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Research Article

Establishment of Emergency Teaching Model and Optimization of Discrete Dynamic Calculation in Complex Virtual Simulation Environment

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Virtual surgery is a typical application of virtual reality technology in the medical field, which can help improve the success rate of surgery and reduce medical costs in various aspects such as medical training, surgery planning, and intraoperative navigation, and is becoming a hot research topic and a frontier subject in the medical field. The establishment of virtual surgery simulation system involves the intersection and penetration of various disciplines, and the research is difficult, and many functional modules are still not perfect. This study focuses on the key technologies in the virtual surgery simulation system, focusing on two core modules, the soft tissue modeling method and the collision detection algorithm, to improve the accuracy of the soft tissue model deformation under the condition of meeting the real-time system. The biomechanical properties of soft tissues are studied, the viscoelastic properties are analyzed, and the viscoelastic theory is used as the basis for soft tissue modeling; the geometric model is established by using a complementary method of surface model and tetrahedral mesh cells, with the surface model covering the outer surface for visual rendering and the tetrahedral mesh cells for skeleton support of the physical model, so that the model has a better visual effect and deformation effect, which enhances the model fidelity that is enhanced by the better visual effect and deformation effect; the soft tissue physical modeling method is summarized and summarized to lay the foundation for soft tissue model optimization. The experimental results show that the bilateral teleoperation system under analog control can give the operator a better haptic sensation (smaller value of input impedance felt by the operator when doing free motion from the robot) while ensuring good positional tracking and force tracking effects. This method solves the problems of collapse distortion and lack of viscoelastic properties of the traditional mass-spring model, and improves the accuracy of model deformation. Based on the improved algorithm, the viscoelastic hybrid filled sphere model of the liver organ is successfully established, which proves that the modeling method is feasible and effective.

1. Introduction

The development of medical simulation education technology has evolved from the earliest human anatomy models, to local functional training models, computer-driven models, and now to the most cutting-edge virtual training systems with haptic perception technology (i.e., virtual reality technology) and physiologically driven integrated simulation systems [1]. Physiologically driven simulation systems are mainly used in the field of medical education, using various technical means such as sound, light, and electricity to simulate various human physiological signs and pathological characteristics on a model human with the same appearance as a real person, and the monitoring instruments connected to the simulator can display various physiological data and simulate a specific clinical scenario; as a "doctor," the trainee is able to respond to the "condition" [2]. The trainees, as "doctors," perform the corresponding medical operations and medication on the simulator for the "condition," and then further treat the simulator according to the medical theory until the "patient" is cured or relieved according to the corresponding response generated by the simulator [3]. This comprehensive simulation of the treatment environment and modalities creates an interactive teaching scenario for the participants to learn how to treat patients in an environment close to the real situation [4].

Teachers in the chemical and chemical experimental teaching content of safety knowledge taught are completely dependent on the experimental textbook, but the safety content in the experimental textbook is old, not comprehensive enough, but also failed to update in a timely manner, and the actual operation of students is very different. Teachers, especially new faculty members, are limited by their own knowledge and are slow to respond to many commonsense safety hazards [5]. In addition, the teaching process of students' proficiency in experimental skills and understanding of experimental safety vary, teachers cannot care about the actual operating ability of each student, it is impossible to know the true level of student mastery, resulting in the actual experimental operation process that is still a small accident, and teachers are tired to cope with the experimental courses and content reform and innovation to improve the quality of teaching [6]. With the help of simulation software can greatly improve the quality of teaching, to ensure the safety of experimental courses, which is mainly reflected in the following: through the software management platform statistics, students' learning hours, questions and answers, quizzes, performance statistics, and other data can accurately grasp the cognitive ability of students and the ability to master the experimental safety; teachers can also be rich in theoretical knowledge, practical cases, and hands-on skills through the software platform, to improve their own understanding of professional courses. In addition, in the process of safety simulation exercises, students can raise experimental operation questions to teachers online and get solutions through teachers' online answers and actual exercises of the simulation system to meet experimental teaching needs [7]. Chemical and chemical experiment safety virtual simulation software can optimize experimental teaching resources, mainly reflected in the following: first, to reduce the use of chemicals, conventional experimental courses due to poor safety awareness of students, improper operation, or unskilled, not only resulting in many small accidents, such as breaking glass equipment, accidentally pouring all kinds of chemical reagents, etc., but also resulting in unsatisfactory experimental data, the need to repeat the experiment, and resulting in great loss of drugs and instruments and equipment [8]. After students use the preuse of virtual simulation software, not only safety awareness is enhanced but also have a prethought and operation, thereby improving efficiency and reducing the occurrence of accidents; second, we reduce instrument loss, improve the utilization of the number of instrument sets, and can reduce the rate of instrument failure [9]. Usually, experimental courses for large classes, students study time, and the use of instruments and equipment are too concentrated, resulting in some students on the operation of laboratory instruments rusty, and resulting in some instruments and equipment serious wear and tear or even damage [10]. For example, in the PVT curve test experiment in the chemical industry, if the students do not properly operate, will lead to the mercury tube burst, which is not only very easy to cause accidents but also damage to the equipment [11].

