Virtual Arm Representation and Multimodal Monitoring for the Upper Limb Robot Assisted Teletherapy

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Abstract: The use of technology in rehabilitation therapies targets the sustainability of health systems and the improvement of quality of life of the user (therapists, patients and informal carers). Robot or exoskeleton assisted rehabilitation systems, which are based on neurorehabilitation principles, are tools that not only help patients move the arm with precision; they also help reduce the fatigue of the therapist during the process. One of the challenges of the virtual reality based robot assisted upper limb rehabilitation is patients' immersion within the therapy to achieve an improved progress of the rehabilitation. This paper, presents a new virtual reality therapy that has been created using the Armeo Spring exoskeleton. A 3D representation of the arm serves as an interaction mechanism with the virtual world. This makes the user more aware of the movements that he/she is making and improves the rehabilitation outcomes. It also encourages the user motivation and engagement to the therapy. Additionally, an application for the multimodal monitoring of the patient has been developed, together with tools for the online assessment of patients. These developments allow the physician to review the therapy without being in the same place and time, optimizing the use of hospital's human resources.

1 INTRODUCTION

Cerebrovascular accidents (CVA) and spinal cord injuries (SCI) are currently the most common causes of paralysis and paresis with reported prevalence of 12,000 cases per million and 800 cases per million, respectively. Disabilities that follow CVA (hemiplegia) or SCI (paraplegia, tetraplegia) severely impair motor functions (e.g., standing, walking, reaching and grasping) and prevent the affected individuals from healthy-like, full and autonomous participation in daily activities.

Moreover, the societal habits increase the number of such episodes. The risk factors of the today's society are reported by the World Health Organization at (McKay et al., 2004). Together with the societal habits, the progressive aging of society (World Heath Organization, 2011) calls to urgently find new systems that will help mitigate the effects of resource demand of such patients on the healthcare system. In the path to guarantee the successful implementation, deployment and use of the solution, these systems should also improve the quality of life of the involved people (therapists, patients and informal carers).

One of the possible intervention points to palliate the burden of healthcare systems is stroke rehabilitation. Neurorehabilitation is a process that aims to recover the capabilities to carry out regular activities, lost by a neurological disease, by re-learning or by active problem resolution. Neurorehabilitation is based on the concept of Neuroplasticity. According to experts, the brain is able to establish new conections between neurons

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that are able to subtitute lost sinapsis to a greater or lesser extent. This is usually targeted by repetitive therapies.

Traditionally, neurorehabilitation processes have been based on the mobilisation of paralysed extremities to avoid the stiffness and retractions of joints and muscles. The most common therapy is the Bobath method (Bobath, 1990) based on the hierarchical organisation of the Central Nervous System (CNS). According to Bobath, the direct handling of the body at key points such as the trunk is able to control afferent input and facilitate normal postural reactions. According to this concept, postures must be used to inhibit spasticity and tonic neck reflexes and to facilitate righting and equilibrium reactions.

With pass of time, new approaches have been defined (Cano-de-la-Cuerda et al., 2012), such as the task oriented rehabilitation process, which is based on the functional task achievement, rather than on the automatisms that are used for the task completion. This method argues the repetition-based therapies in the cases where they lack a functional purpose. This approach seeks training cognitive, psychological and sensitive aspects not taken into account by the Bobath therapy.

The introduced therapies require several human resources such as doctors and different therapists (physical, occupational…). In most cases, therapists need to be present during the therapy execution.

The latest advancements in robotics and neuroscience have shown that robotic systems or exoskeletons can facilitate functional task oriented rehabilitation processes. According to several authors, this type of therapy is more efficient for the reduction of the effects of altered motor control. Robot or exoskeleton assisted rehabilitation systems, which are based on neurorehabilitation principles, are tools that not only help patients move the arm with precision; they also help reduce the fatigue of the therapist during the rehabilitation process. This type of rehabilitation is usually developed together with a virtual reality environment. Additionally, this type of system provides the therapists with tools to make complete and objective studies over the evolution of the patients. The key factors for a successful robotic-assisted therapy have been already described in a previous study (De Mauro et al., 2012).

One of the challenges of the virtual reality based robot assisted upper limb rehabilitation, is patients' immersion within the therapy, to achieve an improved progress of the rehabilitation. This challenge is mainly motivated by the lack of a realistic representation of the arm in the available games. The lack of realistic representation is caused by a lack of bioinspiration of the solution. This lack of realism creates a lack of identification of the patient with the virtual world, which negatively affects the active role of the patient, and their motivation. Therefore, the development of more realistic arm models will improve the three key factors (bioinspiration, active role of the patient, and motivation) implied in the identified challenge. Additionally, the analysis of state of the art on robotic device based rehabilitation therapies has underlined the need of remote therapy support and the definition of a structured movement quantification data format, interoperable with other rehabilitation systems.

