# Vibraestim: Low-cost prototype for detecting the threshold of vibration perception of thick fibers

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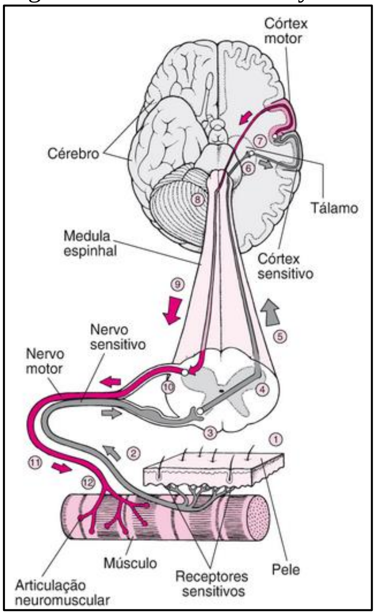
**ABSTRACT**
Peripheral nerves are actually bundles of nerve fibers. Some are very small (with diameters of less than 0.4 mm) and others are thicker (with diameters of up to 6 mm). The thicker fibers carry messages that activate muscles (motor nerve fibers) and tactile and position sensitivity (sensory nerve fibers). The smaller sensory nerve fibers transmit sensitivity to pain and temperature and control the body's automatic functions, such as heart rate, blood pressure and temperature (autonomic nervous system).

**Keywords:** Vibraestim, Coarse fibers, Nerve fibers.

## INTRODUCTION

The human nervous system is divided into the peripheral nervous system and the central nervous system, and can be represented as shown in Figure 1.

Figure 1- Human nervous system.

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Peripheral nerves are actually bundles of nerve fibers. Some are very small (diameters less than 0.4 mm) and others are thicker (diameters up to 6 mm). The thicker fibers carry messages that activate muscles

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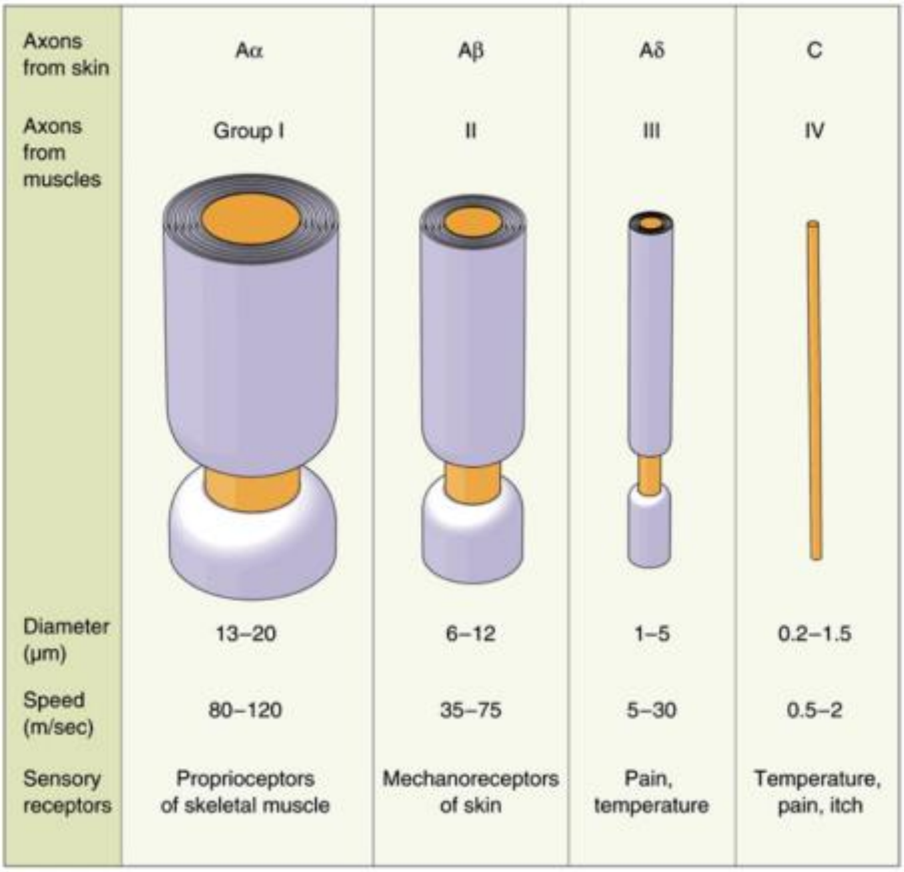
(motor nerve fibers) and tactile and position sensitivity (sensitive nerve fibers). Smaller sensory nerve fibers transmit sensitivity to pain and temperature and control the body's automatic functions, such as heart rate, blood pressure and temperature (autonomic nervous system).

