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Editorial

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Flexible electronics for intelligent sensing and soft systems

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Flexible electronics have developed from a materials and device concept into a broad platform for sensing, interaction, and soft system integration. The key advantage extends beyond mechanical compliance. Flexible electronics enable sensing functions to be deployed on curved, moving, or deformable surfaces while integrating materials, microstructures, transduction mechanisms, signal processing, and application scenarios within a unified design framework. This integration is opening new routes for wearable healthcare, human–machine interaction, soft robotics, and intelligent operation in environments where rigid devices are difficult to use.

The field is also facing a set of connected technical challenges. High sensitivity must be maintained over a useful pressure or strain range, and flexible devices must remain stable under repeated deformation, environmental disturbance, and interdevice variation. Multimodal platforms need to decouple signals rather than simply amplify them. At the system level, reliable calibration, low-power acquisition, real-time interpretation, and application-specific validation are as important as the sensing element itself. The papers in this first part (Part I) of the special issue "Special Feature on Flexible Wearable and Implantable Electronics and Applications" illustrate how these challenges can be addressed through complementary strategies in structure design, material processing, modeling, algorithms, and system integration.

Part I comprises one review article followed by five research articles. Together, these contributions cover flexible and soft actuation, iontronic pressure sensing, tunable strain sensing, magnetic force sensing, laser-induced graphene sensing arrays, and hybrid temperature-humidity monitoring. The collection also spans a wide range of use cases, including underwater robotics and communication, wearable pulse and motion monitoring, physiological observation, and soft robotic interaction. The common thread is a shift from isolated device performance toward flexible platforms that can perceive, interpret, and respond in real situations.

The review by Shen H et al. (2026) organized the development of flexible magnetic force sensors around fabrication, sensing mechanisms, force decoupling, performance, and application. It compared analytical modeling with data-driven approaches for converting magnetic signals into multidimensional force information, and surveyed applications in wearable

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devices, robotic hands, and soft robotics. The review also identified practical bottlenecks that remain important for translation, including non-uniform magnetic particle distributions, laborious calibration, signal drift, and degradation during cyclic use. Its discussion of bio-inspired design, universal calibration, transfer learning, and artificial intelligence-enhanced integration provided valuable insights for improving consistency and scaling up these sensors beyond laboratory demonstrations.

Zhang et al. (2026) presented a bio-inspired hybrid reconfigurable flexible underwater manipulator that combines rigid self-propulsion modules with modular soft joint modules. The authors developed a soft universal joint model that remains applicable under non-constant-curvature bending and large deformation, thereby extending the modeling range beyond the classical constant-curvature assumption. They further established a priority-based controller that coordinated trajectory tracking with safety-related tasks such as obstacle avoidance and joint-limit protection. Simulations and water-tank experiments, including spiral motion, pitching, linear motion, and obstacle avoidance, showed how flexible morphology and task prioritization can be combined for operation in confined and dynamic underwater environments.

Xiang et al. (2026) developed a high-sensitivity flexible iontronic pressure sensor for both pulse signal detection and underwater intelligent communication. A micro-pyramidal architecture and a carbon-nanotube/ionic-liquid composite sensing layer give the device a sensitivity of 370 kPa^{-1}, response and recovery times of approximately 20 ms, and stable operation over about 20000 cycles. The sensor captures weak human pulse signals with high fidelity. After encapsulation for aquatic operation, it also detects tactile Morse-code signals, which are classified by a deep-learning algorithm. This work demonstrates the potential of flexible sensors for bridging biomedical monitoring and cross-medium human–machine interactions. Recent tactile sensing work further illustrates this transition from sensing hardware to learned perception by reconstructing super-resolution spatial information from sparse sensing units (Kong et al., 2025).

Shen Z et al. (2026) introduced a tunable gated strain sensor that integrates a detachable negative-Poisson-ratio metamaterial structure. The detachable layer modulates the local strain field and allows the sensing response to be adjusted after fabrication by changing the embedment depth, thickness, and microstructural dimensions. The resulting device achieves a strain range from 0% to 100%, with a gauge factor of 3049. A smart resistance-band system further shows personalized motion recognition for users with different heights, highlighting the value of tunability for wearable sports and health monitoring.

Luo et al. (2026) reported a high-sensitivity and robust laser-induced graphene sensing array for spatiotemporal pulse mapping. Precision-machined microgrooves on a polyimide substrate create stress-concentration structures that enhance sensitivity, while MoS_2 modification fills pores and cracks in the laser-induced graphene framework to improve consistency between sensing units. A chemical bonding strategy between polyimide and the outer polydimethylsiloxane layer reduces the influence of atmospheric humidity. The array achieves a sensitivity of 2.205 kPa^{-1} in the 0–15 kPa range and a maximum interdevice error of 6.61%. These properties support reconstruction of pulse signals at the Cun, Guan, and Chi positions. The work also highlights the need for larger-population validation and further reduction of interdevice crosstalk.

Liu et al. (2026) addressed temperature-humidity crosstalk in wearable multimodal sensing through hybrid integration and algorithmic compensation. A copper-constantan thin-film thermocouple provides temperature measurements, while laser-induced graphene interdigital electrodes coated with graphene oxide provide capacitive humidity sensing on the same flexible substrate. The different ionic and electronic conduction mechanisms reduce intrinsic coupling, and a second-order compensation model further corrects the temperature-induced humidity drift. The platform reaches a humidity sensitivity of 31 pF/%RH (relative humidity) and a temperature sensitivity of 29.88 μV/°C, with humidity errors within ±2% RH after compensation. A flexible printed-circuit acquisition module enables wireless operation, and demonstrations include respiration, cough, exercise-related skin changes, and skin-garment microclimate monitoring. That study demonstrates how device architecture and signal processing can be jointly designed for reliable multimodal measurement.