This thesis is based on the concept of a physiologically driven integrated simulation system, with computer software engineering and embedded technology as the means of implementation, and combined with the characteristics and needs of teaching obstetrics and gynecology medicine for research design and implementation. The use of chemical and chemical experimental safety virtual simulation software can quickly disseminate safety knowledge to students and can also change the teacher-lecture-based model into a student-centered independent learning teaching mode, which can guide and inspire students to further think about the key details in experimental safety, and thus cultivate students' subjective initiative [12]. Through the simulation of various scenarios to learn all kinds of experimental safety knowledge, to understand the experimental project safety precautions, for the subsequent course of practical experimental operations to improve the awareness of safety precautions, the software can also present different nature of the experimental course of different operational characteristics, such as inorganic chemistry in an acid-base neutralization reaction, and students can learn through simulation to acid-base reaction how to avoid overheating, and strong acid and strong alkali contact with the first aid methods. In the organic chemistry experiment, first aid is required in case of fire in nitrification reaction; in physical chemistry experiments, first aid and safe evacuation are required in case of mercury meter rupture. In chemical principle experiments, students learn how to deal with excessive filtration pressure and how to adjust stirring too fast, etc. Through vivid images of operations to solve such safety risks, students gradually improve their awareness of self-prevention in the process.

2. Related Work

Although the use of chemical and chemical laboratory safety virtual simulation software can improve learning efficiency and teaching quality and reduce the occurrence of safety hazards, continuous improvement is needed. First, the safety knowledge base already available needs to be regularly updated with the types of hazardous chemicals, various new standards, and new management regulations issued by the State Security Bureau, the Ministry of Public Security or the Ministry of Education, etc., which can keep students and teachers abreast of safety developments [13]. At the same time, it can update the investigation causes of safety accidents and the regulations for handling safety accidents [14]. It can implement dynamic interaction with users. Second, with the addition of different simulation scenarios of the project, the software can further add more mature and innovative experimental safety projects, and can increase the number of student simulation projects to improve the efficiency of the safety laboratory. For example, by setting up actual factory simulation exercises, students can first simulate the practice stage, be familiar with the basic system, laws and regulations, and factory management process of the factory, and closely combine the content of chemical safety knowledge with the content learned, so as to lay a certain foundation for students to carry out production practice and even work in the enterprise in the future [15]. Third, the use of virtual simulation experiments can ensure the improvement of the quality of experimental teaching, but the virtual environment makes the students wrong operation that also cannot really perceive the actual production caused by the scene of safety accidents [16].

Therefore, there is a need to improve the urgency and urgency of accidents caused by students' misuse of software, so as to improve students' awareness of independent prevention [17]. From the perspective of the course itself, discrete mathematics contains a variety of content, many concepts, many formulas, and symbols, strong theoretical content is relatively abstract and boring, and the name of the course also leads students to believe that this is a mathematics course, not a professional foundation course [18]. If the course is not combined with professional knowledge, students will think that it is a class "I do not know what it is for," so they will be less enthusiastic to learn. Moreover, because there are no computer hours and no computer assignments, this course cannot be immediately applied like other programming courses, so students cannot be convinced to treat this course with the same enthusiasm as other professional courses [19].

Virtual reality (VR) is a very high-tech information technology that emerged at the end of the 20th century. It is a collection of simulation technology, human-computer interface technology, computer graphics, multimedia technology, network technology, sensing technology, and other technologies [20]. In the virtual digital environment generated by virtual reality technology, the user interacts with virtual objects through specific devices, creating a great sense of reality in terms of vision, hearing, touch, etc., with an immersive experience [21]. The continuous advancement of computer technology has facilitated the rapid development of virtual reality technology, which can be applied in many fields such as education, medicine, entertainment, and industry [22]. Virtual surgery is the application of virtual reality technology in the medical field, which uses computer technology to build a virtual medical environment, draw a virtual organ model based on medical image data, and perform various operations on the virtual organ through specific equipment to simulate the entire surgical process [23]. Virtual surgery is not limited by time and space, and has the characteristics of repeatability and noninvasiveness, which can help improve the success rate of surgery and reduce medical costs, and has very important research significance [24].

