Smart Wristband for Gesture Recognition

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***Abstract*—This paper is concerned with developing a smart gesture recognition wristband device. In this paper, tendon movements around the wrist are used to distinguish and classify different hand gestures. These tendon movements are measured by FSR sensors. Polydimethylsiloxane (PDMS) was used to encapsulate the sensors, which made the wristband elastic and comfortable for people with different wrist dimensions. The sensor data was subsequently collected and sent to a computer via low energy Bluetooth technology. MATLAB was used to process and classify the data using ensemble subspace discriminant classifier. The accuracy is about 99.4%. The paper also investigated how twisting the wrist would impact the accuracy of gesture recognition. The result illustrated that wrist rotation could make more gestures distinguishable. Overall, the wristband is wearable, chargeable, portable and capable of recognizing over 6 gestures with a high degree of accuracy.**

***Index Terms*—Gesture recognition, Force sensitive resistors, Subspace discriminant Classifier, Wearable electronics**

I. Introduction

With the development of Internet of Thing (IoT), gestures could be regarded as a way to control intelligent household electrical appliances. The most common way of gesture recognition is image processing, but a flaw of this method is that the prediction accuracy would be impacted by light intensity. Besides, it is unpractical that a camera is always in front of us to record our instructions [1]. The wristband for gesture recognition is designed for this reason. The sensors surround people's forearms and could measure tendon movements while making different gestures.

If a gesture recognition wristband could capture tendon movement in real-time, the technology could be developed into a human-computer interface [2]. The wristband could be applied in virtual reality gaming to replace gamepads. This technology can massively increase the degree of freedom in VR gaming. It could also play a critical part in other applications, including IoT and smart home. Gesture recognition wristband has a broad application prospect.

Surface Electromyography (SEMG) sensors [3], piezoelectric sensors [4] and Force-sensing resistor (FSR) sensors [5] are suitable for gesture recognition wristband. Generally, sensors are placed around our wrist to sense tendon movements and make the prediction [6]. This paper will make comparison of previously published work and explore the feasibility of using FSR sensor to collect real-time data and make prediction.

II. Methods

This project involved FSR sensors, Bluetooth Low Energy(BLE) technology, Polydimethylsiloxane (PDMS) material, PCB design and machine learning. FSR sensors were chosen for its low power consumption, thin material and high accuracy. BLE technology was applied to ensure wireless communication between wristband and master device, which could be computer or smart phone. PDMS material was used to manufacture the frame of the wristband. It would make the wristband elastic and suitable for people with different wrist dimensions. PCB driver board was designed for eliminating the influence of bad contact. Machine learning was applied in classifier training section. In this project, subspace discriminant classifier were chosen because it has the highest accuracy. With the trained classifier, the computer could do the real-time gesture recognition and realize human-computer interaction.

A. FSR Sensor

FSR sensors are variable resistors which resistance is depending on pressure. As is demonstrated in the circuit below, the resistance R1 of FSR sensor decreases when pressure increases, vice versa. Typically, the resistance of FSR sensor without pressure is infinity. It would decline to less than 10Ω while adding 5N pressure to the sensor. Therefore, the driver circuit was designed to transform the variable resistor to a detectable signal, the voltage-divide circuit was a reasonable solution. The output voltage of the voltage divider depends on following function:

$$I_c = \frac{R_1}{R_1 + R_2} V_{CC} \tag{1}$$

It was significant to choose a proper value of load resistor R2. The load resistor, in a way, influenced the sensitivity directly [7]. To ensure sensors could collect valid data, the value of load resistors should be in a proper region. After several tests, the value of load resistor was determined to be 200kΩ.

B. Data Acquisition and Transmission

To make the wristband portable and wearable, the wristband should be able to transmit data in a wireless way. BLE technology was used in this project for its low power consumption. It was an extensively applied data transmission technology in short distance. Comparing with traditional Bluetooth, the BLE technology has shorter transmission distance but consume less power. NRF52832 is a Cortex-M4 based BLE chip, which can also collect analog signal. The Rx and Tx current are 5.4mA and 5.3mA respectively. Therefore, nRF52832 was chosen for data acquisition and transmission.

