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DEVELOPMENT OF GAMES TO HUMAN REHABILITATION USING A WII REMOTE CONTROLLER

Rogério Sales Gonçalves
Lucas Antônio Oliveira Rodrigues
Federal University of Uberlandia
School of Electrical Engineering
Campus Santa Mônica
38400-902 Uberlândia /MG, Brasil
rsgoncalves@mecanica.ufu.br; lucas.ep@outlook.com

Abstract. *The science of rehabilitation shows that repeated movements of human limbs can help the patient regain function in the injured limb. Thus, this paper describes the development of games to help in the rehabilitation process of the upper limb, assisted by a cable-based parallel robot created for the same purpose.*

Keywords: *rehabilitation, Wii remote, parallel robots, games*

1. INTRODUCTION

The advances in the robotics technologies are crescent and its applications on the medical sectors grow proportionally. As a consequence, robots are now a helpful tool on the rehabilitation of the human leg and arm movements (Takeuchi and Izumi, 2013). This fact stimulates the development of new structures and methods for this area, which is also the main objective of this paper.

One can identify three important areas for the application of robots to human health: the robotic surgery, the assistant robots and the rehabilitation robots (Gonçalves and Carvalho, 2012). All these areas have advanced considerably due to the development of control systems, video cameras, micro and nano technologies, new materials, and so on.

Physical medicine and rehabilitation is intended to treat, recuperate, or alleviate the disabilities caused by chronic diseases, neurological damage, or injuries resulting from pregnancy and childbirth, car accidents, cardiovascular diseases, and work. Rehabilitation is a comprehensive and dynamic process-oriented physical and psychological recovery of the disabled person, in order to achieve social reintegration.

Rehabilitation had been advanced and developed greatly in the twentieth century, especially in the periods after major disasters such as wars, in order to treat lesions.

The rehabilitation process involves several activities, from diagnosis to prescription of treatment, where the prescribed treatment must facilitate and stimulate the recovery processes and natural regeneration. In general, the process involves stimulus and repetitive movements that must be performed several times at various speeds (Takeuchi and Izumi, 2013).

The science of rehabilitation has shown that repeated movements of human limbs can to help the patient regain function of the injured limb (Kuznetsov et al., 2013).

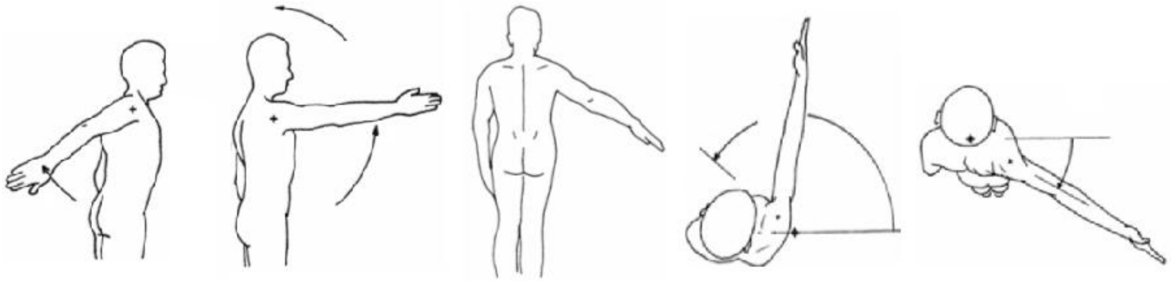
Thus, this paper first presents the human upper limb movements and some robotic structures used to rehabilitation focused to the upper human limb rehabilitation. After the studies about rehabilitation games and the cable-based parallel robot to be used with iterated games is presented. Finally the games developed to upper limb rehabilitation are detailed.

2. THE HUMAN UPPER LIMB MOVEMENTS

To ensure that all the exercises provided by the structure and the games are properly made, a basic study of the upper limb movements range was executed on the beginning of the project. The study is described in the section 2.1.

