

**EDITORIAL****IEEE ACCESS SPECIAL SECTION EDITORIAL:  
WEARABLE AND IMPLANTABLE  
DEVICES AND SYSTEMS**

Circuit techniques, sensors, antennas and communications systems are envisioned to help build new technologies over the next several years. Advances in the development and implementation of such technologies have already shown us their unique potential in realizing next-generation sensing systems. Applications include wearable consumer electronics, healthcare monitoring systems, and soft robotics, as well as wireless implants. There have been some interesting developments in the areas of circuits and systems, involving studies related to low-power electronics, wireless sensor networks, wearable circuit behaviour, security, real-time monitoring, connectivity of sensors, and Internet of Things (IoT). The direction for the current technology is electronics systems on large area electronics, integrated implantable systems and wearable sensors. So far, the research in the field has focused on materials, new processing techniques and one-off devices, such as diodes and transistors. However, current technology is not sufficient for future electronics to be useful in new applications; a great demand exists to scale up the research towards circuits and systems. Recent developments indicate that, in addition to fabrication technology, special attention should also be given to design, simulation and modeling of electronics, while keeping sensing system integration, power management, and sensors network under consideration.

The Special Section consists of 23 contributions, including 4 survey articles covering a variety of topics in line with the call for papers.

In the article, “A review on EEG-based automatic sleepiness detection systems for driver,” by Balandong, *et al.*, a review on different types of measures used in sleepiness detection systems (SDSs) is presented, with their advantages and drawbacks. The review also includes several techniques proposed in ESDSs to optimize the number of EEG electrodes, increasing the sleepiness level resolution and incorporation of circadian information. Finally, the review discusses future directions in the development of ESDS.

In the article, “A survey on the roles of communication technologies in IoT-based personalized healthcare applications,” by Alam *et al.*, the authors propose a survey on emerging healthcare applications, including detailed technical aspects required for the realization of a complete end-to-end solution for each application. The survey explores the

key application-specific requirements from the perspective of communication technologies. Furthermore, a detailed exploration from the existing to the emerging technologies and standards that would enable such applications is presented, highlighting the critical consideration of short-range and long-range communications. Finally, the survey highlights important open research challenges and issues specifically related to IoT-based future healthcare systems.

In the article, “A review on the role of nano-communication in future healthcare systems: A big data analytics perspective,” by Rizwan *et al.*, a first-time review of the open literature focused on the significance of big data generated within nano-sensors and nano-communication networks intended for future healthcare and biomedical applications. It is aimed toward the development of modern smart healthcare systems enabled with P4, i.e., predictive, preventive, personalized, and participatory capabilities to perform diagnostics, monitoring, and treatment. Finally, the open challenges and future directions for researchers in the evolving healthcare domain are presented.

In the article, “Wearable ultrawideband technology—A review of ultrawideband antennas, propagation channels, and applications in wireless body area networks,” by Yan *et al.*, the authors review the latest results in the field of wearable ultrawideband antennas, propagation channels, and their respective applications in WBAN systems. Future directions have been identified for further research as well.

In the article, “Analysis of vertical loop antenna and its wide and flat variant performance in wearable use,” by Berg *et al.*, an analysis is presented of the input impedance and radiation pattern behavior for a rectangular loop antenna, when it is reshaped from a narrow square to wide and flat. Measured radiation efficiency for the antenna in contact with a human tissue phantom was  $-5.0$  dB at 2 GHz and the obtainable bandwidth potential is  $>10\%$ .

In the article, “Integrated design of wideband omnidirectional antenna and electronic components for wireless capsule endoscopy systems,” by Duan *et al.*, a wideband antenna with omnidirectional radiation pattern for wireless capsule endoscopy (WCE) systems has been proposed. The proposed antenna radiates as a slot structure formed between a central

copper cylinder and a copper strip attached to the interior surface of a biocompatible polyimide shell. The integrated design concept, wideband impedance matching, and stable omnidirectional radiation patterns make the proposed antenna a promising candidate for future WCE systems.

