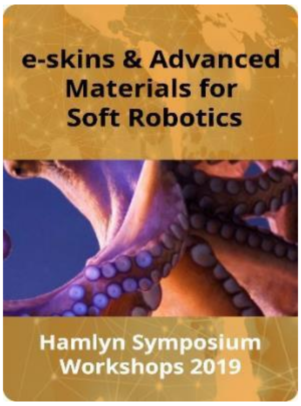

Workshop: e-skins and Advanced Materials for Soft Robotics

Code: SAPM02 | Sunday, 23rd June

Royal Geographical Society

Co-Chairs and Organisers:

Salzitsa Anastasova-Ivanova, The Hamlyn Centre, Imperial College, UK

Panagiotis Kassanos, The Hamlyn Centre, Imperial College, UK Florent Seichepine, The Hamlyn Centre, Imperial College, UK

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08:30-09:00	Registration and Coffee
09:00	**Opening: Welcome & Introduction** *Guang-Zhong Yang, Imperial College London, UK*
09:10	**Triboelectric Nanogenerators for Soft-Robotics and Self-Powered Sensors** *(Keynote) Zhong Lin Wang, Georgia Institute of Technology, USA*
09:55	**Wearable Sweat Sensors for Personalized Health Monitoring** *Wei Gao, California Institute of Technology, USA*
10:20	**Stretchable Triboelectric Nanogenerators as Self-powered Robotic Skins: Toward Actively Perceiving and Responsive Soft Robots** *Ying-Chih Lai, National Chung Hsing University, Taiwan*
10:45-11:15	Coffee Break & Poster Session @ The Marquee
11:15	**Encoding Tissue Mechanics in Silicone** *Sergei Sheiko, University of North Carolina at Chapel Hill, USA*
11:45	**Novel Ultrathin and DNA Shape Change Materials** *David Gracias, Johns Hopkins University, USA*
12:10	**Artificial Muscles for a New Generation of Lifelike Robots** *Christoph Keplinger, University of Colorado Boulder, USA*
12:35	**Soft Robots for Invisible Intuitive Interactions**

Jamie Paik, Swiss Federal Institute of Technology, Switzerland

13:00-14:00 **Lunch Break & Poster Session @ The Marquee**

14:00 **Optoelectronic Sensing of the Deformation of Continuum Structures**
Rob Shepherd, Cornell University, USA

14:25 **Ferromagnetic Soft Continuum Robots**
Yoonho Kim, Massachusetts Institute of Technology, USA

14:50 **A Vision for the Future of Soft Electronics and Robotics**
Open Panel Discussion

15:25 **Closing Remarks**

Posters presented in our workshop by non-Hamlyn people:

1. **Actively Perceiving, Self-healable, and Transparent Triboelectric Skin for a Soft Robotic Hand**
   Yung-Chi Hsiao, Hsing-Mei Wu, Ying-Chih Lai
   Department of Materials Science and Engineering, National Chung Hsing University, Taiwan.

2. **Wearable sensor reliability in continuous vital sign monitoring from acutely unwell hospital admissions,**
   Meera Joshi[1], Mansour Sharabiani[1], Hutan Ashrafian[1], Sadia N Khan[2], Kenny McAndrew[2], Sonal Arora[1], Richard Kwasnicki[1], Graham S Cooke[3], Ara Darzi[1]
   [1]Department of Surgery and Cancer, Imperial College London, UK [2]West Middlesex University Hospital, Twickenham Road, UK [3]Division of Infectious Diseases, Imperial College London, UK

3. **Monolithic Solder-on Nanoporous Si-Cu Contacts for Stretchable Silicone Composite Sensors**
   Michael Kasimatis[1], Estefania Nunez-Bajo[1], Max Grell[1], Yasin Cotur[1], Giandrin Barandun[1], Ji- Seon Kim[2], Firat Güder[1]
   [1]Department of Bioengineering, Imperial College London, UK
   [2]Department of Physics, Imperial College London, UK.