To program nRF52832 for data collection, 8 Successive approximation analog-to-digital converter (SAADC) channels need to be enabled. Programmable Peripheral Interconnect (PPI) was used to provide a hardware channel to connect peripheral event and task. PPI channel mechanism was critical in real-time application, which can decrease the CPU load and ensure the timeliness of task execution [8]. After data is collected, it will be sent to master device via Bluetooth. MATLAB has a BLE package could receive the data and execute subsequent classification program.

C. Driver Board Design

A printed PCB board was designed and applied in the wristband as a driver board. The main reason of using PCB instead of wires and breadboard was that PCB can eliminate the impact of bad contact and reduce wires redundancy. To activate nRF52832 module, the input voltage should be within the range of 1.7V to 3.6V. A low dropout regulator (LDO) chip can fix output voltage to 3.3V. Then the power scheme could be a 3.7V lithium battery. Comparing with traditional button batteries, the lithium batteries have higher capacity. The driver board is shown in figure 2, which includes a nRF52832 module, SMD resistors, switch, power notice LED, LDO chip, terminal blocks, programming and ADC input.

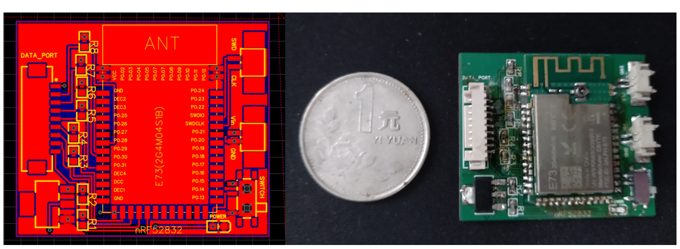


Fig. 1. Driver PCB

D. Wristband Assembly

According to previous research, the wrist dimensions of different people could be very different. Different dimensions of wrist could have different characteristic while gesturing [9]. Therefore, the wristband's material must have adequate flexibility that can obtain similar data despite the thickness of forearm difference. In this project, PDMS material was chosen for its excellent elasticity and flexibility. PDMS is silicon-based molding material [10]. PDMS is widely used in hydraulic fluids and microfluidics chips [11] [12]. PDMS is also a very common used electronic packaging adhesive. During wristband assembly, eight FSR sensors were fixed between two thin layers of silicon film isometrically. PDMS material worked as adhesive between two thin films. With this assembly scheme, the wristband will be extra thin and elastic, which would massively improve the performance of FSR sensors.

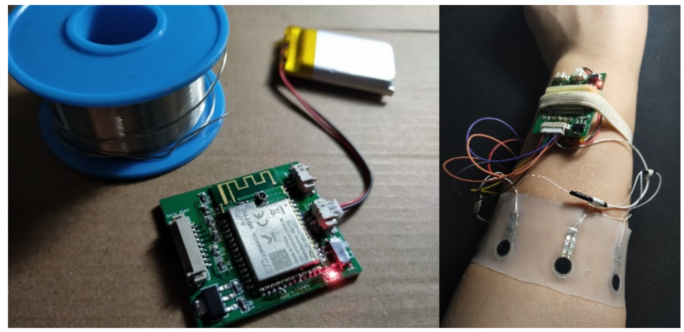


Fig. 2. The wristband

E. Classifier Algorithm

After data was collected and transmitted to a terminal device, a trained classification model would process the data and make predictions. Linear discriminant analysis is an efficient classifier and suitable for Gaussian distribution data set. It divides one dependent variable into the linear combination of other features or measurements [13]. The classifier will use sample data to calculate the mean value and variance of every single class [14]. Ensemble classifier divides predictor into random groups and then trains multiple classifiers. During prediction, each learner will make its prediction and then aggregate them to generate the result. Ensemble method could compensate for learning algorithms by extra calculation. Random subspace ensembles could improve the accuracy of discriminant analysis [15].

