Arm paresis is a very common disability among post-stroke survivors. It is characterized by the inability of a person to perform some specific movements in the arm. A Long term Rehabilitation process plays a key role in the recovery of this kind of disabilities, but such treatment might not be easily accessible to people living away from the cities where most of the rehabilitation centers are located. In this paper, we present our interactive rehabilitation system called "E-Glove" that is aimed to help patients with wrist impairments to perform some daily exercises in a joyful and interactive manner. A 2D golf game that could be played with the glove was developed for this purpose.

Index Terms— Rehabilitation, Tangible user interface, Multimedia, Haptic.

1. INTRODUCTION

Stroke is one of the leading causes of death in the world and of disability in the developed nations [4] [6]. In a recent study, the American Heart Association revealed that more than 795 000 Americans suffer a stroke or a recurrent stroke per year [10]. In a similar study done in 2007, the Health Agency of Canada suggested that 1.3 million Canadians were diagnosed with heart disease and about 300,000 Canadians were living with post-stroke effects [7].

Following stroke, most survivors suffer major disabilities in their functional motor capabilities and become unable to maintain their daily life activities. Arm paresis is very common among stroke patients [8]. It is a neurological syndrome that results in a severe to mild partial loss of movement in the arm. These losses include the inability to move the forearm in the supination and pronation positions, and the wrist in the palmar-flexion and dorsi-flexion ones (figure 1). In order to treat these disabilities, the patient has to go through a long-term rehabilitation process.

Repetitive task training is considered as an effective form of rehabilitation for people with post-stroke impairments. The goal of stroke rehabilitation is to enable the patient to get the highest levels of independence and to help him/her to be as productive as possible. This is done by developing strength, flexibility and balance in the injured segments of the body. Research has revealed that duration, capacity, and intensity of the training session have a huge impact on the motor rehabilitation improvement [9]. However, respecting the guidelines of a long term rehabilitation process might be problematic for many people due to many reasons. For instance, people living in the country side might find it very difficult to frequently travel to the rehabilitation centers that are mostly located in the cities. In addition, a long term rehabilitation process might be very expensive and unaffordable for many people who don’t have adequate public or private insurance. Consequently, patients might decide to stop the treatment, and lose their chances of having a normal life. These reasons have motivated the developers to design innovative rehabilitation tools and systems that could be used at home and that allow the therapist to remotely monitor the progress of the patient through networked systems.

In the case of arm injuries, Therapists recommend some stretching exercises to be performed on a daily basis. Some of them include range of motion (ROM) exercises such as flexion/extension of the wrist and fingers, and pronation/supination of the forearm. Others include speed of motion exercises such as opening/closing the hand, or turning right/left the wrist as fast as possible. Researchers have designed various systems aimed for different types of arm impairments and that target each specific parameters of training depending on the patient’s needs. For instance the authors in [13] have designed a robot to assist in the rehabilitation of shoulder and elbow of stroke-patients. In another work, Dovat [14] developed a two-degree-of-freedom interface for rehabilitating the hand grasping of the patients.

In this paper, we present our system called “E-Glove” that targets post-stroke patients with wrist disabilities. In contrast to the existing work done in the rehabilitation domain, our system provides a cost-effective home rehabilitation solution for patients in general, especially those who live far away from the treatment centers. In addition, the system extends the functionalities of the current passive rehabilitation devices by transforming them into digital ones that could be used as interfaces with computer games designed for training purposes. Our E-Glove consists of a regular glove mounted with an
accelerometer that helps track 6 types of forearm and wrist motions. These motions are recommended by the therapists for improving the wrist movement [15]. They consist of the wrist ulnar deviation, radial deviation, palmar-flexion (extension), dorsi-flexion (flexion), and the forearm supination and pronation motions (Figure 1). The glove is also mounted with a couple of actuators that provide vibrotactile feedback depending on the state of the game. The glove is associated with a software golf game that requires the patient to make appropriate wrist motions in order to drop the ball in the hole.

