Human Interface for a Neuroprothesis Remotely Control

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Abstract: Neuromuscular Electrical Stimulation (NMES) and Surface Electromyography (sEMG) have been widely explored by the scientific community for the rehabilitation of individuals with motor deficits due to stroke. The literature shows the benefits of sEMG-activated NMES use in both motor rehabilitation and neural plasticity stimulation. Currently, there is a strong tendency to expand the clinical environment, and the internet can be used by healthcare professionals to do detailed follow-up and interact with their patients remotely. This work presents a neuroprothesis activated by sEMG that allows configuration and monitoring of usage parameters remotely. Two control platforms were developed for different user profiles; health professionals (Web Interface) and neuroprosthesis users (Smartphone Application).

1 INTRODUCTION

Stroke consists of a neurological deficit that occurs when there is a lack of adequate blood flow in a particular brain region, either by obstruction (ischemic, of 85% of the cases) or by rupture (hemorrhagic) of the vessels resulting in a cerebral infarction (Sacco et al., 2013). As a consequence, spasticity as a change in skeletal muscle control, caused by an imbalance of signals from the Central Nervous System to the nerve endings of muscles, and a muscular hypertonia are verified. As an example, the flexor pattern of the elbow, wrist and fingers is a commonly observed condition in these individuals, which makes it impossible to perform ordinary everyday tasks that use the movement of these joints independently, such as combing the hair, brushing teeth, typing in keyboard of a computer, etc. (Carmo et al., 2015).

Approximately 15 million people worldwide have a stroke each year; even where advanced technology and facilities are available, 60% of those who suffer a stroke die or become dependent, causing immediate and devastating changes both in their lives and those closest to them. Although the incidence of stroke is declining in many developed countries, the absolute number of strokes continues to increase because of the ageing population. By 2050, the proportion of the world's population over 60 years is estimated to be 22% reaching 2 billion, 80% living in low- and middle-income countries (Mackay and Mensah, 2004a,b; WHO, 2015). It is important that such care is taken to control, prevent and manage these events.

The techniques for rehabilitation of individuals with motor deficiency, due to Stroke, are widely explored by the scientific community. The Neuromuscular Electrical Stimulation (NMES) is a widely used technique in rehabilitation of individuals with motor dysfunctions. Over the years, works such those developed by Kralj et al. (1993), Hara (2008), Shin et al. (2008), Lin and Yan (2011), Hu et al. (2012), Meadmore et al. (2013) and Hara (2013) have demonstrated the effectiveness of this technique for reduce the time needed to re-establish patients' condition from a stroke.

Kralj et al. (1993) showed that, since the 1970s, a NMES have been applied as a therapeutic means of effective treatment to improve the range of wrist and finger extension motions and to prevent the contractures caused by flexor spasticity. Hara (2008) and Hara (2013) presented a home-based rehabilitation program with power-assisted FES. However, the system did not allowed configuration and monitoring of usage parameters remotely by health professionals. Instead, patients received training for equipment configuration and electrode positioning and the exercise protocol that they should accomplish. However, they attained, using a multi-channel near-infrared spectroscopy (NIRS) study, a greater cerebral blood flow

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during an EMG-controlled NMES therapy. Shin et al. (2008) showed, in a random experiment, that the use of an EMG-triggered NMES to the wrist extensor for two sessions (30 min/session) a day, five times per week for 10 weeks could results in a significant improvement of motor function and also in a reorganization of the sensorimotor cortex. Lin and Yan (2011) also applied NMES with sessions in the same frequency, but for a period of only 3 weeks. They observed not only significant improvement of motor functions, but also the maintenance of it for at least 6 months. Promising results were also achieved by Hu et al. (2012) using an EMG-driven electromechanical robot system integrated with NMES and by Meadmore et al. (2013) using a multi-channel NMES system in goal-orientated tasks.

