The New Computational Analysis Tool for Upper Limb Movement in Physiotherapy Biomedical Applications

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***Abstract*—The present project aims at developing an interface capable of capturing, analyzing and stimulating movements of persons who have some motor dysfunction in the upper arms due to accidents or congenital disabilities, i.e., those who need rehabilitation treatment. In this paper, we have used accelerometers with the objective of capturing the movements carried out by the user. These movements are captured in the form of analogical signals represented by voltage variation. Hence, it requires the use of a microcontroller to handle the data. This microcontroller controls how the data will be sent to the computer, and also, it makes possible the transformation of the signals into the digital format, which facilitates the processing steps and the computer analysis. When the obtained data are sent to a computer, their numerical transformation step starts off with speed and it is plotted on the user screen in an animated form representing the user's movement. The user receives an instantaneous evaluation of his movements throughout the time spent to execute it. The results obtained from the experiments show that this is a promising tool. As it is a prototype, it still needs several improvements. We believe this tool can become a commercial technology with great accessibility and low cost.**

Keywords*–*Computational Physiotherapy; Accelerometers; Rehabilitation Treatment; Biomedical Visualization.

I. INTRODUCTION

With the growing use of acceleration sensors in technological products, such as video games [1], mobile phones and computers, we believe the development of a system capable of analyzing and stimulating the recovery of patients who suffer from some minor arms dysfunction as a result of accidents or some pre-existing physical handicap is needed. The benefit of this technology would be of great help and of a strong social and intellectual impact. These technologies offer social and personal benefits to the bearers of motor handicaps [2][3][4].

Therefore, the present research proposes the conceptualization and the building of an electronic device capable of rehabilitating upper limbs using current hardware and software technologies.

In the scientific literature, there are studies about the use of accelerometers for physical evaluation of elderly and children [5][6][7][8], involving gait rehabilitation and very little about rehabilitation in the field of physiotherapy, mainly for upper limb movement. Thus, this fact is, our object of work.

Therefore, the main contribution of this research is a new computational analysis tool for upper limb movement in physiotherapy. The proposed system generates an output containing all the movement information in a plain text format, saving it in an embedded database. The containing information are the positions of the selected arm during the task presented as a challenge by the system to the user. This information can be compared with previous database register to validate the conformity of the movement. The system is also able to compare this information with movements from other users and samples, which guarantee that the relation between the number of attempts and the movement accuracy tends to shorten each time the system is used. Another interesting point is that it sets out the accelerometer information and transforms it in ”position in space” information, making possible that this same data can be applied in a range of other organizations for comparison and also permits the application to evolve in terms of hardware and software without losing the historical information, being that way, independent of future technologies and computational architecture.

The present article is organized in the following way: Section II addresses other works depicting the application of accelerometers in medical applications, Section III introduces the technology employed. Section IV describes the analysis of results obtained, and finally, Section V presents the conclusion.

II. STATE OF ART

Some studies on accelerometers in medical applications can be found in the literature which some of them show the use of accelerometers in intervention programs to promote physical activity in children and adolescents [5][6] and include methods for assessing physical activity focused on older adults [7][8]. Others are using accelerometers for mechanic impact analysis in the prostheses of a bilateral lower-limb amputee during the gait [9], aiming to elicit more precise answers.

Michaelsen et al. [10] proposed to use accelerometers to access to identify of changes in movements of subjects with hemiparesis, showing to be an alternative to measure movements.

With respect to these studies, our research is innovative because it presents a rehabilitation tool to the upper limbs, for children and adults, using a playful manner, a video game for better interaction of the patient with his rehabilitation process.

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III. Proposed Methodology

Because of the need of improving some of the methods applied in physiotherapy and of facilitating the rehabilitation of patients with upper limbs motor handicaps, the present research proposes an interactive and functional limb movement analysis tool. Therefore, the methodology here described uses an exploratory approach of observational and empiric procedures. To this end, the present methodology is organized in four steps, such as shown in Figure 1.

