Enhanced Vision System to improve safety in Robotic Single Incision Laparoscopic Surgery

V. Penza[1,2,3], E. De Momi[1], A. Bertini[1], A. Bussi[1], F. Righetto[2], R. Zaltieri[2], L. Mattos[3] and A. Forgione[2,4,5]
[1] *NearLab, Department of Electronics Information and Bioengineering , Politecnico di Milano, Milano, Italy*
[2]*ValueBiotech srl, Milano, Italy*
[3] *Department of Advanced Robotic, Istituto Italiano di Tecnologia, Genova, Italy*
[4]*AIMS Academy, Milano, Italy*
[5]*Ospedale Niguarda Ca' Granda, Milano, Italy*

***Abstract*—Minimally invasive abdominal surgery can reduce the trauma of large wound to a minimum, but introduces technical difficulties for the surgeon, who has to deal with at least three instruments in a single incision. These drawbacks can be overcome with the introduction of robotic arms inside the abdominal cavity. In this work we propose an architecture to increase the safety during intra-operative robotic Single Incision Laparoscopic Surgery (SILS) based on intraoperative registration of pre-operative images and dynamic active constraints. In the pre-operative phase the surface rendering of organs allows the surgeon to identify important structures to be protected during the surgery. A subsequent step consists in registering these images to the intraoperative images acquired using on board stereo-cameras. The precision of this latter step is highly dependent on the stereo vision calibration of the imaging system.**

We present the evaluation of the accuracy of our stereo imaging system. Preliminary results show that the number of frames for high quality stereo camera calibration is 35. In this case, the camera calibration accuracy satisfies the clinical requirements for organ motion tracking.

***Keywords*— Enhanced vision system, stereo vision, safety, camera calibration.**

I. INTRODUCTION

ANY surgical abdominal wound performed in open surgery carries the risk of infection or dehiscence and can contribute to post-operative chest infection, ileus and immobility. Minimally invasive surgery can improve the physiological and immune responses associate with open surgery, reducing the trauma to a minimum [1]-[2]. Single Incision Laparoscopic Surgery (SILS) has been advocated as the next step towards even less invasive surgery. However, SILS introduces limitations in terms of maneuverability: the clustering of instruments in a single access port increase instrument collisions and the surgeon has to operate with instruments crossed to achieve triangulation for tissue retraction. The operative view is also restricted and the tactile sensing reduced, resulting in a long learning curve and increased operative times [3]. These drawbacks has inspired the recent development of advanced robotic systems for SILS [3]. Robotic-assistant may be able to restore the perception of intuitive operating to the surgeon. The commercial systems Da Vinci® and Amadeus® have been modified with a set up for SILS, and projects like SPRINT[4] are based on concept of single port surgery. In vivo devices need automatic tracking and localization systems in order to know exactly their position and to better use the potentials of the surgical tools that are completely hidden to the eyes of the surgeons. Difficulties for the surgeon remain the loss of depth perception in case of monocular endoscopic camera and the limited field of view of the endoscopic camera (usually 70°) [5]. These gaps can be reduced by computer technology enhancing the view of the surgical field. There are multiple software allowing segmentation of organs in CT/MR images and 3D modeling and visualization of patient anatomy. It is possible combine the pre-operative 3D modeling with intra-operative information provided by endoscopic camera and to develop a computer guiding system [6].

In order to enhance the operative vision and to improve the safety in robotic SILS, we propose a novel architecture in which it is possible to extract a 3D model of the patient from CT scan, merge pre-operative planning with intra-operative 3D reconstruction from stereo vision and define safety areas during the surgery. The surgeon will be allowed to select manually or with the robotic arm zones in which the robot cannot act in order to preserve important structures. These areas will adapt in real-time to compensate for tissue motions and deformations. A general scheme of the proposed architecture is shown in Fig. 1. In this work we present the workflow for the extraction of the surface rendering of abdominal organs and the architecture set up in order to calibrate the endoscopic stereo cameras. Preliminary results show that the camera calibration accuracy satisfies the clinical requirements for organ motion tracking.

