Abstract

One of most important aspects in neuromotor rehabilitation, is the need for the patient to having a feedback about the success of performing exercises prescribed by the therapist. This feedback is commonly carried out by therapist, telling the patient if they realize their exercises correctly; however this process is subject to the appreciation of the therapist and the patient. On the other hand, recent studies show that vibrotactile biofeedback is a very useful tool in the physiological process of neuromotor rehabilitation. This work presents the design, construction and evaluation of the operation of a remote system of neuromotor rehabilitation of the upper limbs using active markers and image processing. The purpose of this system is to assist patients with injuries to shoulders, elbows or wrists, providing a feedback audio-vibrotactile as a factor of correction in the movements of the patient. The system has a graphical interface for the user to set the length of the session and to detect the correct position of the active marker; it will display both the number of hits, as the average time between them. Currently test was performed with eight different patients, taking an accurate measurement of patient outcomes in different sessions.

Keywords: Neuromotor rehabilitation; Vibrotactile biofeedback; Image processing; Neuromotor stimuli

1. Introduction

According to the 2010 national census, 5.1% of the Mexican population suffer from some kind of disability [1], being the motor disability, the most common (58.3% of the total number of persons with disabilities); in the world, about 15% of the world population live with physical disabilities [2]. The motor disabilities are divided into two groups, the thick motor disability and fine motor disability. The first group of disabilities causes movement problems associated with strength, speed and balance, in activities such as: walking, running, jumping, crawling, etc. In the second group are the problems where coordination and high precision are needed, making it difficult to undertake activities such as writing, punching, threading and movements that need good eye-hand coordination [3]. The neuromotor rehabilitation process is based on the concept of neuroplasticity, this concept offers the possibility of improving the performance and neural capabilities of patient, and it is also considered as the biological basis that supports the rehabilitation of cognitive functions that are lost due to brain damage, is defined as the science that studies the whole neurons, the structure of their networks and their role through new experiences. This is achieved through rehabilitation routines that are based on the repetition of a motor activity,
with the objective of transmitting an incentive to patients and perform a re-association of neurons to the movements of the affected limbs [4].

Rehabilitation for the motor disability, joint passive exercises (exercises that the patient does not perform voluntary) and active exercises (the patient performs movements to exercise the affected muscle or limb) [5], in order to improve the condition of the patient, as well as try to integrate the movements into the daily social activities.

It should be noted that both, image processing and vibrational feedback conventionally are used in virtual reality systems to improve the quality of user interaction with the system [6], as telemannipulation in 3D [7], however, image processing is one of the tools that has recently been used to help the rehabilitation of patients. Whether analyzing medical images of different lesions [8], or using markers and assets to monitor recovery and improve mobility in the family environment of patients with accidents, strokes and more complex systems that include rehabilitation through robotic systems [5]. On the other hand, various studies have been published that argue that the vibratory stimuli during the rehabilitation process produces excellent results, and not only as therapy muscle or bone through the principle of reflex muscle contraction [9], or to provide a sensory increase [10], but also as a feedback to the user, indicating success or failure in exercises conducted during the therapies that make up the process of rehabilitation [11], this is called vibrotactile biofeedback.

Talking about focused image processing to the rehabilitation, we can find the implementation of tables for the rehabilitation of the upper limbs, by processing of images acquired from a camera, positioned in a perpendicular axis to the table, in the table surface unfurled a set of trajectories, and using a passive marker defined the movements of the user [12]. There are some works about vibrational feedback, focused on patients with problems of vestibulopathy, using sensors of tilting and feedback for the correction of the position [13]. In a similar way, tri-axial accelerometers of a cell phone are used to evaluate the slope of the patient, by activating the pulse vibrotactile from the connector of the cell phone earphones [14], experiments proposed for this type of equipment is performed via a platform of random movements [15]. In the other hand The applications of systems that integrate vibration pulses, bright or acoustic signals as well as image processing are commonly in virtual and augmented reality [16], and it is possible to integrate sensors and magnetic actuators to be considered as a vibratory stimuli factor [17]. In the same way a planar robot can be used to perform a more successful rehabilitation [11].