Schwann cells surround each of the nerve fibers and form many layers of a fatty insulator known as the myelin sheath. Peripheral nerve dysfunction may be due to lesions of the nerve fibers, the nerve cell body, the Schwann cells or the myelin sheath ( SILVERTHORN, 2017) .

Nerves are connected and communicate their signals through synapses. Thus, the movement of a muscle involves two complex nerve pathways: the sensory nerve pathway to the brain and the motor nerve pathway to the muscle. Nerve fibers are classified according to transmission speed and diameter, as shown in Figure 2.

Figure 2– Classification of nerve fibers.

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Diabetic foot is defined as “infection, ulceration and/or destruction of deep tissues associated with neurological abnormalities and peripheral vascular disease in the lower limbs [...] often leading to amputation”. Most of these patients' hospitalizations are due to the worsening of these ulcers, mainly in the lower limbs (CARLESSO et al., 2017).

According to OCHOA-VIGO et al. (2005), the assessment of the patient's peripheral sensitivity is essential to diagnose and treat peripheral nerve injuries, especially in conditions such as leprosy and diabetic foot. This assessment should be part of the routine physical examination of people with diabetes, as the risk of acquiring diabetic foot increases 40 times in these patients . In this case, the doctor should examine the patient's feet for early signs and symptoms.

To this end, tests such as the Semmes - Weinstein (SW) monofilament , the tuning fork and the biotensiometer are used . The SW monofilament is a manual instrument that contains a nylon fiber with a strength of, for example, 10 grams, being applied to the sole of the foot, at an angle of 90 degrees, using the yes-no response technique to the touch of the device in regions of the foot. The technique instructs the person to say yes, every time they notice the application of the fiber. The inability to distinguish the SW monofilament at four points or more is indicative of loss of the feeling of protection (SOUZA et al., 2005). The tuning fork is the simplest instrument, and the vibratory sensitivity test is performed with the specific 128 Hz tuning fork (SARAIVA et al., 2023). Finally, the biothesiometer allows for greater frequency variation, but its cost is the highest.

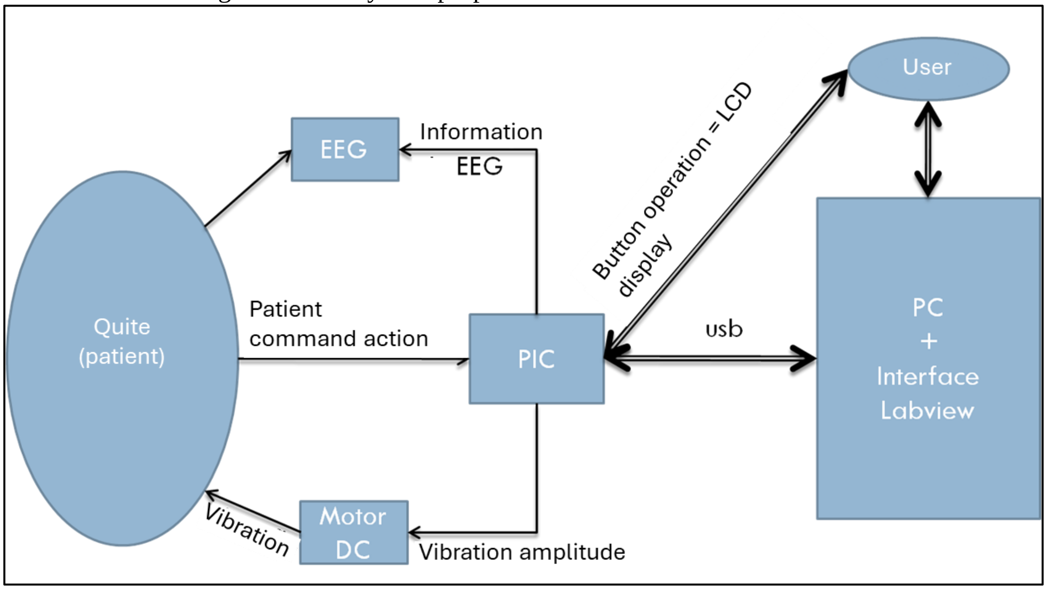
## GOAL

The objective of this work is to present the beginning of the development of a low-cost prototype that can assist in detecting the vibration perception threshold of thick fibers, helping to evaluate the prognosis and evolution of the diabetic foot. This prototype was named VibraEstim.

