Ankle Positions Classification using Force Myography: an exploratory investigation

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Abstract—**Monitoring the movements of the ankle may be highly relevant for applications such as sport injury prevention, rehabilitation, and gait analysis. This paper explores the feasibility of employing force myography (FMG) on the distal end of the lower leg to detect ankle position. FMG signals corresponding to 7 different ankle positions were recorded from three healthy volunteers. Using a linear discriminant analysis (LDA) classifier, the system achieved averaged prediction accuracies of 94% and 85% in cross validation and cross-trial evaluation, respectively. The results of this proof-of-concept study demonstrate the feasibility of using FMG to detect ankle position and its consequent potential use for acquiring information relevant to leg movement and gait.**

I. Introduction

Lower limb activity detection and monitoring is an active research topic, with applications in a wide range of areas such as sport injury prevention, rehabilitation exercises, and senior activity monitoring [1][2][3]. Ankle movements such as plantarflexion, dorsiflexion, inversion, eversion, lateral axial rotation, and medial axial rotation, are not only basic lower limb activities in daily life, but also are widely used in rehabilitation exercises and assessments of locomotor functions of weak persons such as stroke survivors [3][4].

Traditionally, surface electromyography (sEMG), a non-invasive technique for registering electrical activities generated by the motor units of the skeletal muscles, is widely used for lower extremity activity sensing [1][5][6][7]. However, this technique is often subject to external electrical interference and sweating, which requires sophisticated and expensive equipment to extract data with high signal-to-noise ratio [8].

Force myography (FMG), as an alternative muscle activity sensing technology of sEMG, has been recently investigated for upper extremity gesture recognition [9][10][11][12]. FMG utilizes force sensing resistors (FSRs) surrounding a limb to register the volumetric changes of the underlying musculotendinous complex during muscle activities. FSRs are thick inexpensive polymer film devices which exhibit a decrease in resistance when an increase in force is applied to its sensing region [17]. FSRs have been used in shoes (insoles) to monitor lower extremity activities through the estimation of foot pressure distribution on the ground [13][14]. By placing FSRs around the distal end of the lower leg, proximal to the ankle, we expect various ankle movements can be detected. Encouraged by the successes of detection of upper extremity activities using FSR bands on the forearm or the wrist [12][16], we hypothesize that the FMG on the ankle would be able to distinguish ankle positions with an accuracy of over 85%. The confirmation of this hypothesis will add valuable insight and contribution to research in detection of lower extremity activities.

This paper presents a preliminary study that explores the feasibility of using an FSR strap, worn on the distal end of the leg, to classify ankle positions. Three participants performed 7 ankle movements and the FMG signals were recorded using a custom-made wireless FMG strap with 8 FSRs. The signals were then used to train and test a classifier. The results show a feasibility in using FMG for ankle position classification.

II. Materials and Experimental Setup

A. FSR Band

A customized strap was designed for capturing FMG signals from the lower leg using 8 FSRs, as shown in Fig. 1.1. The InterLink 402 FSRs (InterLink Electronics Inc., Camarillo, California, United States), which are single-zone, two-wire FSRs with a force-sensing resolution of 0.1 N and a sensitivity range of 10 N [17] was used. The FSRs were placed 3.2 cm apart, supported by a thin layer (about 1.5 mm) of plastic sheet to provide a firm back support. The total length of the strap was approximately 32 cm. Velcro tape was

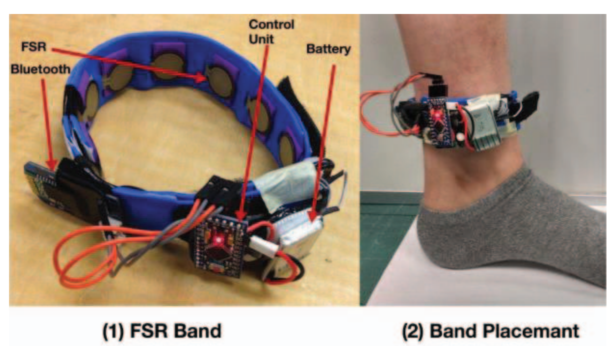

Fig. 1. The FSR band system for signal acquisition and the strap placement on the ankle.

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used to tie the strap around the subject's ankle. The forces detected by the FSRs were converted to voltages via the control unit on the band and the signals were then transferred to a laptop using a Bluetooth modal built into the control unit, as shown in Fig. 1.1. A customized Labview (National Instruments Inc., Austin, Texas, United States) interface was developed to acquire FSR signals and guide the participants to perform ankle movements by showing corresponding ankle position pictures on the screen.

