A Supervised Autonomous Approach for Robot Intervention with Children with Autism Spectrum Disorder

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Abstract: Technological solutions such as social robots and Objects based on Playware Technology (OPT) have been used in context of intervention with children with Autism Spectrum Disorder (ASD). Very often in these systems, the social robot is being fully controlled using the Wizard of Woz (WoZ) method. Although reliable, this method increases the cognitive workload on the human operator. They have to pay attention to the child and ensure that the robot is responding correctly to the child's actions. In order to mitigate this, recently, researchers have been proposing the introduction of some autonomy in these systems. Following this trend, the present work targets a supervised behavioural system architecture using a novel hybrid approach with a humanoid robot and OPT to allow the detection of the child behaviour and consequently adapt the robot to the child's action, enabling a more natural interaction. The system was designed for emotion recognition activities with children with ASD. Additionally, this paper provides an overview of the experimental design where the interventions will be carried out in school environments in a triadic setup (child-robot-researcher/therapist).

1 INTRODUCTION

Autism Spectrum Disorder (ASD) is a developmental disability defined by the diagnostic criteria that include deficits in social communication and social interaction, and the presence of restricted, repetitive patterns of behaviour, interests, or activities that can persist throughout life (Association 2013; Mazzei et al. 2012). Although, nowadays the diagnosis can be done correctly around the 36 months old, the intervention is still a relatively unexplored field. Due to the diversity and specificities of symptoms, professionals have found some difficulties in developing effective interventions.

Some interventions performed in the last years use robots, mechanical components, and computers. Studies conducted with recourse to these materials show that children with ASD have a great affinity with them (Tapus et al. 2012; Dautenhahn & Werry 2004). It has been demonstrated that subjects diagnosed with ASD show improvements in social behaviours such as imitation, eye gaze, and motor ability while interacting with robots. Based on this previous works, it is possible to conclude that robots are very promising in intervention/therapies. Most of these works have been exploring the interaction between children and the robots, focusing on tasks such as imitation and collaborative interaction (Dautenhahn et al. 2006; Wainer et al. 2010). Although the results have been interesting, some of the studies in the literature use non-humanoid robots or systems with no (or at least low) adaptation to the activity. In this sense, most of the interactions with robots are often rigid, ambiguous, and confusing. Additionally, the interaction is triadic (child-therapist-robot) where the therapist/experimenter interacts together with the children. Thus, it is important to introduce some adaptation to these

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platforms in order to enrich the interaction with the user and lighten up the cognitive burden on the human operator. Additionally, to the use of robots, researchers have been using objects with playware technology (OPT). These devices are tangible interfaces developed for children's play and playful experiences for the user (Lund et al. 2005). In general, the use of these technologies have been very useful in intervention with these children (Dautenhahn & Billard 2002). However, in general, they do not adapt to children behaviour. Others tries to introduce some adaptation by using wearable devices which can be invasive. Furthermore, none explores the use of an adaptative hybrid approach, using a social robot and an OPT, to interact with children with ASD.

Following this idea, the present work proposes a supervised behavioural system architecture using a hybrid approach to allow the detection of the child behaviour and consequently adapt the robot to the child's action, enabling a more natural interaction. The goal of this approach is to introduce some level of automation in a supervised manner. Additionally, the present work consists in the development of an OPT to be used as an add-on to the human-robot interaction with children with ASD in emotion recognition activities.

The present paper is organized as follow: section 2 presents the related work; section 3 shows the proposed approach; the experimental design is described in section 4; the final remarks and future work are addressed in section 5.

2 RELATED WORK

Nowadays, distinct technological strategies have been used in the intervention process with children with ASD, mainly through the use of Objects based on Playware Technology (OPT) and social robots (Lund 2009; Pennisi et al. 2016). Different social robots have already been used successfully in robot assisted therapy (Pennisi et al. 2016), helping children to develop their skills. Many of these systems helps to deliver a standard and effective treatment to children with ASD by using the Wizard of Oz (WoZ) method, where the therapist or researcher fully controls the robot. Despite of being a successful method (Huijnen et al. 2016), it requires an additional operator other than the therapist that is engaging with the child in the triadic setup. However, some configurations (Costa et al. 2015; Costa et al. 2019), uses a keypad where the researcher/therapist controls the interaction. Although it does not need an additional operator, this approach imposes a cognitive load on the researcher/therapist during the intervention. Additionally, systems that employ the WoZ method usually do not record the child's behaviour (body posture, facial expressions, eye gaze, among others) which might not be suitable to use in live Human Robot Interaction (HRI) scenarios (Zaraki et al. 2018). Therefore, it is paramount to introduce some degree of autonomy, enabling the robot to perform some autonomous behaviours whilst keeping track of the interaction data.

