'Autistic Robots' for Embodied Emulation of Behaviors Typically Seen in Children with Different Autism Severities

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Abstract. The goal of this work is to enable interactions of humans with a humanoid robot that can be customized to exhibit behaviors typically observed in children with Autism Spectrum Disorders (ASD) along different severities. In a first step, we design robot behaviors as responses to three different stimulus families, inspired by activities used in the context of ASD diagnosis, based on the Autism Diagnosis Observation Schedule (ADOS-2). We implement a total of 16 (possibly blendable) robot behaviors on a NAO humanoid robot according to different autism severities along 4 selected features from the ADOS-2. In a second step, we integrate those behaviors in a customizable autonomous agent with which humans can continuously interact through predefined stimuli. Robot customization is enabled through the specification of a feature vector modeling the behavioral responses of the robot, resulting in 256 unique customizations. Our autonomous architecture enables the robot to automatically detect and respond to parameters of the interaction such as verbal and non-verbal stimuli, as well as sound location. In a third step, we evaluate our designed isolated behaviors in the autonomous system by running a study with three experts. This work paves the way towards potentially novel ways of training ASD therapists, interactive solutions for educating people about different forms of ASD, and novel tasks for ASD therapy with adaptive robots.

1 Introduction

Children with Autism Spectrum Disorders (ASD) suffer from impaired communication and social abilities, as well as possibly motor and cognitive skills. ASD manifests itself very differently across individuals, not only in severity but also in the areas of development that it affects [1]. Available diagnostic tools for ASD used by therapists provide us with a behavioral model of such individuals. They do so by linking a taxonomy of typically observed behaviors to values on a set of features that have been identified to be relevant for characterizing

A. Kheddar et al. (Eds.): ICSR 2017, LNAI 10652, pp. 105–114, 2017.
https://doi.org/10.1007/978-3-319-70022-9_11

the condition in its diverse forms. In particular, the Autism Diagnosis Observation Schedule (ADOS-2) [10] is a state-of-the-art tool for diagnosis through interaction and observation of a child's behaviors in a controlled environment. In a previous work, we aimed at simulating ASD behaviors from high-level child descriptors [2], utilizing the behavioral model of the ADOS-2 diagnostic tool. In this work, we focus on visualizing, in an embodied way, selected behaviors associated with the ADOS-2 model. We exploit the standardized aspect and systematic coding rules of the ADOS-2 to design behaviors on a NAO humanoid robot that emulate behaviors typically present in children with ASD of varying severities. Our behaviors are compliant with the descriptions and specifications found in the detailed ADOS-2 coding rules. The designed robotic behavior database captures different severities of ASD along the scale of values of 4 selected ADOS-2 features, namely ones related to response to name calling, response to joint attention, speech, and pointing. We integrated these behaviors as part of an autonomous agent capable of detecting interaction parameters, such as stimulus type and location, and respond according to the customization of its characterizing feature values. The designed interactions were evaluated through a study involving three therapists an ADOS-2 training certification.

We foresee several real-world applications that motivate the embodied emulation of ASD behaviors in robots. First, current therapist training for ASD diagnosis procedures heavily relies on videos and theoretical material, ignoring the important interactive and embodied component required for a successful administration of the tool. Utilizing robots capable of exhibiting typical ASD behaviors in an interactive way may possibly help to complement the existing training. Second, most educational resources about ASD that exist are in the form of written material, although some more interactive resources for kids, such as videos[1], have been created. We believe that an interactive [9] and embodied resource, such as an interactive autonomous 'autistic robot' could be more efficient to expose people to the implications and the different forms of ASD. Third, imitation tasks have a special place in ASD therapy [8], because imitation ability is often impaired in children with ASD [4]. We believe that an autonomous, customizable, and adaptive robot that is able to both match its behavior to that of the child, as well as demonstrate a desirable behavior for the child to imitate, can be very useful in the context of ASD therapy.

