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Limitations of Surface EMG Signals of Extrinsic Muscles in Predicting Postures of Human Hand

Ramana Vinjamuri, Zhi-Hong Mao, Robert Sclabassi, Mingui Sun

Abstract— **This paper explores the limitations of sEMG (surface Electromyography) signals collected from the extrinsic muscles in the forearm in predicting the postures of human hand. Four subjects were asked to try ten extreme postures of hand which need high effort. Two of these four subjects were asked to try ten more normal postures which did not need effort. During the experiments, muscle activity and static postures of the hand were measured. The data obtained were analyzed by principal component analysis. The results obtained revealed the limitations of sEMG signals of extrinsic muscles in reproducing the postures of the hand.**

I. INTRODUCTION

HUMAN hand is an excellent example of versatile architecture which can easily accomplish numerous tasks with very least effort possible. Researchers have been trying to analyze the complex architecture of human hand. The extrinsic muscles which stretch over the forearm and the intrinsic muscles which are within the hand are responsible for all the actions of the hand. In most cases normal postures of the hand do not need much effort when compared to extreme postures which involve full extension or full flexion of fingers. For instance, American Sign Language (ASL) characters do not need much effort of muscles when compared to the extreme postures that are used here (refer to Methods). In other words, extreme postures require high magnitudes of potentials generated in muscles where as for normal postures very low magnitudes of potentials are generated which are not easily detectable by surface electrodes of EMG machine. Surface Electromyography (sEMG) has many advantages in the sense that it is noninvasive but it has many limitations because its reach to the muscles is very limited.

This raises the question of how far can sEMG signals of extrinsic muscles in the forearm be dependable in prediction of static postures of hand. In our study it was evident that zero or very low values of sEMG potentials were generated in 8 different muscles for normal static postures of hand (in this study ASL numerical characters from 0-9 were used). Also for the same set of 8 muscles but for ten extreme postures (refer to Methods) higher magnitudes of potentials were detected by the surface electrodes. This finding is also in agreement with the anatomy of human hand [1] that extrinsic muscles and also intrinsic muscles affect the functionality of hand. To be precise, extrinsic muscles form the dominant set of muscles but not the complete set of muscles responsible for all the postures of human hand. In similar studies done by Sebelius et al. [2] sEMG signals collected from the phantom hand of an amputee are used in predicting the postures. Amputees successfully predicted ten different postures through a trained artificial neural network. But not all static postures of human hand can be predicted in this way with sEMG signals of just the extrinsic muscles.

Two matrices were obtained, one for the sEMG signals vs. postures and the other for joint angles (measured by CyberGlove®) vs. postures for both cases of ten and twenty postures. These matrices were analyzed using Principal Component Analysis (PCA). Studies based on PCA were also done by Braido and Zhang [3] to examine the temporal covariation between joint angles. In our experiments, it was found that number of principal components (PC's) of sEMG signals in the case of ten extreme postures was same when compared to number of PC's in the case of twenty postures and the number of PC's of joint angles in the case of ten extreme postures was less when compared to the number of PC's in the case of twenty postures. Results imply that surface EMG signals failed to predict normal postures. The physiological interpretation of the problem was supported quantitatively by PCA. Also, eigen vectors corresponding to PC's revealed information which was in sync with anatomy of hand.

II. METHODS

A. Experimental setup

The experimental setup consists of CyberGlove® equipped with 22 sensors which can measure angles at all the finger joints including distal inter phalangeal, proximal inter phalangeal and meta carpo phalangeal joints. Also in the

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Ramana Vinjamuri is graduate research assistant working towards PhD in Department of Electrical and Computer Engineering at University of Pittsburgh.

Zhi-Hong Mao, PhD is assistant professor in Department of Electrical and Computer Engineering, University of Pittsburgh (e-mail: maozh@engr.pitt.edu).

Robert Sclabassi, MD, PhD is professor of Neurological Surgery, Neuroscience, Psychiatry and Electrical, Mechanical and Bio Medical Engineering, University of Pittsburgh.

Mingui Sun, PhD is associate professor of Neurological Surgery in the Departments of Neurological Surgery and Electrical and Bio Engineering, University of Pittsburgh.

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setup is Delsys® EMG machine (Bagnoli 8) with 8 single differential surface electrodes (non invasive).