The objective of the present work is to develop a realistic representation of the affected arm with the aim to increase users' motivation. Furthermore, the research also targets the design and implementation of the architecture and data structure to support remote therapy and guarantee the interoperability with other rehabilitation systems.

In section 2, a state-of-the-art in the field is presented. In section 3, we detail our solution's design and implementation while in section 4 we present the main results obtained from our solution's implementation. Conclusions and future work are presented in section 5.

2 STATE OF THE ART

The lost of mobility or paralysis of upper extremities is identified among the possible consequences of a person suffering a stroke. The rehabilitation process followed in these cases is composed of active or passive training of the limbs and articulations, in all the possible directions and with the largest run possible. This process is usually done by performing a large number of repetitions, which exhausts, mentally and physically, both the patient and the therapist. Therefore, the use of virtual reality (VR) systems can help motivate the user. Currently most of the available VR systems are not accessible to the people with critical impairments, such as those who have suffered from stroke or cerebral palsy. Thus, the scientific community has worked in the use of VR systems with the assistance of robotic systems or exoskeletons.

In the following section, the different technologies related to the identified research topics will be studied. First, VR or games based systems for rehabilitation, (including the design concepts) will be analysed. Exosketons and robotic solutions used for upper limb rehabilitation will then be examined.

At the end of this section, technologies and further considerations related to the remote monitoring of the therapy support will be presented.

2.1 Virtual Reality based Rehabilitation

The virtual reality systems can be classified as fully-, semi- or non-immersive systems (Prashun et al., 2010). The classification refers to the level of perception of presence in a non-physical world and the technology used to present the virtual world to the user. A monitor, a projector or VR glasses are normally used for each of these modalities. Alternatives include the combined use of real objects, augmented reality and VR to create a mixed-reality (Hilton et al., 2011). This way, the tasks of the rehabilitation solution can be brought closer to real life tasks. This leads to a larger level of cognitive learning and user acceptance, while carrying out exercises to improve mobility. Hilton et al., also report on studies that present the benefits training of daily-living activities in VR scenarios has, beside the benefits of the realisation of the exercises, on applying the learned tasks in their real life.

The main variables used for the rehabilitation assessment are the time needed to get to the target position, the speed at which the task is completed, the accuracy of the trajectories and the range of movements. The duration and the frecuency of the therapy varies from study to study(from 45 minutes to one or even two hours). Frecuency also varies from 3-5 weeks upto 11-13 weeks with a repetition of 5 days per week.

2.1.1 Rehabilitation Game's Design and Adaptation

For the design of rehabilitation games, many factors need to be taken into account. One of the most important ones is the feedback received by the user, from the action being carrying out. This feedback can be of different types: e.g. auditory, haptic or visual. Feedback makes user motivation to increase, either being to achieve a concrete task, achieve a higher score or else (Maclean et al., 2000).

Different studies (Burke et al., 2010; Sveistrup, 2004) have underlined that the representation of the user or his affected extremity in a virtual world is very positive for accepting and engaging with the therapy. In this type of system there is a continuous feedback, so the user can focus on the affected extremity, being conscious of the movements he/she is doing.

Alankus et al. stress the importance of adapting the games to each user and their evolution based on different factors (Alankus et al., 2010). One of the identified factors is that games should allow the user a certain error margin and that errors consequences should be constructive rather than catastrophic.

Another important factor is the game's difficulty. An excessive difficulty level can lead the user to stop playing the games. On the contrary, an excessive simplicity would get the user bored.

A study by N. Hocine et al. (Hocine and Gouaich, 2011) shows that a dynamical difficulty adaptation system, while maintaining a stable success rate, influences positively the perceived difficulty, making the therapy more satisfying and rewarding for the patient. It is therefore important to gradually increase the game's difficulty, based on patient's evolution. Besides, the gradual increase of difficulty attracts user's attention. This distraction can be used to facilitate patient's pain management, since when the patient is entertained, he/she is not so conscious of pain.

Moreover, the games should also adapt to the evolving user mobility capabilities. At the beginning of the rehabilitation user's mobility is very limited, so the working area of the game should be reduced compared to more advanced phases of the rehabilitation process.

