# Wavelet Based Neuro-Fuzzy Classification for EMG Control+

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*Abstract:* High accuracy of multi degrees of freedom in prosthetic control is hard to obtain because uncertainty exists between different movements. Neuro-fuzzy technology is suitable to deal with such problems. Therefore, in this paper a wavelet based neuro-fuzzy approach to classify EMG signals for movement recognition is adopted in order to decrease classification error. EMG signals are analyzed with wavelet transform, and feature vectors are constructed by SVD transform from wavelet coefficients for further movement recognition. A neuro-fuzzy network is designed as classifier, its initialization and training are also involved. Comparison results with such method and traditional ones are provided to show its efficiency. High recognition and reliability are achieved in preliminary experiments.

*Keywords*: Neuro-Fuzzy Network Wavelet Transform EMG Classification

## I. Introduction

EMG signals are preferable for prosthetic control since they can well reflect motion intensions. One challenge of this method lies in recognizing as more movements as possible from one channel signal detected by surface electrodes. The traditional way for solving this question is to extract statistical features from time or frequency domain, or take AR coefficients as feature vectors. However, EMG signals are non-stationary in nature, so the above traditional way to extract features are not effective enough to represent movement information. Wavelet transform is considered as a powerful tool to deal with such problem. So, in this paper, we attempted to extract feature vectors by wavelet analysis.

To improve the accuracy of prosthetic control, classification is another important part in designing the whole system. Artificial neural network is considered as a good selection because of its nonlinear map abilities. However, EMG signals are not strictly repeatable, and may sometimes even be contradictory. Moreover, transitional phases exist in continuous movement, and signals at this time reveal somewhat uncertainty, make it difficult for accurate classification. Fuzzy logic seems can make up that shortcomings since it is possible to discover patterns which are not easily determined by other methods, and contradictions in the data can be tolerated. Further more, the experience of medical experts can be incorporated. So, neuro-fuzzy classifier would be a good solution for EMG classification.

In this paper, fuzzy system was done with neural network, and a neuro-fuzzy classifier (NFC) was designed to realize movement recognition. C-mean clustering algorithm is used for initialization of fuzzy membership functions. Rules are stored by weights from training. High recognition and reliability are achieved in preliminary experiments.

## II. Classification Scheme

In designing a movement recognition system for prosthetic control, key factors for obtaining high accuracy and more degrees will be first discussed. The first is extracting feature vectors for EMG signal representation. Effective feature vectors may be most important for achieving more freedom and higher accuracy in prosthetic control. New signal analysis methods, such as wavelet transform that has been widely used in many fields, may be devoted to such question. Another factor to be involved in is what is most responsible for wrong movement recognition. According to our research, wrong classification tends to occur during movement changing,

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for uncertainty exist at this time. So, fuzzy technology is chosen to resolve it. The last problem may be very practical: how to make such a system suitable for various patients? It is well known that patterns fit for one person may wary much for the other. Good classification system should be subject-independent. To achieve this goal, parameters of classifier must be changeable for various persons. That is, adaptive ability should be considered in designing. C-Means clustering is used here to solve the problem. The classification system is shown as follows:

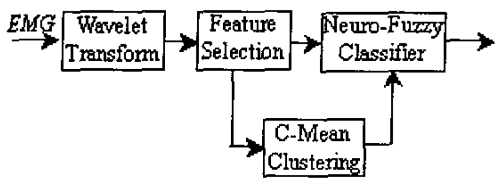


Figure 1: Classification System for Prosthetic control

## III. Wavelet analysis and feature construction by SVD transform

Wavelet transform is a powerful time-frequency method for non-stationary signal analysis. It can decompose signals into different scales and provide more information in time and frequency domain, thus emphasis the differences among signals and help to improve the classification accuracy. Wavelet transform is considered to be superior to FFT in getting multi-resolution analysis.

Discrete wavelet transform with Mallat algorithm[1] is used in this paper as follows:

$$\left.\begin{aligned} a_k^0 &= f_k \\ a_k^j &= \sum_n a_n^{j-1}\overline{h}_{n-2k} \\ d_k^j &= \sum_n a_n^{j-1}\overline{g}_{n-2k} \end{aligned}\right\}(k = 0,1,\cdots,N-1) \qquad (1)$$

Recursive applications of above algorithm lead to a decomposition of the EMG signal into a matrix of sequences[2], as shown in Fig. 2. (here four scale decomposition is adopted). The shadowed part is filled with zero. According to Englehart[3], Coiflet 4 shows better property in analyzing EMG signals, and in this paper we also take such wavelet.

