Robotics Agent Coacher for CP motor Function (RAC CP Fun)

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Abstract—A gap of several decades exists between the latest technological achievements in humanoid robots, machine learning algorithms, and artificial intelligence, and the applications used by professional caregivers, especially in the field of pediatric rehabilitation. Robotics Agent Coacher for Cerebral Palsy motor Function (RAC CP Fun) is an attempt to implement advanced humanoid robotic technology, principles of Socially Assistive Robotics (SAR), and a motor learning approach in rehabilitation of movement disorders of central origin. Application of the recent advances in these areas offers an opportunity for a leap forward in rehabilitation practice. RAC CP Fun targets children with Cerebral Palsy (CP), and is designed to improve their motor function and activities of daily living. In terms of International Classification of Functioning, Disability, and Health (ICF), acceptance by the World Health Organization, the novel algorithms of RAC CP Fun aim to facilitate children's activity and participation through pleasurable game-like human-robot interaction. At the same time, these algorithms utilize the motor learning approach, which is based on principles of repetition, stages of learning, appropriate feedback, random practice, and enriched environments. In this paper we introduce the experimental architecture, scenarios, and architectural design of RAC CP Fun, and findings from pilot experiments. Implementation of socially assistive robotics in neuromuscular rehabilitation may also stimulate the development of new treatment interventions for a wide variety of diseases and disorders through effective physiotherapy practice.

Index Terms—social assistive robotics, cerebral palsy, motor learning

I. INTRODUCTION

Cerebral palsy (CP) is the most prevalent physical disability originating in childhood. CP is a spectrum of non-progressive syndromes of posture and motor impairments that result from an insult to the developing central nervous system (CNS). In the last 40 years the prevalence of CP has risen to well above 2.0 per 1000 life births. [1]

Assistive robot-mediated therapy based on physical interaction has been a very active area in the last few years, including in CP interventions. It appears to be beneficial for hand training, motivation, and perception [2]. Robotic systems for training CP by forced repetition and supporting movement error reduction were found to be useful [3]. Social assistive robotics (SAR) [4], the class of robots that assist users primarily through social rather than physical interaction, have not been tested in CP treatment.

Fig. 1. RAC CP Fun functionality based on ICF Framework.

This paper introduces an innovative project, designed to develop a novel robotic computational interactive system for therapeutic motor training: Robotics Agent Coacher for CP motor Function (RAC CP Fun).

2. THE NEED AND OBJECTIVES

The World Health Organization’s International Classification of Functioning, Disability, and Health (ICF) [5] views functioning and disability as a complex interaction between the health condition of the individual and the contextual factors of the environment as well as personal factors. According to the ICF model, an important goal of rehabilitation services is to optimize children’s participation at home, school, and community life. In terms of ICF (Fig. 1), the conventional physiotherapy (Therapist) mainly targets the body structure: muscles, joints, etc. Through recent technological and clinical achievement, children's activity and participation (Motor Actions and Games) is promoted through pleasurable game-like human-robot Interaction.

The scientific world has made a significant leap in the last three decades in the field of motor control and learning, following discoveries related to brain plasticity and the ability of the central nervous system to change as a result of practice
of meaningful motor functions. A motor learning approach, which is based on the principles of repetition, of learning (Adaptation), appropriate feedback (Motivation), random practice and enriched environment (Conceptual Interference), may be implemented today through the application of state-of-the-art technology, specifically SAR algorithms and approaches.

RAC CP Fun promotes a novel approach to the rehabilitation of children with CP. The project aims to integrate novel algorithms for motor and social interactions between the robot and children with CP, into the very well accepted ICF model. Moreover, the integration of RAC CP Fun into the ICF model can be extended to other disorders and physiotherapy techniques.

The objectives of RAC CP FUN include:
- development of learning algorithms for social interaction between a robot and children with CP, through interactive motor exercises;
- development and implementation of an integrative platform for movement detection and measurement;
- verification and validation of a novel robotic platform with children with CP and a therapist during its use in a clinical setup.

Children with CP were selected as the target population, since they have restricted mobility, typically have previous experience with technology use, and a desire to participate in game-like interactions with a robot. Participation of a limited number of children, combined with low degrees of participants’ mobility, makes it possible to conduct an efficient vision-based scene analysis. The core issue of therapy for children with CP is motor training. The up-to-date 3D movement measurement equipment and modern methods and algorithm of movement analysis provide an excellent basis for efficient robot-child interaction and training. Moreover, previously tested therapeutic setups proved that children interact well with a robot with a toy-like appearance.

Fig. 2. System architecture of RAC CP Fun.

3. ARCHITECTURAL DESIGN

A preliminary experimental architecture was defined (Fig. 2). It includes the personas (physiotherapist and children with CP), equipment (humanoid robot, movement measurement equipment, computer), and the interactions between them. This setup satisfies the special requirements of both clinical and non-clinical environments, such as kindergartens for disabled children or pediatric rehabilitation units.

Furthermore, a comprehensive description of all possible scenarios is essential. The scenarios include complete detailed description of therapeutic setups, motor tasks, subtasks, and particular movement exercises. The developed elements of scenarios form a hierarchically structured library of movement primitives and tasks. The main features of the physiotherapist’s interface, including detailed descriptions settings and reports, are described below.

Fig. 3. The scheme of the RAC CP Fun modules and data flow.

The RAC CP Fun scenarios include precise definitions of measurable parameters (i.e. reaction time, acceleration of particular body segments, range of motion, etc.). Exact type of feedback is defined for each specific motor behavior of a child with CP, his motor learning stage, pathology characteristics, and personal behavioral status (mood, motivation, attention, etc.).

