Eidgenössische Technische Hochschule Zürich
Swiss Federal Institute of Technology Zurich

ICRA 2014 Full-Day Workshop:

Soft and stiffness-controllable robots for MIS

by Kaspar Althoefer
Fumiya Iida
Thrishantha Nanayakkara
Hongbin Liu
Emanuele L Secco
Helge A Wurdemann

ICRA 2014

IEEE Robotics & Automation Society

IEEE

1 June 2014, Hong Kong

Welcoming Message

Dear Colleagues and Friends,

It is our great pleasure to welcome you to Hong Kong for the **Workshop on Soft and Stiffness-Controllable Robots for Minimally Invasive Surgery** at the **2014 IEEE International Conference on Robotics and Automation** (ICRA 2014).

This workshop aims to bring together medical experts active in the field of minimally invasive surgery and roboticists creating and studying soft and stiffness controllable robot devices. We will explore the synergies that will arise from robotic surgeons cooperating with such modern robots to conduct advanced surgical interventions previously not possible.

This ICRA 2014 workshop will provide a review of current technology used in robot-assisted minimally invasive surgery and explore the current paradigm shift from traditionally rigid surgical tools to robotic systems that are highly redundant, soft and possibly capable of changing their structural stiffness to adapt to surgical needs.

The workshop will explore the advantages of these new robotic concepts and the challenges that lie ahead to create functional robot systems that can be employed in the operating theatre of the future.

Round table discussions will focus on obstacles and challenges and the future direction of robotic surgery. The workshop will also act as a platform for wider discussions and encourage multidisciplinary collaboration between engineers and surgeons.

Welcome to Hong Kong and I hope you enjoy the workshop.

With kind regards,

Professor Kaspar Althoefer
King's College London

Dr Hongbin Liu
King's College London

Professor Fumiya Iida
ETH Zurich

Dr Emanuele L Secco
King's College London

Dr Thrishantha Nanayakkara
King's College London

Dr Helge A Wurdemann
King's College London

09:00AM - 09:25AM **Enabling technologies for soft actuation and stiffness control in endoscopy and minimally invasive surgery**

Arianna Menciassi

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The BioRobotics Institute
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Abstract: Most devices for endoscopic and minimally invasive surgery are very application specific and are normally rigid, lack a sufficient number of degrees of freedom (DOFs) and/or are incapable of modifying their mechanical properties based on the tasks to be performed. The current philosophy in commercial instrument design is mainly focused on creating minimally invasive surgical systems using rigid tools equipped with dexterous tips. Only few research efforts are aimed at developing flexible surgical systems, with many DOFs or even continuum kinematics.
Inspired by biological animals, such as earthworms or octopuses, we envision creating soft and stiffness-controllable medical devices with a totally different perspective than usual.
Several soft technologies are suitable for meeting the aforementioned capabilities, and in this talk a brief review of the most promising ones is presented. How specific technologies can be applied in the design of novel manipulators for flexible surgery or flexible endoscopes will be illustrated, by discussing their potential and by presenting feasibility tests of prototypes responding to this new design philosophy.

Publications: L. Phee, D. Accoto, A. Menciassi, C. Stefanini, M. C. Carrozza, P. Dario, "Analysis and Development of Locomotion Devices for the Gastrointestinal Tract" **IEEE Transactions on Biomedical Engineering**, Volume: 49 Issue: 6 , Jun. 2002, pp. 613 -616.

M. Cianchetti, T. Ranzani, G. Gerboni, I. De Falco, C. Laschi, A. Menciassi, "STIFF-FLOP surgical manipulator: Mechanical design and experimental characterization of the single module", *IEEE International Conference on Intelligent Robots and Systems*, 2013, pp. 3576 – 3581.

M. Cianchetti, T. Ranzani, G. Gerboni, T. Nanayakkara, K. Althoefer, P. Dasgupta, A. Menciassi, "Soft and stiffness-controllable robots for minimally invasive surgery", accepted for **Soft Robotics 2014** (to appear).

