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

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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 - 09:15AM **Welcome Message**
Kaspar Althoefer, King's College London

09:15AM - 09:45AM **Enabling technologies for soft actuation and stiffness control in endoscopy and minimally invasive surgery**
Arianna Menciassi

Contact Details: Associate Professor of Biomedical Robotics
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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:

09:45AM - 10:15AM **Challenges and perspectives toward the novel dexterous machines**

Fumiya Iida

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Abstract: Inspired from the numerous examples of soft bodied animals, there have been an increasing interest in the use of soft deformable structures in robotic systems to enhance their flexibility and dexterity for the challenging tasks that are impossible otherwise. In this talk, we discuss our efforts to tackle engineering challenges such as fabrication, modeling, and control of bio-inspired soft robots while speculating the applications in the near future. In particular we discuss the use of soft continuum bodies for next generations of mechatronic systems. Here we make use of unconventional soft functional materials for soft elastic mechanical bodies as well as dynamic reconfiguration of body shapes and other mechanical properties. The technological and theoretical components can be further extended toward a broader range of applications, especially those implemented into human-friendly environments, such as medical, rehabilitation and other types of assistive devices. In the end we discuss how the recent development and understanding of soft robotics technologies can contribute to the further progress in medical applications.

Publications: Rolf Pfeifer, Hugo Gravato Marques, and Fumiya Iida. 2013. Soft robotics: the next generation of intelligent machines. In Proceedings of the Twenty-Third international joint conference on Artificial Intelligence (IJCAI'13), Francesca Rossi (Ed.). AAAI Press 5-11.

Liyu Wang; Iida, F., „Towards "soft" self-reconfigurable robots," Biomedical Robotics and Biomechatronics (BioRob), 2012 4th IEEE RAS & EMBS International Conference on , vol., no., pp.593,598, 24-27 June 2012.

NOTES:

10:15AM - 10:35AM **Sensor Embedded Soft Pneumatic Actuator for an Endonasal Instrument**

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

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École Polytechnique Fédérale de Lausanne (EPFL)
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P. Pasche, C. Ikonomidis
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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.

10:35AM - 11:00AM **MORNING COFFEE BREAK**

11:00AM - 11:30AM **Robot learning by imitation and exploration with the STIFF-FLOP robot**

Sylvain Calinon

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Abstract: In minimally invasive surgery, tools go through narrow openings and manipulate soft organs. The recent developments of continuum robots with variable stiffness aim at providing flexible robotic tools that can move within organs and reach remote areas inside the body. In this talk, I will focus on the problem of designing learning interfaces to assist the surgeons, by enabling the transfer of skills from demonstrations. I will first show that robot programming by demonstration encompasses a wide range of imitation strategies that can be exploited in surgery scenarios. It goes from simple mimicking of the demonstrator's actions to higher-level forms of imitation by extracting the underlying intent from the demonstrations. I will then discuss the problem of designing compact representations of skills, with a focus on statistical learning, dynamical systems and optimal control. The combination of these approaches aims at facilitating the superposition/reorganization of motion primitives and local feedback behaviors in time and space. For continuum robots, we can take inspiration from invertebrate systems in nature to seek for new versatile representations of motion/behavior primitives. In particular, the incredibly varied skills achieved by the octopus arms can guide us toward the design of such robust encoding scheme.

Publications: Calinon, S., Bruno, D., Malekzadeh, M.S., Nanayakkara, T. and Caldwell, D.G. Human-robot skills transfer interfaces for a flexible surgical robot. **Computer Methods and Programs in Biomedicine**, 2014.

Calinon, S., Bruno, D. and Caldwell, D.G. "A task-parameterized probabilistic model with minimal intervention control". In Proceedings of the *IEEE Intl Conf. on Robotics and Automation (ICRA)*, 2014.

Bruno, D., Calinon, S. and Caldwell, D.G. "Null space redundancy learning for a flexible surgical robot". In Proceedings of the *IEEE Intl Conf. on Robotics and Automation (ICRA)*, 2014.

NOTES:

11:30AM - 11:50AM **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

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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.

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 - 12:20PM **RoboSoft Coordination Action for Soft Robotics**
Matteo Cianchetti, Scuola Superiore Sant'Anna

12:20PM - 01:30PM **LUNCH BREAK**
Note that lunch is not included in the registration. The participants should make their own lunch arrangements.

01:30PM - 02:00PM **Advancements and challenges of STIFF-FLOP for low and mid rectum cancer treatments**

Kaspar Althoefer

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Abstract: The da Vinci® Surgical System has been employed to conduct minimally invasive or keyhole surgery. Despite a number of notable advances over current laparoscopic methods, such as reduced training time for the surgeons, ease of use of the robotised system and improved ergonomics for the surgeons, the da Vinci® system continues to make use of rigid instruments severely restricting the areas they can reach during operations. Severing the physical interaction with the patient results in a complete loss of haptic feedback to the robotic surgeon and is considered another disadvantage of the da Vinci® system.

A number of new robotic, surgical systems are appearing in research labs worldwide. The University of Washington are testing a robot system called Raven which is to help surgeons to „see" and navigate around the heart during cardiac interventions, guiding the instruments to the right place. Their approach uses 3D ultrasound imaging to show internal organs in real time. A tele-operated pneumatic surgical system has been developed by Tokyo Institute of Technology providing the surgeon with force feedback, whilst miniaturised snake-like manipulators are the focus of the robotics team at Carnegie Mellon University and at the Hamlyn Robotics Centre in London.

