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Editorial

Advances in Architecture, Protocols, and Challenges in Internet of Things: From Technologies to Applications

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With the rapid development and widespread application of Internet of Things (IoT) technology, we are in an era of digital transformation, where the integration between the physical and digital worlds continues to deepen [1–3].In this context, this Special Issue aims to explore the latest developments in the field of IoT, the evolution of relevant protocols, and the challenges faced. As a key technology connecting objects and networks, the IoT has shown enormous potential in various domains. In smart homes, IoT technology enables interconnected household devices [4,5], allowing for smart control and remote monitoring, thereby enhancing convenience and comfort in daily life. In industrial automation [6,7], IoT technology facilitates real-time communication and data exchange between devices, thus improving production efficiency and resource utilization. In smart city management [8,9], IoT technology can assist cities in achieving functions such as smart transportation, intelligent energy management, and environmental monitoring, thereby enhancing the efficiency and sustainable development capabilities of urban operations. However, as the scale of the IoT continues to expand and the number of application scenarios increases, it also brings about numerous technological and security challenges. One of these challenges is interoperability and standardization issues among IoT devices. Devices produced by different manufacturers may use different communication protocols and data formats, leading to ineffective interaction and integration between devices. Additionally, IoT devices typically have lower computing and storage capabilities, making them vulnerable to security attacks [10], which could result in issues such as data breaches [11] and device tampering [12]. Furthermore, privacy protection and data security are also significant challenges faced by the IoT. A large amount of personal and sensitive data are collected and transmitted by IoT devices, and if leaked or misused, it could have serious implications for individuals and society.

Therefore, this Special Issue is titled "Advances in Architecture, Protocols, and Challenges in the Internet of Things", focusing on the innovation of IoT architecture, protocols, and the various challenges encountered in practical applications. We aim to provide a platform for an in-depth exploration and exchange of ideas for researchers in the IoT field, facilitating collaborative efforts to explore the development directions of IoT technology and promote its broader application and advancement across various domains. Following peer review, this Special Issue includes seven papers (one review, five articles, and one communication). L. Zhang et al. (Contributor 1) proposed a fuzzy learning-based method for predicting human emotion labels in the IoT by considering the ambiguity of composite emotions and emotion labels. This method can simultaneously handle multiple fuzzy emotion labels. Initially, the authors utilized fuzzy sets to construct a fuzzy label distribution system representing facial expressions. Subsequently, two fuzzy label distribution prediction methods based on fuzzy rough sets were proposed to address the issue of composite emotion prediction. By calculating upper and lower approximations, the probability of a sample belonging to an emotion could be obtained. The experimental results demonstrate that the algorithm not only effectively predicts human emotion labels, but can also be applied to other label distribution prediction tasks. This method represents a more general approach to label distribution prediction, making it suitable for deployment in artificial intelligence-based IoT systems.

Additionally, in the IoT, infrared (IR) image preprocessing is often employed for image denoising and enhancement to facilitate small target detection. Traditional denoising methods based on nuclear norm minimization (NNM) average all feature values, blurring specific details, thereby failing to achieve satisfactory denoising performance. J. Chen et al. (Contributor 2) proposed a method that combines weighted nuclear norm minimization (WNNM) with adaptive similar patch fusion for searching IR images based on group sparse representation. They adaptively select similar structural blocks according to specific computational criteria and use k-nearest neighbor (KNN) clustering to form more similar groups, which helps in the recovery of complex backgrounds with high Gaussian noise. Furthermore, the authors narrowed down the feature values with different weights in the WNNM model to solve the optimization problem. The results demonstrated that the proposed method can recover more detailed information in the images. This algorithm not only achieved good denoising performance in regular image denoising, but also demonstrated excellent performance in denoising IR images. It showed effective denoising results on commonly used datasets as well as real-world IR images.

Speech synthesis is one of the key technologies in IoT [13,14]. At this stage, end-to-end speech synthesis systems are capable of generating relatively realistic human-like voices. However, the commonly used parallel text-to-speech systems currently suffer from the loss of useful information during the two-stage conversion process, resulting in the monotonous control characteristics of the synthesized speech, with insufficient expression of features such as emotion. This makes emotion-based speech synthesis a challenging task. To address this issue, W. Zhao et al. (Contributor 3) proposed a new system called Emo-VITS, which is based on the expressive speech synthesis module VITS, aiming to achieve emotion control in text-to-speech synthesis. They designed an emotion network to extract global and local features from reference audio, and then fused these features using an attention-based emotion feature fusion module, enabling more accurate and comprehensive emotion speech synthesis. Their experimental results demonstrate that, compared to networks without emotion, the Emo-VITS system outperforms other networks in terms of naturalness, sound quality, and emotion similarity, albeit with a slight increase in error rates.

W.-W. Jin et al. (Contributor 4) proposed a deep learning model for road surface damage detection based on local minimum gray-value feature points. Initially, they segmented image patches from image windows composed of feature point neighborhoods to form an image patch dataset. These image patches were then fed into a Convolutional Neural Network (CNN) for model training, where they extracted features from the image patches. During the testing phase, feature points and image patches were selected from test images, and the trained CNN model could output feature vectors for these feature image patches. All feature vectors were combined into a composite feature vector, serving as the feature descriptor for the test image. Finally, a model classifier constructed using Support Vector Machine (SVM) was utilized to classify whether the image window contained damaged areas. The experimental results demonstrate that the proposed road surface damage detection method based on feature-point image patches and feature fusion achieves higher accuracy and efficiency.

