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Editorial

Introducing the Special Issue on "Ubiquitous Sensing for Smart Health Monitoring"

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Sensors continue to pervade our surroundings in undiminished ways. These can range from cameras to wearables for health and environmental monitoring, to low-cost sensing for safety, structural health, threat detection, logistics, and a myriad of other applications. The Internet of Things (IoT) promises to encompass billions if not trillions of interconnected objects that can sense, communicate, compute and actuate, as well as possess intelligence, multimodal interfaces and physical or virtual attributes. By incorporating concepts from pervasive and ambient computing, the IoT fuses the digital and physical worlds and is the indisputable enabler of ubiquitous sensing. Smart health monitoring for the tracking and diagnosis of physiological issues, early disease detection, prognostication and prevention relies on ubiquitous and unobtrusive monitoring systems, the types of sensors deployed within such systems, sensor networks, data modeling, algorithms and more.

The abundance of data generated from smaller, faster, intelligent and more pervasive sensing integrated within our current health monitoring systems has two actionable advantages: (1) to predict health hazards and (2) to improve the underlying sensors in these systems. Therefore, it is invaluable to explore ever advancing areas such as the design and development of sensors within such systems, novel mechanisms of tracking clinically relevant biometrics, re-purposing known sensing modalities for tracking emerging diseases and reviewing trends in the literature to focus on shortcomings in data acquisition and processing, analysis and study design. Here, the promise of pervasive sensing lies in healthcare stakeholders being able to monitor their patients outside the walls of the clinic/hospital, minimize or avoid invasive procedures and promote a shift from a reactionary symptom-focused healthcare model to a proactive model.

This Special Issue addresses the above topics through six articles that focus on four main themes, encompassing novel materials by way of flexible electrodes, emerging biometric tracking methods, by way of radar-based respiratory monitoring, fitness and activity tracking and leveraging wearables for monitoring communicable and noncommunicable diseases. These articles highlight opportunities for further work, ultimately to bridge the gulf between the copious lab research and the disproportionately scant commercially viable healthcare applications. Below is a background and brief synopsis on each of the six published reports.

With an estimated 17.8 million deaths in 2017, per the World Health Organization, cardiovascular diseases are the leading cause of mortality worldwide. The acquisition, post-processing and analysis of electrocardiography (ECG) signals including the heart rate output are key to the diagnosis, control and prevention of many cardiovascular diseases. The fidelity of such signals relies in part on the underlying sensors, commonly, wet electrodes made up of silver-silver chloride (Ag-AgCl). In their communication, "Paper-based Flexible Electrode Using Chemically-Modified Graphene and Functionalized Multiwalled Carbon Nanotube Composites for Electrophysiological Signal Sensing", Hossain et al. [1] show that chemically converted graphene and functionalized multiwalled carbon nanotube composites developed in a solvent and drop cast on nylon filter paper outperformed conventional off the shelf Ag-AgCl electrodes in terms of skin contact impedance and

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ECG signal amplitude. These novel flexible electrodes serve as a potential candidate for emerging personalized ECG monitoring devices.

Electromagnetic wave biosensors have attracted attention of late, owing to their many benefits such as being noninvasive or minimally invasive, label-free and cost-effective. One traction-gaining category within this class of sensors comprises short-range radar for non-contact vital sign monitoring, such as heart beat and respiratory rate in drivers. Since 2019, over 1300 peer-reviewed articles were published in this very category. Furthermore, advancements in automotive radar technology have evolved into additional consumer safety features for in cabin sensing by way of occupancy, intrusion and child detection solutions. In their article, "Non-Contact Driver Respiration Rate Detection Technology Based on Suppression of Multipath Interference with Directional Antenna", Yang et al. [2] detail solutions to address the multipath effect when implementing a 2.4 GHz continuous wave forward-scattering radar respiratory detection system in an automobile.

