A surgical Cockpit for Minimally Invasive Surgeryi

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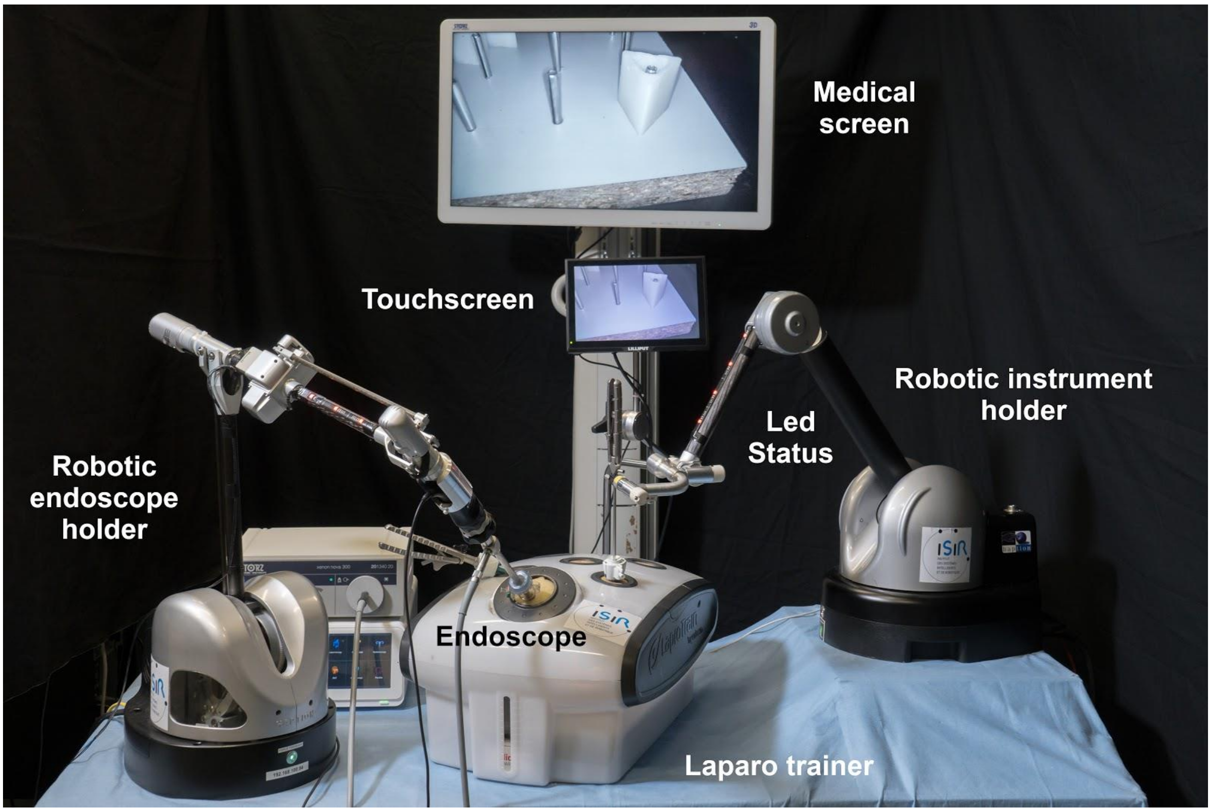
Abstract:
The Surgical Cockpit is a robotized platform for Minimally Invasive Surgery targeting the treatment of diseases affecting the digestive, urologic and gynaecologic systems. The platform is designed to assist and enhance the surgeon's gesture without disrupting the customary surgical workflow, which is standardized according to the type of intervention. Existing surgical platforms feature a Master-Slave approach, where the surgeon remotely manipulates a master console that drives the instruments via a slave robot. On the contrary, the Surgical Cockpit does not cut off the close contact between the surgeon and their patient. The choice of lightweight, transparent robotic arms seamlessly fits into surgical frame: the robots are placed at the patient's bedside and hold the tools and the endoscope, both conveniently fixed at the end-effector through magnetic clippers. This configuration enables a robot-surgeon co-manipulation paradigm.