2.1 Shoulder and elbow movements

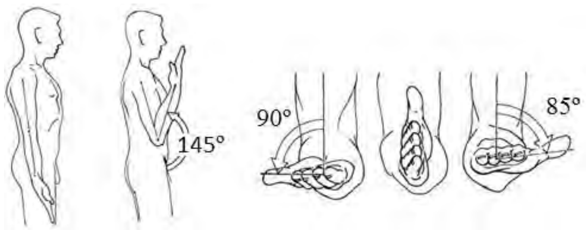
The shoulder is the proximal joint of the upper limb that has three degrees of freedom. This joint has the following movements: horizontal Flexion and Extension, Adduction/Abduction, vertical Flexion and Extension and Medial Rotation. A scheme for shoulder movements is shown in Fig. 1. The range shoulder are: vertical flexion 0° to 180°; vertical extension 0º to -45/-50°, abduction 0º to 180°; adduction 180° to 0º; horizontal flexion 0º to 140º and horizontal extension 0º to -30/-40° (Kapandji, 2000).



(a) (b) (c) (d) (e)

Figure 1. Shoulder movements. (a) vertical extension, (b) vertical flexion, (c) abduction, (d) horizontal flexion, (e) horizontal extension (Kapandji, 2000).

Anatomically the elbow consists of a single joint with only one joint cavity and have two distinct functions: flexion-extension and supination-pronation. The flexion occurs with the displacement of the hand toward the shoulder and has range of 145º, Fig. 2(b). The extension is the opposite movement. The supination-pronation is the rotation about the longitudinal axis of the elbow, Fig. 2(d), with amplitudes of 90º of external rotation and 85 º of internal rotation, Fig. 2 (Kapandji, 2000).



(a) (b) (c) (d) (e)

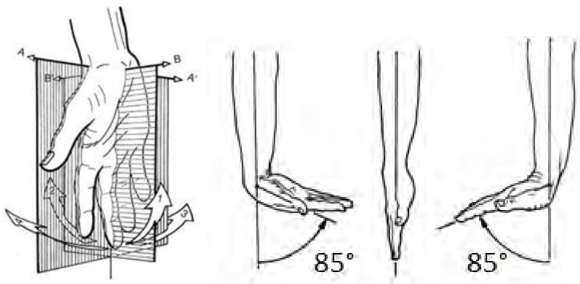
Figure 2. Elbow movements. (a) the reference position, (b) flexion of the 145°, (c) supination of 90°, (d) reference position, (e) pronation of 85°(Kapandji, 2000).

2.2 Wrist movements

The wrist is an articulation with two degrees of freedom which connects the hand to the forearm. It is able to execute the movements of abduction-adduction and flexion-extension. The rotation of the hand do not occur specifically on it, but on the radio ulnar articulation, which belongs to the elbow and the forearm (Kapandji, 2000).Thus the wrist can be noticed as a spherical joint, except the movement limits.

For the study of the wrist is necessary to define the geometrical references of the hand. Assume the longitudinal axis of the hand as the one defined by the third metacarpean bone in straight position, also defining the front and sagittal plane, Fig. 3(a).

The flexion-extension moves occur on the sagittal plane, Fig. 3(a). These movements starts from the anatomic position, on opposite, Fig. 3(c). On the flexion, the palm goes towards the lower surface of the forearm, Fig. 3(b), and on the extension, Fig. 3(d), the dorsal surface of the hand goes towards the upper surface of the forearm. The amplitude of both movements is 85°. The maximum angle only happens when there are no abduction or adduction on the wrist and the hand is in supination position (Kapandji, 2000).



(a) (b) (c) (d)

Figure 3. (a) Frontal plane (AA’), sagittal plane (BB’), (b) flexion on 85° , (c) anatomic position a 0°, (d) extension on 85° (Kapandji,2000).