This paper presents a system for rehabilitation by active movements, and for this reason, in this work a system that operates remotely was developed, the system uses active markers and image processing to interact with the user through activities such as monitoring of zones established in a graphical user interface, using a audio- vibrotactile biofeedback system, based on communication by radio frequency avoiding to reduce the user movements. The interface detects the incidence of the active marker within the target area, assessing not only the number of incidents in established areas, but also the speed, accuracy and difficulty of the toolpaths programmed for the rehabilitation of the upper limb section. The equipment has been designed to operate with patients between 15 to 45 years old and in a height range of 1.60m to 2m.

2. Development of the system

This section describes the design, integration and operation of the system for neuromotor rehabilitation. This system uses an indicator asset placed on the palm of the hand; it also has a system of control and communication in the back. The entire system is divided into two modules: active marker and a graphical interface to interact with it. Active marker module (Figure 1a) consists of a control system whose main component is a PIC6F628A micro controller, charged of light activation, vibration and sound signals, that are indicators of success and error within the sessions of rehabilitation, the electronic circuit also controls communication by radio frequency, with a personal computer. Figure 1b shows the stages of the second module, corresponding to the graphical user interface that carry out the processes of acquisition and processing of images, necessary for the location of the active marker (coordinates $x_m$ and $y_m$), and finally comparing the position of the marker with the target zones (coordinates $x_t$ and $y_t$).

The operation of the system begins in the graphical interface, by setting the number $n$ of areas that the patient must reach and coordinates $x_t$, $y_t$ in each of these areas as well as tolerance $\epsilon$ given by the size of the area (by reducing the size of $\epsilon$, undertakes to carry out more precise movements). This process is done by the therapist, according to the type of injury and needed rehabilitation. Once the initialization stage is done, the system starts finding the spatial location of the marker. This is iteratively captured an image with the current position of the active marker, this process is carried out at 30 fps. Subsequently evaluates the $x_m$, $y_m$ marker active on the screen position and $x_t$, $y_t$ of zone $i$ is compared with the determined position, if the marker is not within the area of zone $i$, a signal is sent by radio frequency for activation of vibration of the
marker in the Palm of the user, indicating that it is not in the position required for the exercise, when the user active marker is located in the requested area, the systems activates an audible signal and sends a signal for cancelling the vibration, indicating that the first objective of the exercise was completed, and establishing a new zone until the end of exercise. At the end of exercise the system evaluate both the time and the accuracy of the user's movements. Figure 2a describes the flowchart of the behavior of the graphical interface of a simplified form, and the graphical user interface, made for this system is shown in Figure 2b, it shows the graphic interface of the user, made for this system.

Fig 1. (a) module of the active marker; (b) module of the graphic interface

2.1. Graphical user interface

The main function of this module is managing the course of rehabilitation exercise, since it regulates the video frame capture; the establishment of the target zones, in which the user must position the active marker; and sends the enable/disable signals to the marker. This interface is designed on the platform of Matlab, using the image acquisition toolbox.

One of the initial tasks of the interface, is the definition of how many target areas will be used during the session, as well as image capture, and secondly the processing of the captured images to locate the active marker on the screen, then laying down the target areas, for the assessment of the user's movements during the period of rehabilitation, it is worth mentioning that the points to evaluate by the interface, is the fulfillment of the conditions of the target areas that are involved in the exercise, and the speed with the user reaches in a satisfactory manner each one of them.

The acquisition of the images is done with a webcam with a maximum resolution of 1.3 megapixels and a capture rate of 30 fps. To increase the speed of capture and processing of the images and that the system can operate in real time, capturing images is done with a resolution of 320x240.

Fig. 2. (a) Flowchart of the graphic interface of a general way; (b) graphic user Interface
Where $v_b$ is the activation variable vibration function, $s_d$ is the variable activation of the auditory signal, $m_k$ is the active marker variable, $Z_1, Z_2, Z_3, Z_4$ are the positions which the user must reach, $c$ is the counter assigned to the increased number of zones or the change from one area to another when this is accomplished.

