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Advanced Interactive Device in Virtual Knee Arthroscopic Surgery

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Abstract. Regarding the lack of interactivity for Virtual Knee Arthroscopic Surgery, which leads less immersion in simulated surgery, a new advanced interactive device in Virtual Knee Arthroscopic Surgery based on displacement sensor and Data acquisition card was developed. Based on study of degree of freedom on Knee Arthroscopic Surgery, a new interactive device on simulating real surgery was proposed. This device simplifies true operation for four degrees of freedom. Each displacement sensor captures information from one degree of freedom, then sends the information to the data acquisition card to carry out analysis and treatment for the purpose of synchronization on the computer, then realize realistic simulation of surgical procedures. The creative design of the interactive device makes it possible to flexibly adjust the location and angle of simulated scalpel and endoscope according to different operator and reach the requirement of immersion of virtual reality.

Introduction

Virtual surgery, also called surgery simulation, which is one of the virtual reality technologies are applied in the domain of medicine. Using the realistic rendering technology of computer graphics, the VR technology can show us anatomic structure, anatomic position, physical characteristics and physiological characteristics perfectly. And it can simulate different phenomena and build a virtual environment for doctors during the virtual surgery. Furthermore, with the help of interactive devices, it makes doctors get the information from the virtual organs and achieve the simulation of the whole surgery by the way of interacting with the virtual human organs.

The instruments of arthroscopic surgeries cost a lot and there are a great number of surgery requirements. But, there are not enough skilled doctors. The main reason for it is that the arthroscopic surgeries are restricted by many factors, for example, the narrowed sight, the restricted cooperation of hands and eyes, the limited scope of the instruments and the high challenge of the operations. Accordingly, the surgeries will not successful if the doctors are lack of enough trainings and experience. However, at present, in order to make doctors familiar with the whole procedures, they are trained to look into the operation of experienced doctors which make the trainers dot not get the right interactive information between instruments and human organisms. Compared with the increasing of the surgery requirements, short of skilled doctors is becoming a bottleneck of limiting the development of arthroscopic surgeries.

To find a better way of training and educating, shortening the time and reducing the cost is a problem urgently needing to be solved. And based on VR technology, the doctors can be trained by the surgeries training system at all times and places at very low cost. There is no doubt that it is valuable for the development and spreading of surgical technique.

The analysis of degree of freedom

Due to its particular characteristics, knee arthroscopic surgery can only involve four kinds of degree of freedom, i.e. the movement of scalpel along the feed direction, the rotation of scalpel, the horizontal and longitudinal rotation of scalpel taking the wound as the core. During the real operations, the complex movements of scalpel can be seen as movements along the four directions of degree of freedom mentioned above. Fig.1 illustrates the degree of freedom of knee arthroscopy movement. The arrowhead twisting around the X axis stands for longitudinal movement of scalpel; the arrowhead twisting around the Y axis stands for horizontal movement of scalpel; the arrowhead pointing up and down along the Z axis stands for the feed direction movements of scalpel; and the rotation around the Z axis stands for the rotation of scalpel itself.

After analyzing the degree of freedom of operations, the key assemblies of interactive device are illustrated just as figure 2. The rotation along X axis of the device is realized with the help of connection shaft 1 and 2 connected to X axis; the rotation along Y axis of the device is realized with the help of connection shaft 1 and 2 connected to Y axis; the rotation along Z axis of the device is realized by the rotation of angular displacement transducer; movements of slider of linear displacement transducer along the slide bar just imitate the feed motion of scalpel along Z axis.