The following is an illustration of an RAC CP Fun scenario. The children sit in ordinary chairs. The RAC CP Fun sits down on a chair and says “Look at me and do as I do”. Then it demonstrates the exercise: “Stand up” (stands up), “raise your hands to the sides” (performs), “count to five” (counts loudly), “put your hands down” (performs), “and sit down” (sits down). Then the robot moves to one of the children, says “Would you
like to play with me? Do it with me,” and performs the same actions again. The child’s performance is evaluated according to the scheme presented in Table 1.

The robot's feedback reactions (phrases) to the child are given according to the feedback algorithm that will be developed. According to this algorithm, feedback will be positive or negative, quantitative or qualitative, given at every trial or not, etc. To create a pleasurable interaction, the RAC CP FUN will sing songs and express emotions during the session.

Each child will perform the task session several times. The robot will then say “Thank you, it was pleasure to play with you. Now, I will see what your friend can do,” and will move to another child.

The modules of RAC CP Fun were developed on the basis of the scenario descriptions. An outline of the main modules and data flow is presented in Fig. 3.

<table>
<thead>
<tr>
<th>Action</th>
<th>Evaluation parameter</th>
<th>How to measure</th>
<th>Robot's feedback</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sit-to-stand transition</td>
<td>Time to initiation</td>
<td>Time from the verbal order to the displacement by at least 20 cm</td>
<td>“Good, you started to move quickly!” or “Come on, you can do it!”</td>
</tr>
<tr>
<td></td>
<td>Time to complete</td>
<td>Time from the verbal order to the displacement by 30 cm and ending of movement</td>
<td>“That was quick!” or “Wow, you are doing it quickly now!”</td>
</tr>
<tr>
<td>Hands Rising and holding</td>
<td>Quality</td>
<td>Deviation of the hands’ positions from the horizontal level. Symmetry</td>
<td>“Keeps your hands higher,” or “Look at me, hold your hands as I do,” or “Good, try to raise you left hand higher.”</td>
</tr>
<tr>
<td></td>
<td>Duration</td>
<td>Time of the hands’ position in the horizontal state</td>
<td>“Can you hold your hands longer next time?”</td>
</tr>
<tr>
<td>Counting</td>
<td>Sound recognition</td>
<td>Sound detection</td>
<td>“I cannot hear you count, louder!”</td>
</tr>
<tr>
<td>Stand-to-sit transition</td>
<td>Accuracy</td>
<td>Time of vertical displacement to the initial point.</td>
<td>“Be careful, you should sit and not fall!”</td>
</tr>
</tbody>
</table>

4. PROOF OF CONCEPT: ONE-ON-ONE FIRST MEETING

To prove the concept of the proposed system, we performed an experiment wherein the children meet the robot [6] for the first time in their lives.

1) Background: The interpersonal space in human interactions has been widely studied in social psychology, since the seminal paper by Hall [7] who coined the term proxemics.

2) Hypothesis: Children accept the robot, create a positive interaction, and accept its authority.

3) Participant Pool: 18 children with normal development, between age 4 and 8, one half are male and one half are female.

4) Procedure: The robot interacted with a child as shown on Figure 5. We evaluated the proximity: the robot moved from Social Space to Public Space and, finally, to the child's Personal Space. We also tested the possibility that a robot could provide some authority to the children: the robot invited children to dance with it.

5) Measures: Interaction level, during each stage of the experiment, measured as a function of eye contact (binary value) and face/body/voice expressions of emotions of child.

6) Results (Figure 6): All but two children created positive interactions with the robot. Three danced with the robot.

5. DISCUSSION

SAR approach has been tested for rehabilitation before RAC CP Fun. Implementation of SAR was attempted in interventions for children with autism spectrum disorders in order to encourage children to initiate and sustain social interactions with a parent, therapist, sibling, or peer [8]. SAR systems designed to improve therapeutic compliance through verbal, non-contact coaching and encouragement have been tested for post-stroke rehabilitation [9, 10].

Some studies have demonstrated the benefits of the robot’s physical embodiment in human-robot social interactions, e.g., therapeutic interactions of elderly participants suffering from Alzheimer’s disease with a SAR promoted cognitive stimulation through a music game [11]. SARs have been shown to provide empathy and unconditional positive support [12], thereby increasing motivation [13], an important determinant of training outcomes.

RAC CP Fun will implement the rehabilitation and treatment approaches for children with CP that have been extensively explored during the last two decades (see for example [14,15]) and based on repetition of training, appropriate feedback, stages of learning, random practice to enhance problem solving, and enriched environment. Motor learning coaching treatment results in significantly greater retention of gross motor function and transfer of mobility performance to unstructured environments than conventional...
rehabilitation approaches [16]. These methods emphasize function in a natural environment, however have not used other key elements of motor learning such as the organization of practice, timing, adaptive training, and various types of feedback [17], that are considered in algorithms of RAC CP Fun. These algorithms are also based on Fitts and Posner’s classic learning stages [18].

6. CONCLUSION

Our work to date demonstrates the promise of RAC CP FUN, a new research area of social assistive technology with immeasurable potential. Socially assistive robotic technology is still in its infancy, but the results of our experiment demonstrate how assistive robotic platforms can be used in the near future in hospitals and homes, in training and therapeutic programs that monitor, encourage, and assist their users.

This multidisciplinary project will not only open a window to other advanced applications of advanced robotic interactive technology, but may also stimulate the development of new treatments for a wide variety of diseases and disorders through effective physiotherapy practice.

REFERENCES