3. Discrete Optimization in First Aid Models

3.1. Virtual Simulation of Biomechanics in First Aid. Soft tissue modeling technology, as one of the core technologies of the virtual surgery simulation system, is a hot spot for research at home and abroad. Due to the complexity of soft tissue structure, establishing a model that fully conforms to the biomechanical properties is an ideal point that cannot be reached by current modeling techniques. In order to reduce the complexity of modeling, this study will focus on the study of viscoelastic properties by analyzing the biomechanical properties of soft tissues and use them as the theoretical basis for modeling. By reviewing the current modeling methods, the advantages and disadvantages of various modeling methods are summarized and analyzed to lay the foundation for the next step of algorithm improvement. Due to the diverse composition of human soft tissues, the biomechanical properties of soft tissues are differently reflected in different directions in space, which is called anisotropy. When modeling soft tissues, it is usually assumed that the model is segmentally homogeneous and all isotropic according to the research needs in order to reduce the modeling difficulty. It has been found that viscoelasticity is a property common to almost all biological soft tissues, but the strength or weakness of the expression varies. Viscoelasticity is also the most typical mechanical property of soft tissues under the action of external forces, which is usually characterized by creep, relaxation, and hysteresis. When the stress of a viscoelastic material remains constant, the strain continues to increase with time, called creep properties. When the strain remains constant, the stress decreases with time, showing the relaxation characteristics. When a load is cyclically applied to a viscoelastic material, the relationship between stress and strain during loading is often different from that during unloading, which is called hysteresis.

When soft tissues are subjected to a certain loading force, they undergo some deformation. If the load is small, within the elastic limit, the soft tissue will return to the initial state after the load is withdrawn. If the load is too large, the soft tissue structure is damaged and cannot be restored to its original state when the elastic limit is exceeded. When the load is withdrawn, the strain on the soft tissue does not immediately become zero, a property called soft tissue plasticity. However, the classical plasticity theory is not fully applicable to the analysis of soft tissue properties because the living soft tissues have a strong self-healing ability, and after a period of time, the damaged soft tissues can restore themselves. Soft tissue biomechanical properties are complex, and it is difficult for current modeling techniques to reproduce the complete biological properties. Through the above aspects of soft tissue biomechanical properties, it is found that viscoelasticity is the most prominent mechanical property of soft tissue, so this study will focus on viscoelasticity theory and use it as the theoretical support for model building, and other properties are not considered as the focus of this study.

Viscoelastic materials, as the name implies, are materials with both elastic and viscous properties, and their stresses and strains are time-dependent. As shown in Figure 1, viscoelastic materials exhibit characteristic curves when the strain remains constant and the stress decreases as time t increases during the $[t1,t2]$ time interval, and creep curves, where the stress remains constant and the strain increases as time t increases during the $[t1,t2]$ time interval. The incompressibility of soft tissue refers to the fact that when soft tissue is deformed by external forces, it will only deform within a certain range and will not keep increasing deformation as the external force increases. When soft tissue modeling is performed, it is common to approximate soft tissue as a quasi-incompressible body, considering that its volume does not change with pressure changes.

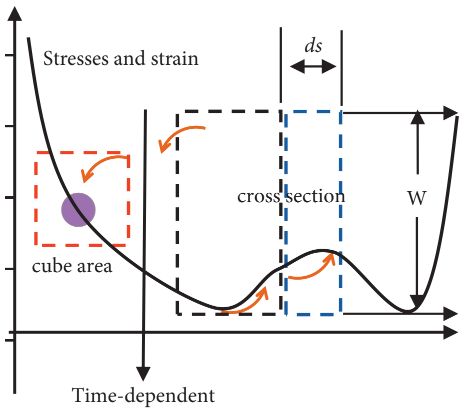

Figure 1: Viscoelastic curve.

Viscoelastic materials also include nonlinear viscoelastic bodies and linear viscoelastic bodies. A nonlinear viscoelastic body refers to a nonlinear variation of stress and strain with respect to time, and similarly, a linear viscoelastic body has a linear variation of stress and strain with respect to time. Geometric modeling is the basis of soft tissue modeling, which mainly represents geometric information such as organ shape. According to the characteristics of the model, geometric modeling can be divided into two modeling approaches: surface model and body model drawing. The surface model mainly records the position and geometry of the surface of the object, and cannot represent the internal information of the object. The body model is a three-dimensional unit to construct the whole organ, including the surface and the interior of the organ, which can be cut, sutured, punctured, and other series of operations. The topology of the body model commonly used in geometric modeling includes tetrahedron, hexahedron, and superhexahedron. The specific properties of the superhexahedral model are still under further research and are less commonly used. The hexahedral model has a simpler structure and relatively uniform mass distribution, so it is more suitable for models with regular shape and uniform mass, but the computational accuracy of this model is low, and its stability is not good, as shown in Figure 2. The tetrahedral model structure is less difficult to construct and more efficient to divide the mesh than the first two models; therefore, the tetrahedral mesh is usually used as the basic cell in virtual surgery, which can better describe the physical properties of soft tissue.

