

Modeling and Simulation of Uterine Fibroids Based on Virtual Reality

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Abstract. This paper introduces a virtual interactive system to visualize the growth of uterine fibroids and its impact on the surrounding soft tissue, in which virtual reality, soft tissue deformation are mainly used. The system uses Autodesk Maya to build three-dimensional models of standard uterine and common uterine fibroids, then simulates the growth of uterine fibroids and the deformation of soft tissues through Unity. Soft tissue deformation is mainly based on weighted average normal method: Collision detection algorithm and influence radius are used to determine the deformation region of organ mesh; By calculating the weighted average normal of the deformation area, the deformation direction is determined, and the gauss smoothing is transformed into a weighted factor to generate a new deformation mesh. The system can simulate the growth of common uterine fibroids, and can be used for presentation and prediction of uterine fibroids, physician training, surgical assistance, electronic medical records, etc.

Keywords: virtual reality, soft tissue deformation, weighted average normal, collision detection, gaussian smoothing.

1. Introduction

Uterine fibroids are the most common benign tumors in gynecology, and the prevalence rate is 20 % ~ 40 %. Every five women of reproductive age has one person suffering from this disease[1-2]. Traditional gynecological ultrasound images and MRI images can effectively diagnose uterine fibroids, but due to the limitation of two-dimensional images, the relationship between uterine fibroids and uterus cannot be stereoscopically presented. In clinical applications, in order to more intuitively assist disease analysis, surgical planning and promote doctor-patient communication, it is urgent to generate three-dimensional stereoscopic display images.

In this paper, the virtual interactive system provides a rapid method to establish three-dimensional uterine fibroids lesions. By using three-dimensional modeling technology, the standard uterine organ model without lesions and the common uterine fibroids lesions model are constructed in advance. Based on gynecological ultrasound images or MRI images, in the same spatial coordinate system, through simple operation, the fibroids lesions can be placed in proper position. After the lesion attribute setting is completed, the growth of uterine fibroids and the deformation of surrounding soft tissue can be simulated. Finally, the two-dimensional medical image information is simulated in the three-dimensional virtual spatial coordinate system.

2. System Design

2.1. System Application Scenarios

The system can be used for medical education and training, auxiliary surgical analysis, doctor-patient communication, etc. After the experienced doctors interpret the medical images of patients, the three-dimensional evolution and final state of the growth of uterus lesions can be observed by simply operation with the help of this system. The system allows users to mark and measure the lesion area, and the generated three-dimensional navigation map can be combined with the patient's medical record information to store and establish an three-dimensional medical record file. The generated three-dimensional cases enable other doctors and the patient to intuitively understand the condition, and also assist surgeons to accurately locate organ lesions during surgery.

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2.2. System Simulation Objects

In order to simulate the growth of uterine fibroids as realistically as possible, it is necessary to understand the growth of real uterine fibroids. At present, there are many methods of clinical medicine for the classification of uterine fibroids. This article refers to 《Obstetrics and Gynecology》 [3], according to the relationship between fibroids and uterine muscle wall, the three most common uterine fibroids are as follows :

- Intramural fibroids: fibroids are located in the muscle wall, surrounded by muscle layers. They are most common in patients with first onset, accounting for about 60-70%.
- Subserosal fibroids: intermural fibroids grow toward the serous membrane and protrude on the surface of the uterus, and are in direct contact with the serosal layer, accounting for about 20%.
- Submucosal fibroids: intermural fibroids grow into the uterine cavity, protrude into the uterine cavity, and directly contact the mucosal layer, accounting for about 10%.

This system is mainly aimed at the simulation implementation of the above three common uterine fibroids.

2.3. System Structure

This system uses Autodesk Maya as a modeling tool for the uterine model and common fibroids models, and uses Unity to complete the entire simulation process and interactive function development as well as cross-platform release. The system architecture diagram is shown in Fig.1.

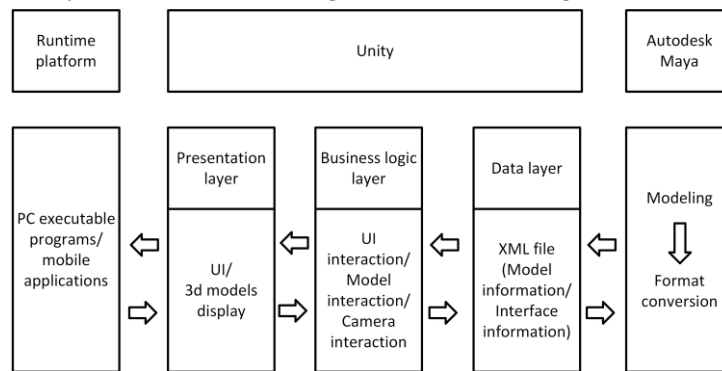


Fig. 1: System architecture diagram.