4. **An Active Reconfigurable Surface for Prosthetic Socket**
   Mehmet Kelleci, Harshal Sonar and Jamie Paik
   Reconfigurable Robotics Lab (RRL), École Polytechnique Fédérale de Lausanne, Switzerland

5. **Ultrathin Hybrid Graphene Skins for Biosensing and Actuation**
   Weinan Xu1, Santosh K. Paidi2, Zhao Qin3, Qi Huang1, Markus J. Buehler3, Ishan Barman2, David H. Gracias1,
   [1]Department of Chemical and Biomolecular Engineering, Johns Hopkins University, Baltimore, Maryland 21218, USA,
   [2]Department of Mechanical Engineering, Johns Hopkins University, Baltimore, Maryland 21218, USA,
   [3]Department of Civil and Environmental Engineering, Massachusetts Institute of Technology, Cambridge, Massachusetts 02139, USA.

6. **6. Development of artificial blood pump using dielectric elastomers**
   H Godaba[1,2], CH Yap[3], J Zhu[1], K Althoefer[2]
   [1]Department of Mechanical Engineering, National University of Singapore
   [2]Centre for Advanced Robotics @ Queen Mary, Queen Mary University of London, UK
   [3]Department of Biomedical Engineering, National University of Singapore.

7. **Magnetic floating microrobot with preferred magnetisation direction for electronic wet transfer**
   Antoine Barbot, Haijie Tan, Florent Seichepine, Guang-Zhong Yang
   The Hamlyn Centre, Imperial College London, UK

8. **Shape memory alloy driven micro-tentacle actuator**
   Hyun-Taek Lee, Florent Seichepine, Guang-Zhong Yang
   The Hamlyn Centre, Imperial College London, UK

Keynote Speaker:
Zhong Lin (ZL) Wang, Georgia Institute of Technology, USA

Keynote Title:
Triboelectric Nanogenerators for Soft-Robotics and Self-Powered Sensors

Abstract:
Developing wireless nanodevices and nanosystems is of critical importance for sensing, medical science, environmental/infrastructure monitoring, robotics, artificial intelligence and even personal electronics. It is highly desirable for wireless devices to be self-powered without using battery. Triboelectric anogenerators (TENGs) have been invented based on coupling effect of triboelectrification and electrostatic induction by using soft, stretchable and even degradable materials, aiming at building self-sufficient power sources for mico/nano-systems and self-powered sensors. Triboelectrification is a universal phenomenon that exists for all of the materials regarding their chemical structure and physical shape. This presentation will focus on the fundamental science of triboelectrification, the displacement current theory, technological applications of TENG with an emphasis of their potentials for soft robotics and flexible/stretchable electronics.

Biography:
Dr. Zhong Lin (ZL) Wang is the Hightower Chair in Materials Science and Engineering and Regents' Professor at Georgia Tech, and Founding Director and Chief Scientist at Beijing Institute of Nanoenergy and Nanosystems.

Dr. Wang pioneered the nanogenerators from fundamental principle to technological applications. His research on self-powered nanosystems has inspired the worldwide effort in academia and industry for studying energy for micro-nano-systems. He coined and pioneered the fields of piezotronics and piezo-phototronics for the third generation semiconductors. Wang is ranked No. 1 in Google Scholar public profiles in Nanotechnology & Nanoscience both in total citations and h-index impacts: http://www.webometrics.info/en/node/198.

Dr. Wang has received 2018 ENI award in Energy Frontiers; Global Nanoenergy Prize, The NANOSMAT Society, UK (2017); Distinguished Research Award, Pan Wen Yuan foundation (2017); Distinguished Scientist Award from (US) Southeastern Universities Research Association (2016); Thomas Router Citation Laureate in Physics (2015); World Technology Award (Materials) (2014); Distinguished Professor Award (Highest faculty honor at Georgia Tech) (2014); NANOSMAT prize (United Kingdom) (2014); The James C. McGroddy Prize in New Materials from American Physical Society (2014); MRS Medal from Materials Research Soci. (2011).