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By definition, the abduction is the movement of distancing the limb from the symmetric plane of the body, and the adduction, the opposite movement. Both movements happen on the frontal plane, Fig. 3(a). The wrist abduction is also called radial deviation and reaches up to 15°, Fig. 4. The adduction, or ulnar deviation, has different amplitudes according with the adopted reference, it is used an amplitude of 45° for practical meanings, Fig. 4(c). It is important to note that the adduction reaches 25 to 30° when the hand is in pronation position, and the abduction-adduction moves are minimal on the flexion or extension position, due the tension on the carp ligaments.

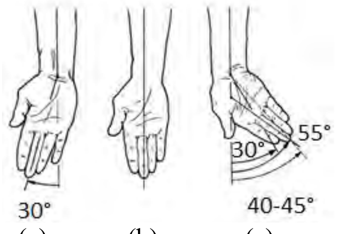

Figure 4. (a) abduction on 30°, (b) anatomic position, (c) adduction (Kapandji, 2000).

3. THE USE OF ROBOTS ON MOVEMENT REHABILITATION

There are three types of mechanical systems used for movement rehabilitation: robots, cable-based manipulators, and exoskeletons. Industrial robots can be used because they provide a three-dimensional workspace with a wide range of flexibility to execute different trajectories, which are useful for motion rehabilitation. The cable-based manipulators consist of a movable platform and a base which are connected by multiple cables that can extend or retract. The exoskeleton is fixed around the patient's limb to provide the physiotherapy movements (Gonçalves and Carvalho, 2012).

The mostly used robotic structures on the physiotherapy processes actually are the serial structures. These robots have different purposes and ways to recovery the movements of the joints on the human limbs. Common applications of these robots are strength help, muscle recovery and general exercises of the basic movements (Kemna and Culmer, 2009). The majority is actuated by servomotors or DC motors, and some uses pneumatic actuators like, e.g., the structure proposed by Tsagarakis and Caldwell (2003). The structure projected by Kemna and Culmer (2009), and the exoskeleton developed for rehabilitation of all human upper limb joints, Fig. 5, proposed by Ren et al. (2009) are examples of DC motor actuated serial robots, applied on the therapy of the human arm movements.

However, serial systems are, generally, heavy, complex to fit on the different sizes of the human arm, requires more caution during the operation. Another problem with exoskeletons is to make the rotation center of the actuator mate with the location of the each articulation to be worked.

The parallel structures, on the other hand, are less applied on the human rehabilitation processes. Nevertheless they have less weight and can present more exact positioning, which helps to keep the safety during the operation.

An example of this kind of mechanism is the structure developed by Takaiwa and Noritsugu (2005), Fig. 6, which is a parallel robot with pneumatics actuators. The displacement of the cylinders allows the movement of the central part, executing the basic wrist movements. The project made by Spencer and Klein (2008) characterizes another example of a parallel system. This one uses a bar mechanism to execute the movements and a motion-based game controller, which reduces the cost of the structure and simplify its control system.

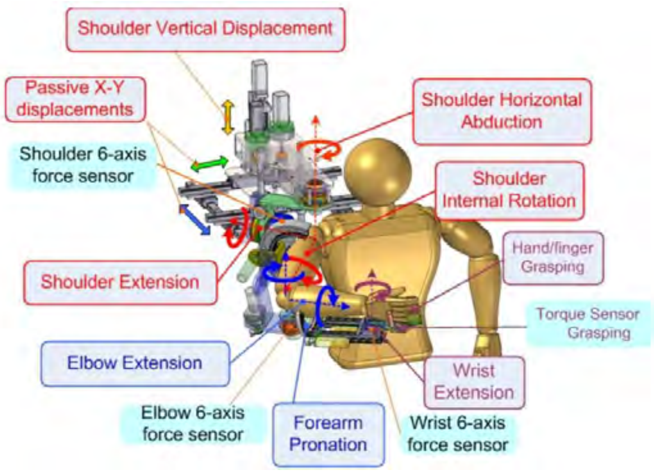

Figure 5. Serial structure applied on upper limb rehabilitation proposed by Ren et al. (2009).