Following this trend, there has been a concerning in developing more adaptive approaches to interact with children with ASD.

Some of the works in the literature (Mazzei et al. 2011; Bekele et al. 2014; Bekele et al. 2013), use a combination of hardware, wearable devices and software algorithms to measure the affective states (e.g. eye gaze attention, facial expressions, vital signs, skin temperature, and skin conductance signals) of the child in order to adapt the robot behaviour. Bekele et al. (Bekele et al. 2013; Bekele et al. 2014) developed and later evaluated a humanoid robotic system capable of intelligently managing joint attention prompts and adaptively respond based on measurements of gaze and attention. They concluded that the children with ASD directed their gaze towards to the robot when prompted with a question by the robot. Furthermore, the authors suggested that robotic systems endowed with enhancements for successfully captivating the child attention might be capable to meaningfully enhance skills related to coordinated attention. However, the completion rate of the activity was 60% for the ASD group, mainly due to the fact of the willingness of these participants to wear the LED cap even for a brief interval of time (i.e. less than 15 min). This wearable device was a crucial part of the system since it allowed to track the children gaze during the activity. Thus, there is a need for the development of non-invasive systems and the use of such technologies with children with ASD with common sensory sensitivities (Rogers & Ozonoff 2005).

In order to overcome the use of wearable devices, other projects (Esteban et al. 2017; Koutras et al. 2018) use an array of cameras and depth sensors that allows the robot to perform tasks autonomously. These sensory devices are usually precisely fixed, having into account the background and the lighting conditions, in a static structure around a table where the robot is placed, being limited to a controlled environment. Although this approach minimizes the noise in the robot perception system, laboratorial settings are usually not suitable for children with ASD, since it can be stressful, taking a considerable time for them to adapt to a new environment. Therefore, a recent approach (Zaraki et al. 2018) proposes the use social robots and how to introduce some autonomy in non-clinical environments. The authors use the Kaspar robot with a robotic system called Sense-Think-Act that allows the robot to operate with some autonomy (under human supervision) with children in the real-world school settings. The system was successful in providing the robot with appropriate control signals to operate in a semi-autonomous manner. They further concluded that the architecture appears to have promising potential.

Similar to the use of social robots, researchers have been using OPT to interact with children with ASD. The term "playware" is suggested as a combination of intelligent hardware and software that aims at producing play and playful experiences among users (Lund et al. 2005). This technology emphasizes the role of interplay between morphology and control using processing, input, and output. These objects can take up different embodiments such as modular buttons, coloured puzzle tiles (Lund 2009), Lego-like building blocks (Barajas et al. 2017), among others. Although there is some works concerning the use of OPT with children, only a few research projects have been exploring the use of this technology as an intervention tool with children with ASD. (Lund 2009), used the developed tiles in a game with ASD participants which consisted in mixing the tiles in order to produce new colours. They observed that OPT can be playful tools for cognitive challenged children. Since the use of these objects as well as the use of social robots with children with ASD have presented positive outcomes, the authors proposed and evaluated in (Silva et al. 2018) the use of a hybrid approach (a social robot and an OPT) in an intervention process with children with ASD. The preliminary results demonstrated the positive outcomes that this child-OPT-robot interaction may produce.

3 PROPOSED APPROACH

In order to conduct an effective child-robot interaction in a supervised manner it is important for the system to be able to infer the participants psychological disposition in that way adapting the intervention process. Therefore, it is paramount to have a framework able to extract different sensory data. Taking this into account the following section shows the proposed framework.

3.1 Framework

The proposed system, depicted in Figure 1, is composed of a humanoid robot capable of displaying facial expressions, a computer, two OPT devices, an RGB camera, and a 3D sensor.

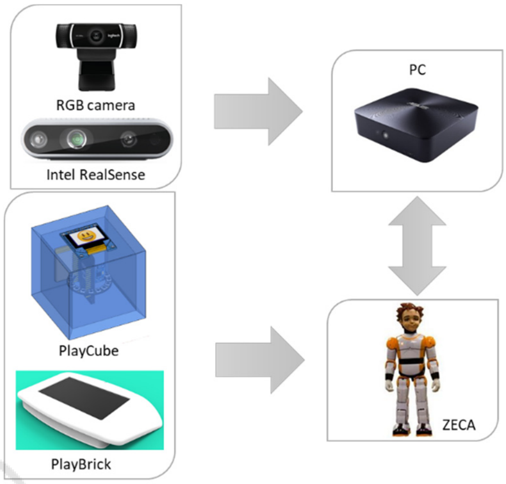

Figure 1: The proposed system. Starting from the left bottom: PlayBrick, PlayCube, Intel RealSense D435, HP RGB camera, computer, and the humanoid robot ZECA.

