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Clinical application of humanoid robots in playing imitation games for autistic children in Iran

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Abstract

Autistic children are often impaired in initiating and responding to Joint Attention. In recent years, there has been an increase in the application of robots in diagnosis and treatment of autism. The purpose of the current research is primarily to originate the proper therapeutic scenarios and to implement two interactive humanoid robots as therapy assistants in autism treatment in Iran. In this paper, our focus is specifically on developing the necessary tools to improve joint attention and imitation in autistic children. To this end, the humanoid robots were programmed and teleoperated via Microsoft Kinect Sensor and Phantom Omni Haptic Robot to elicit reactions consisting of imitation of humans by the humanoid robots and vice versa. Our research target was to increase social interaction and involve autistic children in dyadic/triadic interactions.

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Keywords: Human-Robot interaction (HRI), Autism Spectrum Disorders, Humanoid Robots, Joint Attention, Imitation

1. Introduction

Statistics have shown an epidemic increase of Autistic Spectrum Disorders (ASD) worldwide since the 1960s, and this trend is also true for Iran. Autism is considered a brain development disorder which causes a lack of correct information processing, partial or complete impairment in language learning, impaired verbal and non-verbal communication, and problems in interpreting social situations (Edwards; 2011 and Scassellati; 2003). Autistic

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disorders are characterized by three major behavioral disorders: impaired interaction, impaired social communication, and impaired imagination and social creativity (Pouretemad; 2011).

There is no clear cut agreement on the prevalence of autism, and estimates vary from up to 100 out of a population of 10,000 (Pouretemad; 2011). The most recent statistics indicate that 1 out of every 88 children born in the United States is autistic (Scassellati; et-al, 2012). It is expected that more than 30,000 Iranians younger than 19 years old suffer from autism disorders. Autistic children share some common behavioral patterns which can generally be detected and modified. Individuals with autism often have some form of disorder in initiating and responding to joint attention (Pouretemad; 2011).

In recent years, robots have been increasingly used in education (Meghdari and Alemi; et-al, 2013) and autism diagnosis and treatment (Kozima; et-al, 2001 & 2007, Pioggia; et-al, 2007, Billard; 2003, Ferrari; 2009, Kim; et-al, 2012, Stanton, et-al, 2008). Research focusing on applying robots in autism treatment have pointed out that robots increase enthusiasm, focus, and attention; and cause novel social behaviors such as joint attention and automatic imitation. Research also indicates that autistic children work quite naturally with robotic technologies (Scassellati; 2003 and Diehl; et-al, 2012). When interacting with robots, people are mainly impressed by the robot's appearance (Scassellati; et-al, 2012). A variety of robots with different appearances and functions are currently being used around the world as therapy assistants in autism treatment; such as, Infanoid (Kozima; et-al, 2001), a robot the size of a human infant, is able to move its hands and to open and close its mouth and fingers; Face (Pioggia; et-al, 2007) a very natural looking robot with silicon skin and high functions in showing facial expressions; Robota (Billard; 2003), a doll equipped with motors and sensors which is capable of moving its hands and feet and dancing; Muu (Kozima; et-al, 2007), a robot with one big eye and a cartoon-like appearance; Bandit (Ferrari; 2009), a humanoid upper body on a wheel base; Pleo (Kim; et-al, 2012), and Keepon (Stanton, et-al, 2008), animal-like robots, respectively, in the shape of a dinosaur and a bird, are some examples of the robots used in the research of autism treatment. The above mentioned robots are being used to elicit such behaviors as imitation, joint attention, and eye contact. The eminent feature of robots is their high level of repeatability and flexibility, as well as working without getting tired or making complaints. Since robots do not humiliate or belittle people, it is expected that autistic people face less anxiety in interacting with them and are more willing to participate in the learning exercises.

Our main objective is to explore clinical applications of two interactive humanoid robots as medical assistants (not a substitute for human therapists) in treating/educating children with autism in Iran (Meghdari, Alemi, Taheri; 2013). As a first step, this paper will focus on developing the necessary tools to improve two main social behaviours in children with autism namely as: imitation and joint attention. Preparing these robots to be used in eliciting their imitation of the patients and the patient's imitation of them, and designing proper therapeutic scenarios to improve autistic children's ability to initiate and respond to joint attention has been the purpose of this study. Our multi-disciplinary research team consists of robotics engineers, applied linguists, autism specialists, and psychologists.

2. Research methodology

The current study consists of the following two phases: the technical phase and the clinical intervention.

