

A Patient-Specific 3D Model for Port Placement in Robotic Surgery

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Port placement is a critical task in robotic laparoscopy surgery. A method for determining optimal port placement is proposed. A patient-specific 3D model of the abdomen was created from 3D images taken by a 3D scanner in the operating room and pre-operative medical images. Using the patient-specific 3D model, and the robot arms' configurations, the accessible 3D points (on the abdominal surface) for one robot arm were calculated. The possible port locations (as 3D points) were selected based on a performance index that is obtained from the outputs of an inverse kinematic problem. Repeating the process for the other robotic arms is expected to yield a set of optimal port locations for the individual patient.

1 Introduction

In robotic laparoscopic surgery (e.g. hysterectomy to remove uterus), as in traditional laparoscopy surgery, the patient's abdomen is insufflated with gas (CO₂) to increase the working space within the abdominal cavity. Surgical tools are then inserted into the patient's abdomen to reach the surgical site. Port placement is, thus, a crucial task that determines the ease with which surgeons can perform the procedure, and to certain extent, the success of the procedure. Location of the entry points for the robot manipulator depends on the target organ location, the patient's body shape, and the robot arms' configurations in the operating rooms (Figure 1).

Both target organ location, and abdominal shape are altered due to gas pressure after insufflation [1,2]. Typically, surgeons select the port locations based on their experience, and the instructions that are usually provided by the robot manufacturer. However, the

variability of patients' physical characteristic, anatomical structures, and different operational settings often render the instructions and guidelines inadequate for a precise and exact port placement [3]. Poor decision making in the port-placement phase may lead to serious complications and injuries as reported in previous studies [4].

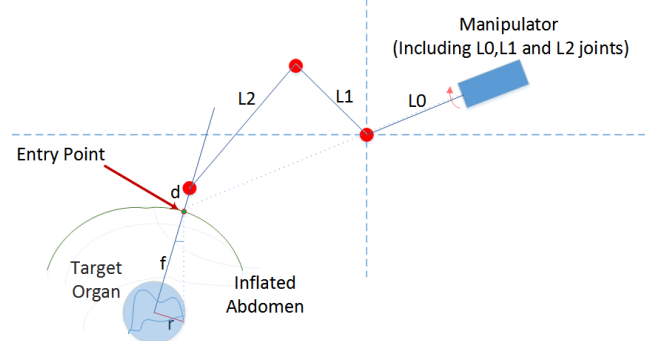


Figure 1. A graphical configuration of a Da Vinci Robot manipulator (3 planar joints) for an entry port.

In particular, poor port-placement may restrict the endoscopic view of the target organs and motion of the robot manipulators during surgery [5,6]. Researchers have proposed various solutions and guidelines to overcome the difficulties that surgeons might face for planning the ports on the patient's abdominal surface [7,8]. However, these solutions do not take the morphological changes of the abdomen (due to the insufflation) into account. To design and develop a real-time decision aid for minimally invasive robotic surgery, we proposed using a 3D scanner (Kinect, Microsoft [9]), and pre-operative medical images (CT scans) to create a patient-specific 3D model of the insufflated abdomen in the operating room. The patient 3D model, combined with the configuration of the robotic arms (Da Vinci, Intuitive

[4]), is used to calculate optimal points for the ports on the abdominal surface (Figure 1). Then, the entry ports (on the patient 3D model) can be projected on the abdominal surface after insufflation.

2 Material and Method

Data collection for the proposed approach was performed on patients who underwent hysterectomy procedure at the ICO- Institute of Cancer Research in Nantes, France. A 3D scanner (Kinect) was mounted above the patient's abdomen (Figure 2).

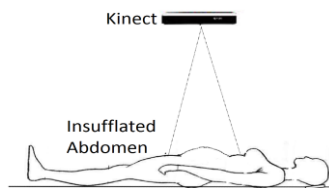


Figure 2. Kinect experimental set-up to capture 3D image from the abdominal surface before and after insufflation.

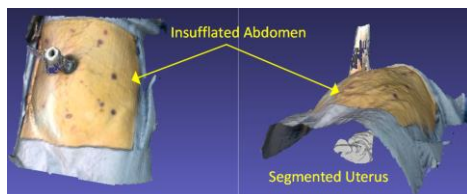


Figure 3. A Patient-specific 3D model including the target organ (uterus) in a hysterectomy procedure

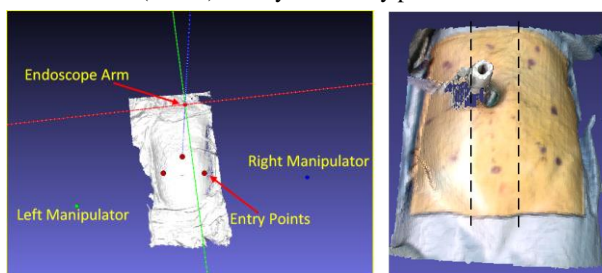


Figure 4. Left: The robot arms' positions (the endoscope is in the middle).

Right: The endoscope area is between the two dashed lines. The depth image, captured by the Kinect, was used to create a 3D model of the abdomen after insufflation, called the external model. Pre-operative CT scans of the same patients were used to create another 3D model, called the internal model. The purpose of making the internal model was to place the target organ within the external model. The two models were aligned using four natural landmarks on the body surface that were fixed during insufflation -- two points on the end of the rib cage and the two on the front edge of the pelvic bone. The output of the alignment is a patient-specific model which is a 3D shape of the insufflated abdomen, with the target organ clearly embedded (e.g., uterus in Figure 3). All the 3D points on the abdomen surface were given to an inverse kinematics algorithm to verify that they

were accessible for the left, right, and the endoscope arms [6]. Also, a performance index for the accessible points was calculated for each arm separately [6]. To reduce the number of calculations for all the points on the surface (150,393 points), we divided the points (on the abdomen) into three groups (Figure 4) based on the port-placement guideline provided by the manufacturer [3]. The middle group (the area between the two parallel dashed lines -- as determined in the guideline) is suitable for the endoscope arm during a hysterectomy procedure.

3 Results and Conclusions

The accessible points for the endoscope arm were found and highlighted on the abdominal surface in green, as shown in Figure 5. The 3D points with the highest performance index (greater than 0.19), among all the accessible green points for the endoscope arm (the performance index range: 0.16~0.23 with avg=0.18, and std=0.01), are shown in blue in Figure 6. In this paper, we present only results for the endoscope port. To complete the calculation for the other ports for the left and right manipulators, a similar process needs to be performed for the left and right regions of the abdomen.

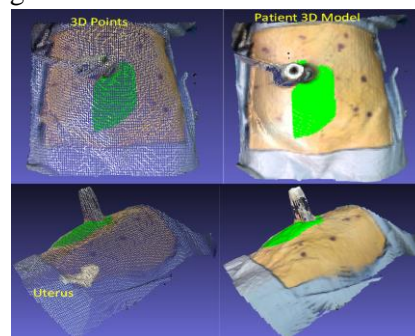


Figure 5. The accessible points (green color) for the endoscope arm, Top: front view, Bottom: side view.

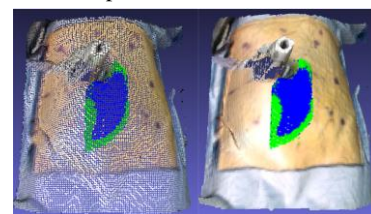


Figure 6. The highest performance points (the blue points) for the endoscope arm.

Using the preferred points following our proposed approach, in addition to considering other factors in the port placement problem (such as potential collision between the robotic arms), we plan to optimize the locations of the entry ports in our future work.

4 References

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