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Wearable electronics and future application in healthcare

Jianing He

School of Mechanical and Electronic Control Engineering, Beijing Jiaotong University, Beijing, China

24222006@bjtu.edu.cn

Abstract. Over the past decades, the growing demands for disease management have spurred advancements in wearable electronics, enabling more comprehensive and precise monitoring of vital signs. The integration of these devices with artificial intelligence has not only enhanced detection efficiency and user interaction but also deepened research in this field. This article provides a comprehensive review of the up-to-date development of wearable electronics while attach importance to its relation with health care. The application of wearable electronics in monitoring both human's and animal's condition are also discussed. The findings reveal that wearable devices can not only bring revolutionary innovations to the medical and health field, but also promote the coordinated development of industries such as AI and wireless communication. It also demonstrates that while future challenges will exist, it is still promising for wearable electronics to change humanity's life positively with the assistance of policies, technical breakthrough and market requirement. And the conclusion is that wearable electronics will develop further than health monitoring devices to be a comprehensive platform generating human health, animal and environmental protections.

Keywords: Wearable electronics, healthcare, development trend, research progress

1. Introduction

The past decades have witnessed the rapid development of electronic equipment's monitoring capability, which facilitates the promotion in wearable electronics. Given its immense potential in the medical industry, wearable electronics have garnered substantial attention and in-depth research from scholars across fields such as animal protection and human healthcare. This essay aims to explore the future applications of wearable electronics in healthcare.

Research over the past decades has seen unparalleled transformations in various domains, including intellectual prosthetics, auxiliary robots, energy collection and storage, display sensors, and defense [1]. When concentrating on healthcare field, it can be categorized into invasive and on-skin types, which constitutes physiological monitoring, while there is another sort that consists assistive robotics and smart prosthetics to support disabled people to accomplish daily activities. However, limitations and research gap can be seen in wearable electronics. Those wearable electronics have been restricted caused by long-time instability including temperature, hydrated and mechanical field [1]. For example, according to research conducted by scholars from the University of Basel, limitation is found in smartwatches like Apple Watch and Fitbit that they frequently make mistakes to distinguish stress due to excitement or physical exertion during the process of detecting [2]. Additionally, wearable electronics encounter challenges related to clinical verification, privacy, and ethics.

This paper employs document analysis and case studies to investigate the development of wearable electronics in healthcare and to predict their future trends. This study aims to provide insights into the evolution of wearable devices and their potential impact on the healthcare industry.

2. Theoretical framework

Nowadays, wearable electronics are widely used in virtual reality technology, medical and health care, military and so on. Then it is the principle of wearable devices. To begin with, the core of wearable electronics based on a closed-loop system including perception, data processing, transmission and interaction, which in order to realize real-time monitoring, analysis and feedback of creature's body conditions, movement behaviors or environmental information. The work procedure of wearable electronics can be divided into five stages.

The first stage is data collection with sensors, which includes physiological sensors, motion sensors and environmental sensors mainly. Among three types, physiological sensors are the most widely used one in healthcare. For example, sensors adopting plethysmography are able to transmit light of specific wavelength that will be absorbed or reflected by red hemoglobin in the blood. Then the changes of blood flow during the heartbeat causes fluctuations in reflected light intensity which can calculate the heart rate, while blood oxygen monitoring are determined by analyzing the difference in absorption between red light and infrared light. What is more, the other two types of sensors are able to track body movements and receive environmental information respectively. After collecting, data is processed through the Microcontroller Unit (MCU) in the wearable electronics. Then data is transmitted to mobile phones or iCloud which rely on short-range transmission via Bluetooth or long-distance transmission through network connection, etc.

Apart from the three mentioned above, the remaining two stages consist of human-computer interaction and energy supply. The human-computer interaction refers to enable users to understand the collected data and the interactive functions, which is usually displayed on the screen, and users can interact through touch screen, voice input and so on. And the final part is energy supply includes high-efficiency battery technology due to its limited space.

3. Research progress of wearable electronics in healthcare

The research progress of wearable electronics is discussed in three field in this article, including human physical healthcare, human psychological healthcare and animal protection.

3.1. Human physical healthcare

Globally, over 1.3 billion people suffer from hypertension, yet only 21% have their condition under control. Traditional cuff-based blood pressure monitors are limited by their inability to provide continuous monitoring and their susceptibility to inaccuracies based on how they are worn. However, wearable electronics have greatly improved the situation.

