Decision Support System for NMES Treatments

A solution design

Tiago Franco[ab]
[a] Research Centre in Digitalization and Intelligent Robotics (CeDRI), Instituto Politécnico de Bragança, Bragança, Portugal
[b] ALGORITMI Centre, Universdade do Minho, Braga, Portugal
tiagofranco@ipb.pt

Abstract — **The preservation of functional capacity in old age is associated with a more active and dignified life. Maintaining this capacity is not a trivial task; several diseases can make it difficult to practice regular physical exercises or make it unfeasible, such as knee osteoarthritis. Neuromuscular electrical stimulation (NMES) is a treatment for muscle rehabilitation positioned as an alternative. However, it is still unclear which electrostimulation configurations can produce the most effective treatment. The literature indicates that the difference in treatment depends on the intrinsic characteristics of the patients. In this scenario, a decision support system is designed to assist physiotherapists in data analyses to create a personalized treatment. The proposed treatment relies on a wearable system with an NMES actuator and biofeedback sensors. Thus, it is expected to adapt the NMES in real-time based on unique patient characteristics, such as muscle fatigue. In addition, the system architecture is designed for the treatment session to be carried out at the patient's home, reducing costs and providing more comfort.**

Keywords - Decision Support System; NMES; Muscle Rehabilitation; Artificial Intelligence; Wearable Sensors.

I. INTRODUCTION

Healthy aging is a topic that has an intrinsic interest for all living people in the world. In particular, the preservation of functional capacity is directly associated with prolonging a dignified and active life [1]. Several factors are related to the decrease of the functional capacity in the elderly, such as: slowing down of metabolism causing a direct reduction in protein synthesis [2], changes in muscle fiber types with fat accumulation [3], decreased neural communication between the muscle [4], among others.

Performing physical exercises regularly helps preserve functional capacity by improving strength, endurance, balance, and flexibility. However, physical exercises in old age can be expensive since some pathologies such as knee osteoarthritis (KOA), cardiovascular diseases, and neuromuscular problems can make the execution of some exercises unfeasible, generating a need to attend specialized training centers [5].

One of the aggravating factors of this problem is the delay in finding the necessary treatment. According to the World Health Organization (WHO), the possible recovery becomes more complex over time if the condition is not advanced enough to permanently compromise the functional capacity [1]. In the case of patients with advanced KOA, the difficulty can be even worse since, in addition to being painful, the treatment is carried out in the clinic, usually requiring the help of family members to get there.

A solution positioned as an interesting and less expensive alternative to the traditional training methods could be neuromuscular electrical stimulation (NMES). NMES is a technique that artificially produces muscle contraction by applying an electrical current with surface electrodes on the muscles. NMES is generally applied to improve functional capacity, preservation and recovery of muscle mass, and muscle strengthening [6]. NMES treatment has proven to be safe for muscle rehabilitation in the elderly [7] and effective for conditions such as KOA, mainly improving pain [8].

Despite this, the use of NMES for muscle rehabilitation in the elderly is considered recent. So far, there is no consensus on which configurations produce an adequate rehabilitation [7]. Maffiuletti [9] reports that the effectiveness of electrostimulation depends more on the patient's natural characteristics than on the adjustable parameters of NMES.

In this context, the research area Health 4.0 can play an essential role in constructing treatments that consider individual particularities. Health 4.0 is a recent area that encompasses how health is managed and delivered, considering the latest technological advances that combine concepts derived from Industry 4.0, including the Internet of Things, Big Data, Machine Learning (ML), and mobile applications [10].

Combining these elements provides the fundamental requirements to create patient-centered approaches that were not available before. The key that enables the design of new treatments is the data collected through sensors integrated into wearables or smart devices [11]. Several sensors can acquire high-quality data that can be clinically relevant, for example, motion identification through the Inertial Measurement Unit sensor (IMU), heart rate measurement through the Electrocardiogram sensor, muscle contraction volume through the Electromyogram sensor (EMG), blood pressure through Oximeter sensor, among others [12].

This study explores the components of Health 4.0 to develop a clinical decision support system architecture. The focus of the system is to assist physiotherapists in developing NMES treatment that adapts to individual particularities. For this, the proposed treatment considers being performed at home through a wearable system as an NMES actuator.