The rest of the paper is organized as follows. Section 2 briefly comments on some related literature, Section 3 details the proposed system, Section 4 shows the implementation details, Section 5 shows the proof-of-concept evaluation, and finally Section 6 draws the conclusion and our future work.

![Fig.1 The motions of wrist and forearm supported by the E-Glove](image)

2. RELATED WORK

Using the Cyber-glove and the Rutgers Master II-ND (RMII) force feedback glove coupled with a computer based virtual reality simulations, Jack and his colleagues [2] developed a rehabilitation system for hand and finger rehabilitations. The VR simulations take the form of simple games that encourage and challenge the patient to perform a number of trials of a certain exercise. Four different exercises which aim at improving the range, speed, fraction and strength of the hand movement were incorporated in the system. The intensity of the training is automatically manipulated within the system depending on the performance feedback of each user. The system was tested by three chronic stroke patients over a 2 week period. The results showed an improvement in the hand movement of the patients when tested with the Jebsen and Fugl-Meyer tests. Alamri [11] used the Cyber-glove to evaluate his haptic-based rehabilitation framework aimed to rehabilitate patients with arm impairments. The system is comprised of five virtual games that were designed to test certain abilities of the patient. These games include the following exercises: handling a cup, arranging blocks, navigating a maze, squeezing a ball, and dumbbell training. The main disadvantage of the Cyber-grasp devices when used in rehabilitation is related to its bulky shape which limits the position of the patient during the training. Another disadvantage is concerned with the relatively high price of the device; therefore, it is not affordable for many patients and, consequently, it is not a candidate device for home usage.

Hilton [1] developed a virtual reality system that is based on the concept of performing a daily life activity, specifically coffee making. For this purpose, he used a tangible user interface approach which consisted of mounting the kitchen tools required for making coffee (such as spoons, cups, jars etc…) with sensors that enable the detection of the patient’s actions. For instance, a light sensitive switch was mounted inside a coffee jar in order to detect the activity of opening the jar’s lid. The tangible objects are associated with a virtual environment that represents virtually the same real objects. The actions performed by the patient are actually mapped with the virtual objects in the VE.

Exploiting the high computational performance of the existing game consoles, Morrow [5] used an Xbox to design his VR hand rehabilitation system. Morrow’s main goal was to use off-the-shelf cheap and efficient devices to develop a portable rehabilitation system that could be easily used in both clinics and homes. The author used an Xbox instead of a computer to run the virtual reality graphics by making some hardware and software modifications to the console. A P5-glove that measures the flexion of the fingers and the wrist position was connected to the Xbox instead of the regular joystick. Two games were developed to encourage two types of rehabilitation training: the finger ROM and the finger velocity games. In the finger ROM game, the patient has to uncover a screen that conceals an image by flexing his/her fingers, except the thumb. The image is uncovered in proportion to each finger flexing motion. Now in the finger velocity game, the patient has to flex his/her finger from a flat position to a fist as fast he/she can in order to meet a certain threshold that makes a virtual butterfly circling a palm flies away.

In [3], Piron has developed a tele-rehabilitation system that allows the therapist to create different trajectory training patterns that the patient has to follow. Consisting of two PC workstations, one located at the patient’s home and the other at the trainer’s location, the system enables the therapist to create different sequences of virtual tasks by detecting the object movements that he/she performs through the 3D motion tracking system. The therapist’s movements are then recorded as training tasks and transmitted to the patient who
has similar tracking technology on his/her station. The virtual tasks consist of different movements such as pouring water from a glass, using a hammer, and turning around the center of a doughnut. The complexity level of the task is to be determined by the therapist depending on the recovery pace of the patient. In another work, Holden [12] based his framework on the tracking technology associated with a VR editor that enables the therapist to create a VR training exercise which fits the patient’s therapeutic needs. The framework currently consists of 20 tasks, each with more than one level of difficulty. Each task has a pre-recorded trajectory which visually guides the patient to correctly perform the motion required.

3. SYSTEM DESCRIPTION

In this Section we provide the detailed design of each module of the proposed system.

