Towards standardized surgical robotics interoperability for intraoperative assistance systems

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The introduction of a standardized service-oriented communication architecture for the operating room (OR) in the project OR.Net opened up new possibilities for interoperability of medical devices. Using the open IEEE Standards 11073 a medical device and its functionality can be represented in a tree-like structure with corresponding channels and metrics (parameters). Metric information of medical device functions, e.g. O2-saturation or heart rate measurement is provided in a publish/subscribe-approach using the open surgical communication protocol (OSCP). We defined a 11073-conform medical device description of our surgical robotics system SCORPIO. We used a KUKA LWR iiwa 820R with the robot operating system (ROS) framework and integrated it with a service interface that implements 11073-conform control functions based on the OSCLib. In this way, the motion and safety control mechanisms are separated from the asynchronous service functions. The service interface is used to automatically register the SCORPIO system to a session in the OR. Furthermore, it provides access to the device metrics. Initially, implemented metrics are used to e.g. set coordinate system boundaries, patient registration data or instrument positions for the ROS to automatically provide necessary navigation information. For the first use case of needle placement an intraoperative entry planning system sends registration information to the SCORPIO system and sets the planning instructions to be performed. Path planning and motion control is then handed to the ROS application. Safety mechanism are threefold: (a) A footswitch is directly connected to the robot controller unit to release and stop motion in case of problems. (b) The sent registration data is used to define safezone bounding boxes to be excluded by the path planning. (c) Force feedback can be used to stop robot motion by hand. Subsequent safety and assistance features are intended for other use cases in future work.
Integration of a light weight robot control with an advanced medical image processing platform for optimizing accuracy in medical interventions

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Due to organ movement and tissue pressure needle based interventional accuracy is an important and challenging issue in minimal invasive medical interventions. Using iterative robot control for path correction during the needle insertion is assumed to be a progress for performing more accurate interventions.

We implemented a generic module interface within the medical image processing platform MeVisLab for seamlessly plug-in and plug-out robotic devices into MeVisLab via OpenIGTLink and for controlling the device iteratively for a near-real-time path planning and path correction. This module allows for sending and receiving different kinds of data sets (e.g. transformation matrix, position and rotation, image, status, string). We used this generic module to connect a Kuka Light Weight Robot (LWR iiwa) with MeVisLab to allow for using advanced segmentation and registration features for iterative robot control. The respective status of the Kuka LWR iiwa (position, configuration) is simulated and visualized as 3-D model in MeVisLab. Medical data sets including target pose (position and path towards it) can be send and received via the OpenIGTLink network protocol as well.

This integration of an advanced image processing platform with a robotic device will allow fast prototypical implementation of iterative path controlling scenarios, like segmentation of the target in intraoperative images for iterative refinement of target position in a control loop. With the presented work, segmentation (e.g. of target lesions) and registration (e.g. for aligning pre- and intra-interventional images) algorithms of MeVisLab can be used and directly applied to path re-planning of the Kuka LWR.
Development of a high precision MEMS tilt sensor for navigation systems in robot-assisted surgery

