SMart weArable Robotic Teleoperated surgery

Newsletter #5

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SMARTsurg Surgical haptic feedback system

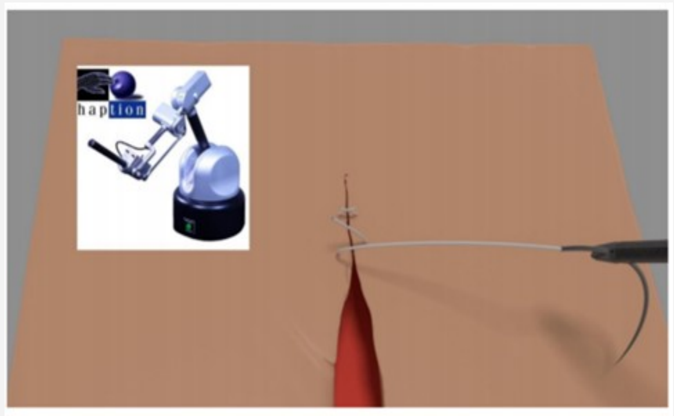
One of the SMARTsurg project objectives is to investigate the requirements for haptic feedback in 3 different surgical areas, cardiology, urology and orthopaedics. Haptic feedback requirements have been established by the many surgeons involved in SMARTsurg survey and their responces have been grouped into the following haptic development tasks:

- Suturing (thread tension) sensing and haptic feedback
- Palpation/Probing sensing and haptic feedback

Haptic feedback in urology

Suturing - Use of the master device for suturing haptic feedback in Virtual Environment

The aim of this task is to investigate the use of haptic feedback during suturing, specifically focused on pulling the thread while tying a knot. The master instrument (Virtuose 6D Desktop) is from Haption. The figure depicts a suturing task simulated in the virtual envirnoment CHAI 3D which has been interfaced with the Virtuose.interacts with a simulated surgical environment that depicts a thread suturing the tissue and modelled thread/tissue tension forces. A virtual needle's position is controlled by the Virtuose 6D Desktop which provides corresponding tension force feedback to the user.



Virtual suturing task; the needle holder is controlled via Virtuose 6D Desktop

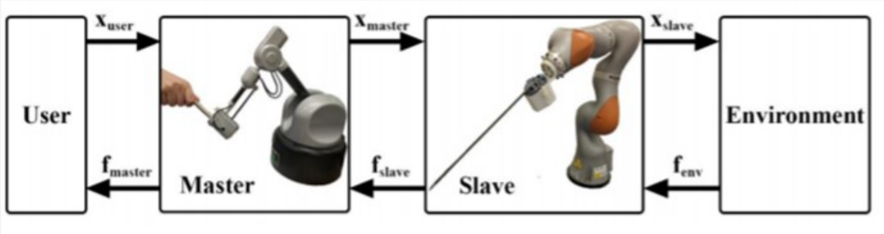
Initial user studies will be conducted where participants will grasp the virtual needle using the master device and pull it as much as they believe should be enough to tie a hypothetical knot. The more the participant pulls, the more tension on the thread will be present (resistance from the master). The maximum pulling force will be recorded. The task will be acompanied with visual cues indicating the thread tension: the two tissue sections will either get closer or further apart and deform when the thread is pulled too much and finally, the thread or tissue will tear if the thread is pulled beyond a limit (at this point, the haptic feedback force is removed). Different trials will involve different levels of force feedback. It will be recorded how much above the optimal force magnitude, defined for each test, the participant will stop pulling the virtual thread. These tests will be based on testing real surgical sutures using a load cell and measuring the required thread tension when creating a surgical knot and forces that tear the thread. The results of the virtual haptic interface experiments will inform how these forces should be modelled in the master device for implementation of haptic feedback in a real environment.

SMARTsurg Surgical haptic feedback system

Suturing - Use of the master device for suturing haptic feedback in Physical Environments

Experimental setup

The three stages of haptic implementation utilise a bilateral master-slave teleoperation scheme. The master device (Virtuose 6D Desktop) controls the position of the slave device (KUKA IIWA) and the force interaction the slave experiences reflected back to the master. The force the master reflects to the user is to be measured via a load cell.



The bilateral teleoperation scheme employed by the SMARTsurg system

Stage 1

Stage 1 is used for verification of the bilateral teleoperation between the master and slave. In this experiment, the shaft of the da Vinci (intuitive surgical system) endoWrist tool is impacted against a soft vertical wall. A SingleTact 0-10 N measurement range force sensor is attached to the shaft to measure the magnitude of the contact force. This force is reflected back to the user via the master device.