3.2. Hybrid Model and Discrete Scheme under Digital Virtual Simulation. By adding an analog differential term to the left side of the stability condition inequality, the hybrid controller increases the range of control gain options (in terms of stability). That is, with the assistance of the analog controller, the digital controller can obtain a larger control gain without compromising the stability of the system. Next, this is further illustrated by experiments to verify this point. In the stability conditions derived for the four different cases above, the proportional gain of the analog controller does not have any effect on the stability inequality. In other words, the proportional gain value of the analog control can be increased as needed without affecting the stability of the teleoperated system under hybrid control. This allows us to obtain a sufficiently large control gain for reproducing the process of contacting a high-hardness surface (in a virtual haptic HMI platform) or for implementing a high-gain slave robot control (in a virtual haptic teleoperation platform). The geometric model is established by using a complementary method of surface model and tetrahedral mesh cells, with the surface model covering the outer surface for visual rendering and the tetrahedral mesh cells for skeleton support of the physical model, so that the model has a better visual effect and deformation effect.

On the other hand, according to (4–35), (4–40), (4–47), and (4–50), it can be seen that, in order to ensure the stability of the teleoperation system, there is an upper limit on the value of the proportional gain DTK of the digital controller, limiting the maximum stiffness that can be achieved in the virtual environment (in the virtual haptic human-computer interaction platform) and the maximum control gain that can be obtained by the slave robot (in the virtual haptic teleoperation platform). However, for practical applications, it is not possible to solely rely on analog proportional control gain. This is because phenomena such as op-amp saturation in the analog controller circuitry can limit the upper limit of control gain in practice. Therefore, in some special tasks when the analog gain is limited, it is still necessary to combine the digital control gain to reach the final proportional gain value. To ensure system stability, while increasing the digital control gain, the whole system can still be guaranteed to be in a stable state by simply increasing the value of the analog differential term according to the derived stability condition inequalities (4–35), (4–40), (4–47), and (4–50). This is the effect of mutual assistance between the two types of control in the hybrid controller, as shown in Figure 3. That is, both the proportional and differential terms in the analog and digital controllers are essential in order to improve the transparency of the system (system performance) while ensuring its stability.

A bilateral teleoperation system based on the FPAA analog/digital hybrid method control can provide better system performance (system transparency) than under a single control method (pure analog control method or pure digital control method) while ensuring stability. On the one hand, a purely analog control system is not easy to debug during the design process and not easy to further modify once the entity is completed, while on the other hand, there is a mutual constraint between the digital control proportional gain and the sampling period, and the product of the two must be less than an upper limit that exists for stability assurance, so the performance of a purely digital control teleoperation system is limited and may not meet the mission requirements. The advantages of combining FPAA-based control and digital control are analyzed in detail by deriving and analyzing stability inequalities. In this study, the stability and system performance (transparency) of the teleoperated system under the hybrid method control are compared with those of the same system under the pure digital control method and the pure analog control method,

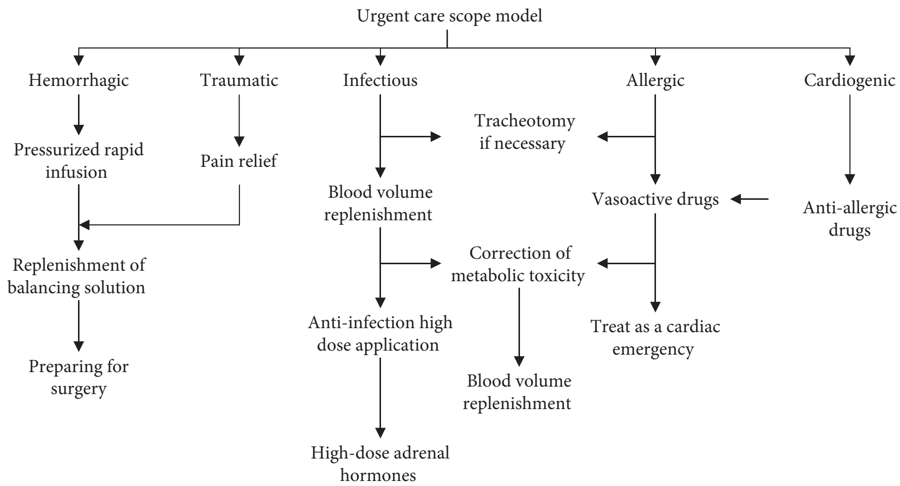

Figure 2: Urgent care scope model.

