A Robotic System for Rehabilitation of Distal Radius Fracture using Games

Kleber O. Andrade[1], Gisele G. Ito[2], Ricardo C. Joaquim[1], Bruno Jardim[1], Adriano A. G. Siqueira[1], Glauco A. P. Caurin[1], Marcelo Becker[1]

[1]Mechanical Engineering Department, University of São Paulo, São Carlos, SP, Brazil
[2]University of Vale São Francisco, Petrolina, PE, Brazil

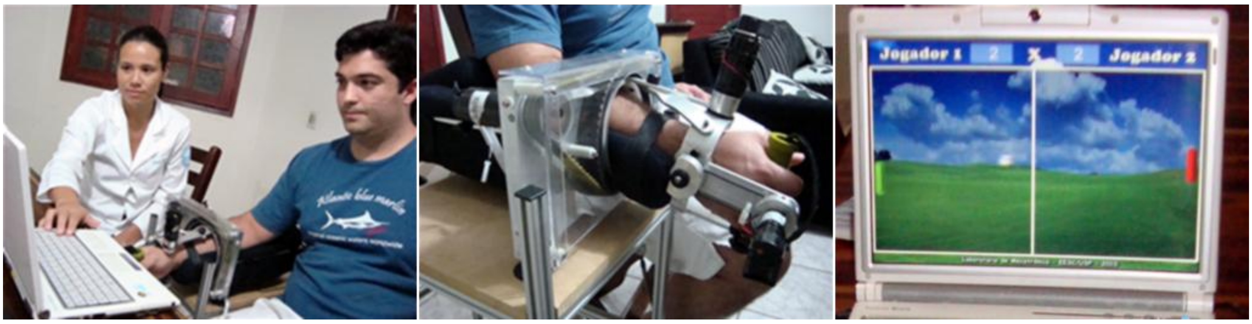

Figure 1: User testing the proposed system. From left to right: a user with the device for rehabilitation playing the pong game against the therapist playing with the keyboard; a close-up on a user performing the movements; a game screen in which the user performs the movements.

Abstract

This work integrates robotics and electronic games with the objective of producing more motivating and attractive therapeutic activities in distal radius fracture rehabilitation (wrist region). The proposed robotic system allows the reliable measurement of all wrist angular motion amplitudes. In order to achieve this goal, a framework is proposed that allows the full integration between the designed game and the developed hardware. The framework stores data from the game and from the robot movements for further analysis. The prototype was tested in healthy subjects, and a questionnaire was used to produce qualitative impressions concerning the system.

Keywords: Robotic Rehabilitation, Robotic Games Integration, XNA

Authors' contact:
[1]pdjkleber@gmail.com,
[2]gito29@hotmail.com,
[1]{rcjoaquim, bjfisica}@yahoo.com.br,
[1]{siqueira, gcaurin, becker}@sc.usp.br

1. Introduction

Radius distal fractures represent one sixth of all fractures of the body which are treated in emergency departments [Hunter et al. 2002]. It occurs in people of all ages and in different modes. The wrist region and also the hand are very vulnerable because they represent primary tools for the occupation, defense and human expression. The bone continuity disruption imposes downtime for the calcification that can last from six to eight weeks [Cotran et al. 2000]. Wrist fracture causes pain and acute loss of physical function and has an impact on social and emotional function. Dystrophy or complex regional pain syndrome is a debilitating consequence occurring in between 1% and 20% of patients with distal forearm fracture [Lips et al. 2010].

New and more efficient treatment approaches to this type of fractures suggest the rehabilitation of the patient in specialized services, which considers besides anatomical and physiological characteristics also psychological and social aspects. The dialogue between the hand surgeon, the hand therapist and the patient, represented in the ideal triad (Figure 2), requires a single communication protocol, which must be well-known and easily accessed, defining therefore a basis for a coherent and effective rehabilitation. According to Ferrigno [2007], the proposal of rehabilitation "is directly linked to the trust built by that triad and has a fundamental role in the appropriated recovery, as well as in the treatment efficacy".

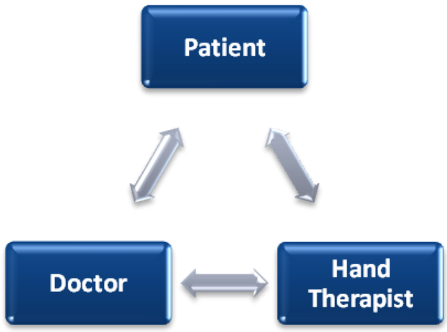

Figure 2: Ideal triad for an efficient rehabilitation process.

