Robosoft2019 Workshop on "Toward the nature of information processing in soft machines: bridging flexible electronics and morphological computation."

Organizers

Kohei Nakajima (The University of Tokyo, Japan)
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Summary

Animals adapt to their changing environments with their soft bodies. Their ability to exploit their flexible bodies and their outsourcing of the functionality of the control to their deformable morphologies are referred to as "morphological computation." Conventional robotic systems are mechanically static, and they are unable to change their bodies to levels that are satisfactory for flexibility to achieve the adaptability and intelligence that is comparable to animals. In response to this situation, soft technologies are currently being studied simultaneously in different fields and many notable attempts have been reported worldwide. For example, various flexible sensors that do not damage the natural dynamics of the soft body have been reported. In addition, the body morphology can be designed using a novel three-dimensional printing technique, which works with soft materials. By integrating these soft technologies with morphological computation, we expect that the science of soft robots will further prove its potential to generate novel application domains. This workshop will focus on the recent advancement in material sciences, flexible electronics, and morphological computation, and provides an opportunity for active discussion about the state-of-the-art technologies to take place, as well as for the sharing of common views about future challenges.

List of speakers

- **Koichi Suzumori (Tokyo Institute of Technology, Japan)**
  "MEXT KAKENHI Project on Soft Robotics in Japan"
- **Kenjiro Fukuda (RIKEN, Japan)**
  "Ultra lightweight organic solar cells as power solution for soft robotics"
- **Hyunsoo Yang (National University of Singapore, Singapore)**
  "Flexible spintronic devices: sensor, memory and THz component"
- **Kuniharu Takei (Osaka Prefecture University, Japan)**

"Flexible sensors for healthcare applications and soft robotics"

- **Jian Zhu (National University of Singapore, Singapore)**
  "Bio-inspired soft robots based on various soft actuators"
- **Ryuma Niiyama (University of Tokyo, Japan)**
  "Bio-inspired musculoskeletal robots"
- **Thrish Nanayakkara (Imperial College London, UK)**
  "Conditioning the body to reduce the entropy of random variables"
- **Francesco Giorgio-Serchi (University of Edinburgh, UK)**
  "The power of flexibility: exploiting deformability and stiffness control for aggressive underwater propulsion"
- **Fumiya Iida (University of Cambridge, UK)**
  "Adaptation of sensor morphology as morphological computation"

<u>List of posters</u>

- **Hiroyuki Nabae (Tokyo Institute of Technology, Japan)**
  "MEXT KAKENHI Project on Soft Robotics in Japan"
- **Hiroyuki Nabae (Tokyo Institute of Technology, Japan)**
  "Motion control of soft robots realized by ion exchange membranes"
- **Yuta MURAYAMA (Chiba University, Japan)**
  "Development of flexible wings inspired by avian feathers"
- **Sakito KOIZUM (Chiba University, Japan)**
  "Development of flexible flapping mechanism inspired by insect musculoskeletal system"
- **Masato Komori (Shibaura Institute of Technology, Japan)**
  "Gel machines based on the chemo-mechanical cycle"
- **Hiroshi Ito (Kyushu University, Japan)**
  "Reconstitution of biological rhythms and pattern with living matter"
- **Takuya Umedachi (University of Tokyo, Japan)**
  "Bio-inspired autonomous decentralized control for soft-bodied robots"
- **Hiromi MOCHIYAMA (University of Tsukuba, Japan)**
  "Real-time Shape Estimation of an Elastic Rod using a Robot Manipulator equipped with a Sense of Force"
- **Toshinori Fujie (Tokyo Institute of Technology, Japan)**
  "Ultra-thin, flexible, inkjet-printed neural electrodes with mechanically gradient structure"
- **Kenjiro TADAKUMA (Tohoku University, Japan)**

"Branched extendable mechanism based on nemertea proboscis"

- **Yongping Pan (National University of Singapore, Singapore)**
  "Efficient learning from recursive least square estimation"