As rehabilitation involves a motor learning process (Krakauer, 2006), the use of a taxonomy of tasks, such as Gentile's (Adams, 1999), can be relevant here for both assessing the patient abilities and building a coherent therapy plan gradually increasing the movements complexity. According to Gentile, four factors are to be taken into account: the environment (whether it is changing in time and space or not), the intertrial variability (if the target changes between trials), the patient's body motion and the use of extremity. Other factors pointed by A. Reinthal et al. (Reinthal et al., 2012) include whether the task performed is continuous or discrete and whether it requires unilateral or bimanual dexterity. By increasing the movements' complexity, the patient gradually learns again how to perform successfully activities of daily living, which involves coordination between complex movements and variations of the environment. In the case of rehabilitation, intertrial variability is a key factor to trigger a process of generalization of the movement,for example for the patient to be able to grab an object regardless of its position (Krakauer, 2006).

Even if there is an increasing amount of games targeted to rehabilitation, until now not all entertainment possibilities present at mainstream games are being exploited (Rego et al., 2010). For example, there are no rehabilitation games, where competitive, collaborative or net gaming is possible among multiple users. These functionalities would probably increase patients' motivation.

2.2 Exoskeletons and Upper Limb Rehabilitation Systems

The actual exoskeletons' market is limited in available models and their price is very high. These are the main reasons for their low deployment. Following, some of the commercially available or scientifically reported exoskeletons are presented.

The Armeo Spring (Hocoma, 2013) is a exoskeleton that embraces the whole arm, from shoulder to the hand. This model is indicated for those patients that have lost partially or completely upper limb functionality, either caused by a brain, spinal or muscular damage. This model has six degrees of freedom (three in the shoulder, one in the elbow and two in the wrist) without any robotic actuator. Therefore, it is considered a passive system. The Armeo Spring can be adjusted to patient arm's weight, so that patient doesn't need to practise any force to hold his arm. This way, a patient can make use of his residual upper limb functionality.

With the aim of increasing the motivation and acceptation of the therapy by the patient, the Armeo Spring comes with different games that provide auditory and visual feedback to the user. The exercise area of the patient can be personalised to the patient's mobility range in each phase. Once the game has finished, the session's data is written into an excel spreadsheet for patient's evolution assessment.

InMotion (InMotion, 2013) is an upper limb (hand, arm, and shoulder) rehabilitation system. The system is composed of three robotic systems: InMotion Arm Robot, InMotion Hand Robot and the InMotion Wrist Robot. These robotic systems have a force-feedback system that helps users with mobility limitations or users that lack coordination for completing the objectives. As the patient evolves and regains movement capabilities, the system decreases the provided assistance in order to keep a certain level of difficulty.

Qiu et al. defined a system (Qiu et al., 2010) combining a force-controlled haptic interface (Haptic Master) with a ring gimbal obtaining a six degree of freedom, force-controlled robot targeted to the upper limb rehabilitation. Adding the ring gimbal as the end effector adds the possibility of forearm rotation and records three more angles of freedom. The system includes different games and the possibility to limit the working area to adjust the therapy to each patient's capabilities.

With regard to exoskeleton systems based combined therapies, August et al. defined a rehabilitation system (August et al., 2011) that was composed of computers, projectors, semi-transparent mirrors, and light emitters to build a multisensory therapy space, where the user can interact with both real and virtual objects. The main idea behind this type of therapy is that some users can lose the perception of their body and their localisation while participating in a virtual reality based therapy, which is overcome with the integration of real object. The mix of real and virtual objects can help improving the motivation, as well as the auto-perception of the body.

Some systems use the electromyography (EMG) to monitor the biofeedback of the user. The objective of this type of systems is to improve patient's abilities and his muscular activity. With this aim, games are designed to use this type of biofeedback to control some game elements. One of the games (Ma et al., 2010) proposes to shoot balls to a target. The proposed system for the game uses a movement tracking system to move the shooter left-right and up-down, while the EMG signal is used for shooting the ball.

Similarly, other systems use brain computer interaction (BCI). These systems are used to know the emotional or the concentration state, to assist the users with limb movement through robotic systems. Ang et al. created a system (Angob et al., 2010) combining a BCI system and a haptic robot (MIT-Manus) for rehabilitation therapy. The users had to make some initial tests for the system to identify the signals related to their hand and arm movements. After the initial signal training, neuro-feedback is used to assist the user in completing the targeted task. Even if the obtained results were worst than those with the haptic robot itself, the help and the information that these systems can provide to the therapists, is clear. The information on the brain activity complements the input for assessing patient's evolution.

2.3 Rehabilitation Remote Delivery

Telerehabilitation applications are categorized

(Brienza and McCue, 2013) into two main operating models. The first application type is named as real-time interactivity application, and it refers to those applications that mimic face-to-face interactivity in a medical facility. The second application type is named as store-and-forward application, and follows an asynchronous communication. A good insight into the state of art of telerehabilitation systems can be found at (Parmanto and Saptono, 2009).

