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Wireless vibrotactile wireless optical device for motor activity assistance motor activities

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ABSTRACT

This article describes the research that leads to the development of a wireless optical device capable of generating vibrotactile mechanical stimuli at different points on the skin and at desired frequencies by means of sixteen actuators contained in a portable bracelet designed for any extremity of the human body. This prototype allows control over each actuator used as a stimulation point, actuated independently by wirelessly transmitted commands to a rechargeable stand-alone control system in the bracelet. Usability tests were carried out, with respect to tactile perception, which proved the correct functioning of the device. In perspective, the development, after a variety of validation tests with a large sample of patients with and without neuropathy, aims at creating a database to be used as set point values in front of these patients with the expectation that the system will also be used in patients with movement deficits, and employing tactile perception as a psychomotor stimulant in the execution of motor activities.

Keywords: motion deficit; tactile perception; tactile feedback.

1. Introduction

Owing A motor disability in a person can be caused by different reasons, mainly by accidents of different types or by diseases or neuronal lesions that, in one way or another, partially or totally paralyze the movement of the upper and lower extremities of the human body. When this type of disability arises, it is necessary to initiate a rehabilitation phase which requires different stages and methodologies with long assistance times, so that patients tend to abandon the procedures, leaving the recovery treatment unfinished.

In addition, there is a continuous worldwide growth in the number of patients in need of rehabilitation therapies, which has increased the pressure on

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health systems and, consequently, the reduction of time and resources available for treatment.

Regarding rehabilitation, it is often a tedious and lengthy process that can even last for months, even if several sessions are performed per week; it is carried out through recurrent visits to rehabilitation and physiotherapy centers at home, involving valuable human resources[1]. Under these considerations, it is essential to investigate more effective ways of performing therapies, so following a technological approach is very promising. In the above sense, technology and robotics currently offer users a multitude of advanced devices oriented to research, science, industry or entertainment, capable of simulating with great realism different haptic sensations (proprioceptive, tactile and vestibular). Such devices are characterized by providing physical contact between the computer and the user, as well as force and tactile feedback to the subject interacting with virtual or remote environments[2,3]. These advanced devices are able to make the user believe that they touch or collide with virtual, solid or deformable objects, they are also able to provide different haptic textures depending on the type of surface of the object (rough, smooth, frictionless, sticky, penetrable, among others).

On the other hand, research on the use of robotic and virtual reality technologies in patients with neuromotor deficits has been widespread in recent years[4,5]. Although the results reported in the literature seem promising, and their potential benefits extend to diverse patient populations, their application is strongly restricted to large-scale regional hospitals, but very limited to local physical therapy clinics, and they are practically unavailable for home training programs[6].

This has motivated the recent growth of virtual reality applied to serious video games for rehabilitation; such games have a potentially high impact due to their easy distribution, their applicability to a wider range of motor disabilities, and their potential for assigning “high-dose” and “high-intensity” training protocols[7,8]. However, despite the extraordinary technological improvements in this field, much research remains to be done. Among the problems to be addressed are: (a) the absence or limited possibility of sensorimotor feedback in the form of tactile contact; (b) limited interaction schemes, mainly oriented to very generic tasks involving reaching and hitting mobile virtual objects, which are still far from patients' real-life situations; (c) limited realism, generally focused only on visual aspects, but without convincing physical realism, which limits the possibility of assigning progressively more complex functional motor tasks requiring greater fine dexterity; (d) many systems are generic, but not focused on specific drugs; (e) poor understanding of the role in recovery of assigning different levels of therapy difficulty and especially how to assign the optimal dose, according to the clinical and personal conditions of the patients; (f) the reduced validation and extensive clinical evaluation in controlled studies of many systems; (g) the need to understand the relationship between the characteristics of these types of systems and their impact on patient recovery.

The use of virtual reality and mobile computing technologies in rehabilitation systems, affordable in local or home environments, is also currently feasible; however, such systems have the important limitation of lacking motor actuation and control capabilities because they are not integrated with any robotic system. In order to provide feedback to the patient on their performance/errors, it would be beneficial to provide haptic feedback in such virtual reality systems during training by introducing the sense of touch into the multisensory feedback loop and augmenting the visual and auditory channels[9]. Furthermore, having the tactile sensation of touching virtual objects-in addition to audio and vision-could play a major role in assisting in the process of relearning manual movement control skills in patients; Therefore, the integration of portable devices capable of providing haptic feedback is important, although this has received little attention from the scientific community - resulting in a precarious literature—but it has gradually begun to arouse more and more interest.