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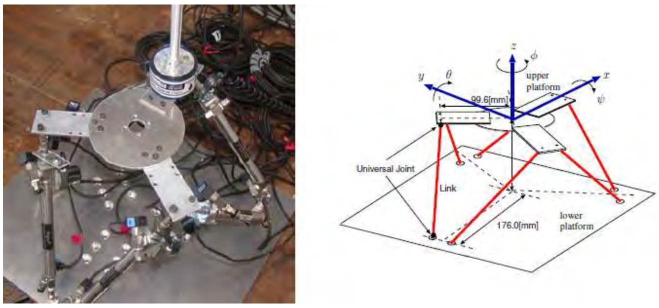

Figure 6. Pneumatic parallel structure and its schematic, proposed by Takaiwa and Noritsugu (2005)

The disadvantage of the parallel structures is the limited workspace, mainly on the limitation of the actuators path and the possibility of segments collision (2009). Likewise in 1985 Landsberger and Sheridan (1985) proposed the replacement of the linear actuators or segments for cables on Stewart platforms.

Robotic parallel structures actuated by cables are robotic systems that a fixed platform and a moving platform are connected by multiple cables (Hiller et al., 2009). The mainly difference of a parallel structure actuated by cables to the others mentioned above is that the moving platform is parallel operated by multiple cables. They can be actuated by multiple types of motors and different geometric arrangements. These structures are able to move the moving platform by the change of the cable length while preventing the others to become loose. Thus, the platform can only pull the terminal element, and no push. The cable tensions should be limited to avoid damage or deformation of the cables or the platform (Tsagarakis and Caldwell, 2003). Other advantages are the bigger workspace, few movable pieces and small masses on movement. Nunes et al. (2011) has proposed a four cable parallel structured applied on the rehabilitation of the shoulder and the elbow, Fig. 7.

4. THE USE OF GAMES ON MOVEMENT REHABILITATION

The use of games on the rehabilitation processes has become a common topic on the recent researches. The most notable treatment is for Cerebral Vascular Accident, which causes loss on the movement capability on 66% of the surviving cases (Burke and McNeil, 2009).

Burke and McNeil (2009) explored the concept of Amplified Reality, creating games that processes images captured from a webcam and project the game on the real scenario. They also present Virtual Reality games using simple objects and the Wii Remote controller. The Virtual Reality games uses magnetic sensors placed on the patient's arm that interacts with real objects, aiming to reach the goals generated by the game. For the Amplified Reality games, the player uses his own image, generated by the webcam, to play the game, giving the sensation to play with a mirror. The last game, using the Wii Remote uses its accelerometers to monitor the movements on the player's hand, which needs to hit the right time of musical notes, simulating the playing method of a xylophone or drums Burke and McNeil (2009).

Alankus and Lazar (2010) also apply the same concepts of games using webcams and Wii Remotes to create games focused on Cerebral Vascular Accident Victim's Therapy. The author describes in his paper, the right procedures to acquire and process the signal from the Wii Remotes on rehabilitation applications. It is also emphasized the significance of creating adaptive games, due the diversity of movement ability presented by the patients recovering from this kind of disease.

5. THE ROBOTIC STRUCTURE PROPOSED

The games developed on this paper are in development to work with the cable-based parallel structure presents in Fig. 7 (Gonçalves and Rodrigues, 2011). This structure consists in a robot that uses a four cables system to move the patient limbs, connected to a splint. Such system is actuated by four DC motors, associated to encoders to determine their angular position and load cells to monitor the tension on the cables. The control of this system is accomplished using a network composed of five microcontrollers PIC 18f4550, using the I2C protocol for data communication. Figure 7(b) shows the prototype and Fig. 7(a) its scheme.

The operation of this robot is based in the "Learning by Demonstration" logic, i.e., the structure is programmed to repeat the movements directly done by the operator. Thus, the robot can be easily operated by medicine professionals, without requiring much training or programming knowledge. This is possible once all the cables are provided with individuals load cells, which balances the tension on the cables and keeps it on a low value, enough to allow the arm to stay on the desired position.

