Dean&Francis
ISSN 2959-6157

A Study on the Progress of Microelectronics in Wearable Devices

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Abstract:
In recent years, wearable devices have become a hot issue, and microelectronics technology is an indispensable technology in the process of manufacturing wearable devices. In this paper, the definition and application fields of microelectronics technology and wearable devices are first reviewed, and then the theoretical knowledge related to microelectronics technology, i.e., the application of integration methods, low-power technology, and wireless communication technology, is summarized. Then the applications of wearable devices are described in detail, and the research results in recent years are summarized. The most important application of wearable devices is the exploration of human body functions, including the two major application areas of physiological parameters in medical devices and motion detection in smart wearable devices. It concludes with a look at how future research can make wearable devices more convenient for people to use, as well as centralize more functions in smaller devices.

Keywords: Microelectronics; wearable devices; medical detection.

1. Introduction

All Microelectronics is a new technology that has developed with integrated circuits, especially very large-scale integrated circuits. The term microelectronics initially refers to scales on the order of microns, where functional expression is carried out by controlling the behavior of electrons. As device sizes continue to shrink into the nanometer scale, the connotation of the term microelectronics is also expanding, and it is now generally accepted that microelectronics refers broadly to electronics that encompass both the micron and nanometer scales. Microelectronics has a wide range of applications in many different fields such as computer chips, in-vehicle electronics, satellite communications, display devices, and wearables. As for wearable devices, since the debut of Google Glass in 2012, under the situation that the innovation space of smartphones is gradually narrowing and the incremental market volume is close to saturation, smart wearable devices as the next hotspot in the smart terminal industry have been widely recognized by the market, especially in the fields of textile and apparel [1], military applications [2], and medical devices [3]. However, there are still some shortcomings in the existing products and research. Most of the wearable devices currently on the market are mainly “wearable”, while there are only a few “wearable” products. Wearable devices

ISSN 2959-6157

dominated by smart bracelets, watches, and glasses are not the best choice for collecting data and transmitting information, nor are they the best place for placing sensors. In contrast, clothing, as a rigid consumer demand, has incomparable advantages such as softness, comfort, foldability, and long-term wearability, and is more easily accepted by consumers. In terms of military applications, it is necessary to further reduce the existing military smartphones, handheld command terminals, portable detection instruments and other equipment, and integrate smart helmets, smart watches smart clothing and other equipment, minimizing the impact of the equipment on the body's flexibility. Moreover, the power supply under field conditions is difficult, so the battery life of smart wearable devices is also a major problem. In the field of medical devices, the data received from the sensors in these medical wearables can be distorted and noisy as most wearables involve interaction with the epidermis. Causes of noise include constant body movement and hairs on the skin, resulting in reduced adhesion between the skin and the wearable device. At the same time, the wearer is exposed to sound field environments such as hospitals where there is a lot of noise, human voices, and other distractions, which can seriously affect the wearer's voice experience [4]. Moreover, most diagnostic techniques involve the use of samples such as blood, urine, and saliva, and medical wearables have found limited integration with these samples. Therefore, more efforts are needed to integrate medical wearables with platforms that can support the use of biological samples with medical wearables and are available to end users. In addition, the use of artificial intelligence algorithms (e.g., supervised learning regression algorithms) could be used to track the behavior of multiple parameters of prognosis. Similarly, the security of the wearer is important, and since medical wearables contain protected health information (PHI), there is a need for uncompromised privacy. For this reason, secure communication protocols in medical wearables are crucial to ensure the security and privacy of the wearer [5]. In this paper, we mainly review the principles of microelectronics technology applied to wearable devices and the application areas of wearable devices in recent years, and look forward to the future research direction of wearable devices.

2. Microelectronics Key Technology and Integration

2.1 The Way Various Types of Sensors are Integrated in Wearable Devices

2.1.1 Integration position of the various types of sensors

Depending on the field to which they belong, wearable devices are different and therefore have different integration methods.

Heart rate sensors applied in the medical field usually use photoelectric volumetric tracing (PPG) to measure the heart rate by detecting the change in the volume of blood flow. These sensors are integrated on the surface of wearable devices, close to the user's skin, and are characterized by their small size and low power consumption. They are able to continuously monitor the changes in the user's heart rate, which is important for health monitoring and exercise tracking. The pressure sensor, on the other hand, is directly integrated into the stress area of the wearable device for measuring pressure and can be used for posture monitoring, muscle activity analysis, and exercise recovery, providing data on the user's body posture and movement status. Still another type of sensor is the Inertial Measurement Unit (IMU).IMUs typically integrate accelerometers, gyroscopes, and magnetometers, and these sensors are integrated into the core of the wearable device. IMUs provide spatial orientation and motion information that is critical for things like motion tracking, posture control, and navigation, and fusion algorithms can further improve the accuracy and stability of the data. Some sensors that measure environmental data such as temperature sensors, humidity sensors, and barometric pressure sensors are integrated at appropriate locations in the wearable device in order to accurately sense changes in the surrounding environment. These sensors provide a comprehensive view of comfort and are especially important for health monitoring in outdoor activities and extreme environments.