G. Chen et al. (Contributor 5) proposed a novel algorithm to solve the resource allocation problem for enhanced Mobile Broadband (eMBB) and Ultra-Reliable and Low-Latency Communications (URLLC) services with the help of dual connectivity (DC). Firstly, the authors considered a heterogeneous network scenario that encompassed two typical network slices. In this scenario, DC was employed to address the issue of lower quality of experience for users caused by limited network resources in small base stations (SBSs) [15]. Building upon this, the authors formulated an optimization problem with weighted objectives of system throughput, system quality, and additional system energy, and they proved that this problem is an NP-hard problem. Next, due to the non-convex and combinatorial nature of the problem, the authors proposed a slicing resource allocation algorithm called the dueling double deep Q-network with long short-term memory (LSTM-D3QN), aiming to improve the overall utility of the network while ensuring quality of experience (QoE). The complexity of this algorithm was also analyzed. Simulation results showed the effectiveness and convergence of the proposed algorithm by comparing it with other Deep Reinforcement Learning (DRL) algorithms. In addition, the authors extensively compared the utility of the system and the QoE of users with and without the assistance of DC technology, demonstrating that users and the network system achieve higher QoE and throughput in most cases when aided by DC technology. Furthermore, the authors assessed the impact of different numbers of users in the environment on different optimization objectives. The proposed algorithm was able to maximize the overall utility of the system while ensuring user experience quality.

The fifth-generation mobile communication system, 5G, provides high bandwidth, low latency, and massive connectivity for various IoT applications [16]. The widespread adoption of 5G has brought about significant changes in the IoT domain [17,18], fostering the development of intelligent transportation, smart factories, and smart cities. Various IoT technologies such as autonomous driving, intelligent video, autonomous mining faces, industrial control, and intelligent robot inspection are crucial in the field of smart mining. In key areas such as main transport routes, mining faces, and underground substations, frequency-domain interference and crosstalk are major factors affecting the stability and reliability of 5G signals. To improve the performance of 5G in mines, L. Zhang et al. (Contributor 6) designed a fusion anti-interference scheme. Based on deep complex networks and blind source separation, this scheme enables the periodic monitoring and filtering suppression of signal interference. The test results demonstrate that this method achieves 20% higher suppression capability for frequency-domain excitation compared to traditional equalization methods. Regarding frequency-domain crosstalk, the proposed method can eliminate 90% of the interference without introducing additional delays when compared to traditional blind source separation methods. Additionally, it ensures the high bandwidth and low latency characteristics of 5G communication. S. Szymoniak et al. (Contributor 7) published a survey on key protocols and authentication protocols in the Internet of Things (IoT). They collected research papers focusing on security issues, particularly in the context of the IoT. These papers propose new protocols aimed at addressing vulnerabilities in existing protocols, defining secure communication processes and encryption techniques. The authors analyze the security levels, vulnerabilities, and computational and communication costs associated with these protocols. Furthermore, they discuss the theoretical aspects of the IoT environment, encryption methods that can be employed for secure communication, and network attacks that could compromise the security of the considered environment. In their paper, they emphasize the importance of key protocols, distribution processes, and the authentication of users or devices in such networks. These processes provide crucial communication steps as they prevent unauthorized users from accessing session keys and unauthorized access by users or devices.

In conclusion, in this era of digital transformation, we are facing tremendous opportunities and challenges. Firstly, it is necessary to strengthen interoperability and standardization among Internet of Things (IoT) devices, promoting unified communication protocols and data formats across industries. Secondly, it is important to enhance the security of IoT devices, including improving the security design of the devices themselves and establishing comprehensive security monitoring and response mechanisms. Additionally, it is essential to strengthen the protection of personal privacy and data security by enacting relevant laws, regulations, and policies to regulate the collection, transmission, and usage of IoT data, ensuring the security and privacy rights of individuals. To fully leverage the advantages of IoT technology and address the challenges it faces, comprehensive measures need to be taken. Through these measures, we can better promote the development and application of IoT technology, achieve deep integration between the physical and digital worlds, and propel digital transformation to new heights. From complex emotion prediction to infrared recognition, speech synthesis, road damage detection, network slicing resource allocation, and the periodic monitoring and suppression of signal interference in 5G communication in mines, the development of these technologies not only drives innovation in the IoT field, but also profoundly impacts our lives and work. Through continuous research and innovation, we can better understand human emotions, improve the efficiency of security monitoring, enhance communication reliability, effectively manage resources, and respond to challenges. The application of these technologies not only makes our lives more convenient, safe, and intelligent, but also creates a more connected and intelligent world. In the future, we need to continue strengthening cooperation, jointly overcome technological and security challenges, and promote the healthy development of IoT technology. Only through continuous innovation and collaboration can we better seize the opportunities of digital transformation and achieve shared progress between technology and society.

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