Guest Editorial
Innovations in Wearable, Implantable, Mobile, & Remote Healthcare With IoT & Sensor Informatics and Patient Monitoring

WEARABLE, implantable, mobile, and remote healthcare have rapidly entered the era of digital health across various IoT applications such as monitoring, recording, and tracking the key signs of people's health to improve their lifestyle and health disorders. Innovations in IoT devices play a vital role in assisting patients in managing their health conditions. Thanks to the advent of modern communication technologies and Internet of Things (IoT) paradigms that have made the implementation of biomedical devices nearly universal. Now with the evolving industrial revolution, patients and healthcare providers are expecting something more. Practically speaking, healthcare wearables have experienced tremendous growth in the past few years, and it is expected to grow even more shortly, making it an ideal space for the biomedical informatics research community to solve complex healthcare problems and more informed decision making to improve human health. One of the most renowned applications of mobile healthcare technologies includes implantable devices. Wearables are generally used for preventative and recreational wellness management. Simultaneously, implantable techniques are applied towards the management of chronic conditions (blood pressure, diabetes). Furthermore, in the current scenario of the COVID-19 pandemic, research on wearables and connected healthcare is more important than ever, as it greatly assists the patients with chronic conditions and other individuals to monitor their health without having direct contact with the physicians. Thus, effectively preventing the spread of a pandemic situation and acting as a lifeline to the end-users. Despite the vast benefits of wearables and mobile healthcare technology and sensor informatics, its real-time growth is hindered due to various barriers. Some of the typical challenges include higher cost, complexity in access to wearable device data, medical errors, privacy, security, and network connectivity concerns. Looking forward towards the path of wearable, implantable, and mobile health monitoring systems, IoT and sensor informatics technologies such as distributed machine learning and 5G networks play a prominent role. It adds an increased level of convenience to the end-users that they never experienced before by enabling efficient organization and analysis of the health records to improve patient health outcomes. In short, this is a very diverse research area. The new wave of technological innovations in IoT and sensor informatics will lead to a multidisciplinary approach that ranges from vital sign and activity monitoring to dealing with emergency situations. More than ever, advanced research on this background paves the way for an efficient healthcare integrated technology that is both simple and trustworthy to be used in real-time. Hence, we can conclude that the future of healthcare applications will create a breakthrough through advancements when they effectively implement innovative IoT and sensor informatics paradigms. This special issue invites submissions that solicits research on designing, developing, and assessing innovative sensor informatics tools and algorithms for remote and electronic healthcare and well-being. The major scope is to apply innovations in informatics and data analytics in the practice of remote healthcare and patient monitoring. The key objective is to improve remote healthcare outcomes and services and fulfill the unique application needs of the end-users (ease of use, precision healthcare, safety, privacy, trust, etc.). Suitable submissions that discuss system advances, techniques, and approaches relating to health informatics and IoT healthcare device analytics are most welcomed. We particularly encourage interdisciplinary and applied research in this stream.

In [A1] the authors investigate the feasibility of using wrist-based electrodermal activity (EDA) signals collected from wearable devices to predict people's stress status and identify possible factors impacting stress classification accuracy. They use data collected from wrist-worn devices to examine the binary classification discriminating stress from non-stress. For efficient classification, five machine learning-based classifiers were examined. They explore the classification performance on four available EDA databases under different feature selections.

In [A2] the paper presents the UroSound, the first platform that performs non-intrusive sound-based uroflowmetry with a smartwatch. They study the feasibility of using a smartwatch to assess how well the urinary tract functions by processing the sound generated when the urine stream hits the water level in the toilet bowl, which can be modelled through the sound envelope. Signal-based features related to the sound envelope were extracted from a smartwatch's built-in microphone. The constructed model achieves a good correlation between acoustic and standard uroflowmetry in terms of the voiding shape and it can extract relevant voiding parameters. This indicates that accurate and remote measurement of the ambulatory characteristics of voiding dysfunction can be achieved with smartwatch-based uroflowmetry. UroSound also facilitates the collection of a voiding diary by measuring multiple uroflows during daytime and nighttime.

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In [A3] the authors develope a novel fuzzy logic application for the classification of key parameters within running gait assessment (for recommended shoe type). The presented method provides a more real-world assessment of running gait, as captured in a low-resource setting with an IoT enabled wearable. In doing so, simulations are provided with a (near real time and) significantly higher resolution gait feature fuzzy extraction layer (pronation and foot strike), with a mean average error within 4% of previous work utilizing manual thresholds with lower resolution.

Musculoskeletal models play an essential role in ankle rehabilitation research. The majority of the existing models have established the relationship between EMG and joint torque. However, EMG signal acquisition requires higher clinical conditions, such as sensitivity to external circumstances, such as motion artifacts and electrode position. To solve the nonlinear and time-varying nature of joint movement, a Functional Electrical Stimulation (FES) model was proposed in [A4] to simulate the whole process of ankle dorsiflexion. The model is combined with muscle contraction dynamics based on Hill model and ankle inverse dynamics to connect FES parameters, torques, and ankle angles.

