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Interactive Intelligent Systems and Haptic Interfaces

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Haptics, which involve human touch sensing and tactile feedback, play a crucial role in the physical interactions of humans with their environment. Touch sensing constitutes the most intuitive and natural way for humans to interact with the digital world, and human–machine interfaces (HMIs) are at the core of these interactions. Over the past decade, the advances in HMIs have revolutionised areas such as robotics, healthcare, assistive technologies, autonomous vehicles, and augmented/virtual reality (AR/VR). More so, the remarkable progress in related underpinning technologies such as 5G/6G communication, internet of things, tactile internet, neurocomputing and machine learning provides a clear prospect towards the realisation of the envisioned smart society. As efforts towards these technologies continue to rise, more intelligent systems and various methods of human interaction with these systems will also continue to evolve.

Apart from the conventional physical touch interaction, humans are now able to interact with 2D objects which are displayed as 3D objects via mid-air displays. In addition to different perception modalities in humans, tactile feedback plays a significant role for an efficient bidirectional interaction with the environment and enriches the user experience. Today, HMIs which can provide both tactile sensing and feedback have also been explored. Overall, the quality of the user experience while interacting with these systems, largely depends on the intuitive nature of the HMI in use, and their ability to provide easy to understand information. Over the years, both wearable and non-wearable HMIs have significantly evolved and effectively adapted for use in various intelligent systems such as those for human-robot interaction, human-in vehicle interaction, assistive technology, and VR/AR.

One of the several challenges in HMIs technologies are issues such as bulky size, lack of intuitiveness, and high control precision, especially for monitoring the human motions or transmitting complex commands. However, novel wearable technologies are gradually revolutionizing our life by integrating the flexible sensors onto our body for a more intuitive and accurate detection of physical command through our body. More so, the burgeoning field of material sciences has increasingly enabled the fabrication of novel stretchable and even implantable devices to sense or stimulate the human activities during various interactions scenarios. With this, future intelligent systems are envisioned to be more intuitive and interactive. To develop a highly intuitive and intelligent interactive system, it is highly advantageous and encouraged to consider existing HMI technologies, tactile sensors, materials, computational techniques, soft actuators as well as advances in haptic interfaces suitable for the realization of such systems. To showcase the recent advances in this rapidly growing field, we have organised this special issue of *Advanced Intelligent Systems* focusing on "Interactive Intelligent Systems and Haptic Interfaces". It covers various existing intelligent systems, HMIs, sensors, soft actuators, materials, and computational techniques, for applications in robotics, autonomous vehicles, and smart flexible/wearable electronics. The following paragraphs, summarizes the key contributions to this special issue.

Christou et al. (article number 2000126) realised an interactive 3D touch surface using frustrated total internal reflection and four-sided pyramidal pseudo-holographic projection. This pseudo-holographic display allows gesture-based control and smooth touch interaction through facile and inexpensive hardware and open-source software tools. In another related work, Christou et al. (article number 2100090) also presented an air-based haptic feedback device, named "Aerohaptics", which has the capability to deliver mid-air tactile feedback while the user is interacting within a custom-made pseudo-holographic display. The haptic feedback provided by this device has a controllable intensity and is capable of being directed on to specific location of the user hand during interaction with a virtual object. The reported device is quite simple and cost-effective as it does not require any wearable peripheral. Buhl et al. (article number 2100037), presented a technique for customising the tactile and visual perception of organic light emitting diodes. This provides opportunities for the realization of transparent and flexible devices for application in various objects such as clothing, windows etc. for tactile and visual interaction. To achieve this, the authors utilized a polymer coating to customize the tactile and visual perception capabilities of an OLED substrate. This has the potential to enable the adjustment of haptic and optical characteristic of devices without altering their OLED spectral emission characteristics. Shuo et al. (2100074), presented a comprehensive review on tactile and visual perception which provides the fundamentals, insights, and working mechanisms of tactile and visual sensing, as well as their various applications.

Recently, hand gesture recognition has attracted huge interest, as an approach for human-machine interaction, and flexible

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The ORCID identification number(s) for the author(s) of this article can be found under https://doi.org/10.1002/aisy.202100172.

