NEUROFEEDBACK VIBROTACTILE SYSTEM FOR PARKINSONIANS OVERCOME FREEZING OF GAIT: FIRST STEPS IN THE DETECTING THE MOST PERCEIVED FREQUENCY*

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Parkinson's Disease is a neurodegenerative disorder for which there is still no cure affecting the non-motor and motor systems. One of the most serious gait disorders are the freezing episodes, denominated by Freezing of Gait. This paper address the development and validation of a neurofeedback vibrotactile system through a belt for parkinsonians overcome freezing of gait, aiming to detect the most perceived frequency. With the system developed and validated in healthy subjects it was verified that the higher frequencies, within the frequency range perceived by human skin and the cerebral cortex, are more easily perceived independently of the gender of the subject and the interval of feedback.

1. Introduction

Parkinson's Disease (PD) is a neurodegenerative disorder of Central Nervous System for which there is still no cure [1], [2]. Even though PD itself is not fatal, this disease affects motor and non-motor system causing hard complications to the patients in a devastating way and consequently decreasing their quality of life. Regarding to the motor symptoms include an ongoing loss of motor control, bradykinesia, rigidity, postural reflexes instability, resting tremors and a wide range of gait disorders [1].

One of the most serious gait disorders are the freezing episodes, denominated by Freezing of Gait (FOG). FOG corresponds to a temporary, sudden and involuntary inability to ongoing motor movement, usually, lasting few seconds

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[1], [2]. It was founded that patients usually have less difficulties in motor tasks when external cues are provided by neurofeedback systems. The sensory cueing corresponds to the use of temporal or spatial external stimuli in order to improve gait initiation, continuation and, in general, the patients' movement. The vibrotactile systems is considered an efficient sensory cueing to provide neurofeedback to the parkinsonians, helping them to overcome freezing episodes and consequently improve the gait performance and their quality of life [3]–[5].

Based on these findings, this paper proposes the development of a neurofeedback vibrotactile system thought a belt. The system is intended to be used by parkinsonians to overcome FOG episodes. This paper focuses on detecting the most perceived frequency, and the localization of the haptic motors within the belt at the abdomen.

This paper is organized as follows. The section 2 reports the developed system, explaining why the vibrotactile feedback is provided in the abdomen, why is used a determined number of vibrotactile units, and why we use a determined frequency range of vibration in the trials. Moreover, it is described the system validation. The section 3 presents the obtained results and some discussion. Lastly, conclusions and future challenges are pointed out.

2. Methods

2.1. *System Overview*

The proposed system consists in a processing unit, the haptic drivers, the vibrotactile units (DC motor), Bluetooth Module and a Matlab interface, as can be seen in the Figure 1. The system is powered by a Lithium-Ion Researchable Covert Battery with 12V (recommended voltage).

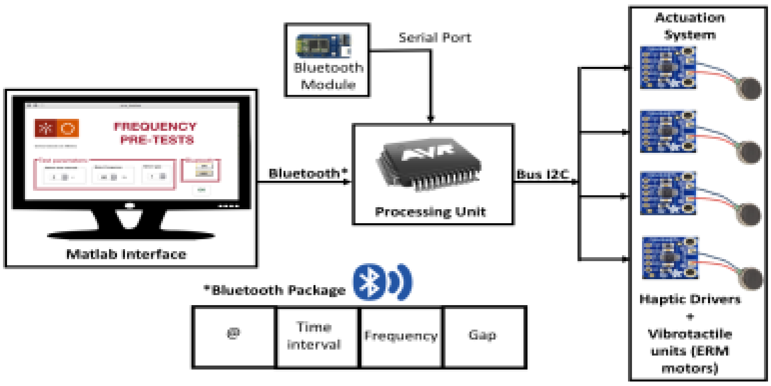

Figure 1. System's overview, illustrating the main components and interfaces between them.

2.1.1. *Actuation System: Haptic Drivers and Vibrotactile Units*

Regarding to the haptic drivers, it was used the Adafruit Industries' DRV2605 Haptic Driver, which allows to obtain an extremely adjustable haptic control of actuators, Eccentric Rotating Mass (ERM) and Linear Resonance Actuator (LRA), over a shared I^2C-compatible bus. This driver contains a smart-loop architecture, which provides a reliable motor control, a consistent motor performance and a feedback-optimized ERM drive providing automatic overdrive and braking that is important once creates a simplified input waveform paradigm. The DRV2605 Haptic Driver was composed by five pins: the supply pin (VDD), being recommend use a 2.5-5.5V; the two I^2C-compatible bus pins (SCL and SDA): and the multi-mode input I^2C selectable pin (IN/TRIG). The four used haptic drivers were supplied by 3.3V and it was used the PWM (Pulse-Width-Modulation) mode, using, consequently the pin IN/TRIG to provide the PWM sign.

