Electromyography Controlled Functional Electrical Stimulation Data Acquisition System for Leg Rehabilitation

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Abstract: This study aims to develop a device that will help in the physical leg rehabilitation. The usage of functional electrical stimulation (FES) for rehabilitation is a relatively new practice in the Philippines, therefore acquiring data for a baseline study on the use of a device utilizing electromyography (EMG) and FES is important in upgrading the methods used in rehabilitation. The device incorporates flex sensor, EMG and FES which is controlled by an Arduino microcontroller. It aims to electrically stimulate the muscles needed on ankle dorsi-flexion, plantar flexion and knee extension flexion movements. The flex sensor acts as the trigger unit for the electrical stimulation. Acquired EMG signals will determine the level of stimulation of the FES. Using this system, the researchers intend to determine the effectiveness of using this device in the physical leg rehabilitation.
Example: FNH_Santos_J.C_full paper
WCF_Cruz_N.T_Paper2_full paper
HCT_Vidal_M.R_Paper1_version2_full paper

Key Words: flex sensor; microcontroller; real-time monitoring; surface electromyography (EMG)

1. INTRODUCTION

1.1 Subsection

Throughout the world, there have already been numerous technological researches in the field of physical rehabilitation. In first world countries, therapists are already using robotic and muscle stimulation technologies that leads to shorter rehabilitation time [1]. However, in the Philippines it is a continuous struggle to deliver optimal rehabilitation specially to stroke victims. [2]. Physical therapy aims to give the patient total independence despite having disabilities through physical training and therapy. Some of the improvements in the field are the use of electric muscle stimulants specifically Functional Electrical Stimulation (FES) and Electromyography (EMG) which measures the electrical activity of the muscles [3]. Individually, EMG and FES were already proven to effectively improve the rehabilitation of stroke patients. Integrating both of them together in rehabilitation can yield to promising results [4]. Using electromyography in combination with functional electrical stimulation determines the level of stimulation needed from the remaining voluntary muscular function according to the desired motion of the user which allows for a device to be developed [5].

2. DESIGN

The device is composed of three major components: electromyography, functional electrical stimulation, and flex sensor . The three components are connected using a microcontroller Arduino MEGA 2560.

2.1 Electromyogpraphy

The MyoWare muscle sensor was used to acquire the EMG signals. It is an EMG sensor from Advancer Technologies powered by the Arduino microcontroller and is composed of a board that measures rectified and filtered muscle signal. The output is in volts, depending on the amount of muscle activity from the targeted muscle [6]. The board comes with stackable shields that help in the overall functionality of the sensor. The board can be powered using an LED shield or a power shield. The LED Shield is a blue colored 10-segment bar graph used to show the magnitude of the measured EMG signal which acts as a visual indicator of the filtered signal obtained from the sensor [7]. An isolation amplifier soldered on a proto were also added to protect sensitive devices like the EMG from electrical noise [8][9]. For hygienic purposes and ease of use, surface electrodes are recommended. Silver/silver chloride (Ag/AgCl) are pre- gelled disposable electrodes sized about 1cm or smaller (diameter). A good advantage of this type is that adhesive gel electrodes can easily be repositioned in case of errors, fit for testing purposes [10].

2.2 Functional Electrical Stimulation

FES devices have two distinct parts; a microcontroller and a stimulator. The microcontroller allows the programming and control of the different parameters of the stimulator [11]. The stimulator is the source of the electrical impulses. Stimulator output circuits are either voltage or current controlled. The researchers designed a two (2) channel MOSFET circuit with signal LEDs based from a study conducted by Breahna [12] as the stimulator circuit. The stimulator circuit has a power supply of 18V and the MOSFET used is an IRF520 N channel mosfet in switching configuration, while the microcontroller supplied the programmed stimulation criteria based on the EMG signal measured. The microcontroller was also responsible for the pulse width modulation and generation. The frequency of stimulation will depend on the EMG signaled measure from the subject and will thus range from 16-50Hz to cater to both low and high frequency stimulation for leg (16-30 Hz for low; 20-50 Hz for high). The effective duration was set to 10-50ms to allow the saturation of the stimulation and activation of targeted muscles.

2.3 Flex Sensor

The flex sensor is used to determine the correct timing of stimulation during the procedure. A flex sensor is placed either on the ankle or the knee of the patient depending which muscle is to be rehabilitated. The flex sensor bends as the person performs ankle dorsiflexion-plantarflexion and knee extension-flexion movement. The resistance measured as the sensor bends determines the angle displacement. The angular values measured is to be compared with the threshold values set in the program, and when met triggers the FES to start or stop generating electrical pulses [13].

