Soft Matter

EDITORIAL

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Introduction to Soft Robotics

Anand Kumar Mishra,[a] Zhihong Nie,*[b] Jamie Paik[c] and Robert Shepherd*[a]

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Soft Robotics blurs the lines of traditional robotics using materials science.

Soft Robotics is not entirely new. It is the next step in the progression of Smart Systems, Adaptive Matter, and Smart Materials communities focused on robotics applications. The key difference is the degree of complexity and level of systems integration. In a way, Soft Robotics is Smart Systems with an exclusive focus on using soft sensors and soft actuators; whereas Smart Systems was primarily focused on micro-electro-mechanical systems (MEMS), Soft Robotics focuses on mobility—the machine moves relative to the external environment.

With Soft Robotics, material properties now define how a robot functions. Unlike their rigid counterparts, soft robots rely on the careful selection and manipulation of materials to achieve movement, sensation, and interaction with the world. This introduction will explore the crucial role materials science plays in unlocking the potential of Soft Robotics, examining how material properties enable unique capabilities and highlighting the ongoing collaboration between materials scientists and roboticists that is pushing the boundaries of this exciting field.

Roboticists use Sensing, Acting and Responding (S–A–R) loops to cause machinery to automatically interact with the world. The hardware used for these loops is typically built for precision—linkages made stiff so the control software does not have to guess where its body is located, motor torques set to move these members with knowledge of their body's

[a] *Department of Mechanical and Aerospace Engineering, Cornell University, 124 Hoy Road, Ithaca, NY 14850, USA. E-mail: rfs247@cornell.edu*
[b] *State Key Laboratory of Molecular Engineering of Polymers, Department of Macromolecular Science, Fudan University, Shanghai 200438, P. R. China. E-mail: znie@fudan.edu.cn*
[c] *Reconfigurable Robotics Lab, Ecole polytechnique federale de LausanneMED 11326, Station 9 CH-1015 Lausanne, Switzerland*

Anand Kumar Mishra

Anand Kumar Mishra received his PhD in Biorobotics from Scuola Superiore Sant'Anna and the Italian Institute of Technology, Italy. He was a postdoctoral researcher from 2018–2023 and currently serves as a Research Associate at the Department of Mechanical and Aerospace Engineering, Cornell University. His research is focused on bioinspired soft robotics and biohybrid robots, emphasizing the role of soft materials, engineered living materials, and advanced manufacturing in developing dexterous and multifunctional bioinspired soft robots, with applications in agriculture and plant biology.

Zhihong Nie

Zhihong Nie is a Professor in the State Key Laboratory of Molecular Engineering of Polymers and Department of Macromolecular Science at Fudan University, and a Fellow of the Royal Society of Chemistry. Prior to this position, he was a tenured faculty member at the University of Maryland, College Park. His current research focuses on molecular and nanoparticle self-assembly, biomedical imaging and delivery, programmable soft materials, and microfluidics. He has received various awards including the National Science Fund for Distinguished Young Scholars, NSF CAREER Award, and 3M Non-tenured Faculty Award.

position based on encoders located in these motors, and vision the only additional sensing used to inform the controller what to do with its body. These systems are built based on environmental stability and unchanging body conditions. Furthermore, all components of the robot's S–A–R capabilities, including their power systems, are modules; distinct in function and hardware.

Our role as materials scientists is to improve the efficiency of these loops and produce more enduring and agile robots. Many of the innovations in Soft Robotics stem from the use of gradient mechanical–electromagnetic–chemical–thermal properties that more diffusely blend S–A–R modules; the ultimate result will likely be a system where the S, A, R, and power systems are blurred, indistinguishable and integral. This themed collection contains innovations that point in this direction.

We hope that the exciting innovations in this themed collection inform and excite the current and next generation of materials scientists to work towards closing the S–A–R loops with more diffuse, organic integration of hardware, as well as the development of control paradigms (software and hardware) that take advantage of these developments. In the future, robots will not be stiff because the control loops can't understand their body's shape, as they work with the environment instead of solely against it. In the future, robots will bend – not break.

Jamie Paik

Jamie Paik is director and founder of the Reconfigurable Robotics Lab (RRL) of the Swiss Federal Institute of Technology (EPFL). The RRL's research leverages expertise in design and advanced manufacturing toward reconfigurable robotic platforms that push the physical limits of materials and mechanisms. Her latest research effort is in soft robotics and self-morphing Robogami (robotic origami). Robogami transforms autonomously its planar shape to 2D or 3D by folding, just like the paper art, origami. Soft-material robots and robogamis are designed to be interactive with users and their environments through both innate and active reconfigurations. Such characteristics of the RRL's robots have direct applications in medical, automobile, space, communication, and wearable robots. While this novel technology has been published in multiple academic journals, the RRL's spin-offs, MIROS and Foldaway-Haptics, have pushed the boundaries of the industrial applications of these robots as seen in TED. The latest robogami is part of Mercedes' 2020 concept car, Avatar, presented during CES 2020, and MIROS in 2023 and 2024.

Robert Shepherd

*Robert Shepherd is an associate professor at Cornell University in the Sibley School of Mechanical & Aerospace Engineering. He received his BS (Material Science & Engineering), PhD (Material Science & Engineering), and MBA from the University of Illinois. 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 and mechanical design to improve machine function and autonomy. We rely on new and established synthetic approaches for soft material composites that create new design opportunities in the field of robotics. He is the recipient of an Air Force Office of Scientific Research Young Investigator Award, an Office of Naval Research Young Investigator Award, is a Senior Member of the National Academy of Inventors, and his lab's work has been featured in popular media outlets such as the BBC, Discovery Channel, and PBS's NOVA documentary series. He is an advisor to the American Bionics Project (**americanbionics.org**) which aims to make wheelchairs obsolete. He is also the co-founder of the Organic Robotics Corporation, which aims to digitally record the tactile interactions of humans and machines with their environment.*

