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Using Piezoelectric Films for Classification of Upper Arm Motions: A Preliminary Report

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Abstract— **Recently, it has been reported that finger motions could be recognized from the forearm signal detected by accelerometers. However, accelerometers are sensitive to vibration or unintended motions, which could cause large noise when classifying different hand motions. This is why our research group wanted to explore the usability of other kinds of sensors for upper arm motions classification. Therefore, the objective of this study was to examine the usefulness of a piezoelectric film for hand motion classification and its robustness to unintended motions. Experiments were conducted to record signals from the piezoelectric films for different hand motions, while the subject was asked to move the ipsilateral shoulder, the contralateral hand, or the legs. The results showed that the desired hand motion could be distinguished using a piezoelectric film despite of unintended motions.**

I. INTRODUCTION

In recent years, detecting upper-limb motion intentions for prosthetic control purpose have attracted growing research attention [1]. It has been reported that, up to 10 wrist and hand motions could be recognized from 2-3 channels of forearm electromyogram (EMG), for the use of prosthetic hand control [2][3][4]. However, EMG is greatly influenced by electric noise, changes in the skin impedance and location of the sensors, which affect greatly the discrimination of complex hand motions.

The contraction of the muscles causes the skin surface to stretch. This motion has been used as an alternative or support to EMG. For example, Kishi et al. in [5] used accelerometers placed on the forearm to measure this motion in order to classify tap motions from three fingers (index finger, middle finger, and ring). This signal measured the degree of contraction of different muscles for each tap.

However, the accelerometers' sensitivity to vibration or unintended motions (e.g. tremor of the body, motions of the other hand) could cause large noise in the system, making the classification harder or even impossible. Therefore, concomitant movements of the trunk, shoulder, and elbow when operating a prosthetic hand make classifying motions very difficult if accelerometers are used.

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This is why, our research group wanted to explore other types of sensors that were not affected by concomitant unintended body movements in order to improve the classification of upper limb motions. For this purpose we tested a piezoelectric film, and compared them to the accelerometers, for hand motion classification. Therefore, the objective of this study was to examine the usefulness of a piezoelectric film for hand motion classification and how unintended motions would affect it. The use of piezoelectric films to classify different hand motions for prosthetic applications hasn't been explored to the best of our knowledge.

II. MATERIAL AND METHOD

A. Subjects

Four 23 years old male subjects participated in the experiments. They were informed about the experimental procedures and asked to provide a signed consent. All subjects were healthy with no known history of neurological abnormalities or musculoskeletal disorders.

B. Devices

The accelerometer MMA7260Q (Freescale Semiconductor), and the piezoelectric film LDT1-028K/L (Measurement Specialties) were used. A 2.0 KHz sampling frequency was used to record the raw bio-signals for off-line analysis.

C. Procedure of Experiment 1

Experiment 1 was aimed at examining whether it was possible or not to discriminate hand motions while moving the ipsilateral shoulder, the contralateral hand, or the legs. The accelerometer and the piezoelectric film were attached to the forearm as shown in figure 1. A grasping motion and an opening motion of the hand were classified from the signals from the piezoelectric film and the accelerometers attached to the forearm (Figure 2). The subjects were asked to perform each of the following motions for 10 times:

- Condition 1: Only hand motion. The subjects had to move their hand while sitting on a chair and extending their arm completely to the front.
- Condition 2: Hand motion with ipsilateral shoulder motion. The subjects had to move their hand, while moving their arm. The subjects were also required to be sitting and to extend their arm completely to the front.

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- Condition 3: Hand motion with contralateral hand motion. The subjects had to move both hands, with their arms completely extended to the front, while sitting.
- Condition 4: Hand motion with leg motion. The subjects had to move their hand, while stamping their feet and extending their arm completely to the front.

Furthermore, the subjects were asked to close and open their hand at a pace denoted by a metronome set to 60bpm, while the experimenter pressed an on/off of a switch, which marked the start and end of the recording signal.

