PHYSIOTHERAPY SUPPORT WEB-BASED SYSTEM FOR REHABILITATION ROBOTICS: AN INITIAL ARCHITECTURE

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Abstract. *Life expectancy is significantly growing worldwide due to technological advances associated with healthcare. However, elderly and impaired people compose the global population subset with increasing demand for rehabilitation. However, in essence, current rehabilitation process consists of repetitive exercises, entailing tiresomeness and discouragement. Therapy with robots and serious games may provide motivation and commitment to the treatment, anticipating better outcomes. Its usage was recommended by American Heart Association (AHA). In their recent studies AHA pointed the highest assessment (Level A) for inpatients and outpatients rehabilitation using the combination of robots and games. Nevertheless, the current purveyance of information related to patient's performance is not appropriate enough to meet current therapist's necessities. This work proposes an initial architecture of a web-based system that provides detailed information, and allows proper therapy procedures. The system consists of a web application that retrieves information from a database, outputting explicit or statistically analyzed data. Every motion performed by the patient is captured by robots, represented as data and then sent to the database. These data are considered as system's input, having strength, torque and speed as their attributes. It is expected that the usage of this approach overcome the subjective evaluations currently in use, offering the possibility of obtaining solid fundamentals when preparing prognoses, as well as providing real and good-quality data for further analyses, aiming more accurate prognoses.*

Keywords: *web-based system, rehabilitation robotics, therapy support*

1. INTRODUCTION

Life expectancy is significantly growing worldwide due to technological advances associated with healthcare. According to World Health Organization (WHO), in the course of nineteen years (1990-2009), global life expectancy increased four years (about 6%), expecting an average of a 68-year-old life. Brazil also had a significant growth (increasing 6 years, about 9%), expecting an average of a 73-year-old life (WHO, 2012).

In face of such an expansion, one can notice a bigger contingent of elderly population, entailing in more demand of rehabilitation services (Krebs *et al.*, 2008) that, in order to have a stable health situation, the professional support is required, which characterizes physical therapy.

A portion of this demand comes from people that lack rehabilitation, which propensity of this lack occurs accidentally or naturally. One can understand accidental the occurrence that arises of risk practices, as a wrist fracture due to a motorcycle accident, resulting in motor difficulties, or even disabilities. Under the information of Departamento Nacional de Infraestrutura de Transportes (DNIT), in 2010, there were 99,802 vehicle accidents having survivors; from this total of vehicles, about 24.56% were motorcycles (DNIT, 2010). In opposite of accidental occurrences, the natural ones happen unpredictably, or the ways to perform a premature detection are absent. According to WHO, per year, 15 million individuals worldwide suffer from stroke. Five million of this total tends to death and other five million become permanently disabled (WHO, 2012). Considering the remaining portion, one can say these are naturally prone to rehabilitation.

Motor disabilities are not always come from local lesions. External factors should also be considered, as the integrity of impulses sent from the nervous system to the member to properly perform its motor functions (Silva *et al.*, 2012; Horak, 1990). Both dependencies require rehabilitation, being susceptible to traditional methods treatments that provide, in a medium or long term, good outcomes from the patient's effort that were gained during sessions of physiotherapy.

Rehabilitation, in essence, consists of repetitive exercises, entailing tiresomeness and discouragement (in case of not having discipline) and, consequently, negatively affects patient's performance (Burdea, 2002; Robertson *et al.*, 2010; Rego *et al.*, 2010). Despite the existence of traditional rehabilitation methods, patient's motivation can significantly contribute to reach higher goals, in comparison to the expected ones. In contrast, recently, the use of robots in rehabilitation has increased (Andrade *et al.*, 2013), which its accuracy is noticeable from the computerized sensing for data collecting, to the ability to interact and motivate patients using game-based approaches (Burdea, 2002). Its use was recommended by American Heart Association (AHA), being assessed at the highest level (Level A) for outpatients and inpatients (Class I e II, respectively) (Miller *et al.*, 2010; Andrade *et al.*, 2013). The Department of Veterans Affairs, as well as the Department of Defense, recommend movement therapy with robots as an adjunct to the traditional therapy in patients with arm functions deficit, focusing in motor improvements.