When it comes to customizable robots, there has been some work on personalizing robot behaviors according to some specified features or parameters to account for human differences [11,12,15]. In the context of ASD, while the use of robots in ASD therapy has received a growing interest [3,13], robot customization and personalization to different ASD individuals [7] has not yet been thoroughly investigated. Ironically, robots and agents are commonly informally described as 'autistic' [5,16] (referring to their lack of social intelligence), but it is in fact not always true that real ASD behaviors observed in humans are less complex versions of non-ASD behaviors. In fact, ASD may introduce interesting and rich subtleties, idiosyncrasies, and proactive behaviors not seen in typically

[1] https://www.youtube.com/watch?v=Ezv85LMFx2E.

developing individuals. In relation to emulation of ASD behaviors by robots, some work has been done on real-time motion imitation of children with ASD [14], however, to the best of our knowledge, enabling robots to exhibit characteristic ASD behaviors along severity scales, based on standardized behavioral models, has never been realized before.

The rest of the paper is organized as follows: Sect. 2 describes our approach to designing customizable and autonomous 'autistic robots', Sect. 3 presents an evaluation of our designed robotic behaviors, and Sect. 4 concludes and presents some future work directions.

2 Customizable 'Autistic Robot' Approach

Based on the model on which ADOS-2 builds, we designed 16 behaviors on a NAO robot and integrated them in a autonomous agent architecture that can be customized according to the specified feature values. The robot is able to automatically detect the interaction parameters, such as verbal and non-verbal stimuli, as well as sound location.

2.1 Designing ASD Behaviors for a Robot Based on ADOS-2

The ADOS-2 diagnostic tool contains 29 different **features** characterizing different behavioral aspects of a child suspecting of having an ASD, including communication, reciprocal social interaction, and restricted repetitive behaviors. We selected 4 out of those features to inform our design of robotic behaviors emulating behaviors of children with varying ASD severities. The features are: 'Response to name', 'Response to joint attention', 'Overall level of non-echoed speech', and 'Pointing'. Similarly as with a child, those features can characterize the responses of our robot to different stimuli. We consider three **stimulus families**, namely: calling attention by calling the name (N), calling attention

Fig. 1. Example of the stimulus families considered in this work, inspired by the 'presses' of the ADOS-2 tool. Shown pictures are for the 'Calling name' family. For the 'Calling for joint attention' family, the stimuli are: Verbal stimulus: 'Look!' - Verbal stimulus: 'Look at THAT!' - Activating the object. For the 'Asking for snack preference' family, the only stimulus is the verbal stimulus: 'Which snack do you like?'.

towards an object (JA), and asking for snack preference (S), each of which contains a set of stimuli with the same intention or purpose. Those stimuli, inspired by the hierarchical 'presses' of the ADOS-2, are summarized in Fig. 1. In a regular ADOS-2 session, the therapist goes through the stimuli in a hierarchical order until a satisfactory response is obtained from the child. We reproduced this interaction scheme in the videos used to evaluate our behaviors, as will be discussed in Sect. 3. The version of the ADOS-2 used in this work is the Module 2, destined for children with phrase speech capabilities.

The 4 features we selected each take on discrete values between 0 and 3, corresponding to ASD **severities** along the corresponding feature (in other

Table 1. Summary of the designed behaviors.

Stimulus family	Relevant feature(s)	Responses			
		Severity 0	Severity 1	Severity 2	Severity 3
Calling name (N)	'Response to name'	Looks at human within second name calling attempt with coordinated utterance "Yes?" (rN0)	Same as rN0 but only responds to 'familiar' human while ignoring 'non-familiar' one (rN1)	Looks in general direction (without eye contact or utterances) of 'familiar' human only while ignoring 'non-familiar' one (rN2)	Only responds to touch on head by exhibiting succession of random gaze shifts; ignores all other stimuli in N (rN3)
Calling for joint attention (JA)	'Response to joint attention'	Immediately looks at object, then human, then back at object (rJA0)	Ignores first stimulus; looks at object only at second stimulus "Look at THAT!" (rJA1)	Ignores first two stimuli; only looks at object when activated and emitting sound (rJA2)	Same as rJA2 but with slight gaze shift towards object without actually looking at object (rJA3)
Asking for snack preference (S)	'Overall level of non-echoed speech'	Says: "I like this snack of all the snacks in the world." (rlS0)	Says: "This one." (rlS1)	Says: "This." (rlS2)	Echoes: "Snack... Snack... Snack... Like... Like..." (rlS3)
	'Pointing'	Clearly points at one of the snacks with coordinated eye gaze (rpS0)	Clearly points at one of the snacks with slight gaze shift not in direction of pointing (rpS1)	Looks at one of the snack but without pointing (rpS2)	Slightly shifts gaze downwards with no pointing (rpS3)

