Guest Editorial AI and 5G Empowered Internet of Medical Things

THE recent developments in biomedical sensors, wireless communication systems, and information networks are transforming the conventional healthcare systems. The transformed healthcare systems are enabling distributed healthcare services to patients who may not be co-located with the healthcare providers, providing early diagnoses, and reducing the cost in the healthcare section. The Internet of Medical Things (IoMT), which includes medical devices, wearable devices, sensors and apps, is a critical piece of the digital transformation of healthcare, as it allows new business models to emerge and enables changes in work processes, productivity improvements, cost containment and enhanced customer experiences. IoMT can help monitor, inform and notify not only care-givers, but provide healthcare providers with actual data to identify issues before they become critical or to allow for earlier invention.

While IoMT offers enormous benefits, the ubiquitously connected devices also pose new challenges. On the one hand, there has been a great improvement in cyberinfrastructure in the era of Industry 4.0, which enables high-frequency long term observational medical data being collected with the help of IoMT. How to convert these data into relevant critical insights that can then be used to provide better care poses a great challenge. On the other hand, although IoMT applications can run well on exiting wireless communication technology, i.e., 4G LTE, there will be others in the future that will require single-digit milliseconds latency and massive bandwidth such as telesurgery. To tackle these challenges, integration AI and 5G into IoMT may achieve an elegant breakthrough in terms of seamless interoperability, low cost, high speed, and low latency, and increased efficiency.

This special issue is meant to present the state-of-the-art research on AI and 5G empowered IoMT. This special section provides a venue to comprehensively cover algorithms, frameworks, technologies, and applications of AI and 5G empowered IoMT. After a strict peer review, 13 papers were selected for publication in this special issue. Details of these selected papers are as follows.

The first paper by Manogaran *et al*. [A1] introduces cognitive data processing method for uncertainty analysis (CDP-UA) to improve WS data management's efficiency. CDP-UA addresses uncertainties in two levels namely aggregation and dissemination of WS data. The uncertainties in synchronizing aggregation and dissemination slot mapping are addressed using classification learning. In the dissemination process overloaded intervals are identified and segregated using regression learning and conditional sigmoid function analysis. The joint learning process helps to classify overloaded and latency-centric dissemination and aggregation instances to improve WS data delivery in the clinical/medical analysis center.

The second paper by Feng *et al.* [A2] proposes a new framework for colonoscopy pathology WSI analysis, including lesion segmentation and tissue diagnosis. It contains an improved U-Net with a VGG net as backbone, and two schemes respectively for training and inference (the training scheme and inference scheme). Especially, they proposed a class-wise Dice loss function to balance the numbers of benign and malignant samples. The abundant experiments demonstrated that our framework yields very good performance on the dataset of the DigestPath 2019 Challenge. The final submission version of our framework achieved a DSC of 0.7789 and AUC of 1 on the online test dataset, and they won the 2nd place in the DigestPath 2019 Challenge.

The third paper by Ju *et al*. [A3] proposes a method called synergic adversarial label learning (SALL) which leverages relevant retinal disease labels in both semantic and feature space as additional signals and train the model in a collaborative manner using knowledge distillation. Our experiments on DR and AMD fundus image classification task demonstrate that the proposed method can significantly improve the accuracy of the model for grading diseases by 5.91% and 3.69% respectively. In addition, the authors conduct additional experiments to show the effectiveness of SALL from the aspects of reliability and interpretability in the context of medical imaging application.

The fourth paper by Cao *et al.* [A4] proposes a novel multichannel lightweight model (ML-Net), that provides a new solution for portable detection devices with limited resources. In ML-Net, each electrocardiogram (ECG) lead is assigned an independent channel, ensuring data independence and preserve the ECG characteristics of different angles represented by different leads. Moreover, convolution kernels of heterogeneous sizes are utilized to achieve accurate classification with only a small amount of lead data. Extensive experiments over actual ECG data from the PTB diagnostic database are conducted to evaluate ML-Net. The results show that ML-Net outperforms comparable schemes in diagnosing MI, and it requires lower computational cost and less memory, so that portable devices can be more widely used in the field of Internet of Medical Things(IoMT).