This logic is implemented dividing the operation of the robot in two modes. The first phase is the "learning" mode, where the operator directly moves the patient's limb with his hands the way he wants the structure to repeat. Once the

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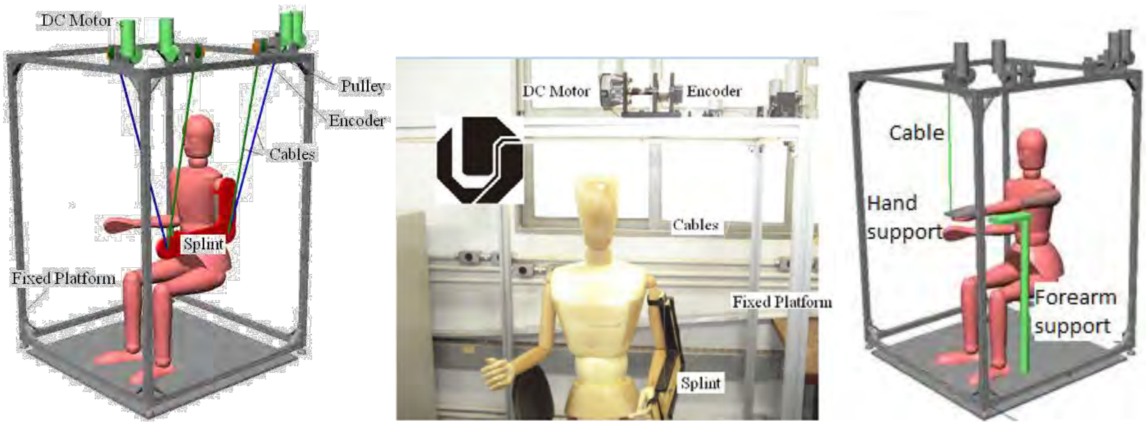
"learning" phase is finished, the "execution" mode is started, and the recorded movement on the previous phase is reproduced consecutively until it is commanded to stop.

Once the games developed in this project are integrated to hardware structure of Fig. 7, a new operation mode will be added to the structure, where it will help the patient to execute the necessary movements to play teach game. The new mode will work similar to the "learning" mode, but it will not save any points and will respond to the patient's moves faster. The score system of the games will also help on the evaluation of the healing process.



(a) (b) (c)

Figure 7. (a) Scheme of proposed structure, (b) prototype, (c) the structure to hand and elbow rehabilitation.

6. GAMES DEVELOPED

It was chosen to work with the Wii Remote controller due its good functionality, accessible prices and diffused knowledge. To program the games, a specific game development system is used, called "Gamemaker 8.1". Although this module is developed for simple applications, it supports a line based programming language similar to the common languages and allow a specific open source expansion module that support the Wii Remote inputs, which makes it able to reach the project objectives.

The Wii Remote controller has three accelerometers, one for each Cartesian direction, to measure the motions, an infrared camera, to allow a pointing system similar to the computer's cursor, and 11 input buttons. To synchronize the controller with the computer, a Bluetooth device is used and it is installed as a Human Interface device.

To interface the controller with the computer, a free software designed specifically to the Wii Remote was used on a Windows Operational System. The chosen software is called "GlovePIE". It consists on a Development tool to the Nintendo Controller which has its own programming language, based on Java, which comes with premade classes to interact with all the sensors and buttons of the remote controller, like a human interface device, similar to a keyboard or a mouse.

GlovePIE allows the proper reading and processing of the Wii Remote sensor's data. Thus, the angular positions and speeds of each movement of the controller can be connected to any command of a keyboard or mouse. To map properly the movements of the Wii Remote, it is compared to the helicopter main moves. By doing this comparison, it's possible to define Wii Remote's Pitch, Roll and Yaw moves, as shown on Fig. 8.

