An Intuitive Control of Eye Surgical Robot with Inertial Measurement Unit (IMU) Sensor

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***Abstract*— Vitreoretinal surgery is known to be a challenging operation in the ophthalmic microsurgery domain. It requires delicate motion and sensitive perception. Robot-assisted vitreoretinal surgery is a promising technical solution for help surgeon to perform a better surgery with less consideration of physical limitation and delicate motion. Currently, most of the surgical robot is remotely controlled with a joystick or a master controller. In this paper, we propose to control the robot with IMU sensor which is mounted on the robot directly, thus the surgeon can intuitively interact with this sensor to achieve an easier and better control with an acceleration of learning curve of the surgical robot control. The experimental result shows the feasibility and effectiveness of our proposed design.**

I. Introduction

Vitreoretinal surgery has been successfully used in clinical trials for years and saved lots of patients' vision. However vitreoretinal surgery proposed a delicate and dexterous motion which propose a challenge for the surgeon. The precision requirement of vitreoretinal surgery varies depending on the specific operation. For the ILM peeling process, the surgeon can do it quite well, which means the 182 µm accuracy (the hand tremor RMS amplitude [1]) is enough. For the sub-retinal injection, the average thickness of retina is around 200 µm, therefore, 20 µm would be an acceptable position accuracy. For the retinal vein cannulation, the ideal position accuracy would be 20 µm, since the diameter of branch retinal veins is typically less than 200 µm. The robot-assisted vitreoretinal surgery has been proposed more than 30 years which was intended to extend the surgeon's physical limitation. In September 2016, surgeons at Oxford's John Radcliffe Hospital, performed the world's first robotic Internal Limiting Membrane (ILM) peeling, in which the surgeon removes one membrane from a specific area of the retina. The eye surgical robot named Robotic Retinal Dissection Device (R2D2) with 10 µm accuracy was used in the clinical trials [2], which proved the safety of robot-assisted surgery.

Even though the surgical robot has been developed and tested on human trials, there are still many points can be improved. This paper we focus on developing an easier and more intuitive control concept to provide the surgeon which can reduce the learning curve. The device is designed mounting on the end effector of the robot, thus the surgeon can easily control the movement of the robot by dragging the device. Taylor et al [3] developed a steady hand robotic system for vitreoretinal surgery using the cooperative control method which the robot hand and human hand hold the surgical instrument simultaneously. The way to have the interaction with the human hand is using a force sensor to sense the force applied on the end effector. Different from using a force sensor, in our research, lightweight and low-cost design is proposed based on the inertial measurement unit (IMU) sensor. The overall cost for the cost is within 40 dollars which is much affordable than a delicate force sensor which is normally thousands of dollars.

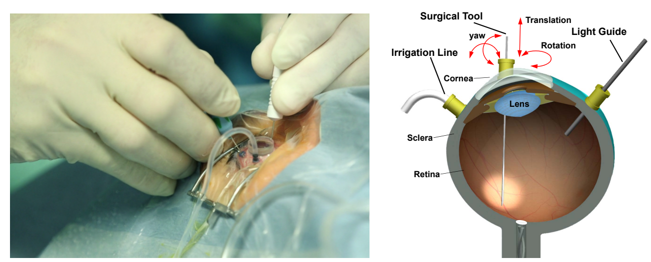

Fig. 1. A conventional vitreoretinal surgery setup.

II. Method

The BMI 160 6-axis IMU produced by DFROBOT is chosen for the pseudo compliance control of the our robot arm. In order to manipulate the robot by directly interacting with its end-effector and meanwhile measure the robot's orientation with IMU device, two aspects of problems need to be solved: the first problem is to design an algorithm which exploits the IMU data and let the robot follow it. The other problem is how to assemble the device onto the robot.

A. Software development:

There are two possible methods to calculate the orientation deviation between the robot's end-effector and IMU. The first possibility is utilizing two identical IMU and fix one of them to the robot, while another could rotate around the end-effector. So that the orientation error could be calculated by comparing the two sensor feedback. The block diagram of this approach is depicted in Fig. 2.

Another approach is estimating the current robot's orientation by calculating the forward kinematics. The block diagram of

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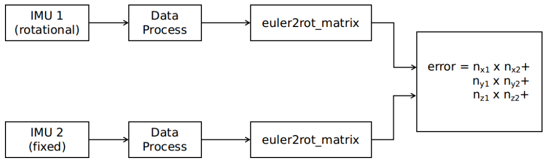


Fig. 2. Block diagram for orientation deviation estimation with comparison of two IMU data

this approach is depicted in figure 3.

