Rehabilitation for Children while Playing with a Robotic Assistant in a Serious Game

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Abstract: Traditional neuro-rehabilitation therapies are usually repetitive and lengthy, reducing motivation and adherence to the treatment and thus limiting the benefits for the patients. Moreover, exercises are usually not customizable for the patients, further increasing their disengagement with the treatment. The outcome is then a boring session day after day. This is more pronounced when the patient is a child. However, the execution of these repetitive movements is really needed, as it alters the properties of our neurons, including their pattern of connectivity. Correctly driven, this process finally allows to improve the neural functionality. The question is then: how can we improve the motivation and immersion of the patients into the therapy? We could try to convert the boring therapy into a funny one. This will help to the patients, but also to the practitioner. For this end, computer-assisted technologies have been extensively employed in the last years. Within this research field, this paper proposes to engage the child to the therapy by immersing her into an augmented reality scenario, where it will play several serious games. The adherence to the session will be further increased by incorporating a social robot as a playmate. This robot will be a personal trainer, that will perform the session in the real world with the patient. Additionally, the robot will be able to record the data for each session. This data could be subsequently used by the rehabilitation specialists for monitoring and/or adapting the therapy to the patient's needs.

1 INTRODUCTION

Exploiting the use-dependent plasticity of our neuromuscular system, neuro-rehabilitation therapies are devised to help patients with some motor impairment. These therapies take advantage of the fact that the motor activity alters the properties of our neurons, including the pattern of their connectivity, and thus their functionality (Leocani and Comi, 2006). Hence, a sensor-motor treatment where the patient makes certain movements, will help him to (re)learn how to move the affected body parts. Because lack of arm-movement control directly affects activities of daily living and independence (Whitall et al., 2000), this improving of the upper-limb motor function is of great importance.

The basis of the rehabilitation process is the repetition of certain movements, being the recovery correlated with the frequency and intensity of these movements. On the contrary, passive movements -postures- are insufficient to alter motor recovery. Hence, the focus of the rehabilitation should be on movement coordination (active) rather than muscle strengthening (passive) (Hermano and Hogan, 2009). This traditional rehabilitation process comes at a cost: therapies are usually repetitive and lengthy, reducing motivation and adherence to the treatment and thus limiting the benefits for the patients (Steultjens et al., 2003).

Clinical experiments demonstrate that motivation is an important factor for successfully addressing a lengthy neuro-rehabilitation therapy and it is usually employed as a determinant of rehabilitation outcome (Colombo et al., 2007). Hence, active engagement towards a therapy is typically equated with motivation. Technology-assisted training can provide engaging and task-oriented training using patient-tailored feedback to support the (re)learning of motor skills (Timmermans et al., 2009). From pioneering systems such as the Lokomat from Hocoma (Jezernik et al., 2003), the application of computer-assisted

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technologies to rehabilitation has generated a positive feedback from therapists. For instance, the ArmeoSpring, a more recent proposal from Hocoma, is a robotic tool to improve therapy by facilitating intensive and functional movement exercises. As it is proposed by Colombo et al, this tool supports the therapy by motivating, game-like tasks (Colombo et al., 2007). Video games have long been known to be engaging to play. Thus, if rehabilitation games with a similar degree of engagement are created, it will be possible to improve the therapeutic results. For this end, gaming consoles that combine entertainment and exercise such as the Nintendo Wii or the Sony Eyetoy can be employed. On the contrary, commercial games could not be useful for people with motor function problems. They are often too fast and frequently provide negative feedback when they are lost (Burke et al., 2010). The design of rehabilitation games requires the a priori definition of the specific profile of the patient and the rehabilitation objectives. Some of these rehabilitation games employ virtual (augmented) reality technology to immerse the patient in a virtual scenario. For motor function rehabilitation, it is also common to incorporate technology to track the movements of the patient. This tracked data can be then used to drive a graphical representation of the patient (or a part of her) in the virtual world. The advantages of this scenario are twofolds: it enables the patient to achieve a high degree of control onto her activity on the game; and it improves the degree of engagement of the game. Both issues improve the rehabilitation therapy, increasing the patient's control of her movements (there is a goal like in functional-based therapies) or her motivation.