2.3 Microcontroller

Arduino MEGA 2560 is used as the microcontroller to process and program all the sensors and components in the device. It is the main brain of the device incorporating the EMG and flex sensors to control the level of stimulation and timing of the FES. The acquired EMG values by the microntroller are compared with the threshold values set in the program that will then determine the level of stimulation of the FES. The frequency value of the FES varies according to the range of EMG values set as threshold values on the program. If the EMG values measured differs from the threshold value, FES will stimulate with varying frequencies accordingly. Moreover, the microcontroller also processes the flex sensor for the right timing of stimulation of the device. Arduino MEGA 2560 set the flow of the device which starts from acquiring EMG values and angle displacement from the patient to determine the proper timing and level of stimulation of the FES. MATLAB is also used to generate a real-time graph of the EMG. MATLAB has a support package for Arduino that enables the MATLAB to interactively communicate with the Arduino board to make a real-time graph.

3. EXPERIMENT SETUP

Five healthy individuals were considered as participants in the experimental study. They were aged 18-25 years old with no history of any knee or ankle pathological condition. All subjects were able to walk without support and can stand from a seated position. The benefits and risks of participating in the study was disclosed to each subject, and each subject signed a written consent form. Only five subjects were considered since the primary purpose of the study is to develop a feedback control mechanism of FES using EMG signals for data acquisition to be used as baseline data for further development of leg rehabilitation.

A total of eleven (11) experiments were conducted in this study. The first three experiments were to test if the three components: EMG, FES, and flex sensor are working correctly. The next set of experiments acquired the EMG signals of the test subjects in their normal and fatigued states while performing knee extension, knee flexion, ankle dorsiflexion, and ankle plantarflexion. It can be seen that after performing a set exercise for the gathering of the fatigued subject's data, there is a decrease in the EMG values and an onset of noise as the subject begins to struggle to perform the movement. Another set of experiments were conducted to test the deviceon their normal and fatigued states while performing knee extension, knee flexion, ankle dorsiflexion, and ankle plantarflexion. The test subjects were asked to answer a series of question to quantify the level of sensation felt and describe the feeling while being stimulated.

4. RESULTS AND DISCUSSION

A trend can be seen from the experiments that involved the measurement of the EMG signal gathered. Healthy EMG signals from all test subjects show good muscle responses. However, with the onset of fatigue, EMG signals tend to drop and decrease in value. Additionally, EMG noise artefacts have been observed as the test subjects begin to struggle to perform the movement required. Figures 1 and 2 shows the difference between EMG signals from same motion of healthy and fatigued patients.

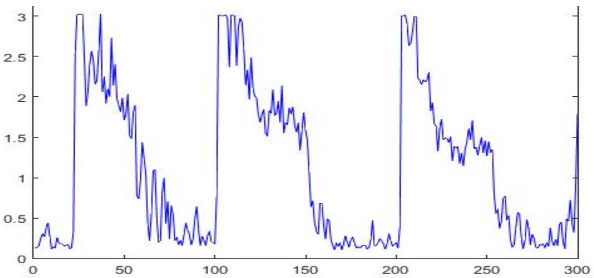

Fig. 1. Ankle Plantarflexion EMG Signal – Healthy Patient

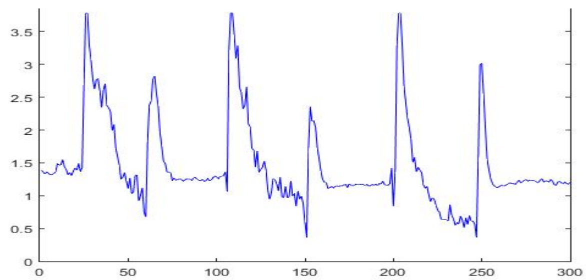

Fig. 2. Ankle Plantarflexion EMG Signal – Fatigued Patient

The correlation between the EMG signal measured and the amount of stimulation can be observed from the qualitative analysis gathered from the test subjects (Table 1 & 2). The healthy subjects in their normal state received a level of stimulation ranging from 20-50 Hz. This means that an instantaneous pulse of stimulation is only needed as the test subject can perform the required movement with ease. High frequency muscle stimulation has been shown to increase muscle activation times from previous studies. For the healthy subjects in their fatigued state, the level of stimulation would typically range from 16-30 Hz. Lower frequencies tend to penetrate deeper into muscle groups and the stimulation pulse would create a much larger action potential due to the spread of the stimulation. Therefore, the test subjects found it easier to perform the required movements.