Robotics and games serve as tools to improve communication between medical doctor, patient and therapist. The therapist needs to assess and to supervise the patient’s progress identifying possible needs for adjustments on the procedures, which in their turn will only take place if they are discussed and approved by the medical doctor. The angular motion amplitudes are usually measured with the aid of goniometers. This evaluation process comprehends part of the health care, whose results are not easily available and reachable by the involved staff. Additionally, measurement results from goniometers are not reliable.

The evaluation of the results obtained during the rehabilitation processes of patients that present wrist fracture demands special care in rehabilitation centers. According to Hunter et al. [2002], some of the reasons are the high cost of health care, the variation in practice among the different centers and individuals and the need for assessments and standardized results. The discussion on the determination of hand function is strongly linked to the analysis of the range of motion (ROM). According to Cantrell and Fisher (cited in Hunter et al. [2002]), "a large volume of medical literature, rheumatology and hand surgery were concentrated in range of motion of the fingers as the first source of data on the success or failure of many of our forms of treatment."

Although traditional methods of rehabilitation are available, the use of robots in recent years brought remarkable advances to the medical field, providing more accurate and reliable tools for the treatments. In an attempt to improve the patient’s confidence concerning the use of robotic systems, the electronic games are introduced. These games must make patients feel more motivated and interested to attend the treatment because rehabilitation is based on the principle of repetition, therefore less attractive to patients.

The objective of this work is to develop a portable robotic system which, together with computer games, will be a specialized device for applying the distal radius fracture treatment protocol developed at the Indiana Hand Center [Cannon 2001]. As first results of this investigation, a prototype is presented that is already able to motivate rehabilitation through its integration with computer games. The system also provides quick and reliable assess to the movement amplitudes, enabling immediate visualization of the results and may be even used to intelligently increase the challenges suggested to the patient as the game changes levels.

This article is organized as follows: in the next section a list of related works is presented. Section 3 is concerned to assess the proposed method, the hardware, and the application framework. Experiments and results are presented in Section 4. Concluding the paper, Section 5 presents a discussion of the results, some remarks and future works.

2. Related Work

Digital games are already found in rehabilitation processes and physiotherapy gym. Whether in the gym or personal training, there is a clear tendency that the presence of games will increase in treatments due to their playful side and entertainment. The game maker Nintendo Wii Fit Plus ®, for example, was the first video game to gain official support from the National Health System (SNS), UK.

The Nintendo Wii (Wiimote) control technology has attracted many researchers to explore its use as an affordable alternative to perform multiple tasks. Games such as Funsphysio, from the Brazilian company FisioGames, founded in 2009 in Florianópolis, aims to assist in the rehabilitation of upper limbs using this technology [FisioGames 2010]. In Decker et al. [2009], it is also used a Wiimote, together with a velcro and a circuit board containing infrared LEDs to capture the angle of flexion and the extension of the wrist. Other works adopt cameras to monitor and analyze the movement in a finer resolution [Murgia et al. 2008], while Attygalle et al [2008] uses two Wiimotes with a force sensor for a more robust data collection.

Most games that use the Wiimotes as the main source of data are limited to patients who can pick up objects [Gallego and Simone 2007; Leder et al. 2008]. An alternative to this approach is the use of virtual reality, which allows the inclusion of patients who can not grasp objects [Kuttuva 2005], as well as games that use video capture with webcam [Burke et al. 2009] when dealing with subjects affected by stroke.

Robotics has been also aiding rehabilitation processes, normalizing it or recording and helping to document it, as is the case study of the Sensory-Motor Systems Lab at ETH in Zurich - Switzerland [ETH 2007]. The study group developed a robotic arm (Figure 3) to assist in the rehabilitation of movements of patients recovering from strokes. The process is measured by the device, which acts in accordance with scripts of interactive computer games.

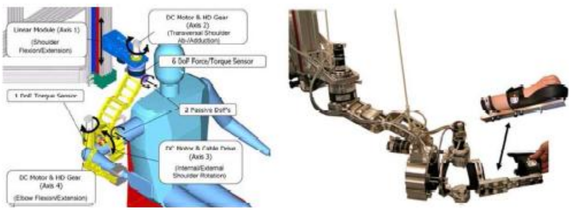

Figure 3: ARMin System [ETH 2007]

The Department of Bioengineering at Imperial College London has chosen to develop systematic exercises to improve the performance of people with disorders using robotic interfaces like the system HandCARE (Figure 4) [Dovat 2008].

