Wearable Technology (2021) Volume 2 Issue 2, *pp.* 20–26.
doi: 10.54517/wt.v2i2.1655

ORIGINAL RESEARCH ARTICLE

The design and realization of flexible wearable wireless music controller

Weixin Li[1,2], Haiqing Jiang[2], Xinrong Hu[1*]

*[*1] School of Computer Science and Artificial Intelligence, Wuhan Textile University, Wuhan 430200, Hubei, China*

[2] Technical Research Institute, Wuhan Textile University, Wuhan 430200, Hubei, China. E-mail: hxr@wtu.edu.cn

ABSTRACT

By using flexible sensors and micro-control units, a wireless controller that can be integrated into clothing for cross-platform music control has been designed and implemented, providing a new idea for making a simple and low-cost flexible wearable sensing system. The design and implementation of a wireless controller that can be integrated into clothing for cross-platform music control provides a new idea for the preparation of a simple and low-cost flexible wearable sensing system. Based on the flexible fabric sensing material, a simple structured sensor piece is proposed as a button for the controller with good wearing comfort. The sensor element is capable of sensing finger presses up to 15kPa. ESP32 is used as a micro-control unit for sensing signal acquisition and data processing. Using the Bluetooth chip integrated inside the ESP32, the controller can be connected with terminal devices of different platforms for wireless data transmission. The results show that the prepared wireless music controller can be stably connected with both Windows computer terminal and Android cell phone terminal, and the sensor recognition accuracy of finger press is 99.7%, which indicates that the flexible fabric sensor has a broad application prospect in the field of wearable devices.

Keywords: flexible sensors; wearable devices; ESP32; wireless music controller

1. Introduction

With the development of technology, wearable devices are widely used in medical, human-computer interaction, motion capture and other fields[1–6], and the wearable devices market is growing at an explosive rate. According to the *2020 Global Wearable Devices Third Quarter Data Report*[7] issued by IDC in December 2020, the number of wearable devices shipped worldwide increased by 35.1% year-on-year to 125.3 million units, and the number of wearable devices shipped worldwide in 2019 was 336.5 million units. Although the number of wearable devices shipped has increased compared to previous years, the top three wearable devices with the highest market share are headphones, watches and bracelets, according to IDC's research. Generally speaking, the main functions of wearable devices are to monitor human physiological signals (such as heart rate, pulse, pressure, step count, etc.) and to control cell phones and computers through human-computer interaction with wearable devices. In order to achieve these functions, wearable devices usually use rigid sensors as sensing units and thermoplastic silicone vulcanizate (TPSIV) or thermo-

ARTICLE INFO
Received: August 9, 2021 | Accepted: September 30, 2021 | Available online: October 17, 2021

CITATION
Li W, Jiang H, Hu X. The design and realization of flexible wearable wireless music controller. Wearable Technology 2021; 2(2): 20–26.

plastic polyurethane (TPU) rubber as the housing for the wearable device to fit well on the body. In contrast, flexible fabric materials[8–11] have good flexibility and have promising applications in the field of wearable devices. However, the characteristic that flexible fabric materials are not easily integrated with circuits due to their inherent intolerance to high temperatures also makes it difficult for sensors made of flexible fabric materials to be integrated into clothing.

Commercially, Levi's has cooperated with Google to launch the Commuter Trucker Jacket[12] in 2016, which incorporates conductive fibers in the left cuff and encapsulates Bluetooth, battery and other modules through an "electronic tag" on the side. This smart jacket account can be controlled by finger operation in the conductive fiber area, such as adjusting the volume, switching songs, answering phone calls, etc. The material used in this smart jacket is a kind of conductive fiber, which can sense the user's finger movements. However, its production process is complicated, which makes the smart jackets expensive and greatly limits their industrialization and practical application. The domestic smart clothing has many functions such as electric heating and magnetic therapy, and smart clothing products with information processing functions are still blank. In order to explore the application prospect of combining flexible fabric sensing materials and computer technology to make wearable devices, this paper designs and implements a flexible wearable wireless music controller based on flexible fabric sensors and ESP32 microcontroller unit, which has the characteristics of simple structure and easy fabrication and cross-platform use.