words, higher values are associated with more severe ASD). The ADOS-2 manual provides a detailed description of the sets of behaviors that correspond to each feature value, and we take advantage of those descriptions to design 16 robot **behaviors**, consisting of, for each separate feature/value pair, one selected behavior that was easily reproducible on a robot. A robot behavior consists of an animation of the robot's joints as well as possibly speech. Some of our behaviors require the specification of some environmental parameters (e.g. looking behavior takes as a parameter a 3D point to look at). Table 1 presents a summary of our designed behaviors, in response to the stimulus families defined above. In the presence of more than one relevant feature for a stimulus family (e.g., S), behaviors are **blended**, meaning they are run simultaneously.

2.2 Integration into Autonomous Agent Architecture

The designed behaviors were integrated as part of an autonomous agent capable of having continuous interaction with one or more humans, according to the predefined stimuli it recognizes. More importantly, the agent can be customized by specifying an arbitrary severity for each feature, resulting in 256 unique customizations. The architecture of the autonomous agent, including a perception module with speech recognition, touch recognition, and sound localization to modulate the robot behaviors, is summarized in Fig. 2. We implemented this

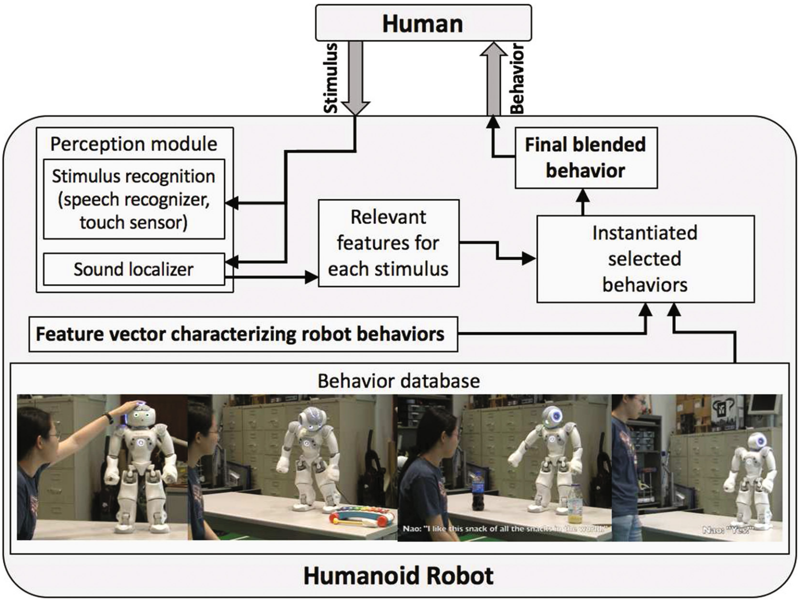

Fig. 2. Architecture of our customizable autonomous 'autistic' agent; stimuli are recognized and trigger different behaviors according to the customizable feature vector characterizing the robot.

architecture on the NAO robot using the NAOqi Python API through the Choregraphe suite.

Because of perceptual limitations of the robot, some parameters needed to be hardcoded or estimated simplistically, while others were easier to detect completely autonomously. Below are some more details on the parameters automatically estimated vs. hardcoded, for each behavior:

- rN0 through rN3: The location of the voice was estimated using NAO's microphone array and used to modulate the eye gaze of the robot. The 'familiar' and 'unfamiliar' humans were distinguished simplistically, based on the location of the voice. It was assumed that the 'familiar' person would always be on one side of the robot (e.g., left) and the 'unfamiliar' always on the other (e.g., right). The touch sensor on NAO's head was used for rN3.
- rJA0 through rJA3: Because of the robot's perceptual limitations, the location of the object used for calling joint attention was hardcoded in rJA0 and rJA1. For rJA2 and rJA3, it was estimated using sound localization, since the activated object (in our case a xylophone) emits sound. For motion stability purposes (robot loosing balance at times), the location of the human, needed only in rJA0, was hardcoded.
- rpS0 through rpS3 (rlS0 through rlS3 are simple speech utterances): Two snacks were present on the table, whose positions we hardcoded. The preferred snack position was used to modulate the eye gaze and pointing of the robot.

