NAOTherapist: Autonomous Assistance of Physical Rehabilitation Therapies with a Social Humanoid Robot

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***Abstract*— The main goal of NAOTherapist is to provide a social robot with enough autonomy to carry out a non-contact upper-limb rehabilitation therapy for patients with physical impairments, such as cerebral palsy and obstetric brachial plexus palsy. Our robotic system is focused on pediatric patients aiming to increase their motivation and engagement with the treatment. The robot shows a set of prescribed exercises and the patient has to repeat them correctly by imitation. The rehabilitation tool supervises and gives a set of clues and correction mechanisms to help them during the training. The system has been initially evaluated with a large number of healthy children, a first experience of 3 pediatric patients and a long-term evaluation with 8 patients during 4 months.**

I. INTRODUCTION

Neurorehabilitation therapies focus on the recovery of damaged neuronal areas and muscles by the repetitive practice of certain motor or cognitive activities. Some of the main challenges to be faced are to maintain motivation of the patients while going through these therapies and the large amount of time required by the therapists, specially with children. The development of novel devices may be a way of addressing these challenges to ensure the progress of the patient while providing clinical support to professionals.

The field of Socially Assistive Robotics comprises all those robotic platforms that provide assistance to people through social interaction [1]. These robots have demonstrated improvements in the commitment and positive effects on the motivation of several groups of patients who suffer from physical impairments (cerebral palsy, stroke) [2] or cognitive disorders [3]. These novel approaches are expected to obtain a better adherence to clinical treatment. Additionally, these systems offer novel rehabilitation tools to relieve the workload of professionals while reducing the socio-economic costs. Some requirements are important to be considered: the appearance of the robot, fulfilment of the clinical objectives through social interaction and the autonomy of the platform. Although some of the previous works attempt to fulfill these requirements, our proposal is more ambitious, since we focus on the complete autonomy of the system: a clinical support tool for the automated definition of therapies adapted to each patient, together with non-teleoperated execution while monitoring the planned sessions by a social humanoid robot.

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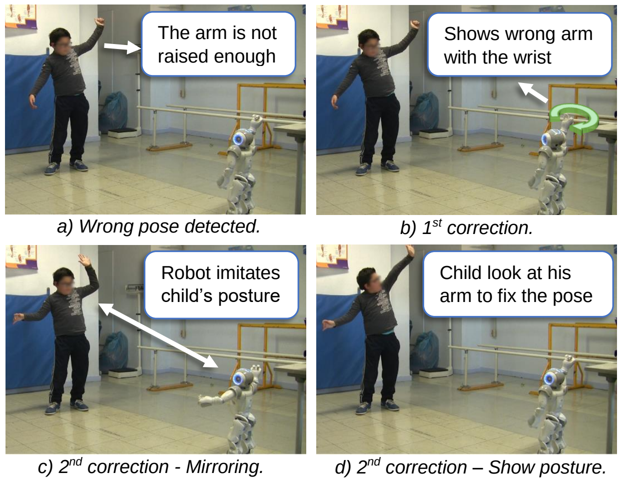

Fig. 1. The social robot helps the patient to carry out correctly the pose by using the speech-based and the mirror-based correction mechanisms.

Our proposed system is called NAOTherapist and it is the result of a new development phase in the Therapist project [4]. In the first approach, a bear-like robotic platform called Ursus executed a sequence of preprogrammed behaviors to carry out rehabilitation movements. We consider that during physiotherapy sessions, the lack of human intervention and a fluent interaction promotes an active engagement. We have taken all these elements into account in designing the NAOTherapist architecture [5]. In essence, the use case[1] consists of a NAO robot which performs a set of prescribed arm-poses that a patient has to imitate. The robot is able to react autonomously and check the pose of the patient helping him to correct it, if required. We ensure that the patient feels supported while doing the exercises by giving him a set of different clues and correction mechanisms as shown in Figure 1. The robotic platform has been evaluated among three different phases as described in Section IV.

II. NAOTHERAPIST ARCHITECTURE

The main goal of the NAOTherapist architecture is to provide the robot with enough autonomy to carry out physiotherapy sessions without the need of a human teleoperator. So, the robot needs to perceive and understand the environment and react in accordance with the goals of the session. This automatic reasoning is carried out using Automated Planning techniques [6], where the perceived environment is encoded as a symbolic representation of the state of the world.