Regarding the remote delivery of exoskeleton or robotic system based rehabilitation, Oboe et al. propose a haptic robot based remote rehabilitation (Oboe et al., 2010). Their system allows the therapy execution, even if the therapist and the patient are in remote locations. The patient is provided with a slave device, which transmits both the movement and the applied force to the master device, hosted at the therapist's side. Since the haptic system works two-ways, the therapist can assist or correct patient's movement.

Following, table 1 identifies the gaps and the consequences detected during the state of art study.

Table 1: Gaps and consequences detected over the State of the art.

Gap	Consequences
Lack of realistic upper limb representation in the rehabilitation games.	Lack of patient's identification with the virtual world. Lack of motivation.
Lack of possibility to carry out actions remotely.	Need of specialised personal in place.
The punctuations and timing of the games are not always significant for the patient's evolution assessment.	Cannot objectively evaluate patient's evolution.
Lack of exercise recordings for offline studies.	Systems do not allow reproducing movement or visualising patients, neither locally nor remotely.
Lack of standardised movement data format to compare it with other tools.	Data cannot be complemented with information from other systems, such as Kinect based solutions.

3 SOLUTION'S DESIGN AND IMPLEMENTATION

As presented in the previous section, traditional and new robotic device based rehabilitation therapies have some limitations. This paper's implementation tries to overcome the following:

- Lack of realistic upper limb representation
- Remote control / action impossibility and lack of interactive online evaluation tool
- Lack of exercise recordings for offline studies, lack of medical evaluation oriented measures, and lack of standardised movement data.

3.1 Architecture Design

An architecture has been designed for coping with the limitations identified. To guide the reader, the defined architecture is depicted at Figure 1. The designed architecture is composed of three elements: *Rehabilitation Centre (PC + Armeo), Service Layer (PC) and Medical Professional's Client (PC)*.

The Rehabilitation Centre is the responsible to provide the user with the necessary games to carry out the rehabilitation exercises. While the user is doing the exercises, the system monitors and records multimodal data. On the one hand, a webcam records the user for an offline analysis of the movement. On the other hand, joint's movement data is recorded for a more exhaustive study of the exercises carried out by the user. Joint's movement data is later processed and presented graphically by visualisation tools.

The Server layer stores and provides access to the multimodal (data and videos) patient recordings and the interactive online evaluation tool. This tool has been developed using a visualisation toolkit and Java Applet technology, with the aim to deploy it in different platforms.

The Medical Professional's Client is a graphical rehabilitation sessions playback tool. From this client, the medical professional is able to visualise both the recorded data and videos. This client integrates the server layer's interactive online evaluation tool, which graphically represents the recorded data and allows evaluating data through functionalities such as the distance measurement between two points.

The developed architecture design, allows the different tools to work independently from their location. This enables robotic device based rehabilitation therapists to conduct the therapy remotely, not needing to have an expert present at the rehabilitation sessions.

3.2 Rehabilitation Centre

The rehabilitation centre's client is composed of an

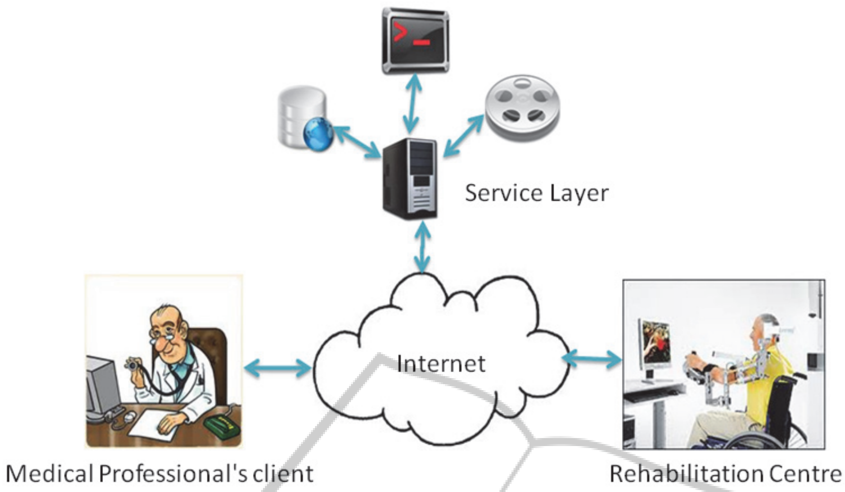


Figure 1: Architecture Design.