In [A5], they propose a novel application of data augmentation to address various rotation errors of wearable sensors for robust pre-impact fall detection. In such systems, sensor rotation errors are inevitable because of loose attachment and body movement during long deployment. Two augmented models with uniform and normal strategies were compared with a non-augmented model on the original dataset (no rotation error) and a validation dataset (with rotation error). The validation dataset was constructed with three types of rotation errors, namely, pitch, roll, and compound roll and pitch (CRP) at three levels of range.

In [A6] they propose a novel framework to passively monitor pulse rate during the time spent by users on their personal mobile devices. The framework is based on passively capturing the user's pulse signal using the front-facing camera. Signal capture is performed in the background, while the user is interacting with the device as he/she normally would, e.g., watch movies, read emails, text, and play games. The framework does not require subject participation with the monitoring procedure, thereby addressing the well-known problem of low adherence with such procedures. They investigate various techniques to suppress the impact of spontaneous user motion and fluctuations in ambient light conditions expected in non-participatory environments. Techniques include traditional signal processing, machine learning classifiers, and deep learning methods. The performance evaluation is based on a clinical study encompassing 113 patients with a history of atrial fibrillation (Afib) who are passively monitored at home using a tablet for a period of two weeks.

In [A7] they present a novel deep learning method (KD-Informer) for BP waveform estimation using the non-invasive PPG signal. At the same time, they integrate the prior information of pulse patterns with the SE-ResNet module into the knowledge transfer branch. The proposed method uses a KD strategy to obtain information about potential associations between physiological sequences in a more lightweight architecture than existing sequence learning deep networks for PPG.

As an important carrier of healthcare data, Electronic Medical Records (EMRs) generated from various sensors, i.e., wearable, implantable, are extremely valuable research materials for artificial intelligence and machine learning. The efficient circulation of EMRs can improve remote medical services and promote the development of the related healthcare industry. However, in traditional centralized data sharing architectures, the balance between privacy and traceability still cannot be well handled. To address the issue that malicious users cannot be locked in the fully anonymous sharing schemes, in [A8] they propose a trackable anonymous remote healthcare data storing and sharing scheme over decentralized consortium blockchain. Through an "on-chain & off-chain" model, it relieves the massive data storage pressure of medical blockchain. By introducing an improved proxy re-encryption mechanism, the proposed scheme realizes the fine-gained access control of the outsourced data and can also prevent the collusion between semi-trusted cloud servers and data requestors who try to reveal EMRs without authorization.

In [A9] the authors observe that noise causes an accuracy drop in the previous CA framework, thus discovering that different signal-to-noise ratios (SNRs) require different sizes of CA models. They propose a two-stage noise-level aware compressed analysis framework. First, They apply the singular value decomposition to estimate the noise level in the compressed domain by projecting the received signal into the null space of the compressed ECG signal. A transfer-learning-aided algorithm is proposed to reduce the long-training-time drawback. Second, they select the optimal CA model dynamically based on the estimated SNR. The CA model will use a predictive dictionary to extract features from the ECG signal, and then imposes a linear classifier for classification. A weight-sharing training mechanism is proposed to enable parameter sharing among the pre-trained models, thus significantly reducing storage overhead.

Although obstructive sleep apnea and hypopnea syndrome (OSAHS) is a common sleep disease, it is sometimes difficult to be detected in time because of the inconvenience of polysomnography (PSG) examination. Since snoring is one of the earliest symptoms of OSAHS, it can be used for early OSAHS prediction. With the recent development of wearable and IoT sensors, in [A10] they propose a deep learning-based accurate snore detection model for long-term home monitoring of snoring during sleep. To enhance the discriminability of features between snoring and non-snoring events, an auditory receptive field (ARF) net was proposed and integrated into the feature extraction network. Based on the feature maps derived by the feature extraction network, the detection model predicted a series of candidate boxes and corresponding confidence scores for each candidate box, which denoted whether the candidate box contained a snore event from the input sound waveforms.

Alzheimer's Disease and Related Dementia (ADRD) is growing at alarming rates, putting research and development of diagnostic methods at the forefront of the biomedical research community. Sleep disorder has been proposed as an early sign of Mild Cognitive Impairment (MCI) in Alzheimer's disease. Although several clinical studies have been conducted to assess sleep and association with early MCI, reliable and efficient algorithms to detect MCI in home-based sleep studies are needed in order to address both healthcare costs and patient discomfort in hospital/lab-based sleep studies. In [A11], an innovative MCI detection method is proposed using an overnight recording of movements associated with sleep combined with advanced signal processing and artificial intelligence. A new diagnostic parameter is introduced which is extracted from the correlation between high frequency, sleep-related movements, and respiratory changes during sleep.