Stage 2

Stage 2 of the experimental testing mimics a minimally invasive suturing scenario. In this experiment, a trocar is penetrated through the artificial skin with the shaft of the surgical instrument (a needle driver) passing through the trocar. The jaws of the needle driver hold a suture, with the jaws held firmly in place via locking cogs in the housing that attaches to the KUKA flange. An organ is replicated by a foam pad on which a suturing task is to be performed using the master-slave system. The forces that the shaft exerts on the trocar during the performed task are measured by two SingleTact forces that are mounted inside the trocar, with these forces reflected to the master device.

Stage 3

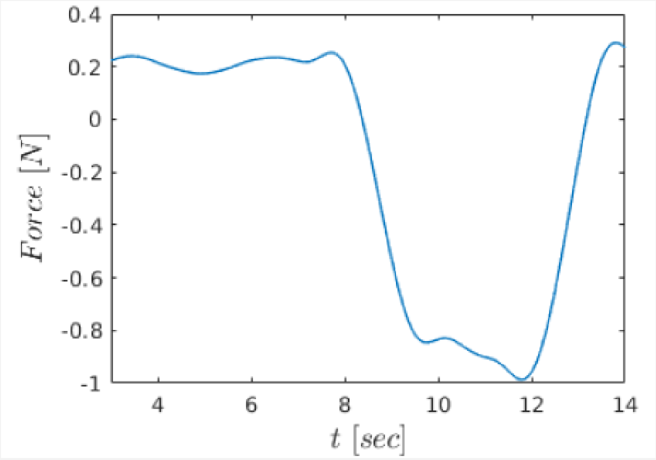
The experiments in stage 3 will be conducted using a three fingered surgical instrument prototype. The experimental setup will be similar to stage 2; however, instead of the foam pad a phantom kidney will be utilised. Further, the forces exerted by the shaft whilst suturing will be estimated by a load cell mounted on the KUKA flange. The shaft forces will then be estimated from the measured flange forces and reflected to the user via the master device.

Custom housing that interfaces with da Vinci endoWrist tools and mounts onto the KUKA flange

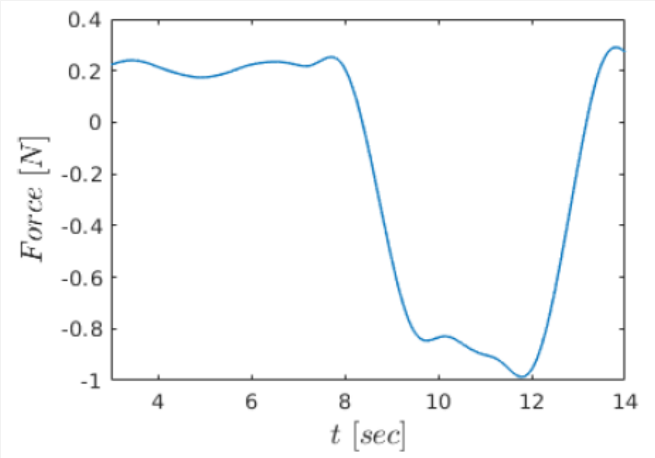
SMARTsurg Surgical haptic feedback system

Preliminary results for Stage 1

In this stage the operator is teleoperating the slave arm by holding and moving the end-effector of the master device. The motion of the end-effector of the master arm in the Cartesian space is directly mapped to the motion of the end-point of the instrument that is attached on the slave arm. The operator moves the master device so that the slave arm moves the instrument shaft in the y direction towards the soft wall. When the instrument comes into contact with the wall (t = 9 – 12s), the force measured by the SingleTact sensor is fed back to the master device. The sudden force feedback causes the operator to slightly recede to the opposite direction (detail at t = 9s) whereas the slave arm, having detected a collision stops its motion temporarily. After that, the operator teleoperates the instrument shaft away from the soft wall. The delay between the master and slave arm is caused by the current teleoperation scheme and will be minimised in later versions. The figure show the force that is measured on the shaft in the y direction which is proportionally applied to the master device.