Once coefficients of wavelet transform is obtained, then singular value decomposition can be used to get feature vectors:

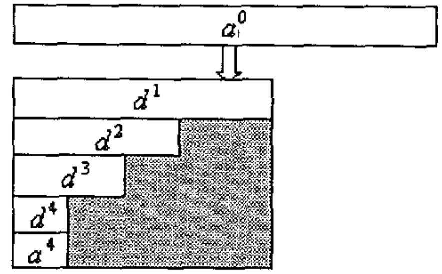


Figure 2: Wavelet Analysis on EMG and Its Coefficients Matrix

$$A = \sum_{i=1}^{k} \lambda_i \mu_i v_i^T \qquad (2)$$

$A$ denotes matrix composed from wavelet coefficients, and $\lambda_i$ is singular value used in the following as feature vectors. They can be calculated by finding positive square roots of eigenvalues of $A^H A$.

## IV. Neuro-Fuzzy classifier design

A traditional neuro-fuzzy network is to chose singleton fuzzifier, product-inference logic and center-average defuzzifier. Chan et al[4] have used such a network to finish EMG recognition successfully. However, such a network would be too bulky. For example, if we take 5 feature vectors, as in this paper, and three fuzzy sets {Large, Medium, Small} for each feature, then the number of neurons in first hidden layer would be $(C_3^1)^5$ =243. So, such a method is discarded in this paper.

Instructed by Yupu Yang[5], A simplified neuro-fuzzy network based on connectionism is adopted in this paper, which can be shown in figure 3. The number of input nodes equals to feature numbers, and the output nodes equals to movements to be recognized. The node functions in layer 2 realize fuzzying, three subsets for each feature, and altogether 15 nodes. Layer 3 mapping fuzzy inference logic between input and output membership functions, and

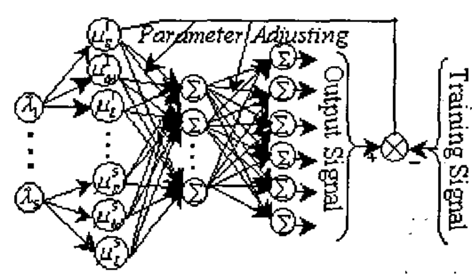


Figure 3: Structure for Adopted NFC

rules are stored in weights after training. Possibilities of each movement can be found by values of output from layer 4, and defuzzying is not adopted here because judgments about commands can be got directly by simply comparing.

Good features will be able to represent all or part of the items in the same class at the very beginning, so that blindness to initial definition of fuzzy sets is avoided and convergence is accelerated in the next training stage. Based on this idea, the fuzzy set's centroid and width was initialized using the results of C-Means algorithm. The whole process for neuro-fuzzy training can be describe as follows:

1) Calculate the means and widths of each cluster by C-Means algorithm, then the results are assigned to each fuzzy sets for initialization.

2) Choose the input patterns for learning. In view of correct recognition, the input patterns should be typical as much as possible.

3) Train the FNN with the learning patterns till success. Here gradient decree algorithm is adopted to make output error minimum.

Three Parameters, that is, centroid and width for fuzzy sets of features and weighs of network is trained and stored for further classification for unknown patterns. Training step is 0.01.

## V. Experimental results

Six kinds of functions termed as elbow extension (EE), elbow flexion (EF), wrist pronation (WP), wrist supination (WS), hand open (HO) and hand close (HC) are tested in this paper. To exam whether the NFC works well or not, samples between different movements are specially added. In case of each six function, EMG signals measured from surface electrode were all divided into small segments, each contain 256 points for wavelet analysis, and by this way altogether 150 6 groups of samples are carefully collected, 100 6 for training and 50 6 for testing. Only one output exceed 0.7 and the other less than 0.4, a conclusion is drawn that one function occur. Comparison on accuracy with traditional MLP (with structure of 5 14 6) and our classifiers with the same input vectors are given as follows:

Table 1: Comparison on accuracy of MLP with NFC

| | EE | EF | WP | WS | HO | HC |
|---|---|---|---|---|---|---|
| MLP | 92% | 94% | 86% | 88% | 90% | 94% |
| NFC | 98% | 96% | 90% | 92% | 94% | 100% |

## VI. Conclusions

In this paper, a wavelet based neuro-fuzzy approach for classification of EMG patterns is proposed. Such a method is considered to be superior to those traditional EMG recognition methods, since it improves the system both by signal analysis and by classifier design. Proper feature selection and clustering for initialization of classifier may also help to improve the whole property. Further test on different subjects will also be tested to check whether such a system will be subject-independent.

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