In [A12] they present a contactless and real-time respiration monitoring system, the so-called Wi-Breath, based on off-the-shelf WiFi devices. The system monitors respiration with both the amplitude and phase difference of the WiFi channel state information (CSI), which is sensitive to human body micro movement. The phase information of the CSI signal is considered, and both the amplitude and phase difference are used. For better respiration detection accuracy, a signal selection method is proposed to select an appropriate signal from the amplitude and phase difference based on a support vector machine (SVM) algorithm.

All papers tackle different but extremely aligned with the topic on "Innovations in Wearable, Implantable, Mobile, & Remote Healthcare with IoT & Sensor Informatics". We would like to thank all the authors who contributed their great work to this special issue. We would also like to acknowledge the contribution of many domain experts who have participated in the peer-review process, and provided helpful feedback to the authors to improve the quality of the articles. We would like to thank Professor Dimitrios I. Fotiadis, the Editor-in-Chief, and the publishing team for their support and very helpful suggestions and comments during the delicate stages of concluding the special issue.

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Appendix: Related Articles

[A1] L. Zhu et al., "Stress detection through wrist-based electrodermal activity monitoring and machine learning," *IEEE J. Biomed. Health Inform.*, vol. 27, no. 5, pp. 2155–2165, May 2023, doi: 10.1109/JBHI.2023.3239305.

[A2] L. Arjona, L. E. Diez, A. B. Martinez, and A. A. Echevarria, "UroSound: A smartwatch-based platform to perform non-intrusive sound-based uroflowmetry," *IEEE J. Biomed. Health Inform.*, vol. 27, no. 5, pp. 2166–2177, May 2023, doi: 10.1109/JBHI.2022.3140590.

[A3] F. Young et al., "Bespoke fuzzy logic design to automate a better understanding of running gait analysis," *IEEE J. Biomed. Health Inform.*, vol. 27, no. 5, pp. 2178–2185, May 2023, doi: 10.1109/JBHI.2022.3189594.

[A4] X. Zhang et al., "Dynamics combined with hill model for functional electrical stimulation ankle angle prediction," *IEEE J. Biomed. Health Inform.*, vol. 27, no. 5, pp. 2186–2196, May 2023, doi: 10.1109/JBHI.2022.3158426.

[A5] X. Yu, T. Ma, J. Jang, and S. Xiong, "Data augmentation to address various rotation errors of wearable sensors for robust pre-impact fall detection," *IEEE J. Biomed. Health Inform.*, vol. 27, no. 5, pp. 2197–2207, May 2023, doi: 10.1109/JBHI.2022.3228598.

[A6] C. Savur, R. Dautov, K. Bukum, X. Xia, J.-P. Couderc, and G. R. Tsouri, "Monitoring pulse rate in the background using front facing cameras of mobile devices," *IEEE J. Biomed. Health Inform.*, vol. 27, no. 5, pp. 2208–2218, May 2023, doi: 10.1109/JBHI.2022.3197076.

[A7] C. Ma et al., "KD-informer: Cuff-less continuous blood pressure waveform estimation approach based on single photoplethysmography," *IEEE J. Biomed. Health Inform.*, vol. 27, no. 5, pp. 2219–2230, May 2023, doi: 10.1109/JBHI.2022.3181328.

[A8] J. Liu et al., "Conditional anonymous remote healthcare data sharing over blockchain," *IEEE J. Biomed. Health Inform.*, vol. 27, no. 5, pp. 2231–2242, May 2023, doi: 10.1109/JBHI.2022.3183397.

[A9] Y.-C. Lo, W.-K. Beh, C.-C. Huang, and A.-Y. Wu, "Noise-level aware compressed analysis framework for robust electrocardiography signal monitoring," *IEEE J. Biomed. Health Inform.*, vol. 27, no. 5, pp. 2243–2254, May 2023, doi: 10.1109/JBHI.2022.3199910.

[A10] X. Hu, J. Sun, J. Dong, and X. Zhang, "Auditory receptive field net based automatic snore detection for wearable devices," *IEEE J. Biomed. Health Inform.*, vol. 27, no. 5, pp. 2255–2263, May 2023, doi: 10.1109/JBHI.2022.3164517.

[A11] S. Khosroazad, A. Abedi, and M. J. Hayes, "Sleep signal analysis for early detection of Alzheimer's disease and related dementia (ADRD)," *IEEE J. Biomed. Health Inform.*, vol. 27, no. 5, pp. 2264–2275, May 2023, doi: 10.1109/JBHI.2023.3235391.

[A12] N. Bao et al., "Wi-breath: A WiFi-based contactless and real-time respiration monitoring scheme for remote healthcare," *IEEE J. Biomed. Health Inform.*, vol. 27, no. 5, pp. 2276–2285, May 2023, doi: 10.1109/JBHI.2022.3186152.