OTKA PD 116121 Final report

Robot-enhanced skill improvement and assessment in minimally invasive surgery

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During the project, a systematic, scientific approach was followed, allowing the current and future scaling of the results (primarily through the international communities we became part of ,such as the Da Vinci Research Kit user group). It was intended not only to create some instances of good engineering, but to lay the foundations of a bigger work, relying on the given hardware and software infrastructure to do excellent research in surgical engineering.

Initially, the team was focusing on the basic theoretical and practical tools for the assessment of surgery, looking for best practices to make the complexity of the domain comprehensive and manageable by ICT tools. The complete relevant literature was screened, mostly relying on the previous activities off the PI. The key identified research areas have been described in conference papers. The supportive clinical partnership has absolutely been key for the whole project, thus active collaboration was built with eminent surgical groups in Budapest and beyond. Our primary partner was the Semmelweis University Dept. for Surgical Research and Technique (Prof. György Wéber), yet other surgeons were also involved (Dr. Nallbani et al. from Honvéd KH, Dr. Csiky from Margit KH and Dr. Szabó et al. from OOI), besides hiring MDs for active project work (Drs Barcza and Nagy). IN the international domain, the key research partner was the ACMIT (Austrian Center for Medical Innovation and Technology, Dr. Gernot Kronreif) and the Johns Hopkins University (Prof. Peter Kazanzides). During the course of the OTKA project, there was a new joint R&D grant won with both parties (FFG Comet K1 and NRI-1).

The engineering thread of the project was primarily done at the Antal Bejczy Center for Intelligent Robotics (IROB) at Óbuda University's University Research, Innovation and Service Center (EKIK). Despite the several administrative hurdles (like moving buildings), the project evolved into a major highlight of the university, attracting several dozens of important visitors from Hungary and beyond. Employing the one and only da Vinci Surgical System in Hungary, together with the Da Vinci Research Kit (DVRK) environment, we transformed the robotics lab into a true interdisciplinary research hub. Together with my students, we performed the engineering design of multiple generations of sensor-integrated surgical simulators that allows for data collection towards objective skill assessment. It was completed, tested and published, serving as the basis of multiple thesis projects and a handful of publications (Fig 1.).

Two alternative setups have been built for force sensing: one 6 DOF force sensor integrated with a newly developed manual box trainer, and another 3 DOF setup mounted on the da Vinci robot's large needle driver tool (through a custom-designed adapter). The adjoin software programming and data collection toolboxes have been implemented on Arduino (for the manual training box) and on the DVRK platform (for the da Vinci). This robotic setup is typically only capable of measuring lateral forces, therefore an extension was designed to extend its range of sensing to all 6 DOF. The physical motions of the tools (and particularly the camera) were tracked with a custom-developed visual servoing algorithm.