The vibrotactile units are mini vibration motors 2.0mm (Seeed Studio Electronic), a special type of ERM motors, coin vibration motor, also known as shaftless or pancake vibrator motors. These motors works with DC voltage (3V) with an offset (non-symmetric) mass attached to the shaft.

2.1.2. *Wireless Communication and Graphical interface*

In order to obtain a wireless communication, it was used a Bluetooth Module, the HC-06 Itead Studio. This module use the Bluetooth 2.0, being constituted by the supplied pins (VCC and GND), data input and output pins (RX and TX, respectively). It is noteworthy that this module only allows a range of 10m of wireless communication.

The graphical interface was programed in MATLAB and allows to the user to select the test's parameters and send them to the processing unit aiming to control the experimental tests.

2.1.3. *Processing Unit*

About the processing unit, it was used the Arduino Mega 2560, supplied by the lithium-ion battery to ensure the system's portability. The Mega 2560 is based in the microcontroller Atmega 2560, that has a clock speed of 16MHz; a USB connection; a power jack; a reset button; 54 digital input/output pins (of which 15 can be used as PWM outputs); 16 analog inputs; 4 UARTs (hardware serial ports); three serial ports; and one built-in LED. Furthermore, the mega 2560 also supports I^2C (TWI) being the SDA and SCL pins responsible for data and clock transmission, respectively. The microcontroller has 8-bit timers (Timer 0 and 2) and 16-bit timers (Timer 1,3,4 and 5).

A frame containing 4 characters (“@”, time interval, frequency and the gap) is sent through the Bluetooth communication as shown in figure 1 (Bluetooth package). It should be noted that the first character corresponds to the recognition byte and the remainder to the variables that are used to establish the selected parameters through the interface. When an interruption of service to the communication occurs, it is first checked if the first character is an “@”. If so, it resets the communication variables for the subsequent assignment of the respective selected values. Then, if the communication is finished, the whole process of experimental tests is initialized.

For the I^2C communication and control of the haptic drivers, it is used the Wire.h library and a specific library of Adafruit_DRV2605.h, respectively. In addition to establishing the I^2C communication protocol, it is selected the PWM mode for the haptic driver, being the PWM that dictates the DC voltage applied to the vibrotactile units. Thus, by varying the duty-cycle of the PWM it is possible to vary the voltage that is supplied to the motors and consequently to control the frequency and amplitude of vibration.

2.1.4. *Wearable System: the Belt*

In order to develop the system, it was necessary to consider three factors: first, what is the best region in the human body to provide vibrotactile feedback; how many vibrotactile units should be used; and what vibratory frequency must be provided.

After an intensive study on the literature, it was proposed the development of a device that allows stimulation of the abdomen, once it is intended to be used during walking and in daily tasks. In fact, the hands and soles of the feet are the body zones with the highest vibration sensitivity [6], however, the use of insoles is excluded, as they would limit the footwear to be used of each patient, and it was mentioned that it caused some discomfort. Concerning to the hands’ area (wrist and forearms), as it is intended that the device can be used during daily tasks, this zone should be free [7]–[10]. Thus, it is proposed to develop a belt, placed around the abdomen.

Next, it was necessary to take into consideration how many vibrotactile units to use. In order not to require too much cognitive effort to perceive the feedback from many units, it was proposed to use four units. It is also important to point out that the arrangement of the units was considered equidistant and considering the navel and spine because these zones are used as anatomical references for the perception of vibrotactile patterns [11]–[13]. In this way, the four vibrotactile units that are used are arranged in the navel, in the right and left side and in the column.as can be seen in the figure 2.

Figure 2. System's overview, illustrating four planes.

