Interactive Social Robots in Special Education

A. Amanatiadis, V.G. Kaburlasos
Human-Machines Interaction Lab
EMaT Institute of Technology
Kavala, 65404, Greece
aamanat@ee.duth.gr, vgkabs@teiemt.gr

Ch. Dardani
PRAXIS Treatment and Counseling Unit
42 Venizelou Str., Kavala, Greece
christina.dardani@praxis.gr

S.A. Chatzichristofis
Department of Information Sciences
Neapolis University
2 Danais Avenue, 8042 Paphos, Cyprus
s.chatzichristofis@nup.ac.cy

***Abstract*—This paper presents advances in robot-assisted special education by specially designed social interaction games. The therapeutic objectives include an improvement in social communication and interaction skills, joint attention, response inhibition and cognitive flexibility of children diagnosed with Autism Spectrum Condition (ASC). To achieve the aforementioned objectives, imitation games with humanoid robots are implemented. Preliminary application results suggest that robot-assisted treatment can improve children behavior. Hence, an engagement of humanoid robots in special education is encouraged. Further improvements are planned by computational intelligence techniques toward increasing the humanoid robot autonomy.**

***Index Terms*—Autism, Human-Robot Interaction, Humanoid Robots, Imitation Games, Lattice Computing, Special Education.**

I. Introduction

The term Cyber-Physical System (CPS) denotes a device (typically, in hardware) endowed with sensing and reasoning capacities and an adaptive /decentralized /autonomous behavior also within a networked environment, e.g. Internet-of-Things (IoT). There is a global interest in CPSs in various application domains including health care, agriculture, energy infrastructures, transportation, community safety and manufacturing [4]. Recently, CPSs have been proposed in an educational application domain with emphasis in special education [7]; more specifically, *social robots*, including NAO, have been proposed. Note that a framework for the engagement of interactive social robots has already been presented by different authors [28]. Moreover, there is a keen interest in applications of social robots in education [22], [32] and, in particular, in special education [11], [29].

Our interest here is in interactive social robot applications in special education. Note that humanoid robots, such as NAO, have already demonstrated their effectiveness for the treatment of children with Autism Spectrum Disorder (ASD), the latter is a medical term [27], or Autism Spectrum Condition (ASC), the latter is a term proposed in robotics instead [9], [10]. However, therapeutic interventions require significant resources in terms of time as well as money from families. The next generation of robots assisting in therapy demands robots tailored to individual needs. In the aforementioned context and motivated by the dropping robot prices as well as the increased robot functionality, we propose interactive games between a social robot and a child toward improving the therapeutic effectiveness at a lower cost for the family.

This paper is organized as follows. Section II presents popular games for treating ASC. Section III delineates data (pre-)processing. Section IV summarizes technical implementation details, it presents preliminary application results and it discusses potential future work. Finally, section V concludes by summarizing the contribution of this work.

II. Proposed Games and Activities

All games and activities were selected on the basis of their potential to enhance functioning at a behavioural as well as at a neurocognitive level. As a result, two major categories of games/ activities were considered: (1) activities targeting at social and communication skills, (2) games targeting at higher order neurocognitive processes and especially theory of mind and executive functions, as summarized in Table I.

The social and communication skills category involved activities in wide spread and scientifically validated autism interventions such as ABA (Applied Behaviour Analysis) and RIT (Reciprocal Imitation Training). Specifically, an imitation game was included requiring the imitation of simple body movements, escalating gradually to the imitation of facial expressions and short verbal emotional expressions (e.g. “I am happy”). Imitation skills are considered to be a prerequisite and a precursor of language and social development in children and have been a major target in a large number of current autism interventions (e.g. RIT) [16]. Additionally, two activities aiming at enhancing joint attention skills were involved, as joint attention skills training are associated to significant social interaction gains in children with ASC.

In the neurocognitive processes category were included games based mainly on two criteria: (a) their similarity to current paper-and-pencil as well as computerized neuropsychological assessments, (b) the available research evidence on their potential to enhance neuropsychological functioning in individuals with neurodevelopmental disorders. As a result, the classic game “Rock-Paper-Scissors” was selected, as recent studies indicate that it has the potential to tap higher-order cognitive processes such as mindreading and theory of mind, as well as activate specific neural circuits implicated in these processes [8], [25]. Theory of mind deficits are currently considered central in autism and training of this cognitive ability has been associated to significant gains in social functioning. Furthermore, three classic games targeting executive functions were included- Simon Says, 3 Card Monte,