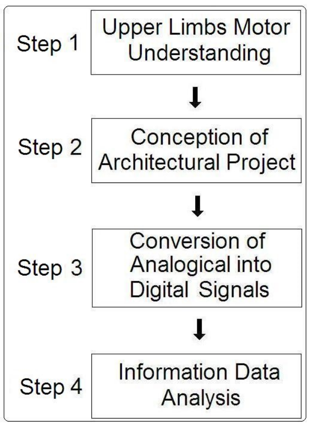

Figure 1. Proposed metnodology.

A. Step 1 - Upper Limbs Motor Understanding

This step presents an analysis and the drawbacks faced by people with motor handicaps of the upper limbs in order to identify the essential requirements of physiotherapy. This is an observational study.

B. Step 2 - Conception of Architectural Project

This step consists of definition and conception of proposed architectural project in order to obtain human biometrics data.

C. Step 3 - Conversion of analogical into digital signals

This step is aimed at the development of a tool capable of converting analogical signals in to digital ones. Digital signals are necessary in order to feed them into the computational tool to be developed.

D. Step 4 - Information data analysis

This step is aimed at the construction of a computational tool to facilitate analysis and execution of physiotherapy procedures.

IV. Experiments and Results

A. Results of Step 1- Understanding of the Upper Limbs Motor Movements

According to the work done by Schonke et al. [11], the human arm is divided into three main parts: the arm, forearm and hand. In a healthy arm, these three parts work together with each movement and no matter how simple the movement is there is an interaction amongst the muscles that cover theses parts of the arm, with each one of them generating a typical rotation, speed and acceleration which can be recognized and standardized by the sampling of mean measurements from different patients. With an unhealthy arm, regardless of the anomaly, the angle formed by the different limbs, the speed of each member, even with a resting position, suffer minimal or marked alterations. The project we developed aims at analyzing these alterations by converting them from the physiologic to the digital form, i.e., if there is any physiologic dysfunction or alteration in this limb, the equipment will be able to recognize and help with the recovery process [12].

B. Results of Step 2 - Conception of Architectural Project

In order to develop the proposed computational tool, the architecture design project is divided into two parts: Hardware and Software.

1) Hardware Project: This project consists of the capture and analysis of signals generated by the accelerometers, besides the transformation of signals from the analogical to the digital form [13]. The circuit here developed counts primarily with the accelerometers [14], which serve as sensors for the capture of movement, as shown in Figures 2 and 3.

Figure 2. MMA7260Q accelerometer coupled in your circuit for ease of manipulation [14].

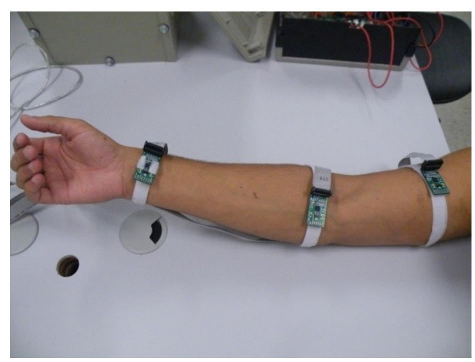

Figure 3. Correct position and fixation of accelerometers on the user's arm.

The accelerometers [13] work as sensors of movement capture. The accelerometers are fixed to the arm in three different positions: wrist, forearm and shoulder. These sensors are capable of analyzing and generating output data in the form of potential differences (volts), and in this way informing whether the region under analysis is at rest or moving, in addition to the movement velocity and direction in three dimensions, all at the same time.

In this phase, data are submitted to a differentiator circuit where the initial potential (offset potential) is compared to that generated by a potential divider circuit and resulting in an output potential difference close to zero.

The three accelerometers are laid on the user arm in the following way: the first lies on the wrist, the second on the forearm and the third close to the shoulder and held in position by Velcroed straps (Figure 3).

The three accelerometers capture the movement of the analyzed region during rest or otherwise, the speed and direction of movements, at all times.

After acquisition, data are sent to a differentiator circuit, where the initial potential (offset potential) is close to zero; during the second phase data are sent to a low-pass filter [15], where noise is minimized and input potential is amplified in order to increase the voltage potential band analyzed. The operational amplifiers generate a Chebyshev low-pass circuit with an input voltage potential gain of eight times with a 50Hz cut-off frequency [16]. This voltage potential gain facilitates the analysis and conversion of analogical to digital data given that data will be represented with a maximum of 8 bits. This is illustrated in Tables I and II.