Figure 4: Functional Arm and Hand's Rehabilitation using virtual reality [Dovat 2008]

3. Methods and Experimental System

Within this section, all implementation details are discussed. First, an overview of the basic concepts that are related to the proposed technique is provided. The hardware available for the concept implementation is then presented, followed by the description of the adopted software and its corresponding implementation. Finally, the experiments are discussed in more details, including the description of hypothesis, dependent and independent variables, and what data was collected from the tested application and from the form applied to each participant.

3.1 Concept

The experimental system is based on the use of the dedicated hardware Wrist Rehabilitation System, a game to stimulate the therapy and a framework for hardware integration with the platform of the game. Thus, all data relating to the rehabilitation process will be acquired according to Indiana protocol, described as follows:

- Start after 6 weeks: active motion (muscular contraction of the patient) till the limit of pain.
- After one week: active-assisted motion.
- After 2 weeks: low passive motion (motion without muscle contraction).
- After 3 weeks: active motion of resistance from 0.5 to 1kg.
- After 4 weeks: active motion of resistance above 1kg.

The exercises should be done every hour for 10 minutes. In this paper, we focus to the beginning of the protocol (active motion). The data for optimal range of motion that will be implemented in the appliance, follows the norm of the Brazilian Society of Hand Therapists [Oliveira and Araújo 2005], which can be seen in Table 2.

Table 2: Standard test angular [Oliveira and Araújo 2005]

Joint	Movement	Degrees of Range
Forearm	Pronation	0 - 80
	Supination	0 - 90
Wrist	Extension	0 - 70
	Flexion	0 - 80
	Radial desviation	0 - 20
	Ulnar desviation	0 - 30

The game implemented for this study measures and stores only the angle of pronation/supination (pronation: palm down; supination: palm upward) (Figure 5). Tests were conducted in a group of five healthy people, with the inclusion criteria: health professionals, professionals in the exact sciences, postmenopausal women and young men and adults. The last two groups represent the population that is most affected by this type of fracture, while the first two are responsible for creating and using new technologies for health.

Through the games, we expect the system stimulate an improvement in range of active motion of the angle of pronation/supination. Besides data collection at the end of each test, plus the data obtained for further analysis on the system, a questionnaire about the system, with space for criticism and suggestions for future improvement based on several knowledge, will also be answered.

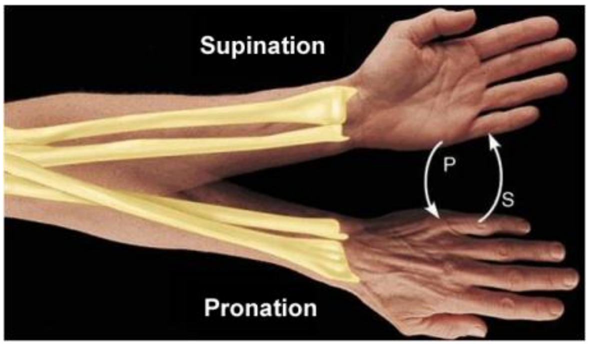

Figure 5: Movement of pronation and supination

The survey was carried out after the review and approval by the Ethics Committee on Human Research at the Federal University of São Carlos (UFSCar).

3.2 Hardware

The Wrist Rehabilitation System, showed in Figure 6, is a hardware module built in the Mechatronics Laboratory as a platform for test concepts in the pos-graduated student's works. It was built for measure the wrist movements for assists rehabilitation process based in its protocol procedures.

It has three degrees of freedom: flexion/extension of the wrist, ulnar/radial deviation and pronation/supination of the forearm. It considers anthropometric data to support the forearm, a handle to support the hand and a Velcro to stabilize it, if the flexion of the finger is impaired. Also if you need to work with only two degrees of freedom it has a mechanical lock for each one.

For active and passive motions, this module still has three DC motors, Maxon DC motor´s, with encoders and a Control Drive - EPOS – which is responsible for control and measuring each degree of freedom from the patient wrist.