The selection of the extrinsic muscles for the experiment was based on several criteria. Firstly, the selected muscles must be playing a key role in particular posture of the hand chosen for a task. Secondly, muscles of interest were to be detectable by surface electrodes. For these reasons, we have selected the following eight muscles – Flexor Digitorum Superficialis (FDS), Flexor Pollis Longus (FPL), Flexor Digitorum Profundus (FDP), Extensor Digitorum (ED), Extensor Indicis (EI), Extensor Digiti Minimi (EDM), Abductor Pollis Longus (APL) and Extensor Pollis Longus (EPL). These muscles are responsible for flexion, extension and abduction at most of the fingers and joints. Experimental setup for one of the postures is shown in Fig. 1.

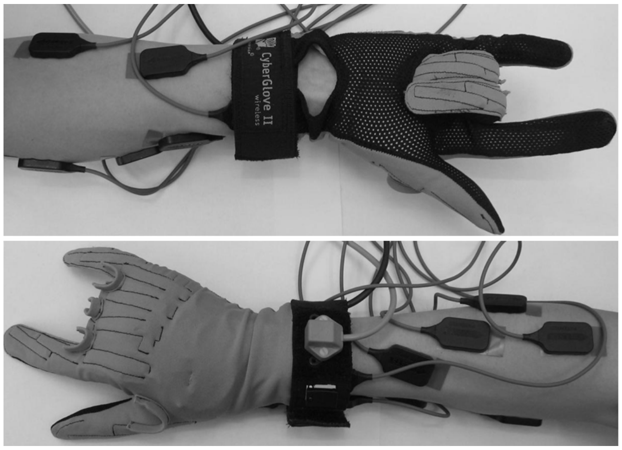

Fig. 1. Experimental setup (anterior-top, posterior-bottom)

B. Experiment

Four subjects participated in this experiment. Before the experiment started there was a trial period where subjects practiced all postures. The subjects were asked to try ten different extreme postures as depicted in Fig. 2. These postures are called extreme because they involve extreme flexion and extreme extension of one or multiple fingers depending on the posture. For instance, in posture P1 all fingers are extended at their MCP joints. These postures are different from normal postures.

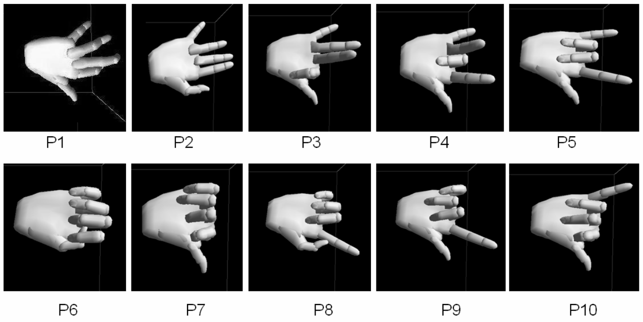

Fig. 2. Ten extreme postures (P1-P10)

Of the four subjects two subjects were asked to try ten more normal postures. For our experiment we adopted numerical ASL characters as shown in Fig. 3 as normal postures which need a little or less effort. These postures are quite different from extreme postures. There is a lot of effort on muscles in extreme postures but not in the case of normal postures. During the experiment subjects were asked to try these 20 different postures one after the other with a delay of 1-2 minutes in between postures. After ten extreme postures a recess of approximately 10 minutes was given in order to avoid effects of extreme postures. This recess was long enough for the subjects to forget the effort of muscles in the extreme postures.

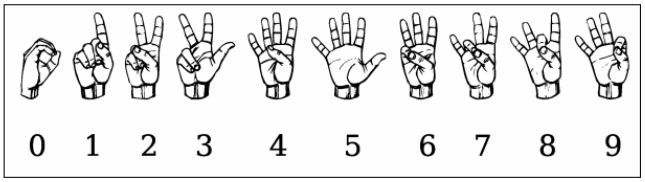

Fig. 3. Normal postures—ASL numerical characters (adapted from http://www.wikipedia.org)

Through out the experiment muscle activity was recorded with eight surface electrodes measuring the activation potentials of the muscles listed in the setup. Each posture lasted for 15 seconds, meaning EMG and Glove data were recorded for 15 seconds. In this experiment, only 15 sensors of CyberGlove® were used that correspond to joints of all the five fingers. EMG data were analyzed using Delsys® EMGWorks Version 3.0 and information about 15 angles corresponding to joints of all the five fingers in a vector of radians are obtained from CyberGlove®.

