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Performance of Electromyography Recorded Using Textile Electrodes in Classifying Arm Movements

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***Abstract*—Electromyography (EMG) signals are commonly recorded using the Ag/AgCl gel electrodes in myoelectric prosthetic control. While a gelled electrode may provide high-quality EMG recordings, it is inconvenient in clinical application of a myoelectric prosthesis. A novel type of signal sensors-textile electrodes should be ideal in control of myoelectric prostheses. However, it is unknown whether the performance of textile electrodes is comparable to commonly used electrodes in classifying arm movements. In this study, the custom-made bipolar textile electrodes were fabricated using copper-based nickel-plated conductive fabric and were used to record EMG signals. The performance of EMG signals recorded with textile electrodes in identifying nine arm and hand movements were investigated. Our pilot results showed that the average classification accuracy across six able-bodied subjects was 94.05% when using textile electrodes and 94.26% when using conventional electrodes, with no significant difference between the two types of electrodes (p=0.81). The pilot results suggest that the textile electrodes could achieve similar performance in classifying arm movements in control of myoelectric prostheses as the gelled metal electrodes.**

I. Introduction

CURRENTLY, most commercially available motorized artificial arms are controlled with myoelectric signals recorded from remaining muscles on an amputated arm. This control strategy requires a pair of remaining agonist-antagonist muscles for control of a degree of freedom (DOF). As a result, given a limited number of muscles available after amputations, the current prosthesis control method can not control a prosthesis with multiple DOFs. For example, for a transhumeral amputee, the remaining arm muscles only have parts of biceps and triceps which can serve as EMG signal sites to control prosthetic movements. When all the three joint DOFs of elbow, wrist, and hand are required, the user must trigger a “mode switch” such as making a co-contraction of the agonist-antagonist muscle pair to sequentially select which of these joints is desired to be actuated. Obviously, switching to different modes is slow and cumbersome. Moreover, using a same agonist-antagonist muscle pair to control different joint movements is non-intuitive and very difficult for users to learn the contraction/co-contraction of these muscles, because the applicable residual muscles may not be physiologically associated with the joint DOFs (such as using the residual biceps and triceps muscles to control hand opening and closing).

A significant improvement over the conventional method is the use of EMG pattern recognition based prosthesis control [1-15], which is grounded on the assumption that EMG patterns contain information about the desired movements of the residual limbs [3]. Using a pattern classification technique, the distinguishable characteristics of EMG patterns can be used to identify a variety of different intended movements which are sent to a prosthesis controller to implement the corresponding movements; this does not require independent muscle control sites for each controlled motion. Thus, this control approach may allow users to control a multifunction prosthesis intuitively and more easily.

In the previous studies of myoelectric prosthesis control, the commonly used EMG sensors are metal electrodes, which can be categorized into two types, wet and dry electrodes. A wet electrode uses electrode gel to improve the skin-electrode coupling property for high-quality signal acquisition, but it may have several disadvantages in clinical application of a myoelectric prosthesis. The electrode gel tends to dry out over time, causing the change of skin-electrode contact impedance and it is inconvenience to put the gel on each electrode in the socket donning of a prosthesis everyday. In addition, adhering wet electrodes to skin may cause skin irritation and allergies. A metal dry electrode does not require the use of electrode gel, but its poor contact between the dry electrode and skin causes large contact resistance and signal recordings are much more prone to motion artifacts and noise. Recently, textile electrodes have been attracting more and more researcher’s attention and are expected to become an alternative to the metal electrodes.

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It is well know that a textile electrode has a good performance in ventilation, flexibility, folding, bonding and do not need any electrode gel. Furthermore, fabric electrodes can easily attach to clothes and be conveniently and comfortably cleaned, re-use, and long-term using without adverse reaction [16-18]. These properties make textile electrodes be the ideal sensors for EMG signal recordings in control of a myoelectric prosthesis in clinical applications. However, it is unknown if the performance of textile electrodes in control of myoelectric prostheses is comparable to commonly used metal wet electrodes. In this study, we used the commercial conductive woven to make textile electrodes for EMG signal recordings and investigated the performance of EMG signals in control of multifunction prostheses. The performance of the textile-electrode EMG recordings compared with that of the wet-electrode EMG recordings, which determines if it is possible to use a textile electrode to replace a wet electrode in control of myoelectric prostheses.