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TABLE I
PROPOSED GAMES AND THEIR THERAPEUTIC OBJECTIVES

Interactive Game	Therapeutic Objective	Protocol	Previous Studies Utilizing Humanoid Robots
Imitation (Ingersoll [16])	Imitation skills, social-communication skills	Based on reciprocal imitation training	Duquette et al. [12]
Rock-Paper-Scissors (De Weerd et al. [8], Perry et al. [25])	Mindreading, theory of mind, cognitive flexibility	Standard game protocol + individualized reinforcers	-
Turn taking games (ball games, sentence completion etc.) (Nadel [24])	Social interaction skills, joint attention	Standard game protocol + individualized reinforcers	Robins et al. [26]
Simon says (Halperin et al. [14])	Response inhibition, imitation	Standard game protocol + individualized reinforcers	Chao et al. [5]
3 Card Monte (Halperin et al. [14])	Attention/tracking	Standard game protocol + individualized reinforcers	-
Freeze dance (Halperin et al. [14])	Response inhibition	Standard game protocol + individualized reinforcers	Zhang et al. [33]
Attention cueing through toys and music (Kryzak et al. [21], Vaiouli et al. [30])	Joint attention	Based on the Greenspan Floortime approach	Kajopoulos et al. [20]
Flying Objects	Response inhibition, attention	Standard game protocol + individualized reinforcers	-

Freeze Dance. According to previous research, these games have the potential to improve several executive functions such as response inhibition, attention and planning, in children with neurodevelopmental disorders [14]. Deficits in executive functioning are often present in children with autism and training in this area has been linked to improved educational as well as social performance. Finally, in the neurocognitive processes category a new game is introduced, the “Flying objects” requiring one child to announce different objects and the other to respond as quickly as possible by raising its hand, only when an object that can fly is announced. The rationale underlying this strategy is that the responding child should resist its impulse to raise its hand in non-flying objects and resembles highly the Go-No-Go task of contemporary neuropsychological assessments.

III. Mathematical Background and Knowledge-Representation

We engaged pattern recognition models in the *Lattice Computing (LC) paradigm*; the latter (LC paradigm) has been defined as “an evolving collection of tools and mathematical modeling methodologies with the capacity to process lattice-ordered data *per se* including logic values, numbers, sets, symbols, graphs, etc” [13], [17], [18], [19], [23], [31]. An advantage of LC-based modeling is the rigorous fusion of numerical and non-numerical data also toward computing with semantics, e.g. words, etc

Proposed NAO vision system employs a localized version of Color and Edge Directivity Descriptor (CEDD) and the Bag of Visual Words model to its recognition tasks. The CEDD is a global descriptor first introduced in [6] for the indexing of large image collections and the execution of retrieval tasks. As its name suggests, CEDD consists of a color extraction component and a texture extraction unit. CEDD was designed with particular attention to size and storage requirements without compromising its discrimination ability making it appropriate for the low computational capabilities of the NAO robot. More specifically, CEDD begins by dividing images of any size into 1600 rectangular image areas, referred to as Image-Blocks. The algorithm’s objective is to categorize the Image-Blocks according to their combined color and texture information and compactly represent them with a single Image-Block vector. Ultimately, a single vector is produced that serves as the descriptor of the image for indexing and retrieval tasks. The scalability on characterizing single feature points has already been demonstrated [15]. The localized equivalent of CEDD outperforms the matching accuracy of many other descriptors, such as SIFT or SURF. In this work, we applied Fuzzy Lattice Reasoning (FLR) techniques [17] on vectors computed by CEDD for pattern recognition as it will be detailed elsewhere.

IV. Implementation and Application

All proposed games have been implemented in the NAO humanoid robot, considering a hierarchical modularity and independency framework against the different available humanoid robotic platforms. Thus, only common proprioceptive sensors and knowledge of leg and arm kinematics were incorporated for developing the games, allowing their implementation in any commercial humanoid robot without any restrictions and compatibility issues. The main challenges faced during the implementation were the low processing power of NAO [1], its low-resolution embedded camera and the inter-process communication between the robots. The proposed solution included simple vision processing algorithms based on color features [3] and the use of the Robotic Operation System (ROS) for inter-process and multi-robot communication.

In this work we implemented simple imitation games. The objectives included the development of imitation- and social-communication- skills. Children were included in this study according to the following criteria: (i) Age between 6 and 12 years; (ii) Official diagnosis of autism from either a public hospital or a center of mental health; (iii) Intelligence quotient of 70 by either the WISCIII (i.e., Wechsler Intelligent Scale for Children, in Greek) test or the RPM (Raven’s Progressive Matrices) test; (iv) Mother tongue should be Greek. Children were excluded from this study according to the following criteria: (i) Official diagnosis of a developmental disorder or a genetic- or a metabolic syndrome (e.g. Downs’s); (ii) Epilepsy; (iii) Movement disorders; (iv) Treatment by psychotropic medication (e.g. antipsychotics).

The research protocol included four consecutive sessions as detailed in Algorithm 1. More specifically, Session$\#1$ corresponds to step 2, Session$\#2$ to steps $3-5$, Session$\#3$ to steps $6-29$, and Session$\#4$ corresponds to steps $30-31$. Our applied research protocol required one additional confirmation (i.e., $noCorrect = 2$), in case a child succeeded in an imitation game, whereas it required two additional confirmations (i.e., $noWrong = 3$), in case a child failed an imitation game, before concluding an imitation game G_i, $i \in \{1, \ldots, N\}$.