The global fitness industry commands a revenue amounting to USD 94 billion. While the fitness app market is only 3.35% of this figure (USD 3.15 billion), and dominated by the Android operating system, it is estimated to rapidly reach a revenue amount of US USD 16 billion by 2026. Although this projection is linked to several factors, such as smartphone ubiquity, push for improved health and countering rises in adult and childhood obesity, it is also a reflection of the easy access to fitness information in our very own pockets and how many of us harness that for augmenting our wellness needs. In the review article, "Mobile Applications for Training Plan Using Android Devices: A Systematic Review and a Taxonomy Proposal", Tavares et al. [3] have developed a hierarchical taxonomy incorporating more than 30 features for characterizing freely downloadable Android apps that subsume functions of a personal trainer for achieving individual fitness goals. The authors also highlight the need for a validation of the most desirable fitness applications that is rooted in scientific methodology.

Lack of physical activity has been identified as a leading risk factor for global mortality, owing to its association with several cardiovascular and respiratory disorders. Physical activity trackers by way of wearable devices placed on the wrist, ankle, waist, thigh and inside pockets help to counter the rise in inactivity levels. In the article, "Validity of a Smart-Glasses-Based Step-Count Measure during Simulated Free-Living Conditions", Cristiano et al. [4] compare the use of custom smart glasses embedded with an inertial measurement unit to a range of commercial activity trackers for parameters, such as walking speed, walking surface, walking type, climbing stairs and fixed duration free walks. The custom smart glasses offer a comparative and an accurate step count measurement modality. Such reports lend credibility to the use of the nascent human–computer interface wearable glasses (with head-mounted displays) as reliable activity/fitness trackers.

Severe respiratory acute syndrome coronavirus 2 causing coronavirus disease 2019 (COVID-19) has wreaked an unprecedented worldwide health crisis of late. Curtailing the spread of COVID-19 has hinged on three tactics: (1) behavioral changes, (2) testing, tracing and isolation and (3) if those are ineffective, lockdowns. Within the second tactic, tracing has mainly relied on the ubiquity of smartphones. However, alternative approaches involving wearables are being investigated and making headway. In the article, "An Internet of Things Approach to Contact Tracing- The BubbleBox System", Polenta et al. [5] debut BubbleBox, an IoT COVID-19 contact tracing system comprising a benchtop proof-of-concept wearable wristband, Android app, cloud back-end server and a web front-end application to contain outbreaks by contacting and testing potentially infected individuals. Furthermore, privacy concerns are discussed by proposing anonymous tracing solutions and implementing permissioned blockchain as a secondary security measure.

Owing to IoT advancements, wearables have long held the potential to serve as electronic health records, thereby elevating the health sector to more efficient states of interoperability and seamless communication. Nowhere has this been better realized than in utilizing wearables for episodic and continuous monitoring of noncommunicable conditions, such as asthma, chronic obstructive pulmonary disease and cardiovascular diseases, to name a few. In fact, the next 20 years may result in a global cost savings of USD 200 billion by increasing healthcare's reliance on wearable technologies. Wearables, in concert with artificial intelligence, hold the promise of effectively predicting the onset of dormant conditions prior to severe accompanying symptoms, thus guiding patients towards earlier and more cost-effective treatment options. These initiatives can alleviate the overall healthcare burden by lowering hospital costs, and subsequently operating costs in those environments. In the review article, "Wearable Sensors for Monitoring and Preventing Noncommunicable Diseases: A Systematic Review", Kristoffersson and Linden [6] analyze seven databases to perform a systematic analysis of 84 reports in total characterizing the use of wearable sensors for monitoring nine categories of noncommunicable conditions and diseases. They delve into the system architecture of such devices and provide details on the sensors used along with the measurement outputs and characteristics of the population sampled in each study. In doing so, the authors highlight discrepancies in study demographics with respect to age and gender, and the vital role that wearables play as continuous health monitoring tools for early disease detection and/or prevention.

Beyond the focused topics in this Special Issue, readers are encouraged to further dwell upon and consider means of addressing the ensuing opportunities and potentials. The fullest potential of ubiquitous sensing for smart health monitoring will advance in the coming decades, in association with machine learning techniques, not only for prescriptive and predictive analyses, but to generate data and approaches for improving the underlying sensing systems themselves. Ultimately, the Internet of (healthcare) Things is positioned to impact the industry by advancing human health and lessening its currently high economic burden.

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