MINIATURIZED WIRELESS CONTROLLED ELECTROSTIMULATOR

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Abstract: This project introduces a new approach to hardware and software controlled solutions in the electrical stimulation field. A miniaturized, portable and wireless electrostimulator was designed and its development steps and also a new perspective to control the stimulation parameters in real time are exposed in this paper. Our system allows the control and automation of the stimulation session with high flexibility and easiness, using a user-friendly interface for a computer or an Android platform, which communicates with the portable and wireless device. The hardware performance was tested with a skin electric model, achieving the expected results. The presented solutions have high applicability in the scientific and ambulatory electrostimulation context.

1 INTRODUCTION

The electrical stimulation is a technique widely used in research with contributions of high applicability in the clinical environment and the sports field. Combined with surface electromyography, this technique enables a better understanding of neuromuscular recruitment, exploring opportunities for study and development of protocols for performance evaluation and physical rehabilitation (Lake, 1992).

The electrical stimulation (ES) is a nervous activation generated by the application of low frequency electric current, which will produce a recruitment effect in the stimulated muscle group. The electrical stimulation can be applied directly on the muscle's surface, designed by electrical muscle stimulation (EMS), or in the nerve structure, designed by functional electrical stimulation (FES) (Bajd et al., 1999; Thrasher and Popovic, 1999).

The stimulation of a particular muscle group is controlled by frequency, amplitude and pulse width of the electrical current applied (Robertson et al., 2006; Cheng et al., 2004). Currently, the electrostimulator systems can be classified into two types: the open-loop system and closed-loop system. The first is characterized only by the stimulus control applied through the electrostimulator. The latter stands out not only for controlling the intensity, frequency and pulse width but also by the outcome evaluation of muscle response to stimulation. This assessment is made by processing the signal from sensors such as accelerometers, goniometers, gyroscopes and electromyography sensors (Zhang et al., 2007). The signals obtained with these sensors will enable the analysis and assessment of the muscle's recruitment response and, at the same time, provide feedback for the stimuli generation, adjusting the stimulus to its response. Despite the characteristics reported above, current systems that integrate electrostimulation usually have limitations in terms of usability and portability or in terms of control flexibility and synchronization. This paper exposes a solution to overcome these limitations by developing a miniaturized and portable electrostimulation device, capable of controlling the stimulation parameters with high flexibility and enabling synchronization with external devices.

In the following section the development of the electrostimulation system's hardware and control interface is described and we also depict the specifications and characteristics of this system. Section 3 will report and discuss the performance results of the system in a skin electric model. Section 4 concludes the work by stating its main contributions and exposing the advantages of the developed system.

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2 SYSTEM DEVELOPMENT

2.1 System Control

The hardware was designed and developed to allow greater flexibility in the stimulation control parameters. This implementation delegates the real-time control in an external application where it's possible to manipulate the entire stimulation protocol. The hardware architecture accepts the input commands from a computer or an Android Smartphone via bluetooth, raising new possibilities of portability and processing performance in the electrostimulation field. Currently, both designed interfaces allow the user to choose the frequency, duty cycle, amplitude in voltage and in current of the stimuli, as shown in figures 1 and 2. It's also possible to choose the channel and time of stimulation. In the customizable configurations of the application the user can choose a pulsed stimuli session.

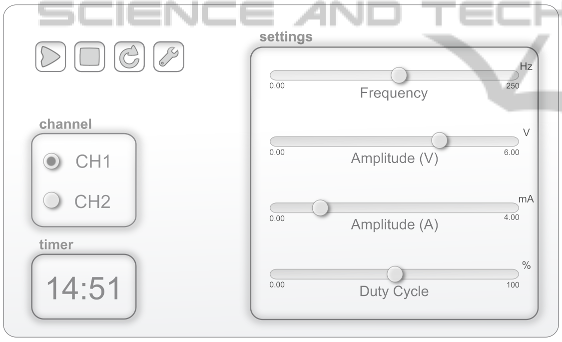

Figure 1: Computer interface scheme for stimulation session control.

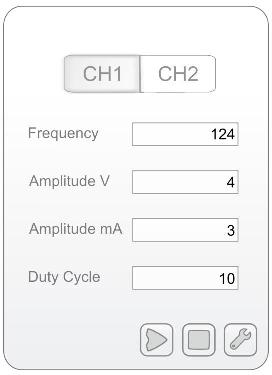

Figure 2: Android interface scheme for stimulation session control.

