Endoscope/Laparascopic Robots and Automated Camera Guidance in Medical application

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Abstract

This literature research is given clear overview on various single arm camera application in medical field and mostly focused on the existing robots and technology for single arm medical robots. Clearly, this study explains the overview of the endoscope camera in surgical procedure.
Key words: *Medical robotic arm, Endoscope robotic arm, Tool tracking, Gaze control and voice control*

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1 Introduction

Development of endoscopic surgery and medical robotics, surgery using endoscope robots has become a representative of robotic surgery now a days. Expectations for a minimally invasive surgery have increased year by year with the dramatic advancement of image diagnosis technology, including CT and MRI. A camera (endoscope) and surgical instruments are inserted into tiny holes made in the patients' abdomen or chest region for surgical procedures. Compared to abdominal or open chest surgery, endoscopic surgery has less pain and has a greater advantage in cosmetic appearance as well as the economic advantages, resulting in its growing popularity. The most distinctive feature of endoscopic surgery is that the surgical field is observed through images taken by an endoscope, rather than the naked eye. The most important element to surgical safety and efficient operating is how well an endoscope reveals the field of view during surgery. Generally, a camera assistant operates the endoscope. The operation of the endoscope needs fine adjustment for the angle of the field of view and the distance of the surgical area as well as correct aiming of the endoscope at the surgical field.

Camera assistants sometimes operate the endoscope according to instructions of a surgeon; however, **camera assistants need to operate the endoscope using their judgment in understanding the surgeon's intentions so that they can move the endoscope according to how the surgery is progressing moment to moment**. The operation of an endoscope by camera assistants requires as much proficiency as that of surgeons. There are not many surgeons who have sufficient proficiency in endoscopic surgery, which requires special techniques. In fact, it is not unusual for surgery to be interrupted due to a camera assistant not being sufficiently proficient in using the endoscope and is unable to obtain the exact field of surgery required. To solve this problem, "endoscope robots that can hold and position an endoscope instead of a human camera assistant have been developed.
The commercialized endoscope robots operate according to surgeon's instructions with switches by hand or voice recognition technology. There are some robots, still being studied, which automatically position the endoscope while the robot itself interprets the surgeon movements. The endoscope positioning system (Nishikawa et al., 2006, Nishikawa et al., 2008)developed by Nishikawa et al. represents an automatic endoscope positioning robot.
Research study [1] as included different kind of existing single arm robots such as :

- FreeHand.
- HIWIN MTH H 100 robotic endoscope.
- Endex.
- FIPS Endoarm.
- AESOP (Automated Endoscope System for Optimal. Positioning).
- Begin and Hurteau.
- RoboLens.
- Tadano et al
- EVOLAP.
- PMASS (Postural Mechatronic Assistance Solo Surgery).
- Tonatiuh II.
- COVER (Compact Oblique-Viewing Endoscope Robot).
- SWARM.
- LapMan.

- Naviot.
- LER (Light Endoscope Robot), ViKY (Vision Kontrol endoscopY).

2 Endoscopic Robotic Camera Representation at Surgery

An endoscope camera is a long, narrow, flexible tube containing a tiny light and camera at one end. This camera carries pictures of your upper digestive tract to a television screen. The doctor and nurse can see your esophagus, stomach, and small intestine better on this monitor. The pictures can also be recorded and printed.
Endoscope robots support surgery coming in contact with patients while the robots and surgeons closely interact. Industrial robots perform work which has been planned in advance under a closed, unvaring environment; however, endoscope robots are used for surgery in the medical front with high entoropy, where mistakes or failures are unacceptable.