3.1. Overview

The main idea of the proposed system is to translate the wrist exercises of the patient into interactive gaming actions meant to provide entertainment, and thus motivate him or her to spend more time exercising without feeling quickly bored. The human arm structure is composed of seven degrees-of-freedom, and therefore it is very difficult to detect all its movements when moving freely in the air. However, with a fixed arm, it is possible to detect the wrist movement in the x and y axis. By properly mounting the accelerometer on the glove, the pitch (rotation around y axis) and roll (rotation around x axis) motions could be sensed with the use of a 3D accelerometer. To achieve our interactivity goal, we integrated multimedia technologies to the system. Research revealed potential benefits of multimedia when used in physical therapy [11]. For this reason, we have incorporated music in our game, and we triggered some haptic vibrations for indicating a successful ball drop. Figure 2 shows the overall system architecture with the various components involved. The functionality of each module is explained in the subsequent sections.

3.2. Communication Module

This module provides a full-duplex communication between the sensors mounted on the Glove (hardware) and the computer game (software) through a RS232 cable. Its main duty is to receive and transmit data between the micro-controller and the computer.

3.3. Game Controller Module

The game controller receives the rotation measurements on the x and y axes from the E-Glove interface and use them to control the ball movements in the game. The pitch and roll values received are converted to a proportional velocity vector that displaces the ball in a 2-dimensional world. For instance, the bigger the pitch rotation angle is, the faster the ball travels on the Y axis. A low pass filter is applied to the values received in order to smooth out any sudden changes in the ball velocity and therefore allow for a more realistic experience. In addition, the Game Controller transmits commands to the vibro-tactile motors whenever a ball gets accurately into the hole.

3.4. Sensory Data Manager

This module constitutes the heart of the system. The tasks accomplished by this module could be described by the following:

3.4.1. Sensory data analysis

Upon receiving the digitized raw data from the 3D accelerometer, the Sensory Data Manager analyzes them to determine the appropriate tilting angles on the x and y axis. The accelerometer provides a vector of voltage gains output for each of the x, y, and z axes; however, the tilt angles can be only determined on the x and y axis due the sensitivity resolution problems encountered in accelerometers. The acceleration on each axis is related to the voltage gain, voltage offset, and the accelerometer's sensitivity, and can be determined with the following equation:

\[
A_{(x,y,z)} = \frac{V_{\text{out}(x,y,z)} - V_{\text{off}(x,y,z)}}{S_{(x,y,z)}}
\] (1)
where \( A \) is the acceleration calculated on a specific axis, \( V_{out} \) is the output voltage gain of the accelerometer, \( V_{off} \) is the offset voltage measured on each axis when the accelerometer is perpendicular to gravity, and \( S \) is the sensitivity of the sensor provided by the manufacturer.

Once the accelerations on the three axes are known, the pitch and roll angles could be calculated by equations (2) and (3) respectively:

\[
\text{Pitch} : \alpha = \tan^{-1} \left( \frac{A_y}{\sqrt{A_x^2 + A_z^2}} \right) \tag{2}
\]

\[
\text{Roll} : \beta = \tan^{-1} \left( \frac{A_z}{\sqrt{A_x^2 + A_y^2}} \right) \tag{3}
\]

It is worth noting that the roll angle represents the pronation/supination motions exclusively. However, the pitch angle will represent either the palmar-flexion/ dorsiflexion motions or the ulnar/radial deviations. This is due to the fact that those 4 movements always occur in the \( y \) axis and can never be done simultaneously. For instance, while performing a pronation/supination exercise (move the ball right or left), the patient can only do palmar-flexion/ dorsiflexion motions (move the ball up and down). Another option would be to do first the ulnar/radial deviation movements (move the ball up and down) and then the pronation/supination ones.

3.4.2. Data Relaying

On the first hand, this module relays the data between the accelerometer and the game controller once they are computed by passing them over to the Communication Module. On the second hand, it sends the appropriate activation signals to the vibro-tactile actuators whenever a command is received from the Game Controller.

