Autonomy for Surgical Robot Systems

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Minimally Invasive Surgery (MIS) denotes the surgical modality also known as keyhole surgery, i.e., surgery through small incisions rather than a large incision as used in open access surgery. In MIS, trocars are introduced through small incisions into the body cavity. A camera and instruments are introduced through the trocars to perform surgery. Patient-related benefits of MIS include shorter hospital stays, lower risk of complications, less bleeding and pain, and a faster return to daily activities.

Today, Robotic Minimally Invasive Surgery (RMIS) is favored over conventional laparoscopic minimally invasive surgery or open access surgery since RMIS offers the patient-related benefits of MIS along with improved dexterity, vision, instrument handling, and surgeon work posture. Surgeons perform RMIS from a console, teleoperating the robot. However, there is a potential that automating particular surgical tasks may improve consistency and precision besides reducing the surgeon's workload. Ultimately, this could improve hospital throughput in the future.

This thesis studies surgical task automation based on the idea that the robot should apprentice to the surgeon. To facilitate this research, we first implemented an improved controller for the Raven-II surgical robot. Despite improved trajectory-following, the accuracy of the Raven-II was not satisfactory for automating surgical tasks. As an alternative, we developed an entirely new platform for non-clinical surgical robotics research. The platform is based on UR5 robots (Universal Robots A/S) and custom-made adapters for mounting and actuating standard surgical instruments. Through a series of small experiments, the platform was demonstrated to be feasible for surgical task automation.

Based on the idea that the robot should apprentice to the surgeon, we applied a learning from demonstration scheme to automate surgical suturing – a task which frequently occurs in surgery. In multiple experiments, we evaluated our approach both with the da Vinci Research Kit (dVRK) – another platform for surgical robotics research – and our own platform. Autonomous suturing was achieved in a simplified scenario. Also, we used the same based learning from demonstration method in a human-robot collaborative task, where the motion of one manipulator was automated, based on the motion of manually controlled manipulator.

Finally, to improve sensing capabilities of surgical robots, the thesis explores using existing visual feedback and applying a convolutional neural network to locate a suture needle and surgical instruments. We also describe integrating bioelectrical impedance sensors into existing surgical instruments. Measuring bioelectrical impedance interoperaratively can potentially assist the surgeon with locating pathological tissue or function as an additional sensor input to an autonomous system.