Note that, for all behaviors, the speech recognizer was used to detect all verbal stimuli, which triggered the corresponding responses, when applicable. When idle, the robot was animated through a subtle 'Breathing' behavior in which the robot slightly shifts its weight from one foot to the other. A video showing sample interactions with our autonomous NAO robot showing 'non-autistic' versus 'autistic' behaviors is available for online viewing[2].

3 Robot Behavior Evaluation

In order to evaluate the validity of our designed interactive behaviors with respect to the formalism of the ADOS-2, we ran an evaluation study with trained ASD therapists. The aim of the study was to investigate: (1) whether the therapists would assign to the features characterizing the designed behaviors the same values as the ones on which their design was based, and (2) whether the therapists would agree in their evaluation, and how this agreement would differ according to different stimulus/response pairings.

3.1 Method

We devised a video-based survey showing short videos[3] of the isolated designed behaviors in the context of an interaction with a human (or two for the

[2] https://youtu.be/OuRTQtMpIWo.

[3] Videos available at https://www.youtube.com/playlist?list=PLud58ggSlX1QESo6aAchznqTfs6UFFzWm.

behaviors requiring more than one person). Based on what they saw in the video, the participants were asked to provide a value between 0 and 3 on the relevant feature(s) of each video, according to the description for each value in the ADOS-2 manual. Detailed instructions were given in relation to feature coding, background on robot's capabilities, and simplifying assumptions. In particular, the participants were instructed to 'diagnose' the robot the same way they usually do it with children, by coding the feature value they thought best characterized the response they observed in the video. They had the possibility to watch the video as many times as needed. Also, they were instructed to use information only from the current video, after the first stimulus was started (even though some of the features usually require several samples to form a good judgment). Finally, they were asked to ignore any expression unrelated to motion or speech, including the occasional beeps from the speech recognizer and color changes of the NAO's eyes.

The videos were organized into three tasks (N, JA, and S), corresponding to the stimulus families discussed in Sect. 2. Because behaviors were blended in task S, and to reduce the number of videos shown to the participants, we set the feature value to be the same, in all videos for that task, for both language and pointing features (0,0 - 1,1 - 2,2 - 3,3). The total number of videos was hence 12, four for each of the three tasks. The order of the three tasks in the survey was randomized, as well as the order of the videos within each task. When applicable, the progression of stimuli was performed in the hierarchical order used in the ADOS-2 presses until a response was seen on the robot. The survey also included snapshots of the corresponding ADOS-2 manual to help the trained experts code the severity on each feature based on their observation.

We first ran a small pilot with one trained therapist to get an idea of the expected results, as well as gather feedback on the clarity of the survey, as well as potential points of improvement. When the survey was finalized, we gathered the responses of three other therapists from the Child Development Center at the Hospital Garcia de Orta, Almada, Portugal. The therapists who participated in this study are all certified to administer the ADOS-2 and use it in their regular professional practice.

3.2 Results and Discussion

Table 2 shows the responses obtained from the three experts. We analyzed both the accuracy and the agreement between the experts. The accuracy analysis only discriminated between matching and non-matching responses (with respect to the expected response), while the agreement analysis treated the variables as ordinal.

Our analysis of the accuracy of the responses showed an average accuracy of 83.3%. Additionally, a McNemar's mid-p test on the binary categorical data did not indicate significant differences in accuracies between any pair of raters ($p \geq 0.125$ for all pairs). As our inter-rater agreement measure, we used the average Spearman's correlation coefficient, which yielded an agreement of 0.91. We computed p-values for each pair of rater against the alternative hypothesis that

Table 2. Summary of the feature values assigned by the three experts on each of our designed behaviors. Responses not matching the expected one are colored in gray.

Behavior	rN0	rN1	rN2	rN3	rJA0	rJA1	rJA2	rJA3	rlS0	rlS1	rlS2	rlS3	rpS0	rpS1	rpS2	rpS3	Acc.
Expert 1	0	1	2	3	0	1	2	3	0	1	2	3	0	0	3	3	87.5%
Expert 2	1	1	2	3	0	1	2	3	0	1	2	3	0	1	2	3	93.8%
Expert 3	0	1	1	2	0	1	2	3	0	0	2	3	0	0	1	3	68.8%

the correlation is greater than zero, using the exact permutation distributions, yielding $p \leq 1.34\text{e}{-6}$ for all pairs, hence indicating general strong agreement between the experts (as expected). It is to be noted that expert 3 was more reluctant in giving higher severity values, as all of the 5 mismatches for that expert were due to underestimates of the expected feature values.