II. MATERIALS AND METHODS

The proposed system consists of two independent steps. In the pre-operative phase 3DSlicer 4.3.1[7] is used to extract the surface rendering of the organs of interest from CT dataset, while in the intra-operative phase two digital cameras are placed on the tip of an endoscope to provide a 3D view of the scene inside the abdomen and allow a 3D reconstruction of the structures of interest.

A. *Preoperative surface rendering*

Providing a 3D visualization of the pre-operative patient data is the first step to develop an enhanced vision system. It enables the surgeon to highlight important structures, as main vessel or cancer area, information that are fundamental during the surgery. The 3D volume of the organs is extracted starting from the CT scan of the patient abdomen. The main targets are liver, kidneys, spleen, gallbladder, pancreas, aorta and main veins. They are initialized by drawing a seed inside the organs of interest. An active contour model [8] then evolves to segment the organ in the sagittal, coronal and axial planes. The 3D surface model is computed through a marching cubes model, runs triangle reduction and triangle smoothing algorithms [8].

In Fig. 2 the result of the surface rendering of the main structures to be considered in robotic SILS is shown.

B. *Stereo camera calibration architecture*

The first step needed for the intra operative 3D visualization and reconstruction is the calibration of the stereo cameras. A modular architecture is set up to read the images from the digital cameras, synchronize them and to perform the stereo calibration. The stereo cameras are synchronized via hardware, setting the triggering of one camera to the other. The framework ROS allows to develop a nodelet [9] in order to read the two images simultaneously. The calibration package performs at first the intrinsic calibration of each camera and afterward the extrinsic stereo calibration. The OpenCV algorithm used to solve for the focal lengths and offset is based on Zhang's method [10]. The Brown method is used to solve for the distortion parameters [10].

C. *Experimental protocol*

The experimental set up consists of two cameras (uEye LE, IDS). The resolution is 640x480 pixel, and they run at 15 fps. The baseline between the two cameras is 3.8mm. The planar object used for the calibration is a chessboard of 8x6 squares of 4.1 mm.

The evaluation of the calibration is done checking the re-projection error (rpe) of the stereo calibration, as in Eq. (1). It is computed by projecting the three-dimensional points of the chessboard into the image using the final set of calibration parameters and computing the root mean square of the distance between the corners detected p_d and reprojected p_r, in the image reference frame.

$$rpe = \frac{\sqrt{\sum_{i=1}^{N} (p_d - p_r)_i^2}}{N} \qquad (1)$$

where $N = number\ of\ frames\ x\ corners$.

The camera calibration is developed using the framework ROS (Robot Operating System) [11] and the OpenCV library [12]. The protocol transport used is TCPROS (TCP-IP).

Test are performed varying the number of frames (5, 15, 25, 35) in order to define which is the amount of frames necessary to obtain the best results. For each set of frames 12 trials are execute and the median and interquartile ranges of the rpe are computed. In Fig. 3 the set up used for the test is shown.

III. RESULTS

In Fig. 4 are presented the results of test on calibration, in terms of reprojection error for the stereo calibration at different number of frames.

The results show that the dispersion from the median of re-projection error decreases as the number of frames increase. The median of the reprojection error using 35 frames is 1.14 mm.

IV. DISCUSSION

The architecture proposed allows the surgeon to identify important structures both in the pre-operative and intra-operative phase. The surface rendering merged in the intra-operative scene will put in evidence important areas not directly visible through the endoscope and to be preserved. It will use to plan the surgery and the entry point of the robotic arm. In the intra-operative phase, the calibration of the cameras has a fundamental role in the 3D reconstruction, and can be affected by error if the two images are not synchronized. The ROS framework allows us to read the images simultaneously. The number of frames to be used for a rpe in the stereo calibration that satisfies the clinical requirements for organ motion tracking is 35. The decreasing of the error dispersion increasing the number of frames can be related to the fact that increasing the frames the range of rotation of the chessboard in the image plane increase. Future steps needed for the 3D vision will provide the undistorted and rectified images, which can be used to improve the extrinsic calibration.

