Endoscopic Transsphenoidal Surgical Robot With Optical Tracking Control

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INTRODUCTION

Endoscopic transsphenoidal surgery (EETS) is a minimal invasive surgery for treating a pituitary tumor [1]. In EETS it is needed to insert the sinus surgical tool together with an endoscope through nasal cavity enlarging and passing nasal openings before removing the adenoma and it requires a skillful surgeon [1]. To remove the tissues and the soft bone in the surgical pathway surgeon normally uses an endoscopic visual feedback. During the EETS procedures, the surgeon requires a high skill of knowledge about anatomical structure but the conventional endoscope provides only 2-D images. Determining the positions and orientation of surgical tools is depended only on surgeon's experience. Fatigue from long-time surgery is also a reason for hand quiver and tiredness in surgeon [1],[2]. This research presents a new robotic system to assist in normal procedure of EETS as shown in fig.1. A real-time 3D navigation system is used in this proposed system, which is based on imaging technique with optical tracking occurring in the period before a surgical operation. The tracking system is used to develop a virtual endoscopy along with the surgical tool and provides a 3D model of the bone structure. The bone anatomy 3D model in the workspace is created by using CT pre-operative images [3]. The real-time surgical tool navigation along with virtual endoscope is provided by the optical tracking system along with the 3D model.

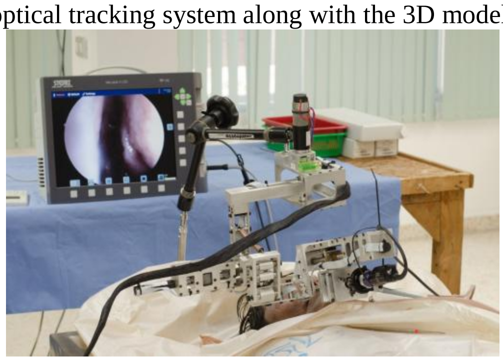

Fig. 1 BART LAB EETS robotic platform in cadaveric experiment.

MATERIALS AND METHODS

Motion analysis of a surgical tool is to a great extent in all the type Minimal Invasive Surgery. To design and develop a new robotic system for supporting in a surgery and also for a surgical tool navigation system study on tool motion is valuable [2]. During EETS the surgical tool motion data are collected using an optical tracking system. To estimate and collect the position of the markers during surgery, optical markers are attached with the surgical tools and computed using MATLAB program. The workspace and the motion behavior of surgical tools can be easily calculated using the collected motion data. Using a homogeneous transformation the tool's position can be calculated from the marker to the tool tip [4]. The difference of patterns in markers can be identified using a set of passive markers and stereo camera. The position and orientation data of the object attached with the optical marker is recorded in 3-dimension. The commercial optical tracking system, Polaris® Vicra® system from Northern Digital Inc. is used during the experiment shown in fig. 2 [1] [4]. To estimate the motion of robot to deliver remote center of motion for the EETS procedures, a robot motion analysis experiment is carried out and to evaluate the robot system a commercial optical tracking system from NDI is used [1].

Fig. 2 Medical tool attached with optical marker.

There are numerous tools used during the EETS procedures. The main objective of this research is to develop a robotic surgical support system to hold an endoscope and a medical anatomize, guiding tools along the path of a planned surgery [4]. Perceiving the limitations and motion analysis of the surgical tools is important because it is needed for the design of a robot for its purpose. The position and orientation relationship between the tools attached to optical markers are represented by using the homogeneous transformation matrixes. Using the tooltip calibration method the homogeneous transformation matrix from attached marker to the tip of the tool can be attained [1]. By applying the transformation shown below the homogeneous transform from optical marker attached at the end of the tool handle can be calculated.

$$ {}^{Marker}_{End}H = {}^{Marker}_{Tip}H \; {}^{Tip}_{End}H \qquad {}^{Tip}_{End}H = \begin{bmatrix} 1 & 0 & 0 & x_{tip}+L \\ 0 & 1 & 0 & y_{tip} \\ 0 & 0 & 1 & z_{tip} \\ 0 & 0 & 0 & 1 \end{bmatrix} $$

$$ {}^{Marker}_{Tip}H = \begin{bmatrix} c\alpha c\beta & c\alpha s\beta s\gamma - s\alpha c\gamma & c\alpha s\beta c\gamma + s\alpha s\gamma & x_{marker} + x_{tip} \\ s\alpha c\beta & s\alpha s\beta s\gamma + c\alpha c\gamma & s\alpha s\beta c\gamma - c\alpha s\gamma & y_{marker} + y_{tip} \\ -s\beta & c\beta s\gamma & c\beta c\gamma & z_{marker} + z_{tip} \\ 0 & 0 & 0 & 1 \end{bmatrix} $$

RESULTS

An optical marker was attached to the robot to collected tool pose controlled by the robot. A phantom was used to implement in the experiment. The representative of the nostril entrance made by the plastic cylindrical tube illustrated in fig. 3.

