Editorial

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Artificial Intelligence-enabled contactless sensing for medical diagnosis

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Artificial Intelligence (AI) is an emerging technology which aims to make intelligent machines, especially intelligent computer programs. It can be utilized to enable human intelligence on machines, but the ability of AI does not have to confine itself to biologically observable methods. It can identify hidden relationships, correlations, and trends that may not be apparent in traditional viewpoints. As a result, AI-enabled technologies have achieved significant achievements for medical care including diagnosis, treatment, drug discovery, and healthcare management [1].

Continuous monitoring of patients plays a crucial role for medical diagnosis and treatment. Nonetheless, existing monitoring techniques have inherent limitations. Numerous methods necessitate the use of uncomfortable or cumbersome devices, with certain devices even being invasive. Consequently, patients have to face restrictions on their daily activities, and the duration of monitoring is curtailed. Moreover, some monitoring methods are cost-prohibitive, demanding specialized equipment and trained personnel for operation.

To resolve this challenge, radio frequency (RF) based wireless monitoring schemes which enables contactless, non-invasive and continuous monitoring have been proposed [2]. Specifically, human activities would modulate the propagation of RF signals, which makes it possible to extract human information from the variation of RF signals. Benefiting from AI's ability to identify hidden relationship between signal variation and human activities, contactless self-medication management, Parkinson detection, sleep monitoring and cardiac activity have been achieved the past decade.

In the realm of chronic disease management, self-medication is a prevalent practice. However, due to challenges introduced by inadequate professional guidance and medication adherence, patients often encounter issues related to medication self-administration. Errors in self-medication can impose additional burdens on both patients and healthcare institutions. To address this, in 2021, Zhao proposed an innovative AI system that analyzes wireless signals within patients' homes to identify errors in self-medication [3]. Utilizing the reflection of wireless signals from the human body, the system can extract the signal corresponding to the activity of the patient. By applying AI techniques to analyze the signals received by sensors, the system can effectively track specific movements associated with self-medication. Consequently, this approach enables not only monitoring of medication timing but also assessment of whether patients adhere to the correct steps of using the medication device. This wireless sensing-based solution alleviates the burden on healthcare institutions and does not impose any inconvenience on patients' daily lives.

For medical treatment, in-depth knowledge of an individual's health status and physiological functions is crucial for healthcare professionals to develop treatment plans and preventive measures. Continuous monitoring of physiological signals such as respiration and heart rate holds significant importance in individual health management, disease prevention, and treatment. Present monitoring approaches typically employ portable and wearable devices to record parameters like heart rate, respiration, and sleep quality. Wireless sensing utilizes reflected signals extracted from the chest and abdomen of the human body to monitor vital signs. This is achieved by analyzing the phase and amplitude variations caused by respiration and heartbeat. In 2021, Wang achieved precise monitoring of human vital signs using commercially available millimeter-wave devices [4], demonstrating median errors of 0.19 breaths per minute and 0.92 beats per minute for respiration and heart rate, respectively. The continuous monitoring of physiological signals also holds critical significance in disease diagnosis. Parkinson's disease, the world's fastest-growing neurological disorder, had over 1 million patients in the United States as of 2020. Regrettably, there are currently no medications capable of reversing the progression caused by the Parkinson's disease. Consequently, early diagnosis of Parkinson's disease represents a significant area of research. Traditionally,

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Parkinson's disease diagnosis relies on clinical symptoms. However, the characteristic motor symptoms of the disease often manifest several years after its onset. The relationship between respiration and Parkinson's disease was identified as early as 1817 [5]. In 2022, Yang introduced an AI-enabled wireless sensing aimed at achieving early diagnosis of Parkinson's disease [5]. This pioneering approach employs RF signals to track nocturnal respiratory patterns for detect Parkinson's disease and monitor the progression of the disease over time. This technology provides an objective, non-invasive, and cost-effective method for monitoring Parkinson's disease.