Algorithm 1 The Research Protocol for Imitation Games

1: The NAO has been programmed "off-line" to play a set $\{G_1, \ldots, G_N\}$ of imitation games;
2: The therapist meets a child's parents in order to (i) inform them about the study and (ii) receive a (written) consent;
3: The therapist meets the child in order to inform it about both the NAO robot and the games they are going to play;
4: The child meets the NAO and it exchanges salutations with it – Music and dance at the presence of a therapist;
5: On the spot evaluation of a child by a therapist using both a "Likert scale" test and a "basic body movements" test;
6: The child enters the room with the therapist and sits on the Chair in front of NAO;
7: The NAO hails the child;
8: **for** $i = 1$ to $i = N$ **do**
9:   The NAO instructs the child regarding the game G_i they are going to play;
10:   The NAO demonstrates game G_i by playing it with the therapist; the demonstration may be repeated, if necessary. Then, NAO asks the child to play game G_i;
11:   Let $noCorrect = 0; noWrong = 0$;
12:   **repeat**
13:     NAO plays game G_i with the child;
14:     **if** Game G_i was played right **then**
15:       NAO rewards the child by gestures and sounds;
16:       $noCorrect = noCorrect + 1$;
17:     **else**
18:       NAO corrects the child;
19:       $noWrong = noWrong + 1$;
20:     **end if**
21:   **until** either $noCorrect = 2$ or $noWrong = 3$
22:   **if** $noCorrect = 2$ **then**
23:     NAO rewards the child;
24:   **else**
25:     The therapist demonstrates the correct response;
26:   **end if**
27:   Intermission for rest;
28:   The therapist decides whether to go on or exit;
29: **end for**
30: The NAO informs the child that their game is over. It tells the child that it had good time and asks whether the child also had good time. The session concludes by doing jointly something pleasant like dancing, singing, etc.
31: The parents, the child as well as the therapist evaluate their experience in a Likert scale based on a questionnaire.

Fig. 1. A child with autism playing an imitation game with robot NAO.

Imitation games $G_i, i \in \{1, \ldots, N\}$ considered in this work regard either "body movements" or "words and phrases" or "sounds and movements" of an animal. More specifically, first, regarding "body movements", possible imitation games are: raise the left hand; raise the right hand; raise both hands; touch the head; touch the knee, etc. Second, regarding "words and phrases", possible imitation games are: point at an object either in the room or in the school bag and utter the name of the object; utter short phrases of every day life such as "I need water", "Give me the glass, please", etc; utter a bit longer phrases indicating personal preferences such as "I love eating potato chips", "I hate eating okras", etc. Third, the child is required to recognize "sounds and movements" of an animal.

A. *Preliminary Application and Results*

Our study was carried out in the Music-Therapy room of the PRAXIS Treatment and Counseling Unit. The equipment we used included a table upon which robot NAO was placed, and a Chair where a child was sitting facing NAO (Fig. 1). Two children with mild ASC were engaged in this study using "sounds and movements" of an animal imitation game.

Our experiments have confirmed that a social robot is more readily accepted than a human by children with autism. The reason is that humans may charge the aforementioned children emotionally, whereas robots do not. Hence, a child with autism can respond to a statement/gesture issued by a social robot more readily than to a statement/gesture issued by a human. In conclusion, a social robot can teach children with autism more effectively than humans. In addition, a social robot is available around the clock.

Technical drawbacks of our preliminary application regarded maninly some (minor) voice recognition problems. More specifically, the NAO could not always recognize words spoken loud as well as words spoken with a wavy intonation.

Our study has met with very encouraging acceptance by children, parents as well as professionals. In particular, the parents and therapists stressed that NAO helps their children participate in a "structured" social environment, e.g. the child learned to respond after a "beep" sound issued by the robot, thus containing its impulsiveness. Furthermore, they all regarded NAO as an instrument for social integration rather than for social isolation of a child with ASC.

Future work will pursue improving certain technical drawbacks especially regarding voice recognition problems. It will also pursue increasing the autonomy of NAO in order to engage it in more sophisticated games by endowing it with LC models possibly by a multiple constraint satisfaction approach [2]. Future work will also consider more severe cases of ASC.

V. Conclusion

This paper has described a social robot NAO application in special education with emphasis in ASC. A pertinent list of games was presented comparatively. Preliminary application results regarding imitation games of a social robot with children have been encouraging.

Acknowledgment

This work has been supported by a Stavros Niarchos Foundation (SNF) fellowship program for promising young scientists. The authors gratefully acknowledge the support of both Mr. I. Aggelidis and Mr. X. Pallikaridis in carrying out the experiments in the premises of the PRAXIS Treatment and Counseling Unit in Kavala.

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