EPOS (Easy-to-use Positioning) is a controller for DC and Brushless servomotors. This digital amplifier can perform current, position or velocity control of the motor, with set-point values defined through serial (RS-232), USB or CANopen interfaces. A set of real variables, including shaft position, velocity and motor current, can be measured using these interfaces. Also, this device can measure up to 8 analog inputs.

Requiring a supply voltage of 11-70VDC, the controller is capable of 10A max continuous current and 25A peak current. Efficiency is up to 90%. Maximum motor speed is 25.000 rpm for 2-pole motors. A maximum encoder input frequency of 1 MHz, eight digital inputs, two analog inputs, and four digital outputs. The communication between the EPOS is through the CAN bus , shown in figure 8.

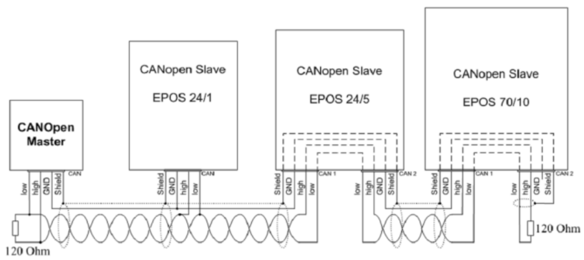

Figure 8: CANopen Network Structure

Thanks for the Epos controller, this hardware module can measure the wrist angles and communicate to the game by a RS232 link. All the data collected will be stored and processed in the same computer where the game runs.

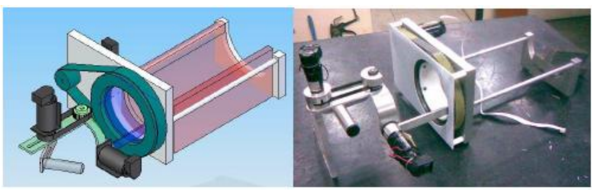
Figure 6: Prototype

3.3 The Framework

In this section, we present a framework that provides the integration between the robotic system shown in the previous section, with games developed in C # and XNA. The language C # (pronounced C Sharp) is an object-oriented language developed by Microsoft along with the architecture. Net (pronounced dot net), the only language that works with XNA.

XNA (XNA's Not acronymed) was developed by Microsoft to simplify the development of games for PC and Xbox 360. Furthermore, it allows quick access to peripherals (keyboard, mouse and gamepad Xbox 360), graphics hardware, audio controls, network and storage of information in files or database. [Boden et al. 2009]. The game has been programmed in C # with XNA. Future applications may be also implemented without restrictions in different high level programming languages to meet the needs of the user or project.

The framework developed so far, which is named RobRehab (Figure 7) is modular, so as to be easily used, modified and even replaced by any robotic system controlled by an EPOS.

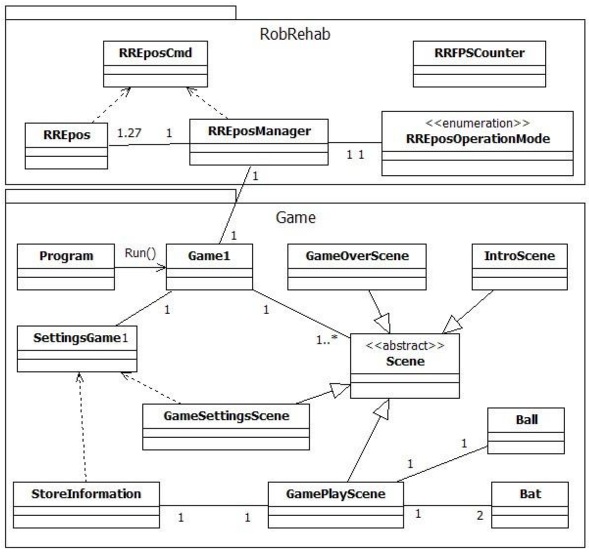

Figure 7: Pong´s game Class Diagram and RobRehab framework

The framework is composed by the following classes:

- **RREposCmd:** class that defines methods to access the library functions EposCmd.dll order to be used with C #.
- **RREpos:** defines the complete structure of EPOS in order to use the digital inputs and outputs, the analog input and encoder, as some defined operation.
- **RREposManager:** run up to 128 networked EPOS CAN between them, as the hardware developed for acquisition or transmission of control data.
- **RREposOperationMode:** defines the methods of operation of the set of EPOS to be used as position mode, velocity mode or current mode.

- **RRFPSCounter:** a component of the game to know how many frames per second the game is running.

