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Development of a Novel Intraoperative Information Monitor System for the Vascular Interventional Surgery Robotic System

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***Abstract* - In the master-slave vascular interventional robot system, visual feedback can help surgeons to make better decisions about the surgical operation. A novel intraoperative information monitor system is developed based on the QT development platform. In this system, the numerical value and the curve are combined to display the collision force information of the slave manipulator, the displacement information with the errors of the master manipulator and slave manipulator and the video image of the camera in slave side. Meanwhile, through the color-changeable image to make surgeons more intuitive understanding of the changeable operation force, and then to assist surgeons to operate more smoothly, this system can also record the operation data of different surgeons, which lays a foundation for the research of the recognition and intelligent navigation of surgeon's operation. Finally, the effectiveness of the system is verified by the information communication experiments with the slave robot.**

Index Terms- Surgical monitoring system, vascular interventional procedures, intraoperative information, surgical robots.

I. INTRODUCTION

Cardiovascular and cerebrovascular diseases have the characteristics of high morbidity and high mortality. The main treatment of this disease is vascular interventional surgery. Nevertheless, during the clinical vascular interventional surgery, doctors need to wear 20 kg of lead clothing. Under the guidance of the digital subtraction angiography (DSA) imaging images, interventional instruments such as guide wires and catheters are pushed to the target position to complete the detection of the patient's intravascular environment and the treatment of vascular diseases. On the one hand, the radiation produced during DSA angiography increases the cancer rates of surgeons, on the other hand, the heavy lead clothing causes chronic diseases, such as spinal diseases. Therefore, with the continuous progress of the robot technology, the research of master-slave vascular interventional robot (VIS) system has a good application prospect in solving the above problems. In the master-slave VIS robotic system, surgeons judge the actual operation during the operation according to the two information of the tactile information and the visual information, so as to ensure the safety of the whole operation process.

There are a lot of research programs for the master-slave VIS robotic system. A number of advanced VIS robotic systems, such as: CorPath® Robot System (Corindus Robotics Inc., Waltham, MA, USA) [1], Sensei® Robotic System (Hansen Medical Inc., Mountain View, CA, USA) [2], Amigo® Robot System (Catheter Precision Inc., Ledgewood, NJ, USA) [3], have been developed and commercialized. A novel slave robot was developed, and the theory and method of cooperative operation of guide wire and catheter are put forward, at the same time, the measurement and compensation method of force during operation were also put forward, which largely improved precision of operation, and the effectiveness of the salve robot is verified by clinical trial [4]-[9]. A kind of master-slave robotic system with force feedback was developed, and magnetorheological fluid (MRF) is used to provide the axil force feedback, but this method can only provide smaller force, and the stability of the device with a bigger volume is a little poorer, at the same, although the displacement is measured by optical mouse sensor, the force feedback device is separated with the sensor, which also increases the size of manipulator largely [10]-[16]. A vascular interventional surgical robotic system based on force-visual feedback was proposed, which can increase the safety of the operation [17]. A vascular international vascular robot with fuzzy control and force feedback was proposed, which is achieved by Geomagic Touch X (3D Systems Corp, Rock Hill, SC, USA) [18]. The research on detection for operation skills and operating force used machine learning, Non-interference operation detection and online detection were done to improve the efficiency of the master-slave endovascular surgery robotic system [19]-[26]. The research on safety and training system based on the virtual reality (VR) were presented to improve the surgical operating skills [27]-[30]. A novel robotic mechanism was proposed, which can achieve translation of the balloon [31]. Magnetic micro active-guidewire was designed and evaluation, which is helpful to navigation and surgical safety [32]. However, the real-time operational data of the surgeons is ignored to display in the monitor systems, which is referred to the displacement data of the master and slave manipulator, the intraoperative operating force information and the operation status of the slave

