ePHoRt project: A telerehabilitation system for reeducation after hip replacement surgery

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Abstract

This project aims to develop a web-based system for the remote monitoring of rehabilitation exercises in patients after hip replacement surgery. The tool intends to facilitate and enhance the motor recovery, due to the fact that the patients will be able to perform the therapeutic movements at home and at any time. As in any case of rehabilitation program, the time required to recover is significantly diminished when the individual has the opportunity to practice the exercises regularly and frequently. However, the condition of such patients prohibits transportations to and from medical centres and many of them cannot afford a private physiotherapist. Thus, low-cost technologies will be used to develop the platform, with the aim to democratize its access. For instance, the motion capture system will be based on the Kinect camera that provides a good compromise between accuracy and price. The project will be divided into four main stages. First, the architecture of the web-based system will be designed. Three different user interfaces will be necessary: (i) one to record quantitative and qualitative data from the patient, (ii) another for the therapist consulting the patient's performance and adapting the exercises accordingly, and (iii) for the physician having a medical supervision of the recovery process. Second, it will be essential to develop a module that performs an automatic assessment and validation of the rehabilitation activities, in order to provide a real-time feedback to the patient regarding the correctness of the executed movements. Third, we also intend to make use of a serious game and affective computing approaches, with the intention of motivating the user to perform the exercises for a sustainable period of time. Finally, an ergonomic study will be carried out, in order to evaluate the usability of the system.

I. Project Objectives

A current tread in medicine is home therapy systems. This concept consists in enabling patients to carry out part of the rehabilitation at home and to communicate through the Web the evolution of the recovery process. Thus, health professionals can proceed with a remote monitoring of the patient's performance and an adaptation of the treatment accordingly. This technology could bring several advantages for the individual and the society in terms of healthcare (improvement of the recovery process by the possibility to perform rehabilitation exercises more frequently), economy (reduction of the number of medical appointments and the time patients spend at the hospital), mobility (diminution of the transportation to and from the hospital) and ethics (healthcare democratisation and increased empowerment of the patient).

By taking into account these considerations, the project proposes to develop a Web-based platform for home motor rehabilitation. The tool will be tested on volunteers, due to the fact that it will be difficult to use patients after hip arthroplasty surgery during the workshop. This orthopaedic procedure is an excellent case study, because it involves people who need a postoperative functional rehabilitation program to recover strength, function and joint stability. In addition, due to the condition of the patients, it is difficult to carry them to the hospital. The project intends to tackle three main issues. First, the motion capture technology must be low-cost, in order to be used worldwide. Second, the system should automatically detect the correctness of the executed movement, in order to provide the patient with real time feedback. Third, new computational approaches have to be researched, in order to promote patient's motivation to regularly complete the rehabilitation tasks (e.g., by the use of affective computing and serious games paradigms to detect difficulties and stimulate effort in the patients, respectively).

General objective:

Develop a web-based system for remote monitoring of home rehabilitation, in order to enhance recovery in patients after hip replacement.

Specific objectives:

1) Real time assessment of the correctness of the movements.

2) Recognition of the emotional state of the user.

3) Development of game-based exercises.

4) Implementation of the Web-based application.

5) Ergonomic evaluation of the tool.

II. State of the Art

Movement recognition

Human action recognition is a very challenging topic. It presents more degrees of freedom with respect to system design and implementation when compared to language processing [1]. Different approaches are used regarding the sensor technologies and computational algorithms. The first kind of sensors are wearable devices, which are based on pervasive and mobile computing [2] [3]. A less invasive technique consists in using a vision-based recognition. The Kinect camera has largely contributed to the growth of this approach, due to the fact that it facilitates the extraction of the pertinent features for gesture recognition [4] [5]. Movement recognition has to be carried out through a process flow that usually involves raw data recording and filtering, feature extraction and selection, and classification by the use of machine learning models. A wide range of classifiers have been used for action recognition in the last decades [6]. One of the most successful methods to achieve recognition of daily activity is the discriminative approach. This classification is based on the construction of decision boundaries in the feature space, specifying regions for each class. The main classifiers that implement this type of method for activity recognition are the k-Nearest Neighbour [7], Support Vector Machines [8], the Naïve Bayes [9], and C4.5 Decision Tree [10].