2. System Function and Structure

The flexible wearable multimedia wireless controller designed in this paper is a wearable multimedia control device that can be integrated into clothing and has good wearing comfort. It can be connected to cell phones and other terminal devices via Bluetooth, and can control the music playback in cell phones without taking out the cell phone. The main functions and structure of the system are shown in **Figure 1**.

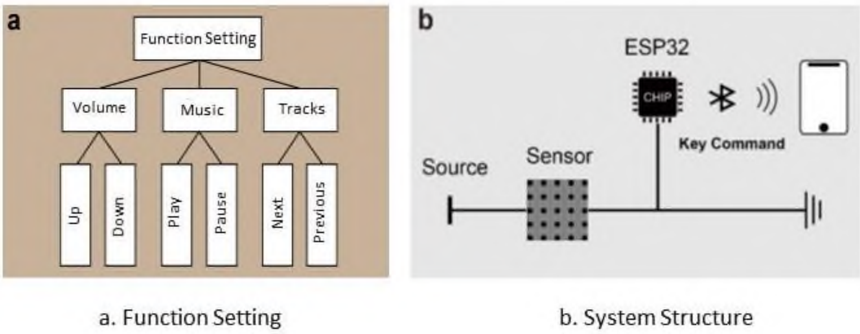


Figure 1. System Function and Structure.

In terms of function setting, the music controller designed in this paper can control the volume up and down, music play and pause, and track switching when the finger taps on the flexible fabric sensor. The system structure consists of two parts: The flexible fabric sensor and the micro control unit. The flexible fabric sensor generates electrical signal changes under the action of external forces. The micro-control unit detects this signal change in real-time and at high speed through circuitry, and then processes the signal data. When a finger tap is detected, a corresponding key command is sent to the terminal device via Bluetooth.

3. System design and implementation

3.1. Design and implementation of flexible fabric sensing structure

Sensing structure design

In order to fit the human body structure and achieve better comfort, this paper uses a flexible fabric sensing material to make a flexible sensor. The structure of the sensor is shown in **Figure 2**.

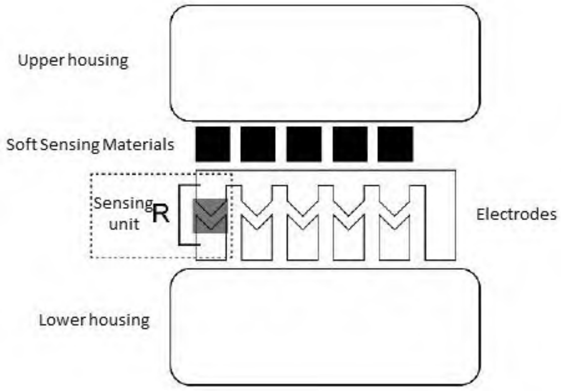
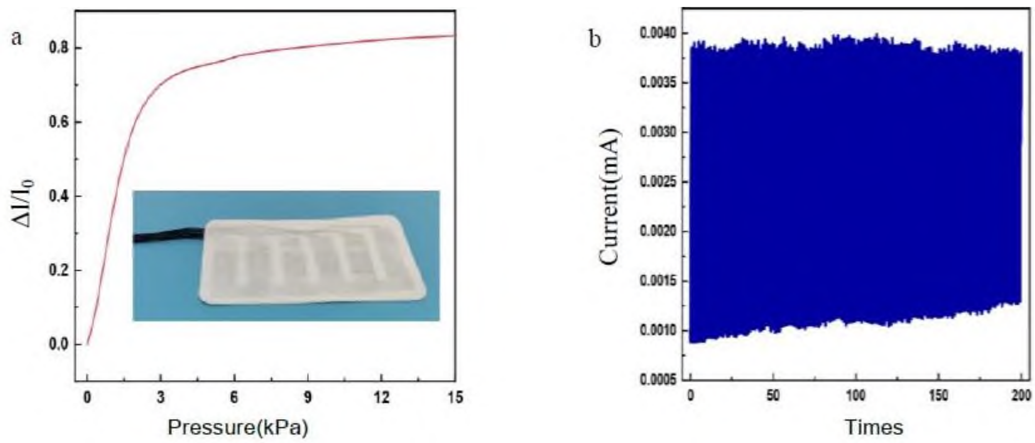


Figure 2. Sensor structure.