2.4. Main Functions of the System

The system has three main function modules, and the functional module design diagram of the system is shown in Table 1.

Table 1: Interactive function division

Uterine organ operation	Uterine fibroids operation	Deformation Simulation
rotation	dynamic loading	weight factor
zoom	transform operation	deformation factor
translucency	growth	deformation strength

Uterine organ operation : Users can control the 720° rotation and the overall scaling of the of the uterine model through mouse or gesture. In addition, the transparency of the organ model can be adjusted through the slider to view the organ model of colored texture and translucent texture. In translucent mode, the user can clearly observe the internal structure of the organ, which helps to place fibroids in the proper position when adding them.

Uterine fibroids operation : Users can add a matching fibroids by dragging its thumbnail, and then place it in the appropriate position by translation and rotation.

Deformation Simulation : Users can control the deformation of the organ model by input parameters.

3. Deformation Simulation Method

With the development and maturity of mesh deformation technology, mesh deformation technology has been widely used in the field of medical simulation, soft tissue deformation is one of the important

applications[4]. Most mesh deformation technologies are based on triangular mesh model, and the research focus is mainly on the movement mode of mesh vertices, among which the direction based on the average normal can well simulate the deformation direction of objects in real life[5]. In order to more realistically simulate the growth of uterine fibroids and the deformation of surrounding soft tissues, a method based on weighted average normals is proposed to simulate the deformation of the organ soft tissue.

3.1. Simulation Process

The key steps of the method are as follows: Firstly, The reference point is determined by collision detection. Secondly, The deformation region is identified by taking the reference point as the center of the sphere and specifying the distance as the radius. Thirdly, Vertices in this region are transformed according to the weighted average normal direction. Finally, the deformation force is scaled by setting the deformation strength, and the deformation result is smoothed by Gaussian blur. The whole simulation flow chart is shown in Fig.2.

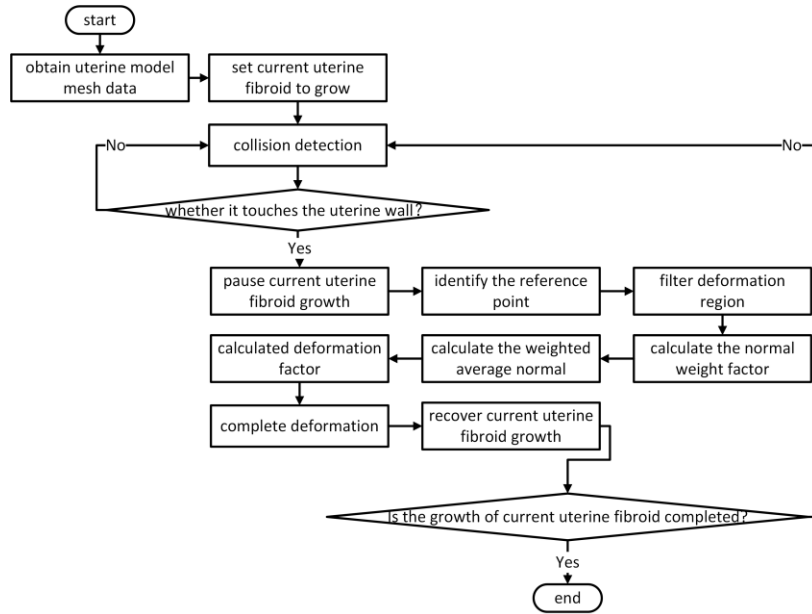


Fig. 2: Simulation flow chart.

3.2. Obtain Uterine Model Mesh Data

Each visible model object (GameObject) in Unity has a MeshFilter component. The mesh properties of the MeshFilter component store all the triangular surfaces, mesh vertices, mesh normals, and basic texture coordinates.

- triangles: a list of triangles containing vertex array indexes. The size of the triangular array is a multiple of 3.
- uv: the basic texture coordinate. For the most common two-dimensional texture, the texture coordinate is represented by a two-dimensional vector (u, v).
- normals: vertex normals, describing the direction of each vertex normal. When the model is rendered, the vertex normal is used to calculate the illumination, and a more smooth transition of illumination can be obtained on the surface of polyhedron.
- vertex: all vertex coordinates on the mesh, with the center point of the model as the origin.

Obtaining the mesh data of uterine organ model is mainly to select vertex normals and vertices for saving.