Several broader trends emerge from these contributions. First, geometry is being used as an active sensing and control resource. Micro-pyramids, stress-concentration grooves, negative-Poisson-ratio metamaterials, porous graphene, and soft universal joints each alter how a flexible system responds to force, deformation, or its surroundings. Second, high sensitivity is increasingly being paired with mechanisms for

consistency and decoupling. Encapsulation, heterogeneous transduction, detachable structures, material modification, and compensation algorithms address different parts of the same reliability problem. Third, flexible electronics are moving toward closed-loop systems. The papers connect sensing with deep-learning communication, motion recognition, pulse mapping, physiological interpretation, or priority-based robot control rather than stopping at a raw electrical signal. Recent work extends this co-design strategy to laser-patterned conductive hydrogels for bioelectronic stimulation and recording (Lu et al., 2024; Zhou et al., 2025). Complementary studies published in *Bio-Design and Manufacturing* connect biomimetic sensing films and machine-learning-optimized soft robotics with broad-range sensing and biomedical validation (Wang et al., 2024; Mao et al., 2025).

Several challenges remain to be addressed. Flexible devices need common benchmarks that report sensitivity together with range, hysteresis, drift, repeatability, calibration transfer, and performance under realistic mechanical and environmental conditions. Long-term stability, scalable fabrication, and validation across users and operating settings will determine whether promising prototypes become dependable technologies. The papers in Part I make progress on these issues while also stating their boundaries, including the need for broader population studies, further crosstalk suppression, more general calibration domains, and improved robustness after repeated use. Subsequent parts of this special issue will extend this discussion as additional contributions are accepted.

We hope that this first part of the special issue will provide readers with an overarching perspective on flexible electronics as an integrated engineering discipline that links materials, mechanics, electronics, computation, and application needs. We thank all authors for their contributions and the reviewers for their careful and constructive evaluations. We also hope that the collection will encourage further work on reliable, scalable, and intelligent flexible systems for healthcare, human–machine interaction, soft robotics, and other demanding environments.

Author contributions

Kaichen XU, Xinge YU, Li ZHANG, Tiefeng LI, Peng ZHAO, Jizhou SONG, Geng YANG, and Kewang NAN conceived the scope of the special issue, reviewed the selected contributions, and prepared this editorial. Kaichen XU drafted and revised the final manuscript.

Conflict of interest

The authors declare that they have no conflicts of interest.

Declaration on the use of generative AI tools

No generative AI tools were used in the preparation of this manuscript.

References

Kong D, Lu Y, Zhou S, et al., 2025. Super-resolution tactile sensor arrays with sparse units enabled by deep learning. *Science Advances*, 11(27):eadv2124. https://doi.org/10.1126/sciadv.adv2124

Liu M, Li Z, Dai Y, et al., 2026. Hybrid integration of flexible temperature and humidity sensors with crosstalk decoupling for wearable physiological monitoring. *Journal of Zhejiang University-SCIENCE A*, 27(10):1138-1152. https://doi.org/10.1631/jzus.A2600298

Lu Y, Yang G, Wang S, et al., 2024. Stretchable graphene-hydrogel interfaces for wearable and implantable bioelectronics. *Nature Electronics*, 7(1):51-65. https://doi.org/10.1038/s41928-023-01091-y

Luo G, Pi D, Li W, et al., 2026. High-sensitivity and robust laser-induced graphene sensing arrays for spatiotemporal pulse mapping. *Journal of Zhejiang University-SCIENCE A*, 27(10):1123-1137. https://doi.org/10.1631/jzus.A2600182

Mao Z, Suzuki S, Nabae H, et al., 2025. Machine learning-enhanced soft robotic system inspired by rectal functions to investigate fecal incontinence. *Bio-Design and Manufacturing*, 8(3):482-494. https://doi.org/10.1631/bdm.2400152

Shen H, Xiang Z, Zhang S, et al., 2026. Flexible magnetic force sensors: manufacture, mechanisms, and applications. *Journal of Zhejiang University-SCIENCE A*, 27(10):1046-1072. https://doi.org/10.1631/jzus.A2600069

Shen Z, Wang M, Fu X, et al., 2026. Tunable gated strain sensor integrating detachable metamaterial structures for personalized motion recognition. *Journal of Zhejiang University-SCIENCE A*, 27(10):1107-1122. https://doi.org/10.1631/jzus.A2600179

Wang G, Meng L, Ji X, et al., 2024. Nacre-inspired MXene-based film for highly sensitive piezoresistive sensing over a broad sensing range. *Bio-Design and Manufacturing*, 7(4):463-475. https://doi.org/10.1007/s42242-024-00292-4

Xiang M, Zhai C, Hao C, et al., 2026. High-sensitivity flexible iontronic pressure sensor for pulse signal detection and underwater intelligent communication. *Journal of Zhejiang University-SCIENCE A*, 27(10):1095-1106. https://doi.org/10.1631/jzus.A2500648

Zhang J, Yu J, Chen Y, et al., 2026. Modeling and priority-based control of a bio-inspired hybrid actuation underwater robot with soft universal joint framework. *Journal of Zhejiang University-SCIENCE A*, 27(10):1073-1094. https://doi.org/10.1631/jzus.A2500507

Zhou H, Jin Z, Xu Y, et al., 2025. Enhanced laser-induced PEDOT-based hydrogels for highly conductive bioelectronics. *National Science Review*, 12(6):nwaf136. https://doi.org/10.1093/nsr/nwaf136