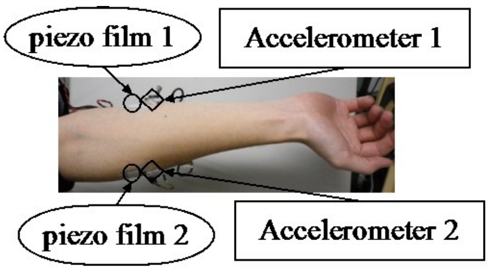
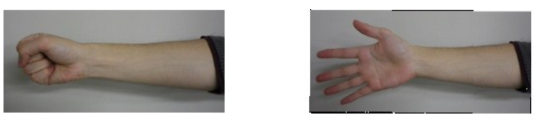


Figure 1. The location of sensor



(a) grasping (M1) (b) opening (M2)

Figure 2. Two hand motions

D. Feature Extraction

Raw signals were processed by a 40Hz lowpass filter and a 50 points moving average. Also, the start and end of the recorded signals were controlled by the experimenter using an on/off switch. Thereafter, the following five features were obtained.

1. The maximum value (F1)
2. The minimum value (F2)
3. The maximum value and the time until the maximum value appears from the starting point (F3)
4. The minimum value and the time until the minimum value appears from the starting point (F4)
5. The norm value (F5)

E. Method of Analysis of Experiment 1

A classifier based on K-means was used. This method calculates the distance between an input vector and the center of gravity of existing clusters c1, c2,…, ci, and assigns the input vector to the cluster to which the distance is minimal. Then the cluster will be updated to contain the new input. Distances were calculated with the expression shown in equation 1.

$$\sum_{i=1}^{K} \sum_{x \in c_i} \left\| x - c_i \right\|^2 \quad (1)$$

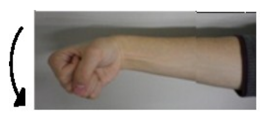
Firstly, the data measured by condition 1 was analyzed. A K-means cluster analysis was conducted using the mentioned five features extracted from the data of each sensor. When the classification rate of condition 1 was 80% or more we considered the result as an effective feature and we called them an EC-Feature.

Subsequently, the other condition were tested for each of the EC-Features found on condition 1 and we examined the difference in the classification between conditions.

F. Procedure of Experiment 2

Experiment 2 was aimed at examining whether 6 different hand motions could be classified or not, while operating the ipsilateral shoulder. The piezoelectric films were attached on the same place as before (Figure. 1). The 6 different hand motions that were classified were: grasping (M1), opening (M2), flexion (M3), extension (M4), pronation (M5), and supination (M6), as shown in figure 3. The subjects were required to repeat the motion for 10 times, in the same conditions as experiment 1.


(a) grasping (M1) (b) opening (M2)




(c) flexion (M3) (d) extension (M4)


(e) pronation (M5) (f) supination (M6)

Figure 3. Six hand motions

G. Analysis Method of Experiment 2

Similar to experiment 1, a classifier based on K-means was used. In experiment 2, the cluster analysis was conducted using EC-Feature of each subject that was obtained in experiment 1.

III. Result and Discussion of Experiment 1

A. Result

Table I, II, III, and IV show the EC-Features and the classification rate obtained for each subject.

TABLE I. EXPERIMENT 1 CLASSIFICATION RATE FOR ALL CONDITION OF SUBJECT A

Condition / Motion	sensor		accelerometer (%)								piezo film (%)				
	ch/axis		1/X		1/Y	1/Z	2/X	2/Y		2/Z	1				2
	feature		F2	F5	F5	F5	F5	F2	F5	F1	F1	F2	F3	F5	F3
	condition1	M1	80	100	90	90	80	80	90	90	100	90	100	100	80
		M2	90	90	90	80	100	90	90	90	100	100	80	100	90
	condition2	M1	80	80	70	100	100	100	100	100	90	80	80	90	90
		M2	30	40	50	50	70	80	50	100	90	90	70	100	80
	condition3	M1	80	80	90	20	100	60	100	90	100	90	100	100	100
		M2	90	90	90	90	100	60	90	40	100	90	90	100	90
	condition4	M1	70	80	30	70	80	40	50	70	100	100	100	100	80
		M2	90	60	70	60	60	80	80	60	100	70	70	100	90
total			8								5				

TABLE II. EXPERIMENT 1 CLASSIFICATION RATE FOR ALL CONDITION OF SUBJECT B

Condition / Motion	sensor		accelerometer (%)						piezo film (%)
	ch/axis		1/X			1/Y	1/Z		1
	feature		F1	F2	F5	F1	F3	F5	F4
	condition1	M1	100	100	100	100	80	100	90
		M2	90	80	100	90	100	100	100
	condition2	M1	60	80	90	70	90	70	80
		M2	50	90	70	30	20	70	100
	condition3	M1	100	100	100	80	100	100	100
		M2	100	100	100	70	90	100	90
	condition4	M1	70	50	80	60	60	100	70
		M2	80	60	80	70	90	100	100
total			6						1