2. BACKGROUND

In current treatments with robots, the exercises are performed with robots as a way to operate an interface that interacts to virtual environments, which drives patient's attention to the immersion, as well as easing the notion of the effort during exercises. Among patient's several immersion stimulating agents, one can notice Serious Games, which its generated data constitute valuable information to be used by physiotherapists, as well as computational applications, such as Artificial Intelligence (Russell and Norvig, 2009), providing the ability to calibrate every manageable attribute (from physical interface aspects, to the difficulty of a running game), in order to equalize conditions for any patient. It is noteworthy that Serious Games has serious purposes, which its entertainment ability acts secondarily as a guide to the true scope, such as healthcare, education, and others (Zyda, 2005).

Robotic devices, when integrated to games, make therapy a great adaptability method, featuring specific games aimed to different kinds of treatable impairments (Andrade *et al.*, 2012). In the context of rehabilitation and games, one can notice the flexibility to create the whole scenario, from every mechanical device involved, to the various details of a game focused in stimulating patient's immersion. It is also noticeable the possibility of use (or even couple to specific devices) game consoles, which has movement-based devices, such as Nintendo Wii, Microsoft Kinect, and others. Table 1 contains information of games placed into this context, as well as its features related to the whole scenario.

Table 1. Scenarios of robots and Serious Games in rehabilitation context.

	Input	**Generated data**	**Persistence of data**	**Analyzes**	**Data access interface**
Silva *et al.*, 2012	Microsoft Kinect (Movement of members, movement amplitude)	Registry of the game session	Database	--	Yes
Caurin *et al.*, 2011	Wrist Robot - EPOS Controller (wrist movements - flexion and extension)	--	No	--	--
Andrade *et al.*, 2010	Wrist Robot - EPOS Controller (forearm movements - pronation and supination)	--	No	--	--
Alankus *et al.*, 2010	Nintendo Wii remotes (shoulder movements - flexion)	--	--	--	--
Andrade *et al.*, 2012	Wrist Robot - EPOS Controller (Wrist movements), Ankle Robot - EPOS Controller (ankle movements)	Time, position, velocity, score and other game metrics	Text file	--	Text editor
Andrade *et al.*, 2013	Wrist Robot - EPOS Controller (Wrist movements – flexion and extension)	Position and velocity	No	--	--
Boian *et al.*, 2003	Servo controller (ankle movements)	Positions, orientations, forces and torques	Database	Yes	Yes
Schönauer *et al.*, 2011	iotracker (movement capture), TMSI Mobi and Gtec g.MOBIlab (eletromyography data)	Members positions, velocities	--	Yes	Yes
Annett *et al.*, 2009	PC MultiTouch tabletop (touch pressure)	--	Yes	Yes	Yes
Burke *et al.*, 2008	Webcam (upper limb movements)	--	Yes	No	Yes
Cameirão *et al.*, 2009	Webcam (arm movements), 5DT Data glove (finger	Upper limb movements	Yea	Yes	Yes

	flexure), g.MOBIlab (Electrocardiograms and galvanic skin response)				

Robots also act in the collection of data (regarding patient's performance) in order to have an input for further analyzes and outcomes, enabling the substantiation of future guidelines to be used by the physiotherapist. Despite of several ways (Tab. 1) of generating analyzable data, it is important to check whether or not every collected raw data has enough quality to obtain relevant outcomes (from clinical perspective), prompting to better acceptance, as well as reliability on measurement accuracy of each involved aspect (Winters and Yu Wang, 2003; Theodoros and Russell, 2008).

The lack of relevant outcomes over the collected data, present in current scenarios of robotics and serious games for rehabilitation, emphasizes need of deeper analyzes in a safe software, in order to make the whole scenario an efficient and more reliable method for physiotherapists. This work aims to build an initial architecture of a web-based system that retrieves the collected information from a database, outputting explicit or statistically analyzed data.

3. SYSTEM ARCHITECTURE

The scope of this work encompasses every session of the rehabilitation robotics scenario, where external agents (from system perspective) make use of the quality processed input, performing statistical analyzes or simply preprocessing the raw data, as well as producing good quality output for support physiotherapist's decisions to conduct treatments.