The structure of the sensor is divided into four parts, the uppermost and lowermost layers are the outer shell, and the middle two parts are the electrode layer and the sensing layer. The upper and lower housings of the sensor are made of smooth and comfortable white knitted fabric. The material used for the electrodes is a flexible conductive fabric (3 Ω/cm), and the sensing unit uses a flexible fabric sensing material with a knitted structure. As shown in **Figure 2**, there are five sets of flexible sensors as five function buttons, which correspond to the volume increase and decrease, music play and pause, and track switching. Each sensing unit will change its resistance under the action of external stress, and the state of finger tapping on the sensing unit can be obtained by detecting the change of resistance.

Sensor fabrication and performance testing

The performance of the prepared sensor was tested by using a force meter and CHI650 electrochemical workstation. The electrical flow through the sensor was continuously collected at different pressures (< 1s5 kPa) with a voltage output of 0.5 V at both ends of the flexible fabric sensor and plotted; the sensor was pressed repeatedly 200 times at a pressure of 3 kPa, and the electrical flow s was recorded and graphed. The corresponding test results are shown in **Figure 3**.



a. Sensor sensitivity test with physical picture of the sensor

b. Cyclic stability test

Figure 3. Physical and performance testing of sensors.

Figure 3(a) shows the sensitivity test results of the sensor and the physical picture of the sensor. The test results show that the current variation of the flexible fabric sensor subjected to pressure in the range of 4 kPa-15 kPa accounts for 20% of the overall variation, but when the pressure is within 4 kPa, the current variation accounts for 80% of the overall variation. The cyclic stability results are shown in **Figure 3(b)** for 200 tests. The results show that the maximum and minimum values of the current flowing through the flexible fabric sensor fluctuate after several taps. The fluctuation range of the maximum value is within 0.0004 mA. Since the flexible fabric sensor uses the fabric structure, after repeated knocks in a short time, the minimum current will gradually increase due to the lack of timely rebound of the fabric structure, but the increase is limited, about 0.0006 mA, which has little effect on the knock determination.

3.2. Hardware circuit design

ESP32 Introduction

ESP32 chip is a dual-mode 2.4 GHz Wi-Fi and Bluetooth integrated chip solution from Loxin. The ESP32 is powered by the Xtensa® 32-bit LX6 single-core processor with 200 MIPS of computing power. In addition, the ESP32 has an integrated 12-bits SAR ADC supporting a total of 18 analog channel inputs with a sampling frequency of 200 ksps.

Signal Acquisition

When a flexible fabric sensor is subjected to external stress, it deforms electrically in the form of a change in electrical resistance. In order to detect the pressure signal of the sensor, the signal can be acquired through the principle of resistive voltage division in a series circuit. The signal acquisition principle and circuit diagram are shown in **Figure 4**.

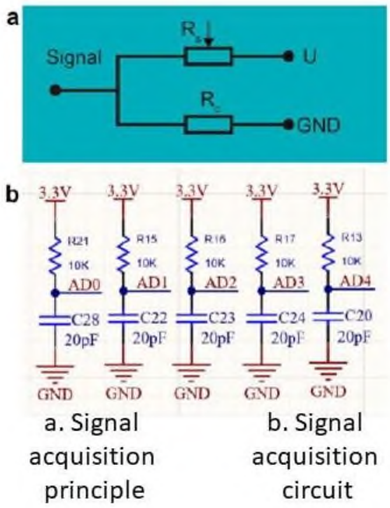


Figure 4. Signal acquisition principle and circuit diagram.