TABLE III. EXPERIMENT 1 CLASSIFICATION RATE FOR ALL CONDITION OF SUBJECT C

Condition / Motion	sensor		accelerometer (%)							piezo film (%)		
	ch/axis		1/X			2/X		2/Y	2/Z	1		
	feature		F1	F2	F5	F2	F5	F5	F4	F1	F2	F5
	condition1	M1	100	100	100	80	80	100	90	80	100	100
		M2	100	100	100	90	80	100	80	100	100	100
	condition2	M1	100	90	90	70	50	20	30	100	60	90
		M2	20	20	70	30	60	90	70	80	50	70
	condition3	M1	100	100	100	100	90	100	80	80	100	90
		M2	100	100	100	100	100	100	60	90	100	100
	condition4	M1	60	50	80	30	60	50	90	80	80	90
		M2	70	80	50	90	70	90	100	90	100	80
total			7							3		

TABLE IV. EXPERIMENT 1 CLASSIFICATION RATE FOR ALL CONDITION OF SUBJECT D

Condition / Motion	sensor		accelerometer (%)								piezo film (%)	
	ch/axis		1X			1Y	2X		2Y	2Z	1	2
	feature		F2	F4	F5	F4	F1	F5	F4	F3	F4	F5
	condition1	M1	90	80	100	80	90	90	80	100	100	80
		M2	100	100	80	90	90	90	80	100	90	100
	condition2	M1	50	40	60	100	60	30	70	90	100	60
		M2	60	90	60	60	50	70	80	30	70	50
	condition3	M1	100	70	100	80	80	70	100	100	90	90
		M2	40	80	40	80	30	80	90	90	80	80
	condition4	M1	90	40	70	70	90	70	70	90	90	70
		M2	50	60	50	60	30	70	70	90	100	80
total			8								2	

For condition 1 we found 29 EC-Features from the accelerometer signals. However, among these 29 features for condition 2, 3, and 4 a classification rate of 80% or higher wasn't achieved. For 3 EC-Features a classification rate between 70% and 80% was found on conditions 2, 3, and 4.

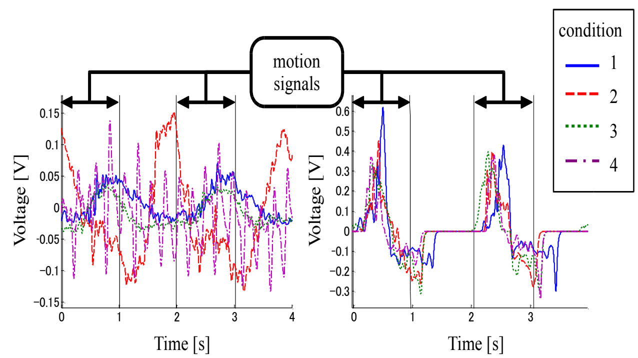
On the other hand, for condition 1, only 11 EC-Features were found from the piezoelectric film signals. Among these features, 4 EC-Features showed a classification rate of 80% or higher for condition 2, 3, and 4. Also, for 9 EC-Features a classification rate between 70% and 80% was found for all the subjects. These results showed that the motion of the arm and the feet has less influence on the piezoelectric film signals.

Moreover among the 29 EC-Features extracted from the accelerometer signals, there were 19 EC-Feature that showed a classification rate of 40% or less for condition 2, 3 and 4. Also, for 24 EC-Features the classification rate was between 40% and 50%. In particular, in condition 2 and condition 4, a decline in classification rate was seen for all subjects.

On the other hand, among 11 EC-Features extracted from the piezoelectric film signals, no classification rate of 40% or less was found, and only for 2 EC-Features a classification rate between 40% and 50% were found for conditions 2, 3, and 4. Therefore, we can notice that there was no significant decline in classification rate when using a piezoelectric film.

B. Discussion

The measured waveform from the X-axis of accelerometer 1 and from the piezoelectric film 1 for subject A's grasping motion is shown in figure 4.



(a) accelerometer 1 X-axis (b) piezoelectric film 1

Figure 4. Waveform of grasp motion of subject A

From the figure we can observe that the accelerometer waveform for condition 2 and 4 are very different from condition 1's waveform. The same tendency can be observed for other subjects and other axis. We can notice how the accelerometers reflected activities due to the shoulder or leg motions, masking the hand opening and closing motion; this is what could have caused the classification rate to decrease.

