Towards open-source, low-cost haptics for surgery simulation

Stefan SUWELACK [a,1], Christian SANDER [b], Julian SCHILL [a], Manuel SERF [b], Marcel DANZ [a], Tamim ASFOUR [a], Wolfgang BURGER [a], Rüdiger DILLMANN [a] and Stefanie SPEIDEL [a]

[a] *Institute for Anthropomatics, Karlsruhe Institute of Technology, Germany*

[b] *Institute of Product Engineering, Karlsruhe Institute of Technology, Germany*

Abstract. In minimally invasive surgery (MIS), virtual reality (VR) training systems have become a promising education tool. However, the adoption of these systems in research and clinical settings is still limited by the high costs of dedicated haptics hardware for MIS. In this paper, we present ongoing research towards an open-source, low-cost haptic interface for MIS simulation. We demonstrate the basic mechanical design of the device, the sensor setup as well as its software integration.

Keywords. haptic interfaces, minimally invasive surgery, low-cost devices

1. Introduction

Haptic interfaces have become an important part of VR simulators for minimally invasive surgery (MIS) training [3]. The widespread use of these systems is still limited by the high costs of special purpose haptic interfaces. The high number of produced units in gaming hardware offers a promising low-cost alternative for specialized high quality, high cost haptic interfaces. Previous research has already shown that the Novint Falcon is a suitable platform for robotic application [6] and can be used to build inexpensive higher DOF interfaces [7]. Open-source technology is ubiquitous in the software stack for haptic technology (e.g. [4]). In contrast, there are currently no efforts to use open design principles for MIS haptic hardware. In this paper, we present ongoing research towards an open-source, low-cost haptic interface for MIS simulation. We illustrate a mechanical design based on rapid prototyping techniques and standard aluminum profiles that allows assembling the device without special purpose tools. Furthermore, we demonstrate the sensor setup as well as its integration into the SOFA-framework [5].

2. Tools and Methods

The design of the haptic interface is heavily based on the Novint Falcon gaming hardware, rapid prototyping technology and open-source software.

[1] Corresponding Author: Stefan Suwelack, Humanoids and Intelligence Systems Lab, Adenauerring 2, 76133 Karlsruhe, Germany, E-mail: suwelack@kit.edu

2.1. Hardware design

Building on experiences in the design of robotics systems such as humanoid robots [1] and robotic manipulanda [2], the design of the haptic device was driven by workspace and feedback force requirements. Due to the relatively high force output of the Falcon, no additional actuators were necessary. The positions of the Falcons with respect to trocar positions were determined using a simulation of the instrumentsâĂŹ workspaces. It is important to point out that both trocar positions can be easily varied in order to simulate different interventions (Fig. 1).

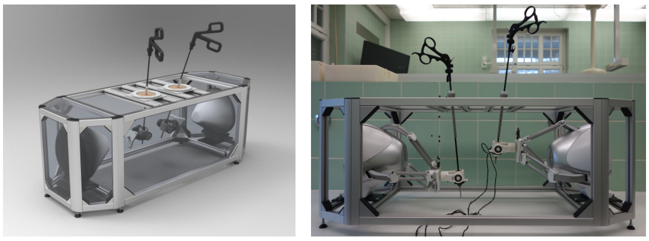

Figure 1. CAD design (left) and prototype (right) of the haptic device

The instruments are attached to the haptic device using a specifically designed grip (Fig. 2) that is manufactured using rapid prototyping techniques. The grip was engineered to be cheap, easily replacable and robust enough to withstand the forces that act at the instrument's tip. In order to derive the exact pose of the instruments, each joint is equipped with a position sensor. These are rotary magnetic position sensors from ams (AS5145 and AS5304), which use a hall sensor array to measure the orientation of a rotating magnet. In addition to the 3 translational DOF from the Falcon Device, the sensors add information about three rotational DOF of the instrument.