Tactile sensory system is mediated by cutaneous mechanoreceptors, which are involved in touch sensitivity, pressure, vibration and sense of position. Mechanoreceptors are usually sensitive to deformation or stretching and are present in various parts of the body, including the skin, muscles, tendons, blood vessels and various viscera [6], [14]. Sensory system, when stimulated, transmits information such as location, intensity, duration, frequency and even the density of stimulated receptors. This information is encoded in subgroups of receptors, axons and neurons that activate the primary and secondary somatosensory cerebral cortex. Therefore, these receptors and their connection to the central pathways and target areas in the cerebral cortex constitute the vibratory sensory system. Many receptors participate in the perception of somatosensory vibratory sensitivity, depending primarily on the frequency of the stimulus. The human's skin can achieve vibration detection thresholds between 80-300Hz, but the cerebral cortex only discriminates frequencies between 80Hz and 250Hz [6], [14]. Therefore, in the proposed system was analyzed a frequency range of 80 to 250Hz.

In the development of the belt, it was also considered that it was intended to be universal, i.e. it could be used for any diameter of the patients' abdomen. For that, a closure was used that allows adjusting the belt for anyone. In Figure 3 it is possible to visualize the developed system.

Figure 3. System developed, illustrating the main components and interfaces between them.

2.2. *Validation*

The validation of the proposed system involved 4 healthy subjects (3 males and 1 female). These subjects mean age was 23.5±0,87 years old.

Since in a future context of the system, vibrotactile feedback will be provided in short time intervals according to the transition of the gait phases, it is important to detect the best perceived frequency in a short time. Thus, in these experimental tests there is a trial interval where half of the interval corresponds to one OFF phase (without stimulation) and the other half to an ON phase (with stimulation), where vibrational stimuli are supplied with the frequencies in test. The subjects must indicate which of the intervals perceived the stimulation. The ON / OFF intervals will start for 8sec each and will decrease to 2sec (2sec every), as is indicated in the figure 4. Each trial will be presented with notice. The capture intervals should never be too close, with a minimum of 20sec between each trial. It is important to note that in these experimental test, all vibrotactile units vibrated at the same time and with the same frequency for each test (80, 100, 120, 140, 160, 180, 200, 220, 250Hz). The participants used phones during the experiment to ensure any external influence of the surrounding environment or even some sound from the engines themselves. Finally, after the experience the subjects answered a questionnaire about the frequencies provided and its perception for vibrotactile units In figure 4, we intend to represent this test, where each line represents a trial: blue line - OFF phase; red line - phase ON.

Figure 4. Schematic representation of the experimental test.

3. Results and Discussion

Firstly, it is important to emphasize that all subjects effectively perceive all the frequencies provided during the vibratory stimulation in the experimental tests. However, better results were obtained for higher frequencies, and the hit percentages decreased when stimuli were given with lower. In fact, the higher the frequency the better the human perception, especially when the time interval that the stimulation is provided is higher. Thus, for frequencies above 160Hz the subjects perceived the received stimuli better. Regarding the pacing time interval, all the participants did not have difficulty in perceiving the stimulation correctly in the test interval.

It is also important to mention that there were no discrepant differences between the male and the female subjects at the level of perception of the vibrotactile feedback.

Regarding to the questionnaires, they allowed to subjectively evaluate the participants' opinions on all the parameters analyzed in the experiment. All subjects evaluated the perception of frequencies and time intervals with a high level.

For the perception of each vibrotactile unit, these values varied from subject to subject. Although it was expected that the vibrotactile units placed in the navel and spine area were the best perceived, three of the participants said that they felt better the feedback provided by the vibrotactile units placed on the sides. This fact can be justified in two ways: firstly, the subjective character of subject to subject; secondly, although all mini vibratory motors are the same and program to vibrate in the same frequency, the exact placement of the motors in the belt could vary from subject to subject, leading to different perceptions.

Ultimately, the subjects did not consider the high frequencies uncomfortable or the low frequencies little perceived, considering possible to perform their daily tasks and perception of the provided vibrotactile stimuli.

4. Conclusion and Future Perspectives

A vibrotactile neurofeedback system was developed that is intended to be implemented in patients with Parkinson's in order to attack FOG. The system developed and validated in healthy subjects allowed us to confirm that the higher frequencies, within the frequency range perceived by human skin and the cerebral cortex, are more easily perceived independently of the gender of the subject and the interval of feedback. Thus, it is intended that parkinsonians detect a vibratory pattern and incorporate their physiological pattern of somatosensory system gait, reducing the number or duration of freezing episodes and consequently improving gait performance, increasing the quality of life of each patient.

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