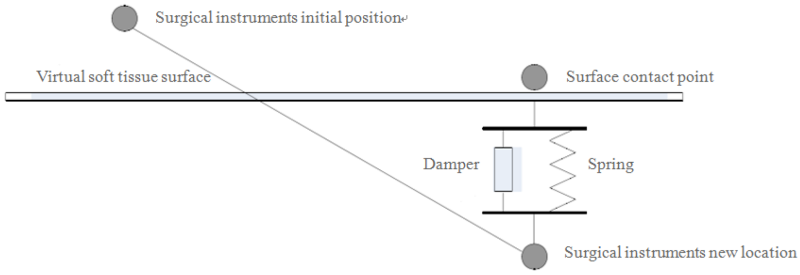


Fig2-4 Force feedback calculating model

By the spring - damper force feedback calculation model, can get virtual hand Art equipment/through 0 on the surface of the soft tissue depth. As a result, the model for calculating the force feedback the mathematical description is:

$$F(t) = Kx + Dx'$$

Where K — spring elasticity;

D — spring damping;

X —displacement surface contact points.

In this case, the force feedback F (t) is in the opposite direction of the x direction and displacement. Due to the different biomechanical properties of different soft tissues, adjusting the damping coefficient of elasticity K and D can simulate the physical characteristics of different virtual soft tissue surface characteristics to simulate human soft tissue. In this force feedback calculation model, the elastic modulus and damping is easy to control, calculation is relatively simple, and therefore in a virtual surgery simulation system, force feedback is calculated by using this model structure in general.

3. Virtual surgery simulation system structure

3.1Build a virtual surgery simulation system

The interaction in a virtual surgery is not only to give in to a realistic visual experience, but also give tactile manipulation in sync experience. Virtual surgery simulation system of soft tissue deformation force feedback in real time interactive simulation systems generally requires relatively high real-time. This is the computing speed of the system and has a high refresh rate requirement. To make vision, the refresh frequency reproduction should feel the force at 500 Hz or more. Virtual surgery simulation system model established in this paper consists of the application shown in Figure 3-1.

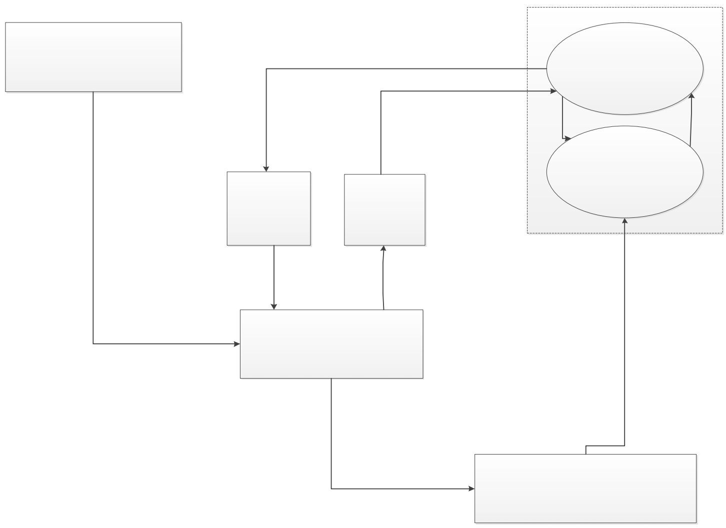


Fig3-1 Virtual surgery simulation system structure

3.2System hardware devices

To build virtual surgery system, the support from the system hardware is inseparable. Hardware components of the system platform are mainly divided into two parts, computers and interactive devices. Interaction devices include visual and tactile interaction devices that interact with the device. Visual interaction is mainly performed by the display device, and is responsible for the visual display of the virtual scene. SensAble haptic device uses interactive technology companies' PHANTOM PREMIUM device interaction force, with input and output functions, connecting users and virtual environments to achieve Interaction Bridge.

Fig3-2 PHANTOM PERMIUM force feedback device

In this paper, the main computer configuration is: INTEL XEON (R) E3-1220 3.10 GHz quad-core processor, 8.00GB of memory, NVIDIA NVS 300 graphics desktop computers.

3.3System software

Virtual surgery system software is the soul of the whole system, and coordinates hardware devices and the functional modules. System software includes collision detection, soft tissue deformation calculation and the calculation of the interaction process such as force feedback. In Win 7 operating system, using Visual C + + 10.0 development environment combined with OpenGL 3D graphics standard to establish a virtual soft tissue deformation model, this provides a realistic visual simulation of deformation to the operator. The applications of SensAble Technologies PHANTOM PREMIUM force feedback device's corresponding Open Haptic software development kit are to achieve tactile rendering.

In Figure 3-3, when a virtual surgical instruments contacts with a model, we made the contact point the center, and stratified on deformation model with surface concentric radiating circle, divided the deformation of an object into a series of concentric rings layer , followed by a radius r, 2r, 3r ...... Though concentric rings are different in each mass point and the radius of the layer, however, because of the surface of the hexagonal symmetry structure I, for convenience of calculation, it can be approximated that the same radius of the ring and the inner layer of the same particles rigid connection. The adjacent layers are of the same spring rate.