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The fifth paper by Zhang *et al.* [A5] proposes a graph based multichannel feature fusion (GBMFF) method to utilize the multichannel features of the wrist pulse signals effectively. In detail, two different sensors, i.e., pressure and photoelectricity are used to capture the three channels of the wrist pulse signals. These are used to generate two different features by applying the stacked sparse autoencoder and wavelet scattering. Each feature of one wrist pulse sample is regarded as a node associated with its corresponding feature vector, and used to construct a graph for one candidate. Experimental results indicate that the proposed AI-based method can obtain superior performances compared to other state-of-the-art approaches.

The sixth paper by Zhao *et al.* [A6] proposes a deep active semi-supervised learning framework, DSAL, combining active learning and semi-supervised learning strategies. In DSAL, a new criterion based on deep supervision mechanism is proposed to select informative samples with high uncertainties and low uncertainties for strong labelers and weak labelers respectively. The internal criterion leverages the disagreement of intermediate features within the deep learning network for active sample selection, which subsequently reduces the computational costs.

The seventh paper by Zhu *et al.* [A7] proposes a two-way multi-ringed forest (TMR-Forest) to estimating the malignancy of the pulmonary nodules for false positive reduction (FPR). Based on their previous work of deep decision framework, named MR-Forest, the authors generate a growing path mode on predefined pseudo-timeline of L time slots to build pseudospatiotemporal features. It synchronously works with FPR based on MR-Forest to help predict the labels from a dynamic perspective. Concretely, Mask R-CNN is first used to recommend the bounding boxes of ROIs and classify their pathological features. Afterward, hierarchical attribute matching is introduced to obtain the input ROIs' attribute layouts and select the candidates for their growing path generation. The selected ROIs can replace the fixed-sized ROIs' fitting results at different time slots for data augmentation. A two-stage counterfactual path elimination is used to screen out the input paths of the cascade forest. Finally, a simple label selection strategy is executed to output the predicted label to point out the input nodule's malignancy.

The eighth paper by Astillo *et al*. [A8] proposes a specification-based misbehavior detection system (SMDS) as an alternative solution to effectively mitigate security threats. Moreover, an outlier detection algorithm is also introduced to validate integrity of unprotected data transmitted by the different components. The monitor agent applies a smoothened-trust-based scheme to assess the trustworthiness of the APS.

The ninth paper by Tanveer *et al.* [A9] proposes a novel Sparse Pinball loss Twin Support Vector Clustering (SPTSVC). The proposed SPTSVC involves the the ε-insensitive pinball loss function to formulate a sparse solution. Pinball loss function provides noise-insensitivity and re-sampling stability. Numerical experiments on synthetic as well as real world benchmark datasets are performed to show the efficacy of the proposed model. An analysis on the sparsity of various clustering algorithms is presented in this work. In order to show the feasibility and applicability of the proposed SPTSVC on biomedical data, experiments have been performed on epilepsy and breast cancer datasets.

The tenth paper by Niu *et al*. [A10] introduces a novel DDTL framework (DFF) for medical imaging. They apply the proposed framework on COVID-19 diagnosis task to justify its proficiency. Moreover, they conduct experiments with another 5 methods with different leaning manners: non-transfer, fine-tuning, DDTL (SLA).

The eleventh paper by Qian *et al.* [A11] proposes a verifiable private set intersection scheme to achieve fine-grained profile matching. On the one hand, the privacy data of patients can be divided by multi-tag to implement fine-grained operations. On the other hand, re-encryption technique is utilized to protect the privacy of patients. In addition, the cloud server may violate the scheme, thus a verifiable mechanism is leveraged to check the correctness of computation. The analysis of security indicates that the proposed scheme can resist the untrusted cloud server and the performance simulation demonstrates that our scheme improves efficiency by reducing the use of bilinear pairs.

The twelfth paper by Moqurrab *et al*. [A12] presents a novel approach to detect clinical entities from clinical notes. Most of the existing studies focus on large and complex architectures to extract the clinical entities accurately but ignore local context. In contrast to existing studies, the proposed study incorporates local context along with global context. The proposed study presents a novel architecture that is based on CNN, Bi-LSTM, and CRF. CNN and Bi-LSTM are used to extract the local and global context, respectively.