3.3. Set Current Uterine Fibroid to Grow

Users can directly drag the thumbnail of the lesion to add a corresponding fibroid to the scene, or drag it to the location reference point to complete the addition. By setting the target size of current fibroid, a simple linear interpolation is used to control the tumor growth to a specified size, as in (1).

$$Scale_{temp} = Scale_{from} + (Scale_{to} - Scale_{from}) * t \quad (1)$$

Among them, t is the growth time, $Scale_{temp}$ is the current size, $Scale_{from}$ is the initial size, $Scale_{to}$ is the target size.

3.4. Collision Detection

This paper uses Unity built-in physical engine for collision detection. To detect collision in Unity, two conditions are required: both objects must have Collider components; there must be at least one Rigidbody Collider in two objects. Because uterine fibroids model is similar to spherical, in order to reduce the amount of calculation, Sphere Collider is used here. For the uterine organ model, its structure is complex, so Mesh Collider is used.

For processing collision information, the trigger mode is used, where the IsTrigger property is checked on the Mesh Collider component. In the process of current uterine fibroid growth, once it collides with the uterus wall, the deformation event will be triggered.

Since the organ mesh changes in real time, in order to ensure the accuracy of collision detection, the organ mesh collider also needs to be updated in real time. Unity allows users to customize the collider boundary, make the collision range fit the model, and update it in real time after the mesh deformation of the organ model.

3.5. Weighted Average Normal Direction

Determine the deformation reference point: The deformation reference point is the nearest mesh vertex to the collision point. When the collision is triggered, it will return the collision point on the organ mesh collider that is closest to the center coordinate of the current fibroid. By traversing the organ mesh vertices, the nearest mesh vertex to the collision point is the deformation reference point, denoted as Q point.

Filter deformation region: The selection of deformation region needs to filter all organ mesh vertices. Take Q point as the center of the sphere, and the influence radius R set by the user as the radius. By calculating the euclidean distance d_i , as in (2), comparing it with the influence radius R , getting the value of labeling function, as in (3), finally the organ mesh vertices is marked to obtain the deformation area. During deformation, only these vertices are modified to reduce system overhead.

$$d_i(v_i, Q) = \|v_i - Q\| \quad i=1, 2, \dots, n \quad (2)$$

$$flag(d_i, R) = \begin{cases} 1 & 0 < d_i \leq R \\ 0 & d_i > R \end{cases} \quad i=1, 2, \dots, n \quad (3)$$

Normal weight factor: The calculation of the normal weight factor is based on the euclidean distance d_i . The closer to the Q point, the greater the impact on the calculation of the average normal. The calculation formula of weight factor is as follows :

$$W_i = 1 - d_i/R \quad i=1, 2, \dots, n \quad (4)$$

Among them, W_i is the weight factor, d_i is the distance between the mesh vertex and the Q point, R is the influence radius .

Weighted average normal direction: The weighted average normal direction can be obtained by multiplying the normal of each vertex in the deformation region by their respective weight factors, calculating the vector sum, and finally normalizing. Thus, the direction of deformation is finally determined.

$$\vec{n} = \frac{\sum_{i=1}^n \vec{n}_i * W_i}{n} \quad i=1, 2, \dots, n \quad (5)$$

3.6. Deformation Factor

Deformation factor refers to the deformation degree of the mesh vertex in the deformation region relative to the deformation reference point. The deformation factor is also related to the distance from the deformation reference point. The closer to the reference point, the greater the deformation factor, the greater

the degree of deformation. Gauss function is used to calculate the deformation factor to make the mesh deformation smoother and more realistic[6]. The calculation formula of deformation factor is as follows.

$$F_{factor} = G_{factor} * power \quad (6)$$

Among them, F_{factor} is a deformation factor, G_{factor} is a gaussian fuzzy factor, and $power$ is the deformation strength given by the user. According to the density function of gaussian distribution, the probability of each vertex in the deformation region is calculated and used as a weight. The calculation function of G_{factor} is shown as follows.

$$G_{factor} = f(x) = \frac{1}{\sqrt{2\pi}\sigma} e^{-\frac{(x-\mu)^2}{2\sigma^2}} \quad (7)$$

Where μ is the mean of x , and σ is the standard deviation of x . The characteristic of the density function of the normal distribution is that it is symmetrical about μ , reaches a maximum value at μ , takes a value of 0 at positive (negative) infinity, and has an inflection point at $\mu \pm \sigma$. Its shape is high in the middle and low on both sides, and the image is a bell-shaped curve above the x-axis.

3.7. Complete Deformation

The mesh vertices in the deformation region are transformed in the direction of the weighted average normal combined with the deformation factor.

$$v' = v + \vec{n} * F_{factor} \quad (8)$$

The size of the tumor growth is used as the evaluation parameter. In the growth process of uterine fibroids, once it collides with the surrounding structural tissue, the growth stops first, and then the soft tissue begins to deform. After each deformation is completed, the size of the current uterine fibroids is judged. If the user set value is not reached, the uterine fibroids continue to grow until the growth of the fibroids is completed and the deformation is completed.

