Guest Editorial
Special Issue on Wearable Sensor-Based Big Data Analysis for Smart Health

THE INTEGRATION knowledge of wearable sensors, wireless communications, and artificial intelligence have brought forth the smart health systems, which empower the consumer's to make a difference to their well-being by connecting data to personalized analysis to timely insights. Therefore, the real-time data obtained directly reflects the personal status of interest and can be used in a variety of healthcare applications in the Internet of Things (IoT), from preventive treatment to diagnostics and rehabilitation, as well as in virtual and augmented reality environments.

However, this consumer-centric journey for smart health is presenting significant challenges and opportunities for wearable sensor-based big data analysis research. Traditional algorithms do not offer flexibility to handle such large volumes of diverse data, and that creates a need for proper mechanisms for data analysis to be able to keep up with the managing, processing, and response requirements along with the data reliability. Significant efforts from both academia and industry have been devoted recently to generate novel technologies, whether in integrating and developing machine learning algorithms for heterogeneous and longitudinal data or developing novel systems or developing new user experience frameworks, and doing all this while ensuring privacy and security of user data.

The overall response to our Calls for Papers on this Special Issue was prodigious, with (no. of total papers) paper submissions from around the scientific world. Each paper was assigned to and reviewed by multiple experts in the relevant areas during the review process with a rigorous two-round review process. Due to the generous support of this JOURNAL'S Editor-in-Chief Dr. Xuemin (Sherman) Shen, we were able to accept 16 excellent papers covering various aspects of wearable sensor big data analysis for IoT-based smart healthcare. In the following, let us introduce these papers and highlight their main contribution.

In the paper, "A Smart Environment-Adapting Timed-Up-and-Go System Powered by Sensor-Embedded Insoles," proposed a feature-rich, real-time, and ease-of-use system focusing on the flat ground walking with or without environmental variance for assessing timed up and go (TUG). The smart insole TUG (SITUG) system enhances the assessment of an individual's gait adaptability by allowing data collection and augmenting data analysis. The whole system is built using a sensor-equipped insole, a smartphone application, and a cloud service module which is capable of providing enough information about an individual's mobility by extracting rich gait features. Using these comprehensive extracted features, the SITUG affords further information related to falls through distinguishing five TUG phases. Compared to the previous version of SITUG, this new version presents a more adaptive and mature system for gait analysis and TUG segmentation.

Smart health care through IoT and big data is delicate due to lack of proficient architecture, real-time data analysis, the configuration of portable devices, and also client-side processing. In "Smart Health: A Novel Paradigm to Control the Chickungunya Virus," a novel IoT enabled system is presented based on the wireless communication and edge computing, where data were collected through the mobile phone and sensor for the Chickungunya Virus. The proposed smart health framework is beneficial to prevent the severe spreading of the Chickungunya epidemic. Several existing protocols, including ME-CBCCP, EESAA, Mod-LEACH, and ERP are evaluated to validate the proposed framework, and it proves that edge computing is the best way to big data handling at the cloud side.

To avoid malicious activities and control the information leakage of big data sensing in IoT-based smart health application, "Lattice-Modeled Information Flow Control of Big Sensing Data Streams for Smart Health Application," anticipated a static lattice model to prevent information flow control over significant data streams. One sensor lattice for a wearable sensor and one for the user sensor with three levels were used to process the flow control faster. Both the theoretical and experimental analysis were considered to validate the proposed model. After the security verification at DSM, the lattice comparison starts working for protesting against information leakage and unauthorized access. Finally, a Kafka clustering was used to evaluate the performance of the static lattice structures for wearable significant data streams, and it fits in big sensing data streams.

In "A Large-Scale Concurrent Data Anonymous Batch Verification Scheme for Mobile Healthcare Crowd Sensing," a large-scale concurrent data anonymous batch verification schemes are proposed for mobile healthcare crowed sensing (MHCS). MHCS is a typical application of IoT and a proficient approach to provide healthcare services. However, quick and effective authentication of bio-information in IoT terminals without revealing the owner's private information is still lack in MHCS. The user-generated data is verified in a batch way while keeping the actual identity of the participants

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preserve. Using the CL-AS algorithm, they designed batch verification and anonymous authentication. Through the performance evaluation, the proposed model achieves a lower computation rate and reduced storage overhead.

