Human-robot interaction as a tool to evaluate and quantify motor imitation behavior in children with Autism Spectrum Disorders

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***Abstract*— Children with Autism Spectrum Disorders (ASD) have difficulties engaging in imitation behavior. Available clinical tests that evaluate imitation rely on subjective observation and categorical "yes" or "no" data. We describe the development of a method to quantify imitation using a robot, kinematic data and a Dynamic Time Warping algorithm. A realistic-looking robot performed movements such as "waving hello/goodbye", "good job fist bump" and encouraged children with ASD and controls to imitate it. Preliminary results show that children with ASD interact positively with the robot and the DTW similarity measure may serve as both a meaningful and objective tool for evaluating the quality of imitation behavior.**

***Keywords*— Robotics, imitation behavior, kinematics, Autism**

I. Introduction

Autism spectrum disorders (ASD) are characterized by impairments in social reciprocity, verbal and nonverbal language, and by restricted and repetitive behavior. Autism spectrum disorders are among the most common pediatric diagnoses in the United States with a prevalence of 1 in 88 children and 1 in 54 males [1]. There is growing evidence that individuals with autism experience motor difficulties as well. Motor difficulties are one of the most common sources of referral for physical and occupational therapy [2].

Recent work in the neuroscience field has shown the link between mirror neurons and autism [3]. Although there is an ongoing debate about the link between mirror neurons and autism, a large number of studies show a positive link between the two. Mirror neurons are known to help in the development of sensorimotor skills, especially with regards to skills required for social development and integration. Some skills like imitation of body and facial gestures are considered important in the development of social interaction.

Understanding the limitations in the planning and coordination of movement and posture is fundamental to a comprehensive understanding of the impairments and functional limitations link to ASD. Slowed or uncoordinated head and arm movements may limit head turning, reaching, pointing, showing and sharing that are key components of initiation and response to joint attention [4]. A child's poor coordination and slowed movement are linked to poor social participation and increased anxiety during playtime [5, 6]. To fully engage in social interaction, a child requires a full repertoire of movement behaviors for use in communication and for understanding the communicative nature of others' movements.

Humans learn new skills using numerous techniques and modalities, in particular through observation and imitation [7, 8]. Imitation of motor gestures and movements is paramount during childhood for the development of social interactions. Contrary to typically developing children, those with ASD do not imitate the movements of other people and do not point towards an object of interest. We believe that their motor imitation difficulties contribute to lack of play and interaction with other children. Children with ASD have difficulties initiating and engaging in imitation behavior.

The advancement and cost-effectiveness of sensor/actuator and computing technology has played an important role in the recent emergence of robotic technology. Recently, use of pattern recognition from sound data as well and the use of human and non-human robots for improving play in children with ASD was considered [9-12]. Several robotic systems have been developed for use in the therapy of individuals in the autism spectrum such as FACE, AuRoRa, Kaspar, and Keepon, but many of them have only been tested under manual operator control, rather than in a truly autonomous, interactive manner [13]. These studies concluded that the appearance of the robot plays an important role in how children relate and interact with such robots.

Researchers at Massachusetts Institute of Technology have recently ushered a new research area in social robotics, where the goal is to create realistic interaction between humans and humanoid robots in manners as intuitive and natural as human-to-human conversation [7]. In other words, the human-like robot hardware has to be controlled so that the overall behaviors are similar to those of humans. People are likely to become familiar with robots that exhibit human-like features, appearance and characteristics. Additional studies confirm that human-like robots that do not have a mechanical-like appearance are treated differently in social settings [14, 15]. On contrast, [16] proposed that is the robot appearance are too close to human-like features, an "uncanny valley" is created which leads to feelings of "repulsion" by humans. Additional research is needed to investigate how individuals with ASD respond to robots as instructional agents. However, studies suggest that leading types of interactions useful in engaging children with ASD are emotion recognition, joint attention, imitation and turn-taking [10, 11, 17].