The FSR strap was donned on the distal end of the lower leg at about 2 inches above the Distal Fibula, where multiple muscles and tendons responsible for ankle movements are attached, including the Tibialis Anterior muscle (inversion and dorsiflexion), the Peroneus Longus muscles (eversion and plantarflexion), and the Deltoid Ligament and Posterior Talofibular Ligaments (medial and lateral support). The strap was comfortably wrapped around the above ankle position to ensure that the pressure did not block circulation or restrict motion, while also keeping a sufficient level of tightness.

B. Experimental Protocol and Procedure

The participants performed a set of 7 basic ankle movements, including neutral, plantarflexion, dorsiflexion, inversion, eversion, lateral axial rotation, and medial axial rotation, as shown in Fig. 2. These ankle movements are widely used in lower limb rehabilitation exercises and functional tests [18]. The participants performed these postures while sitting on a desk several inches higher than their knee, so that they could suspend their foot without touching the ground.

The participants performed each of the 7 ankle movements for 8 seconds, with no resting period between two consecutive postures. The participants repeated the above 7 ankle movements 3 times. The FSR band was not removed until the last trial was finished.

The detailed procedure is described as follows. The participants first sat comfortably on the desk with their shoes taken off. The FSR strap was positioned at the left leg, about 2 inches above the ankle (Distal Fibula). The position of the FSR strap was kept as consistent as possible across the 3 subjects, with the Bluetooth modal and control unit at the lateral side of the foot and the band going counter-clockwise, as shown in Fig. 1.2. Before data recording, the participants were demonstrated how to correctly perform the ankle movements and were given sufficient time to practice. When the test started, a picture describing each of the ankle positions was shown to instruct the subject to move the ankle to the designated position. The picture was changed to describe a different ankle position every 8 seconds until all seven positions were completed.

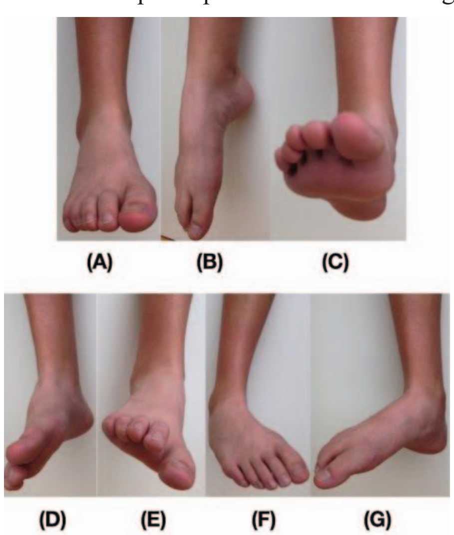

Fig. 2. Ankle positions. (A) neutral, (B) plantarflexion, (C) dorsiflexion, (D) inversion, (E) eversion, (F) lateral axial rotation, and (G) medial axial rotation.

If the subjects found that they posed a wrong ankle position, the current trail would be discarded. There were a total of 3 trails for each subject. Between each trail, the subject could rest as long as they needed.

III. Data Analysis and Results

We recruited 3 healthy male participants (age: 20-50) for the data collection. All the participants read and signed a consent form before entering the study. The ethics form for the study was approved by Simon Fraser University.

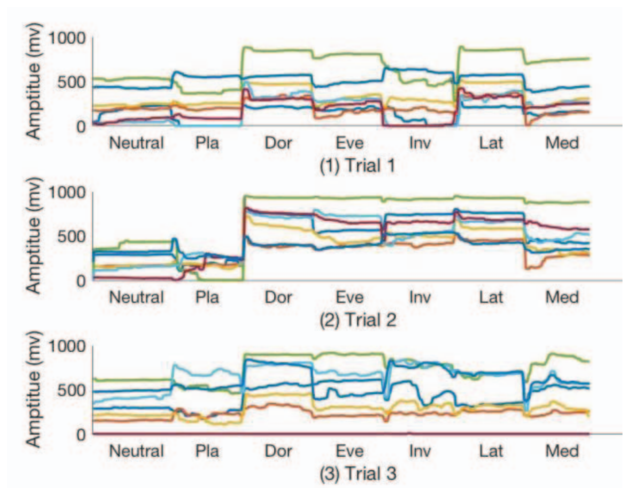

Fig. 3. The raw FSR signals of the 3 trials of subject 1.

A. Signal Processing, Segmentation, and Labeling

The signals of the 8 FSRs went through a median filter using a 5-sample window to remove noise before further processing [19]. The signals were segmented and labeled according to the same class labels shown on screen for each ankle position during data collection. As there was a delay between when the label was shown on the screen and when the participants began to perform movements, we used 6.5 seconds of stable FSR signal from each ankle movement for data analysis, by cutting off the first 1.5 seconds' period of signals, as shown in Fig. 3. The 6.5 s was empirically determined.