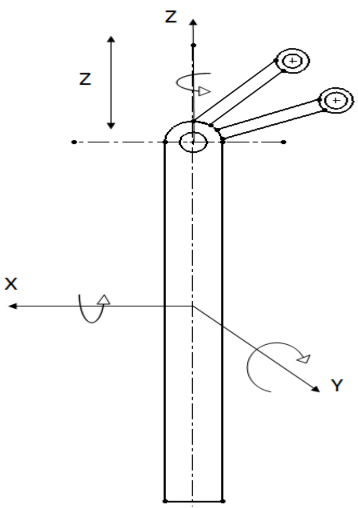

Fig.1

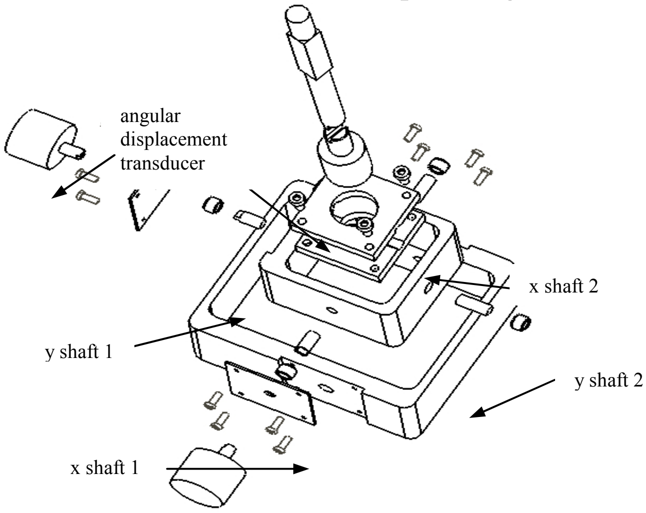

Fig.2

The structure design of operation head

The exploded drawing of operation head of virtual knee arthroscopic surgery interactive device is illustrated by Fig.2. The main assemblies of operation head are external frame, internal frame and the middle part with two components—the upper and the lower one. The central block can rotate within the internal frame which can rotate within the external frame. The rotations toward different directions can be in progress at the same time while keep independent to each other. Such three assemblies are all designed well with the location for the transducer. So it is convenient to fix and disassemble it. The assembly for fastness of operation head is equipped with screws in accordance with national standard which is very easy for fixation, disassembly and replacement as well.

The main function of external frame is to enfold internal frame and to facilitate the fixation of well-assembled operation head to the operation arm. The fixation instruction picture can be seen in Fig.4. The connection bar in Fig.4 is called NO. 1 connection bar to the X axis(X shaft 1). One end of X shaft 1 is connected to the angular displacement transducer, and the other end is in close connection to the external frame. In such a way, the angular displacement transducer can sense the rotation data of X connection axis, i.e. can collect the data of X axis rotation during a surgery. The NO.2 connection bar to the X axis(X shaft 2) is fixed to the other end of external frame with the same fixation methods as X shaft 1. X shaft 1 and X shaft 2 are not only rotation axis but also support axis for the part instituted by internal frame and the central block. Needle roller bearings are fixed within the connection pores, which can reduce the frication between the connection bars and external frame and can facilitate the fluent rotation along X axis direction.

The structure of internal frame differs little from that of external frame but the former is smaller than the latter. Internal frame is used to enfold the central block. The four sides of internal frame all have connection pores just as what Fig.5 is illustrating. Among the pores, there are connection pores in Needle roller bearings is used for the fixation of NO.1 connection bar to Y axis(Y shaft 1). One end of Y shaft 1 is connected to the angular displacement transducer, and the other is connected to the central block which realizes its pore rotation through the Needle roller bearings. Just look at the structure design figure and we'll find the function of Y shaft 1 and Y shaft 2 is similar to the X connection axis. In Fig.5 we can see that another pore is closely connected to the X shaft 2. That is to say, the internal frame rotates taking the rotation axis—X shaft 1 and X shaft 2.