A robot called Bandit was used to guide older adults to perform imitative exercises [18]. This project had a robot perform upper body gestures that the subject imitated, performance criteria were related to achievement of target poses. These projects and others involving the use of robots for assisting humans in a social, collaborative setting can be considered part of a relatively new field called Socially Assistive Robotics [13]. However, to date, evaluation of human-robot interaction is restricted due to lack of objective criteria that rate imitative gestures and movements and quantify the Human-Robot Interaction (HRI). Moreover, currently available clinical tests that evaluate imitation rely on observation and categorical data of "yes" and "no". Use of the robot will provide consistent repeatable imitation tasks that can be evaluated using continuous kinematic measures over time. The purpose of this project was to conduct a feasibility study to examine the utility of a robotic device and human-robot interaction as a tool for assessing and quantifying imitation behavior in children with autism spectrum disorders. We aimed to verify if the system and the analysis algorithm can accurately measure imitative behavior in typically developing children and to compare the results with those of children with ASD.

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II. METHODS

A. Participants

Four children diagnosed with ASD and four controls, age-matched neuro-typical developing children, participated in this study. All participants were boys, aged 6, 9, 11 and 12 years old. Children with ASD were recruited from the Autism Treatment Center in Dallas, Texas, USA. Participants were excluded if they had genetic, infectious, seizure comorbidities or any type of acute musculo-skeletal impairments. Parents gave informed consent for their child participation in the study. All procedures were approved by the Institution Review Board and in compliance with federal regulations.

B. Zeno the Humanoid Robot

Zeno is a child-size, 2 foot tall, articulated humanoid robot by Hanson Robotics with an expressive human like face shown in Fig. 1. It has 9 degrees of freedom (DOF) in the upper body and arms, an expressive face with 8 DOF, and a rigid lower body [19]. The robot is capable of moving the upper body using a waist joint, and has four joints in each on the arms implemented using Dynamixel RX-28 servos. It has a 1.6 GHz Intel Atom Z530 processor onboard and is controlled by an external Dell XPS quad core laptop running LabVIEW [20]. The appearance of Zeno is based on a fictitious character - he looks like a 4-7 year old child, and his head is about ¼ the size of an adult human head. Its unique features include life-like skin made of Frubber™ material.

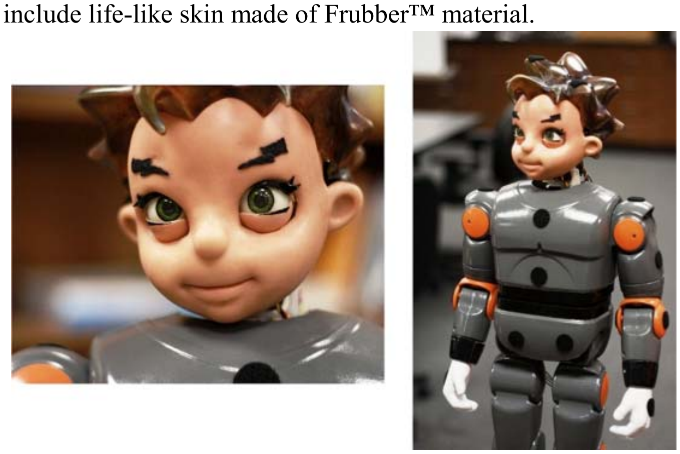

Figure 1. ZENO RoboKind R-30

The appearance of Zeno is a game changing experience thanks to this material and to the robot esthetics. The head of Zeno is powered by 9 servo motors, has 3 degrees of freedom (DOF) at the neck joint, and it is capable of panning, tilting the head back and forth as well as left to right. It also has 2 degrees of freedom in each eye (pan and tilt), and 4 of the servos are used for generating facial expressions (eye blink, jaw motion for smile, eyebrow motion for frown, etc.).

We believe a combination of speech recognition, facial expressions, and head and eye motion is instrumental in the engagement of ASD children for both assessments and potential treatment purposes. We have implemented a real-time sensor, processor and actuator technology, such that the motion of the robot does not appear "choppy" or "lagging" during tracking and interaction with a human. Embedded processors in the robot camera eyes allow processing of 3D visual information at higher speeds leading to fast response times [21]. We have achieved a smooth motion that resembles human-like movement taking into consideration that Zeno has a lower number of DOF compared to the DOF of a human. The smooth motion of the robot is important to generate human-like movement. To make sure this was achieved, we took into consideration the update rate of its control system and the processing power. We have found that the system operates smoother in quad-core processors than in dual-core processor based system. We were able to achieve a 0.0235 second robot response time.