B. Classification Accuracy

Fig. 3 shows an example of the signals from 8 sensors for each of the 7 different ankle positions; the 3 panels of Fig. 3 show the 3 trials' signals from subject 1, respectively. Overall, the signals show distinct patterns between the 7 ankle positions.

Linear discriminant analysis (LDA) was employed to evaluate the performance of the system with the collected data. The ability to use simpler linear signal processing and classification methods such as LDA would indicate that the proposed wearable system could potentially be more easily embedded into a compact, low-power device that is capable of performing online classification. The LDA classifier used in the study was from MATLAB Statistics and Machine Learning Toolbox [20].

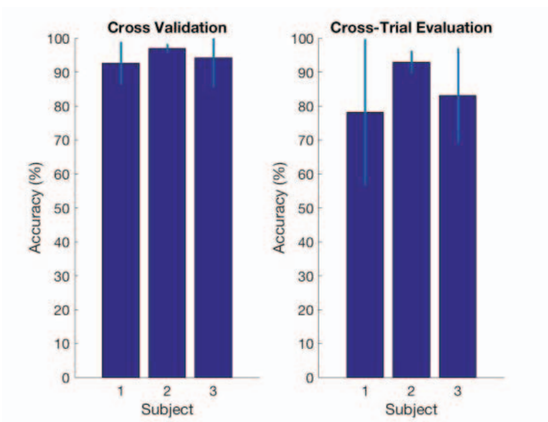

Fig. 4. Accuracies of classification of 8 classes for 3 subjects using LDA. The left panel is the results of 10-fold cross-validation and the right panel is the results of cross-trial evaluation.

We performed 10-fold cross-validation and cross-trial evaluations for the data collected. In 10-fold cross-validation, the data was randomly separated into 10 equal-sized subsets. Among the 10 subsets, one subset was retained as validation data for testing the model, and the remaining nine subsets were used for training the model. This cross-validation process was repeated 10 times, with each of the 10 subsets used as the validation data. The results of the 10 repetitions were averaged as a single performance measurement. In the cross-trial evaluation, the LDA model was trained using the data recorded from the 2nd of the 3rd trials, and then the trained model was used to predict the 1st trial's ankle position data. This procedure was repeated 3 times to cover all the 3 trials for each of the gestures by shifting the training and testing trials. The resulting accuracies of the 3 repetitions'

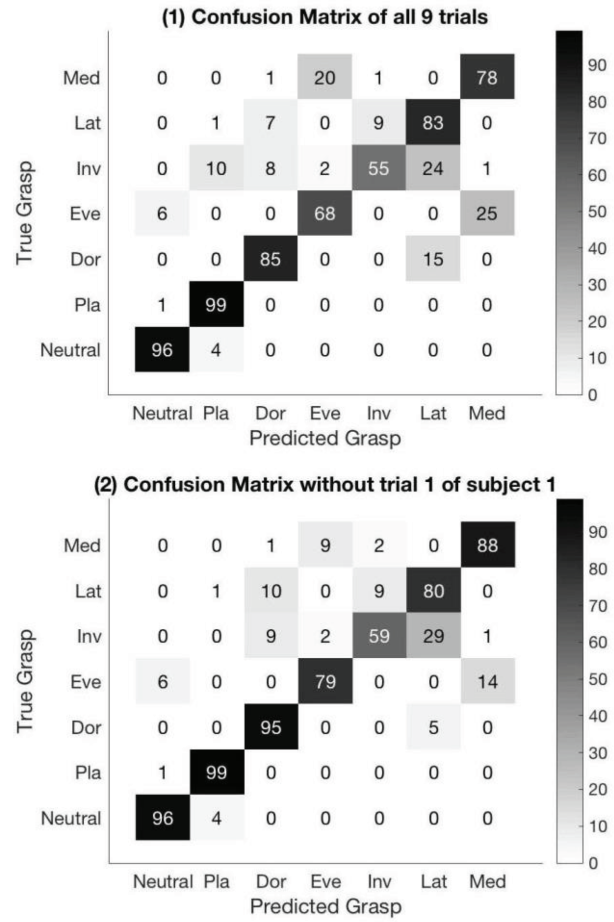

Fig. 5. Confusion matrix of average results of three subjects. (1) includes all 9 trials from 3 subjects; (2) includes 8 trials without trial 1 of subject 1 which is outline. Each number in the cell is the percentage of the samples belongs to the category indicated by the y-axis label was predicted to be the class indicated by it corresponding x-axis label. The labels on x and y axis are neutral, plantarflexion, dorsiflexion, eversion, inversion, lateral axial rotation, and medial axial rotation, respectively.

cross-trial testing were averaged as a single performance measurement.