III. Results & Discussion

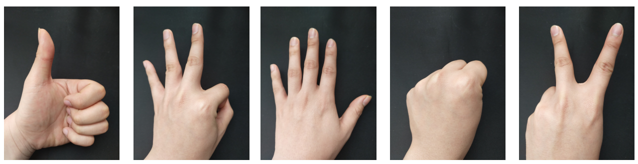
A. Algorithms Assessment

The performance of linear SVM, 10-neighbor KNN and ensemble subspace discriminant were evaluated via confusion metrics. The high precision classifier like cubic SVM and fine KNN could have the training accuracy up to 100%, but the actual accuracy is not always high. Therefore, the test group data need to be applied to the trained model and evaluate practical accuracy. Five different gestures were sampled. Eight channels of FSR sensor value were collected 500 times of each gesture. There are 2500 rows eight columns of sensor data for five gestures, which is rock, paper, victory, good and ok respectively, as is shown in figure 3.

Test groups were used to evaluate the performance of the wristband. There are 1000 rows of data in the test group. The results are demonstrated in the table:

Algorithm	SVM	KNN	Subspace Discriminant
Accuracy	96.4%	91.5%	99.4%

Ensemble subspace discriminant classifier has the highest accuracy when applied to the test group. Ensemble subspace discriminant classifier was chosen in the design.



(a) good (b) ok (c) paper (d) rock (e) victory

Fig. 3. Five Gestures

B. The influence of the angle of wrist

During the modeling and testing the classifier, it was been noticed that slight twisting of wrist would result in the change of sensor values, which might cause unstable measurement. To verify the theory, two gestures in three different angles were sampled. To avoid the finger movement influence the training result of the classifier, the sample only considered holding fist (fist) and stretch fingers (paper) two gestures.

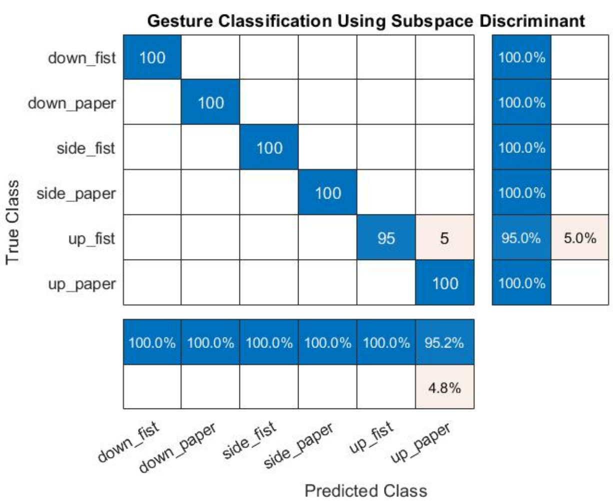


Fig. 4. Test group

The confusion matrices of two training groups are shown above. The result is quite clear, twisting wrist will affect the FSR sensors' measurement. Different angles of wrist correspond to different gestures. The rotation of wrist could be applied to distinguish different kinds of gestures. The negative influence is that gestures could be recognized only when our palm is at the same angle as training sample is collected. Likewise, varying the angle from palm to arm can also have the same effect. In this case, the wristband theoretically can identify more than six gestures.

IV. Conclusion

This paper focused on designing both hardware and software of gesture recognition wristband. The assemble scheme and BLE driver board were first proposed in this paper. The outcome is quite successful and can reach our expectation. We have demonstrated the development of a gesture recognition wearable device that has an accuracy of 99.4%. This was achieved using the ensemble subspace discriminant algorithm. The project also investigated how twisting the wrist would impact the accuracy of gesture recognition. In previous study [9], the researchers trained a general classifier for a larger groups of people using sensor fusion technology. In this paper, we mainly focus on train a classifier for people whose samples were collected. Comparing with previous published work, our design is wireless and portable with higher accuracy, but the classifier is for people in the training group. The design scheme of gesture recognition wristband is proved to be feasible. Further works are to improve stability and capture power from the environment. The technology could be utilized in many situations, including control the sport wristband, smart home and gaming. The wearable and portable feature enhance the prospect of the product.

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