3.4 The Game (Pong)

To validate the concept of the hardware and the framework, it was created a game that allows the user to run only two movements. The game was scheduled the classic Pong, in which the player must hit the ball with his bat (vertical bar) and toss the opponent, scoring a point when the ball passes through another bat. The player controls the bat through the degree of pronation and supination of his/her forearm. Figure 9 illustrates a screenshot of the running game.

Figure 9: Pong game screenshot developed for first tests

Before starting the game you need to calibrate the degree of movement of the wrist of the player, for this was created a settings screen that receives the maximum range of motion performed by the user, as well as your name, ball speed and percentage of challenges. This percentage represents the possibility of the game require a higher turnover than the initial potential of the patient. To calibrate the initial amplitude, the player must accomplish the total pronation and supination of the forearm. The settings screen of a match can be seen in Figure 10.

Figure 10: Hardware calibration screenshot and game according to the player

When a new game starts a file is created with the player's name, date and time. At the end, this file collects information from each cycle starting time set by the therapist and stores the angle that the player reaches that moment, game scores, and other information that are important for patient evaluation. An image of a user testing the system can be seen in Figure 11.

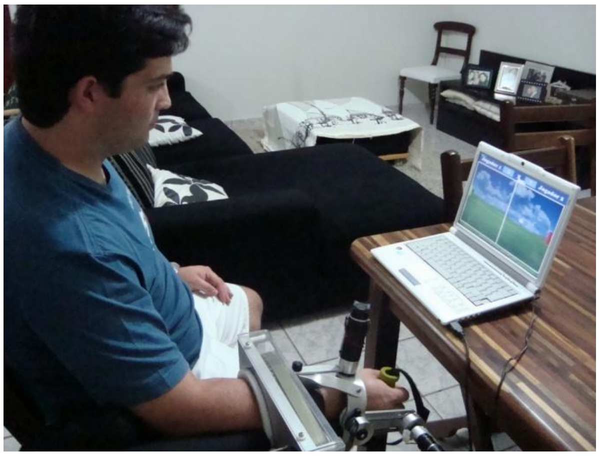
Figure 11: A user testing the system and game.

4. Experiment and Results

In this section, we present evaluation results that were obtained using the proposed framework over a set of five healthy individuals.

4.1 Data Analysis Criteria

To assess the motivation of the game, some data will be treated, following the hypothesis that the game should stimulate the therapy if there are gains in active range of motion. Two criteria were defined as initial data analysis:

a) Maximum Pronation/Supination before the first and second game session.

b) Pronation or Supination change in the score: it was developed a logic which identifies the change in the score. It verifies the value of pronation or supination that the patient reached when there is change in the score. This result is shown in a chart where the values of supination and pronation are shown together to the value of this logic (vector ranging 0-1, taking the value 1 when there is a change in score).

4.2 Data Analysis

Below are shown the results of the analysis of two patients (named as patients 1 and 2). It was shown only two results due to be the most clash between the study group.

Tables 3 and 4 show the results of item a) and Figures 12 to 15 show the results of item b), both for the two game sessions.