Introduction:
In classical laparoscopic routine, surgery is carried out by means of long instruments inserted into an inflated abdomen via a number of tiny skin incisions. The surgeon manipulates the instruments and supervises the task thanks to the visual feedback streamed by an endoscopic camera usually hold by a medicine resident. Such a type of surgery demands the dexterity to be adapted to the environmental constraints that limit the degrees of freedom in the task execution. In particular, the presence of a fixed entry point acts as a movement inverter and introduces a bias in the perception of the tissue stiffness. In addition, this inversion may introduce inefficiencies in the surgeon-resident interaction if the directional movements for the camera positioning are not clearly coded and stated. The platform we propose tackles several downsides of the classical approaches by assisting and/or enhancing the gesture of the surgeon. In particular, the presence of a dedicated endoscope holder enables the surgeon to fully control the camera without any accessory help.

Setup and Features:
The Surgical Cockpit consists of two lightweight, cable-driven, 6DoFs robotic arms. One arm holds the surgical tool, while the second arm holds the endoscopic camera. Their cable-driven actuation ensure a high back-drivability and, in turn, a high transparency when manipulating the arm, thanks to the negligible friction at the joint level. Both robots are able to self-register their position with respect to the entry point [1]. They can sustain the weight of the tool/camera thanks to a gravity compensation module that compute the optimal balance force based on the current insertion level into the trocar. For safety reasons, no compensatory Cartesian moments are applied at the robot end-effector, to ensure a zero-sum force pulling along the skin the surrounds the trocar, perpendicularly to the insertion direction [2]. Natural hand tremor, which is often magnified on the images, is filtered out thanks to a variable viscous field applied either at the instrument tip or handle: for fine movements, requiring a firm gesture, the felt viscosity increases to stabilize the tool, while for agile movements, the viscosity linearly decreases to minimize the perceived hindrance [2].
Both robots are able to lock into a defined Cartesian position and keep the chosen position in a very accurate way: a low-gain integrator in the PID controller ensures that static errors are slowly balanced out and prevents the storage of high energy levels that could be transferred to the patient with harmful



effects. However, for tele-manipulation modes (explained in the following), a non linear term is added to the control law to rapidly overcome non-linearities as friction at the entry point [3].
The fulcrum point distorts the haptic feedback: tool-tissue interaction forces at the instrument tip can be either magnified or reduced depending on the current insertion depth. This can lead to involuntary excessive forces that can damage tissues or organs [4]. Sensorized tools can be used to send back a corrective force to the robotic instrument holder to restore the true interaction force felt by the surgeon [5].
Several control modes have been implemented and tested for the intuitive control of the endoscope. The reference mode is the manual mode, where the surgeon can freely hand-manoeuvre with minimal friction. In case the endoscope is locked into a fixed position, a gentle pull will suffice to unlock it and reposition as deemed best. Image-based navigation can be achieved by displacing the camera via a tactile screen. The user inputs a direction UP/DOWN, LEFT/RIGHT by trailing the finger accordingly. Zoom IN/OUT commands are coded with a 2-finger gesture. The speed is also proportional to the amplitude of the finger movement.
Automatic control can be achieved by controlling the endoscope with the surgical tool. In particular, the “Follow” mode ensures that the instrument tip is always visible on the image, preserving a constant position in the camera frame. The choice of the modality is partly automatic and partly commanded via a foot pedal. Moreover, a particular pose of the camera can be saved and the surgeon can restore it whenever desired through a tactile screen and pedal interface.
Another important aspect of the research is the surgical learning process. Robot-assisted laparoscopic surgery is overtaking classic laparoscopic surgery: it allows to significantly increase the surgeon’s performance while reducing physical/mental difficulties. Several studies have been carried out to analyse the motor skills developed when using the robot, and the impact on performance without the robot [6].

Discussions:
The surgical cockpit is a co-manipulative robotic system for Minimally Invasive Surgery: it features two lightweight, back-drivable robotic arms that allows for safe manipulation of the tools. The surgeon benefits from low-level assistance, such as gravity compensation and trocar detection, up to more

complex interaction modalities, such as endoscope manipulation through a tactile interface or automatic modalities. The platform design is centred around the patient's safety, which is the main decisional driver for the technical development.
Such a setup is our starting point toward the development of Augmented Surgery, by embedding Augmented Reality applications, sensorized tools for enhanced haptic feedback and surgeon-centred human-machine interfaces.

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