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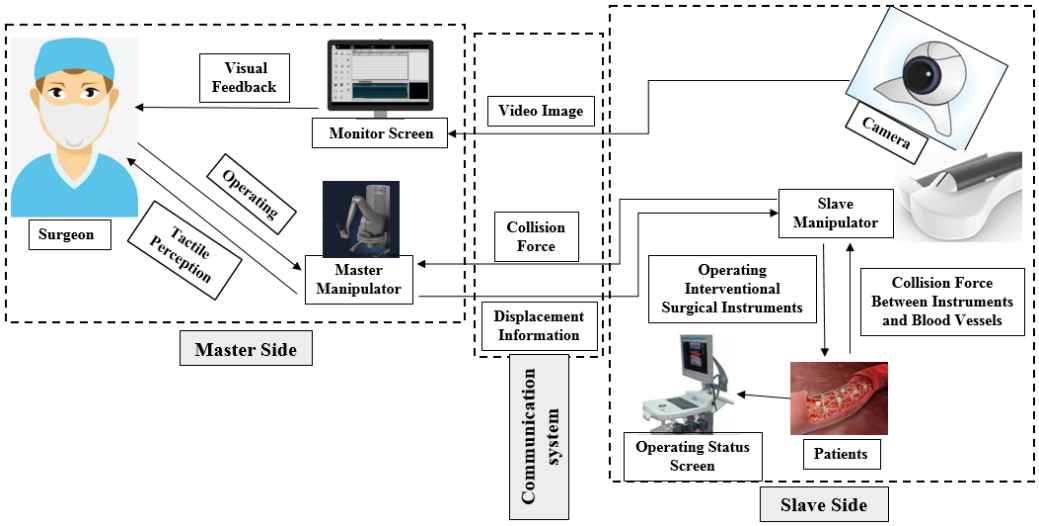

Fig. 1. The master-slave robotic system.

manipulator. The information can make sure the safety better in the surgery.

In this paper, a novel intraoperative information monitor system is proposed based on the the QT development platform, which can be used to portable software systems. And the most distinctive contribution is that when the VIS robotic system is applied, this system can provide the all-round intraoperative information, which can increase the efficiency of the surgery and make sure the safety of the surgery. The remaining of this paper are organized as follows: In section II, the functions of the system are shown in detail. In section III, the implementation of the method for the functions in section II are shown. In section IV, experiments and results are analysed. In section V, the conclusions are presented.

II. Functions of the Information Monitor System

A. *Master- Slave Robotic System*

The technical scheme of the master-slave VIS robotic system is shown in Fig.1. This system includes the master manipulator, the slave manipulator and the information communication system. During the operation, the surgeons can operate the master manipulator in the radiation-proof space, and the displacement sensor on the master manipulator collects the surgeon's operation displacement information and transmits it to the slave manipulator through the information communication system. The guidewire/ catheter is clamped and pushed along the vascular pathway to the target position. During the push process, the collision force generated during the push process of the guide wire/ catheter will be transmitted to the master manipulator, and the force feedback device at the master manipulator will provide the surgeon with the tactile perception. In the whole process, the doctor needs to detect the push state of the guidewire/ catheter in the operating room through the visual information feedback from the camera. Therefore, the development of intraoperative information real-time detection system can not only improve the efficiency of operation, but also further ensure the safety of operation.

B. *Details for the Functions of the Monitor System*

In the master-slave VIS robotic system, on the one hand, the force feedback device is applied to provide the tactile perception to the surgeon, on the other hand, the surgeon watches the screen, which provide the intraoperative information. In the introduction of the master-slave robotic system, the DSA image, the displacements of the master manipulator and the slave manipulator and the collision force are necessary to detect and display on the screen to assist the surgeon to complete the surgery smoothly. Based on the needed in surgery, the perception of the intraoperative information monitor system is shown in Fig.2. In this system, it will include five modules, such as: the serial communication module, the displacement display module, the collision force display module, the data processing module and the video image display module. And the serial communication module will be applied to connect the monitor system with the communication system. The collision force display module includes the circumferential force display module and the axial force display module to show the circumferential force and the axial force when the guidewire/ catheter are pushing in the vascular. The displacement display module will show the operating displacements of the surgeon and slave manipulator. The data processing module is used to save the operating information and form the database for the research of the intelligent navigation. The video image display module are used to show the state of the slave manipulator and the DSA image.

III. Implementation of the Method for the Information Monitor System

This part will show the method in detail to realize the functions of the five modules, which is developed based on