C. Analysis

It was observed during all the postures that the subjects used various efforts at the beginning of the task but they stabilized in last 5 seconds. Though they were trying the same posture for all the 15 seconds the EMG activity was not same through out the task. RMS values of the voltages were calculated using Delsys® EMGWorks Version 3.0. When considering RMS voltages of the activation potentials, an average of last 5 seconds of the task was considered to be the measure of RMS voltage of activation potential. There was not much difference in CyberGlove® data in 15 seconds. For all subjects, for each posture two different matrices were obtained. One is EMG matrix of dimensions 8x10 where 8 muscles (in the same order as mentioned in the setup) correspond to 8 rows and 10 postures correspond to 10 columns. The other is Glove matrix of dimensions 15x10 where 15 angles of joints of the five fingers (three for each finger) correspond to 15 rows and 10 postures correspond to 10 columns. For two of the subjects similar matrices were obtained but with dimensions 8x20 and 15x20 for EMG and Glove matrices respectively. Change in the dimensions reflects 20 postures taken into consideration for two subjects.

EMG and Glove matrices were normalized such that their mean equals 0. This was done by subtracting mean of each row from every element of the row. For each of the normalized matrices covariance matrices were calculated. Eigen values and eigen vectors of these matrices were computed. Information Index was computed using the following equation (1). In this equation λ_1, λ_2 and λ_r correspond to first r largest eigen values written in the descending order of any covariance matrix, where $r \leq m$, the total number of eigen values. If this Information Index exceeds 90% for least possible number of largest eigen values then the number of eigen values is equal to number of PC's. Corresponding eigen vectors are PC's. Our computation behind PCA roots from [4].

$$\frac{\lambda_1 + \lambda_2 + \ldots + \lambda_r}{\lambda_1 + \lambda_2 + \ldots + \lambda_m} \tag{1}$$

III. RESULTS

From the analysis of ten extreme postures for four subjects the following results were obtained. Fig. 4 is a comparison of number of PC's of sEMG signals for different subjects. It is observed here that for the first three subjects the number of PC's (where the curve crosses 90%) is 3 and for the subject 4 it equals 2.

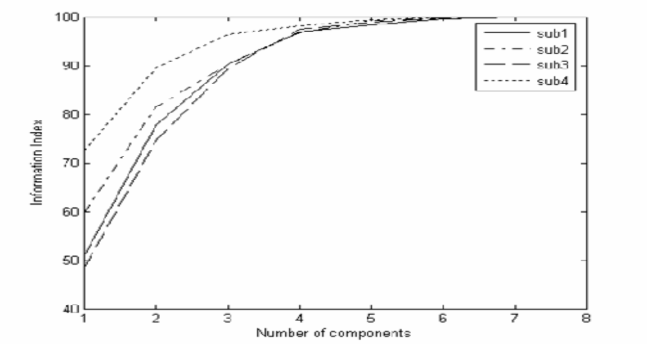

Fig. 4. Information Index plots for four subjects to represent number PC's in sEMG signals.

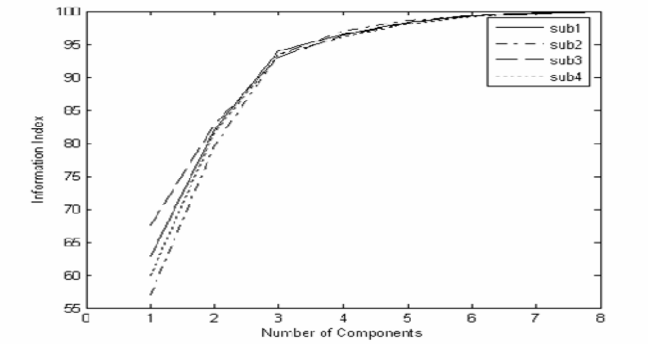

Fig. 5. Information Index plots for four subjects to represent number PC's in Glove signals.

For Glove signals, similar patterns of variations were observed for all the four subjects and about 3 PC's were needed for all the four subjects as shown in Fig. 5. Maximum number of PC's that can be obtained for Glove signals is 15 but only 8 are illustrated here because the remaining 7 values did not make difference.

Interesting results were obtained from the analysis of twenty postures for two of the subjects. For sEMG signals, the number of PC's for 10 postures was same as the number of PC's for 20 postures. For Glove signals, the number of PC's for 10 postures was less than the number of PC's for 20 postures. In order to plot Information Index for both sEMG and Glove signals in the same graphs only first eight eigen values of the Glove signals were considered. As shown in Fig. 6 for subject3 the number of PC's for sEMG signals for both ten and twenty postures is three. For Glove signals, it is clearly evident that the number of PC's in case of twenty postures was 4, which is greater than the number of PC's in the case of ten postures which is 3. Similar patterns were observed for subject4 as illustrated in Fig. 7.