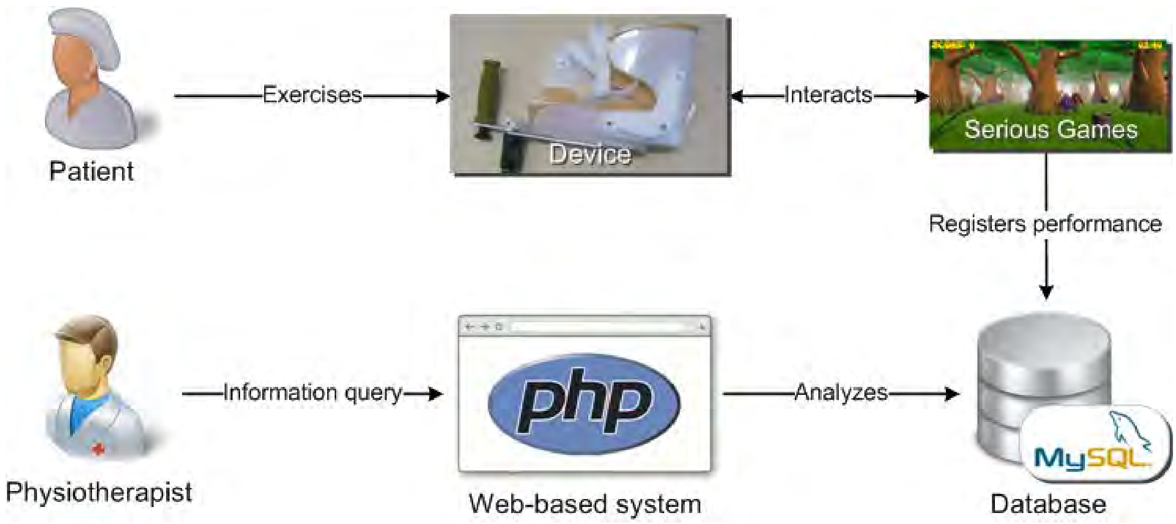

Figure 1. Scope of the web-based system

Two individuals are inserted in the scenario shown in Fig. 1: a patient and a physiotherapist. The patient, once having the device, performs the exercises indirectly, using it as an interface to interact to a virtual environment (a serious game, in this case) that holds patient's attention. The serious game, during its runtime, receives data from the robotic device, process them according to the game logic, and then store in a database, which its data structure should allow further information retrieval, classified by session, time intervals, and other possibilities.

Having the performance data properly stored, a web-based system should query for portions of the available information and output explicitly or statistically analyzed data, in order to support the physiotherapist during a session program. The further topics provide detailed information about the involved parts of this scenario.

3.1 Robotic device

The robotic device involved in this work, designed by (Andrade *et al.*, 2013), aiming an easy access to this technology, offers portability, also enabling the possibility of performing rehabilitation exercises at home, avoiding locomotion to hospitals and clinics. Figure 2 illustrates the physical aspects of this device.

This device offers one degree of freedom (DOF) for flexion/extension movements, being mechanically adjustable in order to alternate between other possibilities of DOF (such as pronation/supination and ulnar/radial deviation). This device was used in this work due to its simplicity using only one DOF at a time. Recent studies (Krebs *et al.*, 2007) show one can conclude that performing more than one kind of movement (i.e., having more than one DOF in the device) simultaneously in physiotherapeutic exercises does not entail in significant improvements. Therefore, satisfactory results can be expected from the device used in this work, avoiding underuse of features.

Figure 2. Robotic device of (Andrade *et al*., 2013)

According to (Andrade *et al.*, 2013), the device is constituted of a forearm bracket Axilo Palmar Salvape® Lite Supp. and a hand stabilizer handle. Movements are performed passively and actively, avoiding gravity effects. A continuous current motor from Maxon Motors is coupled to the robot revolute joint, having a sensor that measures the joint angle. The motor control is done by a servodriver model EPOS 24/5 (supplied by manufacturer). Through a PID controller, this servodriver also do motor position, velocity and current control. The desired positions of the controller are commanded to the servodriver through analog or digital inputs, serial interface, or CAN/CANOpen interface available on the equipment for this communication purpose.