V. CONCLUSION

In this work we propose an enhanced vision system in order to improve the vision inside the abdomen during robotic SILS. The surgeon can rely on the possibility of automatic registration of the pre-operative plans on the intra-operative images, in order to visualize a cancer area or highlight main vessels during surgery. Considering the drawback of organs motion due to respiration, blood circulation and surgical tool interaction a future goal is to track abdominal structures and to define dynamic active constraints in the surgical work space, which will adapt in real-time to compensate for tissue motions and deformations.

REFERENCES

[1] J. E. Varela, S. E. Wilson, and N. T. Nguyen, "Laparoscopic surgery significantly reduces surgical-site infections compared with open surgery", *Surgical endoscopy*, 2010, vol. 24, pp. 270-276.

[2] R. H. Taylor and D. Stoianovici, "Medical robotics in computer-integrated surgery", *Robotics and Automation, IEEE Transactions on*, 2003, vol. 19, pp. 765-781.

[3] G.W. Taylor, J. Barrie, A. Hood, P. Culmer, A. Neville, and DG. Jayne. "Surgical innovation: Addressing the technology gaps in minimally invasive surgery", *Trends in Anaesthesia and Critical Care*, 2013.

[4] M. Piccigallo, U. Scarfogliero, C. Quaglia, G. Petroni, P. Valdastri, A. Menciassi, and P. Dario, "Design of a novel bimanual robotic system for single-port laparoscopy", 2010. *Mechatronics, IEEE/ASME Transactions on*, vol. 15, pp. 871-878.

[5] M. Baumhauer, M. Feuerstein, H. P. Meinzer, and J. Rassweiler, "Navigation in endoscopic soft tissue surgery: perspectives and limitations", 2008, *Journal of endourology*, vol. 22, pp. 751-766.

[6] S. Nicolau, L. Soler, D. Mutter, and J. Marescaux, "Augmented reality in laparoscopic surgical oncology", 2011, *Surgical oncology*, vol. 20, pp. 189-201.

[7] P. Steve, H. Michael; K. Ron, "3D Slicer" ,2004, *Biomedical Imaging: Nano to Macro, IEEE International Symposium on. IEEE*, pp. 632-635.

[8] J. Rossignac, and P. Borrel, "*Multi-resolution 3D approximations for rendering complex scenes* ", 1993, Springer Berlin Heidelberg, pp. 455-465.

[9] Robot Operating System (ROS) - Nodelet, http://wiki.ros.org/nodelet, 2014.

[10] M. Brown, D. Burschka, and G. D. Hager, " Advances in computational stereo", 2003, *Pattern Analysis and Machine Intelligence, IEEE Transactions on*, vol. 25, pp. 993-1008.

[11] M. Quigley, K. Conley, G. Gerkey, J. Faust, T. Foote, J. Leibs, and A.Y. Ng, "ROS: an open-source Robot Operating System", 2009, In *ICRA workshop on open source software*, vol. 3, n. 3.2.

[12] G. Bradski, and A. Kaehler, "Learning OpenCV: Computer vision with the OpenCV library", 2008, *O'Reilly Media Inc.*.

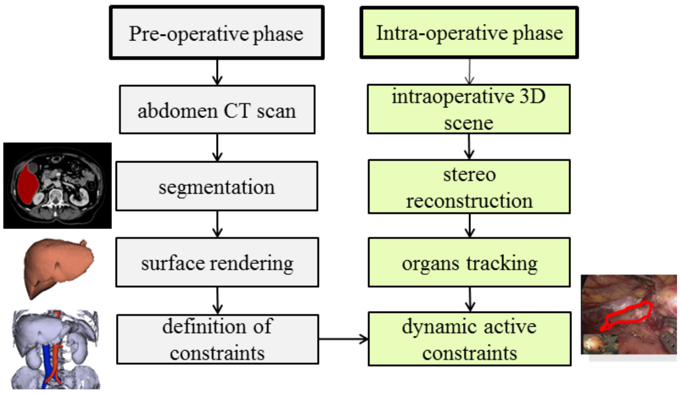

Fig. 1: General scheme of the enhanced vision system. In the pre-operative phase the surface rendering of organs allows the surgeon to identify important structures to be protected during the surgery. A subsequent step consists in adapt these constraints to the intraoperative images acquired using on board stereo-cameras relating to the organ motion tracked.