C. Data collection procedure

The child and Zeno face each other and take turns imitating each other's movements. Zeno RoboKind software allows pre-programming of scripted motions as well as conversation using voice recognition and text to speech software. The robot interacts with children implementing the following behaviors: *verbal dialog: look at me, follow me; imitate my facial gestures, imitate my head-eye motion, imitate arm and hand movement.*

Children are directed by the robot Zeno to follow along and imitate its movements by performing several gestures. Specific movements such as "wave hello/goodbye", signaling "I am hungry" with a "tummy rub", and "good job fist bump" are performed with the left and right arms at least 6 times. Reflective markers are placed on equivalent anatomical locations on the child's body and Zeno structure. The 3D joint position data of the head, trunk and limbs is captured with a 12 camera motion analysis system at 120 Hz (Motion Analysis corp, Santa Rosa, CA). Fig. 2 shows a child participant and Zeno instrumented with reflective markers and performing a wave motion and the system capturing the markers using the Motion Analysis cameras and generating skeletal models of Zeno and child.

D. Data processing and analysis

Data from the motion capture system is in the form of Cartesian coordinates (x, y, z) for positions of the shoulder, elbow and the hand. Since Cartesian positions are more difficult to compare due to dimensional and pose differences (e.g., robot is much smaller than child and rotated in space to

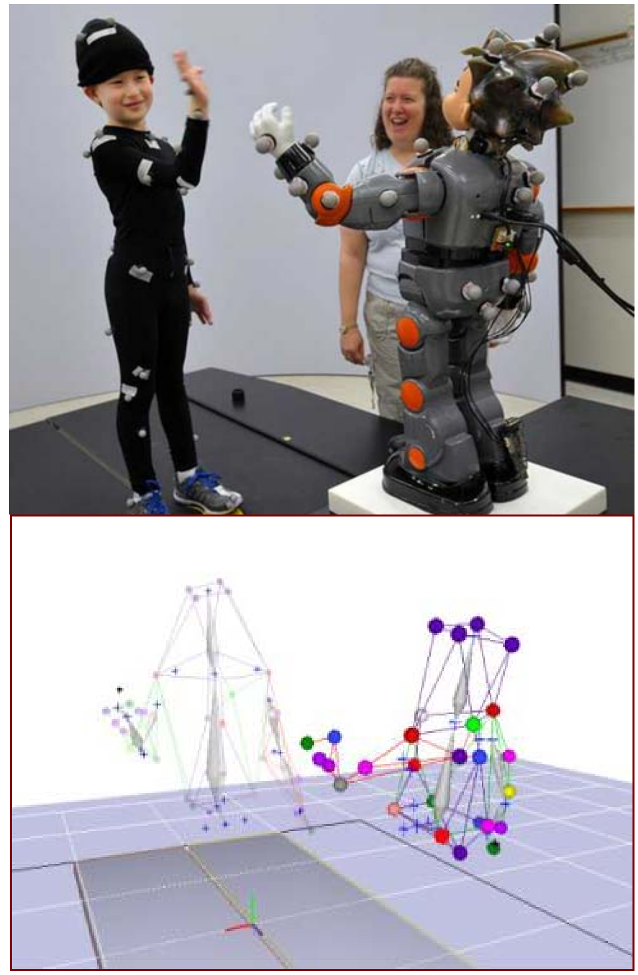

Figure 2. Robot Zeno and child waving (top) and motion capture based on markers for kinematic data (bottom). © *University of Texas at Arlington and © University of North Texas Health Science Center Reprinted by permission.*

face each other), similarity in motion between child and robot is measured using joint angles. Inverse kinematics are used to calculate joint angles from the coordinates provided by the motion analysis system for each joint using the procedures described in [19, 20]. These angles then produce four angle trajectories for each arm. The four angles produced are alpha, beta, gamma and theta, representing shoulder flexion/extension, abduction/adduction, internal/external rotation and elbow flexion/extension. Angle trajectories are preprocessed by z-normalization, subtracting the mean from the signals to remove any offsets and dividing the signals by their respective standard deviations to scale them. This preprocessing is useful to remove the offsets caused by the difference in the kinematic structure of the robot and human subject and also compensate for the difference in the range of motion. The effect of normalizing the data can be seen from Fig. 3 which shows the raw elbow angles of the subject and Zeno on the top and the normalized elbow angles on the bottom.

