Virtual Rehabilitation Arm (VRA)

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ABSTRACT

Robotic rehabilitation is a promising approach to rehabilitation of post stroke impairments. For that reason, a robotic arm is used for the upper-limb rehabilitation of stroke patients. This project is to study, analyze, design and implement a wirelessly controlled manipulator with three degrees of freedom. The manipulator has the possibility to operate in different planes. It allows patients to perform rehabilitation exercises while playing video games. These games are designed based on the rehabilitation protocol taking into account the patient's age, strength, mental condition and the affected regions of the brain. The device is built and tested with a stroke patient under direct supervision of a physiotherapy specialist. The preliminary results demonstrate the importance of the added features such as the inclined plane that is found to correspond to movements needed for daily activities.

1. RECOGNITION OF NEED

From preliminary discussion with several occupational and physical therapists like Dr. Samih Dweik [1], Dr. Akram Amro [2], Dr. Ali Abu-Ghazala [3] and Munther Oweiwi [4], it has been concluded that there is a need for active-repetitive exercises under the therapists' supervision without the necessity of their direct intervention during exercises. However, therapists face a problem in motivating patients who get bored quickly. Patients' motivation is achieved by linking rehabilitation exercises to well-designed computer games. This is done by letting the interaction with the game to be through an active manipulation of a specially-designed mechanism. In rehabilitation exercises, there are other things which are crucial to complete the exercise correctly rather than moving a weak limb without any resistance in the space. For example, strengthening the affected muscles to restore the normal strength. The specially-designed mechanism is needed for strengthening the muscles and increasing their range of motion rather than only motivating the patient. Otherwise the patient could use a computer mouse or a small piece without the need for such a mechanism.

According to physiotherapy specialist Dr. Akram Amro [2], a stroke rehabilitation device must allow the following features: 1) Eye-hand coordination, 2) Combined movements (functional movements), 3) Certain amount of resistance to increase the muscle strength, 4) Completion of visual tasks, 5) Passive movements for some cases.

There are other requirements such as: 1) The device must be safe for both patient and therapist, 2) The device including the game must be suitable for patients of different ages, 3) The device must be convenient for patients with different sizes, 4) Suitable for both body sides, 5) Flexibility in the device. For example, if the patient is sitting on a chair rather than lying in the bed, he/she should be able to use the device [3] and [4].

2. CONCEPTUAL DESIGN AND FUNCTIONAL SPECIFICATION

It is desired to design and produce an electro-mechanical device that relies on computer games as an interaction tool. The process starts when the patient holds the end-effector of the mechanical device with his/her arm as shown in Figure 1 and starts moving in the workspace. Sensors detect this motion and translate the change in position into electrical signals. These sensors are connected to an ARDUINO controller that in turn sends the signals to ZigBee (a special module that allows signals to be transmitted and received wirelessly). The computer can now deal with them as they represent the position coordination in the game that is displayed on the screen, the game could be reaching things for example in which the patient is asked to reach objects that appear sequentially on the screen. Variable loads can be implemented through a linear damper that resists the movement of the patient. The load is changed and controlled by the therapist himself based on the patient situation. The block diagram of the whole system is shown in Figure 2. The device is divided into systems, these are: 1) Mechanical system, 2) Load system, 3) Sensors and interfacing system, 4) Computer and software system.

Figure 1. *The whole system consisting of the mechanical arm which is driven by the patient hand and the computer where the games are displayed.*

2.1. Mechanical Device (block 1)

The design is based on a parallelogram linkage. The main features of this arrangement are: good rigidity of the structure, direct drive of the manipulandum, which eliminates any backlash in the force/motion transmission and minimization the overall inertia, because most of the mass is either fixed, or close to the rotation axes [5]. The parallelogram manipulator choice is based on an open source design called Braccio di Ferro [5].

The original design has two degrees of freedom either in vertical or horizontal plane. A new degree of freedom is added, in this project, to the arm that allows working in an inclined plane. In addition, two important features are added to the device: portability through the wireless interfacing between the mechanical device and the computer and the flexibility introduced by the variable height of the arm to be suitable for all patients.