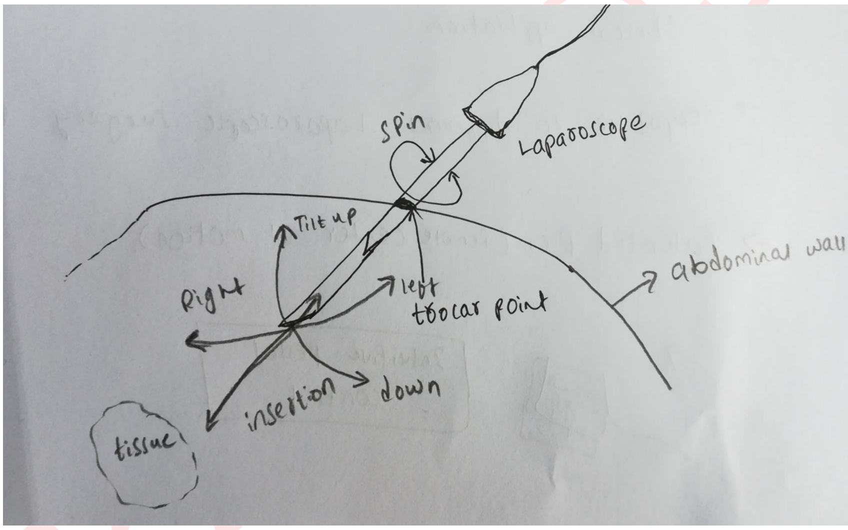


Figure 1: Assumed endoscope camera representations during surgery

Figure. 1 shows insertion overview of the camera into the abdominal wall of the body. Here there are noticeable points which are stated following:

- Camera end-effector tip has not to damage the tissue.
- Related motion constraints take place when camera tool entering into abdominal wall.
- Atleast 3 DOF is needed for better visualization to surgeon.

3 Approach for Robotic Camera Guidance

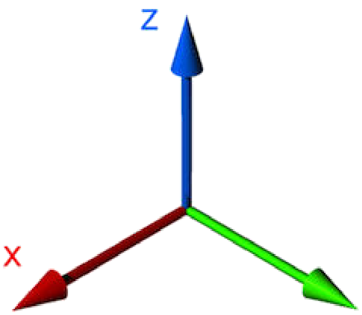
The main focus on robotic aspects, such as kinematics, the human machine interfaces and suitability for endoscope positioning. The question is how can positioning of the endoscope – by means of any motorized endoscope holder – be performed autonomously without continuous manual control by the surgeon. As discussed above, manual control further increases the mental workload of the surgeon. Also, Pandya et al. summarize the problem: It is difficult for the user to obtain optimal camera viewpoints in a dynamic environment or to react effectively to irregular events in the scene due to task overload, latency issues, and complex camera positioning issues. The surgeon has to continually manage the camera position to achieve effective viewpoints through manual control or verbal communication with a second operator."

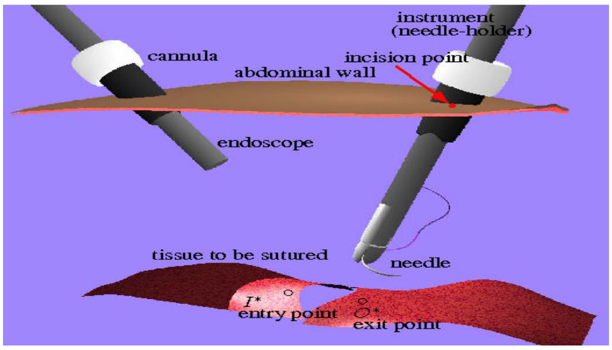
3.1 Mathematical Formulation of Endoscope

The required items are degree of freedom necessary for endoscope operations and safety as a medical equipment. It cannot be called an endoscope robot unless required items are met. First of all, we will describe degree of freedom. As shown in figure. 1, since an endoscope operation during surgery is performed with insertion / retraction of an endoscope, roll around the insertion direction, and pitch and yaw based on the insertion site, the necessary degree of freedom for endoscope robots are four degrees of freedom. Roll is used to correct the top and bottom of image for direct-viewing endoscope and to observe the back of the organs for a oblique-viewing endoscope.
Manipulation of the endoscope camera end-effector at Cartesian space in $\mathbb{R}^{6\times 6}$, however, once the surgeon entering to the abdominal/body then make some motion constraints on the endoscope camera. The required constraints would be like no translations on $\mathbf{X}-\mathbf{Y}$ plane in Fig. 2(a) and only zoom in-out ($\mathbf{Z}$) is allowed in pose-translation and all three orientations are allowed like *Roll, Pitch and Yaw*. However, *Roll* is not mandatory unless we do very small micro surgery.
Therefore, only **3 DOF** $\mathbb{R}^{3\times 3}$ is enough to surgeon for viewing. Let us consider a coordinate frame of endoscope camera end-effector $\{E_c\}$. The camera end-effector pose is stated by.

$$\mathbf{x}_i = \begin{bmatrix} \mathbf{p}_i \\ \mathbf{q}_i \end{bmatrix} \tag{1}$$

where $\mathbf{x}_i \in SE(3) \quad E_c$ which containing the translation and orientation of the endoscope $\mathbf{p}_i \in \mathbb{R}^3$ and $\mathbf{q}_i \in SO(3)$.