Physical rehabilitation and injury prevention are essential in modern treatment or therapy. In "Wearable Sensor Devices for Prevention and Rehabilitation in Healthcare: Swimming Exercise With Real-Time Therapist Feedback," a real-time therapist feedback model is presented based on a sensor device on swimming exercise. They defined three feedback system architectures: 1) therapist; 2) user; and 3) cloud system for rehabilitation therapy. The primary motivation of this paper is divided into two parts. First, to assist the prevention and rehabilitation in the different field of physical activity, they developed a group of a wearable device and second, the system designed with a waterproof wearable sensor device by counting inertial measurement unit (IMU) and real-time therapist feedback. They show that the adoption of wearable sensor-based cloud system will offer additional benefits to healthcare individual's well-being and quality of life.

In a wearable sensor, the key components belong to data collection, storage, and retrieval of data so depending on the data. It is important to optimize the data storage and retrieval. In "Hybrid-LRU Caching for Optimizing Data Storage and Retrieval in Edge Computing-Based Wearable Sensors," the authors purposed a new cache policy called the Hybrid-LRU (PDRAM) to overcome the disadvantages of asymmetry in reading and writing and limited endurance of PRAM. The Hybrid-LRU comprises two different LRU cache policies to differentiate PRAM and DRAM storage mediums. It is the first to distinguish the cache block area and then use the corresponding placing measurement DRAM blocks to the back of the cache list to increase the utilization of DRAM. After a series of experiments, they concluded that Hybrid-LRU improves the performance of PDRAM.

In IoT-based healthcare solicitations, the communication channel openness and data sensibility create privacy preservation in the edge and cloud hybrid computing. In "Cooperative Privacy Preservation for Wearable Devices in Hybrid Computing-Based Smart Health," designed a cooperative privacy preservation scheme for wearable devices. Space-aware and time-aware contexts were considered with identity authentication and data access control. Secret sharing and MinHash authentication is deemed to design space-aware edge computing mode without revealing sensitive data. For time-aware cloud computing mode, ciphertext policy-based encryption is employed for access control. Finally, they perform GNY logic-based security formal analysis for technical correctness and achieved cooperative privacy preservation in smart healthcare with computational cost.

In "Signal Quality Assessment and Lightweight QRS Detection for Wearable ECG SmartVest System," the authors developed a novel IoT-based ECG SmartVest system to onset detection of cardiovascular diseases (CVDs). This real-time and continuous monitoring system consists of four typical IoT components: 1) ECG electrode sensing layer; 2) Bluetooth network layer; 3) cloud saving and calculation; and 4) process application layer, focusing on the real-time signal quality assessment (SQA) and lightweight QRS detection for wearable ECG diagnosis. SVM-based classification with signal quality indices were applied to classify single-channel ECG segments as acceptable and unacceptable. They found that the proposed QRS achieves an F1-score significantly higher than existing two and suitable computation efficiency.

Blind or visually impaired people usually face many difficulties in their daily life, so there needs support like a vision sensor to help them. In "Wearable Vision Assistance System Based on Binocular Sensors for Visually Impaired Users," based on big data and image quality assessment a wearable system is proposed for blind or visually impaired people. A binocular visual sensor was used to collect the data instead of a monocular camera to establish a stable and practical way of visual information collection. Derived stereo-image quality assessment (SIQA) model provides complementary information for images and suitable images for the detection. The convolutional neural network was used to faster recognition of pictures and quick response to cloud computing. Statistical analysis demonstrates that wearable vision system works satisfactorily for the impaired group.

Physical activity (PA) recognition is a key paradigm for IoT healthcare. In "A Hybrid Hierarchical Framework for Gym Physical Activity Recognition and Measurement Using Wearable Sensors," the authors attempted to detect gym physical activity (GPAs) using acceleration. GPARMF—a novel two-layer sensor PA recognition framework is proposed to recognize and classify free weight and nonfree weight GPAs. One-class SVM (OC-SVM) is designed to organize free weight and nonfree weight exercise, and a shallow neural network is utilized to recognize aerobic and sedentary activities. After a series experiment on practical gym ambient with heterogeneous devices, the proposed framework perform better in identifying and measuring GPAs.