The fixation instructions for central block and its related components can be illustrated by Fig.6. The central block is divided into 2 parts—the upper one and the lower one—both of them have notches for solid fixation of Y shaft 1 and Y shaft 2. The central block and its related components rotate within the internal frame through Y connection axis. The central block is also supported by Y connection axis. There is a pore in the middle in both upper and lower part of central block which is used to locate the angular displacement transducer. After all the components in Fig.6 are assembled, hexagon screws are applied for fixation. The original innovation lies that the rotation end of angular displacement transducer is directly connected with the slide bars of linear displacement transducer. During the knee arthroscopic surgery, information on the rotation of Z axis can be collected in the way that the rotation of linear displacement transducer spurs the rotation of angular displacement transducer. The to-and-fro movement of sliding bush of linear displacement transducer just imitates the movement of scalpel in the feed direction and during such a process, the information about the linear movement along Z axis is also collected

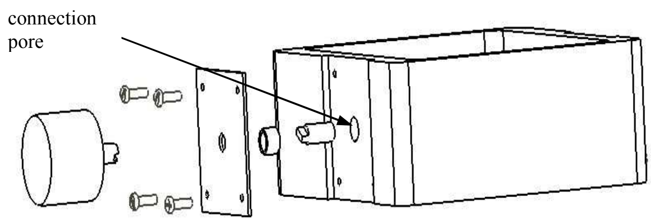

Fig.4

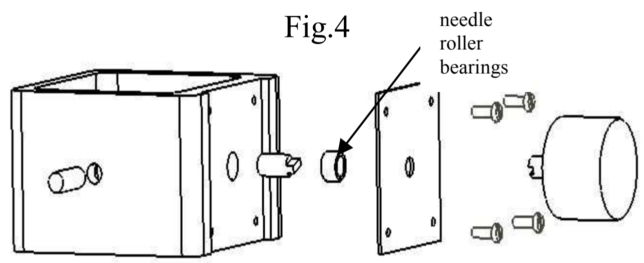

Fig.5

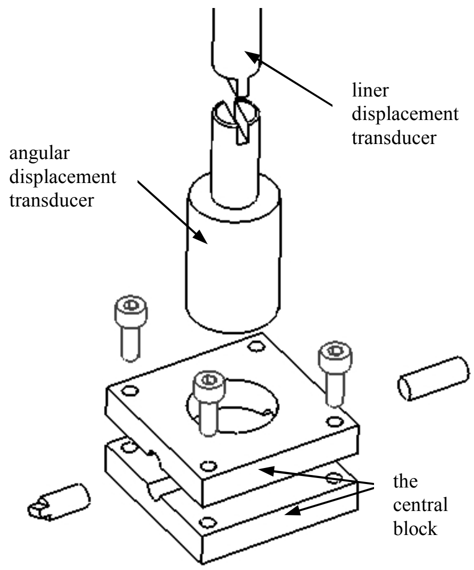

Fig.6

The structure design for operation arm

Operation head is the key component of the interactive device. Its operation should be managed with the support from the operation arm and supporting plate. In addition, due to its structure, operation arm can control and regulate the position and direction of operation head according to the real condition. In order to meet with the function of the design, an operation arm is divided into two parts—the upper one and the lower one. The upper part is connected to operation head while the lower one is connected to the supporting plate. Fig.7 illustrates how to assemble operation head and operation arm. There are notches in the external frame of operation head which can be embed and connected with upper part of operation arm and be fixed with slotted screws. Such a design can keep the operation arm from distortion and deformation due to pressure for a long period.

Seen in Fig.7, as upper part of operation arm and the lower part are supporting the whole operation head, its structure looks thick and heavy. The best solution for this is to use bolts and hexagon nuts for connection. This is the innovation point of such an interactive device structure design. With the principles of disintegration of degree of freedom in mechanical design, revolute pair of operation head can move downwardly. In such a way, the structure design between operation head and operation arm will be simplified. During the virtual operation, one should only adjust the relative angle between upper part and lower one of operation arm by regulating the hexagon nuts, the position and direction of operation head can be changed, which will realize the goal to simulate the real operation during a surgery.

After the assembling of operation arm and both parts of operation arm, the lower part of operation arm should be fixed on the supporting plate. Just as what Fig.8 illustrates, there are threaded pores—M30 in the side of supporting plate and bottom of lower part of operation arm, which is equipped with hexagon screws. When necessary, the relative angle between lower part of operation arm and supporting plate can be regulated to get a best location and direction for operation head.

