A HYBRID SYSTEM FOR THE PREDICTION OF UPPER ARM ARTICULAR SYNERGIES USING STATISTICAL AND SOFT-COMPUTING TECHNIQUES

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Abstract

In this paper the application of a hybrid algorithm to predict elbow position from shoulder angular trajectories during pointing movements is presented. The different trajectories were first clustered by using a statistical procedure and then an Artificial Neural Network (ANN) was trained for each group. The results showed the feasibility of this approach in terms of mean error in the prediction of the elbow and wrist positions.

Introduction

Functional Electrical Stimulation (FES) is a promising rehabilitation technology for people with neurological disorders such as those caused by spinal cord injury, stroke, and head injury [1].

Recently, FES systems have been developed by several research centers around the world to restore impaired functions in persons with motor deficits. In subjects with a cervical lesion of the spinal cord it is very important to restore hand and upper limb functions [2-5].

In all these situations it is mandatory (to obtain clinically useful results) to implement a "natural" (which can mimic the real situation of "able-body" subjects) and simple interface to make the subject able to control the stimulation parameters according to his/her desires. The user must be able to generate a continuos command signal for the control of grasp and reaching. The stimulation control is often done by using the movements of the contralateral shoulder (except for C4 subjects), the flexion/extension of the wrist, the voice and the electromyographic (EMG) signal recorded from shoulder or forelimb muscles [1,6].

For the restoration of the flexion/extension of the elbow in C5 patients, it is possible to obtain a useful way of controlling the stimulation parameters from the study of the synergies between joints during reaching in able-body subjects. In fact, even if the upper limb has a very redundant cinematic structure, reaching is obtained in a very reproducible way [7-8]. In this paper the application of a hybrid technique is presented. The different pointing movements are first clustered using a statistical procedure and then the prediction is obtained by using an Artificial Neural Network (ANN).

Methods

Data were recorded during pointing movements of one subject with no known neurological disorders. Fourteen different movements were performed (five trials for each movement) and recorded by using flexible goniometers [7] (see Figure 1 and Table 1).

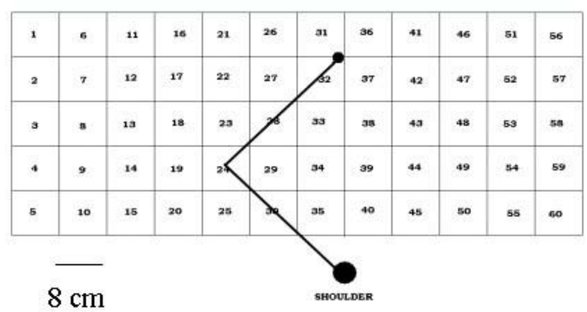

Figure 1: Set-up of the experiments.

In Table 1 the starting and ending positions of the different movements are given.

Movement	Starting Point	Target Point
1	7	18
2	13	26
3	11	25
4	27	4
5	23	52
6	27	60
7	31	10
8	37	6
9	43	20
10	49	50
11	47	4
12	53	32
13	49	58
14	53	26

Table 1: Starting and ending points of the movements.

From the first lobe (related to the forward part of the movement) of the phase space representation of shoulder and elbow angular velocities, the following features have been extracted for the different trajectories:

(1) the linear approximation coefficient C [7];

(2) the phase parameter F=d/D*h,

where h is equal to 1 when the peak of the elbow velocity comes before the one of the shoulder (otherwise is equal to –1), while d and D are the minor and major diameters of the lobe in the forward part of the phase space representation (see Figure 2 and 3), respectively.

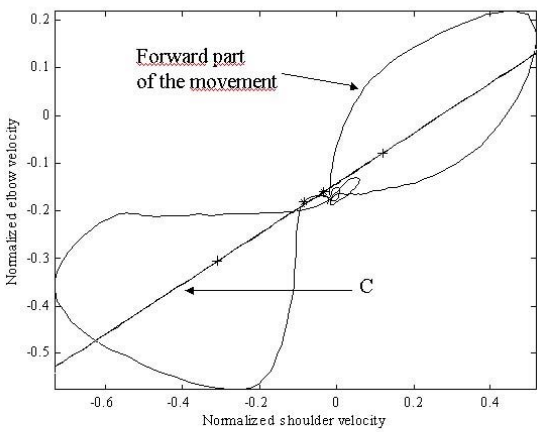

Figure 2: Example of phase space representation. The parameter F is calculated in the first part of the movement (in the present case it is positive).The straight line gives the information about C.

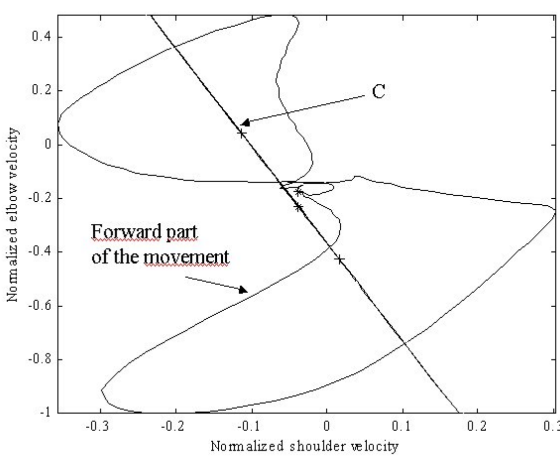

Figure 3: Example of phase space representation. The parameter F is calculated in the first part of the movement (in the present case it is negative). The straight line gives the information about C.