II. METHODS

A. Textile Electrodes

The textile electrodes were fabricated using copper-based nickel-plated conductive fabric in the study, as shown in Fig. 1. The recording size of electrodes was 2 × 1.4 cm and two electrodes were integrated together to form a differential bipolar structure (Fig.1 (a)). The center-to-center distance of the paired electrodes is around 2 cm. The textile electrodes were mounted on a strap that was made by the rubber and nylon materials, as shown in Fig. 1(b).

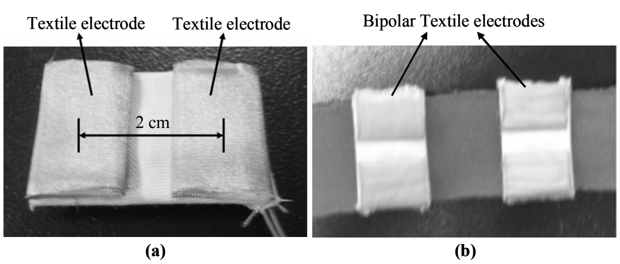

Fig. 1. Custom-made textile electrodes. (a) A bipolar electrode. (b) Two bipolar electrodes mounted on a strap.

B. Subject and EMG Data Acquisition

Six able-bodied male subjects, designated as AB01-AB06, who were free from any neurological and muscle pathology, recruited for the participation of this pilot study. The subjects aged from 20 to 30 years old. The protocol of this study was approved by Shenzhen Institutes of Advanced Technology Institutional Review Board. All subjects were given the written informed consent and provided permissions for publication of photographs for scientific and educational purposes.

EMG data acquisition experiment was conducted twice for each subject. In first experiment, EMG data were acquired using textile electrodes and the location of each electrode was marked and photographed after data acquisition. Then the subject took a rest for about half hour and then eight conventional metal electrodes (*Bagnoli™, Delsys Inc.*) were placed on the same locations as the textile electrodes to acquire EMG data again. To avoid any bias for use of the two types of electrodes, in second experiment, the metal electrodes were used first and then the textile electrodes for EMG acquisition. The time interval between the two experiments was one to two days, depending on the subjects available.

The eight custom-made textile bipolar electrodes were mounted on three straps (Strap A, B, and C). Strap A had two electrodes and placed on the biceps and triceps, Strap B had four electrodes and placed around on the proximal forearm (brachioradialis muscle, flexor carpi radialis muscle, flexor carpi ulnaris, and extensor digitorum communis), and Strap C had two electrodes and placed on the wrist (Pronator Quadratus and dorsal wrist), on the dominated arms, respectively. A large circular electrode was placed on the bony area of elbow in the tested arm as a ground. EMG signals were amplified and band-pass filtered (5-500 Hz), and then sampled at a rate of 1 kHz. EMG data were acquired with a custom data acquisition and processing system for the textile electrodes. A commercial EMG acquisition system (*Bagnoli™, Delsys Inc.*) was applied to collect EMG data when using the conventional metal electrodes.

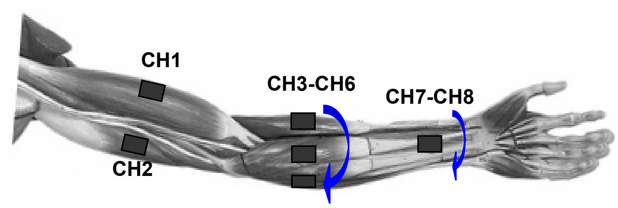

Fig. 2. Schematic diagram of electrode placement on able-bodied subject arm.

Each experiment included eight classes of arm and hand movements plus a "no movement" class that are the most commonly used movements in our daily activities. The eight movements were two elbow motion classes (elbow flexion and extension), four wrist motion classes (wrist flexion and extension and wrist pronation and supination), and two hand motion classes (hand open and close), as illustrated in Fig. 3. During experiment, subjects were asked to watch a video demonstration of each class of movements and to perform the movement in synchrony with the video. Every experimental trial contained ten repetitions of a motion class. For each repetition, the subjects were asked to exert a comfortable level of contraction at a medium force, to hold the contraction for approximately 5 seconds, and then to relax for the next 5 seconds. The ten repetitions of each movement totally produced 50-second active EMG recordings. To avoid muscle and mental fatigue, the subjects were allowed to take a rest of 3 to 5 minutes between trials.