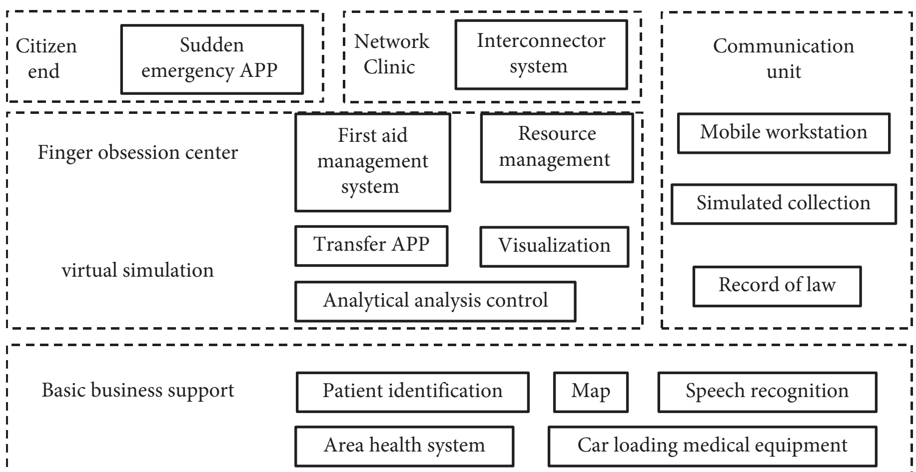

Figure 3: Hybrid modeling scheme under virtual simulation.

respectively. The stability analysis shows that the addition of the analog differential term widens the range of control gains of the remote operating system, which makes the bilateral remote operating system not only meet the stability requirements but also improve the system performance (transparency) at the same time. The experimental part of this chapter includes two parts: the remote three-step switching experiment and the force feedback transparency evaluation experiment. The operator's experimental results show that in both experiments the highest task success rate is achieved when using the bilateral teleoperation system under the hybrid method control.

3.3. Discrete Scheme under Mixed Method Control. In the bilateral remote control system under hybrid control, when the slave robot is in contact with the operating environment or the operating object, the slave displacement generated under the mutual force, and the difference with the displacement of the master robot, is fed back to the master robot by the hybrid control system, according to the set proportion, and at this time, the operator can sense the position feedback information by touching the master robot. The difference between this displacement and the displacement of the slave robot is again transferred as a variable to the slave robot in a set proportion through the control system to move the operation object based on the position feedback and the force applied by the operator through the master robot. In the hybrid control system, the analog controller is connected in parallel with the digital controller, which receives both master and slave displacement information and provides analog and digital control gains, respectively, according to the preset control gain values. In Figure 4, the Euclidean parameterization of the positional tracking error under digital control is 0.042 cm, and the positional tracking error of the system is 0.225 cm when based on the FPAA analog/digital hybrid control. The virtual haptic surgery simulation system under both control methods can reduce the pose tracking error between the master and slave robots when the control gain is increased, but the pose difference of the system under digital control is still significantly larger than that of the same system based on

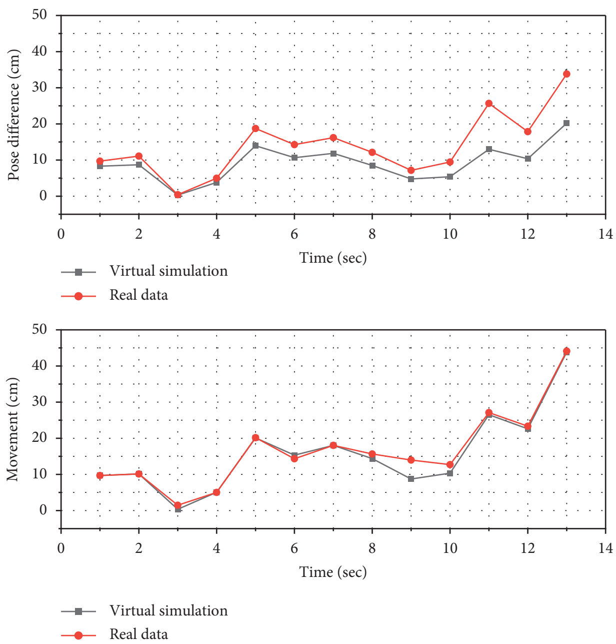

Figure 4: Virtual simulation system under digital simulation.

the hybrid controller at the maximum gain, which shows the superiority of the virtual haptic surgery simulation system under the hybrid control method in terms of transparency. In this chapter, a hybrid approach to control the remote operating system is proposed, which combines a programmable analog gate array (FPAA); first, the analog control part is designed, then the digital control part is designed based on the computer, and finally, the two are integrated to design a bilateral remote operating system under the control based on the hybrid approach.

The effect of force feedback was analyzed by recognizing virtual tissues of different hardness (harder and softer). Such object discrimination experiments have many uses, such as palpation of local cancerous tissue in minimally invasive surgery. In order for the operator to perform object hardness discrimination in a virtual environment, it is necessary that the magnitude of the impedance felt by the operator is as close as possible to the stiffness set by the virtual object. Therefore, if one or both of the virtual objects touched are set to have a high stiffness, the virtual haptic surgery simulation control system needs to provide a large impedance, and the magnitude of the impedance corresponds to the high or low gain of the controller. The control gain of the main robot (human-computer interaction device) in the experiment needs to be high enough to provide high-impedance values to accomplish the task. From the results obtained from the experiments, it can be seen that both different controllers can recognize the softer gallbladder tissue A; however, when the harder tissue B is recognized, the results when a hybrid analog/digital controller is used are significantly better than the simulation results when a single digital controller is used. The experimental results indicate that the FPAA analog/digital control-based virtual simulation system is superior to the same system under single digital control in terms of conveying task-relevant information (e.g., transmission impedance). Soft tissue deformation modeling is the basis of virtual surgical simulation systems and has a significant impact on system accuracy and real-time performance. In reality, chemical and chemical experimental classes usually first explain to students the experimental project, safety precautions, and possible accidents and explain the emergency plan, and then, students follow the steps of the experiment, and the awareness of safety hazards of self-prevention is weak. Students can use the simulation software to independently learn relevant experimental projects through the network at any time.

