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PIEZO Rings: Decoding Hand Gestures via Subtle Forearm Skin Deformations*

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I. Introduction

In the field of Human–Computer Interaction (HCI), humans usually use physical interfaces like keyboards and touchscreens to control computers. Hand gesture recognition (HGR) allows users to interact without these interfaces, which can make devices smaller. However, current recognition methods still encounter significant challenges that limit their practicality in daily life.

At present, various methods are employed for HGR, including optical marker tracking systems [1], computer vision [2], classic data gloves [3], and electromyography (EMG) sensor systems [4]. Optical marker tracking systems on hands to be attached directly to the fingers. Computer vision systems directly distinguish hands optically. Both methods have the problem of optical occlusion. To solve this problem, these methods require multiple camera configurations. In classic data gloves, users need to wear special gloves that cause discomfort. EMG systems allow for the estimation of hand gestures from the EMG signal at the forearms without wearing special devices on the hands. However, the EMG signal is too weak and affected by personal characteristics and muscle fatigue. Therefore, the current methods face issues such as optical occlusion, restricted movements, difficulties in data acquisition, and individual differences. To solve those issues, we propose PIEZO Rings, a set of armband-like devices. We evaluated them by recognizing rock-paper-scissors gestures. As a result, the recognition is successful without optical occlusion, movement limits, and difficulties in data acquisition.

II. Proposal approach

This study presents PIEZO Rings to address the problems in HGR. PIEZO Rings are armband-like devices that measure the physical skin deformation on the forearm as voltage signals, as shown on the left of Fig. 1. PIEZO Rings contain a sensor sensitive to fine mechanical deformation. We employed PIEZORA sensor (Mitsui Chemicals, Inc.) [5], which is a slender, string-like material designed for vibration sensing. When humans bend their fingers, the arm muscles move, and the skin deforms accordingly. PIEZORA Rings detect the fine movements and then allow for estimating hand gestures. So, users do not need to wear any device in their hands and remove concerns regarding optical tracking loss. As a result, it offers a more natural and user-friendly solution for gesture recognition in HCI. After acquiring data based on skin deformation, we employ a convolutional neural network (CNN) to extract features and classify the gestures.

III. Methods

To investigate the effectiveness of PIEZO Rings for HGR, we focused on the hand gestures of rock-paper-scissors. Specifically, we aimed to classify two categories of gestures: “rock to scissors” and “rock to paper”. Each PIEZORA sensor was connected to an amplifier and an AD converter, then the signals were sent to a computer. The sampling rate was 100 Hz. Fig. 1 shows the prototype of the PIEZO Rings on the arm.

In the signal processing phase, we employed a one-dimensional convolutional neural network (1D CNN) on Keras. The architecture of the model is shown in Fig. 2. The model consists of two convolutional layers with 32 and 64 filters, respectively. A max pooling layer follows the first convolutional layer, and the second is followed by a global max pooling layer to aggregate features across the entire sequence. A fully connected layer with 64 units and ReLU

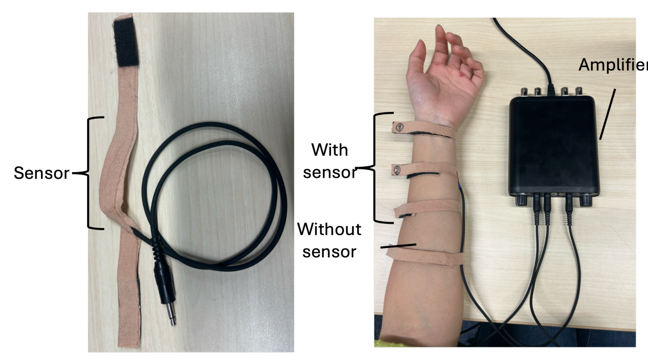

Figure 1. (*Left*) PIEZO Ring, (*Right*) PIEZO Rings fitted on the arm (neutral state)

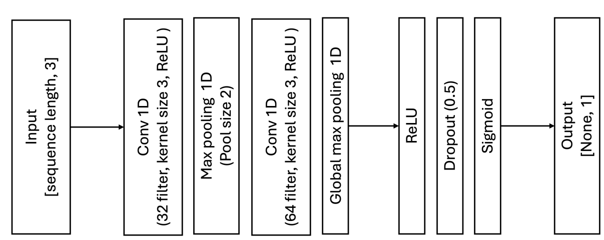

Figure 2. Architecture of CNN

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activation. A dropout layer with a dropout rate of 0.5 is applied to prevent overfitting. Finally, a sigmoid activation function is used at the output layer to perform binary classification, determining whether the gesture changed from “rock to scissors” or “rock to paper”. Here, each data set contains only one transition of the gesture, recording time is two seconds. So, the data size is 200 samples x three rings.