Armeo Spring exoskeleton, a PC, a webcam and the developed software. The rehabilitation centre's software has been developed using C++ programming language, based on the Open Scene Graph (OSG) library. The C++ programming language has been selected to meet the Armeo Exoskeleton application programming interface requirements. OSG has been selected as the game development platform, because it is open, it is a high-level programming language and allows loading models and animations with a base on rotation transformation and allows the translation of loaded objects. This geometric object manipulation features facilitate representing a 3D arm, parting from a robotic model of the Armeo. The rehabilitation centre's software is composed of three modules: *Games Module, Video Recording Module, and Data Recording Module.*

3.2.1 Games Module

The games module is the responsible for capturing the movement data from the Armeo, for graphically representing the user movements and for implementing the games' logic.

Movement Data Capture from the Armeo

Once the data is gathered from the Armeo, the data is processed translating the gathered data into the movements of the virtual arm. This process cannot be publicly described, due to a confidentially agreement signed with Hocoma, Armeo's developer. In case of needing related information, the reader should contact Hocoma.

Graphical Representation

All the objects created for the virtual world have been developed using the Autodesk Maya 3D tool. Maya 3D has been selected due to the facilities it provides to animate skeletons. Since most of the developed objects are simple, the following explanation is limited to the developed arm's model.

For the movement generation of the virtual arm, skeletal animation techniques have been used. These techniques mainly consist on dividing the model in two parts for animation development; the skin representation and the hierarchical interconnection of bones.

In order to develop a realistic arm model, skinning technique has been used. This technique consists on associating the bones with the vertices. In some cases, the vertices can be associated to more than one bone, therefore, weights are established so the vertices act as real as possible. Figure 2 shows the representation of the developed virtual arm. Arm's skeleton is represented in green, while the vertices are indentified by the purple colour.

Figure 3 shows the weights influence. Weight distribution in the wrist can be appreciated in the form of a stronger white colour in areas where there is more weight influence.

The virtual arms' representation has six degrees of freedom (DOF): two in the shoulder, two in the elbow and two in the wrist, which allows representing arm's movements with certain fidelity.

To generate the movement of the virtual arm, the data gathered from the Armeo has been processed to obtain the angles at the six DOFs. From the processed angles, rotations have been applied to the respective points in the skeletons, through functions

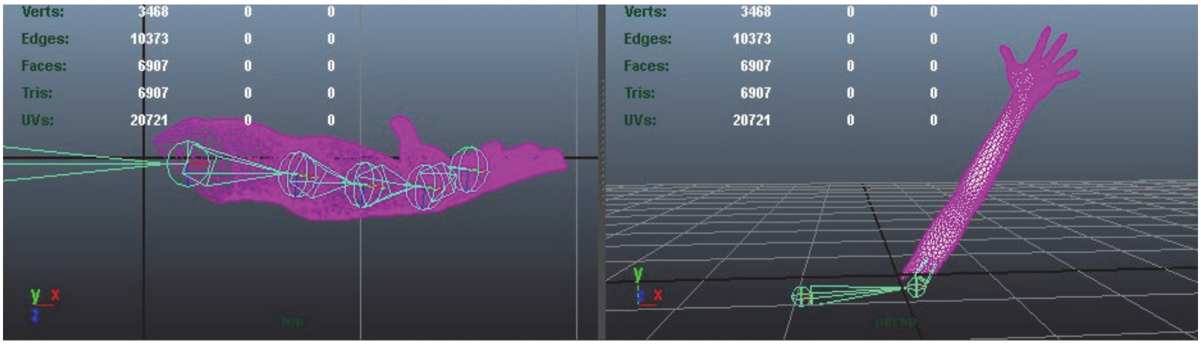


Figure 2: Virtual Arm's Representation.

implemented by the OSG library. Rotations, as well as translations are automatically generated by the OSG library.

The realistic representation of the arm permits the user to be conscious of the movements he/she is doing as shown by studies in immersive virtual reality used with patients with phantom limb pain (Murray et al., 2007). Many people who has suffered a cerebrovascular accident, is not conscious of their upper limb movements. Hence, a virtual representation of their limb can help them seeing an action and reaction effect. This effect can make patients feel more identified with their limbs, which can increase their motivation with the rehabilitation, obtaining better results on the rehabilitation process.

3.2.1.3 Game's Logic

With the aim of providing the user with a more entertaining rehabilitation process, two games have been developed. The games are based on the objects reaching and grasping tasks. These tasks have been selected because they are repeatedly used in users' daily living activities.

