Wearable Resistive-based Gesture-Sensing Interface Bracelet

Yujia Chen[1,2] Xiangpeng Liang[1], Maher Assaad[3], Hadi Heidari[1]
[1]Microelectronics Lab (meLAB), School of Engineering, University of Glasgow, G12 8QQ, UK
[2]University of Electronic Science and Technology of China, Chengdu, China
[3]Department of Electrical Engineering, Ajman University, Ajman, UAE
hadi.heidari@glasgow.ac.uk

***Abstract*—This paper presents a gesture recognition system based on the pressure changes produced by wrist tendon movements for wearable devices. The data of the pressure variations are captured by means of flexible and ultrathin force resistive sensors. A learning algorithm, Support Vector Machine, helps the system to distinguish various hand gestures through developed programming on MATLAB after extracting the key features of data. In order to achieve rapid gesture recognition with a shorter computational time, higher precision and less space complexity, genetic optimization algorithm is used to find the optimal parameter c (cost factor) and g (kernel function parameters) in SVM algorithm. The SVM parameter optimization improves the classification accuracy and the performance of the classifier. Finally, developed wearable resistive-based wrist-worn gesture sensing system classifies the hand gesture with high accuracy (>70%) and the results are displayed on the GUIDE user interface.**

Keywords—Gesture recognition, Force sensitive resistors, Support Vector Machine, Wearable electronics.

I. INTRODUCTION

Gesture recognition has attracted enormous interest as an intelligent and robust human-computer interaction technology in recent years. Rich information and expression in communications can be found in the physical movement of hands. Hence, developing novel gesture recognition technology and hardware with light weight, strong environmental adaptability and user-friendly operation is significant for the application and promotion of human-computer interaction [1-3].

Compared with different methods of hand gesture recognition, pressure-based gesture recognition has relatively fewer attachments and without space limitation [1]. Hence, in this paper, we choose force sensitive resistors (FSRs) to detect the signals based on the pressure distribution around the wrist. However, the challenge of this method involves improving accuracy and adapting itself for different user by a calibration step. Support Vector Machine (SVM), is used to distinguish four hand gestures through developed programming on MATLAB. In the process of debugging, a genetic optimization algorithm has been applied after extracting the key points to find the optimal parameter c and g in the SVM algorithm for better performance and high accuracy. This system also requires a flexible and wearable bracelet to mechanically support the sensors, a PCB board as sensor's readout circuit, a microcontroller to collect the signals from FSR and transmit them to processing computer. At the end, the recognition results can be shown on the GUI interface.

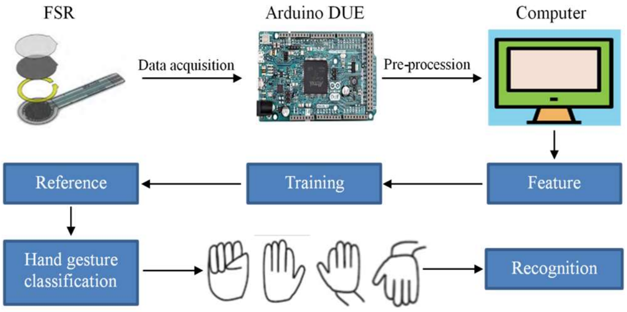

Fig. 1. The flow chart of gesture recognition algorithm.

II. METHODOLOGY

After designing hardware and transmitting the data successfully, the SVM algorithm is used to find the connection between hand gestures and pressure signals of wrist tendon movements collected from the FSRs. The next step is to design a user interface to display the real-time values of the corresponding captured signals from the five channels and its recognition result. The flow chart of gesture recognition in this paper is shown in Fig. 1.

Recently, many approaches show successful examples of producing classification models with the help of machine learning [2-4]. Especially, support vector machine (SVM), one kind of learning algorithm performs ideally in classification. Therefore, we chose this algorithm in this paper because of relatively few sample requirements, nonlinear and high dimensional pattern recognition [5-7].

A. Support Vector Machine Classification

Support vector machine is a method based on multidimensional classification boundary [8]. We can use a two-dimensional data as an example to show the its basic principle. If the training data are distributed on two-dimensional plane, they are clustered in different regions according to their classification. The objective of classification algorithm is to find hyperplane that separates different classes of data by training [9]. For multi-dimensional data, they can be regarded as points in N-dimensional space, and the classification boundary is a plane in N-dimensional space, which is also known as super-surface, one dimension less than N-dimension space. Linear classifiers use hyperplane boundaries, while non-linear

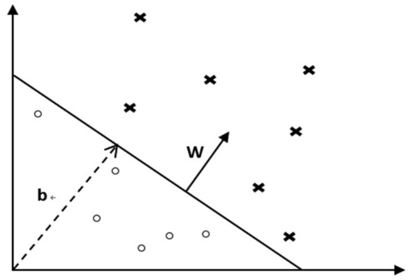

Fig. 2. Linear partition of a binary SVM.

classifiers use hypersurfaces. The linear partition is shown as Fig. 2, and the classification can be determined by the position of the new data relative to the classification boundary.