The Zeno R50 RoboKind humanoid child-like robot ZECA (a Portuguese name that stands for Zeno Engaging Children with Autism) is a robotic platform that has 34 degrees of freedom: 4 are located in each arm, 6 in each leg, 11 in the head, and 1 in the waist. The robot is capable of expressing facial cues thanks to the servo motors mounted on its face and a special material, Frubber, which looks and feels like human skin, being a major feature that distinguishes Zeno R50 from other robots.

Concerning the OPT, two devices were developed: the PlayCube and PlayBrick. The PlayCube (Silva et al. 2019) (7cm×7cm×7cm), has an OLED RGB display with a touch sensitive surface, Inertial Measurement Unit (IMU), a small development board (ESP32) that already has built-in Bluetooth and Wi-Fi communication, an RGB LED ring, a Linear Resonant Actuator (LRA), and a Li-Po battery. Interacting with the PlayCube just means, touching the physical object and manipulating it via natural gestures (e.g. rotation, shake, tilt, among others). The PlayBrick (20cm×11cm×3cm) shares the same internal components as the PlayCube but instead of the small 1.5-inch display that is on the cube, the brick has a 5.0-inch touch resistive display which allows to display more information.

Feedback is a key feature in guiding the children through the play activity, especially children with

ASD. Therefore, both OPT devices have visual and touch feedback, through the use of RGB LEDs and LRA motors. In both devices, the type of feedback is configurable.

Regarding the capture of sensing information, it was used two different sensors, an RGB camera and an Intel RealSense. The camera used is a full high definition RGB HP camera. This camera is used with the OpenFace library (Baltrusaitis et al. 2016) to track the user facial action units and head motion data in order to infer possible distraction patterns.

The Intel Realsense 3D sensor, 90mm x 25 mm x 25mm, (Intel 2019) is a USB-powered device that contains a conventional RGB full HD camera, an infrared laser projector, and a pair of depth cameras. The present work uses the Intel RealSense model D435 along with the Intel RealSense SDK and Nuitrack (Nuitrack 2019) SDK to track the user joints. This sensor was manly chosen due to its smaller size which allows the final framework to be portable. It will be placed on the robot chest.

3.2 The Behavioural Control Architecture

The software architecture includes three main subsystems where two are interconnected via a TCP/IP network and Bluetooth, Figure 2.

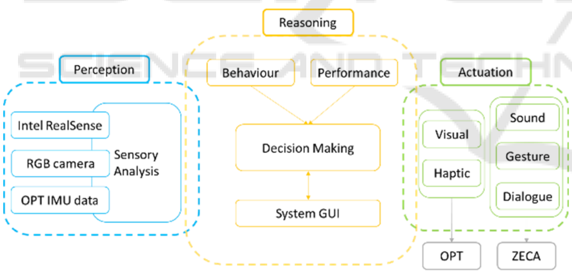

Figure 2: The behavioural architecture is composed of three main layers – the Perception (blue), Reasoning (yellow), and Actuation (green) layers.

The perception layer is responsible for sensing and processing of the data received from the sensors. Since the activities target the recognition of emotions, it is necessary to extract and analyse features that are required by these game scenarios such as: gaze, the frequency and duration of possible movements done by the participant, emotional cues, object tracking, and stereotypical behaviours (such as hands and head shaking).

Regarding the gaze estimation and emotional cues, it is used the open source OpenFace library with the RGB camera. It detects the user face and outputs the facial landmarks, the head pose and eye gaze data, and facial action units. For detecting the child facial expressions, it was trained a Support Vector Machine with a Radial Basis function (RBF) kernel model. This model (adapted from previous work of the research group, Silva et al. 2016) can detect the six basic emotions plus neutral, achieving an accuracy of 89%.

Concerning the automatic recognition of User´s movements, it is used the Intel RealSense with the Nuitrack Software Development Kit (SDK). A 3D sensor is used because of the depth information that is acquired, providing another dimensional information being less sensitive to illumination and subject texture (Esteban et al. 2017). The Nuitrack SDK is able to simultaneously detect up to six people and the 3D positions of 19 joints. The position coordinates are normalized so that the motion is invariant to the initial body orientation and size. Using this information, the User´s moving trend will be computed and a supervised classifier will be trained using a dataset that contains 600 minutes of child-robot interaction (Costa et al. 2019). Additionally, it is also possible to extract the User´s proximity to the robot.