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Complicated minimally invasive interventions, e.g. in the fields of brain and abdominal surgery as well as locally limited high-dose irradiation and the biopsy or resection of tumors, are increasingly supported by surgical robots. In 2013, about 85% of radical laparoscopic prostatectomies have been carried out robot-assisted in the USA. Thereby major advantages are scaling down of surgeon’s hand movement to high-accuracy motions of the surgical instruments, precise locking mechanisms and tremor cancellation. Consequently, healthy tissue, blood vessels or nerves can be prevented from unintentional injury. Due to miniaturization of microelectromechanical systems (MEMS) the placing of orientation detection sensors close to surgical instruments is possible. The integration of the developed high-precision capacitive MEMS tilt sensor for example into an endoscope or near its mounting can facilitate vibration measurements and their compensation to improve accurate instrument positioning. A special fabrication technology for silicon high aspect ratio microstructures was used to increase the aspect ratio of the vertical comb electrodes which magnifies the capacitance gradient. Additionally, the sensitivity of the capacitive sensor is strongly improved by an electrode movement. In this work, further reduction of the fabrication restricted trench size of 4.5 µm to sub-micron trenches below the technological limitations is achieved using the innovative approach of laser-micro-welding. High aspect ratios of initially 15 up to 100 for trench sizes down to 800 nm were fabricated. In addition the electrode gap is reduced using the inherent electrostatic force of the comb sense electrodes and fixed by briefly high current through overhanging touching metal layers. Long time reliability was ensured by laser-micro-welding on the metal layers. Electrical and mechanical tests of the sensor show an increased sensitivity from 7.2 fF/° up to 60 fF/° due to gap reduction. By means of electrical and vibration measurements at 1 g the working range was determined with several Hz up to 2 kHz.
Prototype of an automated photobiomodulation treatment device for in vitro wound healing studies

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Photobiomodulation (PBM) is a light-based therapy that influences chronic wound healing processes. Results from PBM studies often lack repeatability because of inaccurate reporting or incorrect controlling of light irradiation parameters and measurement techniques. The importance of this is emphasized by recent guideline publications outlining the necessary parameters to be reported to assure repeatability. The purpose of this work is to describe the design, construction and validation of a device for performing repeatable LED-PBM treatment in vitro with adjustable parameters. This work aims to provide a baseline design for devices used in LED-PBM experiments, in order to allow researchers quick access to equipment that can deliver reliable and repeatable PBM treatments. The device consists of LED driver electronics with a USB interface and a separate LED module installed on cell culture trays capable of functioning inside an incubator without disrupting its normal operation. The LED placement and selection depends on the application, a sample setup is described here that can guide new designs. Light intensity is modulated with a PWM signal in order to ensure a constant spectrum emission by keeping a constant LED operating point during its ON time. Light wavelength can be modified by altering the relative light intensity settings for different groups of LEDs with different emission characteristics. Spectral irradiance on the targets and spatial irradiance uniformity are measured for validation. The device can be programmed for multiple-week-long experiments with complex treatment schedules through GUI or configuration file which allows for automated operation. The device will be employed in a 21-day long treatment pilot study with an in vitro 3D organotypic tissue wound model. This prototype represents our initial step towards developing a multi-modal advanced wound healing device combining light, mechanical and electrical biostimulation for treating chronic wounds.
Full HD endovideo with 4K panorama overview in laparoscopic optical phantom

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Introduction: Recent 4K monitors can display four times as many pixels than the established full HD laparoscopic endo cameras provide. Consequently, the additional monitor space can be used to present a laparoscopic panorama, computed from the laparoscopic video data, in which the original live video is centrally embedded.

Materials: The digital output of a standard HD endo video system (Storz laparoscope, 10mm 0°, Image 1 HD H3-Z camera head, optical zoom 2x) was connected via an HDMI to USB3 converter to a PC with high end graphics card (Nvidia Gforce GTX980). Custom software computes a depth map from the motion parallax of the telescope. The resulting point cloud is coloured, matched, rotated and scaled, such that the central live image can be embedded seamlessly. The combination of panoramic point cloud and central live image is then displayed on a 55” 4K TV (Samsung UE55HU8290L). Moreover, inertial sensor technology was employed to compensate for inadvertent camera tilt.

Results: The system was successfully tested in an inanimate optical phantom box, using telescope panning or withdrawal to create an overview from which a suitable panorama could be computed. Due to the computational effort, the panorama update is slightly delayed with respect to the endo video. However, this does not present a significant usability issue, since the panoramic point cloud can be clearly distinguished from the live image and rapid camera movement is usually avoided during surgery.

Discussion: Next development steps are the adaption to a 30° telescope, compensation of organ movement / deformation, and removal of instruments from the panorama.

Conclusion: A laparoscopic panorama is feasible and can significantly improve orientation.