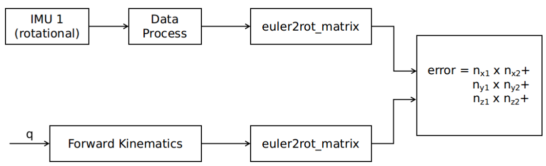
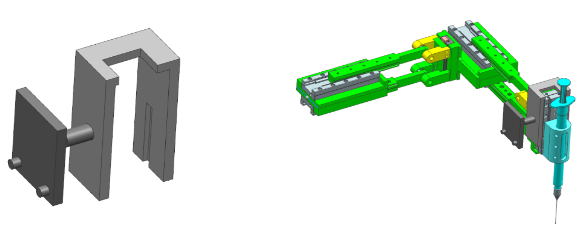


Fig. 3. Block diagram for orientation deviation estimation with comparison of IMU data and robot forward kinematics

Both of these two approaches has its advantages and disadvantages. The first approach is apparently more precise against the second one, however, it demands a mechanical design to hold two IMUs and both IMU needs calibration, a failure of any one of the IMUs leads to failure or instability of the control system. On the other hand, the estimation of orientation with forward kinematics provides a more robust approach but its precision depends highly on the robot's kinematic model.

B. Mechanical design:

In this project, the first approach discussed before (with two IMUs) will be applied. Meanwhile, in considering of the rectangular form of the last link of the eye surgical robot, a shell could be easily designed to match the size of the robot and hold the IMUs effectively.



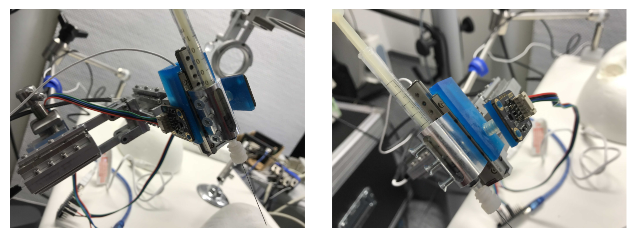
(a) (b)

Fig. 4. (a): Mechanical deign for holding imu. (b): Assembled imu device on robot.

Fig. 4(a) illustrates the mechanical design for holding the IMUs. The shell is designed to match the last link of the robot, it will be fixed on the robot by geometrical constraints. The IMU used for data calibration is assembled on the right side (on the shell) of the holder, whose orientation is identical with the holder and in consequence with the robot's end-effector. Another IMU is assembled on a square platform, which is attached to the shell with plastic pin and a soft spring. The IMU is fixed with the platform with two plastic pins, which aligns with the two holes of the IMU (see Fig. 4(b)). A soft spring is used to connect the shell and the square platform so that the platform together with IMU can rotate around three axes to create the orientation deviation between itself and robot, so that robot can follow its motion. Meanwhile, the spring also provides a slight reverse torque and when a user looses his hand, the platform and IMU can immediately return back to the shell's position and set the orientation deviation to zero, which stops the robot's motion effectively.

III. Test and Analysis

Fig. 5(a) depicts the left side of the device, where the imu for calibration is mounted, this imu doesn't have any rotational or translational degrees of freedom and can only record the needle's orientation. Fig. 5(b) displays the right side of the device, where the imu for leading the motion is assembled. This imu is linked with robot by a spring which could create reversal torque to synchronize the imu and robot's orientation as well as a plastic sleeve which works as damping to avoid vibration and stabilize the system. Thanks to this kind of connection, this imu is able to rotate itself and create orientation deviation, then the same position/orientation PD controller could be applied to compensate this orientation error, hence leading the robot's motion. The



(a) (b)

Fig. 5. (a): Assembled imu for calibration. (b): Assembled imu device on robot.

results show that the robot's orientation follows the motion of the human manipulated right IMU, which makes this device much intuitive for using.

IV. Conclusion

In this paper, we propose to control the robot with IMU sensor which is mounted on the robot directly, thus the surgeon can intuitively interact with this sensor to achieve a easier and better control with acceleration of learning curve of the surgical robot control. The experimental result shows the feasibility and effectiveness of our proposed design.

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