In **Figure 4(a)**, U is the total voltage in the circuit, R_s is the resistance of the sensor, and R_c is the fixed value resistor used for voltage dividing. When the resistance of the flexible fabric sensor changes, the voltage divider U_c at R_c will also change accordingly, and the voltage acquisition point is at Signal, and the change of sensor resistance R_s can be obtained by collecting the change of voltage at Signal. The voltage signal is calculated by the following formula:

$$Singnal = UR_c/(R_s + R_c)$$

Figure 4(b) shows the signal acquisition circuit, which contains five signal acquisition channels, each of which connects a flexible fabric sensor in series with a 10 K fixed-value resistor and connects to the analog-to-digital converter interface of the ESP32. In order to reduce the noise interference in the circuit, a 20 pF capacitor is added in front of the fixed resistor.

3.3. Software Programming

Software Structure

Since the underlying driver of ESP32 is not open source, the hardware needs to be initialized using the official driver functions provided by Loxin. Loxin provides the corresponding software development kit, ESP-IDF, which allows users to easily add their own libraries or other functions and integrates with the FreeRTOS operating system. The program execution flow is shown in **Figure 5**.

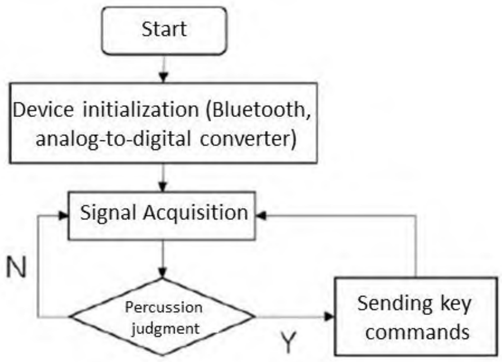


Figure 5. Program execution flow.

After the hardware is powered up, the main program is executed. The main program initializes the hardware, which includes the Bluetooth and analog-to-digital converter modules of the ESP32. After the initialization is completed, the signal is collected in real-time by the analog-to-digital converter. Whenever the signal data is collected, the data collected is evaluated. If the keystroke is valid, the corresponding key command is sent via the Bluetooth module. After the command is sent, the next round of acquisition is performed. If there are no taps, the signal will continue to be collected.

Bluetooth wireless communication

To send key commands to terminal devices, Bluetooth needs to be driven. The Bluetooth protocol stack supported by ESP32 includes Classic Bluetooth and BLE protocols. In order to send multimedia control commands via Bluetooth, the HID (Human Input Device) protocol is implemented using the GATT protocol of BLE. GATT (Generic Attribute Profile) is a low-power Bluetooth device communication protocol. The GATT protocol is used to implement the USB HID protocol, which allows the terminal device to recognize the Bluetooth device as a keyboard. The execution flow of the program is shown in **Figure 6**.

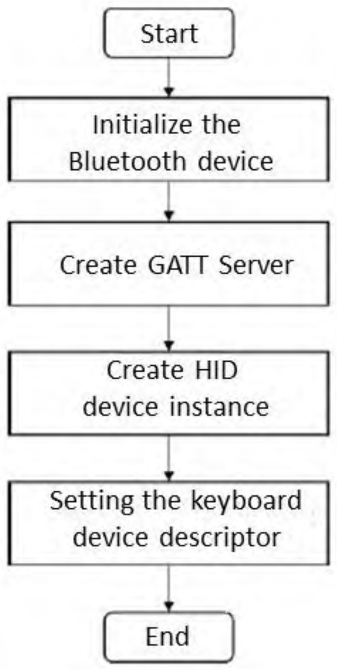


Figure 6. Bluetooth communication operation flow.

Firstly, the program needs to initialize the Bluetooth device, then create the GATT Server instance and set up the callback function. Next, the HID device instance is created, which contains the definition of the device type, manufacturer, HID information, etc. Finally, the HID keyboard descriptor property needs to be provided to the GATT service so that the end device can parse the data transmitted by Bluetooth into keyboard commands. Some of the main descriptions of the HID keyboard descriptors are shown in **Table 1**.