Table 1. ANKLE PLANTARFLEXION (HEALTHY STIMULATION)

	Level of stimulation felt	Pain felt during stimulation	Comments
Subject A	4	NO PAIN	Little contractions
Subject B	1	NO PAIN	None
Subject C	4	NO PAIN	Tingling sensation; Less numbing felt when trying to raise foot to perform plantarflexion
Subject D	5	3	Massage like tingling; Relaxing; Sensation of soft ticklish touch
Subject E	3	NO PAIN	None

Table 2. ANKLE PLANTARFLEXION (FATIGUED STIMULATION)

	Level of stimulation felt	Pain felt during stimulation	Comments
Subject A	5	NO PAIN	Little contractions
Subject B	1	NO PAIN	Tingling sensation
Subject C	3	NO PAIN	Feels muscle contracting; Easier to move muscle even if tired during the stimulation
Subject D	2	1	Pinching feeling; Numbing and weak
Subject E	3	NO PAIN	Tingling sensation; Easier to move while leg is being stimulated

5. CONCLUSIONS

Based from the data gathered and analyzed from the test subjects, an EMG-FES system has the potential to open up new techniques in physical rehabilitation A flex sensor was implemented to trigger the start and end of the electrical stimulation procedure. The angular displacement measured by the flex sensor enables the device to detect what type of movement is being done. Based on the movement of the leg muscle the electrical stimulation will be triggered. Then by measuring the EMG signal of the patient intention of movement can be detected therefore triggering the FES to aid in completing a full functional movement. The device enables varying levels of stimulation based on the EMG values acquired which can help target specific muscles and activate them at the precise time needed to move. This can also prevent intense muscle fatigue due to forced activation of the muscle after using the device.

The results of the experiment show a promising potential of EMG-FES on the rehabilitation of stroke patients. The device was able to increase the motor function of the healthy individuals especially in their fatigued state making it easier to move the targeted muscles thus having a potential as a rehabilitation technique. It still has along way before we can use the device on a clinical setting, but according to therapists from St Lukes Medical Center, the data obtained for the base-line study was shows promising results and opens up opportunities for more research in the development of EMG-FES rehabilitation devices.

5. REFERENCES

M. S. K. P. R. M. W. D. a. L. D. Anthea Rhoda, "Motor and functional recovery after stroke: a," BMC Health Services Research, vol. 14, no. 82, 2014.

"St. Luke's Medical Center Saves Stroke Patients with Organized Brain Attack Team," St. Luke's Medical Center, [Online]. Available: http://www.stlukesmedicalcenter.com.ph/newsroom/pressrelea se/92. [Accessed 25 June 2014].

S. Huff, "Electromyography," 3 August 2012. [Online]. Available: http://www.emedicinehealth.com/electromyography_emg/pag e6_em.htm#author_ and_editor. [Accessed 14 August 2014].

Y. Hara*, "Rehabilitation with Functional Electrical Stimulation in Stroke Patients," International Journal of Physical Medicine & Rehabilitation, vol. 1, no. 6, pp. 1-6, 2013.

A.M.U.A.M.B.S.M.A.C.M.M.A.Crema,"Ahybrid tool for reaching and grasping rehabilitation: the ArmeoFES," in 33rd Annual International Conference of the IEEE EMBS, Boston, Massachusetts, 2011.

S. Electronics, "MyoWare Muscle Sensor," 2016. [Online]. Available: https://www.sparkfun.com/products/13723. [Accessed 5 August 2016].

S. Electronics, "MyoWare LED Shield," [Online]. Available: https://www.sparkfun.com/products/13688. [Accessed 4 August 2016].

S. Electronics, "MyoWare Proto Shield," [Online]. Available: https://www.sparkfun.com/products/13709. [Accessed 4 August 2016].

P. D. Potter, "Application Note Isolation Transformers," 2014. [Online]. Available: http://www.leonardo- energy.org/sites/leonardo-energy/files/documents-and- links/cu0113_-_isolation_transformers_-_v3_0.pdf . [Accessed 4 August 2016].

P. Konrad, "The ABC of EMG," 2006. [Online]. Available: http://www.noraxon.com/wp-content/uploads/2014/12/ABC-EMG-ISBN.pdf. [Accessed 4 August2016].

T. B. a. M. Munih, "Basic Functional Electrical Stimulation of Extremities: An Engineer's view," Technology and Healtchare, vol. 18, pp. 361-369, 2010.

R. B. a. I. Turtureanu, "Functional Electrical Stimulation," in 2nd Int. Conf. on Nanotechnologies and Biomedical Engineering, Chisinau, Republic of Moldova, 2013.

R.Q.S.J.M.S.U.S.S.A.S.K.M.K.a.A.B.S.J.Khan, "Functional Electrical Stimulation (FES) Based Low-cost Assistive Device for Foot Drop – A Pilot Study," IFMBE Proceedings, vol. 56, pp. 113-117, 2016