4. System Simulation Effect

Unity is a cross-platform game development engine. The publishing platform supports Windows, Mac, Android, iPhone and other platforms. The system is finally released into PC-side exe and mobile-side apk through Unity. After the user runs the program, the system can be interactively controlled according to the interface element prompt. The final effect of the system is shown in Fig.3.

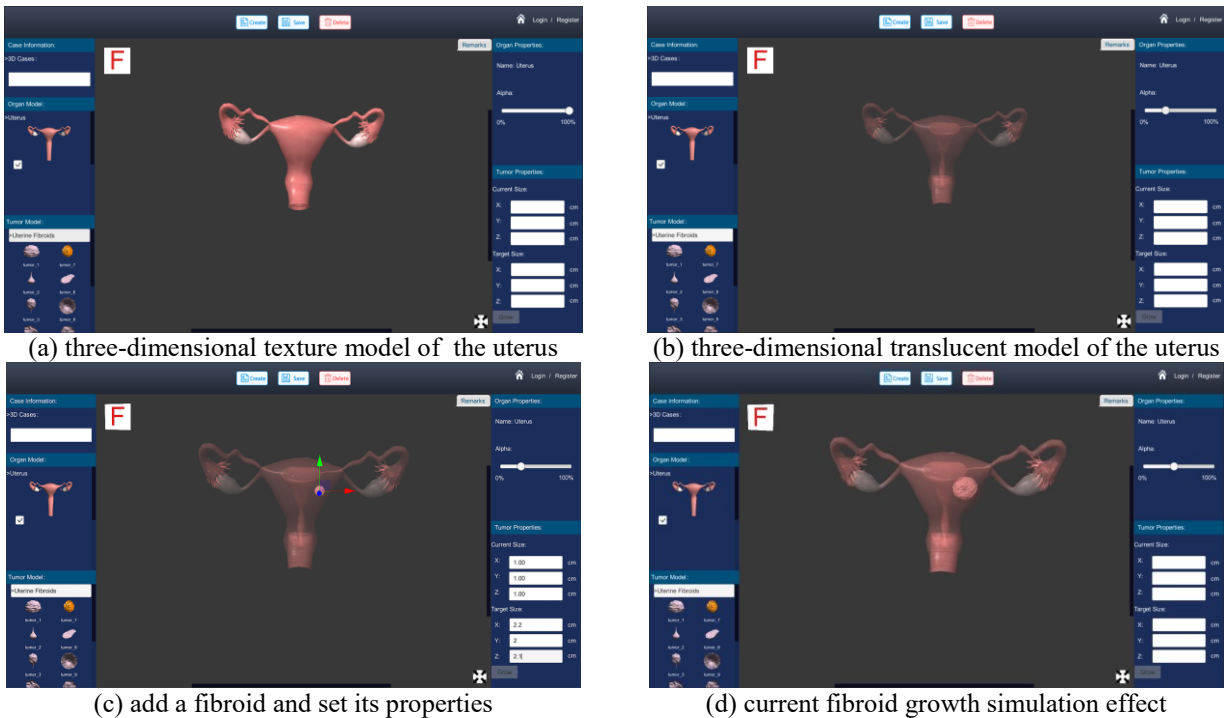


Fig. 3: System simulation effect diagram.

Among them, Figure (a) shows the initial state of the standard uterus, and the user can have an intuitive understanding of the overall structure of the organ; Figure (b) shows the translucent state of the standard uterus. In this state, the user can clearly see the internal structure of the organ, which is more conducive to adding a fibroid lesion; in Figure (c), the user manually adds a fibroid lesion and places it in a suitable position, then sets its properties to simulate the lesion growth. Here, the lesion grows from 1*1*1 to 2.2*2*2.1 (the unit of length, width and height is cm); Figure (d) is the final state of the fibroid lesion, and it can be clearly seen the deformation of the surrounding soft tissue.

5. Conclusion

The simulation system of uterine fibroids can better assist doctors or researchers in preoperative planning, simulation of disease evolution, doctor-patient communication and so on. The research in this area will bring a series of technical changes to the subsequent research on precise surgical positioning, shortening the operation time, improving the quality of surgery. But there are still many shortcomings:

Firstly, what the system achieves is only efficient simulation, which is not equivalent to the true appearance of the lesion. Secondly, the addition of fibroids requires manual operation and adjustment, which increases the operating time. In the future, the system will be improved from these two aspects. For example, the addition and growth of fibroids can be directly completed by analyzing two-dimensional medical images[7].

6. References

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