Gamification

It has been shown that patients train more if the training is combined with attractive training environments [11]. The tasks to complete are built on the concept of serious games. That is, they are presented as a challenge to overcome and the patients improve their score each time they perform the exercises successfully. As for fun games, the main motivational factor is based on the desire to improve the score session after session. This stimulation of the competitive nature of the human being promotes an effortless intensification of the rehabilitation process. The approach has demonstrated its efficiency in the rehabilitation of cognitive and motor functions. For instance, a 3D game was developed for the treatment of aphasic patients [12] [13]. Other motor rehabilitation systems propose an integrated training using the Unity 3D game engine and immersive user interfaces [14]. The Kinect has been used into a number of games under Unity3D for assistance [15] and rehabilitation [16].

Affective computing

If exercises are carried out in front of a machine instead of a human being, the subjects may feel an absence of moral support, especially if they are individuals in a recovery process. To tackle this problem, the project intends to implement an additional computational module that will automatically detect if the patients are facing with difficulties or pain when they perform the rehabilitation tasks. This process could be based on a detection technique of subtle features of body movements, as the algorithms implemented in laughter detection systems [17] [18]. Again, machine learning classifiers will be used to discriminate whether or not the patients are reaching their limits. Besides whole body motion, it is possible to take advantage of the emotion recognition properties of the Kinect v2, in order to identify a situation of pain through the facial expressions of the individual [19]. Also, if visual cues are not enough to perform an accurate classification of the emotional state of the patient, an audio-visual multimodal approach can be considered [20]. Once a situation of difficulty is identified, a positive reinforcement such as a message of encouragement could be displayed.

III. Technical Description

Development of the platform

Architecture. The ePHoRt project is a Web application based on a three layers Client-Server architecture (figure 1). The client layer (browser) will be developed in JavaScript by the use of two possible frameworks: jQuery or AngularJS. The application layer (domain server) will be developed either in Django framework from Python or Java framework. The data server layer (database) will be developed in MySQL.

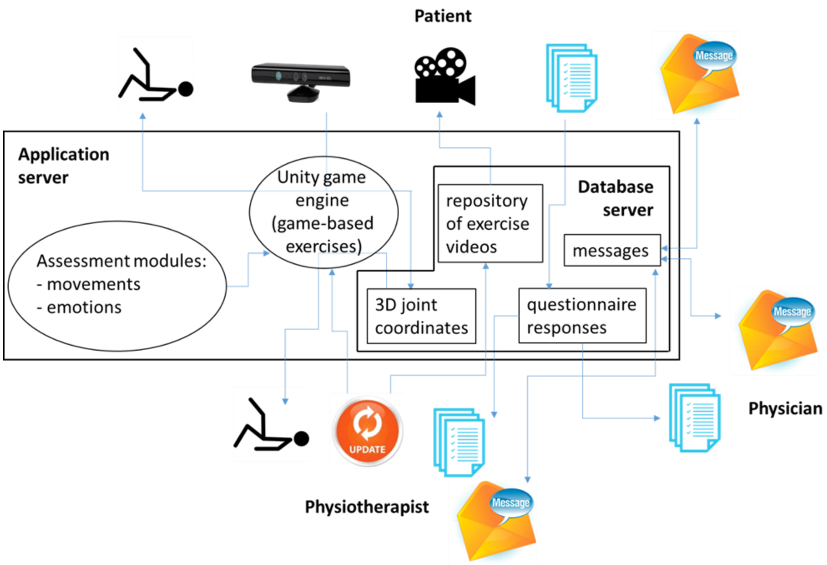

Figure 1. ePHoRt platform architecture

The client and the server layers will be connected by Internet. A different user interface will be implemented for each of the three kinds of user: patient, physiotherapist and physician. After login, the patients will have an access to the programmed exercises they have to achieve. The patient's interface will be composed with two dynamic frames: (i) one to display a video example of the exercises to be completed and (ii) another to display a 3D-avatar that will mimic in real-time the patient's movements captured by the Kinect. The patient will receive a real-time feedback regarding the correctness of the movements, thanks to the assessment module, and game scores. In addition, questionnaires will be available on this interface, in order to record qualitative information. The main functionalities of the physiotherapist's interface will be: (i) accessing to the patient's performance for each exercise, (ii) consulting the answers to the self-reported functions, (iii) watching the three-dimensional reproduction of the patient's movement through an animated avatar and (iv) updating (to more challenging parameters of the same exercise or to new kinds of exercise) the rehabilitation program according to the patient's progress and/or medical advices. Finally, an interface for the physicians will enable them to supervise all the recovery process and communicate with the physiotherapist to authorize or not certain movements according to the specific condition of each patient. The communication between the three stakeholders will be supported by an exchange of messages.