3.2 Motion Planning Approach for Robotic Camera Arms

Depending on the collected input commands or data, the robot manipulator arm has to move either in forward or inverse kinematics way. The forward kinematics use when we control with joystick, voice and foot pedal system. The inverse kinematics come in to act when we use tool tracking system. However, the forward kinematics is easy to solve the motion planning when compare to inverse kinematics task.

3.2.1 Forward Kinematics

Having the joint variables of a robot, we are able to determine the position and orientation of every link of the robot, for a given set of geometrical characteristics of the robot. We attach a coordinate frame to every link and determine its configuration in the neighbor frames using rigid motion method. Such an analysis is called forward kinematics.

3.2.2 Inverse Kinematics

The determination of the joint variables reduces to solving a set of nonlinear coupled algebraic equations. Although there is no standard and generally applicable method to solve the inverse kinematic problem, there are a few analytic and numerical methods to solve the problem. The main difficulty of inverse kinematic is the multiple solutions.
Determination of joint variables in terms of the end-effector position and orientation is called inverse kinematics. Mathematically, inverse kinematics is searching for the elements of joint vector.

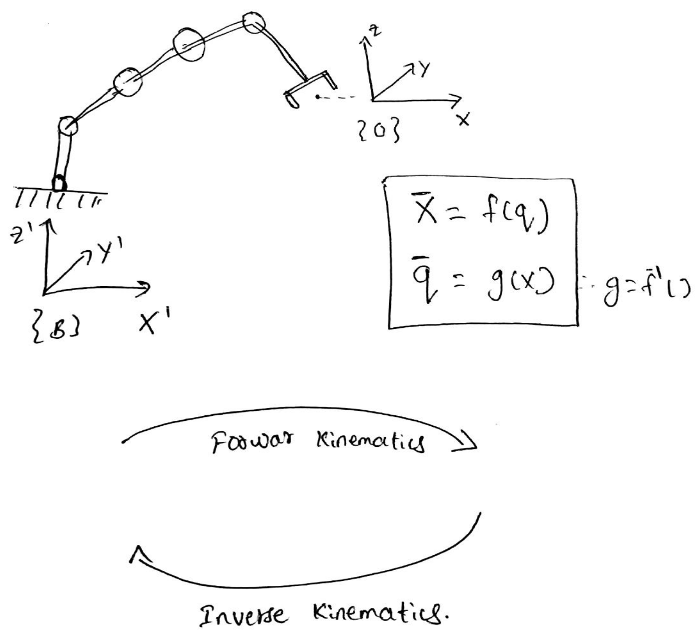


Figure 2: The forward and inverse kinematics of the robotic manipulator

4 Methods of Single Arm Robot Camera

Usually, there are two different kinds of endoscope methods in the existence.

- Tele-operation control robotic camera, i.e controlled by joystick, mouse, pedal, head-mounted sensor, Eye-Gaze and voice controlled. This method is semi-autonomous which the robotic camera arm is guided with surgeon/staff during surgery [2].
- By computer vision technique, Machine Learning, Features extraction and Marker tracking on instrument tip, which fully autonomous control system without any assistance during surgery [3].

