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A Foot-controlled Interface for Endoscope Holder in Functional Endoscopic Sinus Surgery

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1 Background

Endoscopic nasal surgery is with minimal invasiveness for the surgical treatment of nasal disease. During traditional functional endoscopic sinus surgery (FESS), the surgeon uses one hand to hold the surgical instrument leaving the other hand to hold the endoscope. When the surgeon needs to use two hands to perform some complex procedure, an assistant surgeon is required to help holding the endoscope, and this requires good teamwork and long-time training. To solve this problem, researchers proposed to use robots to hold the endoscope, freeing the surgeon's hands for bimanual operation. Sun developed a passive arm with pneumatic locking mechanism to hold the endoscope in FESS, but the surgeon needs to adjust the pose of the endoscope manually, which interrupts the surgery flow and lengthens the surgery time [1]. Many motor-driven endoscope holders have been proposed in literature [2], the surgeon interact with the robot with joystick, voice command, pedals or head movement [3-5]. However, there exists some drawbacks with these interacting methods, for example, joystick requires one of the surgeon's hands, voice command is usually subject to interference and has long time-delay, foot pedals and head movement distract surgeon's attention. Lin used a foot-attached IMU sensor to control an active robotic endoscopic holder, the inversion/eversion and abduction/adduction motions of foot are used to select and control different joints, but the motor can be only selected in order, which is unhandy for the four-joint scenario [6].

In this paper, a similar foot-attached IMU sensor is used, and the joints are selected in an easier manner, based on the angle of plantarflexion. Rather than the angle, the angular velocity of abduction/adduction is utilized to control the moving direction of the active joint. This paper describes the test result of the proposed control interface.

2 Methods

A seven degrees of freedom robotic endoscope holder in our lab [7] is used in this project, as shown in Fig. 1. The first three joints are for global positioning of the endoscope and ensure the remote center of the motion is in accordance with the nostril. The last four joints are for local pose adjustment of the endoscope. The foot-attached IMU sensor will be used to control these last four joints of the robot.
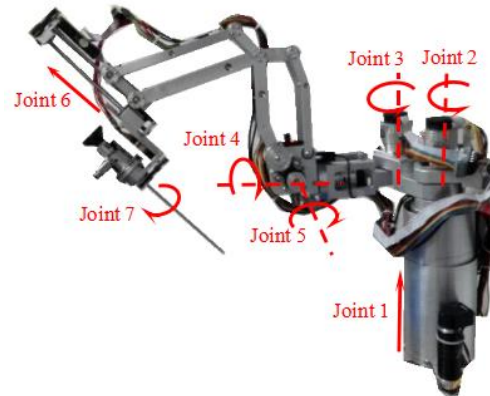

Fig. 1 The 7-DOF robotic endoscope holder

The IMU sensor measurement is collected by an arduino micro-controller and transferred to the host computer by Bluetooth wirelessly, as shown in Fig. 2a. The IMU sensor is fixed on the operator's foot with bandage, to measure the angle α around y axis (plantarflexion angle) and the angular velocity ω around z axis (angular velocity of abduction/adduction) in real time, as shown in Fig. 2b.
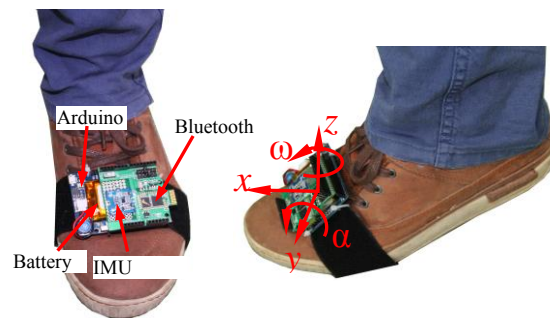
(a) Hardware components   (b) Foot's motion
Fig. 2 IMU sensor fixed on foot

The measured signal from the IMU sensor is processed with Kalman filter and utilized to control the four DOFs of the robot with the following rules:

(1) The angle α is used to select active joint, one active at a time and the α is divided into five intervals. If $0^\circ \leq \alpha \leq 3^\circ$, no active joint is selected and all joints stop moving immediately. If $3^\circ < \alpha \leq 10^\circ$, the 7_{th} joint (roll around the endoscope axis) is selected. If $10^\circ < \alpha \leq 20^\circ$, the 6_{th} joint (feed along the endoscope axis) is selected. If $20^\circ < \alpha \leq 30^\circ$, the 5_{th} joint (pitch around the nostril) is selected. Else if $30^\circ < \alpha$, the 4_{th} joint (yaw around the nostril) is selected.
(2) With one of the joints active, the angular velocity ω is used to control the movement of that joint. If $5^\circ/s < \omega$ *or* $\omega < -5^\circ/s$, the selected joint will start move forward or backward with a constant speed until the other joint is selected. If $-5^\circ/s < \omega < 5^\circ/s$, the joint will keep the last state. All the joints are controlled in velocity mode.