[1]Video of the use case: https://youtu.be/75xb39Q8QEg

The cognition process of NAOTherapist has a design based on three levels of planning [5]. A high level comprises the therapy designer that deals with the task of planning the sessions that form part of the therapy. The medium and low levels are included in the execution of the sessions. A control system is included in the medium level which is in charge of providing the necessary actions that the robot has to execute while sensing and monitoring that the received effects match the excepted ones. The perception process builds the internal state of the world. A Kinect 3D sensor serves the anthropometric data of the patient to infer information such as the correctness of the poses. In case of a mismatch between the expected and actual state of the world after the execution of a medium-level action, a replanning mechanism provides a new plan that meets the new perceived state. The low level corresponds to the path-planning mechanism to move the joints of the robot. It receives specific low-level actions that were previously transformed from the planned medium-level ones.

III. USE CASE

The use case starts when the patient enters the experimental room and the system tracks the patient by capturing his body characteristics. The patient is one or two meters away from the robot. The robot greets him and the training begins after introducing the first exercise. The exercises consist of a sequence of poses. Depending on the exercise, the patient must maintain each pose for a certain amount of time. The robot guides the training process giving instructions and feedback. Each pose of the patient is verified with respect to that shown by the robot. If both poses differ, the system executes a correction mechanism. Patients have two attempts performing a pose correctly as shown in Figure 1: after the first failed attempt, the robot shows the incorrect arm or arms and warns the patient the arms to be corrected. In the second correction, the robot imitates the detected posture and shows him how to move the arms to achieve the correct pose. This is called "mirrored correction". If the patient fails after these two tries, the pose is skipped. The system runs the rest of poses that comprises the exercise sequentially until it finishes. A break is programed between exercises to have a rest. Once all of the exercises are completed, the robot closes the session inviting him to play the next day.

The architecture fulfills all requirements of the aforementioned use case, but the use of Automated Planning also makes it easier to change the activity. We tested this flexibility by using the same architecture with an adapted Simon game[2] with poses instead of colors [7], in which the robot performs several poses in a row and the user has to memorize and perform them to advance to longer rounds.

IV. EVALUATION

The evaluation mechanisms are based on questionnaires to participants, relatives and experts, interaction level from video analysis and logs of the system. The Table I shows

TABLE I
PHASES OF THE EVALUATION OF THE NAOTHERAPIST PLATFORM

	1st Phase	2nd Phase	3rd Phase
	First contact		Long term
Participants	117	3	8
Condition	Healthy	2 OBPP, 1 ICP	6 OBPP, 2 ICP
Age	7.9 ± 1.4	7.66 ± 0.94	6.87 ± 2.42
Gender	53 F, 64 M	3 M	3 F, 5 M
Duration (min.)	5 ± 0.83	13 ± 0.81	24 ± 2.71
Num. of sessions	1	1	11.62 ± 3.93
Place	Schools	Hospital	

the three different stages of evaluation. The first phase was carried out with 117 healthy children to measure the degree of interaction and improve the autonomy of the prototype in accordance with the ongoing requirements. Schoolchildren did not have any problem following the session and they mostly considered the robot as a social entity being actively engaged throughout the activity. Secondly, three pediatric patients[3] from the HUVR had a first experience with the robotic tool and shared their impression of the usefulness of the NAOTherapist prototype. They enjoyed the activity and were delighted to participate in future evaluations. The third phase refers to a long-term evaluation with 8 patients from the HUVR during 4 months, where a constant adherence to the rehabilitation sessions was achieved. These results are still being analyzed and will be published in future works.

V. CONCLUSION

Naotherapist proposes a general framework of hands-off robotics rehabilitation with very promising results. Participants are able to follow the sessions with the instructions provided by the robot. The platform works autonomously and achieves an active engagement by getting the children's attention. Experts believe that the robot is a useful tool for physiotherapy not only for training but also for diagnosis.

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[2]Video of the simon game: https://youtu.be/picw9sD5VH4

[3]Videos of the 2nd evaluation phase: https://goo.gl/ZtfrVQ