Other studies confirm that this practice not only promotes functional recovery but also stimulates the process of neurogenesis, that is, the sequence of events leading to the formation of the nervous system after traumatic events that may have damaged it (Huang et al., 2015). The effects depends on the severity of the impairments, the time since stroke, the intensiveness of the NMES use and more than this the chalenges for the Nervous System. However, there is a trend towards the advantage of sEMG-triggered NMES over cycling NMES, a better motor enhancement due to task-oriented training, and patients retaining some degree of finger extension tend to shift towards a focused activity in the ipsilesional cortical site after NMES induced activity, whereas patients who did not regain finger extension showed enhanced involvement of the contralesional cortical site (Kempermann et al., 2000; Rushton, 2003; Schaechter, 2004; Shin et al., 2008; Quandt and Hummel, 2014).

In addition, a strong tendency to expand the clinical setting for treatment of individuals may be noted in recent years (Piron et al., 2004, 2009). The literature presents works such as Zhang et al. (2008) and Buick et al. (2016) in which the Internet allows healthcare professionals to make detailed follow-up and interact with their patients remotely from their homes.

Based on this context, this work presents a neuroprothesis activated by sEMG that allows configuration and monitoring of usage parameters remotely. Two control platforms were developed for different user profiles; health professionals (Web Interface) and neuroprosthesis users (Smartphone Application).

2 MATERIALS AND METHODS

2.1 Neurostim

Neurostim is a custom made neuroprothesis, based on the application of Neuromuscular Electrical Stimulation (NMES) with surface electrodes activated by surface myoelectric signal (sEMG). Its use aims for the rehabilitation of the upper limbs (hands and wrists) of patients with hemiplegia due to stroke. Both NMES and sEMG technologies are widely known, widespread and used in the clinical area.

The differentials correspond to the proposal of daily use in the home environment, and for this purpose two control platforms was developed; one for the user of the neuroprosthesis and another platform for remote monitoring, allowing the health professional to communicate with the device and to configure the parameters of use, physiotherapy programs, and flow monitoring.

2.2 Interface for the Neuroprosthesis User

The user interface, in the form of a Android smartphone application was developed using Android Studio 2.3.3 is meant to be installed in Android versions 4.0 and superior. The application has the primary purpose of configuring and controlling the neuroprosthesis with the necessary instructions so that, with the use of electric current, the extension of wrist and fingers is promoted when the intent of movement by the user is captured via sEMG.

As a secondary objective, the application should be able to become a communication channel between the user and the healthcare professional responsible for the rehabilitation program so that, adjustments of the parameters of use and information sending about the usage can be done remotely through the internet.

Users who will be using the application have been victims of a stroke. As a consequence, the motor functions of one side of his body were affected, causing them to partially lose the movements of the wrist and fingers. In the smartphone applications, users must be able to:

- Use the neuroprosthesis simply and comfortably
- Use a smartphone application that has a simple interface and allows navigation between features with only one hand, which is possibly the non-dominant hand.

Functionalities and tasks to be performed in the application include:

- Log in to a profile that saves personal information about your device's usage Screen Layout
- Pair the neuroprosthesis with the application to be able to communicate and exchange data
- Consult historical information on past uses of the neuroprosthesis
- Choose mode of operation: rehabilitation program or functional mode
- Setting the parameters of Intensity of stimulation of neuroprosthesis
- Configure sEMG threshold parameters of neuroprosthesis activation
- Start the operation with exercises or daily activities
- Reconfigure the parameters, if necessary, during use
- Send the data collected by the neuroprosthesis in an automatic and transparent way to the healthcare professional responsible for their rehabilitation program
- Receive updates of usage parameters from the neuroprosthesis in an automatic and transparent way, to be able to adapt the usage of the device according to its evolutionary framework during the rehabilitation program

  All data must be stored locally, specially if the smartphone does not have an internet connection at the end of procedure and synchronization can not happen at that time (will be trigger later on whenever a stable connection is available).

2.3 Interface for the Health Professional

The interface for the health professional consists of a web platform programmed in HTML5, PHP and JavaScript to analyze and interact remotely with the neuroprosthesis. The web interface should be able to become a two-way communication instrument with the neuroprotesis, promoting the necessary information to configure its use, as well as an instrument of interaction between the user and the health professional and data analysis. By synchronizing the captured neuroprosthesis data on the respective smartphones, the healthcare professional will get the device's usage history information so progression analysis from a clinical standpoint can be done and remotely perform the necessary adjustments, as all the data will be stored in a MySQL database.