Dr. Wang was elected as a foreign member of the Chinese Academy of Sciences in 2009, member of European Academy of Sciences in 2002, academician of Academia of Sinica (Taiwan) 2018; fellow of American Physical Society in 2005, fellow of AAAS in 2006, fellow of Materials Research Society in 2008, fellow of Microscopy Society of America in 2010, fellow of the World Innovation Foundation in 2002, fellow of Royal Society of Chemistry, and fellow of World Technology Network 2014. Dr. Wang is the founding editor and chief editor of an international journal Nano Energy, which now has an impact factor of 15. Details can be found at: http://www.nanoscience.gatech.edu

Speaker:
Wei Gao, California Institute of Technology, USA

Title:
Wearable Sweat Sensors for Personalized Health Monitoring

Abstract:
The rising research interest in personalized and precision medicine promises to revolutionize traditional medical practices. This presents a tremendous opportunity for developing wearable devices toward predictive analytics and treatment. In this talk, I will introduce fully-integrated flexible biosensors for multiplexed in-situ perspiration analysis, which can selectively and accurately measure a wide spectrum of sweat analytes (e.g., metabolites, electrolytes, heavy metals, drugs and other small molecules). This platform allows us to gain real-time insight into the sweat secretion and gland physiology. I will also demonstrate an integrated wearable sweat extraction and sensing system which can be programmed to induce sweat on demand with various secretion profiles. To demonstrate the clinical value of our wearable sweat sensing platform, human subject studies were performed toward fitness monitoring, physiological monitoring, cystic fibrosis diagnosis and drug monitoring. These wearable and flexible devices open the door to a wide range of personalized monitoring and diagnostic applications.

Biography:
Wei Gao is an Assistant Professor of Medical Engineering in Division of Engineering and Applied Science at the California Institute of Technology. He received his PhD in Chemical Engineering at University of California, San Diego in 2014 as a Jacobs Fellow and HHMI International Student Research Fellow. In 2014-2017, he was a postdoctoral fellow in the Department of Electrical Engineering and Computer Sciences at the University of California, Berkeley. He is a recipient of Sensors Young Investigator Award, MIT Technology Review 35 Innovators Under 35 (TR35) and ACS Young Investigator Award (Division of Inorganic Chemistry). His research interests include wearable devices, biosensors, flexible electronics, micro/nanorobotics and nanomedicine. For more information about Gao's research, visit www.gao.caltech.edu/.

Speaker:
David Gracias, Johns Hopkins University, USA

Title:
Novel Ultrathin and DNA Shape Change Materials

Abstract:
The talk will describe the design of novel ultrathin and DNA shape change devices to address two critical challenges in soft robotics. The first challenge is the seamless integration of inorganic materials with soft-robots to allow them to interact with electromagnetic fields1 which is addressed by the polymer surface modification of ultrathin materials such as graphene to form stimuli

responsive self-folding skins. Although the ultrathin materials are very stiff in-plane, they have very low bending rigidity and can be used to conformally wrap regular or irregularly shaped objects such as live cells and pollen grains. When combined with plasmonic nanostructures ultrathin hybrid skins can enable 3D spatiotemporal spectroscopic imaging.

The second challenge is to create programmable soft-robots that can be mass-produced and operated in parallel without the need for any wires or tethers. The challenge is addressed by the design of new DNA polymerization motor hydrogels2 that can swell significantly based on the highly specific nucleotide base complementary binding. Photopatterning and layering of these DNA gels enable highly specific actuation of soft-robots based on biomolecular cues.

Biography:
David H. Gracias is a Professor at the Johns Hopkins University. He received Ph.D. from the University of California at Berkeley and did postdoctoral work at Harvard University, all in chemistry or related fields. His independent laboratory, since 2003, has pioneered the development of 3D, shape- change, and integrated micro-, and nanodevices of broad relevance. Prof. Gracias has co-authored over 170 technical publications in addition to 31 issued patents.