## METHODOLOGY

The initially proposed system consists of five elements: 1 development kit for a PIC microcontroller, 1 vibrator motor, 1 electroencephalogram (EEG), the PC/ Labview interface, the LCD interface. Figure Figure 3patient and the user who monitors the test.

Figure 3- First system proposed for the thick fiber stimulator.

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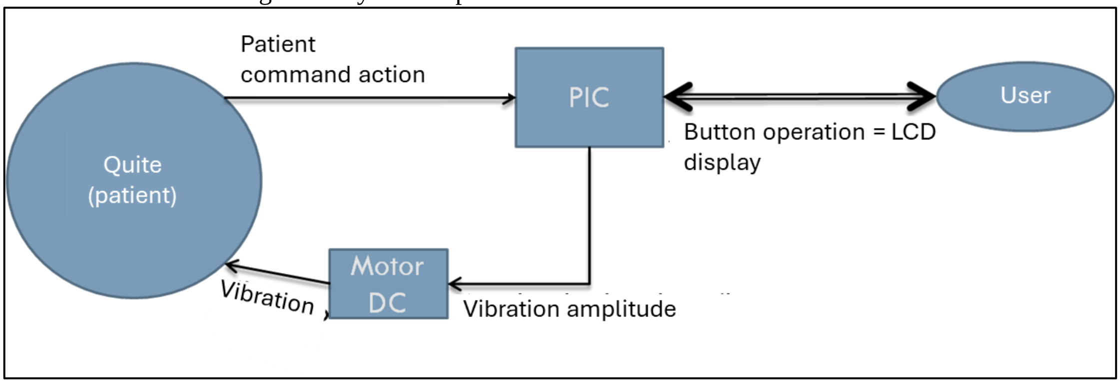
The PC/ Labview interface was only used to collect data in the stage of collecting vibration produced by the engine. The electroencephalogram may be used in future work to acquire the patient's response signal to the vibration produced. Thus, the simplified system developed can be seen in Figure 4.

Figure 4- System implemented for the thick fiber stimulator.

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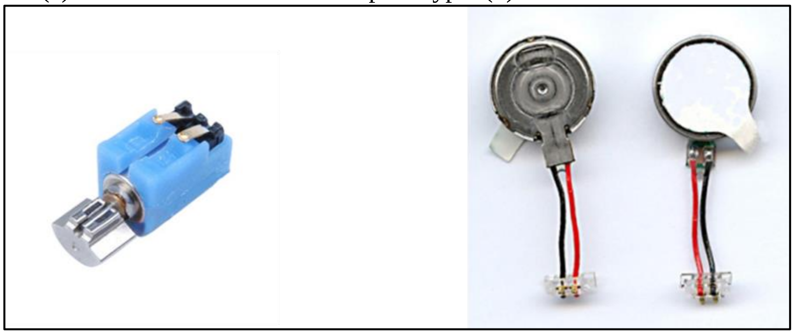
**INITIAL RESULTS**

VIBRATION CAPTURE AND TRIGGERING

The element responsible for the Vibraestim vibration is a DC motor with an eccentric shaft and, because of this unbalance in the shaft, the motor vibrates with a certain amplitude and frequency. Two types of engines were tested, as can be seen in Figure 5.

Figure 5– (a) First DC motor used in the prototype. (b) motor used with eccentric shaft.



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The first motor used, shown in **Erro! Fonte de referência não encontrada.**a, is a motor with an unbalanced rotor. However, this motor did not meet the project because the current varies with increasing load (when pressing more) and requires a surface to propagate the vibration. Typical characteristics of this unbalanced motor are shown in Table 1.