B. Linear Separable Problem

The linear separable classification problem is that the two-dimensional original data can be divided by a straight line or a hyperplane. There are some basic methods for separating data into two classes by using a hyperplane in a multidimensional space:

- **Square closest point method** – The bisector of the line connecting the nearest two points is used in two kinds of points as the categorization line or surface.
- **Maximum interval method** – Classification surface should be found to maximize the interval of the classification boundary. The classification boundary is that the values move from the classification surface to the points of two classes, respectively, until first data point is encountered. The distance between the classification boundaries of the two classes is the classification interval.

The classification plane is:

$$(w \cdot x) + b = 0 \tag{1}$$

The reciprocal of the classification interval is:

$$\frac{1}{2}\|w\|^2 \tag{2}$$

Thus, the optimization problem is expressed as:

$$\min_{w,b} \quad \frac{1}{2}\|w\|^2 \tag{3}$$

$$\text{s.}t. \quad y_i((w \cdot x_i + b) \geq 1, i = 1, \cdots, l \tag{4}$$

The constraints represent the distance from each data point (x_i, y_i) to the classification surface is required to be greater than or equal to 1.

C. Multiclass Classification

Indirect method of solving the multiple classification problems can be divided into two parts: one-against-one and one-against-all. The construction of multi-classifier is mainly realized by combining multiple binary classifiers. In this paper we used 'one-against-one' to design a SVM system between any two classes of samples. K (k-1)/2 SVM system is needed for K classes of samples [10, 11].

D. Genetic Optimization Algorithm

Genetic algorithm (GA) utilizes the principle of biogenetics, combing the idea of survival of the fittest and random information exchanging [12]. Population evolution based on natural selection, exchange, mutation and other mechanisms. In the process of optimization, GA randomly generates multiple starting points in the solution space and starts searching at the same time. The search direction is guided by fitness function. It is a search technology that can search global optimization solution quickly in complex search space [13]. When genetic algorithm is applied to SVM parameter optimization, the basic steps of the algorithm are as follows:

(a) t = 0;
(b) Random selection of initial population P (t);
(c) Calculating the fitness function value F (t);
(d) If the fitness function corresponding to the optimal individual in the population is large enough or the algorithm has been running for many generations without significant improvement of individual's fitness, it will be transferred to step 8;
(e) t = t + 1;
(f) The selection operator method is used to select P (t) from P (t - 1);
(g) After P (t) is crossed and mutated, it should be moved to step 3;
(h) The optimal kernel function parameters and penalty factor C are given. Besides, the training data set is used to obtain the global optimal classification surface.

III. Hardware Implementation

There are four main parts of hardware in this system: FSRs, microcontroller, bracelet and PCB readout.

A. Ressure Sensor and Microcontroller

The FSR were selected in this system due to its light weight, small size, high sensing accuracy, ultra-thin material and low power consumption [14]. The FSR chosen in this system, a two-wire resistance, is medium round (13 mm diameter) [15]. This pressure sensor converts the pressure applied in the thin film area of the FSR sensor into the change of resistance value which obtains pressure information. It can

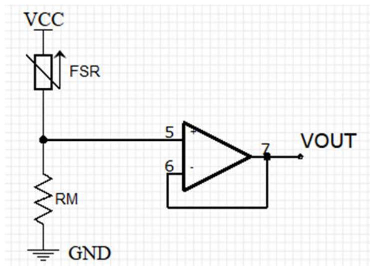

Fig. 3. FSR voltage divider.

be used at pressure of ~0.2N – 20N [16]. Voltage divider shown in Fig. 3 can help measure resistive change to achieve simple force-to-voltage conversion depending on the following equation:

$$V_{out} = \frac{R_M V+}{(R_M+R_{FSR})} \tag{5}$$

In this system, it is important to choose a microcontroller with fast system clock to capture the changing signal, charging with more than five analogue inputs. Arduino DUE which meets the requirements above is chosen to measure the data. The output of the divided circuit for force-to-voltage conversion can be transmitted by the USB interface to the computer in real-time with the help of analog-to-digital converter (ADC) of the Arduino DUE.

B. Bracelet Design

The polyvinyl chloride (PVC) transparent sheet, shown as Fig. 4(a), was chosen to be the substrate. FSR could be easily embedded into this material and fit the wrist. PVC plastic transparent sheet was chosen to be the main body of the bracelet because it is lightweight, flexible, inexpensive and easy to fabricate [17-20]. After fabricating the substrate of wearable bracelet by cutting PVC plastic transparent sheet into strips with the same length and width, the FSRs could be embedded in the bracelet to be attached onto the skin of the user's wrist. Compared with several PVC plastic transparent strips of different thicknesses, the PVC strips with 0.5mm thickness can provide a good wearing feeling and suitable mechanical support among strips of different thicknesses. Finally, the size of PVC plastic transparent strip is shown as Fig. 4(a) is 200mm×20mm×0.5mm.