3.2 Serious game

Relatively new in the research field, this area lacks of empirical fundamentals that prove its effectiveness (Cannon-Bowers and Bowers, 2010). However, in the last decade, the number of researches grew considerably (Rego *et al.*, 2010); nowadays, games aimed to healthcare represent 26% of the whole effort (from the conception to marketing) of the all-genre game production.

Adopting serious games in this context enables the stimulation of patient's activity while performing the due exercises, which its movements are directly related to the arrangement of graphical elements of a running game that suggests different ways of control and interaction to the virtual environment. After being processed by the game logic, every received data is stored in a database for further queries and analyzes.

3.3 Database

Every existing data related to patient's performance roamed a flow (Fig. 2), which its intermediary points handle data transiently or persistently. For example, considering a game in runtime, it waits for data in order to update its logic, send them to a database, and then discard what was received. One can say the data (at the game perspective) are handled transiently. The database, in contrast, persists (store) what is received, enabling further retrievals.

Opposite to the direct persistence in a file system, the usage of a Database Management System (DBMS) offers several advantages, such as the efficiency on data access, data integrity, centered management, concurrency control, and others (Ramakrishnan and Gehrke, 1999). DBMS is a software layer used to robustly and efficiently manage a database, through Structured Query Language (SQL), becoming a critical tool when data volume takes larger proportions. Among the various existing database models, this work makes use of the relational model.

A relational database consists, in essence, of tables and relationships, representing (respectively) real-world entities and actions an application may take during its execution. From a conceptual perspective, one can build a database structure, having a perception of entities and its relationships based on requirement analysis (Ramakrishnan and Gehrke, 1999). An initial representation of this web-based system architecture can be seen in the Entity-Relationship (ER) diagram of Figure 3.

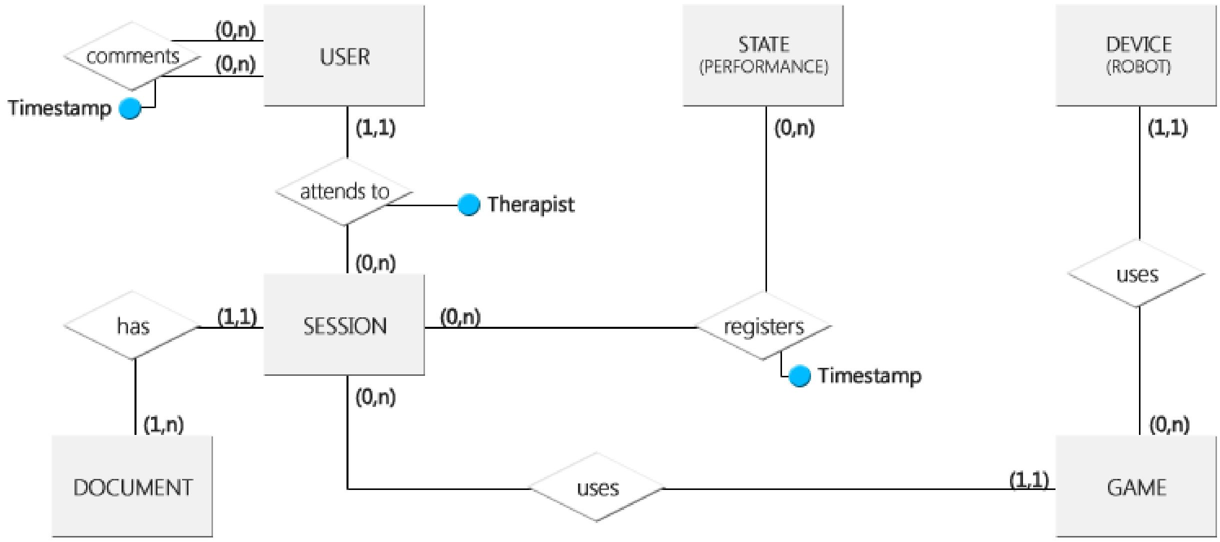

Figure 3. Entity-Relationship diagram of this scenario

It is important to consider certain conventions used in the ER diagram of Figure 3. Entities are represented by rectangle shapes, while rhombuses indicate relationships between line-connected entities. Circles connected to relationships are attributes to be considered and coupled to data. The numbers, along with the entities, are called cardinalities, and can be read as “one to one”, “one to n” or “n to n”. Cardinalities represent the number of minimum and maximum instances an entity (having n as maximum) can hold of the other one (the one on the other side of the relationship, having 1 as maximum). “n to n” relationships entails the creation of another entity (Associative entity), having two “one to n” relationships.