y-component of the relative master/slave position



SingleTact sensor and applied to the master device

Force sensing for haptics in RAMIS

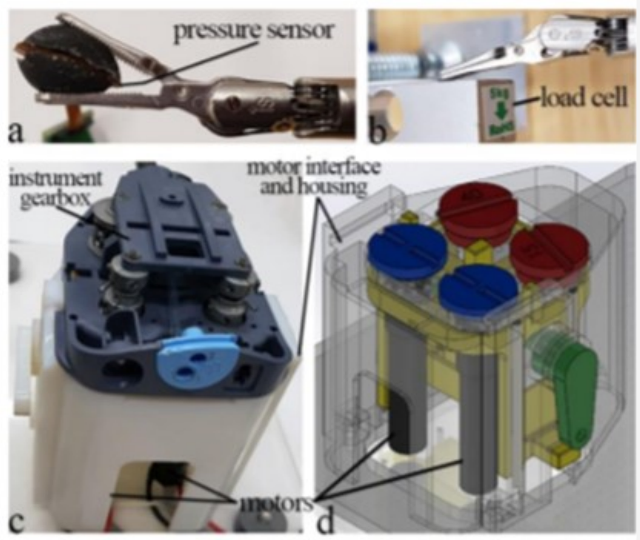
Force and tactile sensing at the surgical site is a pre-requisite for haptic feedback. Many attempts have been made in the last 25 years to develop sensorised surgical instruments as a means to detect interaction forces between the instrument and tissue. However, the size of force sensors and incision ports, the sterilisation of tools at high temperatures as well as the disposable nature of surgical tools have so far prevented integration of tissue force/tactile sensing in laparoscopy and RAMIS (Robot-Assisted Minimally Invasive Surgery).

Sensor-less force sensing

SMARTsurg is using an alternative method to force estimation in a RAMIS context, by acquiring the real-time measurement of the instrument motor current. Off-the-shelf force sensors are characterised and then used to determine the correlation between the motor current and the applied force in palpation and grasping, initially with da Vinci forceps but with the view to use this method for our three-fingered instrument that is under development.

Experimental Setup

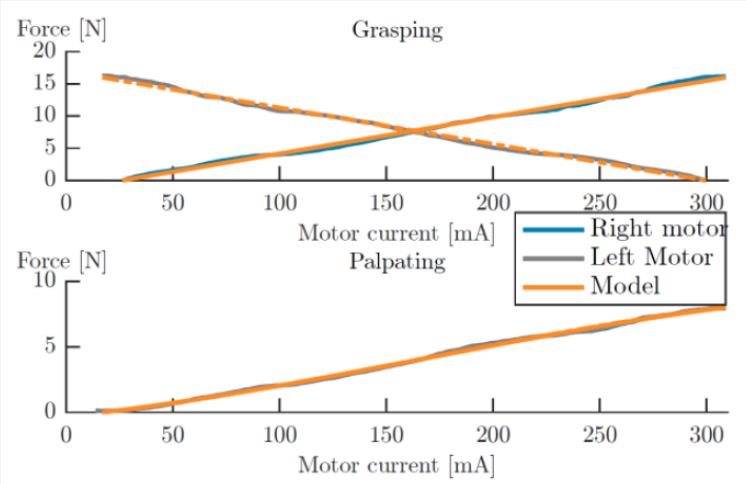
Initial experiments in palpation and grasping were conducted using da Vinci forceps. The sensors were used to measure the grasping and palpation forces exerted by the gripper of the forceps as shown in the following image on a and b parts. For grasping, two 3D printed (TangoPlus, Stratasys) hemispherical domes were attached to either side of the SingleTact sensor for even distribution of the applied load. The instrument has 4-DOF; pitch, roll, yaw and grasp of the jaws which are controlled by four DC motors in a coupled manner. Only the grasp and yaw of the forceps jaws were actuated for the initial experiments via two Maxon DC motors (3.89mNm, 62:1 reduction). A custom housing was made to attach the gearbox of the instruments to the shafts of the motors, as shown in parts c and d. The shafts of the motors were connected to the gearbox of the instrument via the blue cogs highlighted in part d, with the pitch and roll kept constant by the red cogs. Palpation was conducted by moving the two motors in the same direction and supplying them with equal magnitude current; whilst grasping was conducted by moving the two motors in opposing directions but supplying them with equal magnitude current.



Force sensing for haptics in RAMIS

Preliminary results

The correlation between measured forces in grasping and palpation scenarios, and the current of the motors was found by driving the motors using current control. Sensor readings were taken for every 0.1mA increase of the current between 10-309mA (maximum continuous current of the motors). The experiments were each repeated ten times for both scenarios. The results were then filtered using smoothing splines and averaged with a standard deviation of 0.63 (grasping) and 0.12 (palpation). As illustrated in Figure, there is a linear relationship between current and force for grasping, while the correlation of palpation force to motor current can be modelled with a cubic polynomial.