Meanwhile, AI-enabled wireless sensing has also provided new solutions for daily health monitoring. Sleep is widely recognized as an important fact for individual health. Insufficient sleep can result in decreased cognitive function, emotional instability, and weakened immune response, among other consequences. Polysomnography (PSG) is the gold standard for assessing personal sleep quality in clinical settings. However, PSG is both expensive and cumbersome, significantly limiting its clinical practicality. Clinical studies indicate that physiological activity varies across different sleep stages. For example, respiratory rates differ due to fluctuations of cerebral oxygen consumption. Therefore, sleep quality monitoring can be achieved by monitoring respiratory and movement patterns. Zhang developed a practical sleep monitoring system based on RF signals [6]. This system utilizes commercial Ultra Wideband radar devices to monitor respiratory and movement signals during sleep, and employs respiratory to recognize different sleep stages. The system enables non-invasive and contactless daily sleep monitoring.

According to the latest research report from the World Health Organization, cardiovascular disease stands as the leading cause of mortality worldwide. The annual death toll attributed to cardiovascular disease exceeds that of any other disease category. In 2019, approximately 17.9 million people succumbed to cardiovascular diseases, constituting 32 % of the global total mortality. Notably, cardiovascular disease exhibits high incidence rates and recurrence rates with multiple complications, highlighting the crucial importance of early detection and treatment for patient recovery and prognosis. The cardiac activity encompasses a sequence of events transpiring within the heart. From a perspective in cardiac mechanical activity, heart activity can be classified into four distinct phases: atrial contraction, ventricular contraction, atrial relaxation, and ventricular relaxation. Precise mechanical coordination ensures the effective expulsion of blood by the heart and its subsequent circulation throughout the entire body. Seismocardiography (SCG) records the mechanical activity of the human heart, capturing intricate cardiovascular events such as the opening and closing of heart valves, as well as the contraction and relaxation of cardiac chambers. Currently, SCG obtained by measuring chest wall vibrations through the use of an accelerometer attached to the chest. Unsoo proposed a contactless SCG acquisition method based on deep learning radar, enabling the precise timing of five distinct cardiovascular events within a single heartbeat [7]. This approach achieved a median error ranging from 0.26 % to 1.29 %.

From the perspective of cardiac electrical activity, the electrical signals generated and conducted within cardiac muscle cells promote the contraction and relaxation of the heart, thereby driving the circulation of blood. Currently, the main method for monitoring cardiac electrical activity is the electrocardiogram (ECG). As a non-invasive diagnostic tool for detecting cardiac electrical activity, the ECG is one of the important tools used worldwide in clinical settings for diagnosing heart diseases and monitoring heart health. For an ECG examination, multiple electrodes need to be placed on the patient's body to measure changes in the patient's cardiac electrical signals. However, cardiovascular diseases often require long-term continuous monitoring of the ECG to capture incidental cardiac dysfunction events. For patients, wearing electrodes for an extended period can cause discomfort, and the battery life and electrode adhesiveness may compromise the reliability of continuous monitoring. In the aforementioned study, although wireless sensing technology can analyze the mechanical activity of the heart by capturing reflected signals modulated by the human heartbeat, the problem of capturing cardiac electrical activity through wireless signals remains unresolved. Years of research have indicated there exists a mapping relationship between cardiac mechanical activity and electrical activity, but the nature of this mapping remains unclear. AI technology offers a new solution to this problem. Chen proposed a solution for contactless ECG monitoring using wireless sensing [8]. By analyzing the RF reflection signals received by a millimeter-wave radar system with signal processing algorithms, the 4D motion signals of cardiac are extracted. Then, a data-driven deep neural network with an encoder-decoder structure is used to extract the mapping relationship between cardiac mechanical activity and electrical signals, successfully recovering the ECG waveform. This non-contact ECG measurement approach achieves high-precision timing of cardiac electrical events, with a median error of less than 14 ms.

In conclusion, the rapid advancement of AI-enabled wireless sensing technology has opened up new avenues and methodologies for research and applications for medical diagnosis. Leveraging the non-intrusive, continuous, and privacy-protection natures of RF signals, wireless sensing technology provides healthcare professionals with more fine-grained and long-term information of the patient, facilitating the early detection of the disease and highly personalized treatment.

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