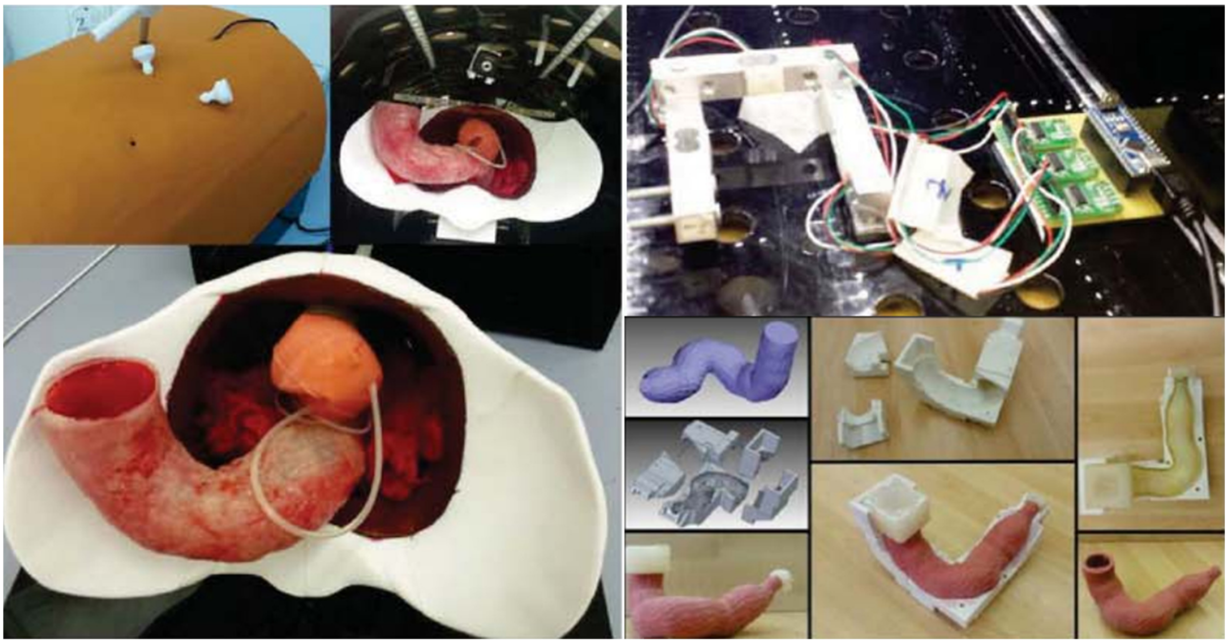

Figure 1. The various anatomical models (phantoms) created for the project, based on the surgical CAD/CAM principle. 3DOF force sensing capabilities have been built in to ensure data stream from the tests.

The most typical MIS procedures of cholecystectomy, prostatectomy and nephrectomy have been chosen (after numerous consultation with laparoscopic surgeons) to become our test cases. For all procedures, the complete workflow has been described, modelled and got recorded in a procedural way, so that the key elements could be selected and realized for the training curriculum. We developed a set of artificial phantoms to replicate the human anatomy. It has been so successful that numerous surgeons approached us for consultation and with new project ideas. Furthermore, ACMIT became a partner of us, relying on supplies for surgical training phantoms.

A dozen of measurements were performed on the initial version of the training box (recorded, analyzed and published), then a handful of experts tried the upgraded version (with soft skin and arbitrary ports), with much better outcome. Novices tried our system in the range of hundreds, since we brought it to many public events, such as science fairs (e.g. Researchers' Night) and expos (Educatio). The da Vinci implementation has seen 25 users so far, but the aftermath of the project is still ongoing.

We continued the work on minimally invasive prostatectomy, and a novel, more complete phantom has been prototyped and tested. We gained significant experience in silicone phantom molding, which means that specific (life-like) structures can be created within the anatomical models, resulting in more realistic surgical scenarios during the training (e.g. clipping and cutting vessels, dissecting structures). These physical realizations allows for better relating to the actual surgical outcome, thus eliminate the need for very complex (e.g. image-based) determination of success/failure.
To facilitate the tests, a more advanced box trainer was created in our lab, and also, novel phantoms have been casted. For the novel nephrectomy application, special sensor models were prototyped to be able to sense and register the proper clipping/cutting of the renal artery and the uterus.
With both the cholecystectomy, the prostatectomy and the nephrectomy training phantoms, we made an

additional round of refinement in the design. During the experiments we recognized that the exploration of the organs is a major, delicate yet time consuming part for which we created a separate blunt dissection phantom to facilitate training. The collected data allowed us to start the automation of this surgical subtask, and our group was the first in the World to demonstrate stereo-camera driven automated robotic blunt dissection (on silicone phantom), presented at the 2017 Hamlyn Medical Robotics Challenge in London with great outcome. To facilitate the automated evaluation of training processes, the ontology-based modelling of the surgical workflow (for our 3 chosen procedures) was started. The first ontology concepts were presented at major conferences, and more importantly, we joined the relevant IEEE standardization groups (P1872.1, P7007 and P2730) to make those results embedded in the future standards of the domain.