In the first game, the user has to touch two balls located on the left and right top ends. Once the user touches the green ball, it changes its colour and the other ball is changed to green, and so on and so forth. Whenever the user completes a series of touching both balls, a point is added to the marker. A screenshot of this game is included in Figure 4.

The second game is based on a ball that changes its location every time the ball is touched and adds a point to the marker. Both games have a duration of two minutes.

The main benefit of these games is having the user conscious of his movements, thanks to the virtual representation of his arm. As the patient evolves and it is capable of doing movements easier, the mobility range can be increased.

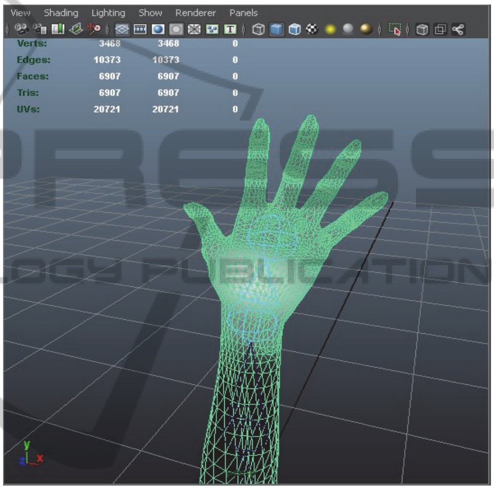


Figure 3: Weight's distribution in the wrist.

3.2.2 Video Recording Module

The Video Recording Module records video of the rehabilitation sessions, for its later offline study. The development of this module has been based on the Open Source Computer Vision Library (OpenCV Library). The OpenCV library is a multiplatform

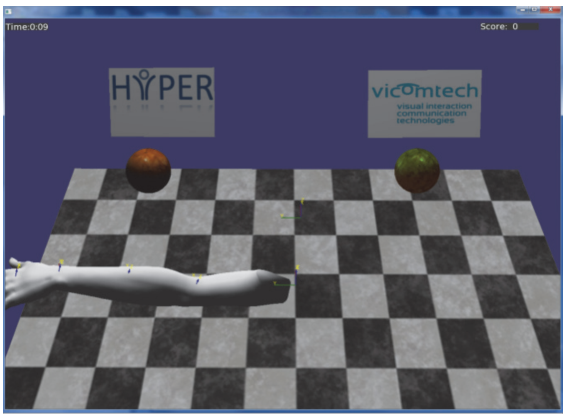


Figure 4: Rehabilitation Game.

library targeted to real time image processing. Additionally, OpenCV has supplementary libraries for machine learning, that implement different algorithms, such as k-nn and Naive Bayes.

The Video Recording Module is started whenever the user selects one of the available games and is stopped when the user finishes playing the game. The video is recorded in a separate thread of the application to avoid interference with the games. Videos are recorded in colour at a resolution of 640x480 and 25 frames per second, which can be easily modified.

The video recording is done through a webcam connected to the PC controlling the Armeo exoskeleton and placed in front of the Armeo.

3.2.3 Data Recording Module

Patient's movement data is recorded by the Data Recording Module. As for the video recording, the movement data is recorded while the user is playing a game. The data is saved in XML format. For the XML structure handling, the Xerces library has been used.

The Xerces library allows to do many XML related tasks (e.g. parse, validate and handle). The library implements the main parsing standards.

Since the main targeted use of the data collection is the visualisation and evaluation of graphical data, the selected XML format for structuring the movement data has been GraphML. GraphML enables to specify data following a graph structure description approach. Additionally, is possible to add specific information required by the application.

The resulting data structure is depicted on the left side of Figure 5. A person can have data from exercises done on different days. The exercises contain data on the movement and position of interest. The regions of interests are the shoulder, the elbow and the hand. Each joint has an associated graph, which is composed of measurement nodes with values on the X, Y and Z axis.

On the right side of Figure 5, an example of the defined interoperability structure is given. This example shows the file's namespace definition, user data, the exercises carried out, and the results of the shoulder's movement data recording.

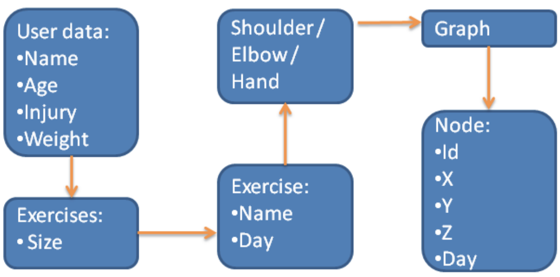
3.3 Service Layer

3.3.1 Interactive Online Evaluation Tool

With the aim of deploying a multiplatform interactive tool for patient evaluation, an interactive online evaluation has been developed using a visualisation toolkit and Java Applet technology.