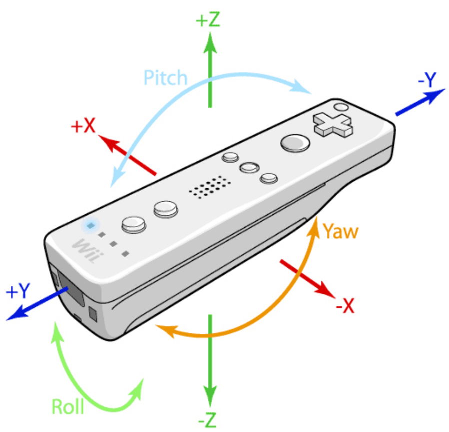


Figure 8. Graphical representation of each angular movement on the Wii Remote.

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6.1 Game for wrist rehabilitation

The first game created was developed for the wrist rehabilitation. It works receiving the signal from the pitch and yaw moves of the Wii Remote, while the player holds the controller in the hand, so it is possible to use the buttons of the controller. On this game, the forearm of the player stays fixed on the support.

The game theme is based on a spaceship travelling through a place full of meteors, as shown in Fig. 9, and the objective is to use cannon to shoot them off. The aiming system is controlled by reading the accelerometers of the controller while the "A" button is kept pressed and the shoot command comes from the "B" button. In the future, if the person does not have the finger movements, the action cannon will be given by voice command. As the game goes, the speed of the meteors also increases, raising the difficult of the game, which means that the score of the game will be directly proportional to the dexterity and ability of the player.

For this game, the X and Y axis of the Wii Remote are collinear to the wrist reference axis, meaning that the controller moves happens on the frontal and sagittal planes. This fact allows the conclusion that the movements of pitch and yaw of the controller are equals to the abduction and flexion moves of the human wrist.

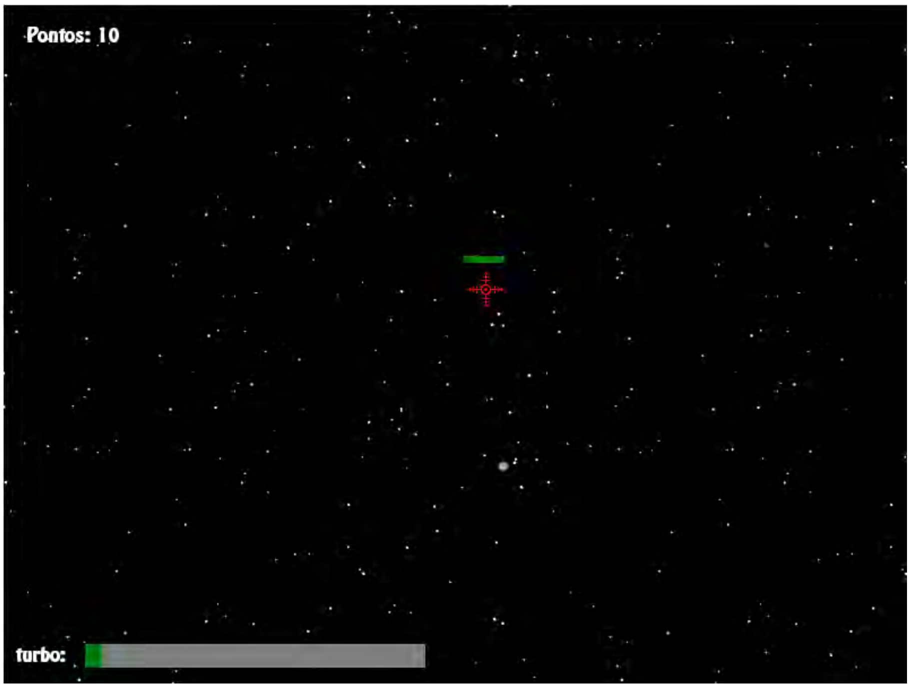

Figure 9. Image of the game used on wrist rehabilitation.

6.2 Game for elbow rehabilitation

The second game created works on the exercises of the elbow rotation, known as supination-pronation. For this game, the controller is placed on the hand of the patient, and its arm is fixed on a support, so only his forearm is allowed to move freely.