2.1.2 Integration methods and techniques

Printed circuit boards (PCBs) are one of the most common methods of integration. Sensors are mounted directly on the PCB by welding or gluing, etc., and use circuit connections to realize data transmission and processing. The advantages of this approach are low production costs, ease of mass production, and ease of integration with other circuit components. However, it should be noted that PCB wiring and electrical noise may have a certain impact on the performance of the sensor, so these factors need to be fully considered in the design. Some studies have shown that flexible printed circuit boards and insulin microneedles can constitute wearable insulin delivery devices.It can reasonably release drugs and monitor drug concentrations in the body when receiving disease signals or user commands, reducing dependence on doctors or hospitals, and realizing optimal timing and results of disease treatments. Also,the wearable drug delivery systems can be non-invasively and directly worn on the body surface, and they can be freely manipulated by both doctors and patients [6].

System-in-Package (SiP) is the packaging of multiple sensors and other electronic components (e.g., processor, memory, etc.) on a single chip to form a highly integrated functional module [7]. This approach significantly reduces the size and weight of the device while improving the performance and reliability of the system. In wearable devices, SiP technology can be applied to a variety of complex functional modules, such as motion tracking, health monitoring, etc., to provide users with a more powerful functional experience.

Flexible circuit board (FPC) integration has soft and bendable properties that make it ideal for sensor integration in wearable devices [8]. By mounting the sensors on FPCs, a tight fit with human skin can be realized, which improves wearing comfort. In addition, FPCs can be designed according to the morphology of the device to realize a variety of complex bending and folding shapes to meet the use requirements in different scenarios. In wearable devices, the FPC integration method is widely used for sensor connection and signal transmission in smart bracelets, smart watches and other products.

Thin-film sensors involve the direct integration of sensor elements onto a thin-film substrate, such as a polymer or metal oxide film [9]. This type of integration further reduces the size and weight of the sensor, which can be tightly fitted on the surface or inside the wearable device, while improving the flexibility and durability of the device.

2.2 Low-power Key Technologies and Applications in Wearable Devices

Ultra-low power precision operational amplifiers, as the core of the sensor chip, have an impact on the accuracy of the sensor, which further has an impact on the accuracy of the wearable smart device. Its power consumption affects the chip operation rate, leading to serious heating of the device, which in turn affects the usage feeling of wearable smart devices. Currently, op-amps are developing in the direction of low supply voltage, low power consumption, and low misalignment. Low supply voltage requires that the designed op-amps have rail-to-rail input/output characteristics. As the most important module in a sensor, the op-amp's internal power consumption and accuracy requirements seriously affect the sensor performance. Therefore, it is extremely important to study the key technologies of precision op-amp circuits with ultra-low power consumption and high reliability for wearable smart devices. Because the two factors of out-of-regulation voltage and power consumption will directly affect the usage feeling of wearable smart devices, which leads to the research on the design of rail-to-rail precision op-amps in terms of accuracy and power consumption. The basic realization principles of rail-to-rail precision op-amps, which include rail-to-rail methods to maintain constant transconductance (triple current mirrors, level shifting, redundant differential pairs, etc.) and two methods for high-precision realization (chopper stabilization and self-stabilizing zero). A novel rail-to-rail input implementation method has been investigated, i.e., a time-interleaved charge pump technique is used to increase the input stage supply voltage, and only PMOS differential pairs are required to achieve the rail-to-rail input characteristics while maintaining good transconductance constancy characteristics, with the input transconductance varying by only 5.6% between the rail-to-rail input common-mode voltage ranges. This method has a simpler structure than the conventional rail-to-rail that requires additional circuit structures to achieve transconductance constancy [10].

