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Intelligent Soft Actuators and Flexible Devices

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Soft actuators and flexible devices such as stretchable sensors, with their inherent compliance, can exhibit large deformation and high adaptability to complex environments. By utilizing various actuation mechanisms, soft actuators have been applied to versatile manipulation, bionic soft robots, energy harvesting, and medical surgery across scales. Moreover, to endow soft robots with abilities of perception and human-machine interaction, stretchable and wearable sensors have been introduced in recent years. These flexible sensors are capable of detecting external physiological signals, e.g., pressure, temperature, and provide feedback for the control system. To date, owing to advances in material science, various types of smart materials have been developed for soft robots and sensors, such as pH-responsive hydrogels used for 4D printing, dielectric elastomers, liquid crystal elastomers, and liquid metal. These smart materials enable soft structures to achieve programmable shape-morphing and perceive changes in environments. On the other hand, the development of manufacturing techniques has revolutionized the construction of soft actuators and flexible devices. For instance, multi-materials printing techniques and hybrid assembly, i.e. combination of top-down and bottom-up approaches, result in new types of 2-D and 3-D flexible devices with controllable material distribution. Also, progress in control strategies and systems, such as built-in feedback control, has led to the realization of high-performance soft robotic systems.

With the growing interest in soft actuators and flexible devices, considerable achievements have been made in this interdisciplinary field. To summarize recent advances and updates in this field, we organized this special issue of *Advanced Intelligent Systems* which focuses on "Intelligent soft actuators and flexible devices". This issue brings a collection of papers covering a wide range of materials, fabrication techniques, actuation, and potential applications for soft actuators and flexible devices, which can be basically divided into the following three key aspects:

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1. Novel materials technologies for flexible devices

Soft materials with stimuli-responsive or conductive properties have demonstrated great potential in constructing flexible devices and robots. For instance, liquid crystal polymers actuated by UV or visible light have been used for intelligent actuators. To enhance the capability of liquid crystal polymers, Yanlei Yu and co-workers developed a facile strategy to synthesize reactive azobenzene-containing liquid crystal polymers (azo-LCPs) and photo-deformable fibers (article number 2000254). These reactive azo-LCPs exhibit stable liquid crystallinity and reversible photochemical properties. In addition, metal oxides/hydroxides materials such as cobalt oxides/hydroxides and manganese oxides can undergo electrochemical actuation behavior through volume-changing redox reactions. Alfonso H.W. Ngan et al. reviewed a class of stimuli-responsive oxides/hydroxides with turbostratic crystal structures (article number 2000215). Liquid metal alloys are widely used in stretchable strain sensors due to their high electrical conductivity under stretch conditions. Run-wei Li and co-workers used selective wetting and transferring process to fabricate a liquid metal-based resistive strain sensor that exhibits broad strain sensing range, ultralow detection limit, high mechanical robustness, and good repeatability (article number 2000235). The flexible sensor exhibits minimal hysteresis and fast response and demonstrates great potential in human health and motion monitoring, and virtual reality applications.

2. Novel actuation and control strategies for intelligent soft actuators and robots

To improve practical outcomes of soft actuators and robots under complex environments, developing suitable and reliable actuation and control strategies is indispensable. Due to the capabilities of generating large deformation and high force output, pneumatic actuation becomes one of the most promising actuation strategies for soft robots. Guoying Gu and co-workers presented a planar laser cutting and stacking fabrication (PLCSF) approach to create multimaterial pneumatic soft actuators and robots with complex structures (article number 2000257). Multiple degrees of freedom pneumatic soft robots including bioinspired soft hand and crawling robots are fabricated to verify the effectiveness and scalable capability of the PLCSF approach. Dielectric elastomer actuators have been widely used in artificial muscles and soft robots owing to their fast response and high energy density. Jinsong Leng and co-workers reviewed dielectric elastomer actuators and their applications in soft robots (article number 2000282). This review summarizes the working principle, designs, and challenges of dielectric elastomer actuators. To perform targeted operations inside microenvironments, mobile micromachines with external power sources or chemical fuels are essential. Mahmut Selman Sakar et al. delivered a progress report on on-board control systems for untethered microrobots (article number 2000233). A novel shape-morphing strategy for the construction of intelligent micromachines with the capabilities of self-locking and unlocking is developed by Huiling Duan and her team (article number 2000232). The strategy for developing tunable locking couplings offers broad potentials for micromanipulation and promises benefits in developing intelligent micromachines with great adaptability to complex situations.

3. Emerging applications of intelligent soft actuators and flexible devices

Soft actuators and flexible devices with shape-changing capability exhibit promising applications in cargo manipulation, energy harvesting, motion monitoring, and medical treatment. Achieving adaptable and effective grasping for various irregular objects has attracted growing attention in the soft robotics field. Li Wen and co-workers developed a bioinspired origami gripper based on the Yoshimura structure to achieve variable effective length and exhibit adaptation to objects with different sizes and shapes (article number 2000251). Biomimetic approach plays an important role in the design and actuation of soft actuators and robots to generate optimized performance. Inspired by natural plants, Ximin He and co-workers reported a liquid crystal elastomer-based sunlight-driven phototropic system that can achieve large-angle reorientation and enhanced light harvesting (article number 2000234). Cilium structures have been widely found in various species and demonstrate capabilities of guiding movements and clearing foreign matters. Yuanjin Zhao and co-workers reviewed recent progress on tailoring flexible artificial cilia actuators and highlighted their applications on particle/fluid manipulation as well as sensors and robots (article number 2000225). Moreover, miniature soft robots are capable of executing various medical tasks. Lianqing Liu and co-workers developed a flexible magnetically controlled continuum robot in a magnetic actuation system, which exhibits improved manipulability and expanded effective workspace in phantoms (article number 2000211). The integration of new actuation strategies and smart materials into robotic systems is crucial to develop a system-engineered miniaturized robot (SEMR). Vineeth Kumar Bandari and Oliver Schmidt reviewed recent developments and challenges in constructing intelligent SEMRs with functionalities including actuation, sensing, and energy supply (article number 2000284).

Soft actuators and flexible devices are rapidly growing research fields. We hope the papers in this special issue could attract researchers from different disciplines and promote more interdisciplinary cooperation. We also look forward to more advancement to accelerate the growth of this emerging field.

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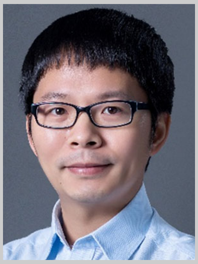

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