Once the current image has been acquired, the image processing is performed; it takes into account the features of active marker (shape and color). In this way, since it uses an ultra-bright blue led as marked, the identification of the color in the RGB original image (Figure 3a) takes only the blue matrix (Figure 3b). In addition, to identify the brightness level, the equation (1) transforms the RGB matrix in a HSV matrix (Figure 3f) and takes the negative of matrix $S$ (Figure 3h) [18].

$$
H = \begin{cases} 
\frac{g-b}{\max(r,g,b)-\min(r,g,b)}, & s_i r = \max(r,g,b) \\
\frac{b-r}{\max(r,g,b)-\min(r,g,b)}, & s_i g = \max(r,g,b) \\
\frac{r-g}{\max(r,g,b)-\min(r,g,b)}, & s_i b = \max(r,g,b)
\end{cases}
$$

$$
S = \frac{\max(r,g,b)-\min(r,g,b)}{\max(r,g,b)}
$$

$$
V = \max(r,g,b)
$$

In this way a binarization of the arrays is performed to $B$ matrix (Figure 3c) and $S$ matrix (Figure 3h) applying the automatic Otsu method, which considers an optimal threshold when the variance between classes (2) gives a minimum value.

$$
\sigma_p^2(t) = P_1(t)\sigma_1^2(t) + P_2(t)\sigma_2^2(t)
$$

Where $P_1$ and $P_2$ are averages for class. Matlab offers the graythresh() function to perform the binarization through the Otsu method to the arrays $B$ (Figure 3b) and $S$ (Figure 3g).

Finally both images are smoothed with the equation (3), to avoid discontinuities.

$$
i'_{x,y} = \frac{1}{k} \sum_{(x,y) \in S(x,y)} i(x,y)
$$

Where $k$ defines the size of the window used for the smoothing of the image, $i'$ is the value of the pixel smoothed by averaging filter and $S$ the set of pixels in the neighborhood of the treated pixel $i$. Figures 3d and 3i shows the result of smoothing $B$ and $S$ matrix respectively.

Finally the resulting images are combined with an “and” logical function to detect the blue highlights of the image (Figure 3e). Finally it is necessary to find the circular objects that represent the active marker. To carry out this step, Matlab allows the labeling and identification of the objects found in the image by using functions like label() and regionprops() respectively. In a future work the segmentation using the Canny algorithm [19] and the Hough transform [20] will be used for its implementation in another computational platform.

Once the identification of the circle corresponding to marker (Figure 3j), the $x_m$ and $y_m$ coordinates (the centroid of all circle points) are calculated by equation (4).

$$
x_m = \frac{\max(x)-\min(x)}{2} \quad y_m = \frac{\max(y)-\min(y)}{2}
$$

Finally the Euclidean distance $d$ between the centroid of the marker located in the $x_m$, $y_m$ and the target point $x_t$, $y_t$ is computed (5).

$$
d = \sqrt{(x_t - x_m)^2 + (y_t - y_m)^2}
$$

If the $d$ distance is greater than the $\varepsilon$ tolerance, it means that the patient has not yet reached the requested position, giving way to the appropriate action, and the vibratory stimulation on the marker is sent. When $d$ is less or equal to $\varepsilon$, an auditory stimulus is sent the patient to indicate that it has reached the desired point, the system increases the value of the objective area and the procedure is repeated until all target points are locate.
The last stage is the control of the signals that are transmitted in the course of the session, using RF communication for the activation of the stimuli which has active marker module. To sending and receiving data in a serial way, the system performs a bi-directional communication in Matlab, where it sets the port of communication, speed in baud and parity.

2.2. **Active Marker**

Active marker consists of a control panel, a group of high brightness blue leds, which establish the point of lighting that will be evaluated by the capture of images, the vibratory stimuli, the auditory stimuli and communication module radiofrequency (Xbee series 2), with an operating frequency of 2.4 GHz, with a current consumption of 40mA both reception and transmission and a distance of 40 - 120 m. In addition to its low power consumption, these modules are low-cost, versatile and simple to use in various topologies. Because of these reasons, the XBee modules were chosen instead of Bluetooth or Wi-Fi technologies. The protocol used for the communication of the modules, is the Zigbee Protocol, a network point to point, with topology star. As it was mentioned above, the function of the control board is the receiving instructions from the graphical user via RF communication interface, subsequent to the evaluation of the position of the marker asset, in order to enable or disable both vibration signals and the hearing as determined success or error by the interface by receiving the signal, setting up a feedback between the system and the user, with the end of a substantial improvement in the accuracy and speed of the movement highlighted in the course of the session of rehabilitation. Figures 4a and 4b shows the control circuit diagram and active marker.