On the other hand, some videos resulted in both lower agreement and accuracy than others, as is reflected in Table 2. While the joint attention task had a perfect match of responses for all participants, some behaviors in the other two tasks contained some mismatches, which we try to analyze next. First, the two behaviors which had the most mismatches were rPS1 and rPS2, referring to pointing behaviors. rPS2 didn't involve any actual pointing with the arm, but we suspect that two of the participants did consider eye gaze as a pointing behavior (which shouldn't have happened). The source of confusion for expert 3 may have come from the fact that we didn't ask them to code eye gaze separately, leading them to think it would be appropriate to code the gaze behavior as part of the pointing behavior. Expert 1, on the contrary, completely denied the importance of gaze for the 'pointing' feature, which is justifiable. The scenario presented made it hard to discriminate between a severity of 2 or 3 on that feature based on the detailed description given by the ADOS-2. rSP1 involved pointing and a gaze shift, but the gaze shift was not in the direction of the object, as is the case for rSP0. We attribute the source of mismatch to the angle of the camera which made it hard to accurately estimate the actual direction in which the robot was looking. The mismatch for rN2 could be explained by the camera angle factor too, but the mismatch for rN0 and rN3 were unexpected, since there was little room for confusion. For rlS1, the mismatch for expert 3 was clearly a mistake, as a two-word utterance such as "This one" should correspond to a value of 1. We believe this mistake was due to the fact that the coding slightly differs between Module 2 (used in this work) and Module 1 of the ADOS-2, the latter being the one the therapists are most used to, since it is the module that is most frequently administered.

An additional hypothesis on mismatches is that the length of the questionnaire may have fatigued the participants, and we expect to see a positive correlation between the presence of errors and the index at which the video appeared in the survey, given the fact that the video order was randomized. We confirmed this hypothesis by computing the Spearman's correlation coefficient between those two variables with a single-tailed t-test for statistical significance. We found a statistically significant positive correlation ($\rho = 0.33$, $p = 0.011$), which suggests that participants were getting more and more fatigued as the survey progressed, making them prone to less sharp judgment.

4 Conclusions

This work demonstrated our approach on enabling autonomous robots to behave like children with ASD of varying severities. First, we designed 16 behaviors for a humanoid NAO robot, according to the categorization in the manual of the ADOS-2 diagnostic tool according to different severities along 4 selected features. Next, we integrated those behaviors in an autonomous agent running on the robot, hence enabling flexible and continuous interactions with humans. Finally, we evaluated our designed behaviors by running a video-based study with three trained ASD therapists. Our results indicate that, even though ADOS-2 possesses a systematic procedure for assigning severity values to features, there is some level of subjectivity in coding, as is the case with behavior-based diagnostic procedures in general [6].

The choice of a video-based survey was justified by the fact that videos of children with ASD are used for training purposes and the fact that inevitable variability in the interaction dynamics of embodied interactions might have an impact on the results. However, it would be interesting to evaluate the perception of our designed behaviors 'in situ', with participants directly interacting with and observing the robot, without being third-person observers. The challenge will be to make our test system robust enough to differences in interaction dynamics between different participants, in order to reduce variability in the interaction, which may introduce noise in our data.

Interactive robots exhibiting typical ASD behaviors with different severities open the door to a number of exciting applications to train, treat or educate a wide range of individuals dealing with ASD. In immediate future work, we will investigate two different research directions. First, we plan to extend this study to better understand the way humanoid robots can be used in an interactive system to train therapists to administer the ADOS-2. Second, we plan to use our system in the context of a therapy task for children with ASD to train their imitation skills, where the robot can be customized to seamlessly switch between matching the child's behaviors and demonstrating desirable behaviors for the child to imitate.

Acknowledgments. This research was partially supported by the CMUP-ERI/HCI/0051/2013 grant and national funds through Fundação para a Ciência e a Tecnologia (FCT) with reference UID/CEC/50021/2013. The views and conclusions contained in this document are those of the authors only.

We thank Jocelyn Huang and Patrick Lin for their collaboration in the development of the robot behaviors, as well as Marta Couto and Patrícia Alves-Oliveira for their help. Special thanks go to the Child Development Center at Hospital Garcia de Horta, Almada, Portugal, for their feedback on this research.

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