Afterwards, the treated data are sent to a micro-controller, where they are organized and orderly sent to the PC via an USP port [17].

2) Software Project: This phase consists in receiving, graphically displaying, analyzing and comparing the digital signal to pre-established movement digital signals with a meaningful concept output to the user.

Therefore, software was developed which is capable to graphically displaying the movement made by the user, who should try to mimic a pre-established movement generated by the system administrator and presented to him.

Firstly, the user visualizes on the computer screen his pre-established handicap motor movement to be performed. After acquisition by the accelerometers, the data are processed.

In the first step, the data are submitted to a differentiator circuit where the initial circuit potential (offset potential) is compared to a potential generated by a potential divider circuit with an output potential close to zero.

In the second step, these potentials are submitted to a low-pass filter with a cut-off frequency of 50Hz to filter out noise and generate eight-fold amplification in order to be analyzed and converted to digital signals by the micro-controller.

In the third step, the generated signal arrives at the micro-controller, where all signals are organized according with each accelerometer and the axis read, and then transformed to the digital format. In the micro-controller, a signal input-output routine was developed using the C programming language.

The newly received information is sent via the USP port to a PC by a USB serial convector cable.

In the final step, the software handles the information. The data are first captured and graphically presented in agreement with the movement performed by the user.

C. Results of Step 4 - Information Analysis

After the movement has ceased, the software evaluates the values obtained and compares them to the values of pre-established movements stored in the database.

Finally, a concept (comparison with what is already stored in the database) or diagnosis is given to the movement and thereafter the movement may be repeated or the user may perform the next movement.

D. Experiments

The software developed with JAVA programming language [18] under the NETBEANS development platform [19] controls the input of digitally transformed signals and presents them in a graphic form.

In addition, the software posses a database where the movements to be repeated by the user and the user own movements are stored in order to proportionate a comparative analysis amongst the movements performed during the patient's (user) rehabilitation.

The proposed tool is also capable of comparing the last movement performed by the user to the pre-established movements stored in the database and return a diagnosis (concept). In this way, the user has the option of repeating or advancing to the next movement. Given that all information is stored in the database, the user has the option of recording this information in portable digital media to be taken to other professionals of the medical area.

The testing phase was carried out after the completion of the project implementation phase.

The differentiator circuit output band results obtained during the testing phase are shown in Table I. These results are the average values regarding all the three axis exactly as it is supplied from our accelerometers. In this case, it's possible to see that our zero value would be in 300 millivolts and that way we can notice that always that the value is below 300 mV it means that the arm is moving against the axis and above it towards the axis. For example, if we have the X axis representing the vertical movement and when the arm is moving left, we have a value varying between 100 mV and 300 mV. When the arm is moving right we have this value between 300 mV and 500 mV, depending on the movement velocity.

TABLE I. POTENTIAL VALUES OBTAINED AFTER THE USE OF THE DIFFERENTIATOR CIRCUIT.

Type/shape of movement	Potential (mV)
Still arm	$\approx$ 300
Towards the axis	Between 300 and 500
Against the axis	Between 100 and 300

In sequence, we used a Chebyshev low-pass filter and then a signal amplifier circuit to improve these signals. With this technique, an eight-fold gain was obtained and the electrical noises were lowered. Our final electric results obtained from the micro-controller input are shown in Table II.

TABLE II. POTENTIAL VALUES OBTAINED FROM THE MICRO-CONTROLLER INPUT WITH THE USE OF A FILTER AND WITH A GAIN OF EIGHT-FOLD.

Type/shape of movement	Potential (V)
Still arm	$\approx$ 2,4
Towards the axis	Between 2.4 and 4.0
Against the axis	Between 0.8 and 2.4

From the values obtained with the proposed device and displayed in Table II, it is possible to calculate the velocity of the arm movement.