During the initial phase of the project, it became imminent to develop a strong and modular custom software framework that may support all ongoing research activities with the DVRK. This was named the IROB-SAF, which is a framework to ease and fasten the automation of surgical subtasks, and can be ported easily onto further robotic platforms, since it is based on the Robot Operating System (ROS). The software includes both stereo vision-based and hierarchical motion planning, with a wide palette of often used surgical gestures—such as grasping, cutting or soft tissue manipulation—as building blocks to support the high-level implementation of autonomous surgical subtasks (Fig. 2.). This open-source surgical automation framework—irob-saf—is available at https://github.com/ABC-iRobotics/irob-saf.

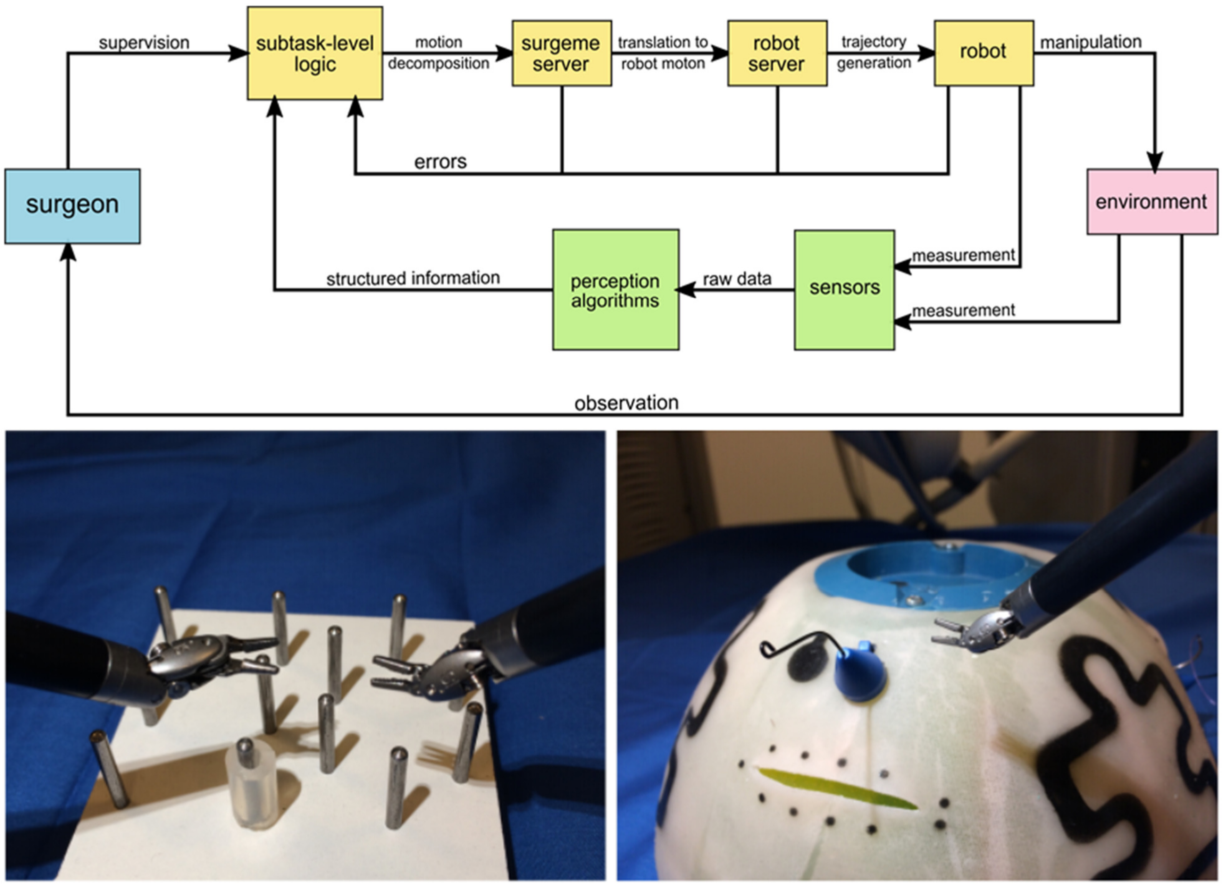

Fig. 2. The IROB-SAF open source framework was developed for the DVRK environment to facilitate surgical task and subtask level automation, such as peg transfer and clever object manipulation.