This paper proposes to combine the engagement capabilities shown by rehabilitation games with hand-off assistive robotics. Given the inherent people tendency to engage with life-like social behaviour, the use of the robot for augmenting or maintaining the patient's motivation provides an important advantage over game-based approaches (Fasola and Mataric, 2011). Thus, socially assistive robots emerge as a new field of robotics whose aim is to develop systems that assist patients through social rather than physical interaction (Tapus et al., 2007). They provide therapy oversight, coaching and motivation using the robot's abilities to interact and maintain the interest of patients. These robots are described as an intersection of assistive robotics (those that provide assistance to a person) and socially interactive robotics (those that communicate with people through social, non-physical interaction) (Feil-seifer and Matarić, 2011). We have developed a system that uses low-cost gaming and robotics technologies for the rehabilitation of paediatric patients with upper-limb motor deficit due to cerebral palsy or brachial plexus palsy (obstetric), but without significant cognitive or communicative deficits.

1.1 Motivation

Cerebral palsy is a neurological chronic impairment usually caused by a prenatal brain defect or by brain injury during birth, that has a specific influence in certain motor areas. It can appear in the first gestation day or within the first three or five years, manifesting with several symptoms including muscle tone, posture and movement disorders. In addition, cognitive impairments, communicative disorders, and convulsive seizures (epilepsy) may be present. The incidence of cerebral palsy is about 2 per 1000 live-births in developed countries and slightly greater, about 2.5 per 1000, in developing countries. Longer prevalence has been detected due to the increase in survival rate in children born with low weight or other risk factors such as premature, maternal-child malnutrition and having a pregnancy with low control. This large incidence has an important impact on the clinical resources. For instance, in 2010, 1.135 new patients asked for a first session on paediatric rehabilitation due to this pathology, and a total of 2.957 patients where attended at the Hospital Universitario Virgen del Rocío (HUVR) in Seville. On the other hand, obstetrical brachial paralysis is defined as a flaccid paresis of an upper extremity due to traumatic stretching of the brachial plexus received at birth, with the passive range of motion greater than the active range motion (see Fig. 1)[1]. Brachial palsy is a paralysis involving the muscles of the upper extremity that follows mechanical trauma to the spinal roots of C5 to T1 during birth. Injuries are transient, with full return of function occuring in 70-92 % of cases (Michelow et al., 1994). In Spain, we find about 160-230 new cases of this pathology per year, which will be associated to other visceral, vascular or cranial injuries. There is certain stability in the incidence of this pathology in recent years, but this ranges from 0.5 to 1.9 per 1000 live-births.

In order to ensure that children suffering from these two pathologies achieve the highest level of recovery possible, it is essential that they start scheduled physical therapy sessions as soon as possible. These sessions should also be regularly conducted (in an ideal case, it would be desirable that each patient will be treated every day). However, both issues are not always possible due to the lack of therapists. In fact, at HUVR, these patients are usually treated one

[1] http://catthsu.com/medlegal.html

time per week. Also, it must be noted that the degree of affectation of each patient is very different according to both the seriousness of the disease and the bodily functions affected, so it is essential that rehabilitation sessions will be personalised. However, the conventional rehabilitation treatment for these pathologies is usually based on the repetition of a set of tedious exercises. This is a problem for paediatric patients due to their young age, as they would prefer doing fun exercises instead of repeating the same movements for twenty minutes. The resulting loss of motivation can be a serious obstacle for the therapy.

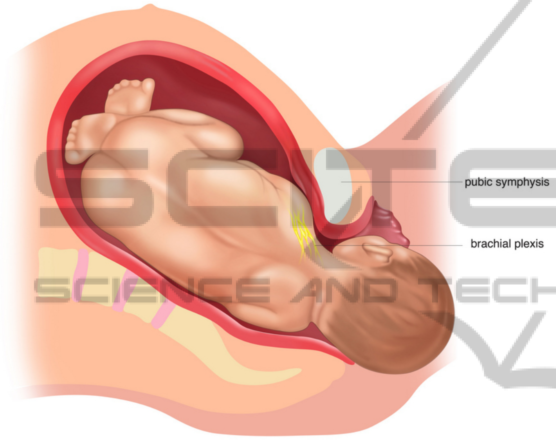

Figure 1: Shoulder dystocia.

The described scenario is then suitable for the application of new therapies based on a socially assistive robot, being the use case where our robot will unfold its abilities. Thus, the robot acts as a coacher in the session, explaining the exercises to the child ('we will now play to') and providing positive messages through verbal and non-verbal channels. Games will be based on an augmented reality framework, where the entire body of the child will be projected inside a virtual world. Within this world, the child could wear a superhero themed uniform and will be encouraged to perform specific exercises. In the pilot study presented in this paper, we investigated the effects of this system on motor recovery but also on acceptance and satisfaction grade from the patients and medical staff.