3. **Results**

Rehabilitation sessions were performed by 8 users, 4 of them were already in rehabilitation for shoulder injury (sprains, strains, dislocations, separations, tendinitis, bursitis, rotator cuff tear, frozen shoulder, fractures, etc.), and the rest of the users are healthy people, in order to establish a comparison between the results of both groups. The duration of sessions was 30 minutes; the system saves the collected data that consist on the number of the target zones achieved by each user, as well
as the average elapsed time between the successes of reaching each zone. In the course of rehabilitation sessions there was presented a noted increase in the average speed between areas of patients with injury, as well as in compliance with the number of zones, while in healthy people, the variations were not significant. Table 1 shows the results of average elapsed time between the achievement of objectives (reference zones) of the 8 users at the first session and at the final session, as well as the number of reached targets in both sessions.

<table>
<thead>
<tr>
<th>Users</th>
<th>average time between marks(S1)</th>
<th>average time between marks(S10)</th>
<th>Number of marks(S1)</th>
<th>Number of marks(S10)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Patient 1</td>
<td>18.3 seconds</td>
<td>10.1 seconds</td>
<td>10/20</td>
<td>18/20</td>
</tr>
<tr>
<td>Patient 2</td>
<td>21.6 seconds</td>
<td>12.7 seconds 9.7</td>
<td>8/20</td>
<td>15/20</td>
</tr>
<tr>
<td>Patient 3</td>
<td>17.1 seconds</td>
<td>seconds</td>
<td>12/20</td>
<td>17/20</td>
</tr>
<tr>
<td>Patient 4</td>
<td>15.8 seconds</td>
<td>8.6 seconds</td>
<td>14/20</td>
<td>19/20</td>
</tr>
<tr>
<td>healthy user 1</td>
<td>8 seconds</td>
<td>4.4 seconds 5.1</td>
<td>20/20</td>
<td>20/20</td>
</tr>
<tr>
<td>healthy user 2</td>
<td>7.4 seconds</td>
<td>seconds 4.3 seconds</td>
<td>20/20</td>
<td>20/20</td>
</tr>
<tr>
<td>healthy user 3</td>
<td>6.6 seconds</td>
<td>4.2 seconds</td>
<td>20/20</td>
<td>20/20</td>
</tr>
<tr>
<td>healthy user 4</td>
<td>6.7 seconds</td>
<td></td>
<td>20/20</td>
<td>20/20</td>
</tr>
</tbody>
</table>

The sessions were planned for a period of three and a half weeks, with a frequency of three times per week and lasting approximately 30 minutes per session, with two periods of rest during the exercises, one every 10 minutes. Figure 5 (a) shows the user interface during the first session of rehabilitation.

![User Interface](image)

![Graph of Results](image)

Fig 5. (a)Healthy user during a session with the auxiliary system of rehabilitation of the upper limb; (b) Comparative graph of the results obtained from the average of time.

Figure 5 (b) presents the results of the progress of the sessions, through the graphing of the average of times of the healthy users (blue line), and the patients in rehabilitation (red line), by every realized session.

4. Conclusions

Taking into account the rate of motor disability of the upper member, both locally and globally, a system for help in neuromotor rehabilitation of the upper limb was done, the obtained results shows that the increasing in the speed of patients who attended the sessions of rehabilitation was notorious, as well as the success of a greater number of areas, and an increase in range of motion of affected extremities, and with this, an increase in the recovery speed of the users. Additionally it may be noted that the decrease in the average time for the Group of patients in rehabilitation, was higher in healthy patients, along the 10 sessions, fulfilling the objectives pursued by this system in this first stage, in future works, it is pretended to include more levels of difficulty, as well as defined paths in order to give as fulfilled each zone and a greater number of patients during the sessions to be able to have more reliable statistical data. It is important to note that at this moment the system can operate in a range of distance from 1.5 to 2.0 m, another consideration is that, in order to avoid problems of recognition of the active marker, the ligh of the room where test are performed must be controlled.
Acknowledgements

This work was supported by the General Council of Superior Technological Education of Mexico (DGEST). Additionally, this work was sponsored by the National Council of Science and Technology (CONACYT) and the Public Education Secretary (SEP) through PROMEP.

5. References