Figure 4 demonstrates the values received from three axes of an accelerometer when strapped to the patients wrist while the calibration is running. Note that as expected, the value that represents an arm while not moving is not the same as the electrical value presented in the Table 1 and Table 2. This occurs because the microprocessor delivers us values between 0 and 255, based on its input voltage. That way our software can estimate the velocity and position using a simple conversion routine. Equally, we can understand, the three calibration values obtained after a hundred rounds will be looked at as our zero value.

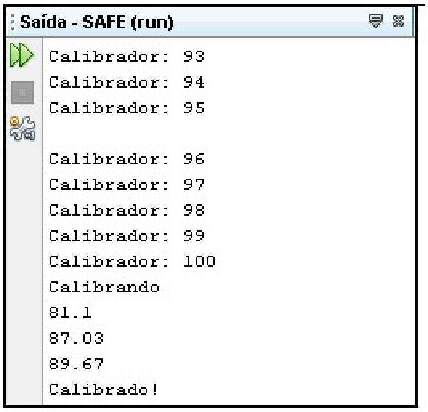

Figure 4. Calibration values from the first accelerometer's three axes, during a test.

Figure 5 illustrates the moment when the user executed a software pre-established movement.

Figure 5. Movement being executed by the user. The movements activate the Mario doll on the path to find his beloved.

The user can repeat the movements as many times as it is necessary and in the same way, the user can see the executed movements during the previous steps. On the screen, the data of the movement carried out by the user can be visualized based on the position related to the axis x and y with the time spent on it (see Figure 6).

In the future work, it will be possible to show the movement in 3D because we already have read the z-axis. However, it will demand one more advanced interface and it will require more powerful equipments.

The result of calculations performed by the software is

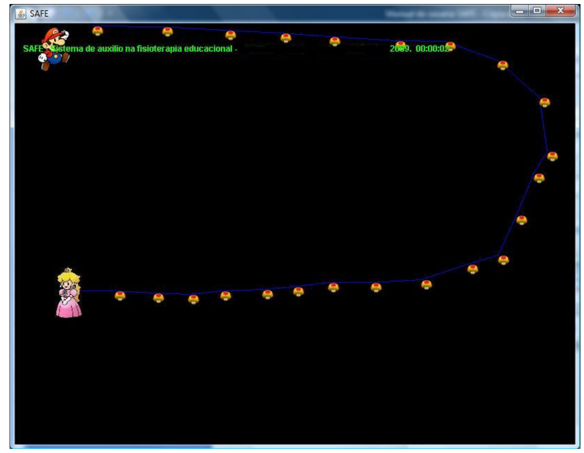

Figure 6. Another example of movement being executed by the user, more simply, Mario to his beloved.

a smooth movement and reflecting precisely the user performance. This makes the use of this tool a viable option for physiotherapy and revealed several improvement opportunities and new applications.

The potential values obtained are translated into a visually comprehensible screen readout, which allows a satisfactory interaction between patient and software output.

V. Conclusion

After the end of testing and performance proofing of the proposed device, named SAFE, we understand that it is a prototype that still needs further improvement in order to have its use in the physiotherapy field.

The biggest hurdle faced in this project was to obtain knowledge of this new technology and its implementation within the academic environment, i.e. the accelerometers. In spite of their presence as portable devices in the market place, these tools still lacks specialists. This prompted us to search for help and assistance from companies and experts abroad and illustrated how complex and painstaking the search for new solutions for the problems faced within this project are.

When analyzed from the academic point of view, we believe that the project proposal was successfully achieved. This conclusion stems from the ability to communicate and present the data obtained and from the employment of the information obtained. Besides, we believe the results obtained here will stimulate a great spectrum of future opportunities of implementation based on this solution.

Given that the programming language used here is considered slow by many when compared to more traditional languages, we believe we managed to make JAVA programming language an ally in the task of showing the user, in a visual way, the arm movements to be used in physiotherapy treatment.

It is worth mentioning that the results here obtained from the executed tests with the accelerometers should present better results when a newer generation of devices are used. This move will allow a lesser compensation from software to hardware deficiency and allowing a more precise and faster communication and processing of information.

There is no complexity in the hardware used and this allowed our experience to be of an easier nature and helped us to elaborate new solutions to the problems faced, in addition to making this project more viable and economically advantageous.

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