From this conceptual approach it is possible to proceed towards a more technical perspective, through a logical model, in order to obtain pure SQL code to be issued to the DBMS.

3.4 Web-based System

The web-based system is the tool to be used for managing the collected data during physiotherapy sessions and obtain some knowledge about each patient, having a feedback about possible improvements, worsenings or constancy regarding performance. A remotely accessible web server should encompass the web-based system, from the web interface, to auxiliary tools used in data processing. The connection to database occurs either directly or indirectly.

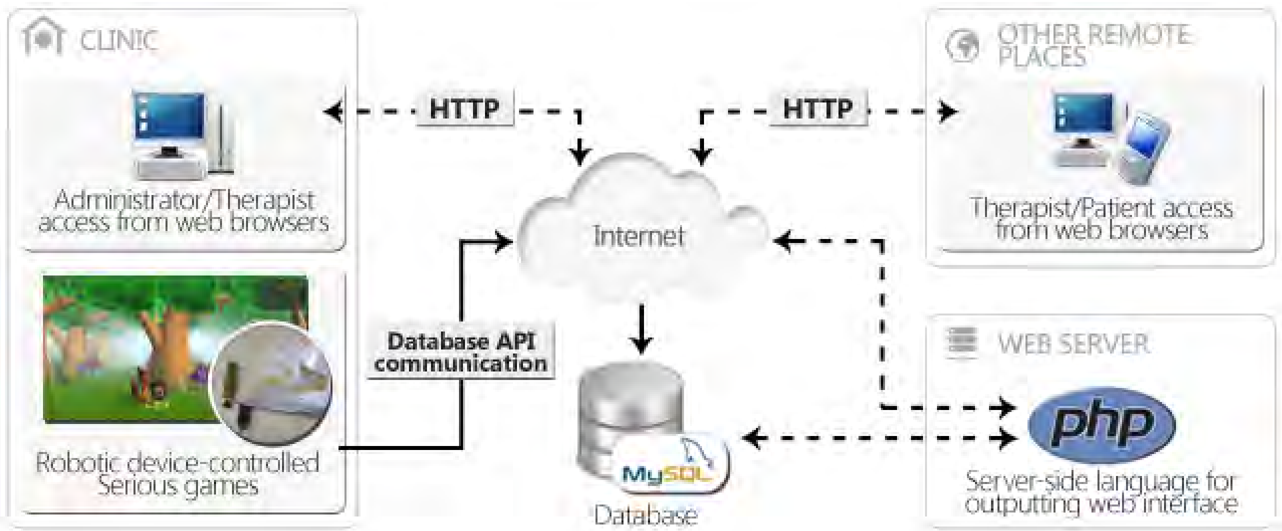

Figure 4. Flow of incoming and existing data

The direct access, by robotic device-controlled serious games, is intended for data insertion only, without accessing any stored data. On the other hand, the indirect access, by the web-based system itself, does not intend to store any analyzable data, querying and analyzing what is already persisted instead. Both ways to access data are made through internet, at remote places. Indirect accesses generally arise from computers and internet-enabled devices, through web browsers, whereas direct accesses occur from clinic equipments (computers and specific devices), through specific database APIs (Application Programming Interfaces), as illustrated in Figure 4.

In order to manage the sections of this scenario, this tool offers specific features that enable the registration of the involved people, such as patients and physiotherapists; the involved games, considering its description, sessions having its usage and other attributes should also be considered; reports regarding patient's performance can be generated, showing its behavior in customizable periods. The ER diagram (Fig. 3) represents these features in terms of data. Figure 5 encompasses three screenshots of the web-based system.