In the article, “Dynamic evaluation and treatment of the movement amplitude using kinect sensor,” by Neto *et al.*, a hybrid solution (software and hardware) named GoNet v2, integrating the computer and the Kinect sensor, has been proposed for biomechanical rehabilitation processes. Experimental tests to evaluate the range of motion of body joints, especially for elbow flexion, elbow extension, shoulder abduction, shoulder flexion, radial deviation, and ulnar deviation, are presented and discussed. According to the evaluation of the specialists, the GoNet v2 gave better results for the flexion/extension of the shoulder (3.61%) and elbow (3.17%), and also the abduction (2.11%) of the shoulder compared with the goniometer. The results showed that the GoNet v2 had high reproducibility, except for radial deviation. The accuracy results were good for the abduction measurements of the shoulder and the flexion/extension measurements of the elbow and shoulder.

In the article, “Mathematical modeling of ultra wideband *in vivo* radio channel,” by Ilyas *et al.*, a novel mathematical model for an *in vivo* radio channel at ultra-wideband frequencies (3.1–10.6 GHz) is proposed, which can be used as a reference model for *in vivo* channel response without performing intensive experiments or simulations. The proposed model was applied to the blind data, and the statistic of error prediction was RMSE = 7.76, which also shows a reasonable model accuracy. This model will save time and cost on simulations and experiments, and will help in designing an accurate link budget calculation for a future enhanced system for ultra-wideband body-centric wireless systems.

In the article, “An automated remote cloud-based heart rate variability monitoring system,” by Hussein *et al.*, a healthcare monitoring service to people living in remote areas was proposed, which was otherwise very difficult owing to the small doctor-to-patient ratio. The researchers also analyzed their monitoring system using two different databases. After analyzing the performance of the proposed scheme, the obtained results for accuracy, sensitivity, and specificity were 99.02%, 98.78%, and 99.17%, respectively. The achieved results concluded that the proposed system was quite reliable, robust, and valuable.

In the article, “Power generation for wearable electronics: designing electrochemical storage on fabrics,” Vilku *et al.*, presented a new class of textiles with electrochemical functions which, when moistened by a conductive liquid (saline solution, sweat, and wound fluid), generate DC voltage and current levels capable of powering wearable electronics on the go. The proposed technology is expected to be of utmost significance for healthcare, sports, military, and consumer applications, among others.

In the article, “Adaptive beaconing based mac protocol for sensor based wearable system,” by Xu *et al.*, an adaptive

beaconing medium access control (AB-MAC) protocol has been proposed to reduce communication delay and improve throughput and energy efficiency for duty cycle-based wearable systems. Experimental results showed that compared with RI-MAC protocol, AB-MAC protocol can reduce the delay by 32%–51%, increase the throughput by 45%–116%, and improve the energy efficiency by 12%–21% without sacrificing the network lifetime.

In the article, “Nano-ferrite near-field microwave imaging for in-body applications,” Ren *et al.*, demonstrated that iron oxide nanoparticles were appropriate for use as contrast agents in biological imaging. They used iron oxide nanoparticles as a nanoprobe because they are widely used in clinical MRI and other molecular imaging techniques.

In the article, “Breathing rhythm analysis in body centric networks,” Fan *et al.*, presented a noncontact and economically viable respiratory rhythm-detection system using S-band sensing technique. The system leverages a microwave sensing platform to capture the minute variations caused by breathing. The experimental results not only validate the feasibility of respiratory rhythm detection using S-band sensing technique, but also demonstrate that the S-Breath system provides good performance.

In the article, “A wireless implantable sensor design with subcutaneous energy harvesting for long-term IoT healthcare applications,” Wu *et al.*, proposed a wireless implantable sensor prototype with subcutaneous solar energy harvesting, which consists of a power management circuit, a temperature sensor, and a Bluetooth low energy module. An application is developed for data visualization on mobile devices, which can be a gateway for future IoT-based healthcare applications. The entire device is embedded in a transparent silicone housing (38 mm × 32 mm × 4 mm), including a 7 mAh rechargeable battery for energy storage. The average power consumption of the implants is about 30  $\mu$ W in a 10 min operation cycle. Two worst-case scenarios (no exposure to light and battery depletion) are considered with ex-vivo experiment simulations.

In the article, “Towards smart work clothing for automatic risk assessment of physical workload,” by Yang *et al.*, a wearable system integrating textrodes, motion sensors, and real-time data processing through a mobile application was developed as a demonstrator of risk assessment related to different types and levels of workload and activities. The system was demonstrated in eight subjects from four occupations with various workload intensities, during which the heart rate and leg motion data were collected and analyzed with real-time risk assessment and feedback. The system showed good functionality and usability as a risk assessment tool. The results contribute to the design and development of future wearable systems and bring new solutions for the prevention of work-related disorders.