1.2 Organization of the Paper

The rest of the paper is organized as follows: Section 2 describes the involved technologies and the proposed therapy. Experimental results are presented at Section 3. Finally, Section 4 draws the main conclusions and briefly introduce future work.

2 METHODOLOGY

2.1 Involved Technologies

Traditional rehabilitation therapies may be tedious. The problem is even worse when the patient is a child. The medical staff in this project has reported us its experience with children and adults. An immediate observation is that the effort of the practitioner to maintain the attention and motivation must be greater when the patients are children. Thus, if the therapist works with paediatric patients, she will usually need to use little games or toys to keep their adherence to the treatment. Within this framework, we have provided the physiotherapists with a new tool: Ursus. Ursus is a robot designed to conduct rehabilitation exercises with children, developed by the RoboLab Group with the collaboration of the Hospital Universitario Virgen del Rocío (Seville). It is a low-cost design in which a static torso holds two robotic arms with five degrees of freedom (DoF) each, a three DoF neck and an articulated mouth. The head is capable of generating simple emotions. The full platform is composed of 14 DoF and is 140 cm tall. After several revisions, it currently looks just like a big teddy bear (see Fig. 2). The final goal for Ursus is to make the patient move the affected upper limb in each therapeutic session according to a predefined plan. These movements should be as correct as possible and repeated with a proper cadence.

In order to achieve this goal, Ursus will try to engage the child in the game. These therapeutic games are more than just entertainment, being their main purpose that the patient performs specific movements for rehabilitation (Rego et al., 2010). As described in Section 1, games can try to improve the immersion of the player into the action by using virtual or augmented reality. To help and encourage the child to play the game, we propose to incorporate to this scenario a robotic playmate. Ursus will explain to the child how to play using synthetic speech and will project on a screen an Augmented Reality (AR) game. In this game the child is the main actor and is encouraged to perform specific tasks such as grabbing some fruits from a tree or throwing them to a basket. A snapshot of the real scenario is illustrated in Fig. 3. Ursus is equipped with a Red-Green-Blue and Depth (RGBD) sensor, such as a Kinect from Microsoft or a Xtion from Asus (Khoshelham and Elberink, 2012) and with speakers. All software and hardware components are running on-board within a conventional laptop powered by the RoboComp robotics framework (Manso et al., 2010) (see (Mejías et al., 2013) for further details about Ursus).

Figure 2: Ursus: a robotic platform for neuro-rehabilitation therapies.

Although we could use the capacity of the OpenNI library for tracking human bodies, we have integrated this ability within a model-based approach for human motion capture. We provide some results on Section 3 (see (Calderita et al., 2013) for further details). The aim is to employ the chest or the torso of the child like a visual landmark of augmented reality. Then, we build a virtual scenario around the child for each rehabilitation session (see Section 2.2 for further details about the games). As we a priori knows the profile of the patient, each game can be easily customizable.

2.2 The proposed Therapy

As Figure 3 shows, when the exercise begins there is one child in front of Ursus. The child motion is captured using the depth channel of the RGBD sensor and the previously commented approach. This human motion capture algorithm is based on the OpenNI library and provides the position and angles of the joints of the person under analysis. This information is further filtered using a kinematic model of the child (Calderita et al., 2011; Calderita et al., 2013) to avoid unreal poses and changing bone lengths. The accuracy of the system is enough to deal with the task since the medical staff does not evaluate more than ten degrees of freedom.

Currently, our serious games are very simple and they only try to encourage the correct performing of certain movements. Nevertheless, the simplicity of these games proved to be valid for the patients in our experimental evaluations (children whose age ranges from 3 to 7 years old). In these games, Ursus controls the device that projects the real image of the child inside of a virtual scenario. This image is also taken from the RGBD sensor but now using the color channels (Khoshelham and Elberink, 2012). In real time, Ursus merges both sources of information to create on the screen a, so called, augmented scenario. It is over this video sequence where the virtual world is projected. The game virtually dresses the child with a red-and-blue themed uniform, much in the spirit of Superman or Spiderman suits. This uniform partially covers the limbs and torso of the child. On the floor, close to the child, there is a big tree with apples next to a basket. Up in the air, an enormous apple is inflated and deflated, seeking to capture the attention of the patient. It should be noted that the location of all objects inside the virtual scenario is relative to the position of the patient, as she is the reference landmark.