These parameters were used to implement the centroid clustering procedure [9]. This algorithm allowed us to cluster the 14 sets in few different categories.

Different feedforward ANNs were trained for each cluster with the aim of predicting the elbow flexion-extension angular velocity from the shoulder flexion-extension angular velocity. The ANNs were implemented using Matlab (The Mathworks, Inc. Natick, MA, U.S.A.). The training procedure was performed by using the "leave-one-out" method [10]. Hand trajectories were reconstructed, assuming no movement in wrist. The proper network architecture was selected assuming the distance between the actual and predicted final hand position as a performance index. The limit of the mean prediction error was fixed for all the clusters in a circular region (with a radius of 4 cm) around the wrist actual final position.

Results

The hierarchical clustering procedure reduced the number of the clusters from 14 to 5 (in Figure 4, the distribution of the features F and C and the position of the centroids after the clusterization are given).

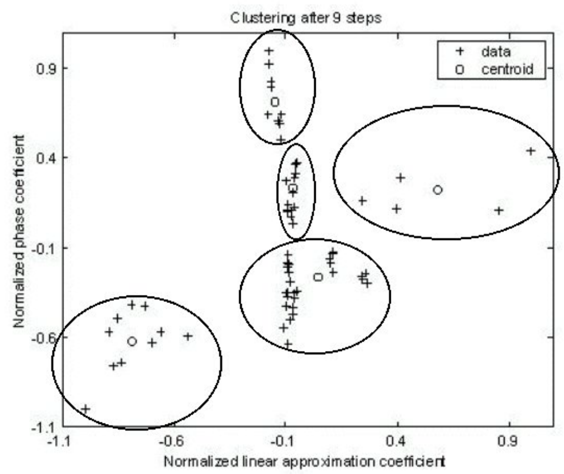

Figure 4: Distribution of the parameters C and F and of the centroids after the clusterization procedure.

In Table 2 the results of the clusterization are given.

Table 2: Results of the clusterization.

Cluster	Movements
1	4,8
2	1,2,3,5,6,10
3	7,9,12
4	11,14
5	13

After a trial and error procedure, the ANN architecture was chosen to have 1 hidden layer with 15 neurons. In Table 3, the results of the prediction for each cluster in terms of mean error in the final positioning of the wrist are given.

Cluster	Mean Prediction Error (cm)
1	4.00
2	3.41
3	1.47
4	3.18

5	1.22

Table 3: Results of the prediction for the different clusters of movements.

In Figures 5 and 6, the results of the prediction of the elbow angular velocity and position are given, respectively (cluster #5).

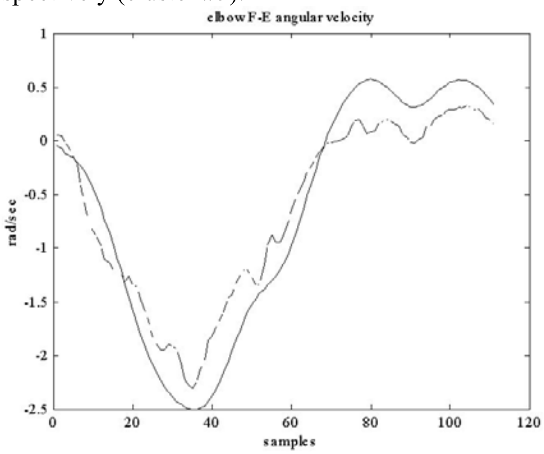

Figure 5: Results of the prediction of the elbow angular velocity (solid line: actual velocity; dashed line: predicted velocity).

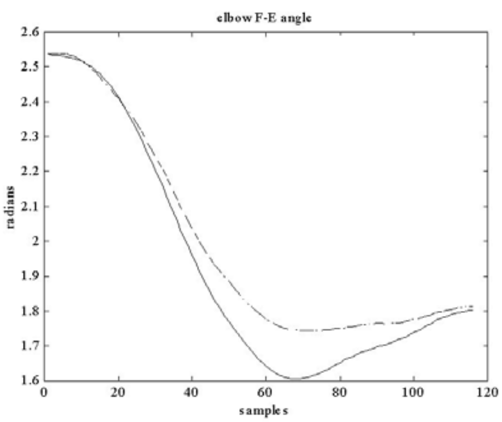

Figure 6: Results of the prediction of the elbow angular position (solid line: actual trajectory; dashed line: predicted trajectory).

Discussion and Conclusions

The results of the experiments show that the clustering procedure can improve the prediction performance allowing us to obtain good results even with a very simple ANN. The number of clusters must be chosen as a trade-off between the need for a good approximation of the elbow position (which means many clusters and/or a time-consuming algorithm) and a reduced complexity of the system also in terms of easiness of use. From the results obtained, the choice of 5 clusters seems to be acceptable.

Future activities will concern the implementation of other soft-computing methods, and the integration of the results in a closed-loop control system for an upper arm FES neuroprosthesis.

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