SMARTsurg Active Constraint Enforcement and the Fingertip Haptic Device

The video demonstrates the remote center of motion in teleoperated Minimally Invasive Surgery (MIS) and the development of Fingertip Haptic Device.

Click here to watch it and don't forget to subscribe to our YouTube channel!

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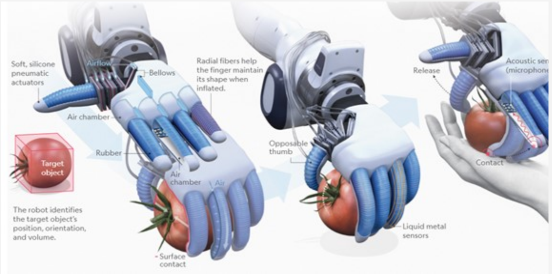
Into the World of Robotics

The robot revolution has arrived

David Berrery

nationalgeographic.com



Designers of the revolutionary RBO Hand 3, a soft robotic hand made of flexible materials, are working to give it something akin to a human's sense of touch. Features include sensors that measure strain via electrical resistance and embedded acoustics to track where fingers are in contact with objects (or humans) and the amount of force.

Read the full article here.

Cobots Are Collaborators. AI Will Make Them Partners

Barry Manz

wevolver.com

Cobots have come a long way in the few years since they were identified as a truly useful addition to manufacturing. At first, they could perform only a single repetitive task, but today they can perform multiple sets of complex tasks dedicated to specific workstations on a production line. They've even been touted as having the ability to "learn"— that is, in the basic sense of the dictionary's definition of acquiring knowledge (i.e., learning) by being taught or through experience. Cobots have currently mastered the first method of learning, through being taught, but not the second experiential-based method, as it requires artificial intelligence (AI) capabilities that cobots currently do not possess but soon will.

Read the full article here.

AI-Controlled Sensors Could Save Lives In 'Smart' Hospitals And Homes

Tom Abate

wevolver.com

Researchers explain how computer scientists and clinicians are trying to reduce fatal medical errors by building "ambient intelligence" into the spaces where patients reside. As many as 400,000 Americans die each year because of medical errors, but many of these deaths could be prevented by using electronic sensors and artificial intelligence to help medical professionals monitor and treat vulnerable patients in ways that improve outcomes while respecting privacy.

Read the full article here.

SMARTsurg Journal Publications

Estimation of Tool-Tissue Forces in Robot-Assisted Minimally Invasive Surgery Using Neural Networks

Abeywardena S., Yuan Q., Tzemanaki A., Psomopoulou E., Droukas L., Melhuish C., Dogramadzi S.

Frontiers in Robotics and AI, 5:56, July 2019

A new algorithm is proposed to estimate the tool-tissue force interaction in robot-assisted minimally invasive surgery which does not require the use of external force sensing. The proposed method utilizes the current of the motors of the surgical instrument and neural network methods to estimate the force interaction. Offline and online testing is conducted to assess the feasibility of the developed algorithm. Results showed that the developed method has promise in allowing online estimation of tool-tissue force and could thus enable haptic feedback in robotic surgery to be provided.

To read the full journal please click here.

Development of an intelligent surgical training system for Thoracentesis

Nakawala H, Ferrigno G, De Momi E

Artificial Intelligence in Medicine, 1-14, January 2018

Surgicaltraining improves patient care, helps to reduce surgical risks, increases surgeon's confidence, and thus enhances overall patient safety. Current surgical training systems are more focused on developing technical skills, e.g. dexterity, of the surgeons while lacking the aspects of context-awareness and intraoperative real-time guidance. Context-aware intelligent training systems interpret the current surgical situation and help surgeons to train on surgical tasks. As a prototypical scenario, we chose Thoracentesis procedure in this work. We designed the context-aware software framework using the surgical process model encompassing ontology and production rules, based on the procedure descriptions obtained through textbooks and interviews, and ontology-based and marker-based object recognition, where the system tracked and recognised surgical instruments and materials in surgeon's hands and recognised surgical instruments on the surgical stand. The ontology was validated using annotated surgical videos, where the system identified "Anaesthesia" and "Aspiration" phase with 100% relative frequency and "Penetration" phase with 65% relative frequency. The system tracked surgical swab and 50 mL syringe with approximately 88.23% and 100% accuracy in surgeon's hands and recognised surgical instruments with approximately 90% accuracy on the surgical stand. Surgical workflow training with the proposed system showed equivalent results as the traditional mentor-based training regime, thus this work is a step forward a new tool for context awareness and decision-making during surgical training.

To read the full journal please click here .

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