The theme of this next game is based on the classic arcade games, and reminds the concept of some famous titles, like Tetris and Pinball. It consists on a room with a variable gravity, which is the point controlled by the player. The room is filled gradually with red and blue balls, and each one shall be directed to opposite corners of the same color of the ball. Every time a ball matches the corners color, the player score up some points, however, allowing a ball to reach the wrong color will end the game session.

To make the ball reach the right corner, the player has to manipulate the room's gravity. The game is developed in order to allow the player to do this manipulation using the roll movement, Fig. 8, and the "B" button of the Wii Remote. Tilting the controller left or right will make the game's gravity to stream to the same position. Similarly, pressing the "B" button will flip the gravity up and down. Fig. 10 shows the ambient of the game.

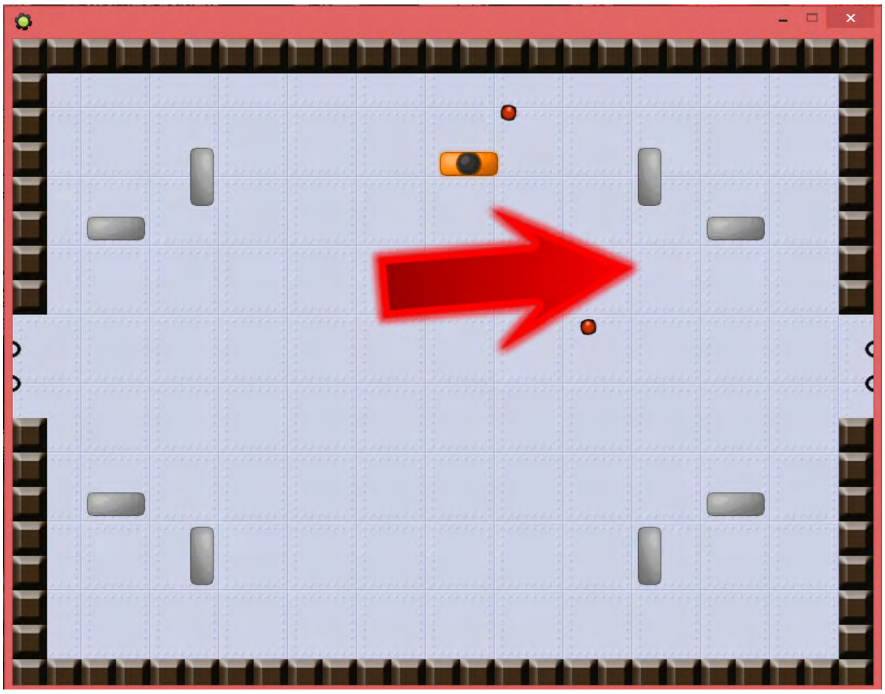

Figure 10. Image of the game used on elbow movement rehabilitation.

The control of the vertical gravity is purposely placed on a button instead of a movement to bring more challenge to the game, so the player will have to be more focused to give the right commands in order to reach the game's high score. Although it sounds simple, to make the balls reach the right corners controlling the gravity with movements and buttons instead of pins or bats can be a non-simple task, but easy enough to a casual time like a physiotherapy session's exercise.

In this game, the Y axis of the Wii Remote coincides with the longitudinal axis of the forearm, allowing the roll movement of the controller to be synchronous with the supination-pronation movement of the elbow. This game will also have a voice-command solution for patients without the ability to move the fingers.

6.3 Game for elbow and shoulder rehabilitation

The last game has a hybrid purpose, meaning that it was projected to attend to rehabilitation exercises for shoulder and the flexion-extension movement of the elbow. This is possible in two different ways, where before the game starts, the medic should set the right controlling position. To work with the shoulder movements, the patient should use a splint similar to the one described on the parallel robot session, so that only the shoulder can perform the necessary movements to control the game. On the other hand, the elbow exercises are accomplished when the patient uses an orthosis on its shoulder. By doing this, the player will be controlling the game using the flexion-extension moves of the elbow and the longitudinal rotation of the shoulder, which is not worked out on the setup mentioned before.