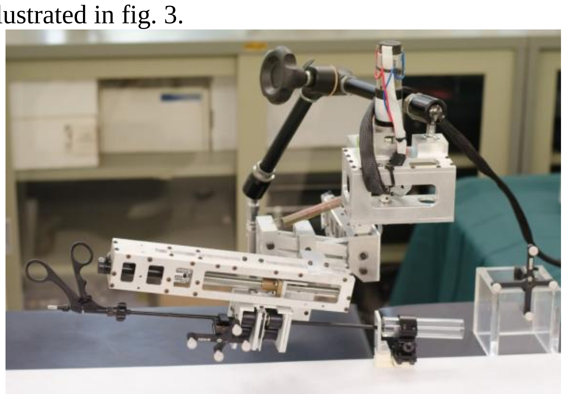

Fig. 3 Robot attached with optical marker for the experiment.

The horizontal plane was represented by another optical tracking system. Controlling algorithm is interfaced by using the joystick. MATLAB Programming was used to record instrument motion. The remote center of motion at nostril entrance must generate to create a mechanical constraint of the surgery. The experiment was executed to confirm that the tool moved with the constraint at the remote center of motion point [1] [4]. The position of the medical tool tip located at the phantom nostril entrance. The movement of the tool was controlled by a joystick and was recorded the motion during the experiment. The 3D plot in fig. 4 (a) represents the tool movement during the experiment time. While the red circle represents the medical tool tip, yellow circle perform as a center of motion point. And the color is indicating the time moment of the record. From the result, the robot can perform tool movement under the constraint at the tool tip and yield the remote center of motion movement [1]. To accumulate the tool movements during EETS a human cadaver-based experiment was conducted. The experiments were carried out in two steps the first step is to break and open the vomer bone and the surgical tool were inserted through the nostril. The second step is to open the sella bone to access pituitary and the surgical tool was inserted through sphenoid sinus. To estimate and record the position of the nostril before the surgery the medical dissector was used.

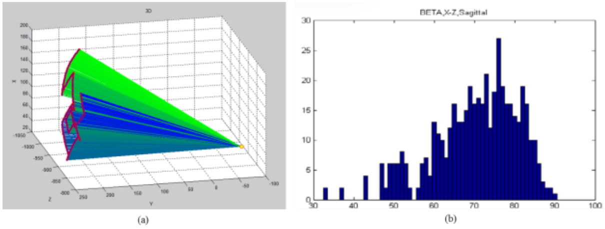

Fig. 4 Robot motion with tool tip (a) at the RCM point (b) sagittal plane.

Fig 4. (b) & fig. 5 (a) - (b) shows the tool motion angle and number of angle in each plane used during the surgery. Fig 4 (b) & fig. 5 (a) - (b) represents the range of angle in a sagittal, coronal and transverse plane for moving a surgical tool. For sagittal plane angle the minimum angle at 33.4 degrees and the maximum angle of 89.72 degrees, 89.00-degree maximum angle with the least angle at 0.15 degree for the coronal plane and in transverse plane 89.91-degree maximum angle with the minimum angle at 45.77 degrees. By using the data from surgical tool angle histograms in each plane, we can estimate the most tool angle used during the surgery to determine the initial position of the robot.

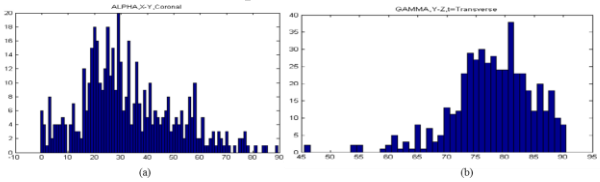

Fig. 5 Robot motion with tool tip (a) at the Coronal plane (b) Transverse plane.

DISCUSSION

The 3D model of anatomy along with the optical tracking system and surgical tool the real-time navigation system can be recorded. To use the real-time navigation applications (image guided system, virtual endoscope etc.) during the surgery, 3D model and surgical tool attached with optical marker need a proper calibration. This research did not focus more on the calibration between optical navigation and 3D model of anatomy. Presently, there are various methods used for calibrating medical images to the patient during the surgery, for example fiducial mask calibration and laser calibration methods. Effective calibration method for EETS is desirable to be further investigated.

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