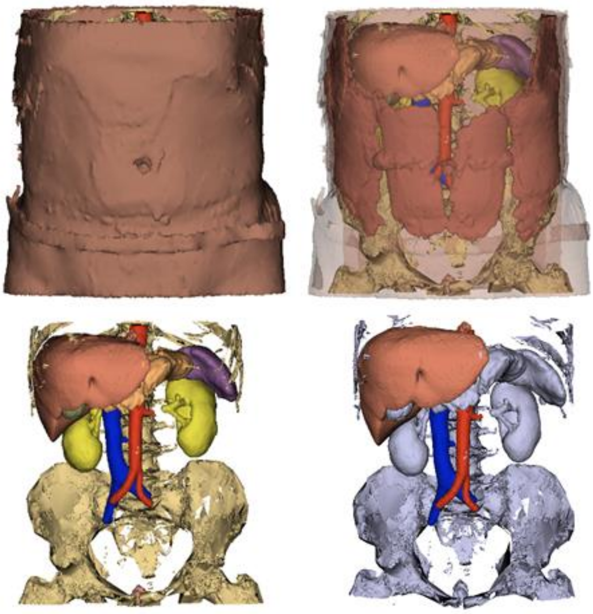

Fig. 2 : Slicer scenes of abdominal surface rendering models, starting from CT scan of a man, using 3DSlicer modules. It is possible to view the models of the skin of the abdomen (up-left) and put the skin in transparency to show the underlying structures (up-right) and plan the entry point. In the lower part the surface rendering of the organs is shown and the vein and the aorta to be preserved from surgery are highlighted with respect to the target organ, which is the liver.

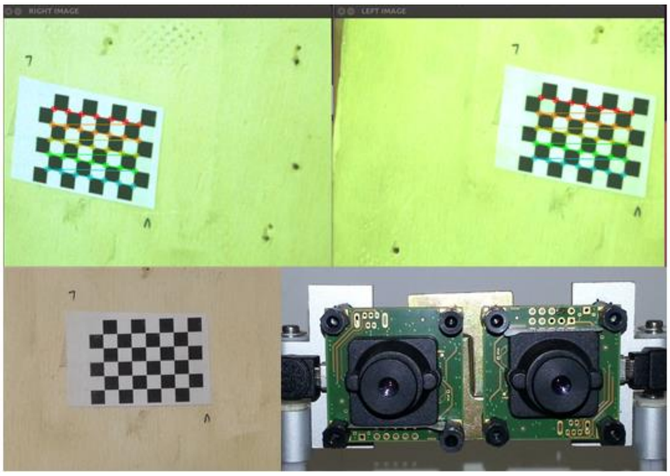

Fig. 3: Experimental set-up: in the upper part the detection of the corners during calibration in left and right images is shown. In the bottom part two digital cameras (right side) are align next to the other. A planar chessboard of 8x6 squares (4.1 mm) is used for the calibration (left side).

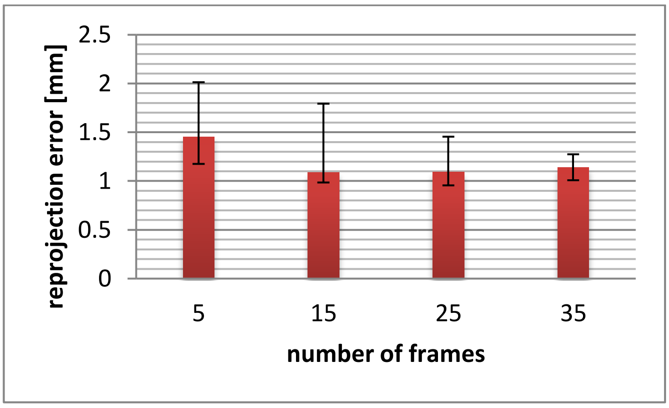

Fig. 4 : Evaluation of stereo calibration in terms of reprojection as a function of different number of frames. The bars represent the median values, and the vertical bars indicate the interquartile range.