It satisfies the desired mechanical rigidity (which is the ability to withstand with the load that result in this case from the patient) while maintaining a relatively lightweight frame. The workspace for the device is an elliptical shape with

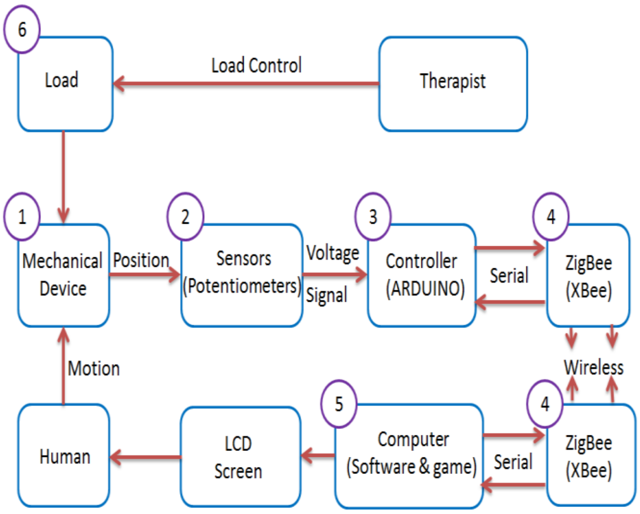


Figure 2. *Block diagram for the whole system.*

800 mm x 400 mm [5] which is suitable for most patients. The device is as well back-drivable with low friction and inertia. The mechanical arm is built using Aluminum and connected to the iron frame by a revolute joint which adds the new degree of freedom. This new degree of freedom provides therapists with three configurations (horizontal, variably inclined and vertical).

2.2. Load System (block 6)

The load system plays an important part in VRA. An increasing load should resist the patient during therapeutic sessions. This load is necessary to increase the strength of the affected upper limbs muscles. To achieve this, the device through a damper resists the patient while moving his/her arm. The patient performs an extra effort to move the hand and with different changing in loads the patient feels the difficulty changing which is related to extra motivation. The changing load is controlled by the therapist himself based on the patient situation.

2.3. Sensors and Interfacing System (block 2, 3 and 4)

As the patient moves the end-effector of the mechanical device, the motion that results in the workspace is detected using motion sensors. The chosen motion sensor must afford a high resolution for determining the accurate position. For this reason, three potentiometers are used (two for the position and the third for the configuration), these sensors translate the change in position into analog electrical signals and provide the information about the absolute position without the need of homing the device before operation. The potentiometers are interfaced with a microcontroller called ARDUINO which through its built in A/D converter converts the analog output of the potentiometers into digital signals.

One important feature of this novel device is portability. To partially achieve that, wireless communication between the mechanical device and the computer is desired. Thus, a special module called ZigBee that allows for signals to be transmitted and received wirelessly is used. ZigBee has two parts: one is connected to ARDUINO and the other is connected directly to the computer. Each part is capable to transmit and receive data at the same time.

2.4. Computer and Software System (block 5)

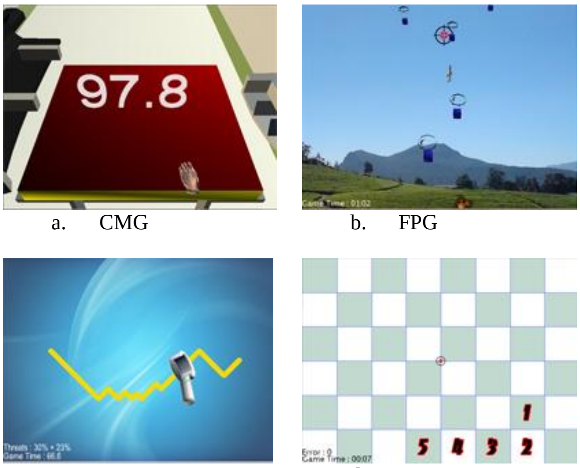
A personal computer is required to host and run interesting games with different levels which calls for interacting with the human through the device sensors and wireless communication module (input) and a game screen (output) and to keep patients' progress. The game requirements are achieved through a capable programming language such as C# that is simple, modern, general-purpose, strong type checking and object-oriented. It is developed by Microsoft [6]. During the game, the compute controls the level of the game and records the patient's progress.

3. SOFTWARE SYSTEM

Every therapeutic session consists of playing different computer games that are designed on the bases of therapeutic protocols. However, one of these games is dedicated to measuring the patient's level and evaluates the progress. It is played at the start of every session. Furthermore, these games help improving the patient's mental thinking if they require the usage of patient's cognitive skills.

This calls for storing and retrieving the patient information and progress. This is achieved by a suitable database management (DBM) system. Moreover, the software system deals with the signals that come from the sensors, and reflect them on the LCD game screen. The software system is divided into four integrated subsystems. Therapeutic Computer Games (TCGs) subsystem consists of four different games. TCGs are designed to achieve eye-hand coordination which is the ability to coordinate the information received through the patient's eyes to control and move his/her arm.