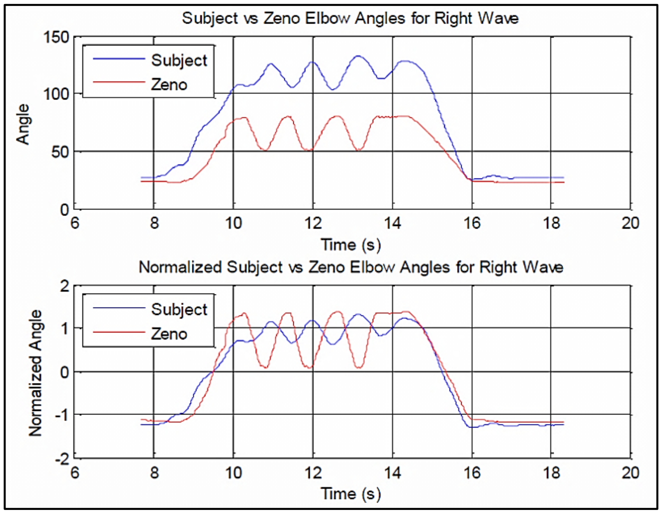

Figure 3. Raw and normalized elbow angles for Zeno and child waving motion.

There is a need in the Autism research community to obtain quantitative measurements of imitation quality. We propose a Dynamic Time Warping (DTW) algorithm to obtain a similarity measure between time series joint angle signals. DTW is an established signal processing method that offers a distance measure between signals similar to the Euclidean distance. However, time-warping is applied to signals to align them optimally, prior to taking the difference. Optimal alignment in this context is the alignment of the signal time samples that makes the total distance between the signals as small as possible. This alignment induces a non-linear mapping between the two signals, e.g. warping of the signals [22]. The strength of DTW is in its ability to compare the similarity between signals by ignoring time-delays and uneven time sampling. This situation is very relevant since the motion of child and robot experiences both these effects. A typical result when using the DTW algorithm, with the gray lines depicting the nonlinear map between two signals can be seen clearly from the right side of Fig. 4.

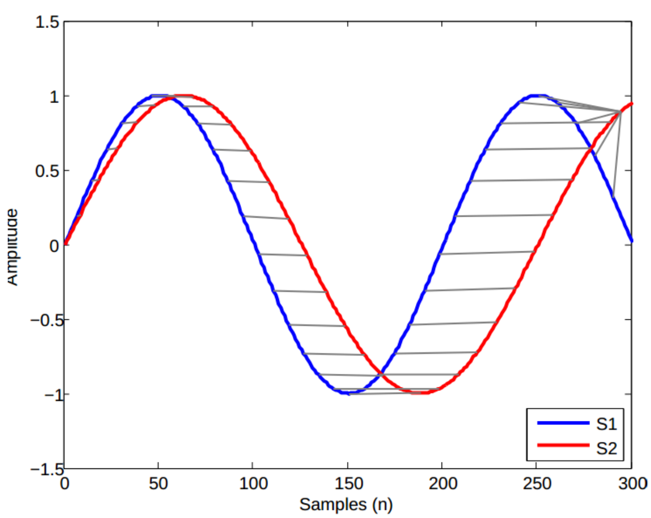

Figure 4. Example of Dynamic Time Warping

III. RESULTS

The DTW algorithm takes each point from the angle trajectory of the ASD subject and compares it to each point on Zeno's angle trajectory. It calculates the Euclidean distance or the magnitude between each point. A matrix is produced with these distances. From this matrix the best path for each point compared is determined and the sum of these distances is the value of DTW. In an ideal situation where both signals are identical (perfect imitation) DTW has a value of zero. An increase in the value of DTW shows an increase in the variation between Zeno motion and the child imitation movement.

Once the DTW values for each joint angle are produced they are used in calculating the overall performance of the child imitation behavior. The angles used to calculate the overall performance may vary depending on the motion being imitated. In the case of a "waving hello/goodbye" motion, beta and theta angles are major contributors to the overall performance of the hand wave. Beta and theta are weighted according to Zeno's range taken from the original data before the normalization of the angle trajectories. The difference between the maximum and minimum for each angle trajectory is found providing a weighted value for each of the two angles. The sum of the weighted value multiplied by its corresponding DTW value for beta and theta, divided by sum of the beta and theta weighted values produce a combined average. This combined average represents the overall performance of the imitation behavior produced by children while following Zeno's movements. The computation of the DTW and the Euclidean distance measures for four pairs of ASD children and their age-matched control performing the wave motion is shown below in Table I. These preliminary results show that the DTW similarity measure can serve as both a meaningful and objective measure for evaluating the quality of imitation behavior. With age, all children improve their imitation behavior. However, children with ASD consistently perform worse than their age-match controls. The combined weighted joint average for the wave motion has a higher value in all ASD children, indicating that their imitation of Zeno's waving motion is less accurate.