The child is verbally encouraged by Ursus to take the apple and put it into the basket. To this end, Ursus uses a probabilistic grammar to generate the adequate sentences in real-time. This algorithm takes into consideration the time from the beginning of the session, the number of repetitive movements performed and the current state of the interactive game. The aim is to encourage and help the child to pass the current level of the game. We consider that the child's motivation will be greater if she thinks that Ursus is a real playmate. And this feeling is enforced by 'humanizing' the human-robot interaction process. Thus, Ursus synchronizes the speech generation with current movements of its lips (Cid et al., 2011) and also with correct non-verbal gestures (e.g. when it says 'yes' or 'no', it simultaneously enforces the sentence with a current motion of its head).

The game suggests repetitive exercises to the child and Ursus encourages her to do these movements through verbal and non-verbal (it also performs the movements) cues. It is a real playmate. Taken into account the patient's profile and how she is responding to the current session, the difficulty of the game can be adapted by the practitioner through a simple control panel. This panel also allows the practitioner to change the boundary of the game, to select other games or to show to the patient previously recorded videos with the exercises to perform. Finally, this control panel also allows to visualize the patient from the RGB camera that is mounted on Ursus. Furthermore, all data is recorded by Ursus, allowing to the medical professionals the off-line visualization of the session. This off-line monitoring (see Fig. 4) of the patient's movements is displayed using a graphic interface (GUI) that not only provides the video sequence, but also numeric information about the amplitude (in milimeters) of the movements.[2]

[2]see a more extended example of the GUI at https://www.youtube.com/watch?v=3NsYDbwsBYs

Figure 3: Ursus, patient and AR-based serious game in action. The picture was taken at the Hospital Virgen del Rocío (Seville, Spain) and provides a good snapshot of the sessions with reals patients.

3 EXPERIMENTAL EVALUATION

3.1 Participants

This work focuses on the rehabilitation of paediatric patients with upper-limb motor deficit due to cerebral palsy or brachial plexus palsy (obstetric), but without significant cognitive or communicative deficits. In order to evaluate the proposed therapy, an experimental group of six paediatric patients was chosen by the medical staff of the Department of Rehabilitation of the Hospital Universitario Virgen del Rocío at Seville (Spain). As aforementioned, the age of the children ranges from three to seven years old. They present upper-limb motor deficit due to cerebral palsy or brachial plexus palsy.

3.2 Rehabilitation Objectives and Preliminary Results

Ursus performed several rehabilitation sessions with this group of patients. The session was presented to the child more like a game with a robotic friend than a repetition of exercises. In any case, the mandatory movements demanded by the games include shoulder flexion and abduction, elbow flexion and extension, wrist flexion and extension, and forearm pronation and supination. There was always a therapist supervising the session. In an on-line fashion, she was able to perceive how the patient made the movements using the information provided by Ursus. This monitoring allowed the therapist to personalise the treatment and determine the evolution of the recovery. Showing calmly the correct movements with his arms, talking about interesting matters for the child, playing music and projecting pictures, videos and augmented reality (AR) games on an external screen, were some of the resources that Ursus pull out to capture the child's attention and interest. It is important to note that the main difficulty here was to detect the attentional state of the patient when using each resource, in order to correctly decide what to do next. Games based on augmented reality technologies were a natural extension for Ursus, which was always tracking the patient's silhouette.

The clinical variables that were used for evaluating the clinical evolution of the patient were passive and active articular balance of the shoulder, elbow and hand; degree of concordance (i.e. precision of the movements performed by the child with respect to theoretical values); motor function of upper-limbs ('Nine Hole Peg Test') and patients' satisfaction ('Goal Attainment Scale'). However, the validation methodology of the therapy must also consider, in our case, metrics related to human-robot interaction. These metrics should quantify the level of attention and engagement between robot and child. In this work, qualitative results were obtained from several polls of all the participants in the experiment (paediatric patients, parents and technical and medical staff). These polls were conducted before and after the sessions and the answers were classified de-