DOI: 10.1002/aisy.202100172

strain sensor is rapidly being explored as a means of measuring the finger motion for accurate hand gesture recognition. Si et al. (article number 2100046) presented a review on flexible strain sensor for hand gesture applications. This review is timely and provides detailed progress on the materials, structures, and operation mechanisms of various flexible strain sensor for hand gesture recognition. While this work focuses specifically on the in-depth review of strain sensors for hand recognition, Ozioko et al. (article number 2100091) presented another review on smart tactile gloves for haptic interaction, communication and rehabilitation, including smart gloves where strain sensors have been utilized for hand gesture recognition. This is also a timely review considering that wearable devices are rapidly finding their way into our lives, and glove-based HMIs have attracted considerable interest in recent years. These gloves are worn on the hand, and hand gesture is one of the most intuitive ways for human to interact. The paper also discussed the possibility and prospects of tapping into the multi-functional capabilities of electronic skin (e-skin) for the realisation of glove-based HMIs for a more intuitive and richer user interaction experience. Further, the huge potential of integrating sensing and actuation for bidirectional haptic interaction for applications such as robotics, healthcare, sensorial augmentation for non-disabled and tactile internet etc. were also discussed. Marius et al., in their work (2100045), provided a framework for designing and evaluating gesture interaction in the low-dimensional space.

Further, soft actuators are increasing becoming attractive for application in interactive human machine interfaces due to their soft and conformal nature. Karipoth et al. (article number 2100092), presented a bio-inspired inchworm and earthworm like soft robot with intrinsic strain sensing capability. Apart from the huge advantage of adding sensing to soft robots for realization of a more intelligent system, the strain sensor presented in this work, (with a high stretchability of up to 900%), could also be adopted for use in hand gesture recognition where it will measure hand movements during interactions. Additionally, Chen et al. (article number 2100075) presented a comprehensive review on low-voltage soft actuators for interactive human interfaces. Low-voltage soft electrical actuators presents advantages such as good safety, low power consumption, small system size. To provide the progress in this field, this review covers three typical classes of electrical actuators, namely electrochemical, electrothermal, and other electrical characteristics. Additionally, the advantages, working principle, device configuration/design, materials selection, including the challenges and solutions were presented. Another review by Ankit et al. (article number 2100061) covers soft actuator materials for electrically driven haptic interfaces. This review summarises the advancement in material for electrically driven soft actuators. It further provided a detailed analysis of the different strategies for improving the electromechanical performance of existing material, and approaches for synthesizing novel materials for such actuators. The paper concluded by reflecting on the challenges in the field and the prospects of this material for future applications

Armleder et al. (article number 2100047), presented a control architecture that can support the deployment of large-scale robot skin in a human–robot collaboration scenario. The authors showed how whole-body tactile feedback can extend the capabilities of robots during dynamic interactions by providing information about multiple contacts across the robot's surface. From the obtained results, this paper concludes that multi-modal tactile information enables robust force control while still simultaneously responding to user's interactions. Taisuke et al. in his work (2100038), provided a potential solution to the tradeoff during physical human-robot interaction using bipedal walking control.

In addition to the advances in human–computer interaction, there has been a recent interest in human–vehicle interaction (HVI) which takes place inside the vehicle. This is owing to the rapidly growing interest in autonomous vehicles. To present the recent progress in this field, Murali et al. (article number 2100122) presented a review on intelligent in-vehicle interaction technologies. This timely article systematically summarized the technologies that are being used or developed to perceive user's intentions for natural and intuitive in-vehicle interaction. Further, it discussed the inherent challenges, potential solutions, and future research direction in this area.

We hope that this special issue focusing on Interactive Intelligent Systems and Haptic Interfaces will bring knowledge, insight, and inspiration to readers. We look forward to the rapid growth of the massive developmental efforts in this field which will lead us right into the envisioned smart society.

Finally, we appreciate all the authors for their valuable contributions, and very thankful to the editorial team of *Advanced Intelligent Systems* for their support and the opportunity to organize this special issue.

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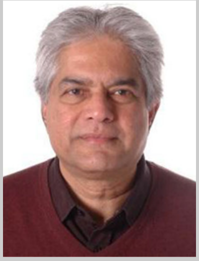

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