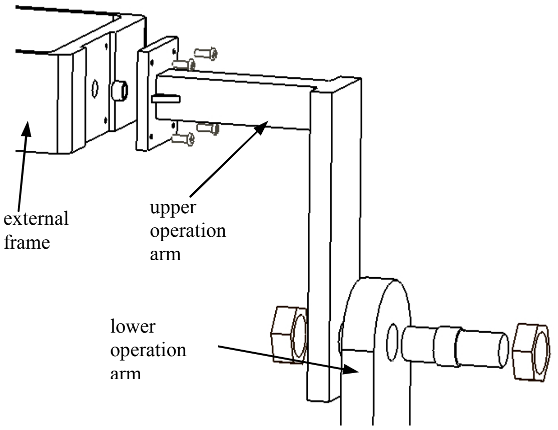

Fig.7

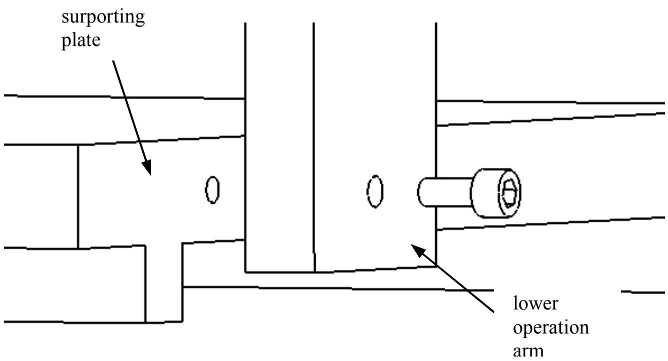

Fig.8

The overall structure design of interactive device and instructions for its usage

Since both hands should be involved for the operation during arthroscopic surgery, one hand for endoscope operation and the other for scalpel operation. Therefore, the interactive device should be equipped with two operation heads which can be operated at the same time, one for imitating endoscope movement and the other for scalpel movement. The overall structure design of interactive device is illustration as Fig.9.

During virtual operation, two hands will hold the sliding bush of linear displacement transducer. The operation head on the left in Fig.9 is used to imitate endoscope and the one on the right for imitating the movement of scalpel. When the operator holds the sliding bush of linear displacement transducer along sliding bar, all the information about such a movement can be collected. In the meantime, the sliding bar controlled by operator can actually move toward any direction. The interactive device will automatically analyze all kinds of movements toward two directions: along X axis and Y axis. The rotation degree will be sensed by angular displacement transducer fixed at the internal and external frames. In addition, through the rotation of linear displacement transducer's sliding bar, the operation of rotating endoscope and scalpel can be imitated. During such a process, the rotation degree can be sensed by angular displacement transducer fixed at the central block connecting to linear displacement transducer's sliding bar.

Data collection card will be the storage for all the information sent from transducers. After analysis and processing, the information will be sent to terminal PC and the picture will come into being spontaneously. The operator can do virtual operations with interactive device while looking at the pictures in the screen.

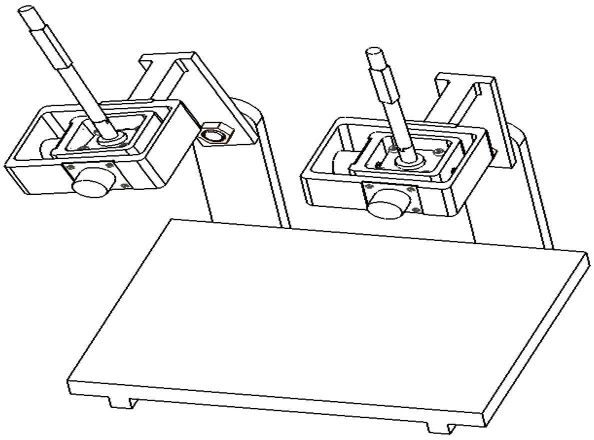

Fig.9

Summary

Based on the real operation conditions in knee arthroscopic surgery and the analysis about degree of freedom during the operation, we can dissemble a complex operation into 4 degree of freedom and an interactive device for knee arthroscopic surgery is therefore designed under the principles of mechanical theories and mechanical design. Such an interactive device can be adjusted to meet different operation habits of users.

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