Speaker:
Christoph Keplinger, University of Colorado Boulder, USA

Title:
Artificial Muscles for a New Generation of Lifelike Robots

Abstract:
Robots today rely on rigid components and electric motors based on metal and magnets, making them heavy, unsafe near humans, expensive and ill-suited for unpredictable environments. Nature, in contrast, makes extensive use of soft materials and has produced organisms that drastically outperform robots in terms of agility, dexterity, and adaptability. The Keplinger Lab aims to fundamentally challenge current limitations of robotic hardware, using an interdisciplinary approach that synergizes concepts from soft matter physics and chemistry with advanced engineering technologies to introduce intelligent materials systems for a new generation of life-like robots. One major theme of research is the development of new classes of actuators – a key component of all robotic systems – that replicate the sweeping success of biological muscle, a masterpiece of evolution featuring astonishing all-around actuation performance, the ability to self- heal after damage, and seamless integration with sensing.
This talk is focused on the labs' recently introduced HASEL artificial muscle technology. Hydraulically Amplified Self-healing ELectrostatic (HASEL) transducers are a new class of self-sensing, high-performance muscle-mimetic actuators, which are electrically driven and harness a mechanism that couples electrostatic and hydraulic forces to achieve a wide variety of actuation modes. Current designs of HASEL are capable of exceeding actuation stress of 0.3 MPa, linear strain of 100%, specific power of 600W/kg, full-cycle electromechanical efficiency of 30% and bandwidth of over 100Hz; all these metrics match or exceed the capabilities of biological muscle. Additionally, HASEL actuators can repeatedly and autonomously self-heal after electric breakdown, thereby enabling robust performance. Further, this talk introduces a facile fabrication technique that uses an inexpensive

CNC heat sealing device to rapidly prototype HASELs. New designs of HASEL incorporate mechanisms to greatly reduce operating voltages, enabling the use of lightweight and portable electronics packages to drive untethered soft robotic devices powered by HASELs. Modeling results predict the impact of material parameters and scaling laws of these actuators, laying out a roadmap towards future HASEL actuators with drastically improved performance. These results highlight opportunities to further develop HASEL artificial muscles for wide use in next-generation robots that replicate the vast capabilities of biological systems.

Biography:

Christoph Keplinger is an Assistant Professor of Mechanical Engineering and a Fellow of the Materials Science and Engineering Program at the University of Colorado Boulder, where he also holds an endowed appointment serving as Mollenkopf Faculty Fellow. Building upon his background in soft matter physics (PhD, JKU Linz), mechanics and chemistry (Postdoc, Harvard University), he leads a highly interdisciplinary research group at Boulder, with a current focus on (I) soft, muscle- mimetic actuators and sensors, (II) energy harvesting and (III) functional polymers. His work has been published in top journals including Science, Science Robotics, PNAS, Advanced Materials and Nature Chemistry, as well as highlighted in popular outlets such as National Geographic. He has received prestigious US awards such as a 2017 Packard Fellowship for Science and Engineering, and international awards such as the 2013 EAPromising European Researcher Award from the European Scientific Network for Artificial Muscles. He is the principal inventor of HASEL artificial muscles, a new technology that will help enable a next generation of life-like robotic hardware; in 2018 he co- founded Artimus Robotics to commercialize the HASEL technology.

Speaker:

Yoonho Kim, Massachusetts Institute of Technology, USA

Title:

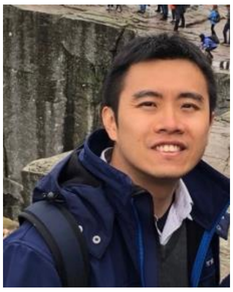
Ferromagnetic Soft Continuum Robots

Abstract:

Small-scale soft continuum robots capable of active steering and navigation in a remotely controllable manner hold great promise in diverse areas, particularly in medical applications. Existing continuum robots, however, are often limited to relatively large scale due to the miniaturization challenges inherent to the conventional actuation mechanisms based on pulling mechanical wires or using bulk magnets for magnetic steering and manipulation. Continuum robots often face another challenge resulting from the significant friction during the navigation. In this talk, we introduce a submillimeter-scale soft continuum robot with hydrogel skin, which can be actuated and controlled by external magnetic fields owing to the programmed ferromagnetic domains. The self-contained actuation system greatly reduces the size of continuum robot, while the hydrogel skin significantly reduces the friction. We demonstrate the capability of navigating through narrow and tortuous paths, which is not easily achievable for both the existing robotic catheters and compact but passive manual devices. Unlike that the bulkier robotic catheters are limited to cardio- or peripheral vascular interventions, our soft continuum robot can be utilized for endovascular

neurosurgery, which is far more challenging due to the considerably small and torturous anatomy of intracerebral vessels. Our development is expected to open new avenues towards teleoperative neurosurgery with much improved accuracy, efficiency, and safety.