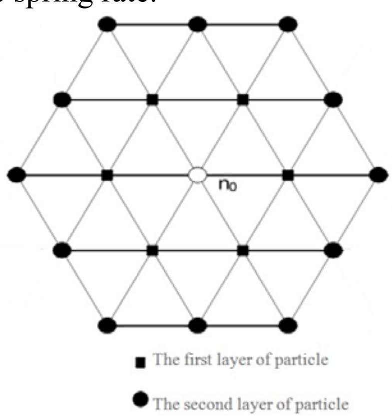


Fig3-3 The virtual body is hexahedral structure model of spring.

A mass-spring model of the whole virtual human tissue system is composed of n Node of the movement of the particle system, the whole system of soft tissue deformation to satisfy such as under the system of differential equations:

$$\begin{bmatrix} \dot{X} \\ \dot{V} \end{bmatrix} = \begin{bmatrix} & V \\ F & M \end{bmatrix} \tag{3-1}$$

Where, the X as the mass displacement, V for particle velocity, F applying in mass- spring on the system of the total force, M is mass matrix of the system. The total force F Contains two parts of internal force $\mathrm{F_{int}}$ and the external force $\mathrm{F_{ext}}$ among them, the internal force F_{int} by mass-spring system deformation which is caused by the spring force F_s and damping forceF_d. So, the total Force F can be expressed as the following form:

$$\mathrm{F} = F_{int} + F_{\mathrm{ext}} = F_s + F_d + F_{ext} = -KX - D\dot{X} + F_{\mathrm{ext}} \tag{3-2}$$

By type (3-1) and type (3-2), we know,

$$\mathrm{M}\ddot{X} + D\dot{X} + KX = F_{\mathrm{ext}} \tag{3-3}$$

Among them, the M is the system $\mathrm{n \times n}$ mass matrix, is diagonal matrix; D for System $\mathrm{n \times n}$ damping matrix is a diagonal matrix; K for the department Banded matrix, for the system Several banded matrices; $\mathrm{F_{ext}}$ is $\mathrm{n \times 1}$ column matrices, expression each mass by external forces the resultant force.

The mass-spring system for any particle i, it must satisfy the following Dynamic equation:

$$m_i a = -f_s - f_d + f_{\mathrm{ext}} \tag{3-4}$$

Then,

$$f_s = \sum_{j\epsilon P(\mathrm{i})} k_{ij} \frac{(\|l_{ij}\| - l_{ij}{}^0) l_{ij}}{\|l_{ij}\|} \tag{3-5}$$

$$f_d = \sum_{j\epsilon P(\mathrm{i})} C_{ij} \left\| (\dot{x}_i - \dot{y}_j) \cdot \frac{l_{ij}}{\|l_{ij}\|} \right\| \frac{l_{ij}}{\|l_{ij}\|} \tag{3-6}$$

Will type (3-5), (3-6) generation type (3-4), too?

$$m_i a + f_s = \sum_{j\epsilon P(\mathrm{i})} k_{ij} \frac{(\|l_{ij}\| - l_{ij}{}^0) l_{ij}}{\|l_{ij}\|} + \sum_{j\epsilon P(\mathrm{i})} C_{ij} \left\| (\dot{x}_i - \dot{y}_j) \cdot \frac{l_{ij}}{\|l_{ij}\|} \right\| \frac{l_{ij}}{\|l_{ij}\|} = f_{ext} \tag{3-7}$$

Finishing,

$$\sum_{j\epsilon P(\mathrm{i})} \{ k_{ij} (\|l_{ij}\| - l_{ij}{}^0) + C_{ij} \left\| (\dot{x}_i - \dot{y}_j) \cdot \frac{l_{ij}}{\|l_{ij}\|} \right\| \} \frac{l_{ij}}{\|l_{ij}\|} = f_{ext} - m_i \ddot{x}_i \tag{3-8}$$

There, m_i for a single particle in the quality of the i, k_{ij} for linking particles i and its adjacent particle j into the connector between the elastic coefficient of spring, c_{ij} particle damping between i and particle j of the damping coefficient, P (i) for the collection of all particles with particle i adjacency, l_{ij} is the distance between the particle i and particle j, $l_{ij}{}^0$ for from initial distance between the particle i and particle j ,α for a particle acceleration when i exercise.

So, for motion displacement and speed of a single particle p is determined by the following differential equation:

$$\begin{cases} \dot{x} = v \\ \dot{v} = \frac{f_{ext} - f_s - f_d}{m} \end{cases} \tag{3-9}$$

4. Computing soft tissue deformation force feedback

In the front, we give computing model of its internal force feedback based on the OpenHaptic applications. The model is based on a single point of contact during the interaction force feedback algorithm. During slow interaction, when the equilibrium is reached, all the particles and deformation should be considered during the calculation of the feedback force. Feedback through interactive device to calculate the force of the operator should be based on the above formula (3-14) performed. It is obvious that from the formula, the size of the feedback force is not only a virtual model of elasticity of the spring member on, but also depends on the combined effect of the depth of the puncture depth and dissemination.

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