Table 1- Typical characteristics of an unbalanced motor.

| | |
|---|---|
| Rated voltage | 3.3V |
| Starting voltage | approx. 2.0V |
| Nominal chain | approx. 10mA |
| Speed | 10000 to 25000rpm |
| Armor Resistance | 30±20%Ω |

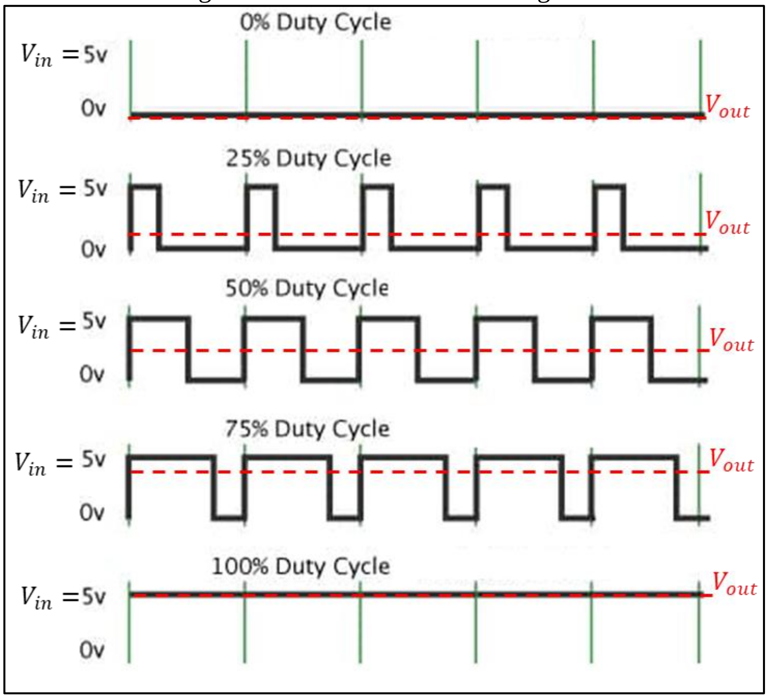
Therefore, the second eccentric shaft motor was used, shown in Figure 6b. To verify the vibration characteristics of this motor, a 3-axis accelerometer ( MMA7260) was used, connected to the NI-ELVIS platform, in order to enable data acquisition using a program developed in Labview 8.5v. The results of the data obtained with this test were:

- When increasing the armature voltage of the DC motor, in certain ranges, there is only an increase in the vibration amplitude.
- Comparing different ranges of input voltage, it was noticed that the frequency also varies.
- Overall, the frequency ranged from 40Hz to 100Hz, meeting the objectives of this project.

To change the vibration of this motor it is necessary to vary its DC armature voltage. One possibility and the one adopted in this work was to activate the motor by a PWM command, varying the work cycle. The basic idea of a PWM command is that when varying the duty cycle (D) the value of the average voltage ( $V_{out}$) varies proportionally with the voltage input ( $V_{in}$):$V_{out} = DV_{in}$.

As the PWM waveform is square, as in Figure 6, a filter is necessary to eliminate the fundamental component and its harmonics. However, for the motor there was no need for this filter, since internally it can be modeled as a low-pass filter (a resistance in series with an inductor) (SEDRA, SMITH, 2011).

Figure 6- Waveform of a PWM signal.

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Due to the characteristics of the DC motor used, the PWM drive had the prerequisites described in Table 2.

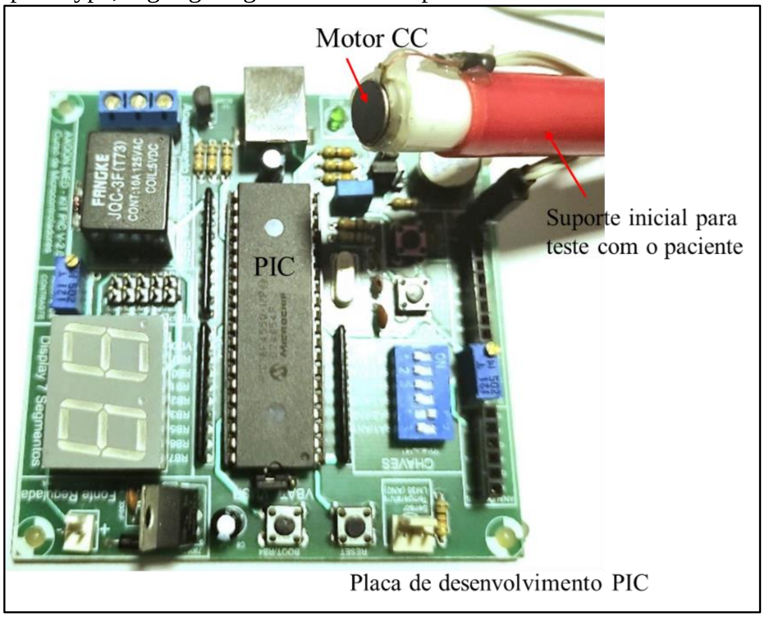
Table 2- PWM prerequisites.

