Guest Editorial of the Special Section on Human Machine Interface for Next Generation Consumer Electronics

I. Introduction

IN THE past decade, benefiting from the exposure of Internet-of-Things (IoT) and information and communications technology (ICT), consumers are experiencing an increased link to electronics in the digital world and enjoying the drastically convenient and smart applications. The human-machine interface (HMI) serves as a channel for users to communicate their intentions, get feedback, and manage numerous systems and gadgets. For consumer electronics, the graphical user interface (GUI) has been widely adopted and continues to be dominant. However, with increasing sophisticated functions has been integrated in consumer electronics, GUIs sometimes become complicated and time-consuming. In most cases, users need to read the instruction or be pre-trained on how to operate the GUI. Thus, people have been forced to adapt to devices in this manner, which is inefficient, indirect, and more machine-centric than human-centric. Meanwhile, the continuous innovating breakthrough in AI (artificial intelligence) has been the focus for technical research across the globe. Deloitte survey indicates that the global AI market has reached USD1.9 trillion by 2019 and is expected to exceed USD6 trillion by 2025, with a compound growth rate of 30% from 2017 to 2025. Artificial intelligence has a profound impact across industries, especially since people are beginning to implement its capabilities across verticals. This is truer in the case of HMI design. One of the most seamless ways that AI is enhancing HMI design is with the use of AI-powered assistants. This includes Siri, Alexa, Google Assistant, and more which allow human interactions with devices using natural language. Indeed, technologies such as touchscreens, voice recognition, gesture control, virtual reality (VR), augmented reality (AR), brain-computer interfaces (BCI), are all included and expected to diversify the next generation of HMIs.

Despite much progress, a plethora of challenges for AI-driven human-machine interfaces have to be tackled. Consumer electronics usually face dynamic implementation scenarios and environments, plenty of research efforts are still required to achieve the best practice of HMI. Therefore, this special session on "Human Machine Interface for Next-Generation Consumer Electronics" focuses on the development and applications of advanced technologies and methodologies for the future HMI in consumer electronics towards a higher level of human-centric smart applications and collaborations.

II. Related Articles

This Special Section of the IEEE Transactions on Consumer Electronics explores various aspects of Human-Machine Interface (HMI) technologies for next-generation consumer electronics, fostering in-depth discussions on the design, development, and optimization of advanced HMI systems. These innovations are driving consumer electronics towards more intuitive, adaptive, and immersive experiences, reflecting the rapid evolution of user interaction paradigms. With the increasing focus on research targeting seamless interaction between humans and machines, this Special Section is both timely and impactful, attracting numerous submissions. Among them, 8 high-quality research papers have been accepted, providing valuable insights and guidance for the future advancement of HMI in consumer electronics, paving the way for smarter, more user-centric devices in the next generation.

All the accepted papers are summarized as follows:

First, two papers focus on voice user interface (VUI), which has been regarded as a more ideal way for interaction with machines. Chen et al. [A1] proposes a novel MambaDC for speech enhancement, which marries the benefits of convolutional networks to model the local interactions and Mamba's ability for modeling long-range global dependencies. This work enhances the information path to machines. In contrast, Wang et al. [A2] focus on the feedback from machines. The authors address audio-driven talking face generation challenges by proposing two novel inference-stage strategies: Manual Temporal Segmentation (MTS) to reduce temporal complexity and Static Facial Reference (SFR) to stabilize dynamic sequences. These works on VUI provide a more flexible HMI in the future.

Two papers focus on gesture recognition (GR), which is an emerging topic in HMI. Fang et al. [A3] combines TD-CNN and a lightweight attention-free transformer (DIFormer), the proposed MDFNet achieves highly accurate device-free gesture recognition by effectively fusing multi-domain features. Besides, Li et al. [A4] proposes PENCIL, a prototype-enhanced compositional learning method for class-incremental hand gesture recognition (CI-HGR), enabling exemplar-free continuous learning of new gestures without catastrophic forgetting. PENCIL reduces the inter-gesture confusion, it also achieves remarkable accuracy with dramatic overhead

Digital Object Identifier 10.1109/TCE.2025.3596448

reduction. These work advance HMI by enabling contactless, fine-grained gesture control and scalable gesture recognition, potentially can be adopted in various CEs.

The authors of the paper [A5] Fan et al. introduces DAIG, a novel domain adaptation framework for cross-subject EEG motor imagery classification, which combines EEGBiMamba for bidirectional temporal feature extraction and inverse Gram matrix alignment to reduce inter-subject variability. By replacing traditional MLPs with Kolmogorov-Arnold Networks (KAN), it achieves significant accuracy improvements, advancing brain-computer interfaces (BCIs) robustness for real-world applications.

This work [A6] from Zhang et al. addresses the challenges of multi-person motion detection by proposing TSRFormer, a model that integrates spatiotemporal and relational features for 3D pose forecasting. The advancements in accurately forecasting multi-person movements contribute to more intuitive and adaptive human-machine interactions, particularly in applications like robotics, gaming, and AR/VR systems.