The paper is structured as follows: first, the materials and methods for the development of the wireless vibrotactile haptic feedback system (DRHVI) are established; then, the proposed DRHVI is described in detail; subsequently, the usability tests of the device in three types of experiments with a healthy person without motor disability or sensory deficit are exhibited; then, the results of the validation of the DRHVI are shown and discussed; and, finally, the conclusions of the research are shown.

2. Methodology and materials

In accordance with the above motivation, a DRHVI was developed that, when used together with complementary systems, could serve as a basis for future research in the area of assistance in the execution of motor rehabilitation activities. The DRHVI prototype is composed of three systems: mechanical, electronic and user interface. Six phases were established for its design and development: (a) characterization of the actuators; (b) selection of the electronic control device; (c) selection of the type of communication; (d) design of the power supply system; (e) integration of the system to perform sensory validation; (f) validation of the vibrotactile flow.

As a result, it was established that the hydraulic feedback system consists of sixteen vibrotactile actuators (minivibromotors), which can be driven randomly or precisely; also controlling the number of motors to be operated and their different frequencies independently.

The control is performed remotely with a system that establishes the communication through two Xbee modules, where one module works as a transmitter (Tx) connected to the central control equipment, equipped with a graphic user interface able to send commands wirelessly to the other receiver module (Rx), connected to a control system that interprets this command to generate PWM signals to the different actuators, regulating the vibration levels by increasing or decreasing the pulse width. Subsequently, all the elements that make up the system (actuators, communication devices, control and power supply) are coupled in a portable bracelet.

As a method of validation of the DRHVI, psychophysical and sensory usability tests were applied.

3. Development of wireless vibrotactile optical feedback system

For the purpose of the research, a profile of use was established in men and women between 16 and 65 years of age (age of labor productivity) belonging to any socioeconomic stratum, with a neuromotor disability (stroke) or musculoskeletal (rheumatism), or with sensory deficit due to neuropathy (diabetes), may present a transient disability condition that affects their quality of life due to the impossibility of performing daily life activities normally. This information suggested the definition of size, shape and frequency variables necessary for the design of the support structure at the interface of the device, in order to make it comfortable for the patient.

3.1. Device design features

To control the behavior of each of the actuators, a wireless communication and control device was designed (**Figure 1**), in which an Arduino NANO microcontroller was implemented as a base that allows the sixteen actuators to be operated simultaneously by means of PWM signals, while transmitting and receiving control commands wirelessly through an Xbee communication module.

The function of the Arduino Nano is to interpret the command received from the Xbee, a receiver that operates under the 802.15.4 specifications. This command contains the information of the motor to be activated, specifying motor number, vibration frequency and the time to be driven. The module allows point-to-point or point-to-multipoint data transmission with a speed of up to 250 Kbits/s and operates in the ISM (Industrial, Scientific and Medica) frequency band.

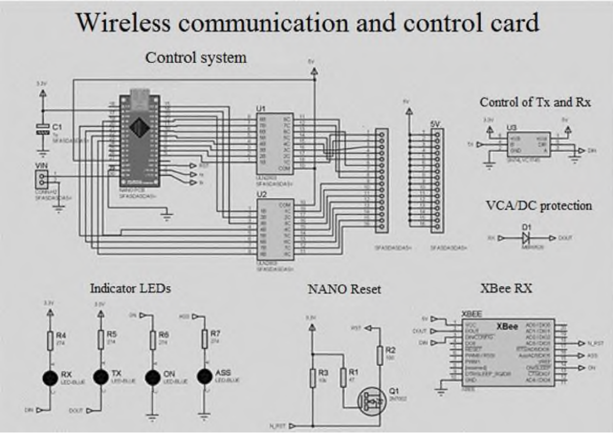

Figure 1. Schematic design of the coupling between the control system and the communication system made with Proteus 8.

Source: own elaboration.

Since two Xbee modules were used, one connected to the interface (Rx) and the other connected to the computer (Tx), it was possible to interact remotely with the actuators that generate optical sensations.