Table 3 – Patient 1 – Maximum Pronation/Supination

Motion	Game 1	Game 2
Max Pronation	-53,50	-56,12
Max Supination	50,89	51,97

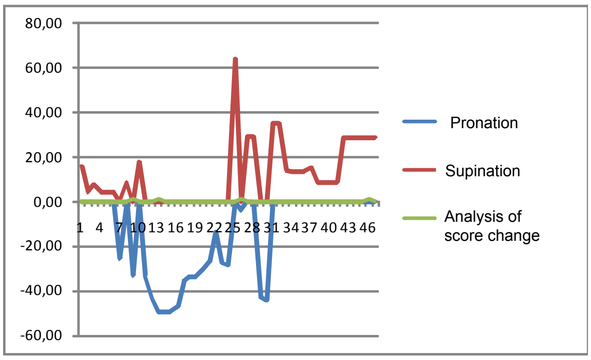

Figure 12 – Game 1 Patient 1

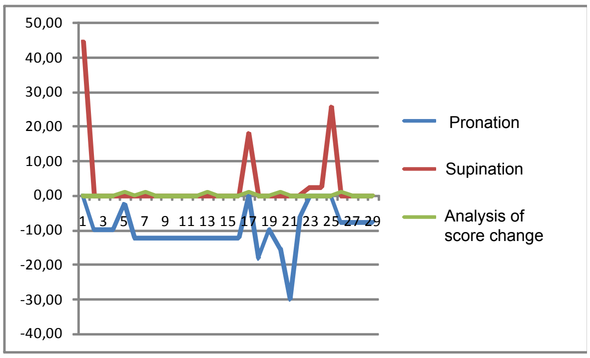

Figure 13 – Game 2 Patient 1

Table 4 – Patient 2 – Maximum Pronation/Supination

Motion	Game 1	Game 2
Max Pronation	-76,57	-76,57
Max Supination	56,87	56,87

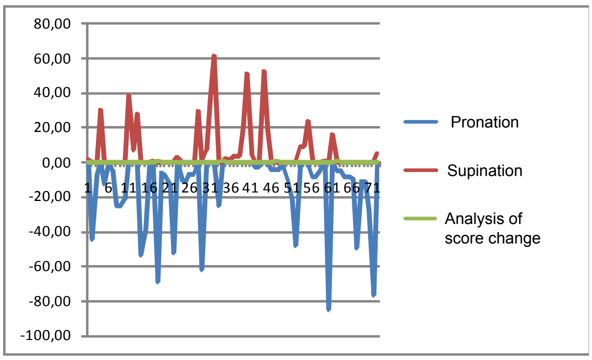

Figure 14 – Game 1 Patient 2

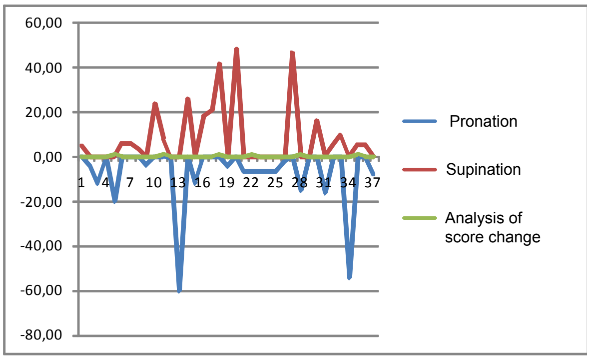

Figure 15 – Game 2 Patient 2

4.3 Feed Back Discussion and Problems

It was observed that the range of motion was not increased for patients who performed the games at the same day and with no interval between them, see Tables 3 and 4. This possibly occurs due to a lack of motivation in the measurement process (step pre game configuration) or the short time between measurements.

In the observation about the amplitudes measured during the game, it can be noted by the graphs of Figures 12-15 that many of the maximum amplitudes were reached just before the change of score, which can lead to a preliminary conclusion that the game would stimulate achieve amplitudes larger than simply the measurement system, or that a greater challenge could also stimulate the therapy.

The analysis of the questionnaires table 5 in Appendix shows that feeling of security during the use of the system, his utility and the use of the game in rehabilitation was totally approved with satisfaction and high satisfaction. Only one person has low satisfaction with the facility of understanding of the use of the system and also only one thinks that will made low use of the system if necessary. The cleaning facility of the hardware and the reliability of the system have been disapproved by 3 tested people answering being low satisfied. The equipment mobility has 4 tested people low satisfied. At least one person finds the ergonomic aspect, the comfort and the design of the hardware totally unsatisfactory. The ergonomic aspect was the major criticized, with more three person low satisfied.

We can resume the following aspects appear to be dissatisfied:

- **Adaptability, the device does not include different sizes of the upper limbs:** find a way to have an adaptable space using Velcro or other fitting that can fit any size arm.

- **Reliability of the handle instability and it is required a degree of muscle strength to make**

relatively large movements: implement impedance control for the turning motion of the handle can be accomplished without effort, and use this type of control to implement the system resistance according to the protocol being used.

• **Design for presenting large motors:** the use of smaller engines to reduce weight initially and give a better look at the hardware, since it is still only a prototype.

• **Transport system for failing to load in a practical way:** optimize and improve transportation equipment

5. Conclusions

This paper proposes the use of the robotic systems and computer games to assist distal radius fracture rehabilitation. A first wrist rehabilitation device was presented as well as a framework to integrate the robotic controllers with the computer games. Results obtained from the evaluation of the system by healthy subjects show that the proposed combination of robotics and games improves the user motivation, increasing the pronation/supination motions.

For future work we intend:

1. **Impedance Control:** aiming to improve the mobility of patients, it is suggested to implement the impedance control in the mechanism so that the friction is compensated and the handling is facilitated in accordance with the proposed treatment by the physiotherapist. In this control strategy the values of the elasticity and damping gains (impedance) of the system can be determined and implemented in the mechanism.