An ideal soft tissue model requires a realistic and natural biomechanical representation of the real soft tissue when subjected to external forces. However, due to the complexity of the human organ structure, the diversity of functions, and other factors, it is very difficult to establish a completely ideal model. In this study, we aim to establish a soft tissue model with viscoelastic properties by focusing on the relaxation and creep properties of soft tissues. When subjected to external forces, the spheres move in the feasible domain and realize the force transmission through the three-parameter structure, driving the movement of other neighboring spheres, and simulating the overall deformation process of soft tissue. The model is actually an improvement of the traditional mass-spring model, adding the filled ball to reflect the “body” characteristics, solving the problem of collapse distortion by using the surface model, while the viscoelastic structure is an improvement of the linear elasticity problem, enhancing the viscoelastic properties of soft tissue and improving the fidelity of the model. The soft tissue viscoelastic hybrid filled sphere model is built based on tetrahedral mesh topology, which can be divided into geometric and physical models. The geometric model is composed of tetrahedral mesh and surface model together, which is used to express the geometry, surface material, texture, and other information of soft tissue; the physical model is composed of three-parameter viscoelastic structure and filled sphere model together, which simulates the deformation process. The tetrahedral mesh topology is the skeleton support of the physical model. The geometric model is coupled with the physical model to jointly express the overall soft tissue properties.

4. Emergency Surgery Example Testing and Feed

The collision detection algorithm is the basis for realizing the virtual surgery operation and is one of the factors affecting the accuracy of model deformation and the real-time performance of the system. The main task of the collision detection algorithm is to detect whether a collision occurs between objects in the virtual environment, and if a collision occurs, it is reported to the main system including collision time, collision depth, and other collision information, and the main system guides the next operation. In the virtual scene, collisions between objects are inevitable. How to effectively avoid the unrealistic phenomenon of “penetration” between collision objects, that is, how the collision detection algorithm can detect and feedback the collision information in time to achieve the realism of the virtual simulation system, is a pressing problem in virtual surgery. This type of algorithm does not require high real-time performance but requires high accuracy. A dynamic collision detection algorithm is an algorithm that detects the relative positions between objects in a dynamic environment to determine whether they intersect or not. The dynamic collision detection is time-sensitive and has high requirements for detection time and detection speed, so the operation rate is an important indicator to judge the performance of the algorithm. Dynamic collision detection algorithm is divided into discrete collision detection and continuous collision detection algorithm.

Spatial domain-based collision detection algorithms are divided into image-space-based collision detection algorithms and graphics-space-based collision detection algorithms. The image-space-based collision detection algorithm mainly uses graphics hardware to determine whether two objects intersect for the planar projection of three-dimensional objects. This algorithm can be used for collision detection between complex objects because it mainly relies on the performance of computer hardware and has low requirements on the application scenario, but it has certain requirements on the CPU load capacity. In addition, the accuracy of the algorithm can be affected by the level of image resolution, leading to the occurrence of false positives. The common feature is that they both use object geometry information for detection calculation, but the difference is that the former uses the grid division of the scene to reduce the detection time, and the latter reduces the difficulty of collision detection and improves the detection speed by constructing a simple structure of enclosing box instead of virtual object detection. The spatial dissection method is suitable for collision detection in simple environments containing few objects due to the high memory overhead and low detection efficiency, while the hierarchical wraparound box is faster and better in real time, and can be applied to collision detection in complex environments.

Virtual surgery is able to make the user in the virtual environment with visual, tactile, and other real feelings, and the force feedback equipment is to provide the user with tactile sensory tools. When the user interacts with the virtual object by touching the hand, it will feel the feedback from the touching object such as surface roughness, softness, and hardness. The Omega.7 force feedback device has seven degrees of freedom: up and down, left and right, forward and backward, x-axis rotation, y-axis rotation, z-axis rotation, and gripping. By inputting force, velocity, and posture information to the force feedback device, the force feedback device can output the direction and magnitude of the feedback force. In the force perception interaction between the actuator and the virtual system, the gravity of the device moving the rod and the mechanical damping force can complete the force compensation during initialization to ensure the accuracy of the feedback force. The basic parameter information of the force feedback device is shown in Figure 5. The model is actually an improvement of the traditional mass-spring model, adding the filled ball to reflect the "body" characteristics, solving the problem of collapse distortion by using the surface model, while the viscoelastic structure is an improvement of the linear elasticity problem, enhancing the viscoelastic properties of soft tissue, and improving the fidelity of the model.