Reaching targets, following paths, and object manipulation are some categories of therapeutic computer games [7]. Here, reaching targets and following paths are chosen for implementation. The difficulty of these games varies from zero to nine, with ten different levels. Collect Money Game (CMG) and Falling Parachutes Game (FPG) are two examples of reaching targets games. Where some targets are shown on the screen and the patient should move to reach them. Steady Hand Game (SHG) and Memorize Path Game (MPG) are two examples of following paths games. The patient must move in a specific path in order to finish the game. These games are chosen and designed as shown in Figure 3.



a. CMG b. FPG

c. SHG d. MPG

Figure 3. *Therapeutic computer games.*

In order to enhance the patient's attention, motivation and motor recovery through brain plasticity, the exercises are required to provide patients with some types of feedback. It could be visual, haptic, auditory and performance feedback. Two screens are used, where the primary screen is for the therapist or for the administrator and the other one is for the patient. The patient cannot see anything except the games, while the therapist can see the games embedded in the window that controls them and allows for choosing the patient account with his/her reports.

Patient's progress can be evaluated by different methodologies. First, according to Section C of Rivermead

Motor Assessment by asking the patient to do fifteen simple arm exercises, and evaluate each movement independently [8]. Second, the progress reports record the patient's parameters while he/she is playing the game. Some of these parameters are the maximum and minimum angles for both the elbow and the shoulder joints which represent the range of motion for these joints, the movement speed of the elbow and the shoulder [9], the average patient's reaction time and the maximum load that the patient can withstand with which indicates the muscles strength. Third, the games results and the progress of these results [10].

In CMG, the patient's performance is evaluated by a progress report that records the number of reached targets and reached bonuses. However, in SHG, the performance is evaluated by the number of collisions, the percentage of valid points, the number of points located on the ideal path and the completion time [11].

The software system is implemented following the Spiral Development Process. The whole system is divided into seven consecutive phases that are built on top of each other starting with a small nucleolus and ending with the fully integrated system that represents the whole system software. The implementation process is tested after each phase to verify its correctness.

4. EVALUATION

The final step in phase 1 is to test the device with a real patient. This test is important to know the first impression of the patient and the physiotherapist, and to check if the whole components work together. Physiotherapist Dr. Akram Amro evaluated the device with a stroke patient. The therapist first tested the workspace and the flexibility of the mechanical arm by moving it in the horizontal plane using both the left and the right hands. He changed the height of the device to check if it is suitable for the user in different situations. The load was set at the maximum and the therapist moved the end-effector. He was asked to decide if the load was small compared to the required practice. His response was that, the load was enough for a patient having stroke since the mission is improving the hand's motion and coordination under different loads and not body building.

After trying the four games, Dr. Amro thought that these games are motivating and allow for the completion of cognitive tasks and coordinated motions. All the games with their ability to increase the difficulty of levels by increasing the speed and the number of objects with random positions that are not predictive are very useful to kill the boringness of the traditional rehabilitation exercise.

The final test was the configuration test especially for the inclined plane. One of the main targets of the project is studying whether the inclined plane is suitable for stroke patients. The surprise was that the physiotherapist reported that the inclined plane is the most useful for performing exercises almost similar to activities of daily living like eating or shaving. The vertical plane is tested also which shows that it is useful because the patient has to lift the total weight of the device while performing the exercise so it is useful for muscle strength.

A female patient (NF, 56 years old) was asked to try the device. She preferred laying on the bed because she was not comfortable on the chair. She was asked about her first impression of seeing the device and if it scary. The answer was that the device is user friendly and not a scary device. Dr. Amro tested her concentration and coordination by asking her follow his finger in different positions. This test was performed before deciding which configuration is suitable for her. Dr. Amro decided that she needs the coordination test and this means that the suitable configuration is the horizontal plane. The patient started with Collecting Money Game two parts one with a load and the other without. She also played Falling Parachutes Game, Memorizing Path Game and Steady Hand Game respectively. She faced initial difficulties in the first game until she got used to it where she scored 79.9, she found these games interesting especially the second and the third games.

5. CONCLUSION

The device is proved to be suitable for stroke patients with either left or right hand impairment. It is suitable also for the patient if he/she is sitting on a chair, lying on a bed or even standing. It is useful for the completion of cognitive tasks and allows for performing coordinated motions in the horizontal and inclined planes. It is thought to be useful for muscles strength especially in the inclined and the vertical planes. The novel feature of the inclined plane is found to be useful for performing activities similar to that of daily living. This device is ready for phase 2 where real clinical testing will be done which will evaluate its effectiveness in physiotherapy.

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