NOTES:

09:25AM - 09:50AM **Title**

Fumiya Iida

Contact Details: Professor for Bio-inspired Robotics
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Abstract:

Publications:

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09:50AM - 10:10AM **Sensor Embedded Soft Pneumatic Actuator for an Endonasal Instrument**

Merve Acer, Chansu Suh, Amir Firouzeh, Philippe Pasche, Christos Ikonomidis, Charles Baur and Jamie Paik

Contact Details: M. Acer
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C. Suh, A. Firouzeh, J. Paik
Reconfigurable Robotics Laboratory (RRL)
École Polytechnique Fédérale de Lausanne (EPFL)
Lausanne, Switzerland

P. Pasche, C. Ikonomidis
Otolaryngology, Head and Neck Surgery department of the Centre Hospitalier
Universitaire Vaudois (CHUV)
Lausanne, Switzerland

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Abstract: The skull based endonasal surgical procedures are often performed by introducing MIS (minimally invasive surgery) tools through nasal cavities to avoid open skull surgery. However, to reach legions through densely packed neurons, narrow and curvy cavities, the procedure requires specific MIS tools with unique set of geometrical, mechanical and functional requirements. Here, we present anon going project on the development of a novel endonasal surgical instrument. This project encompasses the full spectrum of engineering design processes starting from the definition of the required design parameters directly from the surgeons. We suggest actuator and sensor options for the proposed instrument that will be flexible with controllable impedance: the soft pneumatic actuator (SPA) embedded with customizable low profile sensors are presented here. As these are novel components for any medical instruments, we illustrate the design tool for the components as well as the final instrument control consoles. The proposed actuator and sensor units are unique for the instrument but are highly customizable for diverse soft robotic applications.

Publications: Yi Sun; Yun Seong Song; Paik, J., "Characterization of silicone rubber based soft pneumatic actuators," *Intelligent Robots and Systems (IROS), 2013 IEEE/RSJ International Conference on*, pp.4446,4453, 3-7 Nov. 2013.

A. Firouzeh, Y. Sun, H. C. Lee, and J. Paik, „Sensor and actuator integrated low profile robotic Origami," presented at the *IEEE/RSJ International Conference on Intelligent Robots and Systems*, 2013.

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10:10AM - 10:30AM **End user interfaces and actuation systems for (micro)surgical robotics: technologies and future directions**

Matteo Bianchi, Leonardo S. Mattos, Giorgio Grioli, Manolo Garabini, Manuel G. Catalano and Antonio Bicchi

Contact Details: Matteo Bianchi, Leonardo S. Mattos, Giorgio Grioli, Manuel G. Catalano
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Abstract: This work aims at reviewing some of the current technological solutions for end-user interfaces in Robotic Surgery (RS). More specifically we consider vision-based computer assisted user interfaces and haptic feedback systems. As a second step we analyze some of the recent implementation of Variable Impedance Actuators (VIA), that might be used as a driven technology for the development of soft/stiffnesscontrollable robot systems and actuation mechanisms in RS. Applications and future directions are also discussed.

Publications: A. Ajoudani, N. Tsagarakis, and A. Bicchi, "Tele-impedance: Teleoperation with impedance regulation using a body–machine interface," **The International Journal of Robotics Research**, vol. 31, no. 13, pp. 1642–1656, 2012.

M. G. Catalano, G. Grioli, M. Garabini, F. Bonomo, M. Mancini, N. G. Tsagarakis, and A. Bicchi, "Vsa-cubebot: A modular variable stiffness platform for multiple degrees of freedom robots." in *ICRA. IEEE, 2011*, pp. 5090–5095.

10:30AM - 11:00AM **MORNING COFFEE BREAK**

NOTES:

11:00AM - 11:25AM **Title**

Darwin Caldwell

Contact Details: Professor of Advanced Robotics
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Abstract:

Publications:

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11:25AM - 11:50AM **Title**

Thrishantha Nanayakkara

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Abstract:

Publications:

NOTES:

11:50AM - 11:55AM **An intelligent data fusion system concept for the STIFF-FLOP project**
J. Czarnowski, J. Fraś, J. Główka, M. Maciaś, A. Wołoszczuk, P. Sałek

Przemysłowy Instytut Automatyki i Pomiarów PIAP
Warsaw, Poland

11:55AM - 12:00PM **Variable damping control for robotic neurosurgery**
E. Beretta, E. De Momi, F. Rodriguez y Baena and G. Ferrigno

E. Beretta, E. De Momi, G. Ferrigno
Electronics, Information and Bioengineering Department
Politecnico di Milano
Milano, Italy

F. Rodriguez y Baena
Mechanical Department
Imperial College
London, United Kingdom

12:00PM - 12:05PM **Prototype Design of Flexi-Hand for Single Incision Laparoscopis Surgery**
Guokai Zhang, Shuxin Wang, Jianmin Li, Yuyang Sun, and Yuan Xing

Department of Mechanical Engineering
Tianjin University
Tianjin, China

12:05PM - 12:10PM **Customizable Flexible Manipulator for Minimally Invasive Surgery Manufactured by Selective Laser Sintering**
Gerald Horst, Sebastian Koller, Hubertus Feußner and Heinz Ulbrich

Gerald Horst, Heinz Ulbrich
Faculty of Mechanical Engineering
Institute of Applied Mechanics (AM)
Technical University Munich
Munich, Germany

Sebastian Koller, Hubertus Feußner
Research Group MITI
Klinikum rechts der Isar
Technical University Munich
Munich, Germany

12:10PM - 01:30PM **LUNCH BREAK**
Note that lunch is not included in the registration. The participants should make their own lunch arrangements.

