CORE
Metadata, citation and similar papers at core.ac.uk
Provided by KITopen

Collaborative Control for Surgical Robots

1st Paul Maria Scheikl
Institute for Anthropomatics and Robotics
Karlsruhe Institute of Technology
Karlsruhe, Germany
paul.scheikl@kit.edu

2nd David Lanz
Institute for Anthropomatics and Robotics
Karlsruhe Institute of Technology
Karlsruhe, Germany
david.lanz@student.kit.edu

3rd Franziska Mathis-Ullrich
Institute for Anthropomatics and Robotics
Karlsruhe Institute of Technology
Karlsruhe, Germany
franziska.ullrich@kit.edu

***Abstract*—We are designing and evaluating control strategies that enable surgeons to intuitively hand-guide an endoscope attached to a redundant lightweight robot. The strategies focus on safety aspects as well as intuitive and smooth control for moving the endoscope. Two scenarios are addressed. The first being a compliant hand-guidance of the endoscope and the second moving the robot's elbow on its redundancy circle to move the robot out of the surgeon's way without changing the view. To prevent collisions with the patient and the environment, the robot needs to move respecting Cartesian constraints.**

***Index Terms*—closed-loop control, human robot collaboration, robot-assisted surgery, minimally invasive surgery**

I. Introduction

When we talk about robotic surgery, it is easy to mentally jump to a future where surgery is completely automated. The patient reclines into a chair and multiple robotic arms with various tools start the procedure without help of a human surgeon. But this scenario is in the very distant future. Furthermore, we might not even want to fully automate the process. Either way, for the not so distant future, we want to automate some of the tasks that are necessary for surgical interventions. Partly because some of the tasks are challenging to perform with high precision over a long time. Additionally, a lack of qualified personnel exists, in rural areas in particular. In this work we address a special case of assistance tasks in surgery: the task of guiding an endoscopic camera during laparoscopic surgery [3].

In our work we utilize a redundant lightweight robot arm for autonomous guidance of an endoscopic camera for laparoscopic surgery. Our robot is a Franka Emika Panda equipped with torque sensors in all seven joints. As a first step towards our automation goal, we need to collect data of the actual movements of the endoscope during manually performed example surgeries on a surgical phantom. The movements will be generated by telemanipulating the robot. Nevertheless, we want to be able to use hands-on compliant control by the surgeon, to allow corrections of the robot joints and camera pose [4]. For example pre-positioning the robot [2].

Surgeons experienced hands-on compliant control to be natural and very suitable for surgical tasks [1]. We implement controllers that support the surgeon during manual guidance of the endoscopic camera while focusing on safe interaction between human, robot, and the surgical environment.

The surgeon needs to be able to push the robot's elbow out of his way, while the endoscope's pose remains fixed in the workspace. When the surgeon needs more space close to the patient, it is important that the image shown by the endoscopic camera does not change. Furthermore, it is critical that the robot does not harm the patient through a lack of haptic feedback while being hand-guided by the human surgeon. We have to ensure that no tangential forces exist at the incision point. As a constraint for our implementation, the position of the pivot point in the workspace must be known and coincident with the incision point.

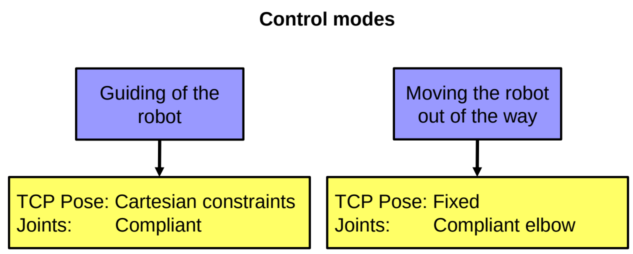

Fig. 1. The two control modes implemented in two separate controllers. Both have different functions (blue) regarding the behavior of the TCP pose and the joints (yellow). During hand-guiding of the robot, the joints need to behave compliantly while the TCP (the endoscopic camera) is allowed to move under Cartesian constraints (no tangential translation relative to the incision point). For moving the robot "out of the way", only the elbow is allowed to move, while holding the current pose of the TCP fixed.

The controllers (see Fig. 2) are split into two main functions as illustrated in Fig. 1.

a) Fixed TCP: In the scope of this work, the Tool Center Point (TCP) is defined as a reference point on the endoscopic camera that describes the pose of the camera. The first function is is fixing the current Cartesian pose of the TCP, while simultaneously allowing the surgeon to push away the elbow of the robotic arm with his hand. For robots with seven degrees of freedom the joints are named in the style of a human arm. Thus the 2nd joint is the shoulder, the 4th joint the elbow, and the 6th joint the wrist (see Fig. 3). Using this kind of robot, it is possible to move the elbow on a circle called *redundancy circle* without changing the Cartesian pose of the TCP; in our case the endoscopic camera. In our work, we evaluate different approaches such as impedance and admittance control regarding safety aspects and intuitive control.