In "Automatic Classification of Fetal Heart Rate Based on Convolutional Neural Network," the authors proposed a model to process fetal heart rate records collected through Android and IOS APP for classification purposes. The FHR is divided into three categories as normal, suspicious, and abnormal. The statistical method was used to extract the FHR features and feed into SVM and MLP to classify the FHR records to get accuracy. After that they divided the high-one dimensional data into d-window segments to feed into a CNN model. In their experiments, the CNN classification can significantly improve the sensitivity, negative predictive value, and accuracy for fetal monitoring data classification.

The paper entitled "Compressive Sensing of Medical Images With Confidentially Homomorphic Aggregations," considered a one-stone-three-bird solution for medical image acquisition and transmission. Medical images can also aid to early detection of emergency conditions and remote online instructor; however, medical images are highly privacy-sensitive and redundant. Due to the large data size, appropriate protection, privacy, and data aggregation or compression are expected in medical image processing. The authors solved three problems simultaneously, first, the lightweight requirement due to the energy and computation power on sensors, then, the aggregation requirement, finally, privacy-sensitive based proper protection. They used the compressive sensing (CS) scheme for image sampling and confidentially transmission and aggregation.

"A Novel Human Activity Recognition Scheme for Smart Health Using Multilayer Extreme Learning Machine" investigated fine-grained activity recognition for monitoring the user in real-time and reminding when it engages unhealthy activity. *K*-means clustering is used to select several keyframes in each action sequence data. After that S-ELM-KRSL algorithm is used to identify the motion from the joint and body-based features. The KRSL is used to find the actual output as it is less noise sensitive. Their proposed scheme can detect early symptoms of mild cognitive impairment and dementia including kicking, pushing, and throwing with satisfactory performance accuracy.

Robotics rehabilitation has been broadly used for improving the neurological patient's therapies instead of conventional physical treatments. "Toward Improving Robotic-Assisted Gait Training: Can Big Data Analysis Help Us?" aimed to propose a system based on the Cloud of Things (CoT) using big data analytics coming from the robotic rehabilitation devices. Lokomat, robotic rehabilitation devices was used to install the sensor for collecting data and statistical was used to allow the clinical operators to forecast best treatment therapy. The exploratory big data analysis proves a moderate correlation between stance and swing biofeedback features of the hip and knee.

IMUs provide an essential context for ubiquitous sensing applications such as wearable motion recognition. "Orientation Independent Activity/Gesture Recognition Using Wearable Motion Sensors" presented an orientation and speed independent gesture/activity recognition system by extracting irrespective novel features. The gyroscopic records are considered to obtain the total angular changes. DTW and thresholding technique was used for segmentation and classification, respectively. Finally, consistent segments are determined by the template refinement technique, and inconsistent segments of a movement are eliminated using a DTW called star-padding. The proposed activity/gesture recognition approach using a wearable motion sensor addressed several challenges and detected useful context.

In a smart health IoT environment, the Life model for time series (LMts) enables real-time predictions and can predict the approximate time of events. The paper "A Concise Temporal Data Representation Model for Prediction in Biomedical Wearable Devices" proposed a mapped interval sequence (MIS) model to discrete time-series arbitrary-length multivariate data in a concise sequence retaining data properties such as time, recency, and scale. LMts is applied to map the data with higher sampling rate into a defined sequence. Their proposed model based on the deep learning hardware can detect and forecast long-term real-time temporal sequences in the form of time series, and from the predicted medical history (individuals health and activity records) model can predict the future health anomalies or events. The deep recurrent network was used to train the concise sequence data.

In conclusion, we first would like to acknowledge our appreciation of all the authors around the world for their support and excellent research contributions. We also would like to thank all the reviewers for their labors in reviewing the papers, and for their valuable comments and suggestions for enlightening the quality of the papers. Finally, we appreciate the advice and support of the Editor-in-Chief of this JOURNAL, Dr. Xuemin (Sherman) Shen, for his assistance in the entire publication process. The organization and publication of this Special Issue was supported by the National Natural Science Foundation of China under Grant 61572231.

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