The system under development takes advantage of the dataset built during NMES treatment sessions to identify differences and similarities in muscles behavior. With this data, it is planned to apply artificial intelligence to recognize the most effective treatments for each group of characteristics. Thus, it is

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intended to understand which intrinsic characteristics can help to formulate a more effective individualized treatment.

Several challenges are raised for the development of the proposed system architecture. In section 2, three major issues are explored with a brief literature review. The first issue clarifies the changeable parameters of electrostimulation and the expected treatment progress. The second issue raises studies that have personalized electrostimulation for muscle rehabilitation. The third issue explores wearable technology and possible sensors that contribute to the proposed solution.

Section 3 shows the architecture of the system designed considering the contributions of the literature review and the requirements of NMES treatment at home. Finally, section 4 shows the conclusions found so far and the lines of research that will be carried out in the future.

II. LITERATURE REVIEW

A. *Electrostimulation treatment for muscle rehabilitation*

Electrostimulation treatments can be found by many names, including neuromuscular electrical stimulation (NMES), functional electrical stimulation (FES), transcutaneous electrical nerve stimulation (TENS), interferential current, among others. Each name refers to the effects that the treatment is intended to achieve with electrostimulation [13]. This study used the terminology NMES since this treatment is usually associated with home treatments and appears in the literature as an efficient and promising treatment for KOA [8].

There is a considerable inter-individual variation in response to NMES. It is believed that some anatomical properties may determine the quality of the muscle response to the application of electricity to the skin. One possible solution to optimize the effectiveness of NMES is the level of evoked force relative to maximal voluntary force, also known as muscle tension. The goal is to adjust the two NMES parameters, frequency, and intensity, to maximize muscle tension [9].

Langeard [7] in a review of the functional effects that NMES has on the elderly, reports that electrical stimulation programs are highly inconsistent. The use of symmetrical rectangular pulses from 100 to 400 μs biphasic was the only common point of all the researched studies. The frequency ranged from 20 Hz to 100 Hz, normally adjusted to the patient's tolerance. In addition to the variant in stimulation characteristics, studies also show differences in the temporal composition of the treatment. The duration of treatment programs can vary from 4 to 16 weeks before reformulation. The number of weekly sessions also varies, from 2 to 4 times a week. Lastly, a single NMES treatment session can take 9 to 40 minutes to complete.

Despite this, several programs have been successful in their purpose. The review points out the treatment configuration between 2 and 4 times a week for at least four weeks, with a frequency between 20 Hz and 70 Hz and with an intensity between 30 mA and 128 mA proves to be safe and adequate to trigger positive effects for muscle rehabilitation in the elderly.

B. *Personalized electrostimulation*

Only one study was found adapting NMES treatment via software to muscle rehabilitation. The other studies presented to explore the adaptation of a more powerful electrostimulation called FES applied to patients with Stroke and severe muscle paralysis. All studies used technology from industrial robotics called a feedback controller to adapt the electrostimulation. A feedback controller is a system that measures variables that cause disturbances in a defined environment and takes corrective action targeting a reference value [14].

Wolf [15] and Meadmore [16] developed a system that used controllers to adapt electrical stimulation according to the desired trajectory in paralyzed arms. The controller searches for the minimum muscle activations to make the arm perform the trajectory with the greatest precision. The data used in the studies were acquired by a robot that moves the patient's arms and records the 3D positions of possible trajectories.

Duenas [17] proposes to accelerate muscle rehabilitation of stroke patients by using an electric bicycle and applying FES to six leg muscles. The author implements a controller that seeks to minimize the minimum stimulation intensity required to follow a comfortable cadence. In this way, the controller activates the muscles in coordination only during the efficient moments of the cycle and activates the motor of the bicycle to supply the rest of the cycle.

