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

Mohammadreza Maddah, Cédric Dumas, Caroline G. L. Cao

► **To cite this version:**

Mohammadreza Maddah, Cédric Dumas, Caroline G. L. Cao. A Patient-Specific 3D Model for Port Placement in Robotic Surgery. *Surgetica* 2017, Nov 2017, Strasbourg, France. hal-01831302

HAL Id: hal-01831302

<https://hal.science/hal-01831302>

Submitted on 19 Jul 2018

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Introduction

Planning port placement is a vital task in a robotic laparoscopic hysterectomy procedure. Decision aids for optimal port-placement can be developed based on:

- Known geometric model of the robotic system (Fig 1)
- Estimated geometric model of the surgical site
- Patient-specific morphology

One critical component of this decision-aid requires the reconstruction of a 3D model of a patient's abdominal cavity, and the robot model.

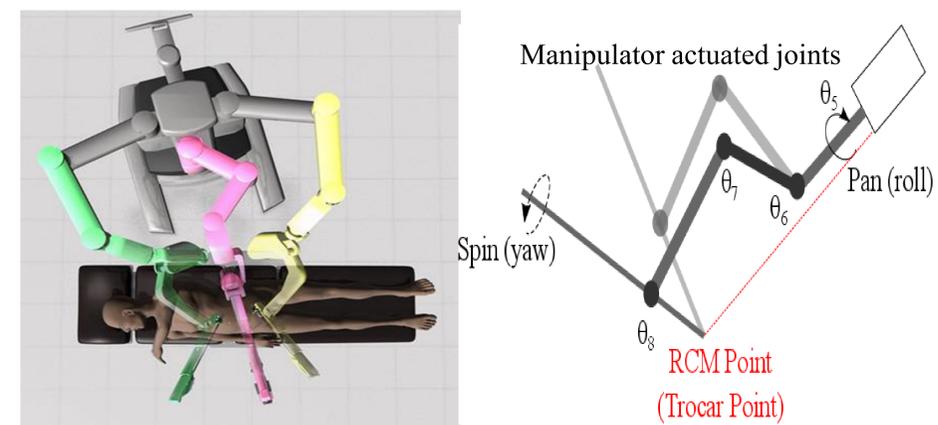


Fig 1: Left: Da Vinci robot assembled to the operating trocars (courtesy of Intuitive Surgical Inc.)
Right: The manipulators actuated joints configuration.

Objective

To find the optimal ports location on the patient's abdomen, the suitability of the points (on the abdominal surface, patient-specific model) for the ports location is preliminary evaluated based on the points accessibility for the robot manipulators. The accessible points are then filtered, and selected by the manipulability index (the manipulators ability to manipulate and pivot the surgical tools at RCM point). The points with the highest manipulability index are marked on the patient's abdomen as the preliminary candidates for the entry ports location of the manipulators.

Method

Patient-specific model:

- The internal 3D model is constructed from pre-operative CT scans. Using 3D image segmentation, the target organ (uterus) is located in the internal model.

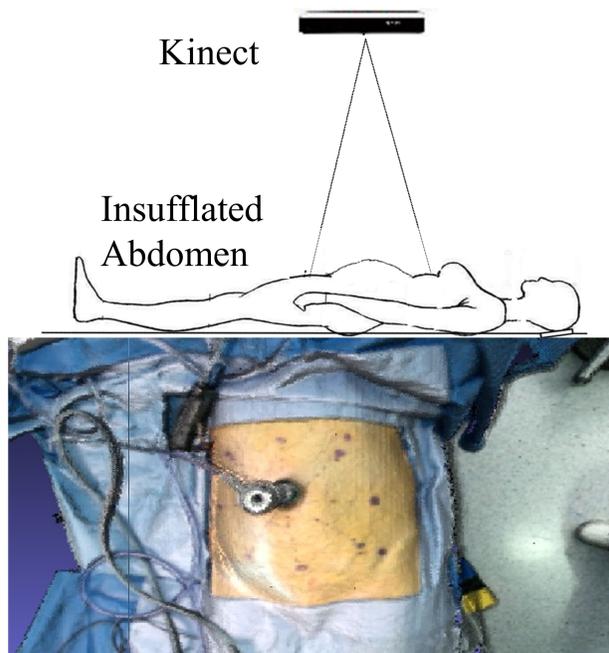


Fig 2: Top: Kinect was mounted above the patient,
Bottom: The external model.