After an analysis of different visualisation toolkits, Java Prefuse library was selected, due to the capability of running developments as part of Java Applets. The developed tool is able to compare the points obtained for the joints, during the different sessions of the therapy.

Each session of each game is represented in a different colour and it is possible to choose both the




```xml
<?xml version="1.0" encoding="UTF-8" standalone="no" ?>
<graphml xmlns="http://graphml.graphdrawing.org/xmlns"
xmlns:xsi="http://www.w3.org/2001/XMLSchema-instance"
 xsi:schemaLocation="http://graphml.graphdrawing.org/xmlns
 http://graphml.graphdrawing.org/xmlns/1.0/graphml.xsd">
  <key attr.name="x" attr.type="float" for="node" id="x"/>
  <key attr.name="y" attr.type="float" for="node" id="y"/>
  <key attr.name="z" attr.type="float" for="node" id="z"/>
  <key attr.name="day" attr.type="string" for="node" id="day"/>
  <userData age="31" injury="ACV" name="Xabier" weight="80"/>
  <exercises size="2">1

    <exercise day="05/09/11-18:06.27" name="game2">
      <shoulder>
        <graph edgedefault="directed">
          <node id="2">
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            <data key="y">0</data>
            <data key="z">0</data>
            <data key="day">05/09/11-18:06.27</data>
          </node>
          <node id="5">
            <data key="x">0</data>
            <data key="y">0</data>
            <data key="z">0</data>
            <data key="day">05/09/11-18:06.27</data>
          </node>
        </graph>
      </shoulder>
```

Figure 5: Data interoperability XML structure.

days and the axis for visualisation. Moreover, it is possible to zoom and move through the display to analyse a specific region in detail. A button of the application allows going back to initial visualisation, centring the image to the workspace of the Applet. In addition to the presented functionalities, the Applet is capable of calculating the distance between two nodes by selecting them in the display.

The Applet works by reading the following parameters: file's directory, username, timestamp, game, joint and axis. Based on these parameters, the XML is read and organised in classes for easier data manipulation and the Applet executes the actions needed for the required graph visualisation. Screenshots of the tool are given in the Medical Professional's client section where it is integrated in a final application.

3.3.2 Web Services

The service layer has been defined to be as compatible with different platforms as possible. Therefore, for the development of this layer, Web services technologies have been used and deployed over an Apache Tomcat server.

Three services have been defined: (1) To store patient's session's XML in the server; (2) To modify the script parameters that launch the Applet; (3) To obtain the urls for the recorded videos.

The client enters as parameters the username/password and the XML file with the data recording. The server is responsible for storing and organising the data in the server.

The Medical Professional's Client integrates with the web service to modify the script parameters that launch the Applet. This integration allows the medical professional to choose easily the graph he/she needs to visualize. The client sends the script's parameter he/she wants to modify and its corresponding value as an input to the Web Service.

In addition, the Medical Professional's Client needs to load the videos paths to play them in the display. For this task, username and the time range is sent to the Web Service and the response contains an array with the paths to the recorded videos.

3.4 Medical Professional's Client

The requirements defined for the Medical Professional's Client were that the client should be able to play rehabilitation session videos and the visualisation Applet without the user having the feeling of using an external application.

After testing different technological options, the application was developed using C# programming language, with .NET Framework version 2.5.

This technology has allowed creating the Medical Professional's Client, playing videos and visualising data natively. From the user interface, a target patient name is selected. The application then communicates with the server and obtains the videos and the visualisation data with the default parameters.

Following, Figure 6 presents two screenshots of the Medical Professional's Client. On the image on.

