University of Basel
Department of Biomedical Engineering

BIROMED-Lab
Medical Robotics and Mechatronics

Master Thesis: Path Planning for Hyper-Redundant Surgical Robots

Context: The MIRACLE project uses a hyper redundant robotic system to perform laserosteotomy in a minimally invasive way. This robotic system can be divided into three sub-robots (macro-, milli-, and micro-robot), each operating on a different scale of motion. The macro-robot (KUKA LBR iiwa) has a large workspace with an accuracy of up to a millimeter and moves the milli-robot through desired poses. The milli-robot is a flexible robotic endoscope, which enters the human body through a natural orifice or an incision. The micro-robot is mounted at the tip of the milli-robot and manipulates the surgical tool, e.g., a laser., with submillimeter accuracy. Each of these robots has multiple DoF and must move the surgical tool as planned. Redundancy in such robots can be used to impose additional constraints (for example, avoiding obstacles or minimizing the joint motion) along with the user commands. Previously we have developed a planner in ROS (Robot Operating System) that calculates robot paths given an insertion pose and target pose [1], as depicted in Figure 1. It considers fixed anatomical constraints and workspace constraints of the robotic endosope, but not that of the macro-robot.

Task description: Your task would be to find robot motion plans for the macro- and milli-robot systems together such that they satisfy workspace constraints of the complete robot and anatomical constraints. You would work with a simulation environment (that respects rigid-body dynamics) to test different planning algorithms, select *optimal* plans for each robot, and visualize the simulated path. If successful, the planned motion is communicated to a real-time controller that executes it on the macro-robot. At the same time, the planned motion of the robotic endoscope is visualized (hybrid simulator). It would be advantageous to design the planner framework in such a way that it can re-plan motion plans as a reaction to changes in the constraints, e.g., changes of the anatomy, change of the planned intervention by the surgeon on the fly.

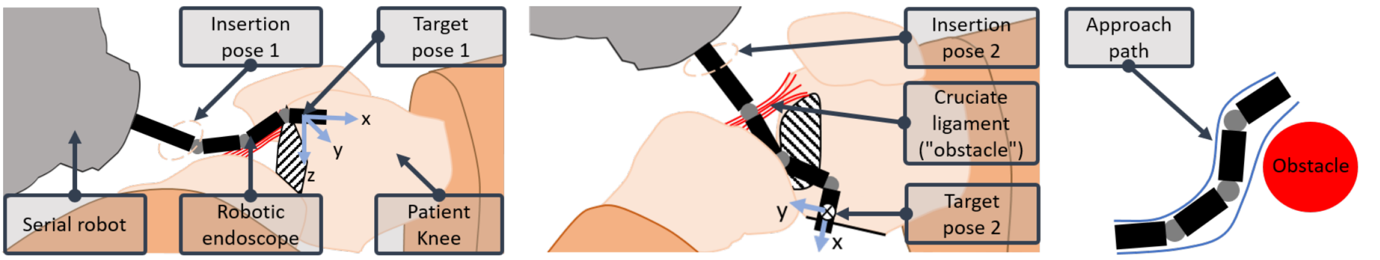

Figure 1: Path planning system for minimally invasive surgery using a robotic system. The first application is unicompartmental knee arthroplasty. The robotic endoscope has to reach various target locations in the knee joint to perform the necessary bone cuts. Two exemplary cuts are visualized in (a) and (b), the distal and posterior femoral cut, respectively. The algorithm computes a viable approach path that considers the kinematics of the robotic endoscope and macro-robot, as well as anatomical and user-defined constraints (c).

Workpackages:

1. Building on the previous work [1], extend the literature survey to identify a feasible architecture for the planner, and select the planning algorithm.
2. Extend the previous work or develop a planning algorithm that finds a feasible robot motion plan given initial and target poses for the robot and anatomical or user-defined constraints.
3. Develop a communication interface between the planner and real-time robot controller (TwinCAT).
4. Demonstrate the planner and communication interface by commanding the macro-robot.
5. Develop and visualize a hybrid simulator that simulates the motion of the robotic endoscope while updating the macro-robot with the real-time state feedback.

[1] Gabriel Konig. Motion planning framework for insertion of a robotic endoscope in the human knee. Master's thesis, University of Basel and Eidgenössische Technische Hochschule Zürich (ETHZ), Switzerland, 2020.

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