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Cognitive Systems Research xxx (2016) xxx–xxx

Cognitive Systems RESEARCH

www.elsevier.com/locate/cogsys

A three-layer planning architecture for the autonomous control of rehabilitation therapies based on social robots ☆

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Received 15 April 2016; received in revised form 28 July 2016; accepted 20 September 2016

Abstract

This manuscript focuses on the description of a novel cognitive architecture called NAOTherapist, which provides 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. NAOTherapist comprises three levels of Automated Planning. In the high-level planning, the physician establishes the parameters of the therapy such as the scheduling of the sessions, the therapeutic objectives to be achieved and certain constraints based on the medical records of the patient. This information is used to establish a customized therapy plan. The objective of the medium-level planning is to execute and monitor every previous planned session with the humanoid robot. Finally, the low-level planning involves the execution of path-planning actions by the robot to carry out different low-level instructions such as performing poses. The technical evaluation shows an accurate definition and monitoring of the therapies and sessions and a fluent interaction with the robot. This automated process is expected to save time for the professionals while guaranteeing the medical criteria.

Keywords: Robotic architecture; Human-Robot Interaction; Rehabilitation therapies; Automated Planning; Socially Assistive Robotics

1. Introduction

Within the rehabilitation domain, some of the main challenges to be faced are to maintain motivation of the patients while going through long and repetitive therapies and the large amount of time required by the therapists, specially with children. The development of novel techniques and devices may be a way of addressing these challenges to ensure the progress of the patient while providing clinical support to therapeutic professionals.

The field of Socially Assistive Robotics (SAR) comprises all those robotic platforms that provide assistance to people through social interaction (Feil-Seifer & Mataric, 2005). In the area of rehabilitation, 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) (Fasola & Mataric, 2010; Malik, Hanapiah, Rahman, & Yussof, 2016; Tapus, Tapus, & Mataric, 2009) or cognitive disorders (autism, dementia) (Cabibihan, Javed, Ang, & Aljunied, 2013; Šabanović, Bennett, Chang, & Huber, 2013). These novel approaches are expected to obtain a better adherence to clinical

☆ This work is partially funded by grant TIN2015-65686-C5-1-R and TIN2012-38079-C03-02 of Spanish Ministerio de Economía y Competitividad. We also are grateful to the medical team of the Hospital Virgen del Rocío in Seville (Spain) for their support and participation.

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http://dx.doi.org/10.1016/j.cogsys.2016.09.003

1389-0417/

treatment. Additionally, these systems offer novel rehabilitation tools to relieve the workload of professionals while reducing the socio-economic costs of therapy sessions. To achieve this purpose, SAR platforms should be designed taking into account some of the key objectives and challenges: the appearance of the robot, fulfilment of the clinical objectives through social interaction and the autonomy to carry out the sessions by being able to respond to unexpected situations (Tapus, Mataric, & Scasselati, 2007). 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, always meeting the medical criteria: 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.

This work focuses on the field of pediatric rehabilitation for patients with motor impairment of their upper limbs, often caused by complications during pregnancy or childbirth. The weakness or loss of mobility of certain parts of the body is the consequence of a brain or nerve injury and affected individuals need rehabilitation to recover their mobility. The objective is to develop a robotic architecture that controls a humanoid robot to perform and monitor customized rehabilitation sessions based on social interaction and providing clinical measurements to professionals to evaluate the outcome of the patient. The core of the rehabilitation sessions are made up of exercises shown by the robot that the patient has to imitate. This manuscript describes the NAOTherapist robotic architecture, a SAR platform which focuses on the autonomy of the robot. It follows the general pipeline model of cognition which is heavily based on Automated Planning techniques (Ghallab, Nau, & Traverso, 2004). It has also been designed with robot-independent and domain-independent criteria.

However, the architecture is not limited to robot control, but its goal is also to support the design and monitoring of the whole robot based therapy. Therefore, our architecture also provides a clinical support tool to facilitate the therapy definition process. Before starting the rehabilitation treatment, NAOTherapist plans the schedule for the whole therapy (Pulido et al., 2014). It finds a suitable combination of exercises for each session adapted to each patient with respect to their capabilities and medical records. This ensures that each patient has a customized training that is focused on their most affected parts.

The target users of this project are children with upper-limb physical impairments caused by obstetric brachial plexus palsy, cerebral palsy or any other disorder that requires long-term rehabilitation processes. These movement disorders may threaten the quality of life and wellbeing of patients for in their daily life tasks (Dickinson et al., 2007). The majority of these patients have to live with disabilities throughout their life, and it is necessary to understand how these conditions affect each patient in order to design a personalized treatment (Krigger, 2006; Ramos & Zell, 2000). The rehabilitation program is an essential part of spasticity management (Shamsoddini, Amirsalari, Hollisaz, Rahimniya, & Khatibi-Aghda, 2014). The treatment is very hard and tiring, so developing new ways of rehabilitation for children may improve their motivation and commitment to the therapy.

NAOTherapist has been designed as a support tool for the human therapist, not a replacement. It has the assistance of the medical professionals of the Pediatric Rehabilitation Unit of the Hospital Universitario Virgen del Rocío (HUVR) in Seville (Spain). They were consulted for the definition of the therapy as well as the execution of the session. This manuscript focuses on the description and technical evaluation of the developed architecture. We want to highlight that NAOTherapist has also been tested with many healthy children in schools and it is currently involved in a long-term evaluation with a group of pediatric patients. All of these conclusions form part of near-future work.

1.1. From traditional to robotic rehabilitation procedures

In order to provide a better explanation of the target problem, it is important to understand the traditional rehabilitation procedure upon which the objectives of this work have been formulated. Fig. 1 shows the rehabilitation procedure defined in the clinical protocol of the HUVR. Each

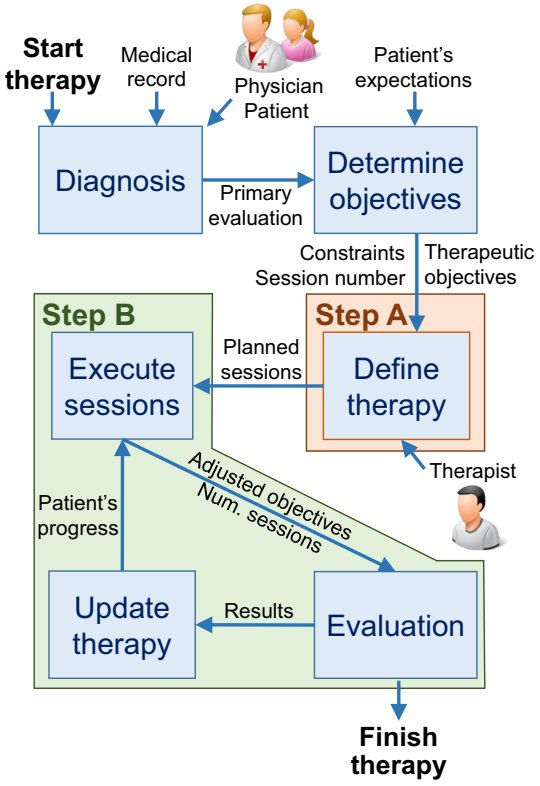

Fig. 1. The traditional rehabilitation procedure of the HUVR for patients with obstetric brachial plexus palsy and cerebral palsy.

Please cite this article in press as: González, J. C., et al. A three-layer planning architecture for the autonomous control of rehabilitation therapies based on social robots. *Cognitive Systems Research* (2016), http://dx.doi.org/10.1016/j.cogsys.2016.09.003