2.3 Application of Wireless Communication Technology in Wearable Devices

The wearable device is an intelligent interactive system with human-like perception ability, which is an intelligent interactive system integrating hardware sensors, processors and software control. Its wearability and convenience determine that it must be combined with wireless communication technology to realize the intelligent controllability of the system. In order to meet the actual needs of the majority of users, wearable devices will inevitably need to be front-end of the device, which puts forward a new demand for wireless communication technology, so the choice of suitable wireless communication technology has been a constraint on the development of the product needs. Combined with the wearable device's own characteristics, its networking technology must be safe and reliable, can meet the effective working distance, the wearable device and the front-end equipment or back-end equipment to establish an effective network communication, which, wireless Bluetooth communication technology is a good choice. Bluetooth devices are small and easy to install. Bluetooth communication node module area within a few square centimeters, with the increasing integration of electronic devices in recent years, its area can be made smaller, so it is easy to deploy and easy to install, but also because of its small size so to the wearable product form factor design to bring a lot of flexibility. In addition, low power, low energy consumption and low cost, making it easy to carry around at the same time also has the possibility of high-volume installation in a specific area. Low power consumption reduces the need for large batteries

ISSN 2959-6157

and also meets the requirements for long-lasting standby, which brings great convenience to users and meets the requirements of energy saving and environmental protection for wearable devices [11]. The most important thing is that the information sharing and interaction of multiple wearable devices can be satisfied in the same networking area. Bluetooth communication technology can meet the large amount of information transmission, and can meet the simultaneous use of multiple devices in a specific area. This feature is very suitable for the technical application of wearable devices, the user only needs to install the corresponding APP according to the technical requirements of wearable products can be independently realized in the same specific area of the different functions without interfering with each other.

3. Applications

3.1 Physiological Parameters

One of the major application areas of wearable devices is the in vitro detection of vital signs and sports health conditions, where the worn sensors are in direct or indirect contact with the human body and transmit real-time detection of data on a number of metrics, e.g., glucose, pH, and pulse. For contact wearable mode, sweat is one of the most targeted biofluids for developing non-invasive wearable biosensors, such as Lu et al. fabricated a wearable self-powered sweat monitoring system, so that the smart system further combines signal transduction and wireless transmission technologies, which can be conveniently and accurately realized to display the sweat information on personal cell phones and assess the physiological status of individuals [12].Pu et al. prepared a microfluidic sensor consisting of a microfluidic chip integrated with a three-electrode sensor for glucose detection, which can realize continuous monitoring of glucose concentration within 48h [13]. For implantable wearable modalities, microneedles provide a minimally invasive method for extracting desired molecules from interstitial fluid. In recent years, it has become possible to detect metabolites such as glucose, lactate, and alcohol from interstitial fluid. Compared to blood collection and analysis, microneedle analysis does not cause discomfort or pain, and these effects can be more prominent in patients who need to be tested daily.

3.2 Motion Monitoring

With the advancement of technology, traditional training methods are gradually being combined with modern technological tools, especially wearable devices, for the purpose of improving training efficiency and effectiveness. These devices are able to monitor the athlete's physiological and athletic data in real time, such as heart rate, blood pressure, trajectory, speed, etc., helping coaches to more accurately analyze the athlete's training status and areas for improvement. From the early days of step counters and heart rate monitors to the advanced devices that can now analyze sports techniques and tactics, the application of wearable technology in the sports field is becoming more and more widespread. In basketball training, for example, wearable devices are used to monitor body data such as heart rate, speed and acceleration. With heart rate monitors, coaches can get a real-time view of the athlete's heart rate changes during training. In general, the ideal heart rate zone during basketball training should be maintained at 120-160bpm, which helps to ensure that the athlete is training at an appropriate intensity. Velocity and acceleration are important indicators of a basketball player's explosive and speedy performance. Using velocity and acceleration sensors, coaches can accurately measure an athlete's top speed and acceleration performance in a sprint or breakaway [14].

4. Challenges and Future Prospects

Wearable devices as materials, chemistry, biology, physics and other multidisciplinary integrated application product has been rapidly developed, but it still has some problems to be solved. Firstly, sweat detection devices cannot be reused, and increasing the discharge system can realize the recycling of the devices. Second, the power consumption of wearable devices for detecting and recording transmission information is large, and most of the devices, although they can carry out continuous detection ranging from a few minutes to a few hours, still cannot meet the demand for long-term wear. Better integration of capacitive devices, such as supercapacitors, can realize smaller and longer-lasting power supplies. Further, wearable devices integrate many components that can affect wearing comfort, while biocompatibility is also an issue to consider. With the development of wireless transmission and new materials, it is possible to enhance the intelligence and reduce the size of the device to make it more comfortable to wear, while combining the natural biocompatibility and biodegradability of biomaterials to address their safety.

5. Conclusion

This paper summarizes the principles of microelectronics technology and the application of wearable devices. With the development of science and technology, wearable devices will inevitably become a necessity in our lives, covering various fields. However, the existing research is still immature, in the future, the development trend of wearable devices should focus on the areas of miniaturization, low power consumption and comfort, which can be conveniently used by countless people in order to open up a new market.

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