4.1 Tele-operated Endoscope Robotic Camera

4.1.1 Joystick operated Endoscope Camera

As per discussed in section 3.1, we need mostly 3 DOF motions. So our joystick is mapped according to required endoscope motions. However, there are many joysticks on market for both commercial and medical field, the small joystick is comfortable and effective for surgeon to control.
In the joystick control mode the TCP of endoscope arm can be moved in Cartesian coordinates according mapped criteria of joystick. For instance a

joystick movement to the left corresponds to a robot movement to the left and so on for right, front and back movements at constant velocity. The robot calculates internally all the necessary transformations. However, If the surgeon wants to change the endoscope robotic arm orientation (but keep the position constant) he only has to map the buttons of the joystick to initiate movement along *Roll, Pitch and Yaw.*

Figure 3: Joystick control robotic endoscope camera @ 79th China International Medical Equipment Fair (CMEF Spring)

4.1.2 Gaze-Guided Endoscope Camera

Although these systems remove the need for human assistants, interacting with these robots may increase physical and cognitive load on the surgeon. Explicit control of these robots through a control interface, such as joystick, foot pedal, voice command controller, or head/face motion-activated system, could be an additional task that distracts the surgeon's attention from the surgical site and may result in frustration and prolonged surgical time. For example, in joystick/button control, the surgeon needs to remove his/her hand from the manipulation of the surgical instruments to re-adjust the laparoscope. Gaze-guided robotic laparoscope system, the surgeon to directly control the laparoscopic view using eye gaze.

Gaze tracking is a technique that continuously estimates where the user is looking by monitoring his/her eye movements. Nowadays, optical eye tracking devices have gained wide acceptation and usage due to their non-invasiveness and inexpensiveness. Eye-gaze tracking has been widely used as a tool to study cognitive science, psychology, neurology, and visual behaviors. Recently, using gaze as a novel modality to explicitly control or implicitly interact with a computer or robot has drawn much attention due to its unique characteristics including affordability, ease of usage

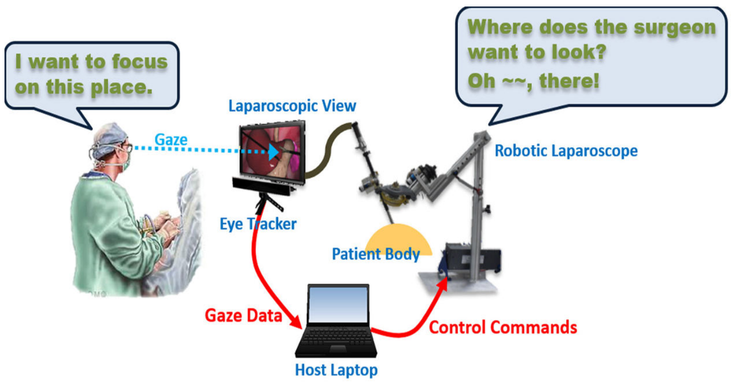


Figure 4: Attention-aware Gaze guided robotic laparoscope system

4.1.3 Voice Control Endoscope Camera

The voice control technique [4] is used from many years and also many speech recognition engines, voice recognition module (such as VR3) and other platforms are helping to recognize the voice commands. Now, it can enable the robotic manipulator to provide the user with task specific semi-autonomous intelligent manipulation assistances (i.e., zoom-in up an endoscope camera and rotation in different directions). For example, the surgeon start operating a robotic manipulator using direction-based voice commands (e.g., “move in”, “move out”, “pitch left”, “pitch right”,“rotate up”, “rotate down”, “rotate left”, and “rotate right”).
In voice recognition based end-effector tool controller is easy to build and give commands according pre-selected voice commands or phrases. In this we have to map respective predefined voice commands to endoscope camera movements. This technique has less computational load, however, voice recognition of different people and environment disturbance is a big task.
Two important things to note is the difference between Voice Recognition and Speech Recognition. The difference between the two is that in Voice Recognition you can train the module to recognize specifically your voice and effectively train it to have an easier time recognizing your voice and the words you speak. In speech recognition the device recognizes words but is not able to be trained to recognize a persons voice.

4.2 Robot camera control by Tool Tracking

4.2.1 Instrument Tracking

The first step is to detect the axis of the instrument. Generally, minimally invasive instruments such as Graspers, scissors, needle drivers, and clip deployment devices.
The problem we address is the use of a robotic arm equipped with a camera in its hand to determine the position of an object of known dimensions. This object can be placed at any location and with any orientation within the robot work-space.