3 Results

The proposed foot-attached IMU sensor with the control logic is tested on the 7-DOF robotic endoscope holder. The experiment setup is shown in Fig. 3a. A 3D printed head with

exact bony information of nasal cavity was used in the experiment. At the beginning of the operation, the remote center of motion point was placed at the entrance of nasal cavity. The IMU sensor was fixed on foot and the operator raised his heel to select different joints, as shown in Fig. 3b. The monitor displayed the angle α, which is divided into five different colored zones, which corresponded with null state and four joints' chosen states.

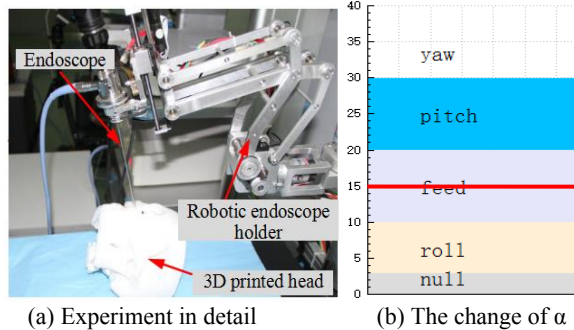(a) Experiment in detail   (b) The change of α
Fig. 3 Experiment with prototype in 3D printed head

To test the performance of the system, the four joints are controlled in sequence. The plantarflexion angle α, abduction/adduction angular velocity ω and the positions of the four joints are recorded in real time, as shown in Fig .4. In Stage 1, α is in the null state, and no joints are chosen. The operator raised his heel until the angle α is in the roll state (Stage 2), the roll joint is chosen, then turned his heel left until $\omega<-5^{\circ}$ /s (Stage 3), the roll joint started to move clockwise. When the operator wanted to stop the joint, he only needed to change plantarflexion angle α to another state (Stage 4, feed state). Similar motions for feed joint, pitch joint and yaw joint are tested. The operator can adjust the endoscope to the target position easily by lifting and rotating his foot continuously. However, since the joints can only be controlled individually, the motion smoothness of endoscope requires further improvement.
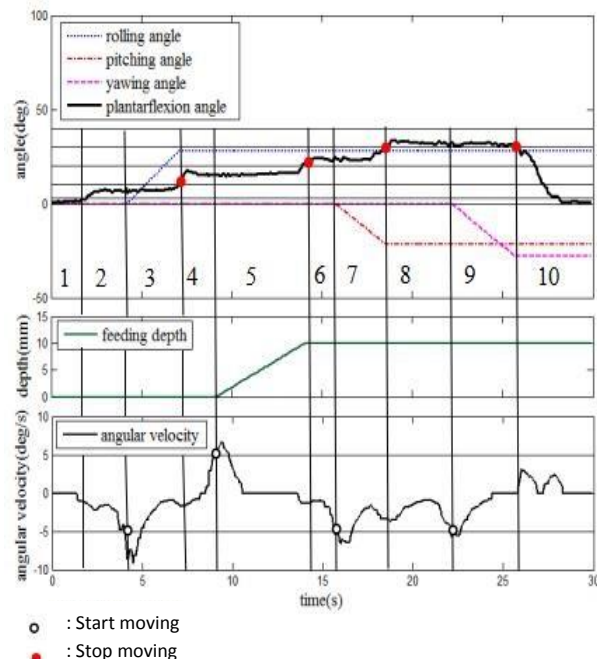

○ : Start moving

● : Stop moving

Fig. 4 The joints' data and the foot's motion in the experiment

4 Interpretation

This paper proposes a new control interface for endoscope holder in FESS, based on foot-attached IMU sensor. The primary experiment shows that the four motions to adjust the pose of the endoscope can be controlled easily. With this interface, the surgeon can use both hands to manipulate surgical instruments and increase the efficiency of surgery.

In this new control interface, the plantarflexion angle is used to select different joints and the abduction/adduction angular velocity is used as a switch to control the move/stop and moving directions of the chosen joint. Compared with the multiple buttons distributed on a foot pedal, the new interface is more intuitive and easier to control. The moving of joints is controlled by velocity, rather than pose information, this will avoid the drift problem of sensors. Furthermore, the motion range of human foot's abduction/adduction is limited, using the pose information to control joints' motion may require the surgeon in a very uncomfortable gesture, using the velocity as a switch to control the move/stop only is more favorable. For the future work, this interface will be tested in clinical scenario by surgeons.

Acknowledgement

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