In order to track the OPT, a Histogram-of-Oriented-Gradient (HOG) based object detector was trained. Additionally, the Dlib correlation tracker (King 2009) is also used, allowing the detection and tracking of the OPT in real-time during an intervention session. This approach is described in detail in (Silva et al. 2019).

Additionally, the OPT IMU data is used to detect if the child is interacting with the system. Furthermore, the IMU information can be used to detect some stereotypical behaviours (such as hand shaking) contributing to the human action recognition.

The reasoning layer is influenced by the child behaviour and performance. Using the information acquired and computed by the perception layer, the system will decide the interaction flow of the intervention. The decided action is displayed on the Graphical User Interface (GUI), Figure 3. The interaction flow will be designed using a sate machine approach. A state machine is a simple model to track the events triggered by external inputs. This is done by assigning intermediate states to decide what happens when a specific input comes, and which event is triggered. The output of this layer will influence the dynamics of the next layer, the Action layer. Therefore, the behaviour displayed by the robot will be influenced by the interaction flow of the session.

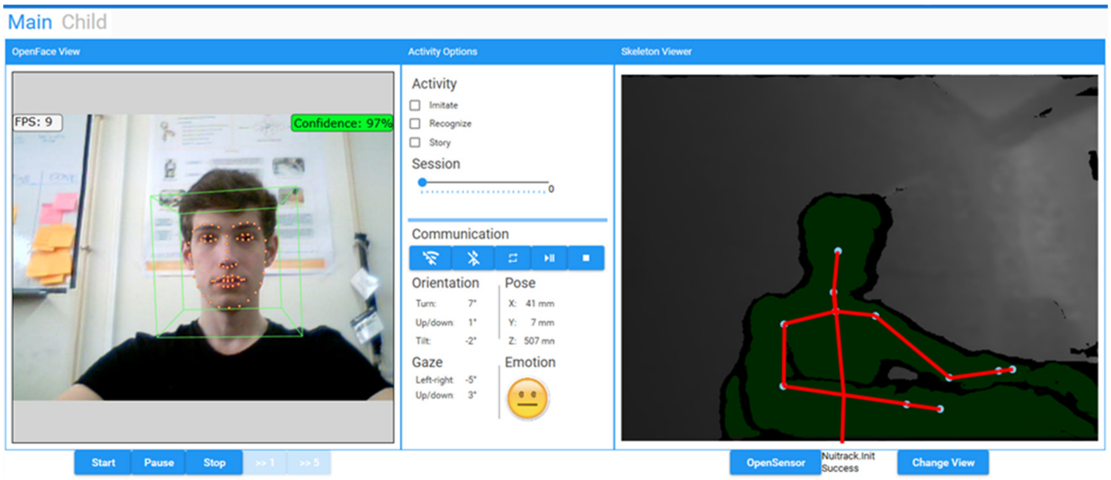

Figure 3: The graphical user interface. The user can easily control the overall system and receive feedback from each subsystem. It is possible to see the participant's facial data (such as gaze, head orientation, facial expression) as well as the skeleton data.

Additionally, the feedback given by the OPT (visual and haptic) will also be dependent of the output of the previous layer.

Since it is a supervised architecture, at any time, the researcher/therapist can pause/resume and start/stop the activity on the GUI.

The GUI will prompt the detected behaviours and recommend possible actions that will be carried out automatically, unless the researcher/therapist intervenes. It is possible to record the session data such as child performance, head orientation, facial cues, IMU data from the OPTs, and skeleton (joints) data. Through the GUI it is established the TCP/IP connection with the robot (ZECA) and the Bluetooth connection with the OPTs (PlayCube or PlayBrick). Additionally, with the GUI it is possible to visualize the children data (e.g. the child performance in all sessions). Furthermore, if desired the researcher/therapist can extend the session time. The progress of the session will be also displayed in the GUI.

4 EXPERIMENTAL DESIGN

In order to evaluate the proposed framework, a study will be conducted in child-friendly environments (such as schools) where the experiments will be performed individually in a triadic setup, i.e., child-robot- researcher/therapist.

The experimental set-up, Figure 4, consists in the child seating in front of the robot, on the child's line of sight, at approximately 85 cm. Behind the robot, two cameras to video record the sessions are positioned. Camera A records only the child and camera B records the overall session. Next to the child is the researcher/therapist responsible for maintaining him/her attention to the task. The PlayBrick or PlayCube is on the hands of the child since the beginning of the session. Since the tests will be conducted in a known, comfortable environment for the child, it is also an unconstrained setting, therefore this layout is proposed in order to provide a basis of comparison between the participants along the sessions.