| | |
|---|---|
| Frequency | 12kHz |
| Duty cycle (total range 0 – 1024) | 200 - 500 |
| Starting duty cycle | 600 |
| Resolution | 4.88mV |
| Iteration step | 50 |
| Maximum voltage | 5V |
| Minimum voltage | 0V |

## PIC MICROCONTROLLER

To control vibration from the PWM drive of the motor and to create the Patient/User/Motor interface, a Microchip microcontroller was used, which has a USB connection to the computer, PIC18F4550. This PIC has 40 pins, among which there are 2 PWM outputs and configurable digital inputs/outputs, it has 4 counters and the CPU frequency is 48MHz. To facilitate development, a developed kit provided by the company AXOON Soluções Tecnológicas em Saúde was used, which allows the quick configuration of a 7-segment display and LCD display for the PIC. Figure Figure 7prototype.

Figure 7- Proposed prototype, highlighting the PIC development kit and the connection with the micromotor.

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PATIENT-USER INTERFACE

The vibration stimulus provided by Vibraestim will be applied to the patient, using a button as an interface that will be activated during the test. The LCD display and LEDs on the development kit board provide the user with information during the test, such as:

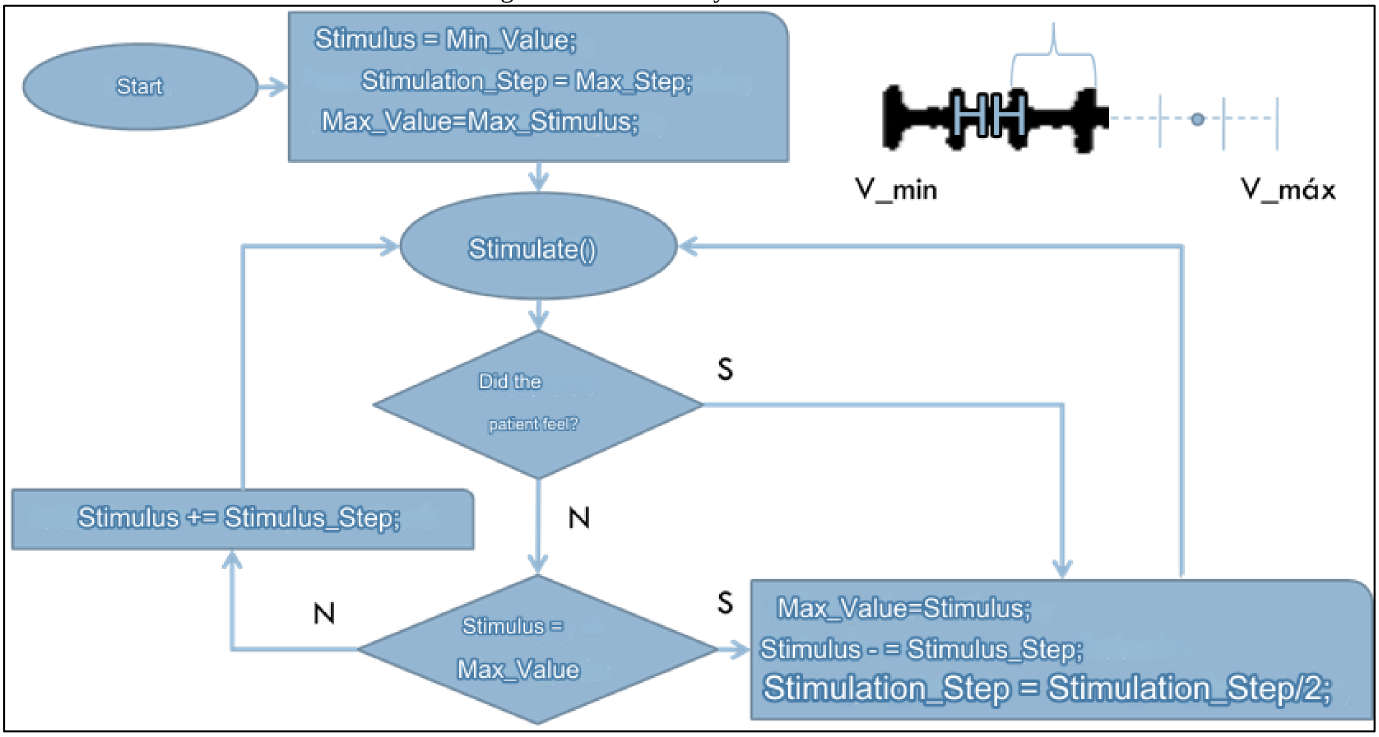
- Wait for the test to start;
- Test started;
- Statistical test;
- Threshold value (in the form of the voltage at the PWM output in mV).