The application layer will contain the logical structure of the platform. This intermediate layer will be connected to the client, through Internet, and to the database server. It will receive and process the requests from the three types of user. Here, the Unity 3D game engine will be used to develop the game-based exercises and animate the avatar [21]. Also, the affective and movement assessment modules will be integrated at this level.

The database layer will be connected to the application layer. Heterogeneous data will be stored into the database, such as: (i) quantitative data about the 3D-coordinates of the movements, (ii) qualitative data about the responses to the questionnaires, (iii) videos of the exercises and (iv) comments made by the physiotherapists and physicians.

Recognition and assessment of movement qualities. Techniques will be investigated to automatically compute a collection of descriptors characterizing the movements patients perform. Analysis will be structured on multiple layers with different time-spans, according to the conceptual model defined in [22] and refined in [23]. At a first stage, raw data captured with low-cost motion capture devices (e.g., Kinect) will be pre-processed to extract time-series describing movement at a local temporal scale (e.g., kinematics, amount of detected movement, postural contraction, symmetry, and so on). Then, movement units will be segmented and further descriptors will be computed by applying analysis primitives to the time-series. Analysis primitives range from simple statistical operations, to application of time-frequency transforms (e.g., periodicity transform), physical models from biomechanics, and machine-learning techniques. Descriptors at this level cover a longer time-span and concern movement qualities, i.e., how a movement is performed. Movement qualities include, for instance, periodicity, impulsivity, rigidity, fluidity, contraction, energy, and hesitation. A particular focus will be on the detection of unwanted protective behaviours such as, for example, guarding, hesitation, abrupt movement, bracing, limping, and so on. The developed algorithms will be trained and tested on a reference archive of exercises performed by selected patients. Algorithms will be collected in a library of software modules.

Detection of the emotional state. The work will concern the automatic analysis of the affective behaviour of patients performing exercises and interacting with the prototypes developed in the project. This includes the detection of typical emotional states that may arise during rehabilitation activities such as, for example, positive dispositions like attention and engagement, or negative ones like boredom, fatigue, stress, and frustration. Techniques will exploit the above-mentioned descriptors of movement qualities, which will be used to train classifiers based on the desired affective categories. Analysis will be grounded on literature in affective computing [24] [25] [26], experimental psychology [27] [28], and humanistic theories [29]. Results will be employed in a twofold perspective: (i) to intervene in real-time for maximizing the effectiveness of the rehabilitation exercise (e.g., by changing feedback when the patients feel bored, by possibly simplifying the task if they feel frustrated, or by increasing difficulty when they are very engaged), and (ii) to perform and gather measurements for assessing quantitatively the effectiveness of the rehabilitation exercise (e.g., by measuring the proportion of time the patients were engaged or positively involved and the proportion of time they were bored or frustrated). The developed algorithms will be trained and tested on a reference archive of exercises performed by selected patients. Algorithms will be collected in a library of software modules.

Game-based exercises. The rehabilitation protocol is planned on three chronological stages: (i) early active motion, (ii) body weight load, and (iii) static gait pattern. The objective of the early active motion is the retrieval of the range of motion (ROM) and dynamic muscular force by mean of controlled active motion regimen. To stimulate the accomplishment of this kind of exercises, following a gamification approach, the patients will have to shoot in a virtual ball (like a football game) located in different spatial positions according to the exercise specifications. Their score will increase each time the task will be correctly performed. The body weight load stage consists in improving the coordination, balance and proprioception with progressive body weight load.

Relevant game-based exercises for this task would be driving a car, fling a plane or catching fruits failing from a tree. In the most advanced phase - Static gait pattern - the objective is to stimulate coordination, balance and proprioception for an optimal gait. Interesting games to implement for this stage would be a dance machine or trying to kill virtual aliens on the floor. In order to follow a progressive rehabilitation protocol, the patient will be permitted to go through the next stage only after getting a certain score in the previous one.