C. Movement Classification

EMG pattern-recognition-based movement classification was performed on analysis windows. For each movement, 50-second active EMG recordings were segmented into a series of analysis windows with a time length of 150 ms and a time increment of 100 ms. Commonly used four time-domain features (mean absolute value, number of zero crossings, waveform length and number of slope sign changes) [3,7,9] were extracted from each analysis window. For each analysis window, a feature set is extracted on each of all the recording channels, producing a 4-dimensional feature vector. After concatenating the feature sets of all the channels, the entire EMG feature matrix (4×8×N, where N is the number of analysis windows). A linear discriminant analysis (LDA) was used to build a classifier for classification of different movements. EMG features from the first half of EMG recordings were used as the training data set to train a linear discriminant analysis (LDA) classifier for the nine motion classes, and EMG features from the second half of EMG recordings were used as the testing data set to evaluate the performance of EMG pattern recognition algorithm for the classification of the nine motion classes. The performance of the trained classifier in identifying a movement was measured by the classification accuracy, which is defined as:

$$\frac{\textit{Number of correctly classified samples}}{\textit{Total number of testing samples}}\times 100\% \qquad (1)$$

The classification accuracies were averaged over all nine movements to calculate the overall classification accuracy for each subject. Paired *t*-test was used to asses the statistic difference of classification accuracy between textile electrodes and gelled metal electrodes.

III. RESULTS

The performance comparison of two types of electrodes in identifying the different arm movements were measured by the classification accuracy. Table 1 summarizes the overall classification accuracy in identifying nine movements in six subjects when using EMG textile electrodes and conventional gelled metal electrodes, respectively. In two tests of textile electrodes, the classification accuracies across subjects showed consistency with an average accuracy of 94.45±2.10% in the first test and 93.65±2.59 in the second test. The classification accuracies in two tests of conventional metal electrodes also were similar with an average accuracy of 93.92±1.77% and 94.60±2.20%, respectively. For each subject, the textile electrodes showed similar performance in classifying the nine arm and hand movements as the conventional electrodes. The average classification accuracy across six subjects over two tests was 94.05%±2.29% when using textile electrodes and 94.26%±1.94% when using conventional electrodes, with no significant difference between the two types of electrodes (p=0.81).

TABLE 1

OVERALL CLASSIFICATION ACCURACY (%) IN IDENTIFYING NINE MOVEMENTS WHEN USING TWO TYPES OF EMG ELECTRODES, RESPECTIVELY

Subject	Textile electrode		Metal electrode	
	Test1	Test2	Test1	Test1
AB01	94.77	92.15	92.17	94.44
AB02	97.45	97.55	94.87	95.88
AB03	95.69	95.27	95.56	97.79
AB04	91.76	90.01	91.21	92.08
AB05	94.59	93.16	94.97	92.21
AB06	92.41	93.74	94.72	95.19
Average	94.45±2.10	93.65±2.59	93.92±1.77	94.60±2.20
Average	94.05±2.29		94.26±1.94	
p-value	0.81			

IV. DISCUSSIONS

The performance comparison of the gelled metal electrodes and textile electrodes in identifying the different arm movements was performed in the pilot study. Compared to the commonly used gelled metal electrodes, the textile electrodes have many properties to make them the ideal sensors for real-time EMG signal recordings in clinical application of myoelectric prostheses. Mounting a textile electrode to cloth is convenient for user's socket donning everyday and comfortable for long-time wearing without any adverse reaction. It is worthy noting that as a kind of dry electrodes, the textile electrodes are prone to causing more motion artifacts and noise in EMG recordings due to the poor contact between electrode and skin. It is unknown if the textile electrodes without the use of electrode gel also could capture enough EMG information for high classification accuracy in identifying different arm and hand movements, as gelled metal electrodes do. Therefore, it is necessary to investigate the usability of the textile electrodes in EMG recordings for control of multifunction myoelectric prostheses.

The results of the present pilot study in six able-bodied subjects showed that using a LDA classifier and four time-domain features, the EMG data recorded using textile electrodes could produce high accuracy (about 94%) for the classification of different arm movements, which was comparable with that of the conventional gelled electrodes. This finding suggests that the textile electrodes can be used in EMG recordings for control of myoelectric motorized prostheses instead of the conventional metal electrodes. Note that this study used classification accuracy to evaluate the performance of pattern recognition algorithms. Classification accuracy is the ability of the algorithm to appropriately recognize the desired movements during each time window (100 ms, here) while the subject holds different movements for several seconds. This accuracy is calculated by post-processing EMG recordings and is not a true measure of real-time function of a myoelectric prosthesis. Recently, we have proposed three real-time performance metrics to assess important real-time control parameters of multifunctional myoelectric prostheses [15, 19]. In the future, using the three performance metrics we will conduct more studies in both able-bodied subjects and patients with limb amputations to further explore the real-time control performance of the EMG recordings with textile electrodes in identifying different upper-limb movements.

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