Virtual rehabilitation system for fine motor skills using artificial neural networks

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Abstract. This work presents a rehabilitation system for upper limbs performed by the acquisition of electromyographic signals (EMG) of a patient with movement limitation after stroke. To determine the physical gestures of the arm, the MYO Armband is used, and to increase the default number of movements (4 gestures), a recognition algorithm is performed using artificial neural networks. MATLAB has been used for the extraction of a vector containing the characteristics through probabilistic signals treatment and to determine the angles of rotation. In addition, an immersive environment is developed in Unity 3D software allowing the user to experience a more motivating therapy. As a peripheral output, HTC VIVE glasses and binaural hearing aids were chosen. To validate this proposal, five users with an age range of 49 to 69 years have made 200 tests in total with the proposed physical gestures (7). In addition, the qualitative validation of the system is done through the SUS usability test and as a result it is obtained (55.25 ± 0.18), demonstrating good acceptance.

1. Introduction
The percentage of people who show some type of injury or disability after having suffered an accident or having a chronic illness increases worldwide [1–4]. These diseases affect the human being without any type of discrimination and among the main ones we can mention the traumatisms, dystrophies, dysplasia, arthritis, and a number of syndromes [5,6]. This entire problem mostly affects the life quality of the patient and restricts him/her from performing his/her psychomotor and sensory activities autonomously. It is usually the lower and upper limbs that are most affected after suffering some type of trauma [7]. Looking to mitigate the ailments that may arise, the so-called rehabilitation appears, where it is included the procedures that it encompasses [8,9]. This process plays a decisive role in the recovery of the body part that has been affected, as long as it is performed in the appropriate manner and with the relevant stimulation [2]. In this way, the pathology development can be diagnosed, prevented, and evaluated, as well as implementing the necessary corrective actions. These procedures
are usually controlled and performed by the treating therapists, where their experience and expertise are predominant in measuring progress in patient recovery [10,11].

Taking into account the experts’ criteria, it has been looked for ways to motivate the patient during their sessions, using technology. Thus, conventional therapy has been combined with the immersive experience found in virtual reality (VR) environments [12]. In this way, repetitive routine tasks are evaded and the uncertainty of the actual percentage of evolution in the recovery process is eliminated [13]. Some proposals that seek to solve this problem are mentioned below. In [14] is presented an interactive system, whose programming language is Visual Studio and data acquisition is done through the Myo Armband bracelet. Applications based on myoelectric signals are present in several investigations and are widely used in rehabilitation programs. This in the cognitive field with brain treatment and for the upper and lower extremities in the development of prostheses and orthoses. In the same topic, [15] combines surface electromyographic (EMG) sensors with integral rehabilitation and physical training. Using a programming algorithm, the flexion and extension of wrist movement is evaluated, thus contributing to the rehabilitation of the user's shoulder. Through this type of research, precedents are established for remote diagnosis and exercise. A virtual system for the rehabilitation of upper limbs in military personnel is described in [16]. The Myo bracelet captures the signals and as output, there is a virtual environment accompanied by the proper sounds. The tests carried out demonstrate the acceptance of the system by users.

In this context, this work presents a virtual reality system that contributes to the process of limb rehabilitation, using an advanced control algorithm that has not been applied in the previous literature. Through the MYO Armband, a low-cost electronic device, the patient's electromyographic signals are detected by performing a physical gesture using 8 sensors. The amplification of these signals is carried out and sent to a personal computer via Bluetooth communication for digital processing in MATLAB. To increase the number of gestures that the input device detects, artificial neural networks are used, adding 3 additional gestures. The Unity 3D software is used for the virtual environment development and the presentation of the tests and their respective results corroborate the correct functioning of the implemented proposal.

This document contains four sections: where section 1 describes the context of the research in the introduction. Section 2 presents the Methodology and section 3 the tests performed and the results obtained. Finally, conclusions and future work are described in section 4.

2. Materials and Methods

In Figure 1 is a structural diagram that allows evidence of the input and output devices, as well as the software to be used and the connection between them.