Table 1: DTW values for joint angles and combined weighted joint average for a waiving motion in children with ASD and age-matched controls. All joint values are 10^3. The lower the numbers, the better the imitation behavior.

Group	Age	Alpha	Beta	Gamma	Theta	Combined weighted joint average
Control	6	0.4421	0.6730	0.2775	0.1145	0.3075
ASD	6	1.2128	1.2128	1.1359	0.7232	0.8913
Control	9	0.6436	0.0792	0.5253	0.3073	0.2247
ASD	9	0.3387	0.6738	0.6899	0.9251	0.7331
Control	11	0.6164	0.2267	0.6409	0.2854	0.2666
ASD	11	0.4473	0.1881	0.4319	0.3228	0.2757
Control	12	0.2350	0.2583	0.5157	0.1159	0.1636
ASD	12	0.5036	0.3178	0.4753	0.6402	0.4954

IV. DISCUSSION

We used a realistic-looking, agile robot Zeno, programed to create gestures and movements such as *"waving hello/goodbye", "tummy rub", "good job/fist bump".* Children were encouraged to imitate the robots movements. Using kinematic data and a novel Dynamic Time Warping algorithm for the kinematic data we quantified the motor imitation behavior.

All children who participated in this study were intrigued by the robot and enjoyed their interaction with it. In our study we have experienced that the robot keeps the children interested during experiments. It is possible that children with ASD react positively to the robot because they perceive it as a toy, an interacting, non-threatening toy and they prefer dealing with the robot than with a human asking them to imitate their behavior. This is in concordance with other studies suggesting that the use of robots in therapy is received positively by children with ASD [17]. Typically developing children were able to imitate the robots movements very well. The DTW algorithm was able to reflect this by calculating combined weighted joint averages that were lower, closer to zero value suggesting "perfect imitation". Children with ASD had consistently higher values than their age-matched controls. Our results are in line with other studies showing that imitation performance can be used to distinguish children with ASD, children with other development disorders and typically developing children [23]. Others have elevated the idea of imitation behavior and began work in designing therapies for ASD targeted towards developing the mirror neuron system, by imitation specific synchronized dance therapy [24].

A major contribution and novelty of this project is the development of a human-robot interaction system and the new DTW algorithm capable of measuring the quality of imitation interaction between a humanoid robot and a human subject. This system enables consistent objective measurement of the imitation behavior that can be used to glean information about the ASD condition. The long term goal is to use the human-robot interaction to identify sources of potential deficits and delays in imitation behaviors and be part of diagnosis and treatment of imitation impairments in ASD.

Like other projects involving robots interacting with individuals, specifically children with ASD, our study although multidisciplinary in nature, has a small number of participants. This makes a good clinical conclusion difficult at this point. Because development is a heterogeneous process in childhood, data collected over time and especially the trajectory of motor development over time are stronger indicators of real motor delays and problems compared to data collected at only one point in time. We are currently assessing and tracking the development of imitation behavior in the enrolled participants at periodical intervals using a cross-sectional longitudinal design.

Motor imitation impairments present in infancy and early childhood may hinder learning during development and contribute to the social and communication impairments observed in older children and adults with ASD. Therefore, early evaluation of imitation behavior delays must be implemented and deficits addressed through early interventions not just for enhancing motor imitation development but also for enhancing social development.

V. CONCLUSIONS

The results of Dynamic Time Warping algorithm showed that children with ASD have poorer imitation behavior (higher discrepancy values of imitation based on weighted joint angle contributions) during the dynamic task compared to control group. The initial data analysis shows that DTW can be a good tool for comparing imitation behavior since it matches the temporally inexact nature of imitation. Future studies incorporating a larger variety of movements of particular interest to the ASD population are needed, as well as a comprehensive evaluation of the DTW algorithm in a larger sample size studies.

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