The last game is also based on the classic arcade games, and this one is inspired on "River Raid" and other 2D flight simulator games. The main objective on this game is to pilot a simple airplane through a field full of hot air balloons, without hitting any of them. The directions of the airplane's moves are directly connected with the moves of the controller, as if it was like an aerial mouse. This is possible associating the coordinates of the computer's cursor to the airplane on the game and to the Wii Remote sensor's signals at the same time.

To raise the challenge of the game, the player will also need to pay attention on the fuel of the airplane, which can be refreshed by picking up the energy icons that appear randomly on the game room. The scoring system of this game is simply directly proportional to the time the player stays with the plane on the air, without colliding with any incoming objects. Fig. 11 shows an image of the game.

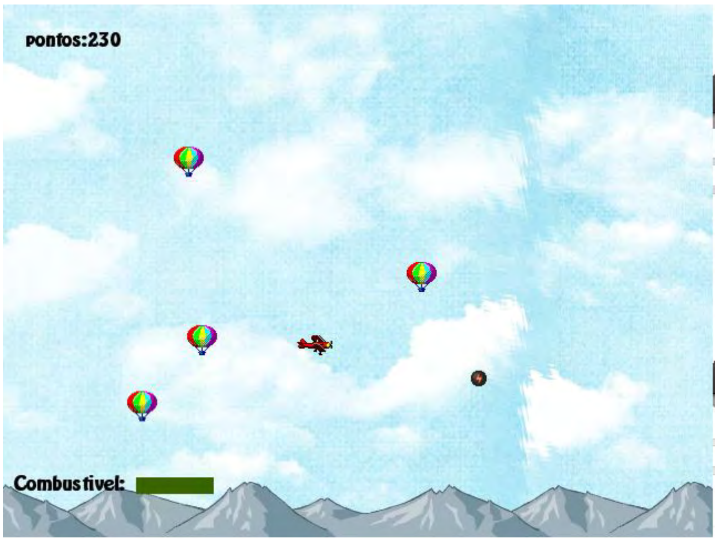

Figure 11. Scene of the game used on shoulder and elbow movement rehabilitation.

Since this game is able to work out with two different setups, there are distinct equivalences of the controller moves to each arm and forearm moves. For the first one, where the arm is fixed on a splint to work with the shoulder movements, the roll of the controller, Fig. 8, is proportional to the abduction of the arm, and the pitch to the vertical flexion of the same. Analyzing the second position, designed to work with the elbow flexion and a longitudinal rotation of the shoulder, the pitch movement is now proportional to the elbow flexion and extension movement and the yaw movement is connected to the longitudinal rotation of the shoulder.

7. GAMES AND PARALLEL STRUTCTURE INTREGRATION

Although all the developed games presents in this paper are able to produce good results working without assistance of other equipment, a way of integration between the games and the parallel structure is being designed by the authors. The main goal of this integration is to help people with low or any mobility of the upper limb to play the games.

To reach this goal, the presented parallel structure will receive a new operational mode, similar to the "learning" phase mentioned before. In this mode, the load cell will monitor the slight tension variations on the each cable in order to determine the weak movements of the patients, and activate the motors to help the move in the same direction.

The first game to receive this integration will be the third game presented in this paper, first on the shoulder setup, and them on the elbow setup.

The future voice command assistance will also help on the integration for the people without the ability to move fingers.

8. CONCLUSION

This paper presented the development of rehabilitation games to human upper limb. Here are presented three rehabilitation games to upper limb joints: wrist; elbow and shoulder respectively.

The use of games inspires the patient to fulfill a rehabilitation procedure with a defined goal by the professional health.

The first test were run on volunteers without movements limitations to determine the normal levels of moves, which will be the objective of the future users of this games. The opinions of the involved volunteers show that the casual entertainment of this games fits to its applications.

The next step after the integration between the equipment and the games are fully done is to begin the tests with the first patients with movement limitations, assisted by physiotherapists and health professionals of the area.

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