In the article, “Wearable depth camera: Monocular depth estimation via sparse optimization under weak supervision,” He *et al.* propose a depth estimation method with a monocular camera. The main idea lies in the weak-supervised learning

model of monocular depth estimation based on left and right consistency. Compared with several state-of-the-art monocular camera depth estimators, the proposed method obtains the highest depth accuracy.

In the article, “WE-safe: A self-powered wearable IoT sensor network for safety applications based on LoRa,” Wu *et al.*, proposed a sensor node, called the WE-Safe node, based on a customized sensor node, and is self-powered, low-power, and supports multiple environmental sensors. Environmental data is monitored by the sensor node in real-time and transmitted to a remote cloud server. The experimental results indicate that the presented safety monitoring network works reliably using energy harvesting.

In the article, “An ultra low power personalizable wrist worn ECG monitor integrated with IoT infrastructure,” by Beach *et al.*, the authors present a wrist worn ECG sensor which integrates with the SPHERE IoT platform—the UK’s demonstrator platform for health monitoring in the home environment—combining a range of on-person and ambient sensors. The design and heart sensing performance of the device are presented in detail, together with the integration with the SPHERE IoT platform.

In the article, “Power management using photovoltaic cells for implantable devices,” by Oo Htet *et al.*, the authors present a novel inductor-less switched capacitor (SC) DC–DC converter, which generates simultaneous dual-output voltages for implantable electronic devices. The proposed monolithically integrated PV powered circuit achieves a conversion efficiency of 85.26% and provides extra flexibility in terms of gain, which is advantageous for future implantable applications that have a range of inputs. This research is, therefore, an important step in achieving truly autonomous implantable electronic devices.

In the article, “Power control algorithms for media transmission in remote healthcare systems,” by Sohdro *et al.*, the authors propose a transmission power control (TPC)-based energy-efficient algorithm (EEA) for when a subject is in different postures, i.e., standing, walking, and running, in wireless body sensor networks. A hardware platform was developed on the Intel Galileo board to test and compare the proposed EEA and conventional adaptive TPC (ATPC) in terms of energy and channel reliability or packet loss ratio (PLR). Experimental results revealed that the proposed EEA obtained energy savings of 42.5% with an acceptable PLR compared with that of the traditional ATPC method.

In the article, “Ion-sensitive field-effect transistors with micropillared gates for measuring cell ion exchange at molecular levels,” by Abdallah *et al.*, the authors present a novel, ion-sensitive field-effective transistor (ISFET) modality to measure cell behavior during the change of cell properties at molecular levels. ISFETs produce low resistance signals and consume low power. The small size of ISFETs enables miniature diagnosis devices that can be affordably fabricated in a massive array format.

In the article, “Exploiting smallest error to calibrate non-linearity in SAR ADCs,” by Fan *et al.*, the authors propose a statistics-optimized organization technique to achieve better element matching in successive approximation register (SAR) analog-to-digital converter (ADC) in smart sensor systems. The authors demonstrated the proposed technique’s ability to achieve a significant improvement of around 23 dB on a spurious free dynamic range (SFDR) of the ADC than the conventional, testing with a capacitor mismatch  $\sigma u = 0.2\%$  in a 14-bit SAR ADC system.

In the article, “Performance evaluation of routing protocols in electromagnetic nanonetworks,” AbuAli *et al.*, investigated three routing protocols: controlled flooding, coordinate/routing for nanonetworks, and hierarchical ad hoc on demand distance vector for nano-networks. Performance of the three protocols with respect to energy consumption and network delay against transmission range and network density has been presented.

The Guest Editors hope that this Special Section will benefit the scientific community and contribute to the knowledge base, and would like to take this opportunity to applaud the contribution of the authors to this Special Section. The efforts of the reviewers to enhance the quality of the manuscripts are also much appreciated.

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Prof. Abbasi is a member of IET and a Committee Member of the IET Antenna & Propagation and Healthcare Network. He has been a member of the technical program committees of several IEEE flagship conferences and technical reviewer for several IEEE and top-notch

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NGCAS' 17, BioCAS' 18, PRIME' 15 and '19, and is an Organizer for several special sessions on the IEEE Conferences. As PI, he has received £1m+ funding from major research councils and funding organizations, including the European Commission, EPSRC, Royal Society, and Scottish Funding Council. He is involved in the €8.4M EU H2020 FET Proactive on Hybrid Enhanced Regenerative Medicine Systems (HERMES).



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