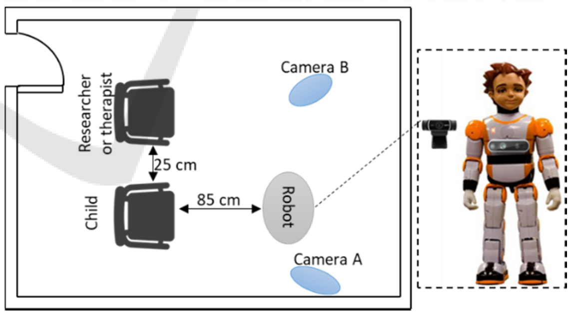

Figure 4: The proposed experimental design with a triadic configuration, where the child is approximately 25cm from therapist and 85cm from the robot.

The experimental configuration includes eight individual sessions in the children´ school: Pre-test, six Practice sessions, and Post-test. The Pre-Test is to measure children' skills; the Practice phase is to implement the activities; and the Post-Test is to evaluate if the competence was acquired. The Pre and Post tests are performed without the proposed system. The first time the activity is performed, the researcher explains the objective of the session and how the system works. The sessions approximately last 10 minutes, except the first that can last 15 minutes due to its training period. The researcher/therapist can extend the default time of the session if needed. However, the session can be interrupted if the child demonstrates irritability, fussiness or lack of interest on the session. The sessions are video recorded for further analysis, using cameras A and B (Figure 4).

The activities played are focused on emotion recognition. Therefore, two game scenarios aiming on improving the children emotion recognition skills were developed: Recognize and Storytelling activities. In the Recognize game scenario, ZECA randomly performs a facial expression and its associated gestures, representing one of the five basic emotions (happiness, sadness, anger, surprise, and fear). The child has to choose the correct facial expression matching the emotion. Concerning the Storytelling activity, ZECA randomly tells one of the fifteen available stories that are associated with an emotion and the child has to choose the correct facial expression matching the emotion. In parallel, as a visual cue, an image is shown representing the social context of the story. The goal of this game scenario is to evaluate the affective state of a character at the end of a story. In order to select the answer, in both activities, the children have to manipulate the cube or brick by tilting it back or forward in order to scroll through the facial expressions displayed by the OPTs. When the child selects an answer, ZECA verifies if the answer is correct and prompts a reinforcement. Simultaneously, the OPTs provide visual and/or haptic feedback accordingly to the child's answer.

The participants are children with ASD aged between 6 and 10 years old with no comorbidities associated. Since the work involves typically developing children and children with ASD, the following ethical concerns were met: the research work was approved by the ethical committee of the university, collaboration protocols were firmed between the university and the schools, and informed consents were signed by the parents/tutors of the children that will participate in the studies.

5 FINAL REMARKS AND FUTURE WORK

The present paper concerns the development of a supervised autonomous system to promote social interactions with children with ASD. These individuals are described as having impairments in social interactions and communications, usually accompanied by restricted interests and repetitive behaviour. Technological devices (such as social robots and OPT) are increasingly being used in intervention processes with children with ASD. However, in general, they do not adapt to children behaviour. Others try to introduce some adaptation by using wearable devices which can be invasive. Furthermore, none explores the use of an adaptive hybrid approach, using a social robot and an OPT, to interact with children with ASD.

Therefore, the present work proposes a supervised behavioural system architecture using a hybrid approach to allow the detection of the child behaviour and consequently adapt the robot to the child's action, enabling a more natural interaction. A full autonomous system is not desired due to ethical concerns (Esteban et al. 2017).

The supervised behavioural framework has three main layers – Perception, Reasoning, and Actuation. The perception layer is responsible for sensing and analysis of the data received from the sensors. The interaction flow is defined in the reasoning layer. Finally, the robot will display the different behaviours and the OPT will give different feedbacks accordingly to the output of the Reasoning layer. Since it is a supervised approach, the system GUI will prompt the detected behaviours and depending on the interaction state, it will recommend possible actions that will be carried out automatically, unless the researcher/therapist intervenes.

Future work includes a continuous improve of the framework and testing the proposed system in school environment in a triadic setup (child-robot-researcher/therapist), following the proposed experimental design, with the goal to evaluate how this hybrid adaptive concept (OPT and social robot) can be used as a valuable tool to promote emotion skills in children with ASD.

The system's level of autonomy should also be increased by adding interactive machine learning, enabling it to learn on the fly.

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