The web interface must become a bi-directional communication instrument with the neuroprosthesis, promoting, through data packets, the necessary configurations so that, with the use of electric current, the extension of wrists and fingers can be promoted when the intention of movement by the user is captured via sEMG. The interface should also be able to become an instrument of data analysis and interaction between the user and the healthcare professional responsible for the rehabilitation program so that, adjustments of the parameters of use and the sending of information about the use can be done remotely.

The interface should be able to configure the neuroprosthesis to the most diverse types of user characteristics. For this, a database will store the parameters referring to each patient and their respective neuroprosthesis. When patients synchronize information with their smartphones, the healthcare professional will get historical devices usage information so that, analyzes of the clinical picture progression can be made and the necessary adjustments are made remotely.

Users who will use the web interface are healthcare professionals responsible for the rehabilitation program for patients who have been victims of a stroke. With the Web Interface, they must be able to:

- Log into a profile that has saved your personal information using the interface

  With the users of the neuroprosthesis under their responsibility registered
- Be able to register new users under your responsibility

  Name
  Last name
  Age
  E-mail
  Social Security Number
  General address data
  Contact
  Patient ID
  Rankin Scale score
  Diagnosis
  Responsible Health Professional ID
- Edit the existing user registry under their responsibility
- Configure the neuroprosthesis remotely

  Rise Time
  Down time
  Plateau Time
  Activation threshold of sEMG
  Intensity of the stimulus
  Execution time or number of repetitions
  Frequency of stimulus

- Analyze the usage data history sent from the smartphone to the cloud database, shared between both applications in a web interface
    - Dates of use
    - Time of use
    - Repetition count
    - Sampling of sEMG sensor readings
    - Time stamp of user parameter changes
- Set remotely usage schedule for configurable parameters

  Relevant information can be printed and exported from the web interface to further analysis on complementary software, whenever is needed.

3 RESULTS

3.1 Neurostim

Neurostim uses an ATmega32u4 (Atmel Corporation) microcontroller to produce symmetrical biphasic constant current pulses with fixed frequency at 20 Hz, two pulse width options 300 μs and 600 μs, and adjustable amplitude from 0 to 40 mA (resistive load of 1k Ω). These parameters have already been studied by the scientific community and are considered to be the most adequate for obtaining muscle contraction patterns (Quandt and Hummel, 2014).

The stimulator is small in size and attached to an armband where there are also the electrodes needed for stimulation and sEMG, with the possibility of relocation of position to allow customization and personalization according to the individualized motor response. The stimulation electrodes are conductive rubber.

The triggering of the stimulation depends on an initial effort of the user captured by a sEMG device called MyoWare (Advander Technologies LCC), defined through the configuration of a threshold of the myoelectric signal. Once the threshold is reached, the stimulation is triggered, following an increase in the amplitude of the graded stimulus to the configured maximum (ramp modulation), remaining for the pre-established time and then ceasing, also with the gradual decrease of the stimulus. A new cycle will only be started if the threshold of the sEMG signal is again reached.

3.2 Interface for the Neuroprosthesis User

Upon start, the application synchronizes all data available at the server side for the logged in user. All information regarding historical data and agenda of usage will be available for consult, as shown in Figure 1. Depending on the setups made by the health professional, the user will have the possibility to choose between modes of operation, maximum intensity, etc.

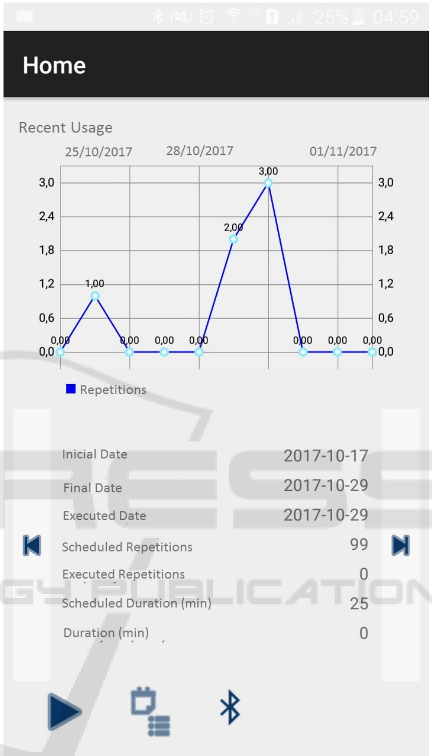

Figure 1: Application screen showing historical usage data.