It is possible to replace the LCD display with a simpler 7-segment display by changing the PIC *firmware*. Using the kit's digital key, the user determines which test will be performed and a button is used to start the test.

STIMULATION TEST

The development of the PIC firmware was developed in C language on the MPLAB 8.2v platform. The test algorithm was developed based on the work of Martins (2008), relating to somatosensory stimulation, which determines the value of the perception threshold for electrical current stimuli.

Figure 8somatosensory stimulation test.

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Considering the limitations of the motor, for example, a minimum voltage value is required to initiate vibration, the test can be described as follows and summarized in the flowchart in Figure 8:

- The patient will be subjected to a noticeable amount of vibration initially. Continuously, the voltage applied to the motor will decrease with a certain step, and with it the vibration.
- The patient will be informed to press the button when they stop noticing the vibration. When this occurs, the voltage applied to the motor will be increased to the previous value and will decrease again with a step lower than the previous one.
- This will be repeated until the minimum step is reached and a voltage value at which the patient perceives the vibration.
- After determining the descent threshold, a statistical test will be carried out to verify whether the patient really feels the applied vibration.

Similarly, the rising threshold will be determined and both will be displayed at the end on the LCD display. The test to be performed is chosen by the user using two keys from the development kit.

## FINAL CONSIDERATIONS

The results obtained from assembling the system are presented below:

- From the description of some healthy individuals to whom we applied the vibration stimulus, the result was that the variation in vibration is noticeable with the variation in voltage applied to the motor. The perception was either an increase in frequency or an increase in amplitude.
- The smallest stimulus that can be obtained with the motor used is a stimulus that can be perceived in the most sensitive parts such as the hand, but is not perceptible in other parts, such as the arm or leg.
- The functioning of the kit and presentation of test results shown on the LDC display and LEDs met the project.

Thus, it can be concluded that it was capable of performing vibration stimuli and it is possible to vary the vibration by changing the average voltage applied to the eccentric motor.

The use of the development kit with the PIC18F4550 microcontroller was very useful, allowing the system to operate in an embedded manner, since the algorithm for determining the vibration sensitivity threshold was implemented in the microcontroller firmware and the important messages for the user of the system can be viewed through the LCD display and LEDs.

On the other hand, the kit has much more than the system really needs. The prototype can be optimized using a PIC that has fewer ports and using only the components necessary to drive the motor and visual indicators. Another improvement to the system would be the implementation of communication with the computer. This communication would aim to memorize the results of the threshold values, for later analysis by the test administrator and chronological memorization to check the progress of a treatment. Furthermore, the user interface can be improved, for example, by adding a small keyboard for choosing the test.

It was noticed, during the experiments with the engine, that a measurement of the engine vibration is necessary in order to calibrate the instrument. From this, it can be verified whether there is a need to control the motor drive, not just controlling the voltage, or even verify the need to change the motor.

Carrying out the test on healthy individuals made it possible to verify that there are areas that are more sensitive to the sensation of vibration than others. This can be observed by applying a very gentle vibration that can be perceived with the fingertips, but cannot be perceived on the arm, for example. Thus, the instrument proved capable of generating vibration stimuli that may be imperceptible depending on the area of application of the stimulus. This is an indication that it could be applied to individuals with neuropathies that affect large fibers, making it necessary to carry out tests with this population.

As a continuation of the project, the collection of the EEG signal can also be included to observe the brain response to the vibration stimulus. It also allows the comparison of the brain response given by the EEG to the mechanical stimulation of the fiber, which is the case of vibration, with the electrical stimulus of the same fiber, as in (MARTINS et al., 2008).

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