C. PCB Design

The printed PCB board based on the schematic was designed to be inserted in the socket of Arduino board. Instead of the microcontroller itself, two pin headers were welded in corresponding position on the printed PCB. Most Electronic components were welded on the top layer such as the 10 kΩ resistors, pin headers, terminals. Especially, we used chip resistors to save the space and curved terminals to be welded on the top layer.

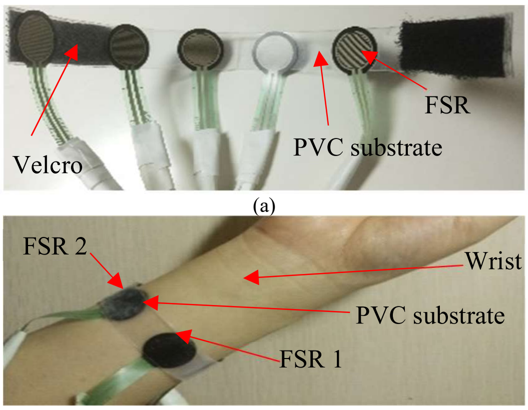

Fig. 4. (a) Final bracelet with FSRs embedded on substrate. (b) The bracelet worn around the wrist.

IV. Software

In this paper, SVM algorithm helps to train the recognition model with signal matrix from several files containing the information of different people through programming on the MATLAB. After designing the model, it is significant to classify real-time data by programming on the MATLAB. In addition, a graphical interface is designed to display the result of hand recognition. The process of designing the interface on GUIDE consists two parts: user interface design and program file.

User-friendly graphical interface can help users to interact with the hand gesture recognition system [21]. In this paper, the user interface is designed with the help of GUIDE environment through programming on the MATLAB shown in Fig. 5.

The main window should contain a button to start the programming, an axis and five static texts(a1-a5) to display the mean value of voltage change from FSRs in time domain, and one big white static text to show the recognition result of four hand gestures: fist, palm, down and up.

V. Experiment Result and Discussion

In this paper, 40 people were invited to be the volunteers including twenty 20 to 50-year-old males and twenty females without any tendon disable. Besides, all the volunteers were tested by right hands with four specific gestures, including fist, palm, up and down. Thus, 160 sets of the gesture information were collected in .txt tiles for training and testing with SVM algorithm as samples.

Firstly, all volunteers worn the bracelet with five FSRs embedded on the substrate. Adjusting the size of the bracelet to set the FSRs to proper position is the second step. Two of FSRs covered the tendon of inner wrist and two of them covered the tendon of lateral wrist. The rest one was put on to the outer wrist. Then the hand gesture recognition interface can capture the obvious pressure change after several experiments of different testing positions.

In the end, we invited several participants whose age in the range of 20 to 50 to make a random gesture from the specific four gestures and hold for 25s. Following it, reproducibility of this system was tested by taking off the

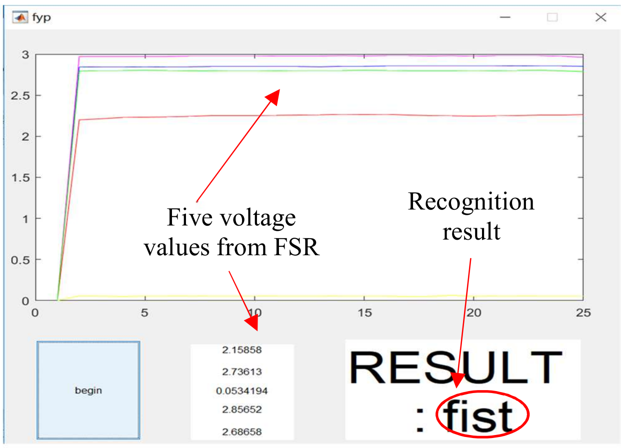

Fig. 5. Graphical interface developed by GUIDE.

Fig. 6. The display of recognition results.

wearable interface and wearing it back for 5 times for 4 volunteers in the same trial.

Using SVM only, the results of initial feature extraction could not achieve the desired accuracy (>70%). For example, the accuracy was 60% with 70% of samples for training and 30% of samples for testing test in SVM classification system. After adding the genetic optimization algorithm with the help of *gaSVMcgForClass* function in MATLAB, we could get a classification model with high accuracy (92%) by comparing the predict labels with the original labels. GUI interface can display the result immediately shown as Fig. 6. The average accuracy of 25 times test is around 75%.

VI. Conclusions

This paper has attempted to propose a wearable wrist-worn gesture sensing device to recognize specific gestures. In addition to five FSRs, the SVM classifiers with genetic optimization algorithm address the issue of calibration and gesture reconstruction. Although the system was designed completely to recognize four specific hand gestures (fist, palm, down and up) by showing the results on the user interface to achieve the desired accuracy (>70%), there are still some challenges of the improvement of this system. For example, during the experiment, the FSRs were unable to show exceptional stability and the recognition time was quite long due to the multiple iterations of algorithms we used. Besides, the results of different tested volunteers showed both high and low accuracy due to the repeatability of device. Overall, further works will involve improving stability, time consumption, repeatability and accuracy of the system.

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