The thirteenth paper by Wu *et al*. [A13] develops a well-designed framework suitables for practical applications for thyroid nodule detection in ultrasound videos. Particularly, in order to make full use of the characteristics of thyroid videos, the authors propose a novel post-processing approach, called Cache-Track, which exploits the contextual relation among video frames to propagate the detection results into adjacent frames to refine the detection results. Additionally, their method can not only detect and count thyroid nodules, but also track and monitor surrounding tissues, which can greatly reduce the labor work and achieve computer-aided diagnosis.

All 13 papers tackle different aspects of AI and 5G empowered IoMT. We believe this Special Issue will raise awareness the importance of IoMT using AI and 5G in smart healthcare systems.

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APPENDIX: RELATED ARTICLES

[A1] G. Manogaran, M. Alazab, H. Song, and N. Kumar, "CDP-UA: Cognitive data processing method wearable sensor data uncertainty analysis in the Internet of Things assisted smart medical healthcare systems," *IEEE J. Biomed. Health Informat.*, to be published, doi: 10.1109/JBHI.2021.3051288.

[A2] R. Feng, X. Liu, J. Chen, D. Z. Chen, H. Gao, and J. Wu, "A deep learning approach for colonoscopy pathology WSI analysis: Accurate segmentation and classification," *IEEE J. Biomed. Health Informat.,* to be published, doi: 10.1109/JBHI.2020.3040269.

[A3] L. Ju *et al.*, "Synergic adversarial label learning for grading retinal diseases via knowledge distillation and multi-task learning," *IEEE J. Biomed. Health Informat.*, to be published, doi: 10.1109/JBHI.2021.3052916.

[A4] Y. Cao *et al.*, "ML-Net: Multi-channel lightweight network for detecting myocardial infarction," *IEEE J. Biomed. Health Informat.*, to be published, doi: 10.1109/JBHI.2021.3060433.

[A5] Q. Zhang, J. Zhou, and B. Zhang, "Graph based multichannel feature fusion for wrist pulse diagnosis," *IEEE J. Biomed. Health Informat.*, to be published, doi: 10.1109/JBHI.2020.3045274.

[A6] Z. Zhao, Z. Zeng, K. Xu, C. Chen, and C. Guan, "DSAL: Deeply supervised active learning from strong and weak labelers for biomedical image segmentation," *IEEE J. Biomed. Health Informat.*, to be published, doi: 10.1109/JBHI.2021.3052320.

[A7] H. Zhu *et al.*, "Two-Way MR-Forest based growing path classification for malignancy estimation of pulmonary nodules," *IEEE J. Biomed. Health Informat.*, to be published, doi: 10.1109/JBHI.2021.3057627.

[A8] P. V. Astillo, G. Choudhary, D. G. Duguma, J. Kim, and I. You, "TrMAps: Trust management in specification-based misbehavior detection system for IMD-enabled artificial pancreas system," *IEEE J. Biomed. Health Informat.*, to be published, doi: 10.1109/JBHI.2021.3063173.

[A9] M. Tanveer, T. Gupta, M. Shah, and B. Richhariya, "Sparse twin support vector clustering using pinball loss," *IEEE J. Biomed. Health Informat.*, to be published, doi: 10.1109/JBHI.2021.3059910.

[A10] S. Niu, M. Liu, Y. Liu, J. Wang, and H. Song, "Distant domain transfer learning for medical imaging," *IEEE J. Biomed. Health Informat.*, to be published, doi: 10.1109/JBHI.2021.3051470.

[A11] Y. Qian, J. Shen, P. Vijayakumar, and P. K. Sharma, "Profile matching for IoMT: A verifiable private set intersection scheme," *IEEE J. Biomed. Health Informat.*, to be published, doi: 10.1109/JBHI.2021.3088289.

[A12] A. Moqurrab, U. Ayub, A. Anjum, S. Asghar, and G. Srivastava, "An accurate deep learning model for clinical entity recognition from clinical notes," *IEEE J. Biomed. Health Informat.*, to be published, doi: 10.1109/JBHI.2021.3099755.

[A13] X. Wu *et al.*, "CacheTrack-YOLO: Real-time detection and tracking for thyroid nodules and surrounding tissues in ultrasound videos," *IEEE J. Biomed. Health Informat.*, to be published, doi: 10.1109/JBHI.2021.3084962.