Design of the user interface. Usability is "the extent to which a product can be used by specified users to achieve specified goals with effectiveness, efficiency and satisfaction in a specified context of use" [30]. In practical terms Usability ensures that a person of average (or below average) ability and experience can use a product for its intended purpose without being deeply frustrated [31]. To ensure a high usability of ePHoRt platform user interfaces, the application will be developed using an approach based on User-Centered Design (UCD). UCD can be characterized as a phased problem solving cycle where user needs are taken into account during the development and validation of the design solutions [32]. UCD comprises: the analysis and specification of the system context of use; the specification of user requirements; the production of design solutions that meet the user requirements and the evaluation of the design solutions that meet the requirements. These activities will be carried out iteratively until a solution is reached that satisfies both the user requirements and the attributes of usability (effectiveness, efficiency and satisfaction).

Evaluation of the tool

Assessment of the Human-System Interaction. To ensure the quality of the human-system interactions during the UCD cycle, several evaluations of usability will be performed. To perform the usability assessment, several methodologies will be applied such as the cognitive walkthrough method or heuristic evaluations. The cognitive walkthrough method [33] is a methodology based on exploratory learning, where a group of untrained individuals (selected so as to be representative of the universe of users) is asked to perform a set of predefined tasks. The aim is to assess how intuitive the product is (learnability), evaluating the extent to which users can use the product and achieve their objectives without having had any training. These evaluations also serve to assess users' satisfaction. Users' feedback is analysed and the need for design improvements is established. A heuristic evaluation is performed by Usability experts and is based on the analysis of the compliance of the interface features against the principles of usability, as defined in the heuristics. The most used heuristic is the Nielsen Heuristics, in which Experts have to classify the severity of each detected problem in terms of product operation (interaction) impact and must recommend improvement measures [34].

Resources needed

The main resources needed for this projects are:

- Kinect v2
- Room for the recordings
- Good Internet access

IV. Work Plan & Schedule

SPECIFIC OBJECTIVES	ACTIVITIES BY OBJECTIVE	START	END
O.1. Develop the platform	A.1.1. Design of the client-server architecture and database	T0	T0+1 week
	A.1.2. Development of a real time evaluation module to assess and validate the correctness of the movement execution	T0	T0+2 weeks
	A.1.3. Development of motivational mechanisms based on gamification and affective computing	T0	T0+2 weeks
	A.1.4. Integration of the different modules in order to proceed with the computational implementation of the rehabilitation protocol	T0+2 weeks	T0+3 weeks
	A.1.5. Design of the user interface	T0+2 weeks	T0+3 weeks
O.2. Evaluate the tool	A.2.1. Evaluation of the automatic classification of correctly vs. incorrectly executed movements	T0+1 weeks	T0+2 weeks
	A.2.2. Iterative and final evaluations of the usability of the system	T0+2 weeks	T0+4 weeks

Work-Packages:

WP.1 – Design of the client-server architecture and database.
WP.2 – Development of a real time evaluation module to assess and validate the correctness of the movement execution.
WP.3 – Development of motivational mechanisms based on gamification and affective computing.
WP.4 – Integration of the different modules in order to proceed with the computational implementation of the rehabilitation protocol.
WP.5 – Design of the user interface.
WP.6 – Evaluation of the automatic classification and assessment of the executed movements.
WP.7 – Evaluation of the system usability.

Deliverables:

1) Prototype for the automatic identification of the movements.
2) Prototype for the automatic detection of the affect.
3) Prototype of the set of serious games.
4) Prototype of the integrative platform.
5) Report on the result of the evaluations (including a statistical analysis of the data).

V. Benefits of the Research

The arthroplasty or substitution of the hip joint by a prosthesis is an increasing surgery all around the world. For instant, official data show an augmentation in 31% from 1997 to 2009 [35] and in 124% from 2000 to 2010 [36] in Spain and USA, respectively. The main criteria to proceed with an arthroplasty are when the individual feels pain and suffers functional impairments [37]. The operation ensures an improvement of all of these symptoms after surgery [38]. However, a postoperative functional rehabilitation program is essential to recover strength, function and joint stability [39]. In the field, physiotherapists cannot regularly monitor the correctness of the exercises performed by the patients. In addition, some people cannot follow the recovery program, due to the fact that their condition prohibits any transportation to and from the medical centres or because they cannot afford a private therapist.