2. **Force Sensor:** it is necessary to design an integrated sensor and robotic system in order to measure the forces during the rehabilitation process.

3. **Framework:** it is also necessary to improve the architecture to allow tele-operated games. This framework will be developed in C++ and Ogre to guarantee a better performance and system stability.

4. **Adaptable game:** another idea is to create an A.I. system to adapt the game parameters. This would allow to change the game parameters as a function of the patients and optimize the rehabilitation process.

5. **Robotic System:** To finalize, a new mechanical design is necessary to improve the ergonomics of the overall system (based on the Questionary presented in the previous sections).

Acknowledgements

The author Kleber de Oliveira Andrade would like to acknowledge the support of Brazilian agencies CAPES (Coordenação de Aperfeiçoamento de Pessoal de Nível Superior). The author Ricardo Cezar Joaquim would like to acknowledge the support of Mechatronics Laboratory for the DC motors used in this work. All authors would like to acknowledge the volunteers who participated in the experiment.

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Appendix

Table 5 – Patient's responses from questionnaire : (U) Unsatisfied ; (LS) Low Satisfied ; (S) Satisfied ; (VS) High Satisfied

Category	Experience (in number of appointments)	Ergonomics	Comfort	Design	Security	Cleaning	Understanding	Reliability	Utility	Equipment Mobility	Game	Use frequency
Healthcare	2 to 10	LS	S	S	VS	S	LS	S	S	LS	S	Very Often
Healthcare	Never	S	S	S	VS	LS	S	LS	S	S	S	Often
Healthcare	Never	S	S	VS	VS	S	VS	S	VS	S	VS	Very Often
Healthcare	Never	VS	VS	S	S	S	S	VS	VS	S	VS	Often
Healthcare	Never	S	S	VS	VS	S	VS	VS	VS	S	VS	Often
Healthcare	Never	S	S	S	VS	S	VS	VS	VS	S	VS	Often
Healthcare	Never	LS	LS	S	S	LS	S	S	S	S	S	Low Frequency
Healthcare	Never	S	S	S	VS	S	VS	VS	VS	VS	VS	Often
Healthcare	2 to 10	S	VS	VS	VS	S	VS	VS	S	S	VS	Very Often
Healthcare	Never	S	S	S	VS	LS	VS	VS	VS	S	VS	Very Often
Healthcare	Never	U		S	S	S	S	S	VS	U	S	Often
Sciences	2 to 10		U	S	S	LS	S	LS		LS	S	Often
Sciences	2 to 10	S	S	LS	VS	S	VS	VS	S	LS	VS	Very Often
Sciences	Never	U	LS	S	S	S	S	VS	S	S	VS	Very Often
Sciences	1	LS	S	U	S	S	S	LS	S	LS	S	Often
Sciences	Never	S	VS	VS	VS	S	VS	VS	VS	VS	VS	Very Often
Sciences	Never	VS	S	S	S		VS	VS	S		VS	Very Often
Woman	Never	VS	VS	VS	VS	VS	VS	VS	VS	S	VS	Very Often
Woman	Never	VS	VS	S	S	S	S	VS	VS	S	VS	Very Often
Woman	Never	S	VS	S	VS	S	S	VS	VS	S	VS	Very Often
Woman	More than 11	VS	VS	VS	VS	S	LS	S	VS	LS	VS	Very Often
Woman	Never	LS	S	LS	S	LS	S	S	S	LS	S	Low Frequency
Woman	Never	S	VS	VS	VS	VS	VS	VS	VS	U	VS	Very Often
Woman	Never	S	VS	S	VS	S	S	VS	S	S	VS	Low Frequency
Woman	More than 11	VS	VS	VS	VS	VS	VS	VS	VS	S	VS	Very Often
Man	Never	VS	VS	VS	VS	VS	VS	VS	VS	VS	VS	Very Often
Man	Never	S	LS	LS	S	LS	VS	LS	VS	LS	VS	Very Often
Man	Never	VS	VS	LS	VS	VS	VS	VS	VS	LS	VS	Very Often
Man	Never	LS	LS	S	VS	LS	VS	LS	S	LS	S	Very Often
Man	Never	VS	VS	VS	VS	S	VS	VS	VS	VS	VS	Very Often