01:30PM - 01:55PM **From STIFF to FLOPpy – A new approach for robot-assisted surgery: Advancements and Challenges**

Kaspar Althoefer

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Abstract: The last decade has seen tremendous technological advancements in the field of Robot-assisted Minimally Invasive Surgery (RMIS). Robotic surgical systems, such as the da Vinci system by Intuitive Surgical have penetrated the operating theatre and have shown to represent a suitable alternative to laparoscopic surgery, at least for a number of procedures such as prostatectomy. Its main advantage over existing techniques is that it allows surgeons to conduct complex procedures in an intuitive way while providing 3D views of the operating area. Limitations, though, stem from the fact that such manipulation devices are built from straight, rigid links and lack tactile sensing modalities as well as haptic feedback. More recent research efforts have focussed on creating surgical robots whose structure is flexible allowing the robot to follow more complex trajectories without negatively impacting on healthy tissue, including systems such as the i-snake (Imperial College) and HARP (Carnegie Mellon University) and concentric tube robots (Webster/Dupont). Departing from these types of robots, which are fundamentally based on a structure made from rigid link elements, EU project STIFF-FLOP proposes a new concept of modern, inherently safe robots for minimally invasive surgery, capable of morphing from a stiff to a soft state. Inspired by the octopus, the vision of the project is to develop a fully-integrated surgical robot system, combining soft and stiffness-controllable mechanisms, pneumatic and hydraulic actuation, tactile and force sensors, haptics as well as advanced control and learnable navigation techniques. The presentation will give an overview of the STIFF-FLOP project, the advancements to date and the challenges that lie ahead.

Publications:

NOTES:

01:55PM - 02:20PM **Skins in Nature and Soft Biorobotics**

Constantina Lekakou

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Abstract: While skin has an important role in controlling permeation of substances, maintaining temperature and sensing, the focus of this talk is the mechanical role of skin in guiding deformation, achieving and maintaining a certain body shape in a soft biorobot. In particular, pneumatically actuated soft robot arms are considered in which the skin contributes to the development of the shape under actuation. Biological inspiration is presented with regards to the skin microstructure of different natural soft hydrostats under actuation and artificial composite material analogues have been fabricated and tested under pneumatic actuation with the results of such tests presented in the talk. The use of such analogues in the design and fabrication of a soft robotic arm for minimally invasive surgery is discussed.

Publications: A.A. Salifu, B.D. Nury and C. Lekakou ”Electrospinning of nanocomposite fibrillar tubular and flat scaffolds with controlled fiber orientation” **Annals of Biomedical Engineering**, 39(10), 2011, 2510-2520.

K. Kanas, C. Lekakou and N. Vrellos “FEA and experimental studies of adaptive composite materials with SMA wires”, **Current Themes In Engineering Science 2007**, Volume: 1045, 2008, pp.101-110,

U. Mohammed, C. Lekakou, L. Dong and M.G. Bader “Shear deformation and micromechanics of woven fabrics”, **Composites A**, 31(4), 2000, pp.299-308

NOTES:

02:20PM - 02:40PM **Control of Elastic Soft Robots using Real-Time Inverse Simulation on SOFA framework**

Christian Duriez

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Abstract: In this work, we propose a new method for the control of soft robots with elastic behavior, piloted by several actuators. The approach is based on the real-time computation of the Finite Element Method (FEM) using the framework SOFA. Using an optimization algorithm, based on a reduced compliance matrix, the model is inverted in real-time. It is used in a control loop, to find the contribution of the actuators (force and/or position) that deforms the structure so that the terminal end of the robot follows a given position. The optimization integrates the internal characteristics of the actuators and the constitutive law of the deformable structure. It is also coupled with the collision response pipeline of SOFA so additional constraints, like rigid or deformable obstacles are integrated in the control algorithm. We illustrate our method using simulated examples of both serial and parallel structures and we validate it on a real 3D soft robot made of silicone.

Publications: F. Faure, C. Duriez, H. Delingette, J. Allard, B. Gilles, S. Marchesseau, H. Talbot, H. Courtecuisse, G. Bousquet, I. Peterlik, and S. Cotin, "Sofa: A multi-model framework for interactive physical simulation," in **Soft Tissue Biomechanical Modeling for Computer Assisted Surgery**, ser. Studies in Mechanobiology, Tissue Engineering and Biomaterials, Y. Payan, Ed. Springer Berlin Heidelberg, 2012, vol. 11, pp. 283–321.

