Robotics and Navigation in Medicine (Project)
Summer term 2020
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Group Project: Image Guided Robotic Needle Placement

Needles are widely used for minimally invasive procedures ranging from biopsies to drug insertion. Compared to manual needle placement, robots have the potential to make the procedures more precise and safer. Using 3D imaging techniques and trajectory planning the needle can be driven to the desired target while keeping a safe distance to bones and other delicate structures.

In this project, you will develop an image guided robotic needle placement system using the Robot Operating System (ROS) framework. For this, you will use a depth camera (Kinect Azure by Microsoft) mounted on a robot arm (Panda by Franka Emika) to record a 3D scan of a chest phantom. You will then register this scan to a high resolution model, obtained from computer tomography. Within the high resolution model you will perform trajectory planning to find a collision free and kinematically feasible path to the target. Lastly, you will exchange the camera for a needle (mock-up) and let the robot perform the insertion.

Project Groups: The project work should be conducted in groups of six students. We will form the groups based on the information provided in the registration form. To be assigned to a project group you need to submit the registration form either via e-mail to martin.gromniak@tuhh.de or manually to our office (E3.088) by the 28th of April.

Lab Access: Each group will be assigned one weekly time slot to work in the robot lab. The lab will be available to you during your lab times as well as by appointment starting from the 25th of May. In the beginning of your first lab session you will receive safety instructions for working in our lab. Therefore, all group members must be present and on time for their time slot. Additionally, your group must have a **functioning implementation of the Panda forward kinematics** by that day and able to present it in the simulator. Otherwise, **no access to the lab will be granted, because of safety reasons!**

Requirements: The following requirements are **mandatory** and need to be fulfilled in order to successfully complete this project:

- Participte in the first lecture on **23rd of April**. If you can not make it, write an email to martin.gromniak@tuhh.de before.
- Submit the registration form for the project by the **28th of April**.
- Submit a project plan including a sketch of the necessary interfaces between the components of your ROS programm, tasks assigned to each group member and a weekly time plan by the **18th of May**.
- Submit **weekly reports** via e-mail to martin.gromniak@tuhh.de starting from the week of 25th of May. These reports should include the contribution of each team member, the progress achieved in each part of the project as well as any problems you may have encountered. Team members not mentioned in more than three of the weekly reports will be considered inactive and excluded from the project.
- Present your needle insertion system between the **27th and 29th of July** during your last lab session.
- Describe your results and choices in a scientific paper consisting of approximately 5 pages due by the **21st of September**. State and explain every assumption made. Provide sources for all formulas you use.

Subgoals: In order to develop the overall system on time, we strongly recommend you to meet the deadlines for the following subgoals:

- Working implementation of forward kinematics in simulator: **25th of May**
- Working forward and inverse kinematics on the Panda: **29th of June**
- Working hand-eye calibration: **6th of July**
- Model recording and registration: **13th of July**
- Planning of feasible needle paths: **13th of July**
- Working overal system: **20th of July**

Consultation Hours: You may consult the teaching assistants during lab times or by appointment.

Recommendations: Remember to test scripts concerning the robot in the simulation environment available via Stud.IP before running them in the lab.

Consider the following exercises as suggestions on how to split the work within your group. You can always find alternative solutions as long as you keep the above requirements.

Task 1: Robot Kinematics
The robot works in the joint space, however, you will need to move in Cartesian space at least for the motion during needle insertion. Therefore, it is important to convert the joint positions to a robot pose in Cartesian space and vice versa. Solve and implement the solutions to the following:

a) Direct Kinematics,
b) Inverse Kinematics.

Task 2: Calibrations
In order to navigate the robot based on the tracked poses from the camera reference frame, you will need to calibrate the camera and the robot relative to each other. Implement the eye-in-hand calibration which returns the transformation from camera to the robot's end effector.

Task 3: Model recording and registration
In order to obtain a 3D Scan of the chest phantom you will need to drive the camera around the phantom. Based on the known robot poses and the calibration from camera to robot you can then stich the individual pointclouds to one model. Afterwards, you can register this model to a high resolution CAD model which you will obtain from us.

Task 4: Trajectory planning
Based on the high resotion model and a desired target, the task is to find trajectories to the target which both keep a safe distance to bones and are executable by the robot.

Bonus Points: You may receive up to 10 bonus points that will be added to the points you obtain in the written examination for

- active participation during lab sessions,
- regularity of weekly reports,
- quality of your final presentation and the subsequent discussion,
- quality of submitted software (reasonable structure, sufficient commenting, performance during final presentation),
- plausibility of chosen algorithms and quality of their implementation/incorporation into your work,

- your ability to critically evaluate results,
- creativity and implementation of additional features,
- content and completeness of the final report including list detailing contributions of each author,
- and quality of writing (structure, appropriate use of figures and tables, no grammar or spelling errors).