Zhang [18] demonstrates the applicability to adapt the same type of NMES electrostimulation that we intend to use. The study implemented the Iterative Learning Control (ILC) algorithm with a musculoskeletal model to calculate the stimulation required to perform the knee extension movement. The only data used was acquired by a goniometer sensor positioned between the thigh and calf to extract the knee angle. The same author also implements an algorithm to measure muscle fatigue and reduce the power of FES using data from an EMG sensor [19]. The study uses nonlinear models to measure fatigue and a Kalman filter on the EMG signal to separate different muscle contractions.

C. *Wearable sensors*

Wearable devices have the advantage of being essentially portable. In a review [11] of wearable healthcare systems, the technology is considered capable of changing the traditional methods of diagnosis, bringing innovation to medical devices. The study raises the importance of using ML and big data analytics on the data produced by wearable devices. The search for user health patterns can provide more accurate health monitoring and diagnosis, such as systems that automatically trigger warning alarms by processing daily user data.

A review [20] was conducted to understand the work that uses biomechanical data to classify KOA through ML algorithms. The study shows a variety of sensors being used for data acquisition, such as ground reaction force, IMU, EMG, and goniometer. The paper reports that several authors have been able to classify pathological progression using ML with reasonable accuracy. This study contributes to understanding which parameters may be more relevant in our problem, mainly because the KOA is a suitable study object with similar symptoms of functional impairment.

EMG and IMU sensors stand out in the literature as most relevant for our study for several reasons. The EMG has already been used to classify the KOA and to limit the electrostimulation

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current considering fatigue. This sensor can provide information about the volume of contraction and muscle tension, which is essential for fine-tuning the NMES, as already seen. The IMU sensor stands out because it can collect the movement produced by the patient. This way, we can measure if the movement increases during the treatment, consequently improving the functional capacity. For example, increasing the amplitude in the knee extension angle represents an improvement in flexibility and muscle strength.

Therefore, the literature review indicates that performing NMES treatment using a wearable system in the patient's home may be more appropriate. In addition to reducing the number of patient visits to the clinic, it also provides a treatment that considers individual muscle responses.

III. SYSTEM ARCHITECTURE PROPOSAL

The system architecture was designed to meet the requirements of home treatment for muscle rehabilitation through a wearable system. The architecture is divided into three layers that ensure continuous communication between the patient and the systems. The first layer refers to Wearable system, which collects sensor data and applies electrostimulation protocol; the middle layer is the mobile app, which serves as an interface for the patient, receiving and sending data between the wearable and the cloud applications; finally, the third layer refers to the cloud, where three APIs of the proposed system are found.

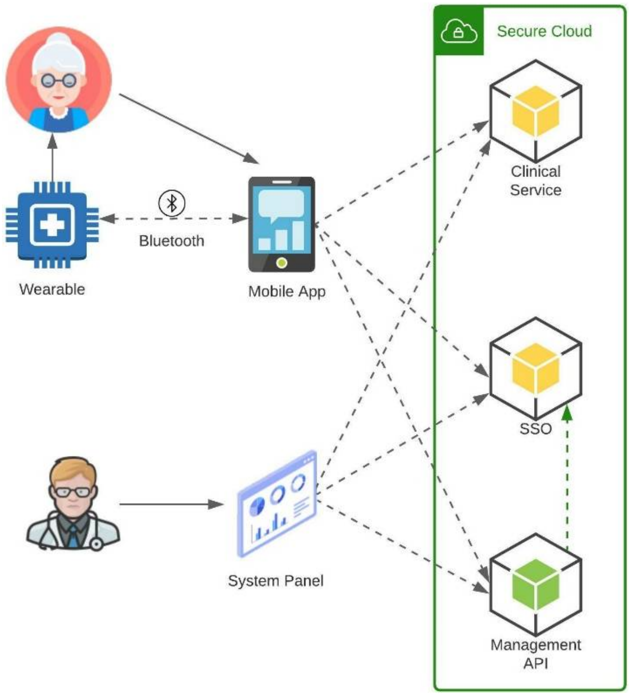

Figure 1. System architecture.

The Clinical Service stores and processes patient clinical data, such as stimulation parameters and biofeedback collected by wearables during sessions. The management API stores personal data such as patient names and addresses. Single Sign-On (SSO) is an access manager and token generation service. This data division seeks to minimize cyberattacks, making it difficult to correlate the patient's name with their response to treatment. In addition, it also centralizes the relevant information for data analysis in the Clinical Service, thus facilitating access to the development of ML models.