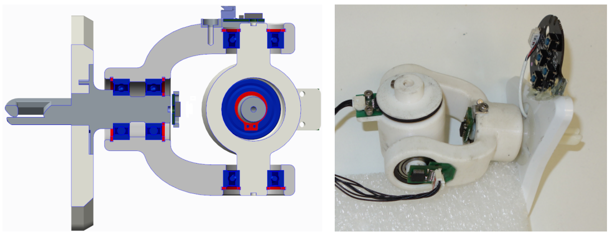

Figure 2. CAD design (left) and prototype (right) of the 3+1 DOF grip

2.2. Software integration

The CHAI3D integration of the Novint Falcon [4] was extended to accommodate additional requirements for handling two devices in the proposed MIS setting. All higher-level functionalities such as sensor data fusion and pose estimation were implemented using the SOFA toolkit [5]. Furthermore the SOFA integration supports the use of the device in scenarios that include deformable model simulation. As the workspace of the Novint Falcon is too small for certain interventions, software-based scaling of the instruments' movements is used to allow adaption to a broad range of applications.

3. Results

Preliminary results suggest that the proposed haptic device is suitable for MIS simulation. The complete system (Fig. 2) weighs 11.2 kg and provides a stable, but still portable platform for clinical applications. The magnetic position sensors provide an accurate measurement of the joint rotations and show no disturbances due to interference. The total cost of 1800€ is very low compared to standard equipment. With the exception of the sensor circuit board, the device can be assembled without specific tools. Only 4 DOFs are necessary in order to compute the pose of an MIS instrument. The additional 2 DOFs of the rotary sensors are used to increase the accuracy through sensor fusion. As the geometry of the device (e.g. trocar positions) can be adapted to different interventions, the additional DOF can also be used to calibrate the geometry of the device.

4. Conclusions

We have presented current work towards the first open-source low-cost haptic interface for MIS simulation. The preliminary results demonstrate the feasibility of the proposed design for research and surgical training purposes. Future work will include an extensive validation and evaluation of the device. For this purpose, studies with surgeons will be conducted in order to find out if the device can achieve similar training results as expensive, high-accuracy equipment. In particular, we will investigate if software scaling is sufficient in order to overcome the limited workspace of the Falcon or if the scaling has to be incorporated in the hardware setup. Furthermore, we will publish the design including all CAD data and circuit board designs under an open-source license at www.open-cas.org.

References

[1] Tamim Asfour, Julian Schill, Heiner Peters, Cornelius Klas, Jens Bücker, Christian Sander, Stefan Schulz, Artem Kargov, Tino Werner, and Volker Bartenbach. ARMAR-4: A 63 DOF Torque Controlled Humanoid Robot. In *IEEE/RAS International Conference on Humanoid Robots (Humanoids)*, pages –, Atlanta, USA, October 2013.

[2] V. Bartenbach, C. Sander, M. PÃűschl, K. Wilging, T. Nelius, F. Doll, W. Burger, C. Stockinger, A. Focke, and T. Stein. The biomotionbot: A robotic device for applications in human motor learning and rehabilitation. *Journal of Neuroscience Methods*, 213(2):282 – 297, 2013.

[3] Timothy R Coles, Dwight Meglan, and Nigel W John. The role of haptics in medical training simulators: a survey of the state of the art. *Haptics, IEEE Transactions on*, 4(1):51–66, 2011.

[4] François Conti, Federico Barbagli, Dan Morris, and Christopher Sewell. Chai: An open-source library for the rapid development of haptic scenes. 2005.

[5] F. Faure, C. Duriez, H. Delingette, J. Allard, B. Gilles, S. Marchesseau, H. Talbot, H. Courtecuisse, G. Bousquet, I. Peterlik, et al. Sofa: A multi-model framework for interactive physical simulation. *Soft Tissue Biomechanical Modeling for Computer Assisted Surgery*, pages 283–321, 2012.

[6] Steven Martin and Nick Hillier. Characterisation of the novint falcon haptic device for application as a robot manipulator. In *Australasian Conference on Robotics and Automation (ACRA)*, pages 291–292, 2009.

[7] Aman V Shah, Scott Teuscher, Eric W McClain, and Jake J Abbott. How to build an inexpensive 5-dof haptic device using two novint falcons. In *Haptics: Generating and Perceiving Tangible Sensations*, pages 136–143. Springer, 2010.