The communication with the smartphone application is made through Bluetooth using the nRF51822 (Nordic Semiconductor) module, where the device can receive and send information in real time according to the setups made on the app (change of threshold and intensity by the user), as shown in Figure 2.

3.3 Interface for the Health Professional

User can login with its credentials at the login page, having access to the list of all the patients under its responsibility as shown in Figure 3. Whenever is needed, new patients can be added.

For each patient, the health professional can setup an agenda containing the usage parameters according to the rehabilitation program strategy, as shown in Figure 4.

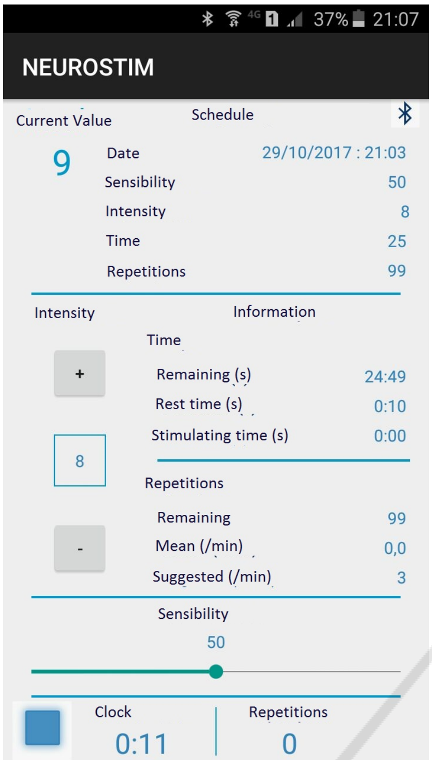

Figure 2: Application screen showing the control functions and readings from the neuroprothesis.

Also, the health professional can visualize data from all the procedures executed by each patient. Information regarding sEMG and usage parameter will be shown in a graph (Figure 5), along with a summary with relevant information about the respective procedure (Figure 6).

Relevant information can be printed and exported from the web interface to further analysis on complementary software, whenever is needed.

3.4 Interfaces and System Evaluation

While awaiting the approval of the ethics committee to perform the usability and clinical performance evaluation of the system, a pilot test was performed to verify if users are able to use the interfaces and if the data storage and communication are well performed. Results were as expected, where an user was able to successfully control the neuropothesis, as well as retrieve and send data to the server on the cloud containing usage setups and procedures informations automatically. Additionaly, another user was able to successfully setup remotely the neuropothesis, as well as retrieve data containing usage setups and procedures information automatically so further analysis and adjustments could be done without having the patient physically present to do so.

4 CONCLUSION

The neuroprosthesis should be versatile enough for the user to feel comfortable using it as a physiotherapeutic element either in the rehabilitation program, or in a functional way to assist in daily tasks. The effectiveness of user interaction is a key to device acceptance.

The smartphone application was developed in a way that simple interfaces allow the patient to perform all expected activities with ease, preventing errors during the stimulation procedures and avoiding non expected behaviors from the electric stimulation.

The web interface was also developed so the health professionals can have significant information about usage and perform analysis to execute eventual adjustments to maximize effectivity to patients treatment.

As the next steps usability and clinical evaluations trials will be performed.