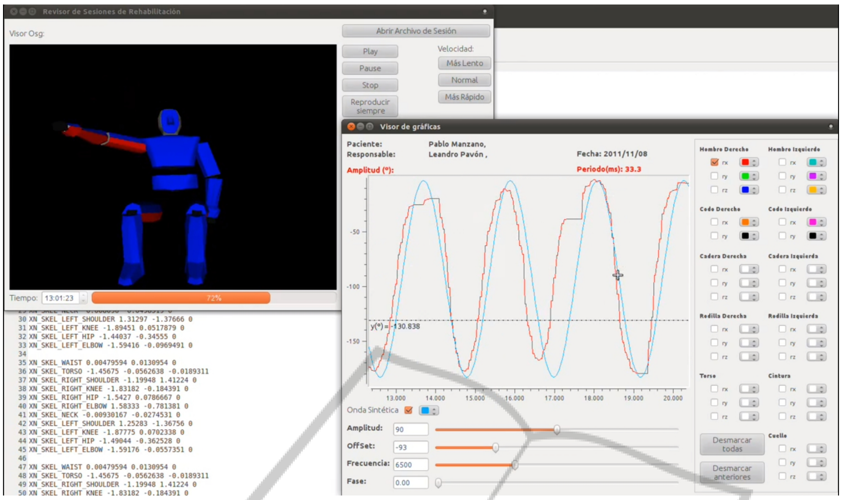

Figure 4: The visualization of the session in the off-line mode.

pending on the satisfaction level of the experience. From them, it can be concluded that the physical appearance of Ursus was quite satisfactory and that patients enjoyed the rehabilitation session and they considered it more fun and motivating than only using the conventional treatment. Moreover, the medical staff also considered the rehabilitation session positive for the children rehabilitation process, and the results recorded by the robot very useful for analysing the evolution of the patients and planning personalized future rehabilitation sessions. Briefly, it can be concluded that Ursus was able to achieve a high level of engagement by the patient, maintaining the levels of motivation and adherence to the treatment.

On the other hand, one of the main contributions of this work is the capability of the robot Ursus to measure and record the whole therapeutic session. As aforementioned, we employ the method recently proposed by the authors in (Calderita et al., 2013) to capture the patient motion. Basically, we propose to use a human model to constraint the body motion to reachable and valid positions. It filters the deviations of the 3D position of several relevant body parts as model limb lengths converge toward stable values in the learning phase (Calderita et al., 2013). Thus, even although the OpenNI tracker provides 3D centroids for all body parts in all processed frames, these values are modified as the model adopts, for every relevant body part, the 3D position that is closest to the centroid provided by OpenNI, but constrained by the human model kinematics. Using this approach, the angular positions of the patient's limbs are recorded in real-time with a precision of a few degrees. As Table 1 shows for the right elbow, the joints positions are also recorded with a precision of only few centimeters. Results depicted in Table 1 show that the proposed method improves the accuracy of the OpenNI tracker, decreasing both elbow mean error and standard deviation.

Table 1: Mean errors and standard deviations of the right elbow, in centimetres (Calderita et al., 2013).

	Mean err	**Std dev**
OpenNI centroids	6.7 cm	2.7 cm
Fixed limb lengths	7.2 cm	2.3 cm
Adaptive limb lengths	4.9 cm	1.7 cm

4 CONCLUSIONS AND FUTURE WORK

In this paper, we describe our short-time experiences on the rehabilitation of paediatric patients with upper-limb motor deficit due to cerebral palsy or brachial plexus palsy (obstetric). The idea of using a social robot as a playmate increased the motivation and interest of the children in the rehabilitation sessions, showing us that the acceptance of Ursus was not a problem in this scenario. It was very nice to see how one of the children, after conducting the session, approached to Ursus to give it a hug. On the other hand, the acquisition of data information about the session was conducted on real-time, in a very precise way (see (Calderita et al., 2013) for further details about our approach for human motion capture). Furthermore, this data can be replayed and analysed at any time by the specialists, allowing them to compare the evolution of the patient, in each session, in a new quantitative way. We expect to improve with this methodology and techniques the current procedures based on standard tests.

Future work focuses on extending these experi-

Figure 5: Ursus interacting with a child.

ences, designing new interactive AR games specifically aimed at generating therapeutic movements while providing a stimulating and joyful experience. Finally, during the sessions, the robot will register all movements made by the child and will compare these movements with the normalized patterns defined by the physicians. The computed difference should be used to generate on-line reinforcement verbally synthesized discourses and expressions. It is important to consider that, despite we have presented a rather simple scenario, the complexity of keeping the child's attention during twenty minutes each session and during tens of sessions, is daunting. Only a well designed robot with a suitable cognitive architecture and the knowledge of trained clinicians provides the necessary material to pursue this kind of research.

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