A Fully Integrated, Intelligent and Quantitative Working Environment for the EMG Evaluation


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Abstract

The evaluation of the EMG signal is a difficult and time consuming task. A great effort has been done during the last decade to offer quantitative and reliable algorithms to support clinicians in this evaluation. This paper describes the new approaches that we have adopted to solve this difficult task. An Expert System (ES) has been developed to guide the electromyographist in the planning and evaluation of the EMG and Nerve Conduction Studies (NCS). The expert system owns the knowledge to interpret the results of the Neurological Objective Exam, to indicate the right sequence of NCS and EMG tests to perform and to achieve the most suitable diagnosis of the site of lesion on the basis of the results of the evaluation of EMG under the three different conditions of registration with needle electrode, i.e., at rest, under weak contraction, by individualisation of the Motor Unit Action Potentials (MUAPs) and under maximum contraction, studying interference pattern. The MUAPs individuation and classification is based on neural networks, while the elaboration of the interference pattern is performed in the frequency domain estimating the quantitative features that are known as discriminating between different myogenic and neurogenic pathologies. These quantitative algorithms and knowledge bases, are integrated into a hybrid system called Hynex, which offers a fully integrated and coherent information environment, to individuate and classify the site of lesion. The Hynex system is constituted by other supporting tools, such as explanation modules, neuromuscular atlases and relational databases, in order to offer a complete intelligent working environment to users.

The porting of the system under an Internet/Intranet solution is under evaluation in order to realise intelligent remote supporting systems.

Introduction

During the last decade great effort has been done to provide clinicians with quantitative and intelligent algorithms to support them in the evaluation of the EMG [1,3,7]. Within an Italian project, financed by the National Research Council, we have developed a hybrid system called Neurap, which is the integration of a symbolic component Neurex, a tutorial expert system, and a connectionist one, Neurap, an Artificial Neural Network (ANN) [4]. Neurex emulates the typical diagnostic process of an expert neurologist for the localisation of the site of lesion: it assists the user in making diagnostic hypothesis, guides the user in planning the optimal sequence of nerve conduction studies and EMG examinations, interpreting their results and achieves the most suitable diagnosis of the site of lesion. Neurap singles out and classifies the MUAPs recorded with an intramuscular needle electrode during a weak contraction. The sampling of the EMG signal and the measurement of the MUAPs is based on an innovative heuristic algorithm. On this basis, the MUAPs classification is done with an unsupervised competitive ANN that creates clusters of
similar MUAPs, with no a priori information about the number of Motor Units and consequently of the clusters.

We have already presented the results of our studies in previous works [5,6]. During the last year new modules of the knowledge base and new quantitative algorithms have been developed. The anatomical knowledge base of Neurex has been enriched with the anatomical knowledge regarding the upper limbs. The neuromuscular concepts of the upper limbs (muscle, nerves, reflexes with their normative ranges) have been added to the anatomical knowledge base. Since the diagnostic process, in the individuation of the site of lesion for the upper limbs is more complex, thanks to a structural approach (KADS) this knowledge has been later successfully added to the knowledge base of the system, in a completely natural way. We are convinced that the problem of reuse and updating of data is considerably decreased developing the domain in a structural way from the beginning of the life-cycle of the system.

The MUAPs individuation and classification has been improved thanks to the introduction of new controls added to the system. But the main work has been the development of quantitative algorithms for the elaboration of the EMG signal during maximum contraction, and the acquisition and formalisation of the knowledge regarding the interpretation of the EMG registration under this situation.

**Neurap**

One of the hardest tasks formulating a neurological diagnosis is the interpretation of the EMG signal. The most accepted quantitative method for the evaluation of the EMG signal is the study of individual MUAPs and quantization of the MUAPs parameters, such as amplitude, duration, and number of phases is used to discriminate between different neuromuscular disorders. Unfortunately, the analysis of the EMG signal in order to individuate and classify the MUAPs is a time consuming process and requires specific skill; consequently only a few number of clinical departments have used it for the daily routine EMG analysis. In the last generation of Electromyographs new specific modules for the automatic analysis and classification of the MUAPs have been presented. This modules are based on pattern recognition, template matching, spike-triggered averaging, statistical and syntactical methods.