Table 1. HID keyboard descriptor

Content	Meaning
0x09,0x06	Device usage for keyboard
0x05,0x07	Usage page for buttons
0x09,0xb5	Next song
0x09,0xb6	Next song
0x09,0xcd	Play/pause
0x09,0xe9	Volume increase
0x09,0xea	Volume reduction

Analog to Digital Converters

In order to collect the signal data of the flexible fabric sensor, it is necessary to drive the analog to digital converter for signal acquisition. The ADC of ESP32 has two working modes, namely ADC-RTC and ADC-DMA modes. The ADC-RTC mode is controlled by the RTC controller, which is suitable for the application scenario where only low-frequency acquisition is required. ADC-DMA mode allows data to be directly copied from one storage space to another without CPU processing. Therefore, in signal acquisition, the acquisition frequency can be greatly accelerated. This paper uses ADC-DMA mode for signal acquisition, analog to digital converter driver process as shown in **Figure 7**.

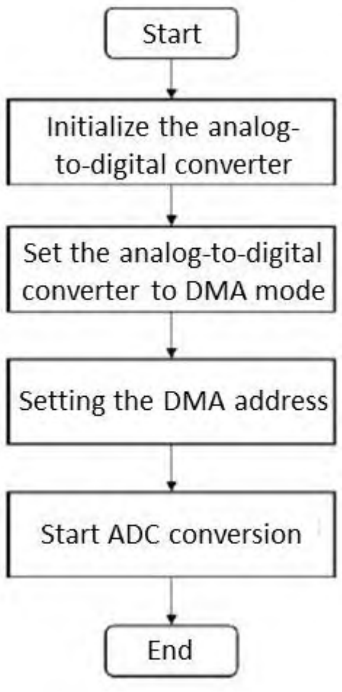


Figure 7. Analog-to-digital converter driver flow chart.

3. System Testing

In order to verify the functional effectiveness and reliability of the design, cross-platform compatibility tests and functional tests were conducted.

3.1. Cross-platform compatibility testing

The flexible wearable wireless music controller connects to the end device via Bluetooth, which includes the Windows desktop and Android mobile terminal. The connection effect is shown in **Figure 8**.

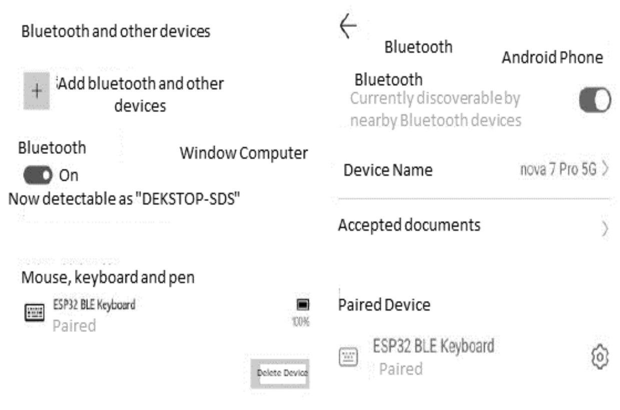


Figure 8. Effect of different terminal connections.

During the test, different types of terminal devices were used to connect to the flexible wearable wireless music controller designed in this paper, and the connection was maintained for an hour. A successful connection was considered when the connection could be maintained for an hour without dropping the connection. Windows desktop devices include Windows desktop and laptop computers, while mobile devices are mainstream cell phones, such as OnePlus, iqoo, Meizu, Xiaomi, and Huawei.

3.2. Functional Testing

After the compatibility test, the functionalities were also tested in this paper. After the end device was connected to the flexible wearable wireless music, each of the five function keys was hit 20 times and the corresponding function was recorded. The success rate of the function test is shown in **Figure 9**.