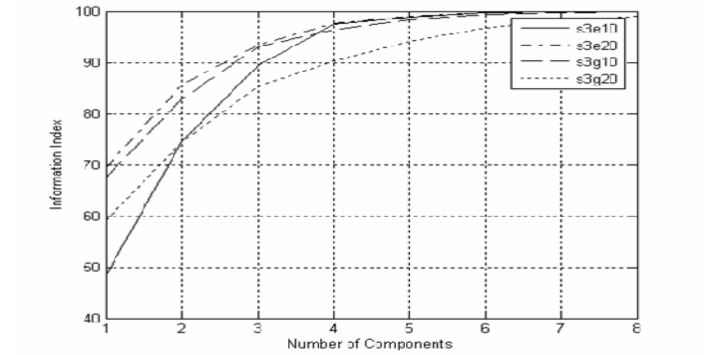

Fig. 6. A comparison of number of PC's for ten and twenty postures for sEMG and glove signals for subject3 (s3e10—subject3 EMG signals 10 postures)

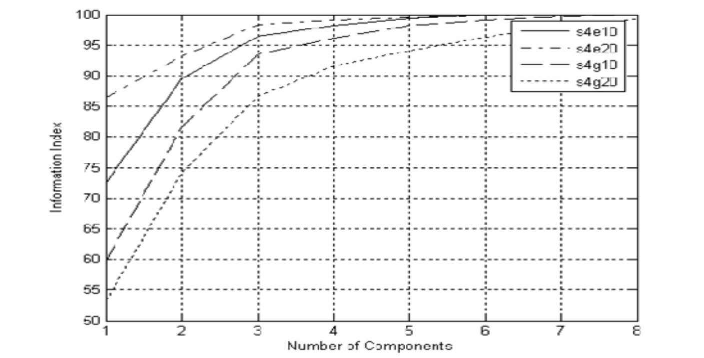

Fig. 7. A comparison of number of PC's for ten and twenty postures for sEMG and glove signals for subject4 (s4g10—subject4 Glove signals 10 postures)

These results suggest that even though there was an increase in the number of PC's from ten to twenty postures in the case of Glove signals there was no such increase in the case of sEMG signals which further suggests that there was no additional variance obtained from normal postures as they did not produce sufficient activation potentials in the muscles which can differentiate them from extreme postures.

IV. DISCUSSION

Results depict that the sEMG signals are not capable of predicting all postures of human hand. One can argue that this can be disproved with a better sophisticated EMG machine. But one cannot deny the fact that there are some natural postures of human hand which do not need much effort of the muscles. Also, there are some postures of the hand which differ only in activation potentials of intrinsic muscles in which cases postures cannot be predicted by measuring the activation potentials of just the extrinsic muscles. Many postures which include abduction and flexion of the fingers involve only intrinsic muscles which are local to the palm.

In eigen vectors of covariance of sEMG signals it was consistently observed in almost all the subjects that last four muscles which are EI, EDM, APL and EPL had higher weights and same positive polarity for first PC. This suggests that thumb, index finger and little finger played a dominant role in these tested 20 postures. This is not just because the above listed four muscles are dedicated to these three fingers. All subjects felt more stress on these fingers. It is opined in the literature [5] that thumb always plays an important role in many actions of hand. These results were supported by PCA in our analysis. Finding the dominant muscles not only helps us to quantify physiological facts of hand but also helps in prosthetics. This can reduce the number of muscles to be considered in prosthetics.

V. CONCLUSION

Surface EMG signals of the extrinsic muscles in the forearm cannot by themselves predict all postures of the human hand. The number of PC's of sEMG signals remained same where as the number of PC's of Glove signals which directly depict postures increased. This was successfully proved by PCA.

Readers should consider the following points:

1) Normal postures of the hand which are frequently used involuntarily by hand do not involve much effort of muscles. Even if they produce some lower magnitudes of activation potential in muscles they are not detectable by noninvasive surface electrodes.
2) Some postures of the hand involve only internal muscles of the hand which do not differ from each other in activation potentials of just extrinsic muscles.

Employing more subjects would make the analysis robust and might reveal dominant muscles to be used for prosthetics.

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