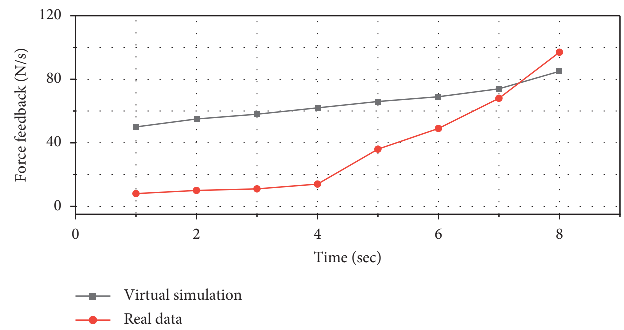

Figure 5: Force feedback device parameters.

To verify the viscoelasticity of the model, the stress relaxation characteristics and creep properties were simulated according to the established intrinsic constitutive equations, as shown in Figure 6, which are the stress relaxation curves and creep curves. When the strain is equal to 0.02 mm and 0.08 mm, the stress decreases with time, which is consistent with the stress relaxation characteristics of viscoelastic materials. The simulation curves show that the strain increases with time when $p = 3$ kPa and $p = 20$ kPa, which is consistent with the creep property of viscoelastic materials. In summary, the established soft tissue viscoelastic hybrid filled ball model with a realistic model and high deformation accuracy is consistent with the real soft tissue deformation characteristics, and has a good visual effect and deformation effect. Through viscoelastic simulation experiments, it was proved that the model has good stress relaxation characteristics and strain creep characteristics. The surgical instruments interact well with the liver, which proves the effectiveness of the collision detection algorithm. The time-domain-based collision detection algorithms are mainly divided into two categories: static collision detection and dynamic collision detection algorithms. Static collision detection algorithm refers to detect whether the intersection between objects occurs in a specific space-time, mainly detecting the mutual position of objects in a static environment before.

The MSM establishes the idea of abstracting soft tissue as a grid of masses connected by massless springs, each with the properties of mass, position and velocity, and the springs connected between adjacent masses that satisfy Hooke's law, as shown in Figure 7. When there is an external force, the particle is subjected to the combined force of the external force and the elastic force, and the acceleration and velocity of the particle are calculated by Newton's second law, and finally, the position change of the particle is obtained to update the particle position and simulate the deformation process. The MSM has a simple structure, is easy to program, has low computational complexity, and has good adaptability to changes in mesh topology but is not very accurate. The idea of finite element modeling is to discretize the soft tissue into a finite number of cells such as tetrahedral and

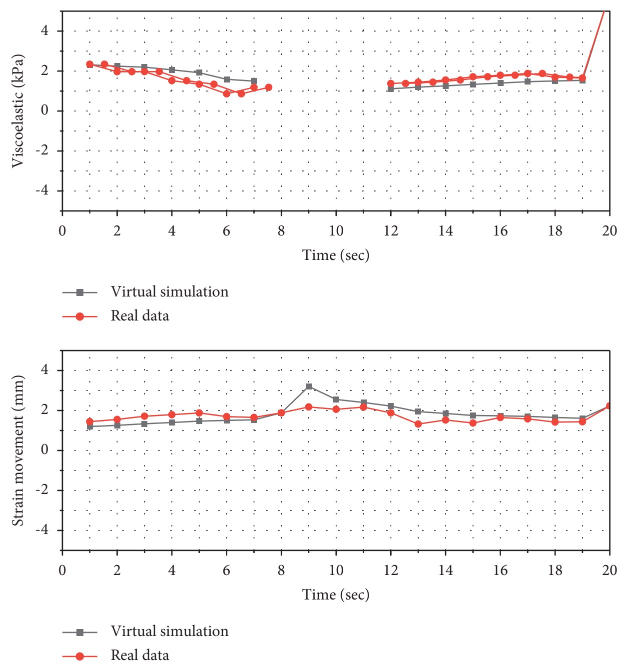

Figure 6: Viscoelastic simulation curve.