Time table

09:00 – 9:30 Koichi Suzumori (Tokyo Institute of Technology, Japan)
09:30 –10:00 Kenjiro Fukuda (RIKEN, Japan)
10:00 –10:30 Hyunsoo Yang (National University of Singapore, Singapore)
10:30 –11:00 Coffee Break
11:00 –11:30 Kuniharu Takei (Osaka Prefecture University, Japan)
11:30 –12:00 Jian Zhu (National University of Singapore, Singapore)
12:00 –13:00 Lunch Break
13:00 –14:00 Poster Session I
14:00 –14:30 Ryuma Niiyama (University of Tokyo, Japan)
14:30 –15:00 Thrish Nanayakkara (Imperial College London, UK)
15:00 –15:30 Coffee Break
15:30 –16:00 Francesco Giorgio-Serchi (University of Edinburgh, UK)
16:00 –16:30 Fumiya Iida (University of Cambridge, UK)
16:30 –17:30 Poster Session II
17:30 –Open Discussion for future collaborations and open-ended social event

Abstracts

- **Kenjiro Fukuda (RIKEN, Japan)**
  "Ultra lightweight organic solar cells as power solution for soft robotics"
  Abstract: Electric power is an important bottle neck to drive the soft robot using the soft actuator. Energy harvesting technology that obtains electricity from the environment has gained much attention in recent years. By realizing a power supply system combining this technology and a battery with a flexible and soft configuration, a soft robot that continuously drives for a long time It is thought that the system can be constructed. Although the ultimate goal is to drive the actuators themselves by electric power, we should consider the energy mismatch between power which energy harvesting systems can generate and the power which soft actuators require to be moved. Nevertheless, such power source systems can be used to drive electronic devices such as sensors attached to the soft robot for a long time, therefore, the flexible electric power source system is promising tools. In

this talk, I will introduce recent progress of our ultra-flexible organic solar cells and discuss the possibilities of our energy harvesting system as power solution for soft robotics. We achieved 3-μm-thick organic solar cells that can be easily attached onto textile and human skins. The power conversion efficiency of such ultra-thin solar cells surpassed benchmark 10% or 10 mW/cm^2 under outdoor light condition.

- **Hyunsoo Yang (National University of Singapore, Singapore)**
  "Flexible spintronic devices: sensor, memory and THz component"
  Abstract: Among recent advances in spintronics, magnetic tunnel junctions (MTJs) have become one of the most useful spintronic devices for magnetic sensors and magnetic memories (MRAM). We introduce the concept of strain engineering in MTJs, and demonstrate that tensile strain can enhance the tunneling magnetoresistance (TMR) by 3 times in MgO based MTJs [1]. In addition, we demonstrate the first flexible MgO based MTJs [2], which could be useful for future flexible magnetic sensors and non-volatile memory applications. Traditional methods of generating and modulating THz waves often require expensive and bulky substrates or extremely sophisticated device fabrication processes. We have successfully developed high performance flexible THz modulators [3] and low-power driven THz emitters [4] that could be mass-produced at low cost, addressing a critical challenge for industrial applications of THz technology. These THz components can function on flexible surfaces without compromising their performance. Fabricating the above devices on a flexible surface opens up many exciting possibilities for it to be incorporated into wearable devices.
  [1] L. M. Loong et al., Sci. Rep. 4, 6505 (2014)
  [2] L. M. Loong et al., Adv. Mat. 28, 4983 (2016)
  [3] J. Liu et al., Opt. Lett. 41, 816 (2016)
  [4] Y. Wu et al., Adv. Mat. 29, 1603031 (2017)

- **Kuniharu Takei (Osaka Prefecture University, Japan)**
  "Flexible sensors for healthcare applications and soft robotics"
  Abstract: Flexible electronics are now of great interests in the field of "Internet of Things (IoT)", which collects a variety of information from any surfaces, analyzes the signals, and feedbacks the results to the users or objects. One of the main roles of flexible electronics is to detect multiple signals from macroscale surfaces as a flexible sensor sheet. In this study, we aim to develop the multiple flexible sensors for two applications to achieve the platforms for securing human life. The first application is to monitor real-time human health conditions by attaching the device on skin like a bandage. Another is to give soft

robotic hands tactile sensibility by detecting tactile and temperature information like a human hand. Fundamental electrical properties of each sensor especially for tactile pressure sensor, temperature sensor, chemical sensors, and acceleration sensors on flexible films are introduced as well as the device demonstration of healthcare and soft-robot operated with pneumatic balloon structures. Although the sensor sheets presented in this talk need a lot of further developments for moving forward realizing the practical applications, the fabrication methods and device concepts may lead a next class of flexible electronics and IoT concept.