Wu et al. focus on [A7] human-robot interface, presents an immersive VR-based robotic teleoperation system enhanced with haptic feedback and adaptive collision avoidance (tele-MPPI) to address key limitations in current platforms. By combining real-time hand tracking, tactile gripper feedback, and predictive motion planning, the system enables safe and precise manipulation of delicate objects in cluttered environments. Experimental results validate its effectiveness in reducing collisions while maintaining operational efficiency, advancing human-robot collaboration for complex tasks.

Another advantage of HMI is to provide a higher level of convenience to enhance user experience, such as crowd counting. Lei and Wang introduce D3CrowdNet [A8] to address the challenge of uneven crowd density distribution by introducing a DPA module to capture depth variations and improve spatial representation accuracy. Its DAGC module dynamically learns density patterns by modeling internal density relationships, while the MCDA mechanism balances focus on individual pedestrians and surrounding crowd context. CEs can integrate advanced crowd counting algorithms to effectively monitor traffic.

We sincerely appreciate the outstanding work and commendable efforts of all the authors who contributed their research to this Special Section. Furthermore, we extend our heartfelt gratitude to the reviewers for their invaluable feedback and professional insights, which they generously provided on a voluntary basis to enhance the quality of the submitted papers. Lastly, we express our deep appreciation to the Editor-in-Chief of IEEE TRANSACTIONS ON CONSUMER ELECTRONICS, Prof. K. F. Tsang, for his unwavering support and guidance throughout the editing process, which was instrumental in bringing this Special Section to fruition.

APPENDIX: RELATED ARTICLES

[A1] M. Chen et al., "Selective state space model for monaural speech enhancement," *IEEE Trans. Consum. Electron.*, vol. 71, no. 2, pp. 5408–5418, May 2025, doi: 10.1109/TCE.2024.3523297.

[A2] Z. Wang, Y. Wang, T. Liu, P. Zhang, L. Xie, and Y. Guo, "Audio-driven talking face generation with segmented static facial references for customized health device interactions," *IEEE Trans. Consum. Electron.*, vol. 71, no. 2, pp. 5398–5407, May 2025, doi: 10.1109/TCE.2025.3565518.

[A3] C. Fang, Y. Wang, M. Zhou, X. Yang, J. Wang, and B. Peng, "Device-free gesture recognition using multidimensional feature representation and lightweight self attention-free transformer," *IEEE Trans. Consum. Electron.*, vol. 71, no. 3, pp. 8727–8743, Aug. 2025, doi: 10.1109/TCE.2025.3580936.

[A4] Z. Li, X. Zhang, Y. Guo, S. Cai, and M. Lao, "PENCIL: Prototype-enhanced compositional learning for class-incremental hand gesture recognition," *IEEE Trans. Consum. Electron.*, early access, May 14, 2025, doi: 10.1109/TCE.2025.3569912.

[A5] C. Fan et al., "A domain adaptation framework by aligning the inverse gram matrices for cross-subject motor imagery classification," *IEEE Trans. Consum. Electron.*, vol. 71, no. 2, pp. 5384–5397, May 2025, doi: 10.1109/TCE.2025.3573773.

[A6] Y. Zhang, C. Cai, X. Luo, P. Li, and Y. Ye, "Temporal-spatial-relation former for multi-person motion prediction," *IEEE Trans. Consum. Electron.*, vol. 71, no. 3, pp. 8742–8751, Aug. 2025, doi: 10.1109/TCE.2025.3582624.

[A7] F. Wu et al., "A VR-based robotic teleoperation system with haptic feedback and adaptive collision avoidance," *IEEE Trans. Consum. Electron.*, vol. 71, no. 3, pp. 8752–8761, Aug. 2025, doi: 10.1109/TCE.2025.3580966.

[A8] Y. Lei and X. Wang, "Weakly supervised crowd counting via depth and density perception with dispersed attention in smart surveillance of HMI," *IEEE Trans. Consum. Electron.*, vol. 71, no. 2, pp. 5372–5383, May 2025, doi: 10.1109/TCE.2025.3548296.

HONGXU ZHU, *Guest Editor (Lead)*
Fano
Hong Kong, China
E-mail: joe.zhu@fano.ai

HAO RAN CHI, *Guest Editor*
Instituto de Telecomunicações
Universidade de Aveiro
3810-193 Aveiro, Portugal
E-mail: haoran.chi@ua.pt

XINYUAN QIAN, *Guest Editor*
School of Computer and Communication Engineering
University of Science and Technology Beijing
Beijing 100083, China
E-mail: qianxy@ustb.edu.cn

RUI LIU, *Guest Editor*
National and Local Joint Engineering Research Center of Mongolian Intelligent Information Processing
Inner Mongolia University
Inner Mongolia 010031, China
E-mail: liurui_imu@163.com

QI LIU, *Guest Editor*
School of Future Technology
South China University of Technology
Guangzhou, Guangdong, China
E-mail: drliuqi@scut.edu.cn