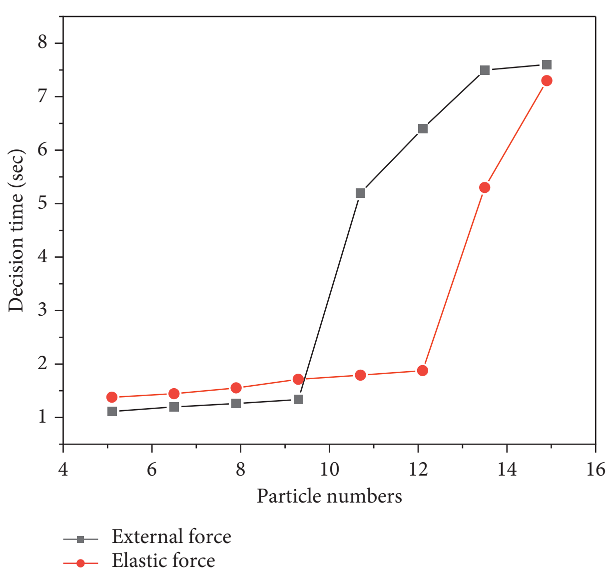

Figure 7: Detection results under different control strategies.

hexahedral. The cells are connected by mesh nodes, and the displacement of any point on the cell is expressed as a function of the displacement of each cell node as a variable. The finite element method is based on the foundation of elasticity mechanics, by accurately modeling the complex solution domain.

An important aspect of the application of teleoperated systems in the medical field is the remote robot-assisted surgical system. This remote surgery system allows medical specialists around the world to communicate and perform surgery face-to-face without long-distance travel, improving surgical outcomes while ensuring small surgical incisions and efficient physician operations. In general, scientists began to pay attention to the control system theory of time delay to carry out the theoretical design of remote operation system and the development of controller. With the use of the internet as a communication network, the problems of time-varying delays and packet loss also became increasingly important to researchers. When the task object is toxic, far away from the operator, or when the required output force is not within the natural range of manual force, a teleoperated system can be used to accomplish the task.

This study focuses on the use of FPAA-based analog control to reduce the impact of controller discretization on the transparency of bilateral teleoperation systems. The discretization of the control system in the bilateral teleoperation system limits the upper limit of the control gain, which reduces the transparency of the system. The FPAA-based analog control can provide a sufficiently large control gain to meet the high-precision positional tracking/force tracking requirements while ensuring the system stability. The hybrid control method combined with digital control combines the advantages of FPAA analog control and digital control. While retaining the advantages of digital control, the system stability range is expanded by adding an analog damping term, while the analog proportional term is added, which also increases the upper limit of the taken value of the control gain, showing a better system transparency and improving the system hard object detection. In this study, the transparency of the analog control in a bilateral teleoperation system is numerically analyzed and experimentally verified by analyzing the transmission matrix parameters of the remote control system. The results of the numerical analysis show that the bilateral teleoperation system under digital control can achieve a system transparency similar to that under analog control only when the sampling period is small enough (as close to 0 as possible) for a selected signal frequency.

The experimental results show that the bilateral teleoperation system under analog control can give the operator a better haptic sensation (smaller value of input impedance felt by the operator when doing free motion from the robot) while ensuring good positional tracking and force tracking effects. A hybrid FPAA analog/digital-based control method in a virtual haptic surgery simulation system is implemented, its stability conditions are derived, and the selection range of stable impedance is expanded. The stability conditions in this chapter consider four cases, such as the system with or without delay and whether the terminal is passive, and extend the conclusions to the haptic simulation system in the multiuser case. The range of values for the proportional gain of the system under the stability conditions is given by the simulation platform developed by the laboratory. Through transparency evaluation experiments, it is shown that the virtual haptic surgery simulation system under hybrid control has a better force feedback effect for hard object detection.

5. Conclusions

Virtual surgery is noninvasive, repeatable, and not limited by time and space, and can help train new doctors, plan surgical paths, and locate surgical instruments, etc. It is significant in improving the success rate of surgery and reducing medical costs. In view of the significance of virtual surgery research, more and more researchers have started to study the technology related to virtual surgery simulation system, and many research results have emerged, but how to ensure both the real-time system and the accuracy of soft tissue model deformation is still a pressing problem to be solved. In order to establish a soft tissue model that conforms to the biomechanical properties, the viscoelastic theory is used as the theoretical basis for modeling by summarizing and analyzing the mechanical properties of soft tissues. By studying the geometric modeling method in soft tissue modeling technology, we propose to cover the surface model on the outer surface of the physical model and use the tetrahedral mesh as the support skeleton of the physical model to make the model have a better visual effect and deformation effect. By studying the physical modeling methods, the advantages and disadvantages of various physical modeling methods are summarized to pave the way for building a more realistic soft tissue model. The soft tissue model of the liver, for example, not only has "body" characteristics but also shows good viscoelastic properties. In order to verify the deformation effect of the model, a virtual simulation platform was built, and the simulation experiments proved that the model has a good deformation effect and high deformation accuracy. The simulation experiments of viscoelastic properties were carried out to prove that the soft tissue has good stress relaxation and creep properties. In the future, the idea of finite element modeling is to discretize the soft tissue into a finite number of cells such as tetrahedral and hexahedral.

Data Availability

The data used to support the findings of this study are available from the corresponding author upon request.

Conflicts of Interest

The authors declare that they have no conflicts of interest or personal relationships that could have appeared to influence the work reported in this paper.

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