Subjects were instructed to attach three PIEZO Rings to their left arm, as shown in Fig. 1. In the figure, the fourth ring had no sensor and fixed signal cables to reduce electrical noise. Initially, they relaxed their arm and placed it on a table; this relaxed condition is referred to as the neutral state. Next, they were instructed to change their hand gestures following the specified order (rock → scissors → paper → rock) and synchronized to the timing alarm as shown in Fig. 3. Then, we collected the same data in a different order to prevent the order effect. The amplifier output had a constant offset. We used the signal at the neutral state to remove this offset. We got five subjects (four males and one female) who participated in the experiment, and two conditions of data were collected, with 150 samples obtained for each condition. The data were randomly split into a 6:2:2 ratio for training, testing, and validation.

IV. Results

The training and testing loss curves were obtained by training the model on the collected training data for 100 epochs, as shown in Fig. 4. The result says that the loss decreases consistently as the number of epochs increases. The final loss on the test dataset was saturated enough and reached under 0.13. Fig. 5 presents the confusion matrix generated by the validation dataset. The model achieved 0.85 in precision, 0.93 in recall, and 0.89 in F1 score. These results demonstrate that the developed model realized both high precision and high sensitivity, ensuring robust performance in classifying the hand gesture transitions.

V. Conclusion

In this experiment, the model was constructed based on data collected from only five subjects. To build a more generalized model, it is necessary to gather data from a larger and more diverse group of subjects. Furthermore, while this study focused on binary classification between "rock to scissors" and "rock to paper" transitions, future work will aim to develop a system capable of recognizing finer hand and finger gestures, such as identifying which fingers are bent.

HGR plays an important role as a direct interaction method in HCI. HGR enables users to operate computers more naturally. Compared with other methods, PIEZO Rings system has the advantages of a bare hand, having no spatial constraints, and facilitating easy data acquisition. In addition to advancing HCI, the non-invasive nature of this system also makes it a promising candidate for applications such as prosthetic control.

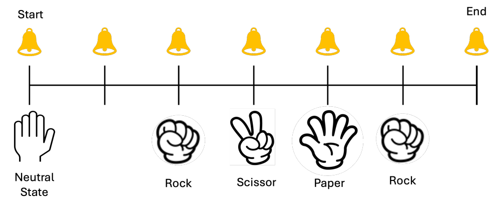

Figure 3. The flow of hand gestures

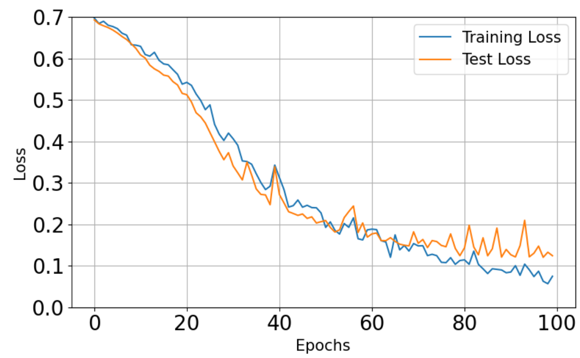

Figure 4. Loss progression

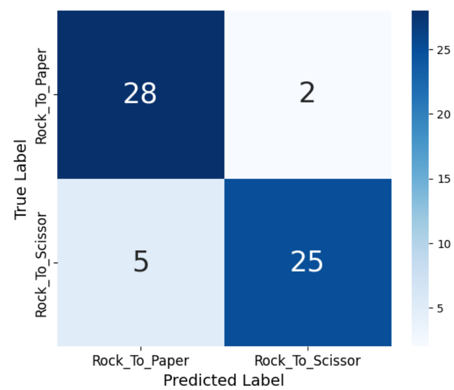

Figure 5. Confusion matrix

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