C. Duriez, "Control of elastic soft robots based on real-time finite element method," in **Proceedings of ICRA** (& Patent application FR 13 51106), 2013.

H. Courtecuisse, J. Allard, C. Duriez, and S. Cotin, "Preconditioner-based contact response and application to cataract surgery," in **Medical Image Computing and Computer-Assisted Intervention (MICCAI)**, Sept 2011. [Online]. Available: http://www.lifl.fr/13courtecu/

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02:40PM - 03:00PM **Palpation with Controllable Stiffness for Robot-assisted Minimally Invasive Surgery**

Nantachai Sornkarn, Jelizaveta Konstantinova, Prokar Dasgupta, Kaspar Althoefer, Thrishantha Nanayakkara

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Abstract: This paper presents a novel design approach to soft probes with controllable stiffness in order to maximize information gain during examining soft tissue to find hard nodules. Unlike stiff probes, soft probes with controllable stiffness provide the unique opportunity to use its own embodiment to dynamically emerge useful internal state transitions that can be more pronounced than stress signals felt by stiff probes for a given hard nodule in the soft tissue. Therefore, such soft probes can be used in robot-assisted minimally invasive surgery, where robotic probes can help the surgeon to verify the location of hard nodules in a target tissue. In this paper, we show experimental evidence of how a certain stiffness of the probe provides maximum proprioceptive information gained via a force/torque sensor mounted at the base of a probe with a controllable stiffness Mckibben type joint between the force/toque sensor and the point in contact with the soft tissue being examined. Our results further predict that humans may also be using a similar internal impedance control strategy at the finger level during probing soft tissue to locate hard nodules. Therefore our findings provide a basis to explore not only novel robotic probes but also to further investigate how human motor control system maybe solving the problem of enhancing tactile and proprioceptive information gain via optimal internal impedance control of the fingers and hand.

Publications: N. Sornkarn, M. Howard, and T. Nanayakkara, "Internal impedance control helps information gain in embodied perception," in *Robotics and Automation (ICRA), 2014 IEEE International Conference on*, May 2014.

J. Konstantinova, M. Li, G. Mehra, P. Dasgupta, K. Althoefer, and T. Nanayakkara, "Behavioral characteristics of manual palpation to localize hard nodules in soft tissues," **Biomedical Engineering, IEEE Transactions on**, vol. PP, no. 99, pp. 1–1, 2014.

03:00PM - 03:30PM **Afternoon Coffee Break**

03:30PM - 04:15PM **Round table discussion**

Workshop Program At A Glance

09:00AM - 09:25AM	**Enabling technologies for soft actuation and stiffness control in endoscopy and minimally invasive surgery** *Arianna Menciassi*
09:25AM - 09:50AM	**Title** *Fumiya Iida*
09:50AM - 10:10AM	**Sensor Embedded Soft Pneumatic Actuator for an Endonasal Instrument** *Merve Acer et al.*
10:10AM - 10:30AM	**End user interfaces and actuation systems for (micro)surgical robotics: technologies and future directions** *Matteo Bianchi et al.*
10:30AM - 11:00AM	**Morning Coffee Break**
11:00AM - 11:25AM	**Title** *Darwin Caldwell*
11:25AM - 11:50AM	**Title** *Thrishantha Nanayakkara*
11:50AM - 12:10PM	**An intelligent data fusion system concept for the STIFF-FLOP project** *J. Czarnowski et al.* **Variable damping control for robotic neurosurgery** *E. Beretta et al.* **Prototype Design of Flexi-Hand for Single Incision Laparoscopis Surgery** *Guokai Zhang et al.* **Customizable Flexible Manipulator for Minimally Invasive Surgery Manufactured by Selective Laser Sintering** *Gerald Horst et al.*
12:10PM - 01:30PM	**Lunch Break**
01:30PM - 01:55PM	**From STIFF to FLOPpy – A new approach for robot-assisted surgery: Advancements and Challenges** *Kaspar Althoefer*
01:55PM - 02:20PM	**Skins in Nature and Soft Biorobotics** *Constantina Lekakou*
02:20PM - 02:40PM	**Control of Elastic Soft Robots using Real-Time Inverse Simulation on SOFA framework** *Christian Duriez*
02:40PM - 03:00PM	**Palpation with Controllable Stiffness for Robot-assisted Minimally Invasive Surgery** *Nantachai Sornkarn et al.*
03:00PM - 03:30PM	**Afternoon Coffee Break**
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