The classification accuracies of 10-fold cross-validation and cross-trial evaluation were 94% and 85%, respectively, as shown in Fig. 4. Subject 1 had the lowest accuracy among the 3 subjects in both cross-validation and cross-trial evaluation, which will be discussed in the next section.

Fig. 5.1 shows the confusion matrix of classification in the cross-trial evaluation averaged from the 3 subjects' data; the

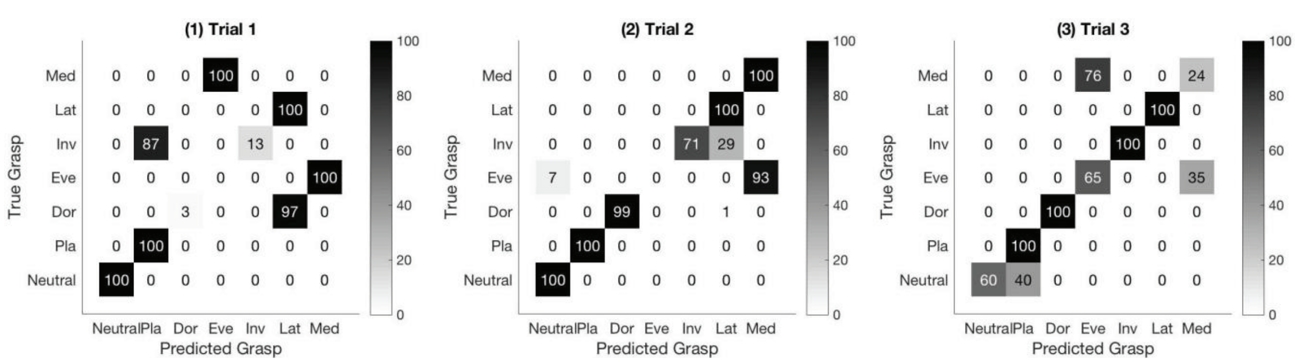

Fig. 6. Confusion matrix of three subject 1. The accuracies of trial 1, trial 2, and trial 3 are 54%, 95%, and 80% respectively.

x-axis is the predicted ankle position type and the y-axis is the true position type. The neutral and plantarflexion ankle positions achieved very high classification accuracies of over 95%, whereas the inversion ankle position had the lowest accuracy of about 55% which is mostly misclassified to lateral axial rotation (24%), plantarflexion (10%), and dorsiflexion (8%). The eversion ankle position had the second worst accuracy, with it mostly being misclassified to medial axial rotation (25%) and a little to neutral position (6%). However, interestingly, medial axial rotation is also mostly misclassified to eversion (20%).

IV. DISCUSSION

The cross-trial evaluation accuracy of subject 1 was much lower than the other two subjects with a huge deviation of about 20%. This is because the testing result of the first trial (trained using trial 2 and trial 3) was extremely low at 54%. We further looked into the confusion matrix for each trial of subject 1 and found that the confusion matrix of trial 1 (Fig. 6.1) shows that eversion and medial axial rotation positions are 100% misclassified to each other. Dorsiflexion is almost (97%) misclassified into lateral axial rotation for trial 1 of subject 1. The most probable reason is that subject 1 mis-executed the ankle movements during the first trial. By removing this outlier (trial 1 of subject 1), the average accuracies of cross-validation and cross-trial evaluations of 3 subjects were increased to 96% and 89%, respectively.

We can see from Fig. 5.2 that inversion position is very easily misclassified to lateral axial rotation, since the participants might have unintentionally laterally rotated their foot, resulting in a similar ankle position to lateral axial rotation. Similarly, this explanation applies to the misclassification between eversion and medial axial rotation.

V. LIMITATION AND FUTURE WORK

This study was the first step toward monitoring lower extremity activities using an FSR band on the lower leg. We will recruit more participants to test the band's usability, as well as test the band for additional lower extremity activities, including gait detection.

VI. CONCLUSION

This paper presents a study that explores the feasibility of using an FSR strap on distal end of the lower leg to detect ankle positions. Three participants performed 7 basic ankle movements wearing a custom-made 8-channel FSR band. The acquired FSR data were used to train and test an LDA classifier, achieving 94% in cross-validation and 85% in cross-trial evaluations, demonstrating the feasibility of using FMG from the lower end of the leg to detect ankle movements. The findings imply a wide range of applications of FMG in monitoring lower extremity activities.

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