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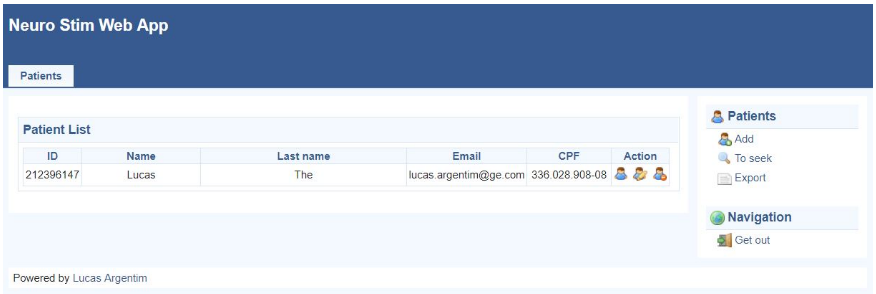
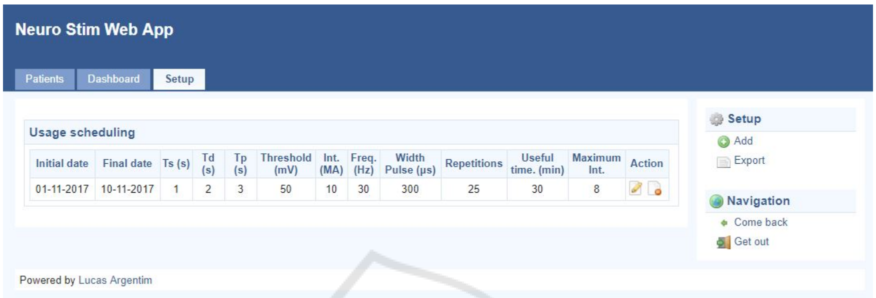


ID	Name	Last name	Email	CPF	Action
212396147	Lucas	The	lucas.argentim@ge.com	336.028.908-08	

Figure 3: Web application screen showing list of Health Professionals patients.



Initial date	Final date	Ts (s)	Td (s)	Tp (s)	Threshold (mV)	Int. (MA)	Freq. (Hz)	Width Pulse (μs)	Repetitions	Useful time. (min)	Maximum Int.	Action
01-11-2017	10-11-2017	1	2	3	50	10	30	300	25	30	8	

Figure 4: Web application screen showing usage parameters agenda for a patient.

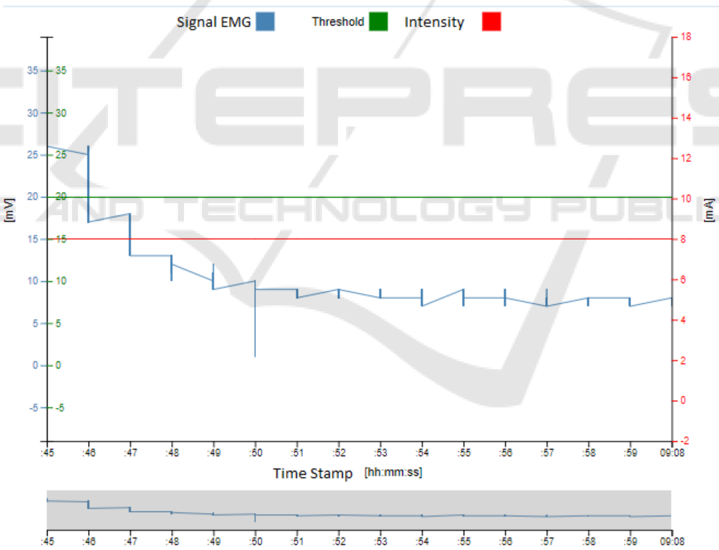


Figure 5: Web application screen showing sEMG and usage information of a procedure.

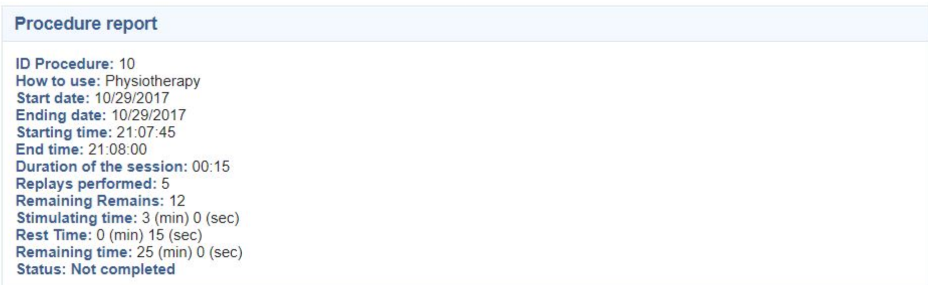


Figure 6: Web application screen showing summary information of a procedure.

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