By taking into account these considerations, the project proposes to develop a low-cost web-based platform for the remote monitoring of the functional rehabilitation protocol that the patient will be able to complete at home. Such a telemedicine system is still very marginally implemented for motor rehabilitation purposes, because of technological and scientific challenges in the movement recognition. Currently, the approaches are essentially based on wearable devices. Here, we intend to use a vision-based motion capture and take advantage of the feature extraction properties of the Kinect v2 camera, which is a quite affordable technology. The main innovation and originality of this scientific study is to integrate in a single platform: (i) a remote monitoring of patients and data sharing of the medical information between the different stakeholder (therapists, physicians and patients themselves); (ii) a real-time recognition of the patient's activities and mood in order to assess the correctness of the movement execution and the level of fatigue, respectively; and (iii) a serious games and affective computing approach to motivate the individual to perform the exercises for a sustainable period of time. To the best of our knowledge, this work was never applied to support the motor rehabilitation of patients after arthroplasty surgeries. According to the outcome of the project, the methodology and technology involved in the platform could be easily reused for the treatment of other physical disabilities, such as stroke.

VI. Profile Team

Yves Rybarczyk is professor at the Nova University of Lisbon (Portugal) and head of the Intelligent & Interactive Systems Lab (SI^2), Universidad de las Américas (Ecuador). In 2004, he received a PhD degree in NeuroRobotics from the University of Evry (France) for his work on the "Modelling and implementation of human-like behaviours to improve Human-Robot Cooperation in teleoperation". His research interests range from Human-Machine Interaction and Robotics to Technologies of Digital Games and their applications in health and learning. Currently his research group focuses on the development of web-based platforms for telerehabilitation and recognition of human activities. He has participated in many national and international scientific projects. He is the author and co-author of over 60 articles and has supervised several doctoral dissertations and master theses. Besides scientific papers, Rybarczyk's group has produced interactive applications and tools for educational and therapeutic purposes. He is also member of the steering committee of eNTERFACE workshops on Multimodal Interactions and reviewer in famous scientific journals and conferences.

Mario Gonzalez received his B.Sc. degree in Industrial Engineering from National University of Engineering, Nicaragua in 2004. He received a Ph.D. in Computer Science from the Autonomous University of Madrid (UAM) in 2012. His doctoral research was carried out within the Research Group of Biological Neurocomputation of the Polytechnic School at UAM. He made a doctoral stay at the Faculty of Engineering of the University of Porto (FEUP), Portugal, funded by the Erasmus Mundus ECW Lot 20 program. He is currently a lecturer and researcher at Universidad de las Américas, Ecuador. He has participated in projects funded by the Economy and Competitiveness Ministry of Spain. He has published in the area of Artificial Intelligence and Multidisciplinary Physics. His field of expertise and experience is information processing using bio-inspired computational systems using recurrent metric networks and complex systems modelling and analysis.

Arián Aladro is a PhD candidate in Health and Sport Science from University of Zaragoza (Spain), leading research on motor learning and physiological stress. After graduating with a bachelor in Physical Conditioning and degree in Physical Culture, he obtained a master degree in Human Movement Sciences awarded by the University of Costa Rica (San José, Costa Rica). He is also a titular professor of Biomechanical and Exercise Physiology with the School of Physiotherapy, Universidad de las Américas (Quito, Ecuador). Prof Aladro has authored/co-authored peer-reviewed papers in fields as social networks and physical activity promotion; musculoskeletal disorder; motor performance; and aerobic exercise and psychosocial stress. Currently, he has an outstanding contribution in the research group of Physiotherapy and Human Movement of the Universidad de las Américas.

Santiago Villarreal holds a Bachelor's degree in Computer Science (since June 2007) and a Master's degree in Web Intelligence (since June 2010) from Jean Monnet University (St. Etienne, France). He is a Professor at Universidad de las Américas (Quito, Ecuador), teaching software development. He also collaborates with the research department with the ePHoRt project

Jan Kleine Deters holds a bachelor degree in Industrial design from the University of Twente and is currently master student at University of Twente in Human Media Interaction. Working on this is project is intertwined with his master thesis and focusses around the real-time classification of Human motion recognition. System design and prototyping as well as machine learning and usability testing are currently his areas of interest.

Researchers needed

We are looking for participants with skills in the following areas of interest:

- Web development
- Artificial Intelligence and Machine learning
- Software engineering
- Signal processing
- Biomechanics
- Physiotherapy
- Human-Machine Interaction

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