2.2 Hardware

In addition to the high control flexibility, the electrostimulator is developed in a real-time wireless data communication, low power consumption and high electromagnetic interference immunity guideline. The system hardware is internally divided into three modules, a digital, an analogue and a power module (as shown in Figure 3):

i) The digital module integrates the bluetooth communication module and the microcontroller. This module establishes communication with the control software, generates and controls the parameters of electrical stimulation - as the total time of stimulation, frequency, duty cycle and amplitude;

ii) In the analogue module the stimulation signal is processed and amplified to guarantee the desired power voltage and current;

iii) The power module supplies the analogue and digital modules. This module also controls the battery level and charging cycle. Whenever it is connected to supply voltage produces the decoupling between the supply and the stimulation circuit, protecting the user.

2.3 Specifications and Characteristics

The device presented is a miniaturized and portable system with 6.5 x 10.5 x 1.9 cm dimensions. It has two independent channels for stimuli output and in order to be able to work as a closed-loop system, it also has a synchronization port that allows real time communication with a signal acquisition system, such as the bioPLUX system (PLUX, 2011), which enables the measurement of the muscle response to the stimulus induced. Figure 4 presents a scheme of the systems communication.

The current version of this electrostimulator enables the generation of 0-250Hz frequencies with a resolution of 16 bits. The amplification module ranges from 0-6V in voltage and 0-4mA in current. The hardware performs the automatic adjustment of the voltage value if it is in constant current mode, or current if it is in constant voltage mode. The ranging values that the system allows are still too low for the application of surface electrical stimulation in humans but have high applicability in invasive applications with, for example, experimental rats where the supra-maximal tension of their nerve is 3mA. The next development step is the adaptation of the existing amplification module for human non-invasive application.

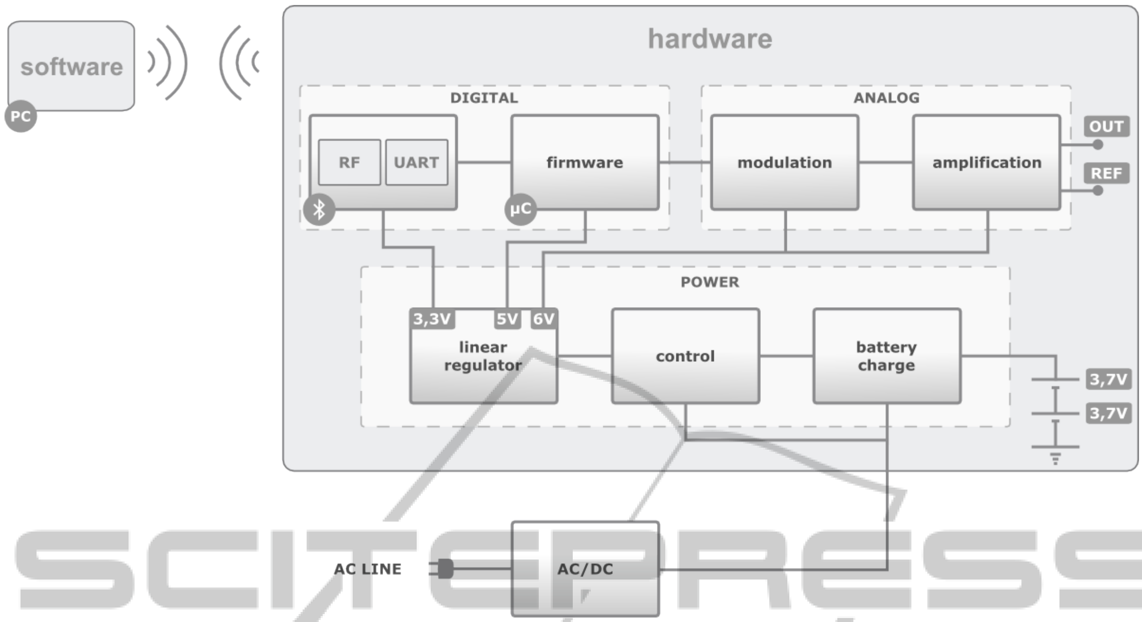

Figure 3: Hardware schematics.

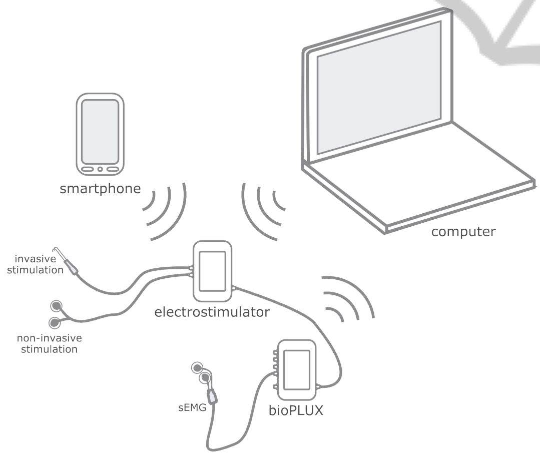

Figure 4: Illustration of the system communication and control flexibility. Example with invasive and non-invasive electrostimulator.