4. IMPLEMENTATION

Our system is comprised of both software and hardware components that are described in the following sub-sections:

4.1. Game Design

The software game was developed using the Java Eclipse on a windows 7 platform. The Java swing library was used to create the 2-dimensional graphics, while the rxtx library was deployed for serial communication between the microcontroller and the computer. Figure 4 shows the game when played by a subject.

4.2. E-Glove interface design

We have used a regular Glove mounted with a triple axis ADXL 335 that reads the tilt angles. The output of the accelerometer is passed through a low pass filter for anti-aliasing and noise reduction. After appropriate filtering, the accelerometer was connected to an Atmega 168 microcontroller on an Arduino Duemilanove board. On the microcontroller a C program was developed to provide a pitch and roll angle measurement readings between -90° and +90°. To provide the vibro-tactile feedback, we have chosen two low voltage (3V) vibration motors that were positioned on the top of the Glove over the hand area. Figure 4 presents the E-Glove front and back view with the various components mounted on it.
5. PROOF-OF-CONCEPT EVALUATION

The goal of the proof of concept evaluation is to ensure that the E-Glove interface is properly simulating the 6 types of movements that were mentioned earlier in the paper (See figure 1), and therefore achieving a proper rehabilitation exercise.

5.1. Experimental set up

An early version of the E-Glove system was tested in the Discover laboratory at the University of Ottawa. We have invited 10 healthy subjects, 8 males and 2 females, age 26-35, to play a game session. During each session, the forearms of the players were strapped on the chair's arm and the system was calibrated, and each player was required to drop the ball in the hole for 10 consecutive times. Figure 4 shows a subject playing a game during one of the sessions.

Table 1 Exercises allowed by the glove

<table>
<thead>
<tr>
<th>Exercise</th>
<th>Normal ROM</th>
</tr>
</thead>
<tbody>
<tr>
<td>Flexion</td>
<td>70°-75°</td>
</tr>
<tr>
<td>Extension</td>
<td>70°-75°</td>
</tr>
<tr>
<td>Pronation</td>
<td>70°-85°</td>
</tr>
<tr>
<td>Supination</td>
<td>70°-85°</td>
</tr>
<tr>
<td>Ulnar Deviation</td>
<td>20°-35°</td>
</tr>
<tr>
<td>Radial Deviation</td>
<td>20°-35°</td>
</tr>
</tbody>
</table>

5.2 Results

We have captured the ROM for each participant upon completion of each session. Figure 5 to 7 shows the results obtained for one of the subjects after playing a session with the golf game. These results are compared with the normal ROM of a healthy person for each exercise. Table 1 presents the ROM values in case of a healthy human being. It is worth noting that these values might vary with body habitus, age, and genetic background; however, the following are the most common values.

As can be seen from figure 5, the maximum pronation angle detected is around 81°, while it is 88° for the supination one. Now for the extension and flexion angles, the system detected an angle of 80° in both cases. Finally, a 45° was detected for the ulnar deviation angle and a 39° for the radial deviation. It is obvious that the measured supination angle goes slightly beyond the normal ROM. It is also the same situation for the ulnar and radial deviations.

We found out after the experiments that it is a really challenging task to obtain a reliable reading for all the participants. This is due to the fact that even with proper
initial calibration and arm positioning, subjects will always make some tiny movements that will sometimes have significant impact on the results. As a consequence, we deduced that the performance of the participants with the system should not be based on the angle measurements of their wrists and rather should be based on a game score or other performance metrics that can be evaluated over a period of time.

7. CONCLUSION AND FUTURE WORK

In this paper, we have presented an interactive rehabilitation glove system that is meant to help in the recovery process of patients with wrist disabilities. Our future work will include the addition of a hand pressure mechanism that helps in improving the grasping capabilities of the patients with hand impairments. In addition, a number of games will be developed in 3D environments with different scenarios that provide the patient with performance parameters that reflect his/her treatment progress.

REFERENCES