![Figure 1. Structural diagram of the developed proposal.](image-url)
2.1. Signal Acquisition

The signal acquisition process is performed using the Myo device, a band containing non-invasive EMG and inertial sensors. Through this device, the movement of the user's wrist muscles can be determined and through bluetooth, this information can be sent to the computer for processing. The programming is usually conditioned to the manufacturer's own software, but in this case through C++ have been able to make changes based on what is required. The electricity emitted by the muscles is measured by the accelerometers and electrodes that are already incorporated. The developers have defined the factory maximum values (MFV) as the standard measurement that allows further data processing. These values have no units and their amplitude varies between -1 and 1.

2.2. Image features

Although the sensors are located in the same position of the muscle without making movement, the nature of the signal causes that the response of the sensors does not register a similar pattern in each one of the captures. In general, there are variations according to the type of gesture, physiological characteristics of each person, gender, musculature, degree of injury, and so on, making the system not applicable to any user. To carry out the extraction of the signal characteristics, a gesture is executed continuously for a period of 20 seconds, where a script is programmed to acquire the samples every 300 milliseconds.

Probabilistic calculations are applied that include absolute value (to obtain a positive only signal) and the arithmetic mean. The 66 average values determined require a neutral value; therefore, an arithmetic mean is again applied to have a standard value, which is used to determine the variance of these data. The number of experiments and analyzes carried out suggest the inclusion of an additional calculation based on the non-repetitiveness of the amplitude of the signals and thereby obtain differentiated values depending on the type of gesture executed. Equation (1) shows the graphic representation of this part of the feature extraction, showing the differentiation of the signals. In this way it is possible to integrate the vector of characteristics that represents the gesture made by the user and is shown graphically in Figure 2.

\[
\begin{align*}
\{ & d_{f_i} = \text{EMG} \text{sensor}_{i+1} - \text{EMG} \text{sensor}_{i} : 1 < i < 7 \\
& d_{f_8} = \text{EMG} \text{sensor}_{>7} - \text{EMG} \text{sensor}_{i} : i = 8 
\end{align*}
\]

(1)

Figure 2. Characteristic vector for the fist gesture acquired by: Female gender (left). Male gender (right).

2.3. Rotation angles

The Myo device additionally allows recognizing the orientation, rotation, and accelerations that the upper member is having, since it includes inertial sensors such as accelerometers, gyroscopes, and a magnetometer. Thus, it is possible to recognize where the end of the user's arm (wrist) is pointing, allowing to point to an object of a scenario realized in VR, while the gestures allow to move it, catch it or suppress it from the scene. By default, the device returns either net acceleration and rotation values or a rotation matrix with rotation axes already included. As described above, the values of rotation
axes can be extracted from the own rotation matrix that provides the SDK of the library of the device. Although the device provides quaternary values, the calculation of rotations can be obtained directly through the rotation matrix. The rotation matrix is represented in equation (2). Where internal values of the matrix are dependent on each other, the values of pitch, roll and yaw.

\[
M = \begin{bmatrix}
    r_{11} & r_{12} & r_{13} \\
    r_{21} & r_{22} & r_{23} \\
    r_{31} & r_{32} & r_{33}
\end{bmatrix}
\]

(2)

2.4. Configuration of the artificial neural network (ANN)
The definition of input and output values allow the training of an artificial neural network type feedforward using the toolkit of MATLAB. The characteristic vector of each of the gestures contains 24 values, within which the mean, variance and differentiation of each of the responses of the 8 EMG sensors are included. The signal acquisition time can be configurable in the user interface, where more samples, better network training can be achieved.

2.5. Interface Development
The popular 3DS MAX software is used for modulation, rendering and visualization of the shapes and objects that will be used in the application. These are saved with a *.fbx extension and then imported from the Unity 3D program for the assignment of textures, colors and hierarchy. Other elements that stimulate the person are also attached, such as environmental sounds that encourage the immersion of the system, complementing the perceived experience. This application is tested by a user in a preliminary way and based on his comments, substantial modifications are made to colors, shapes, sounds and activities that turn out not to be totally comfortable. Finally, the final version of this prototype system is implemented and presented to the end user for validation.

The virtual environment developed presents a landscape surrounded by trees and other elements of nature, a road and a fire truck. This scenario has been considered since we want to offer relaxing conditions, which produce comfort and satisfaction after the accomplishment of the tasks. The activities include the process of driving a fire truck along the road, until it reaches the end and mitigates the presence of fire. During the development of the experiment, seven hand gestures must be made and in this way, a rehabilitation session is being carried out in a different way.