- The external model is constructed from Kinect images after insufflation (Fig 2). The abdominal shape, after insufflation, is demonstrated as a 3D mesh in the external model.
- Using 4 natural landmarks (on the pelvic bone and rib cage), the internal and the external models are aligned to form the patient-specific model (Fig 3).

Robot Model:

- The robotic manipulator (actuated joints) is modeled by D-H parameters (Fig 1).
- Given the target organ location in the patient-specific model, the points on the patient-specific model are assessed if they are accessible for the manipulator by solving the inverse kinematics equation, $X' = J\theta'$. If the Jacobian $\det(JJ^+)$ is not zero, the point is accessible for the robot manipulator.
- The manipulability index, $W = \sqrt{JJ^+}$, is defined based on the manipulators ability to pivot and manipulate the surgical tool at RCM point uniformly (Fig 1). For any specific configuration of the manipulator, $\theta_5 \sim \theta_8$ in Fig 1, W is calculated for all the points on the patient-specific model. The points that satisfy $W > 0.18$ are selected as the preliminary locations of the ports for each of the manipulator (Da Vinci Si).

Results

- The accessible points (in green) for the endoscope manipulator are shown on the patient specific model in Fig 3.

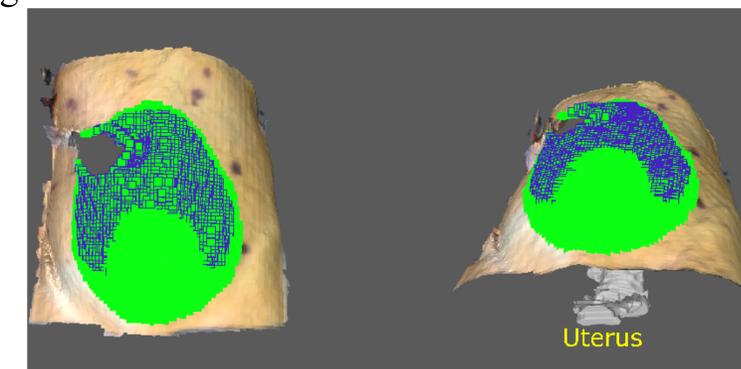


Fig 3: Accessible points for the endoscope (green points)
Highest manipulability points for the endoscope (blue)

- The points with the highest manipulability index for the endoscope, arm1, arm2, and arm3 are shown in Fig 4.

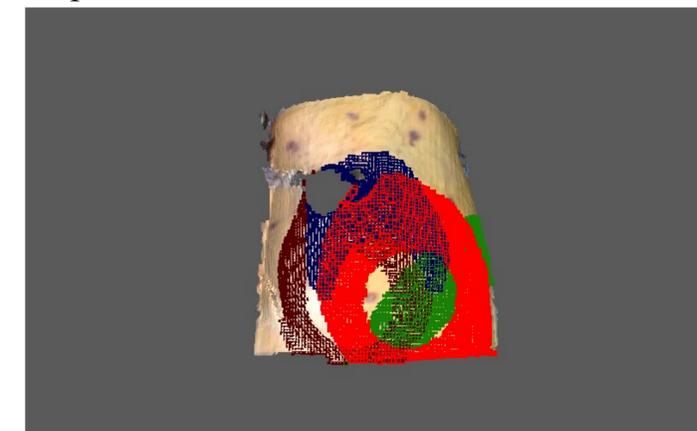


Fig 4: The points with Highest manipulability for the Si manipulators
Blue: endoscope; Green: arm3; Red: arm2; Brown: arm1

Discussion

- Considering the target organ location, the robot joints configuration, and the abdominal shape after insufflation, the accessible points with the highest performance index (manipulability) were calculated. These points are the preliminary locations of the entrance ports that are marked on the patient-specific model.

Acknowledgments

This work was supported by a grant from the Ohio Third Frontier to the Ohio Imaging Research and Innovation Network (OIRAIN).