Then the double layer electronic board was obtained with the pads and metallized surfaces on which the components were mounted (**Figure 2**). This interface has a smaller size than expected, with a low power consumption that provides an optimal performance for the optical feedback system, its characteristics are specified in **Table 1**.

The power supply of the electronic board must be sufficient for it to perform its main functions efficiently, so a suitable power supply system was sought to provide energy for the continuous operation (several hours or days) of the wireless control system together with the vibrotactile actuators.

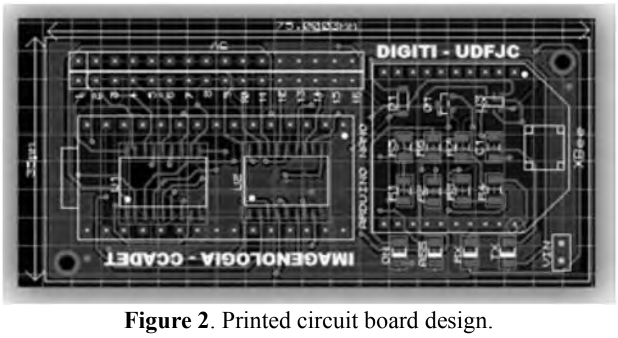

Figure 2. Printed circuit board design.
Source: own elaboration.

Table 1. Features of the wireless control system

Characteristics	Description
Speed	8 MHz
Flash	64Kb
Communication	Wireless connection XBee
Consumption	50 mA active status 2 mA inactive status
Size	7.5 cm x 3.5 cm x 1cm

Source: own elaboration.

After choosing the power supply system, all the systems were coupled and durability tests were carried out, in which satisfactory results were obtained, activating the sixteen actuators while transmitting control commands wirelessly, achieving a duration of more than two days of continuous use. The system is capable of lasting sixteen times longer if one optical actuator is activated at a time, and by not transmitting data wirelessly on a constant basis increases the power efficiency of the device; it is estimated that the device can have an average autonomy of four or five days. The final industrial design that connects the whole device consists of an insulating box containing the development board, a cylinder where the power supply system is fitted and a bracelet to hold the sixteen vibromotors and the points to be stimulated; these actuators were positioned equidistantly (2 cm) in two parallel columns, each one with eight vibromotors to cover a distance of 14 cm (**Figure 3**).

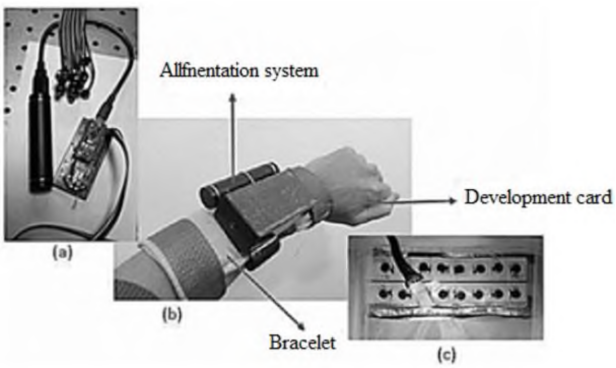

Figure 3. Final design of the vibrotactile handheld device. (a) Electronic control system; (b) final handheld interface mounted on an individual; (c) array of vibromotors of the device.

Source: own elaboration

Finally, to have complete control of the device and to be able to interact with the portable system, a graphic user interface was created that consists of two parts, the first is the control part that serves to characterize the actuators by sending commands through the Xbee module connected to the computer, it also allowed to generate haptic sensations in different points of the skin by selecting the vibromotors and the desired frequencies. The second part is a tool that allows to experiment the vibrotactile flow of a person, generating haptic sensations in a sequential and random way with different intensities, which can help to identify the discrimination capacity between different stimuli in a person.

4. Usability testing

Three types of experiments were performed with a healthy person without motor disability or sensory deficit, with the particular purpose of validating the vibrotactile flow provided by the device by means of feedbacks. The first experiment consisted of evaluating the threshold of cutaneous tactile perception with a series of vibrotactile stimuli applied with varying intensity; with this experiment the threshold frequency of perception of the people could be determined by repeating the experiment three times for each one and constructing the graph that allowed to demonstrate this frequency with variations in its voltage. With this method the device can be useful to evaluate the average sensitivity of a healthy person, or to generate a sensitivity map by zones in patients with tactile sensitivity problems.