According to the research, wearable electronics including flexible mechanical, optical, ultrasonic sensors and flexible electrodes are able to collect BP-related body condition data efficiently and conveniently thanks to the remarkable improvement in flexible devices and signal processing algorithms [3]. Compared to traditional cuff-reading methods, wearable devices have achieved a transformation from passive to active, which means it can provide real-time blood pressure data and monitor the process of changes in the overall physical condition, enabling more precise treatment. Based on research, a brain-computer interface for Electroencephalogram (EEG), electrodermal activity readings and electrochemical sensor included in the in-ear integrated sensor enables it to detect lactate in sweat, which can assist EEG readings to distinguish generalized epileptic seizures from psychogenic nonepileptic and syncopal accidents [4]. This part is the monitoring of neurological health through wearable electronics, which breaks through the barrier of the skull and enables wearable devices to probe deeper into the internal conditions of the human body. In addition, it provides more comprehensive internal organ information than external devices without harming internal organs, facilitating precise diagnosis. Research also shows that the development of this field is expected to replace minimally invasive sensors.

Besides, wearable electronics also promote in working normally under extreme conditions. A study shows that in different hydrated conditions; environmentally compatible properties is feasible by exploration in creative materials and structure design methods [5]. In different environments, the stable operation of wearable devices enables the expansion of their application scope and realizes long-time and steady health monitoring.

3.2. Human psychological healthcare

Nowadays, the percentage of people diagnosing psychological illness is at the range of 20% to 30%. After the outbreak of the pandemic, the number of patients with anxiety and depression increased by 25% even more. Therefore, dealing with psychological illnesses has become an urgent issue. Wearable electronics come to be one of the solutions along with its development. For example, during the treatment of bipolar disorder, lithium medication in the blood needs to be tested to ensure it functions within a specific range. According to the first wearable Li sensor, sweat can be locally stimulated without exertion due to an iontophoretic delivery system. The manipulated flow is accelerated to generate sweat to the Organic Electrochemical Transistors (OECTs) channel which detects Li^+. To generate the sensor data, a particular display board is also designed [6]. With the assistance of wearable electronics, monitoring psychological illnesses will be more convenient and safer, which is conducive to reducing the mortality and disability rates caused by mental illness.

3.3. Animal monitoring

As the problem of environmental protection has gained wider attention, animal protection has become even more important. Due to the fact that the living environments of some endangered animals are difficult to observe over a long period of time, it makes the monitoring of these animals' condition quite challenging. However, wearable electronics enable humanity to monitor those animals remotely. For example, one wearable electronics for monitoring marine creatures shows that minor heartbeat's movements of invertebrate aquatic animals, heartbeats and constant tail movements in aquatic vertebrates are able to be monitored by the Keratin Liquid Metal (KELM) hydrogel. What is more, through distinguishing heartbeat patterns of a variety of aquatic organisms including giant salamanders, sturgeon and scallops, the timeliness and accuracy of aquatic health's assessment are offered a strong method [7]. This kind of wearable electronics promote the ability of marine inhabitants tracing, which is vital to animal protection. On the other hand, monitoring animals' condition also facilitates stock farming. Traditional medical tests for animals, due to human involvement, may cause additional psychological trauma and stress to animals, and are inefficient. According to research about machine learning application in graziery conducted by Varga et al., researchers successfully differentiate different conditions of cows including pathological, reproductive and stressful through a random forest-based regression. Researchers employed four machine learning algorithms to forecast pigs' water needs by analyzing key parameters such as Feed Intake (FI), Mass of Pigs (MP), Pigs' Body Temperature (PBT), Room Temperature (RT), Room CO_2 Concentration (RCO_2), and Room Temperature-humidity index (RTHI). In essence, these predictive models allow for the direct detection of changes in information, thereby providing technical support for informed farm management decisions [8]. Therefore, wearable electronics can enable animal husbandry's sustainable development and efficiency promotion.

In a nutshell, these three aspects of the development of wearable devices have all enabled the control of physical conditions to shift from passive to active. The field has also expanded from human health to animal protection and supervision.

4. Challenges and future directions

4.1. Challenges

Wearable electronics do have great potential, however, there are a variety of limitations exist.

To begin with, deficiencies in the feasibility verification of wearable devices should be noticed. According to the research, although large number of studies reported that it possesses high feasibility and patient compliance, which is larger than 70%, only 5.6% were random and subsequently limited the strength of clinical recommendations [9]. It means that the stability of truly putting wearable electronics into medical use still cannot be fully determined.

