Adaptive assistance to laparoscopic surgery with comanipulation and gesture recognition

Thesis subject supported by the LABEX CAMI, http://cami-labex.fr/

Thesis location: ISIR – Université Pierre et Marie Curie – PARIS 6. Stays planned at ICUBE - Strasbourg
Contact persons:
Thesis director: Guillaume Morel, ISIR, guillaume.morel@upmc.fr
Collaboration: Nicolas Padoy, ICUBE, npadoy@unistra.fr
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1. The CAMI context

Medical Interventions (surgery, interventional radiology, radiotherapy) can benefit from a significant boost for progress in terms of patient-specific optimal planning and performance. To fulfil the patient's demands for quality, senior operators demand to see beyond the immediately visible, to be assisted in their real-time vital decisions and to provide access to enhanced dexterity, while junior operators need to "learn to fly" before being left alone, and public health authorities and companies require demonstrations of the medical benefit of innovations.

The Computer Assisted Medical Interventions LABEX (CAMI LABEX) strategic vision is that an integrated approach of medical interventions will result in breakthroughs in terms of quality of medical interventions, demonstrated in terms of medical benefits and degree of penetration of CAMI technology in routine clinical practice.

Among the different actions undertaken in the scope of the CAMI LABEX, 6 to 10 theses starting yearly are to be financed. Subjects dealing with themes within LABEXs scientific field and resulting from collaboration between different CAMI partners will be favoured. The following thesis proposal falls within this framework.

2. Context and objectives

Laparoscopic surgery is a form of minimally invasive surgery where an endoscopic camera and elongated instruments are inserted into a patient's abdomen through small cannulas. The surgeon uses an image provided by the camera and displayed on a screen to control the movements of the instruments he/she manipulates through the cannulas.

Fig. 1 – A view of a surgical theatre during a laparoscopic surgery procedure

Our aim in this research is to control a comanipulation device for laparoscopic surgery. With this system, both a surgeon and a lightweight, back-drivable robot simultaneously hold the handle of a laparoscopic instrument.

The robot can apply forces to the instrument in order to provide assistance to the gestures. For example, the robot can use elastic force fields to impose a geometrical constraint, or viscous fields, to smoothen the gesture. A first prototype of the device has been fabricated and low level control features (impedance control, self-registration) have been developed, see Fig. 2.

The successful applicant will have to study the higher level of the controller. Namely, he/she will develop a supervision system, able to recognize gestures in real-time and, from this recognition, to adapt on-line the robot parameters for optimal assistance. From a scientific point of view, we expect novelty in the fact that, from the real time gesture recognition, the system will adapt the robot parameters and then check whether the user behaviour adapts consistently with the hypothesis. This reinforcement mechanism is expected to bring robustness in the gesture recognition algorithms.

3. <u>Detailed subject</u>

Context

Laparoscopic surgery is a form of minimally invasive surgery where an endoscopic camera and elongated instruments are inserted into a patient's abdomen through small cannulas. The surgeon uses an image provided by the camera and displayed on a screen to control the movements of the instruments he/she manipulates through the cannulas, see Fig. 1. This approach has been increasingly employed for a number of surgeries since its invention, in France, in the late 70s. Its benefits mainly lie in a faster recovery and a limitation of postop complications.

However, laparoscopic surgery suffers from limitations. Mainly, the gesture is difficult because of the lack of instrument distal dexterity and the indirect and partial vision of the surgical scene.

Within a project named FLUOROMIS, ISIR has developed a unique comanipulation device for laparoscopic surgery. With this system, both a surgeon and a lightweight back-drivable robot simultaneously hold the handle of a laparoscopic instrument. The robot can apply forces to the instrument in order to provide assistance to the gestures. For example, the robot can use elastic force fields to impose a geometrical constraint, or viscous fields, to smoothen the gesture. A prototype has been designed, fabricated, and evaluated through a first animal experiment, see Fig. 2. This lightweight prototype benefits from a high back-drivability. Its workspace has been optimized to fit a laparoscopic instrument workspace. The concept allows for a fast installation, without any registration prior to use (self-registration of the trocar, [1]). Within the framework of a first thesis started in December 2014, ISIR has implemented different force fields and evaluated the efficacy of the assistance in terms of gesture quality.

Objectives

The main objective of the thesis will be to propose methods for the automated adaptation of the robot behaviour to the gestures performed by the clinician. They will allow the robot to switch between the different modes of operation and to select the low level control parameters in real time without the need for the surgeon's input.

A first step will be to establish, from the existing work at ISIR, a library of behaviours adapted to the different steps of a given surgical procedures.

Then, the thesis will aim at developing methods for robot control that do not require any additional channel of communication. Namely, simply by holding the instruments, the surgeon should be able to communicate with the robot without additional buttons, pedals or audio channels.

The successful applicant will develop methods for on-line surgical gesture recognition. There has been a tremendous effort in the research community, over the past decade, in the automatic recognition of surgical activities. The general idea is to collect and analyse in real-time a number of signals, ranging from the surgical tool signals to the endoscopic video stream, to determine what gesture is being performed within a procedure at each time step, see e.g. [2,3]. He/she will investigate the best features to use for recognition and propose a novel recognition approach dedicated to the *co-manipulation* scenario, which is one of the main originality of this work.

Fig. 2 – Prof. Brice Gayet evaluating the ergonomy of a comanipulator prototype during an animal laparoscopic surgery (IMM, oct. 2015)

In the context of comanipulated laparoscopy, two original features will help to make these algorithms robust:

- The robot position sensors provide in real time a robust and precise signal on instrument movements
- The system is a loop. Namely, once a hypothesis has been established, a behaviour will be selected and applied to the comanipulator. This will generate a motor adaptation on the surgeon's side, which can be observed to either reinforce to cancel the hypothesis.

Expected applicant's profile

- Scientific and technical skills and knowledge in:
- Robotics & control (mandatory)
- Programming (C++ is mandatory)
- Image processing and machine learning (mandatory)
- Medical robotics (considered as a plus, not mandatory)

Other skills

- Capacity and willingness to work in a multidisciplinary team.
- Good writing skills in English language (mandatory).

4. Proposed course and method of collaboration within CAMI

The Ph.D. student will mainly be based at ISIR and will prepare a thesis at Pierre et Marie Curie University (UPMC). During the first months (bibliographic study, specification of requirements, etc.) a certain number of meetings between ISIR and ICUBE will take place in order to better define the objectives and a work program.

Research work will mainly take place at ISIR under the direction of G. Morel, with monitoring by the ICUBE, and will result in the implementation on a prototype located at ISIR so as to evaluate different control approaches. In the framework of the development of gesture recognition algorithms, the Ph.D. student will have to plan stays for a few weeks / months at ICUBE for collaborative work.

References:

[1] L Dong, G Morel; Robust trocar detection and localization during robot-assisted endoscopic surgery; International Conference on Robotics and Automation (ICRA), 2016

[2] N Padoy, GD Hager; Human-machine collaborative surgery using learned models; International Conference on Robotics and Automation (ICRA), 2011

[3] A.P. Twinanda, S. Shehata, D. Mutter, J. Marescaux, M. de Mathelin, N. Padoy; EndoNet: A Deep Architecture for Recognition Tasks on Laparoscopic Videos, arXiv:1602.03012, 2016.