Departing from these types of robots, which are fundamentally based on a structure made from rigid link elements, the EU project STIFF-FLOP (STIFFness controllable Flexible and Learnable manipulator for surgical OPerations) has created a soft multiple-segment manipulator with controllable stiffness. I will highlight the conceptual ideas driving the project, report on recent achievements and how these relate to safety considerations in the context of Robot-assisted Minimally Invasive Surgery (RMIS). Challenges emerging when departing from traditionally rigid instruments and progressing towards flexible and even stiffness-controllable surgical tools will be discussed.

Publications: Sareh, Jiang, Faragasso, Noh, Nanayakkara, Dasgupta, Seneviratne, Wurdemann, Althoefer, "Bio-Inspired Tactile Sensor Sleeve for Surgical Soft Manipulators", ICRA 2014.

Noh, Sareh, Jungwhan, Wurdemann, Ranzani, Secco, Faragasso, Liu, Althoefer, A Three-Axial Body Force Sensor for Flexible Manipulators, ICRA 2014.

Li, Faragasso, Konstantinova, Aminzadeh, Seneviratne, Dasgupta, Althoefer, A Novel Tumor Localization Method Using Haptic Palpation Based on Soft Tissue Probing Data, ICRA 2014.

NOTES:

02:00PM - 02:30PM **Skins in Nature and Soft Biorobotics for MIS**

Constantina Lekakou

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Abstract: Soft robotics is particularly attractive for minimally invasive surgery (MIS) to ensure safe interaction with soft tissues and organs, robot arm deformation and navigation though narrow orifices and narrow passages between organs, flexibility and maneuverability of soft manipulators with fluid-like motion. As in the case of soft manipulators and soft actuators in nature, robot skin is an important component of the soft body of a robot arm. While natural skin in animals and plants 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 for MIS 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:

02:30PM - 02:50PM **Real-time FEM inverse simulation for the control of soft robots and for finding soft tissues parameters**

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/12courtecu/

NOTES:

02:50PM - 03:10PM **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.

03:10PM - 03:40PM **Afternoon Coffee Break**

03:40PM - 04:15PM **Round table discussion**

Workshop Program At A Glance

This workshop is an official Soft Robotics TC event

09:00AM - 09:15AM	**Welcome Message** *Kaspar Althoefer, King's College London*
09:15AM - 09:45AM	**Enabling Technologies for Soft Actuation and Stiffness Control in Endoscopy and MIS** *Arianna Menciassi, Scuola Superiore Sant'Anna*
09:45AM - 10:15AM	**Challenges and perspectives toward the novel dexterous machines** *Fumiya Iida, Swiss Federal Institute of Technology Zurich*
10:15AM - 10:35AM	**Sensor Embedded Soft Pneumatic Actuator for an Endonasal Instrument** *Merve Acer et al., École Polytechnique Fédérale de Lausanne (EPFL)*
10:35AM - 11:00AM	**Morning Coffee Break**
11:00AM - 11:30AM	**Robot learning by imitation and exploration with the STIFF-FLOP robot** *Sylvain Calinon, Istituto Italiano di Tecnologia*
11:30AM - 11:50AM	**End User Interfaces and Actuation Systems for (Micro)surgical Robotics: Technologies and Future Directions** *Matteo Bianchi et al., Istituto Italiano di Tecnologia and University of Pisa*
11:50AM - 12:10PM	**An Intelligent Data Fusion System Concept for the STIFF-FLOP Project** *J. Czarnowski et al., Przemysłowy Instytut Automatyki i Pomiarów PIAP* **Variable Damping Control for Robotic Neurosurgery** *E. Beretta et al., Politecnico di Milano and Imperial College London* **Prototype Design of Flexi-Hand for Single Incision Laparoscopis Surgery** *Guokai Zhang et al., Tianjin University* **Customizable Flexible Manipulator for Minimally Invasive Surgery Manufactured by Selective Laser Sintering** *Gerald Horst et al., Technical University Munich*
12:10PM - 12:20PM	**RoboSoft Coordination Action for Soft Robotics** *Matteo Cianchetti, Scuola Superiore Sant'Anna*
12:20PM - 01:30PM	**Lunch Break and Poster Sessions**
01:30PM - 02:00PM	**Advancements and challenges of STIFF-FLOP for low and mid rectum cancer treatments** *Kaspar Althoefer, King's College London*
02:00PM - 02:30PM	**Skins in Nature and Soft Biorobotics for MIS** *Constantina Lekakou, University of Surrey*
02:30PM - 02:50PM	**Control of Elastic Soft Robots using Real-Time Inverse Simulation on SOFA framework** *Christian Duriez, University of Lille*
02:50PM - 03:10PM	**Palpation with Controllable Stiffness for Robot-assisted Minimally Invasive Surgery** *Nantachai Sornkarn et al., King's College London*
03:10PM - 03:40PM	**Afternoon Coffee Break**
03:40PM - 04:15PM	**Round table discussion**

Teaser Presentations

More information and full program on
www. ICRA14-SoftMedicalRobots-Workshop.com