![Pattern Individuation](image1.png)

**New Approach**

In our study a new quantitative method based on ANN for the analysis of the MUAPs has been developed (Figure 1) to single out and classify the MUAPs recorded with an intramuscular needle electrode during a weak contraction. At each recording site 2 to 6 MUAPs may be recorded and almost no operator interaction is requested. The method has been implemented in Neurap, which may be used as a stand alone system.

Other authors have used ANNs for the quantitative MUAPs classification. But our approach is completely different, since we have used the ANNs for the individuation (hardest task) and the consequent classification of the MUAPs.
Neurap is made of five modules: the first one visualises the signal with the recording information (date, sample frequency, sweep, sensibility, low filter, high filter,...) and the anamnestic data (Figure 2). This first module for the off-line visualisation of the signal, has been developed in order to allow the electromyographist to review-reprocess the signal providing the user with a friendly Window-like interface.

The second module does the segmentation of the signal, while the third module, the neural one, decides whether the selected segments from the second module are true MUAPs and classifies them in clusters. The forth module extracts the relevant features of the MUAPs belonging to the individuated clusters and passes on these parameters to the inferential engine of Neurex, in order to formulate new diagnostic inferences. The fifth module is the one that elaborates in a quantitative way the signal recorded during maximum contraction.

MUAPs classification

The segmentation of the EMG signal and the individuation of the possible MUAPs (the second module) is based on an innovative algorithm that takes into account not only threshold criteria (amplitude and rising time), but also heuristics resulting from the clinical experience, acquired and assessed during years of study of the shape of the MUAPs.

The MUAPs classification is done with an unsupervised competitive ANN (Kohonen based) that creates clusters of identical MUAPs, with no a priori information about the number of the clusters. The segments singled out by the second module are presented to the ANN in an incremental way. The ANN matches the segment with the patterns memorised in its topological map and finds out the pattern which is most similar to the current sample. The two last modules work together, in cascade, during the problem solving task of the individuation and classification: the second module has been developed using the assessed experience and skill of the clinicians (deductive reasoning), while the ANN finds out new information in an inductive way.

The forth module visualises, for each selected cluster, the samples in it classified (Figure 3). A cluster has to have more than five identical samples in order to be considered a real MUAP class. The MUAPs features passed on to the ES are the amplitude, number of phases, duration, number of turns, area, rising time and thickness (area/amplitude ratio). The clinician may view for each cluster which MUAPs have been put together and if a MUAP does not appear to be exactly as the others, may discard it. The mean of the values of the meaningful features are then estimated and passed to Neurex.
Maximum Contraction

The Power Spectrum analysis of needle EMG interference pattern is known to be a valid and discriminating diagnostic tool in patients with neuromuscular disorders. The aim of our work was to obtain the power density spectrum of the signal and then to extract significant features from the frequency domain.

An algorithm that computes the Fast Fourier Transform of the signal on-line has been implemented, so to obtain the EMG Power Spectrum (Figure 4). Using this mathematical tool and the periodograms method the signal's power density spectrum was estimated. Three important features were extracted in the frequency domain: RMS, Median Frequency and Mean Power Frequency which are known to be discriminating between myogenic and neurogenic diseases.

Once these quantitative features are calculated, they are passed on to the knowledge base of the Neurex ES in order to confirm/change or reject the hypothesis of the site of lesion, achieved with NCS first and MUAPs classification next.
Conclusions and future development

The integration of the two systems has the following dynamic cycle: the ES suggests a new muscle to be examined, the user records the EMG signal during the three clinical situations: at rest, under weak contraction and maximum contraction and runs Neurap to analyse the signals recorded. Neurap finds out the MUAPs, extracts characteristic features of the retrieved MUAPs and passes them to the KB of the ES that interprets them on the basis of its knowledge. In the same session Neurap passes information on the IP, estimating the values of the selected significant parameters to Neurex. If the ES’s information satisfy the requirements the system stops the examination sessions and communicates its final diagnosis to the user, otherwise suggests a new muscle to be examined.

Hynex meets the two main requirements of the tutorial/assistant hybrid systems [2]: to tutor unskilled people to become experts and to increase the performance/cost ratio both for patients and health-care organisations being a time saving system. Since the system is used with conventional apparatus, displays data in a rapid and correct way we hope to ensure acceptance by the clinicians and to tutor the less experienced doctors.

References