Moreover, the types of sensors and data formats among different devices are not uniform, which causes difficulties in cross-device analysis. There two points together have led to the current situation where there are certain barriers to clinical application. Secondly, it involves certain ethical dilemmas. During the process of data transmission, there is a privacy issue of data leakage. When monitoring the body condition, wearable electronics continuously collects the user's physiological features, geographical location and behavioral habits, etc. These are more sensitive than passwords and the consequences of leakage are more serious as well. For example, among wearable electronics, there is a product that are glasses equipped with cameras, which needs to be subject to strict legal and ethical regulations. However, nowadays the pace of technological development far exceeds the follow-up of laws.

What is more, problems also exist in the interpretation of data. The equipment has collected a vast amount of data, however, what is provided to users is often just a monotonous assessment, such as measuring sleep quality on a 100-point scale. Another remaining issue in this regard is the inability to integrate the data with specific environmental conditions, including stress, drug effects and illnesses.

Moreover, most wearable electronics is unable to combine specific conditions with individuals and provide targeted health advice to non-professionals. The last is the most fundamental constraint on development, representing the existing core technological limitations. On the one hand, the strong ability of wearable electronics causes severe electric energy loss, which will lead to an inability for long-term using. On the other hand, most consumer-grade wearable electronics have the problem of insufficient accuracy. In addition, as users are in non-laboratory environments, it will further affect the accuracy of data monitoring. For instance, the accuracy of blood pressure detecting is influenced by factors including the tightness of the device and body temperature, making it difficult to meet medical certification standards.

4.2. Future directions

Although there are many existing bottlenecks in wearable electronics, their development potential is enormous. For example, the battery life issue mentioned above is being resolved. Smart fabrics were developed in Wuhan University that are able to realize creating electricity energy through the temperature difference between human and the environment in order to drive the glucose sensor to work [10]. With this method, wearable electronics have great possibility to realize reducing the time spent due to device charging removement or even charging without removing it.

Besides, with the advent of the era in which everything is connected, wearable electronics have gained more possibilities. It will able to control smart home devices more conveniently, enabling human beings to live in environments suitable for different individuals and achieve health more effectively. With the strengthening of cooperation among manufacturers, promoting devices interconnection and data sharing, users can enjoy a more convenient and comprehensive cross-device experience.

Last but not least, artificial intelligence, which can be regarded as the most valued industry, is extremely likely to combine with wearable electronics. According to the research, wearable electronics driven by artificial intelligence will provide suggestions including fitness regime, dietary adjustment and so on through health marking, analysis of exercise patterns. It can even predict the risk of injury through movement patterns [11]. AI technology will make the development of wearable electronics more comprehensive and in-depth. Data will no longer be confined to merely being detected and transmitted, but will be further intelligently analyzed to provide more professional and useful suggestions for different environments and individuals. However, it can not be ignored that the future development of wearable electronics will also be accompanied by obstacles. Legal follow-up and technical issues are inevitable problems in the whole process of development and need to be constantly broken through. To sum up, the future of wearable devices will develop in the directions of materialization, intelligence and intangibility, and can be integrated into all aspects of our lives.

5. Conclusion

Wearable devices have evolved from initial data monitoring to enabling preliminary intelligent analysis, integrating multiple industries. At present, this technology has made remarkable progress in human health, enabling monitoring and control of both physical and mental health. For instance, the innovation of flexible materials has greatly enhanced the comfort of wearing and increased the theoretical wearing time. This article also highlights wearable electronics for hypertension monitoring, which can achieve long-term control and active monitoring of physical health and have strong traceability for blood pressure changes. In the realm of mental health, wearable electronics have shown promise in effectively managing conditions such as bipolar disorder, anxiety disorder, and depression. Their applications have also extended beyond human health to the monitoring of animal conditions. These devices can be utilized to protect marine life, manage livestock and poultry, thereby making strides in animal protection and enhancing the productivity of animal husbandry.

Despite its rapid development, this field still faces many difficulties. The individual differences and environmental disturbances have affected the clinical reliability of the data. Technical issues and the lag of the legal regulatory system are problems that will be faced in the present and future development. Overall, however, the future of wearable electronics will hold great potential. It is likely to further optimize battery performance and charging methods, along with promoting the comfort of wearing, extending the monitoring time. Additionally, with the integration of wearable electronics with artificial intelligence and the Internet of Things, its development fields will further and deeply expand. It is expected to establish an individual health warning ecosystem. optimize chronic disease management and remote medical paradigms. Eventually, wearable electronics will surpass traditional health monitoring and become a comprehensive and intelligent platform integrating human health, environmental protection and animal monitoring.

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