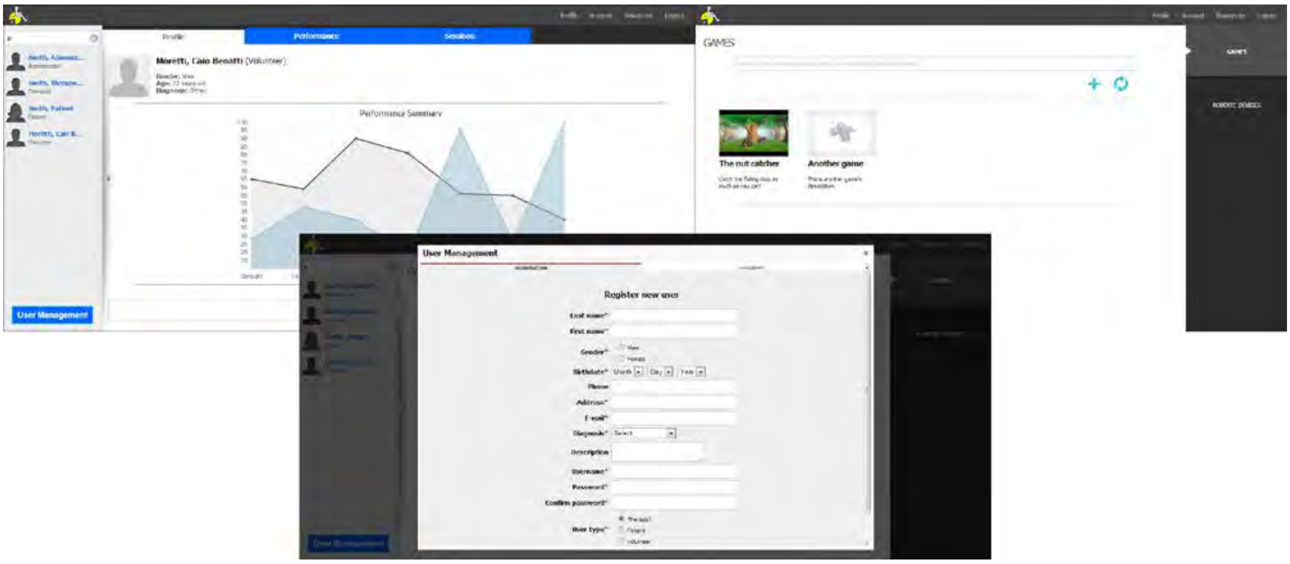

Figure 5. Web-based system screenshots

Every information that roams through the system, such as the acquired input data, should be persisted and retrieved with safety, ensuring confidence and avoiding the access of third-party outside patient-physiotherapist relationship. Thus, data should be encrypted when persisted and decrypted when queried only for those who has the privilege to access the information.

4. EXPERIMENTS AND RESULTS

In order to reach satisfying results in this initial architecture, usability, as well as data security must reveal proper effectiveness.

4.1 Data Security Test

Every stored data within the usage of the web-based system should be available only for properly privileged users, avoiding vulnerabilities and thefts of information. Thus, before being stored into database, data must be encrypted, and decrypted when properly queried. The 128-bit Advanced Encryption Standard (AES) encryption/decryption algorithm (a MYSQL (2013) implementation) was chosen in this work. The AES method consists of a symmetric-key system, having only one key shared by both (encryption and decryption) sides when handling data (Chih-Chung Lu and Shau-Yin Tseng, 2002). Table 2 encompasses the test cases.

Table 2. Data security test cases.

Test case #	Data type	Original Message	Encryption/ Decription key	Encrypted Message (character array)	Decrypted Message	Test result
1	String	This is a String	testKey	125, 65533, 6, 65533, 22, 78, 65533, 65533, 95, 66, 96, 65533, 127, 62, 65533, 72, 6, 65533, 65533, 6, 65533, 65533, 6, 65533,	This is a String	Passed

				65533, 65, 40, 65533, 67, 11, 106, 65533		
2	Number	3.5	testKey	6, 57, 65533, 65533, 3, 19, 76, 65533, 36, 65533, 65533, 70, 65533, 65533, 1000	3.5	Passed
3	Datetime	2013-05-27 14:05:52	testKey	6, 57, 65533, 65533, 3, 19, 76, 65533, 36, 65533, 65533, 70, 65533, 65533, 1000, 6, 74, 65533, 65533, 65533, 54, 65533, 7, 65533, 62, 68, 65533, 78, 106, 17, 28, 54, 65533, 32, 32, 32, 32, 65533, 65533, 65533, 108, 65533, 65533, 65533, 85, 65533, 57, 65533, 65533	2013-05-27 14:05:52	Passed

The test criterion of Table 2 consists of comparing Decrypted Message column to Original Message column. A test case is considered as “Passed” when both columns match to each other (in the comparison). Otherwise, the test case is considered as “Failed”. It is important to consider the Encrypted Message column in an array format, due to the absence of text symbols to represent most of ASCII values.