On the other hand, we can observe from figure 4b that, contrary to the accelerometer, the piezoelectric film signals are very similar between conditions. Therefore, the piezoelectric film showed better discrimination of the opening and closing hand motion. This points out that the piezoelectric film could improve the detection of hand motions for upper limb prosthetic applications.

IV. Result and Discussion of Experiment 2

A. Results

Table V shows the results of K-means cluster analysis for six hand motions when using the EC-Features obtained in condition 1 (Table V).

TABLE V. Result of K-means Cluster Analysis for Six Hand Motions

Subject A								Subject B							
		motion								motion					
		M1	M2	M3	M4	M5	M6			M1	M2	M3	M4	M5	M6
cluster	a	1	6	0	0	2	1	cluster	a	1	0	5	0	0	0
	b	7	1	0	0	0	0		b	1	4	1	1	0	3
	c	0	1	1	0	7	2		c	2	1	2	3	5	2
	d	1	1	0	2	0	4		d	2	0	2	5	1	0
	e	1	0	9	0	0	3		e	4	0	0	0	0	0
	f	0	1	0	8	1	0		f	0	5	0	1	4	5

Subject C								Subject D							
		motion								motion					
		M1	M2	M3	M4	M5	M6			M1	M2	M3	M4	M5	M6
cluster	a	0	2	0	0	5	0	cluster	a	0	1	0	0	7	1
	b	0	4	0	0	4	0		b	4	8	0	0	2	0
	c	5	2	3	2	0	0		c	4	0	2	0	1	0
	d	2	0	6	3	0	0		d	0	0	2	5	0	6
	e	3	2	1	1	1	0		e	2	1	6	2	0	2
	f	0	0	0	4	0	10		f	0	0	0	3	0	1

We can observe that M3 and M4 for Subject A, M6 for Subject C, and M2 for Subject D were classified into a cluster in which 80% or more of the data differs from others. However, the cluster classification for the other hand motions was not achieved. Since these results are not sufficient for hand motion classification, we tried a different feature to further explore the possibilities. The two signals acquired from the piezoelectric film channels were expressed in a phase diagram and the number of points found in each quadrant was used as a feature for phase difference between the two channels. As a result, the classification of the pronation and supination movements was improved greatly for Subject B (see Table IV).

TABLE VI. Result of K-means Cluster Analysis Using Feature Expected a Phase Figure (Subject B)

		motion					
		M1	M2	M3	M4	M5	M6
cluster	a	2	1	3	1	0	0
	b	0	0	0	3	0	10
	c	3	0	1	1	0	0
	d	5	1	1	0	0	0
	e	0	6	4	0	1	0
	f	0	2	1	5	9	0

B. Discussion

Contrary to the classification of 2 different motions in experiment 1, when classifying 6 motions the results showed that it was difficult to classify hand motions accurately and that they vary significantly from subject to subject, thus the results obtained are not good enough to guarantee a good motion classification for a prosthetic hand control. This low accuracy can be attributed to the signal processing and conditioning methods used, and/or to the insufficient information obtained from the extracted features.

Furthermore, the signals obtained from the piezoelectric film could be used as a complementary signal to improve the detection rate of other signals, such as EMG, but this needs to be further explored. In [6], for example, Horiuchi et al. managed to improve greatly the classification rate of different grasping and arm position from around-shoulder muscles by using a combination of accelerometers and EMG sensors. However, before that, it is important to know the limitations of this type of sensors, thus we need to explore other classification methods and explore other features that might effectively extract information from these signals.

V. Conclusions and Future Directions

In this preliminary study we compared the classification rate of hand motions from accelerometers and piezoelectric films, and we examined the influence of concomitant movements (shoulder or feet movements) to the classification rate.

The results showed that the hand motion classification (grasp motion and opening motion) wasn't seriously influenced by the concomitant movements of the shoulder and the feet when a piezoelectric film was as the source signal. On the other hand the accelerometers were more influenced from the concomitant movements, and the classification rate decreased considerably.

Also, the results pointed out that, with the methods tested in this study, it is difficult to classify 6 different motions from only 2 piezoelectric film sensors. Therefore, it is important to explore and improve other analysis method that will allow a better classification of motions from the piezoelectric films in order to fully understand the advantages and limitations of this type of sensors. Furthermore, we should explore how the usage of the piezoelectric films could improve the hand motion classification from EMG sensors for prosthetic applications. In future, we'll test a classification performance values performed in out-of-sample data.

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