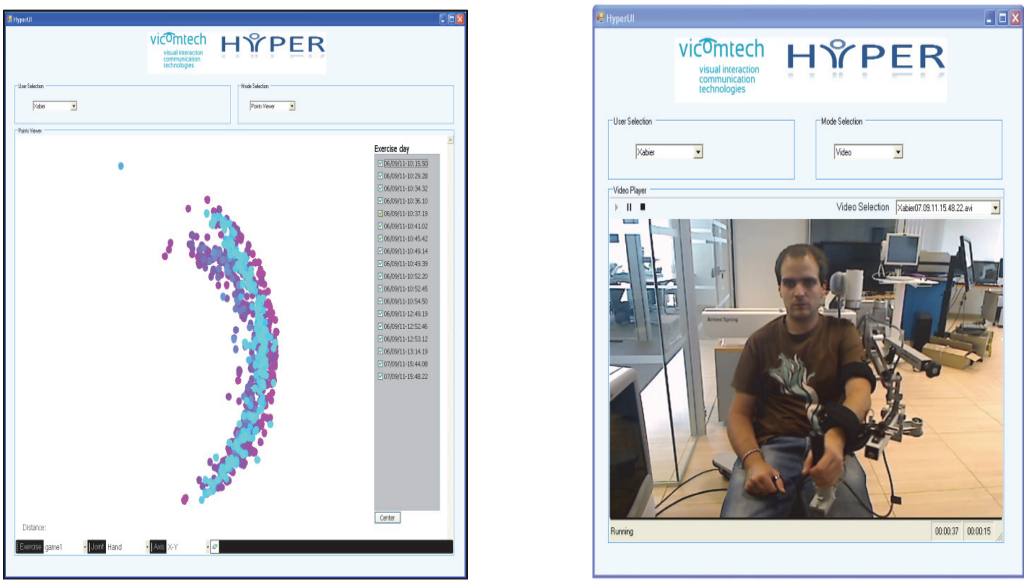

Figure 6: Medical Professional's Client: Analysis Data tool (left) and recorded video in the execution of the rehabilitation tasks (right).

the left, the data visualisation functionality is shown on the image on the right the functionality of rehabilitation sessions' video playback is shown.

4 RESULTS

The main result of the presented work is an exoskeleton based telerehabilitation platform, which targets the improvement of user's motivation and adherence to therapy. The developed platform is a preliminary answer to the gaps detected in the study of the state of the art.

The representation of the patients arm in a virtual world achieves a larger identification of the patient with the virtual world and a larger level of consciousness of his movements, with the benefits of motivation and progress it implies. The developed games, allow carrying the repetitive task in a more entertaining way.

Through the new tools the doctors will be able to be either present at therapy execution or guide the therapy remotely. This allows delegating the therapy setup to less qualified personnel if needed.

The provision of online tools allows improving the care processes at hospitals which helps the sustainability of healthcare systems. Furthermore, it allows experts from different hospitals to analyse the results, building better diagnostics and therapies.

Once the user has completed a therapy session, the specialised personnel can remotely evaluate both the recorded video and the visualisation of movements. Each joint and exercise has its graphical representation and is possible to select the days to be shown and to compare the evolution of the selected joint during the selected day range.

The data recorded by the platform is available to other programs, which enables the comparison of the results with other rehabilitation platforms. This allows validating the obtained information with other experimental systems such as the Kinect based rehabilitation systems. Additionally, the definition of an interoperable data structure enables the combination of different rehabilitation therapies, allowing different device (Armeo vs Kinect) based rehabilitation therapies for hospital and home.

5 CONCLUSIONS AND FUTURE WORK

The characteristics of the developed rehabilitation platform can help patients, doctors and the healthcare system, as presented in the results section. But, in order to validate the real impact of the development, the system needs to be tested with real patients.

As introduced in the previous section, it is important to integrate the developments with other rehabilitation systems such as the ones based on the Kinect for the development of an integral approach to the rehabilitation. This way, the user would be able to continue the rehabilitation therapy at home, as an extension to the therapy started at medical facilities.

The cost of acquiring an Armeo Spring or similar robotic systems is not a cost that all hospitals are able to assume. Therefore, research is needed on tools for hospitals, whose cost is not too elevated. In addition, a detailed analysis of the economic and quality of life of the involved persons, comparing the robotic system tools with conventional therapies, can help clarify the real benefits of these systems, for all involved stakeholders.

Regarding the improvement of the platform, new functionalities to ease the medical professional's work could be implemented. For example, hiding points not contributing to evaluation, adding a functionality to delimit the areas for calculating the mobility range, an automatic comparison between sessions, etc.

With regard to the video visualisation, an implementation of video on demand and streaming technologies will improve the content management and the performance of the platform. Additionally, image analysis algorithms implementation could help complementing the movement data captured.

Another interesting research line identified during the present research is the development of collaborative and competitive game modes for robotic system based rehabilitation. These games could be deployed over the net or at medical facilities where robotic system based rehabilitation is being carried out. Nowadays, there are many successful conventional online games, which lead the authors to think that the life collaboration or competition with other patients can increase their motivation and as a consequence improve their progress.

Due to the fact that each stroke patient has different needs and preferences, games should be customisable, so the virtual world or its containing objects could be adapted. This way, games could be adapted to the specific preferences and needs of each person, which would improve the resulting rehabilitation process.

Last but not least, due to the limited scope of the presented research, the work on security implementation has been limited. Taking into account the confidentially and security needs of using health data, the security aspects of this implementation should be revised for real scenario deployment.

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