The second experiment consisted of establishing the discrimination between two different stimuli, by limiting the distance at which two stimuli were activated at the same time and identifying when they felt like one, which could serve as another metric to evaluate sensory capacity in patients. The third experiment consisted of evaluating the usefulness of the instrument to adjust the localization capacity of variable vibrotactile stimuli that a person has this experiment allowed the validation of the vibrotactile flow by interacting with a virtual image and the device in question (**Figure 4**), the vibrotactile stimulus had to be located on a reference map, with and without the help of a visual reference.

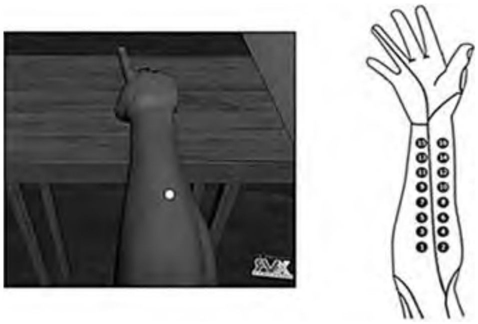

Figure 4. Experiment on stimulus localization. (a) Virtual image of visual reference of the stimulus; (b) localization map of the stimulus in different areas of the arm.
Source: own elaboration.

5. Results and discussion

In the case of the first experiment, the participant was able to detect up to a minimum average vibration of 30 Hz, which corresponds to normal skin detection frequencies. In the second experiment it was found that when the frequencies were higher than ten units (with respect to the level found in the first experiment) for the vibromotors that had a separation distance close to the average distance, only one type of stimulus was felt, so it was determined that it was not convenient to use frequencies higher than this; It was also found that in order to feel the stimulus at the point in question it is necessary to decrease the intensity levels provided to the device for its operation, since at very high frequencies and very short distances there is a perception of saturation in the stimulation provided.

For the third experiment, very interesting results were found. When vibrations were provided at nearby points and other vibration points were indicated in the virtual image, the person reported having a positive response (sensation of stimulation at the indicated point) when the stimulation was not performed at this point, but in a nearby area; This shows that in many occasions the person can be psychologically influenced to feel stimuli where they are not really being stimulated, this happens especially in people who are presenting a motor deficiency in their limbs.

In this case it is obtained that the localization errors were smaller when the participants had the visual aid, the error value was around one centimeter, which is the separation distance between each pair of motors. It is thought that it would be good to extend this test in the future with more people and testing higher intensity levels in order to investigate whether this is preserved or can change depending on the vibration levels. These tests resulted in the proper functioning of the feedback system, the validation of the vibrotactile flow and a final calibration of the actuators.

6. Conclusions

In this work we have presented the development of a portable optical device as a method of biofeedback in motor activity assistance and rehabilitation for patients with transient motor disability and, similarly, for early diagnosis of patients with neuropathy.

The validity of the system has been justified by controlled experiments to evaluate the vibrotactile flow, trying to discriminate or evaluate the possible influences of external factors such as the noise of the vibromotors or the use of sight as a distractor when receiving a tactile stimulus, for this purpose three experiments were conducted with a person without motor disability or neuropathy. When actuating the actuators at high frequencies 120 Hz, the ability to detect a specific point of vibration is lost, since the vibratory force is very high and makes us think that the element that generates it is larger than the area it occupies on the skin, This makes it inefficient for vibrotactile flow validations because it does not allow the discrimination of two or more close stimuli, likewise keeping it active for a long time can cause discomfort or injury to the skin due to the high temperature that the actuator takes with that pattern of operation.

Finally, this device can be integrated into virtual reality applications or training video games for the rehabilitation of human upper extremities. The device could allow to study the validity, efficacy and efficiency of this type of technology in the haptic sensory environment; in addition, it could have possible applications for sensory evaluation in the extremities of other types of patients with sensitivity problems (for example, in diabetics due to the development of neuropathies in their extremities). It is also considered that this device could be valuable as a preventive, diagnostic and monitoring tool in patients with other neuropathies.

Conflict of interest

The authors declare no conflict of interest.

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