The diagram in Figure 2 demonstrates how the services will communicate to adapt electrostimulation during the treatment session. The NMES controller and the Acquisition System belong to the same system integrated into the wearable.

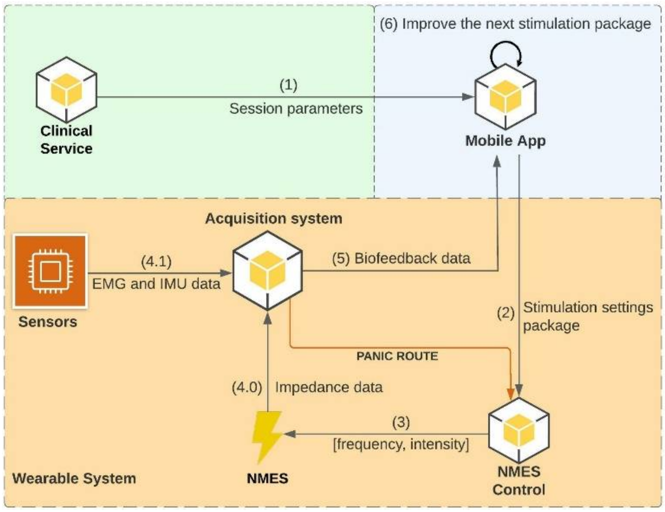

Figure 2. Steps for adapting electrostimulation during treatment sessions.

The proposed treatment for muscle rehabilitation starts with (1) the Clinical Service sending the parameters of the electrostimulation session to the mobile app. (2) The mobile app divides the stimulation session by time, thus sending only a few seconds of treatment per packet to the Wearable System. (3) The NMES controller receives the commands and activates the electrodes with the requested intensity and frequency. (4) The acquisition system starts receiving skin impedance data and sensors data. After a certain period, (5) the Acquisition system sends the data via Bluetooth BLE to the mobile app. Finally, (6) the mobile app analyzes the data received and adapts the instructions for the next electrostimulation package.

The system remains in a loop between steps 2 and 6 during the entire treatment session. Treatment can be stopped by the panic route or by the patient at any time. When the session is over, the patient will respond to a short feedback form about their condition. Finally, the data will be sent to the cloud and made available to the physiotherapist to analyze and modify, if necessary, the treatment protocol for the next treatment sessions.

IV. DEVELOPMENTS AND FUTURE WORKS

The electronic wearable is in the design phase. An article [21] has already been published testing the device's ability to collect the EMG signal and apply an electrostimulation protocol simultaneously during a treatment test.

The next step will be the addition of two IMU sensors to collect the knee extension angle. The first IMU sensor will go on the wearable positioned on the patient's thigh with the EMG sensor and NMES. For the second IMU sensor, it will be necessary to develop a second wearable, less complex, to be

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placed on the patient's shin and provide the necessary reference to complement the angle information. A similar system has already been developed in the literature. The article [22] demonstrated how to use IMU sensors and low-cost controllers to acquire the knee flexion angle.

The proposed system architecture is under development. So far, the minimum operating requirements for all system architecture modules have been implemented. An article [22] was published detailing how the architecture works and clarifying the sensitive data protection strategy. In the paper, the architecture was able to store the EMG sensor data from a simulated treatment session. This data was processed to produce a graphics of muscle contraction moments during treatment. Subsequently, the study on the extraction of EMG parameters will be deepened to elaborate more on graphics. Thus, it is expected to provide relevant information for the physiotherapist to analyze the response of patients to the proposed treatment.

The work described in this article is the main contribution of a Ph.D. in Informatics developed at the University of Minho, Portugal. Since its inception, approximately one year, this study has expanded and reached its milestones, but the challenge of clinical trials in patients still requires a few more steps. The focus is directed to the development of a dataset using the proposed system with healthy people to verify the accuracy of the data acquired. From this dataset, it is also intended to study the change caused by electrostimulation in the EMG signal. And with this, to develop methodologies to extract and categorize the parameters of voluntary contraction.

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