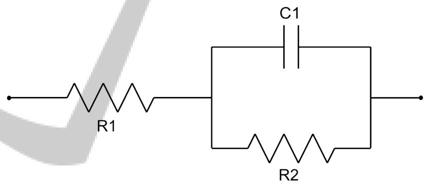

Figure 5: Skin impedance model. From (Dorgan and Lake, 1999).

Table 1: Current variation vs load variation in constant current mode.

Resistance (kΩ)	Current (mA)	Tension (V)
1.72	3.00	5.20
1.29	3.00	3.90
0.99	3.00	2.90
0.72	3.00	2.20
0.25	3.00	0.80

3 SYSTEM PERFORMANCE

To evaluate the current and voltage automatic regulation, we tested the circuit with a skin impedance model (Figure 5). In this model, the resistor R1 models the constant resistance components of the skin and deep tissue resistance. The R2 resistor, with C1 capacitor in parallel, represents the nonlinear dynamics of the skin impedance (Dorgan and Lake, 1999). The advantage of a voltage and current regulation is that we surpass the variations of the tissues galvanic resistance which are being stimulated, ensuring the same current or tension.

To test the constant current mode we programmed a unipolar square wave stimulation pulse with 3mA and variate the model resistor, monitoring the tension and current variations. In table 1 we report the results obtained in the constant current mode.

The same approach was used to test the constant voltage mode. A unipolar square wave stimulation pulse with 3V of amplitude was programmed and we varied the model resistor while the peak-to-peak voltage and current values were acquired. In table 2

Table 2: Voltage variation vs load variation in constant voltage mode.

Resistance (kΩ)	Current (mA)	Tension (V)
1.80	1.67	3.01
1.50	2.00	2.97
1.31	2.30	3.05
1.19	2.53	3.01
0.82	3.64	2.93

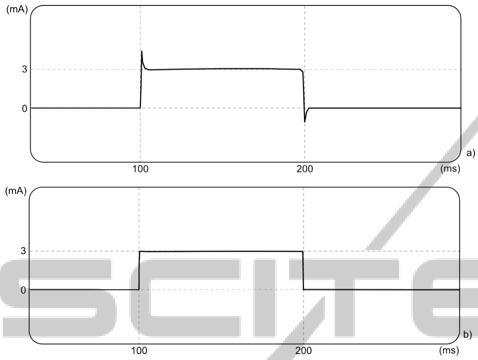

Figure 6: Effect of the skin nonlinear dynamics represented by the C1 capacitor: a) With C1=1μF; b) Without C1.

we report the results obtained in the constant voltage mode.

As it was expected, in constant current mode the voltage varies to equalize the variation in the resistance, keeping the applied current constant.

The same effect, but now applied in the current is verified in the constant voltage mode were the current compensate the resistance variations keeping the applied voltage in the desired value. In constant voltage mode, the system can't keep the voltage regulation for load values bellow 750Ω, because the system is currently limited to 4mA.

The implementation of this model enabled the evaluation of the effect of the skin impedance nonlinear dynamics. For values of C1 higher than 1 μF we observed an overshooting effect which can exceed about 20% the programmed current value. This effect is exposed in Figure 6, which shows the signal of current corresponding to a square wave of 2Hz and 3mA of amplitude with and without the C1 effect.

With this study we evaluated the constant current and constant voltage mode and guaranteed the correct operation of the developed device.

4 CONCLUSIONS

The main contributions of this work are related with the high flexibility in the control of the stimulation session in association with the portability and low dimensions of the device.

With this device is possible to automate a stimulation session and change it in real time, allowing, for example, an external evaluator to analyse the differences in gait according to the protocol that is applied.

The high portability of this system and its user-friendly characteristics may allow its usage in a patient home through ambient assisted living with a real-time protocol controlled in a web based environment by the physician.

5 FUTURE WORK

As a continuation of this work, we are now testing the device in experimental animals, with good results to the date.

We are also implementing a stimuli wave form control, which will enable the study of the effect of different wave forms for stimuli application in the muscular structures.

Another advance to this work resides with the adaptation of the hardware's amplification module for surface electrostimulation application.

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