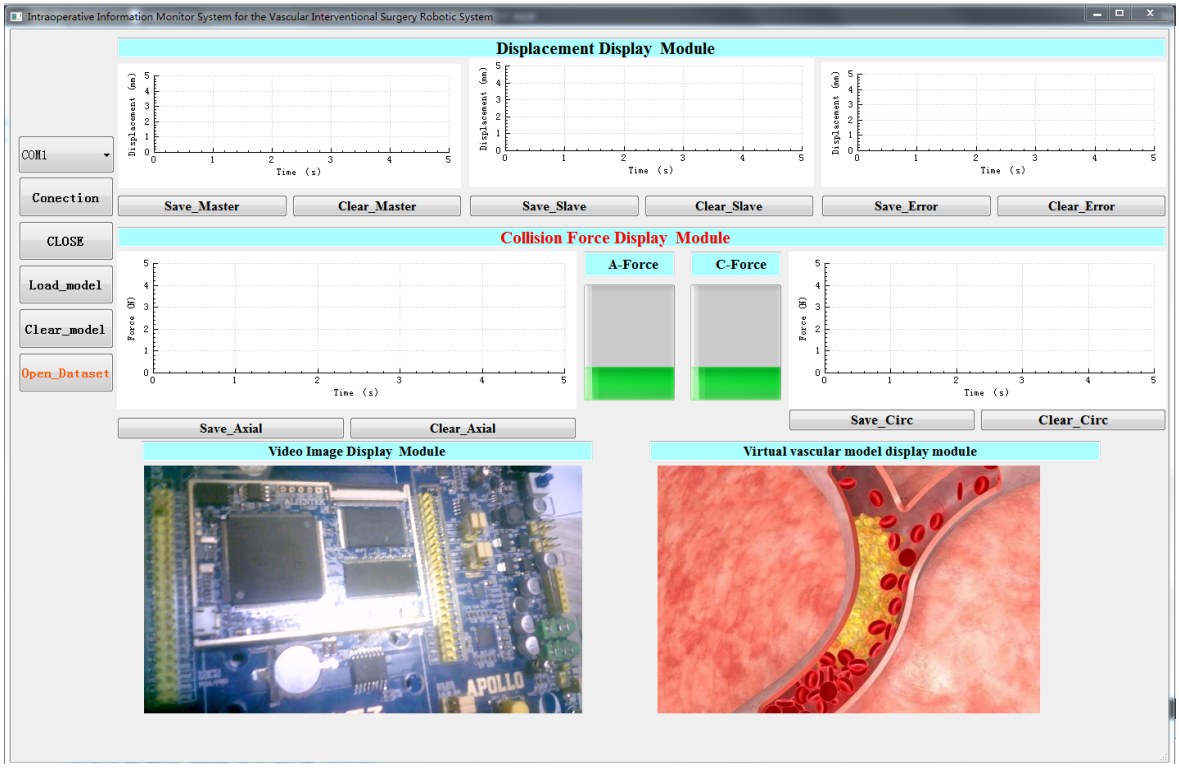

Fig. 3. The developed information monitor system.

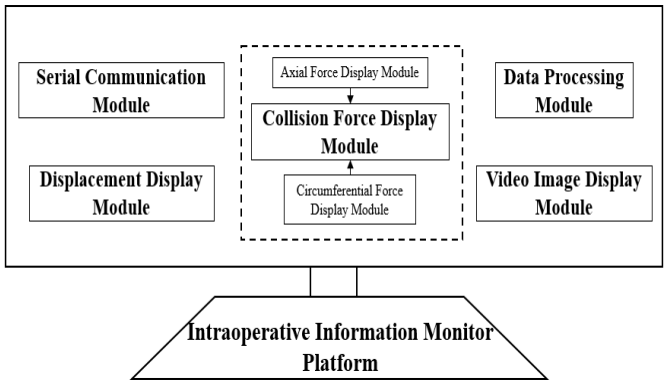

Fig. 2. The Perception of the Intraoperative Information Monitor System.

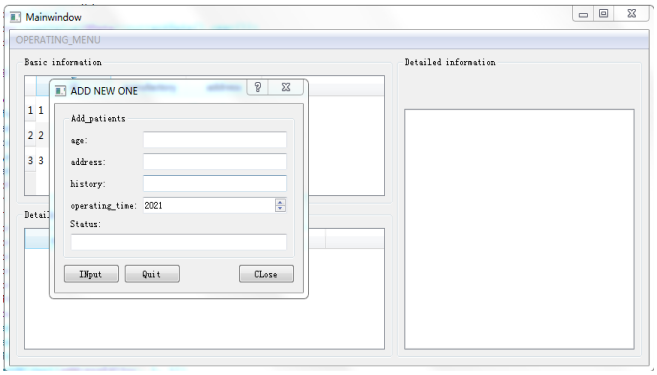

Fig. 4. The data set based on the SQLite.

the QT development platform, and the details of the realization of the five functions is as follows:

1) The serial communication module used the QSerialPort class, when the Serial port is successfully opened, the QSerialPort will try to determine the current configuration of the port and initializes itself, and during the programming process, the setBaudRate(), setDataBits(), setParity(), setStopBits(), and setFlowControl() methods are used to reconfigure the port to the desired setting. And Serial-port communication protocol is also set up. Based on this protocol, the proposed system can identify the meaning of the data set.