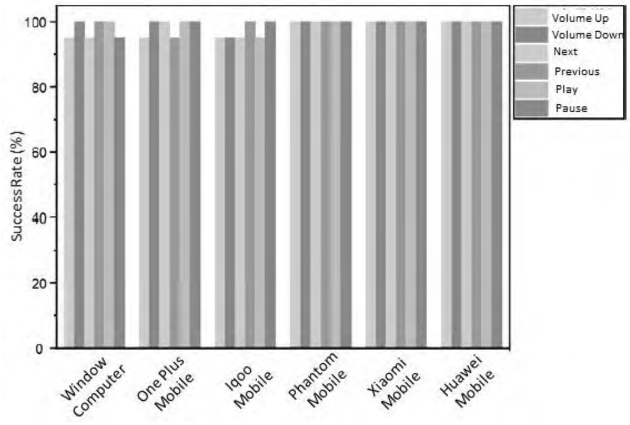


Figure 9. Functional test success rate.

In **Figure 9**, in addition to Windows computers, one plus mobile phones, iqoo mobile phones, other types of mobile phones on the key function trigger rate can reach 100%. The trigger success rate of Windows computer, one plus mobile phone and iqoo mobile phone is slightly lower, more than 96.7%. The reason for this phenomenon may be that these devices themselves are not perfectly compatible with ESP32 Bluetooth. The test results show that the comprehensive accuracy rate of the flexible wearable wireless music controller designed in this paper is 99.7% in different end devices.

4. Conclusions

This paper uses a flexible sensor to create the keypad of a flexible wearable wireless music controller. Through ESP32 signal acquisition and knock judgment, the Bluetooth module of ESP32 is used to connect the terminal equipment and send key instructions. The test results show that the flexible wearable music controller can be used cross-platform, and the success rate of connecting to different platforms is 100%. In terms of functionality, the five key functions work well on different terminals, and the overall success rate of key recognition is 99.7%. The design of this paper combines the disciplines of material, textile and computer to explore the prospect of applying cross research of different disciplines in the field of wearable devices and provide research cases and ideas.

Conflict of interest

The authors declare no conflict of interest.

References

1. Zhang H, Sun L, Liu Y. Development of flexible sensing technology in wearable medical devices. Biomedical Engineering Exhibition 2020; 41(4): 201–205.
2. Cheong I, An S, Cha W, et al. Efficacy of mobile health care application and wearable device in improvement of physical performance in colorectal cancer patients undergoing chemotherapy. Clinical Colorectal Cancer 2018; 17(2): e353–e362.
3. Kwak Y, Kim W, Park K, et al. Flexible heartbeat sensor for wearable device. Biosensors and Bioelectronics 2017; 94: 250–255.
4. Durán-Vega LA, Santana-Mancilla PC, Buenrostro-Mariscal R, et al. An IoT system for remote health monitoring in elderly adults through a wearable device and mobile application. Geriatrics 2019; 4(2): 34.
5. Han L, Ding J, Wang S, et al. Multi-functional stretchable and flexible sensor array to determine the location, shape, and pressure: Application in a smart robot. Science China Technological Sciences 2018; 61(8): 1137–1143.
6. Stewart R. Cords and chords: Exploring the role of e-textiles in computational audio. Frontiers in ICT 2019; 6(2).
7. International Data Corporation [Internet]. Wearable Devices Market Share [cited 2020 Dec]. Available from: https://www.idc.com/promo/wearablevendor.
8. Guo X, Yang K, Zhang C. Development and application of flexible fabric sensor. Woolen Technology 2018; 046(8): 86–91.
9. Wang Y, Wang X, Lu W, et al. A thin film polyethylene terephthalate (PET) electrochemical sensor for detection of glucose in sweat. Talanta 2019; 198: 86–92.
10. Wu S, Ladani RB, Zhang J, et al. Strain sensors with adjustable sensitivity by tailoring the microstructure of graphene aerogel/PDMS nanocomposite. ACS applied materials & interfaces 2016; 8(37): 24853–24861.
11. Rinaldi A, Tamburrano A, Fortunato M, et al. A flexible and highly sensitive pressure sensor based on a PDMS foam coated with graphene nanoplatelets. Sensors 2016; 16(12): 2148.
12. Levi's [Internet]. Levi's® Commuter™x Jacquard by Google Trucker Jacket [cited 2016 May 21]. Available from: https://www.youtube.com/watch?v=yJ-lcdMfziw.