- **Jian Zhu (National University of Singapore, Singapore)**
  "Bio-inspired soft robots based on various soft actuators"
  Abstract: Robots have been proposed to relieve human beings from dangerous environments or tedious manufacturing processes, or mimic human beings or animals in appearance, behaviour, and/or cognition. Most of traditional robots use hard materials. Inspired by natural creatures, researchers recently become more and more interested in soft robots, which are made of soft materials, say polymers. Soft robots exhibit interesting attributes, including material compliance, excellent safety, and environmental adaptability. In this seminar I will discuss several ongoing projects on bioinspired soft robots, such as undersea robots, crawling robots, and climbing robots. These soft robots are developed based on various soft actuators, including dielectric elastomer actuators, pneumatic actuators, and electrostatic actuators.

- **Ryuma Niiyama (University of Tokyo, Japan)**
  "Bio-inspired musculoskeletal robots"
  Abstract: The musculoskeletal system provides a flexible structure and dynamic movement to the animal body. A combination of bones and muscles is also an interesting topic in terms of designing soft and hard. This talk introduces examples of musculoskeletal robots driven by pneumatic artificial muscles. The target tasks are jumping and running activated by feedforward motor commands. Dynamic tasks require carefully designed musculoskeletal structure and optimized muscle arrangement. The talk also presents our recent progress in printable artificial muscles. Soft actuation for bio-inspired machines is one of the grand challenges of soft robotics.

- **Thrish Nanayakkara (Imperial College London, UK)**
  "Conditioning the body to reduce the entropy of random variables"
  Abstract: A system is called an embedded system if it can take good enough actions in

response to states within deadlines imposed by the environment. In that sense living beings and most robots are embedded systems. When states are uncertain, the task of state estimation within deadlines becomes non-trivial. Living beings often take a recursive approach to estimate such random variables. For instance, if someone is asked to estimate the weight of an object, they would bob it up and down several times before concluding an estimate. If we frame it as a Recursive Bayesian estimation process, the agent can significantly benefit from the ability to "morph" the likelihood function to sharpen the posterior distribution. In our studies we see that participants change the elbow stiffness and bobbing behavior depending on the weight of the object in the above scenario. We see similar phenomena in other estimation tasks too. In soft tissue palpation for instance, when a Physician is required to estimate the location of the edge of the liver of a patient using manual palpation, they would regulate the stiffness and configuration of the fingers to condition haptic perception during palpation. In this talk, I will show some recent results of this information morphing approach for efficient estimation of environmental states using a controllable stiffness body. I will show a soft robotic approach to test hypotheses we build based on human behavior.

- **Francesco Giorgio-Serchi (University of Edinburgh, UK)**
  "The power of flexibility: exploiting deformability and stiffness control for aggressive underwater propulsion"
  Abstract: Among sea dwelling organisms, squids and octopuses stand out because they combine extreme bodily softness with unsurpassed swimming agility, thus embodying a unique synthesis of two highly sought for features in novel aquatic robot design. In this talk I will show how, in the case of highly-deformable aquatic organisms, body-shape variations and body compliance are essential to their outstanding performances. By relying on simple analytical arguments I will discuss how aquatic systems capable of impulsively morphing their body can achieve unprecedented manoeuvrability. In addition, I will show how organisms (and the robots inspired from them) which are capable of actively adjusting their degree of body-elasticity can achieve persistent maximum propulsive efficiency at any speed, possibly explaining their incredible evolutionary success.