2) The displacement display module and the collision force display module are used the Qcustomplot class, which is a Qt C++ widget for plotting and data visualization. This class has no further dependencies and is well documented. And this plotting library focuses on making good looking, publication quality 2D plots, graphs and charts, as well as offering high performance for real time visualization applications. And the QCustomPlot can export to various formats such as PDF files and rasterized images like PNG, JPG and BMP.

3) The data processing module is used the SQLite data base, which is an open-source lightweight database software that does not need server, and it can be integrated into other software. In this module, the

displacement data of the master and slave manipulator, the intraoperative operating force information, the operating time and the basic information of the patients and the surgeon are all recorded, of course, all of the information will be kept secret.

4) The video image display module is developed using the QCamera class, this class is easy to operate, and it can realize the display of the video images.

IV. Experiments and Results

And the developed information monitor system is shown in the Fig. 3. And the displacement display module includes three parts, which are used to display the displacement of the master manipulator, the real displacement of the slave manipulator and the errors between both of them. This module can help the surgeon to judge the position of the guidewire/ catheter generally, which can reduce the amount of the contrast agent used for the DSA. And the collision force display module also includes three parts, which are used to display the collision force in slave side. And the axial force and the circumferential force are included, which are connected with the A-Force and the C-Force, respectively. About the A-Force and the C-Force are color-changeable, which can provide the safety warning clearly. And the A-Force and the C-Force are used to show the axial force feedback and the circumferential force feedback in visual, respectively, which is shown in Fig. 5. And the red color, yellow color and the green color represents the danger, warning and safety status, respectively. In the monitor system, there is one pushbutton, which is the open-data set, used to open the dataset shown in the Fig. 4 in detail. In the dataset, we can record the basic information of the patients, including the name, the age, the address and the medical history and so on. Of course, we can add or delete any information in personal. And the video image display module is used to show the intraoperative image on the slave side. On the one hand, through the video, the surgeon can monitor the status of the slave manipulator and the patients, and the DSA image is also included. On the other hand, the expert can also show how to operate the surgery to the new surgeon. In addition, the virtual vascular model display module is used to show the visual reality image of the vascular, this part is only the assumption. But it is helpful for the VIS training system for the surgeons.

Fig.5. The color-changeable image to show the collision force.

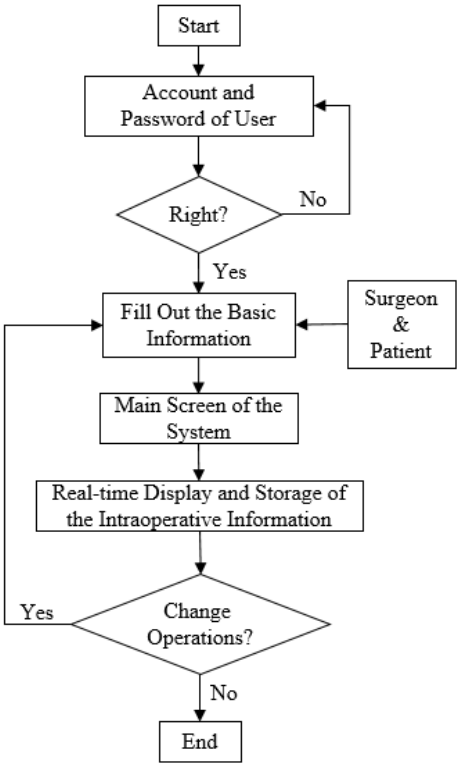

Fig. 6. The workflow of the Intraoperative Information Monitor System.

And the workflow of the intraoperative information monitor system is shown in the Fig. 6, which need the user to register before using this system. And this workflow is likely to the user manual, which can help the user to learn the function of the proposed system easily.

IV. Conclusions

In this paper, a novel intraoperative information monitor system is developed based on the QT development platform, which can provide the all-round intraoperative information, and the special one is the collision force warning method, which adopts the combination method of the color-changeable image of the multi-color rectangular square and the data curve. Meanwhile, the displacements of the master and slave manipulator and the errors of them are all shown by the data curve. In addition, the surgical state video of the slave manipulator is also displayed in this monitor system, and the basic intraoperative information is recorded, which will be helpful for the intelligence of the vascular interventional surgery robotic system. In the future, the performance of the proposed monitor will be evaluated in the vivo experiments.

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