Biography:
Yoonho Kim is a Ph.D. candidate in the Soft Active Materials lab (PI: **Prof. Xuanhe Zhao**) in the Mechanical Engineering Department at MIT. He received a B.S. in Mechanical and Aerospace Engineering from Seoul National University (SNU) in 2013 and a M.S. in Mechanical Engineering from MIT in 2018. Prior to joining MIT, Yoonho was a research assistant in the BioRobotics Lab (PI: **Prof. Kyu-Jin Cho**) at SNU from 2011 to 2013, where he developed mechatronic instruments for laparoscopic surgery with interests in surgical robotics. Yoonho's current research interests include advanced fabrication, design, and mechanics of soft active materials towards unconventional soft robots for medical applications. Through his research, Yoonho wishes to address unmet needs and challenges in healthcare by applying principles in mechanics and design to medical problems. Yoonho is the recipient of the ILJU Academy and Culture Foundation Scholarship in Korea, which is awarded to outstanding graduate students studying abroad.



Speaker:
Ying-Chih Lai, National Chung Hsing University, Taiwan

Title:
Stretchable Triboelectric Nanogenerators as Self-powered Robotic Skins: Toward Actively Perceiving and Responsive Soft Robots

Abstract:
Soft robots with compliant and deformable bodies have shown great potential in vast robot-human and robot-environment applications. Developing skin-like sensory devices allows them to sense and interact with environment. It would be better if the capabilities to feel can be active like real skin. However, challenges in complicated structures, incompatible moduli, poor stretchability and sensitivity, large driving-voltage, and power dissipation hinder applicability of conventional passive sensing technologies. In this talk, we will first present self-powered, super- stretchable and mechanically-durable triboelectric electronic skins. Such tribo-skins can actively sense proximity, contact, and pressure to external stimuli via self-generating electricity. The working principle comes from natural triboelectrification effect. Particularly, it can work regardless of under various deformations required from uses or experiencing tearing damages. Secondly, we will show that the perfect integration of the tribo-skins and soft actuators enables soft robots to perform various actively sensing and interactive tasks including actively perceiving their muscle motions and working states, checking baby diaper conditions, and even detecting subtle human physiological signals. Further, the self-generating signals can drive optoelectronic devices for visual communication and be processed for diverse sophisticated uses. These works can open the crucial doors for the tremendous potentials of wearable/stretchable/deformable electronics, artificial electronic-sensory skins, smart interfaces, and soft robots.

Biography:
Prof. Ying-Chih Lai is an assistant Professor of Materials Science and Engineering/ Research Center for Sustainable Energy and Nanotechnology/Innovation and Development Center of Sustainable

Agriculture at National Chung Hsing University in Taiwan. He received his B.S. in Materials Science and Engineering (minor in electrophysics) from National Chiao Tung University and his M.S. and Ph.D. in Electronic Engineering from National Taiwan University. In 2013, he was a Visiting Researcher at Stanford University under the guidance of Professor Zhenan Bao. In 2014, he was in Centre for Microsystems Technology (CMST) of Inter-university Microelectronics Center (IMEC) as a Visiting Scientist and worked with Prof. Jan Vanfleteren. From 2015-2016, he was a Visiting Scholar at Georgia Institute of Technology under the guidance of Professor Zhong Lin Wang. And, he joined the Department of Materials Science and Engineering at National Chung Hsing University in August 2016. His research interests include self-powered sensors, nanogenerators, electronic skins, soft robotics, and flexible/stretchable/wearable electronics.

Speaker:

Jamie Paik, Swiss Federal Institute of Technology, Switzerland

Title:

Soft Robots for Invisible Intuitive Interactions

Abstract:

The ultimate goal of any soft robotics system is to have a cohesive solution to improve the human – machine interface. For such an interface, it is critical to realize a versatile and adaptable multi-degrees of freedom robotic design. While the findings in soft robotics have broadened the application of robotics, they are still limited to specific scenarios. The next challenge is in pushing the boundaries of multi-disciplinary science interceptions simultaneously: materials, mechatronics, energy, control, and design. Such efforts will lead to robust solutions in design methodology, novel actuators, and a comprehensive fabrication and integration method of the core robotic components. This talk will highlight on the recent progresses in soft- material robots and origami robots that aim at achieving comprehensive solutions toward diverse soft human – robot applications.