3. Tests and Results

3.1. Signal detection test
The acquisition and extraction of characteristics of the EMG signals and the training of the neural network need to be evaluated to validate the accuracy in pattern recognition. In the developed interface this evaluation can be executed, where graphically the characteristics of the signal to be recognized (any of the trained gestures) and the characteristics of the signal acquired in real time are contrasted. In Figure 3 (a) we can see the interface developed in MATLAB and in Figure 3 (b) the patient performing the respective gesture (fist).

3.2. Performance test
As previously mentioned the execution of various muscle gestures allows the feedback of the proposed system, since they allow the acquisition of signals and in turn are combined with the display of images in the virtual reality glasses and sounds. The users who were part of these experiments were five people in an age range of 49 to 69 years (where one of these people had to perform exercises in both hands and the rest only in one). Figure 4 shows a patient performing a rehabilitation session, using the interface developed. The sessions were carried out for 30 minutes, during one month, on Mondays and Fridays. In order to be able to carry out a more adequate follow-up of the rehabilitation process, the health professional must manage an adequate accompaniment in the execution of the activities.
3.3. Experimental Results

The acquisition and extraction of characteristics of the EMG signals and the training of the neural network need to be evaluated to validate the accuracy in pattern recognition. In Figure 5, the graphic representation of the results of 200 repetitions executed is displayed to verify the operation of the ANN.

After completing the execution of the proposed activities, the patients are qualitatively evaluated through the application of a usability test. The results obtained are reflected in the generation of a report, which includes the name of the person, the number of hits and a history of progress over time. The test chosen in this research is the SEQ, which has been developed by Gil-Gomez and has a compendium of 14 questions that must be evaluated on a scale of 1 to 5, whose interpretation varies according to the question. This test evaluates the percentage of immersion, acceptance, discomfort and medical problems that could occur. In the last one, a commentary on the application and the perceived incidence can be added. The questions presented to users are described in tabular form in Table 1.

The collection and analysis of the data obtained from five users show as a result (55.25 ± 0.18). Since the outcome, interpretation of this test says that if the score obtained is higher than 40 it is considered acceptable, it can be defined that this game is widely accepted.
Table 1. Description of the SEQ test and presentation of the results obtained.

| Question                                                                 | Result (N = 5) |
|--------------------------------------------------------------------------|----------------|
| 1. How much did you enjoy your experience with the system?               | 4.75           |
| 2. How much did you sense to be in the environment of the system?        | 4.5            |
| 3. How successful were you in the system?                                | 3.75           |
| 4. To what extent were you able to control the system?                   | 3.25           |
| 5. How real is the virtual environment of the system?                    | 4.5            |
| 6. Is the information provided by the system clear?                      | 4.75           |
| 7. Did you feel discomfort during your experience with the system?       | 4              |
| 8. Did you experience dizziness or nausea during your practice with the system? | 4.25           |
| 9. Did you experience eye discomfort during your practice with the system? | 4.25           |
| 10. Did you feel confused or disoriented during your experience with the system? | 4.5            |
| 11. Do you think that this system will be helpful for your rehabilitation? | 3.75           |
| 12. Did you find the task difficult?                                     | 4.5            |
| 13. Did you find the devices of the system difficult to use?             | 4.5            |
| Global score (total)                                                     | 55.25          |

4. Conclusions
The system described in this document has been designed in compliance with the relevant quality standards and with care for the integrity of the patients as a premise. The proposal developed offers an immersive environment for users by merging the presence of images in the virtual reality glasses and environmental sounds. Since the application of this system and the obtaining of quantitative results from the sessions carried out is a process that takes a long time, an initial qualitative evaluation has been made. The score obtained has demonstrated a value above what was accepted as indicated by the interpretation of the results of the SEQ test and with this, it has been possible to present the user with a suitable tool for his rehabilitation process.

The interface developed is intuitive, easy to use and has not presented any inconvenience to users. Likewise, the follow-up and indications of the medical specialist are very important so that a history of the progress of the sessions executed can be kept. In spite of this, it must be emphasized that this research does not focus on the field of medicine, but rather on the development of applications that allow the improvement of the user's quality of life, and for this reason, a qualitative survey has been carried out. As future works, it is proposed to carry out an evaluation of results after a longer period. It is also desired to use the coupling of signals obtained with the Myo device and the development of other interfaces and thus evaluate their performance in lower limbs.

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