Modern Computer-Integrated Surgery relies detailed measurements on the surgical process, however, the data available from the operating computers—for most cases—is not captured. We decided to build a tool providing a framework for recording, storing and annotating such information (e.g. in the form of Surgical Process Modells (SPMs) built on Ontologies). This created the ground for a wide variety of clinical applications of Surgical Data Science (SDS), which uses input data from the whole duration of the surgical process and medical care, including the initial symptoms and the long-term outcomes (Fig .3.). This approach to surgical interventions require the acquisition and analysis of heterogeneous, multimodal data, which can only be managed if a common framework is developed. We named it the OntoFlow software tool. This framework can later be used in a multitude of applications including radiation protection planning for interventions, analysis software to estimate real-time surgical risk, but eventually leads to systems capable of semantically annotating surgical data, performing semantic reasoning and eventually creating context-aware surgical assistance. Ontological knowledge representation shows promising results in this area (we decided to stick to OWL format, which is the most commonly employed in the community). Arguably, large scale data collection also raises privacy and confidentiality issues, which requires careful consideration, which was investigated during the project. SDS is a rapidly developing interdisciplinary field of medicine, which requires in-depth knowledge of both computer-science and medicine, and during the project, our group has become member of the world-first SDS community, the OntoSPM. There had been two H2020 proposals submitted to potentially allow the continuation of the work initiated.

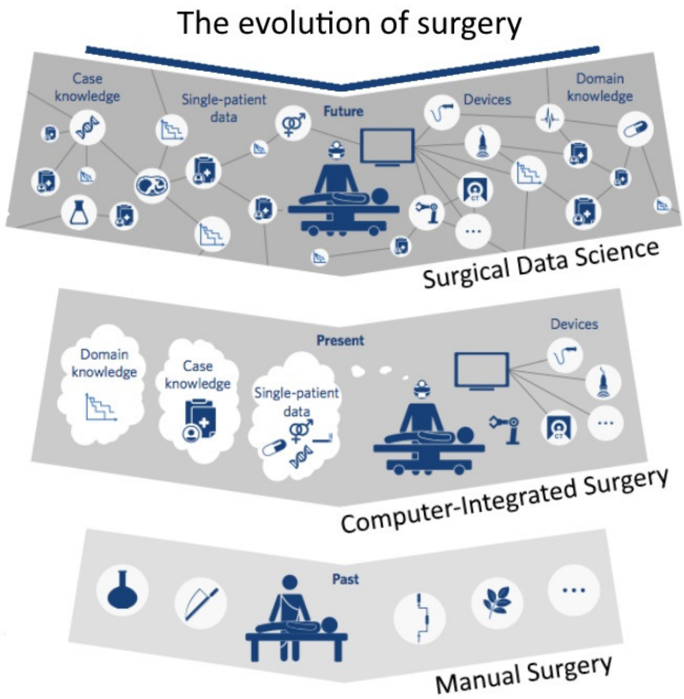

Fig. 3. The fundamental concept of Surgical Data Science: linking IT tools directly to record, analyse and understand surgical data, as don during the project with our OntoFlow software framework.

The team took part in numerous national and international public events, but most importantly, we were hosting the ISO TC 299 WG35 working group meeting on a new safety standard (IEC/CD 80601-2-77: Medical electrical equipment – Part 2-77: Particular requirements for the basic safety and essential performance of medical robots for surgery) for surgical robots, where we could present our results to almost a 100 senior experts from the field. This unique opportunity was further elevated by the Medical Robotics Workshop we hosted in July 2017 where students involved in the project also presented their work. Numerous international conferences, special sessions and workshops have been organized by the team to establish Obuda University as a key player in this field. Moreover, significant public outreach effort has been exerted (mostly by the PI) through public talks (UNESCO plenary in Paris, 2016), appearances (TEDX talk), interviews (national TV and radio) and educational events.

Altogether, this has been a vastly successful project term with numerous results still to come (4 conference papers, 4 journal articles and 3 book chapters are still under review, along with several submitted R&D grant proposals).

Thank you for your kind support!