Biography:

Prof. Jamie Paik is director and founder of Reconfigurable Robotics Lab (RRL) of Swiss Federal Institute of Technology (EPFL) and a core member of Swiss National Centers of Competence in Research (NCCR) Robotics consortium. RRL's research leverages expertise in multi-material fabrication and smart material actuation. At Harvard University's Microrobotics Laboratory, she started developing unconventional robots that push the physical limits of material and mechanisms. Her latest research effort is in soft robotics and self-morphing Robogami (robotic orgami) that transforms its planar shape to 2D or 3D by folding in predefined patterns and sequences, just like the paper art, origami.

Speaker:
Sergei Sheiko, University of North Carolina at Chapel Hill, USA

Title:
Encoding Tissue Mechanics in Silicone

Abstract:
Machines of the Future will synergize biomimetic mechanics with artificial intelligence. An ideal actuator should mimic muscle by being passively elastic while also efficiently converting potential energy into mechanical strokes. An ideal body material should mimic skin by being simultaneously compliant and firm to accommodate actuator motion. One drawback of biological tissues, however, is that their softness requires water, which is an unreliable engineering material. To overcome this challenge, we have developed a universal materials design platform that leverages precision engineering of brush-like network architectures to program mechanical properties of living tissues in solvent-free elastomers. By accurately and independently controlling a multiplet of architectural parameters (polymer code), we replicate jellyfish, lung, skin and fat tissue stress-strain responses within archetypal poly(dimethylsiloxane) networks. Because these materials are solvent-free, they will neither freeze in the Arctic nor dry in the Sahara. No liquid components exist to be squeezed out in subsurface environments or to evaporate in the vacuum of outer space. This design-by- architecture approach lays the foundation for a configurable synthetic engine that will be capable of encoding a broad range of tissue-mimetic mechanical phenotypes within any desired chemistry

Biography:
Sergei Sheiko received his B.S. degree in Molecular and Chemical Physics from the Moscow Institute of Physics and Technology in 1986 and his PhD in Polymer Physics from the Russian Academy of Sciences in 1991. From 1991-1993, he was a postdoctoral research associate at the University of Twente in the Netherlands with Prof. Martin Moller. In 2000, Sergei completed his Habilitation in Polymer Chemistry at the University of Ulm in Germany. He started at the University of North Carolina at Chapel Hill in 2001 and received his tenure in 2005. Currently, Sergei Sheiko is a George
A. Bush, Jr. Distinguished Professor and a Fellow of the American Physical Society. The research program of his group is focused on programming material properties by polymer architecture.

Speaker:
Rob Shepherd, Cornell University, USA

Title:
Optoelectronic Sensing of the Deformation of Continuum Structures

Abstract:
A variety of stretchable sensors exist, typically used as “skins” for high density shape sensing measurements to improve control authority in high degree of freedom (passive or active) continuum structures and actuators. This talk will discuss the use of light as a sensing medium for measuring deformation in the “meat” of these compliant structures and actuators. Two classes of sensors will

be presented, one that relies on the transmission of light through arrays of lossy optical lightguides, and another that uses a sort of diffusing wave spectroscopy in combination with machine learning to infer structure. Use cases for these sensors will be presented as well as discussion of their relative benefits, current challenges, and future directions as it pertains to soft actuators and deformable interfaces.

Biography:

Rob Shepherd is an associate professor at Cornell University in the Sibley School of Mechanical & Aerospace Engineering. He received his B.S. (Material Science & Engineering), Ph.D. (Material Science & Engineering), and M.B.A. from the University of Illinois in Material Science & Engineering. At Cornell, he runs the Organic Robotics Lab (ORL: http://orl.mae.cornell.edu), which focuses on using methods of invention, including bioinspired design approaches, in combination with material science to improve machine function and autonomy. We rely on new and old synthetic approaches for soft material composites that create new design opportunities in the field of robotics. Our research spans three primary areas: bioinspired robotics, advanced manufacturing, and human- robot interactions. He is the recipient of an Air Force Office of Scientific Research Young Investigator Award, an Office of Naval Research Young Investigator Award, and his lab's work has been featured in popular media outlets such as the BBC, Discovery Channel, and PBS's NOVA documentary series