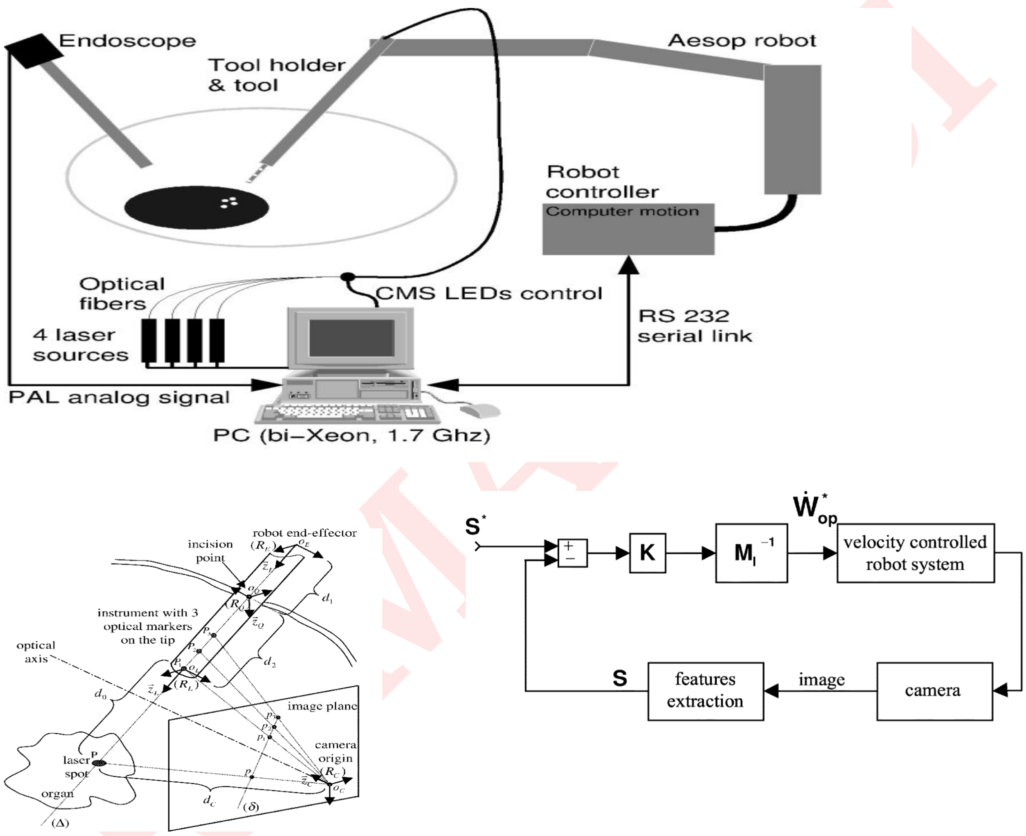


Figure 5: Overview of the instrument tracking system with fully-automated endoscope camera control

Visual Servoing refers to the process of tracking a feature in an image stream, comparing the feature's current position to a desired position and moving an actuator in order to reduce the distance between current and desired feature position. In order to reduce the alignment error in each timestep, the kinematical relation between change of robot position and the camera's field of view must be known. If robot dynamics can be ignored in the outer control loops – which is assumed here given the low accelerations and velocities required for endoscope motion, often a velocity-based control approach is employed. Given a transformation between robot and camera coordinates, the time derivatives of the image coordinates can be written as a Jacobian matrix J.

5 Conclusion

Consequently, after studying different kinds of endoscope camera guidance the joystick is an easy way to implement, also it is easy to learn by surgeons and other OR staff. However, the voice recognition system has been from many years using but not much effective in our research, due to external noise/disturbance and workload by surgeon. Moreover, the tool tracking and visual guided methods are progressed in the field of fully-automated camera positioning system and giving better in surgeon point of view.
The majority of approaches either focuses on improving manual control modalities or looks into visual servoing strategies. Finally, many research studies show that the fully automated endoscope camera usually reduces the work load of the surgeon while doing surgery and at the same time these are complex methods to set-up the system, where it uses inverse kinematics. Therefore, the joystick, voice and other command orientated systems are preferable when we look at semi-automated functionalities and tool tracking is much effective when we need fully-automated system.

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