4.2 Interface and Usability Assessment

As an initial architecture, this web-based system must provide a useful interface in order to improve the software effectiveness as a whole, as well as ensure a good usability both in its current state and in future enhancements. The main role of an interface, in this work, is to provide a human-computer interaction that enables retrievals or insertions of information into the system. Thereby, a reasonable way to perform an interface test is to collect subjective evaluations from humans through a questionnaire that was submitted to a set of volunteers (Tab. 3). The answers arising from the applied questionnaire should emphasize lacks, defects or enhancements to be considered in further adjustments. Questions regarding visual aspects, quality/quantity of information and other subjective features were considered when preparing this assessment tool.

Table 3. Test volunteers set.

Volunteer #	Age	Computer knowledge
1	0-21	High
2	22-40	High
3	22-40	Medium
4	41-60	Medium
5	41-60	Medium

Each volunteer of Table 3, according to its computer knowledge, has assessed human-computer interface features through specific questions, giving a numerical value (in a scale from 1 to 10) as an answer. The final result, a set of arithmetic means, can be seen in Table 4. The questionnaire was prepared based on QUIS[1] (Questionnaire for User Interaction Satisfaction).

Table 4. Final results of the assessment questionnaire.

Category	Question	Minimum Assessment	Mean assessment	Maximum Assessment
Screen	Text readability	Unreadable	8.8	Readable
	Highlight of elements	Overloaded	9.2	Clean
	Number of elements (per screen)	Few	5	Many
	Organization	Confusing	8.4	Organized
	Affordance	Not intuitive	7.8	Intuitive
Operational features	Ease to operate	Difficult	8.4	Easy
	Layout complexity	Simple	3.6	Complex
	Accessibility	Insufficient	7	Rich

[1] http://lap.umd.edu/quis

	Knowledge required	Low	4.8	High
	Instructions	Few	5	Many
	Ease to explore (through trial and error)	Difficult	8	Easy
	Errors/defects	None	2.4	Many
Informational ability	Usage of technical terms	Confusing	7.8	Appropriate
	Alert messages	Useless	7.8	Useful
	Number of information (per screen)	Few	4.8	Many
	Reliability	Not reliable	7.8	Reliable
	Ethical concern	Poor	9	Good

Given the mean assessments of all considered features, one can conclude that this initial architecture provides a proper human-computer interaction, having an acceptable and organized layout that provides well readable content and good perception of graphical elements, which entail in an intuitive tool.

Operational features also showed good results. The web-based system was considered an easy tool, requiring low computer knowledge to operate, due to its rich accessibility, simplistic layout, few errors and/or defects, an average ability to instruct users during its runtime, and other features that distinguish softwares with good exploitability.

The satisfying results of operational features, as well as part of screen features, were achieved due to system’s reliability and good informational ability, appropriately using technical terms, alerting only useful and relevant messages when necessary, displaying only the essence of every content (having ways to obtain more detailed information), and specially concerning about ethical matters.

It is important to consider that a maximum value in the assessment scale not always is the best situation, while the minimum value is not the worst situation. Certain features are best assessed having a balanced value, others are best assessed with a higher value and others with a low value. The difference between the current assessment and the ideal assessment will be considered in future work in order to increase the quality, performing the due enhancements.

5. CONCLUSION AND FUTURE WORK

This paper introduced an initial architecture of a web-based system that offers the ability to manage rehabilitation treatments more efficiently, supporting physiotherapists in decision-making situations due to the large amount of collected data that can be queried explicitly or statistically analyzed. The good results from the performed tests brought the opportunity to emphasize possible enhancements and other adjustments to be performed in future works. The next step from now is the use of techniques to extract non-trivial knowledge from large amounts of collected data, improving the performed analyzes over patient’s performance.

6. ACKNOWLEDGEMENTS

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8. RESPONSIBILITY NOTICE

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