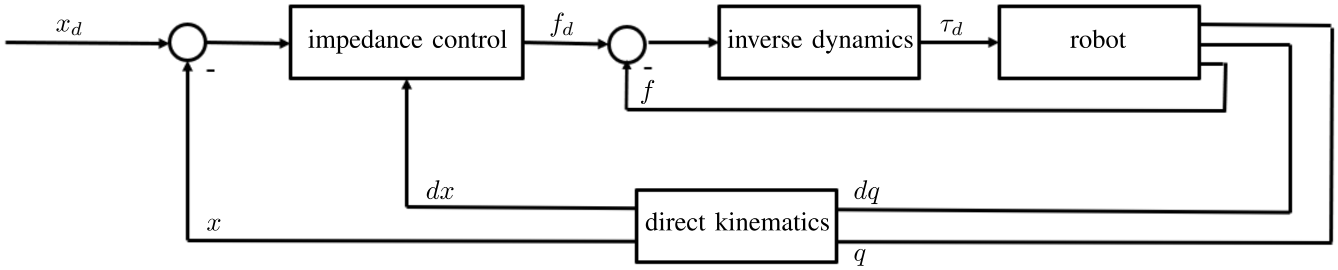

Fig. 2. The impedance controller is calculating a convenient target force (f_d) regarding the difference between actual Cartesian pose (x) and target Cartesian pose (x_d) as well as Cartesian velocity (dx). The difference between actual external force (f) and target force is being transformed by inverse dynamics in torques (τ_d) that are sent to the internal robot control.

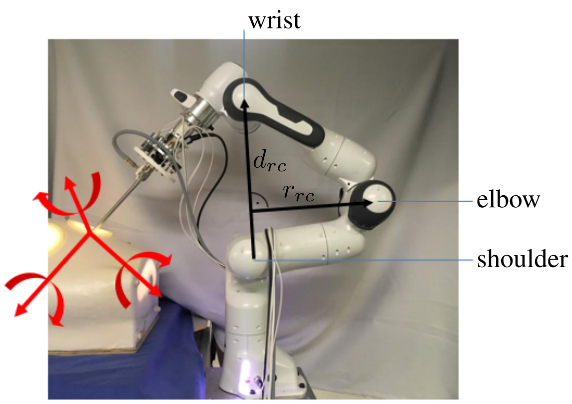

Fig. 3. Franka Emika Panda robot. The joint's names are chosen in the style of a human arm. The rotational axis is shown as (d_{rc}) and the radius of the redundancy circle is shown as (r_{rc}). Since the robot's TCP pose is not allowed to change in relation to the incision point, all possible degrees of freedom are *locked* (thus coloured red).

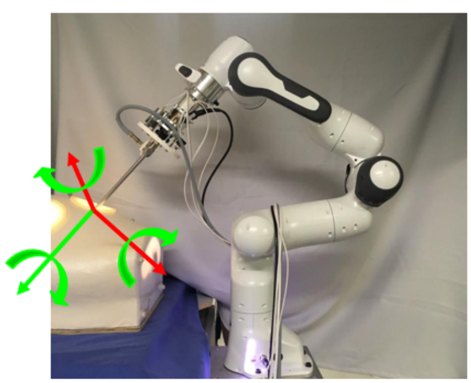

Fig. 4. The incision point (pivot point) is the origin of the coordinate system. The four permitted degrees of freedom are shown in green, the ones that are *locked* are shown in red.

b) TCP under Cartesian constraints: The second function is enabling the surgeon to guide the endoscopic camera with his hands without harming the patient by exerting force on the incision point. For implementing this behavior, we assume that we know the exact position of the pivot point. During hand-gaidance, all motions that lead to tangential forces to the incision point must be avoided. Our controller is realized as an impedance controller with adaptive stiffness and damping regarding position and orientation of the TCP. As a result, we are able to allow rotational movement in all three degrees of freedom around the pivot point, and translational movement only along the endoscope's axis through the pivot point (see Fig. 4).

As a next step we suggest the combination of our control algorithms with an intention recognition approach to switch to the appropriate controller. When the surgeon intends to push away the elbow of the robot to get direct access to the patient, the robot needs to fix the current pose of the TCP while allowing movement in its elbow. On the other hand, when the surgeon wants to move the endoscopic camera by hand-guiding the robot, the robot has to switch to the controller that handles compliant joints under Cartesian constraints for the endoscopic camera.

References

[1] B. H. Siciliano and O. H. Khatib, Eds., Springer handbook of robotics, 2nd ed. Berlin: Springer, 2016.
[2] P. Kazanzides, et al. "An integrated system for cementless hip replacement." IEEE Engineering in Medicine and Biology Magazine 14.3, 1995.
[3] A. Bihlmaier, "Learning dynamic spatial relations," Springer, 2016.
[4] R. H. Taylor, et al. "A telerobotic assistant for laparoscopic surgery." IEEE Engineering in Medicine and Biology Magazine 14.3, 1995.