2.1 Technical phase

Initial step was to identify the necessary capabilities needed for a robot to be used for autistic therapy. According to the desired therapy scenarios, two humanoid robots called NAO and Alice manufactured by Aldebaran-Robotics and Robokind, respectively, are purchased. Each of these robots consists of specific features that will be used in the clinical stage. Additionally, the Alice Robot is capable of showing human facial expressions. The features of the two mentioned robots are as follows:

NAO-H21 Robot: This is a kid-sized humanoid robot with 57.3 cm in length, 4.5 kg in weight, with 21 degrees-of-freedom, equipped with 2 cameras, 2 microphones, 8 foot Force Sensitive Resistors sensors, one 2-axis gyrometer, one 3-axis accelerometer, capable of voice synthesis, different LEDs in eyes, body, and features a 500 MHz CPU. Beside the graphical user interface software, Choregraphe, it can be programmed using C++, Python, etc. To be used in an Iranian context, we have renamed it as "Nima" (see Fig.1).

Alice Robot: Alice, with the Iranian name "Mina", 69 cm high, weighting 5.7 kg, with 32 degrees of freedom (21 degrees of freedom in her body and feet, and 11 degrees of freedom in her face), equipped with two cameras placed in each of her eyes, temperature sensors, a 3-axis gyrometer, PIR, ground contact, and other sensors, and a 1 GHz

CPU, is capable of showing different facial expressions such as joy, sorrow, anger, fear, and so on, thus being of great interest for children. This robot can be programmed in C++ and Java (see Fig.2). The robots' capabilities such as body movements, speech, and facial expressions will be used to design different therapeutic scenarios.

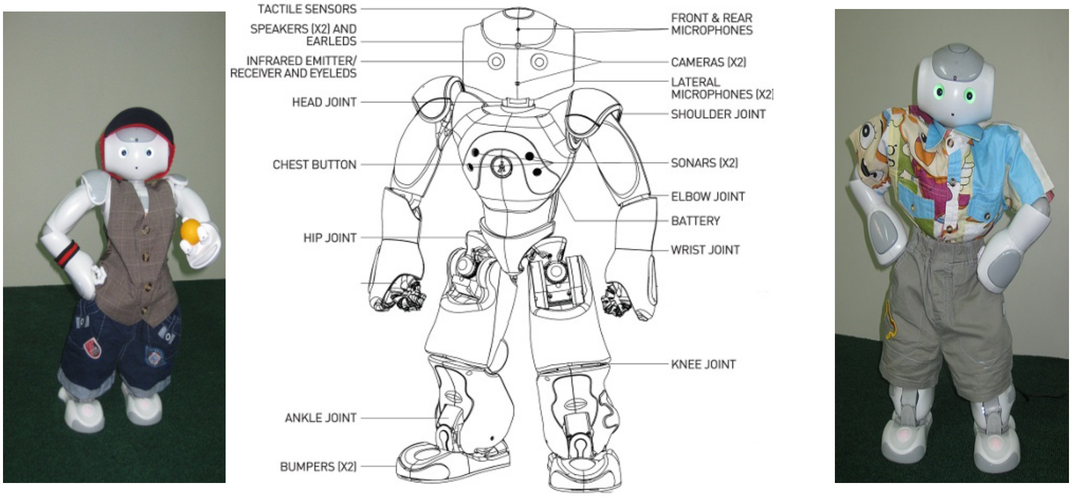


Fig. 1. A schematic overview of the NAO (*Nima*) Robot

Fig. 2. The Alice (*Mina*) Robot

2.2 Clinical interventions

In the second phase of the study, the clinical interventions are being initiated with the autistic children at the "Center for Treatment of Autistic Disorders (CTAD)" in the presence of the robots and therapist. The treatment process for a group of 3-10 years old patients will continue at least for a period of 10 weeks. The approach is a single subject design and the interventions are currently underway. Robots are used in therapy sessions for:

- Quantitative and qualitative assessment of the amount of initiating and responding to joint attention by children with autism and if any improvement is shown.
- Improving social and imitation skills in autistic children.
- Creating a happy, interesting, and exciting teaching atmosphere for autistic children.
- Educating the therapists to be able to apply a robot in different stages of the treatment.

3. Therapeutic scenario design

In this section, the three main objectives of this paper will be discussed in the following subsections:

3.1 NAO real time imitation using microsoft kinect

Imitation of the autistic patients' behavior is an effective way of triggering their attention toward the therapist [3, 8]. Imitation and turn-taking games are considered as good therapy to improve social interactions, sense of self, creativity, and leadership in children and even adults with autism. Accordingly, we plan to achieve real time imitation of upper body movements by the NAO of humans. We have used Microsoft Kinect sensor which gives us the real time position (x, y, z) of the player's joints. Using forward and inverse kinematics, we are able to teleoperate NAO and obtain good real time imitation.

To this end, eight joints of NAO's upper body including Head-Yaw and Head-Pitch from the head, Shoulder-Pitch, Shoulder-Roll, and Elbow-Pitch of both hands are commanded in order to have admissible real time position tracking of the users' hands and head. The base frame, zero positions of the upper body joints of NAO, and the appropriate link frames are shown in Fig.3.

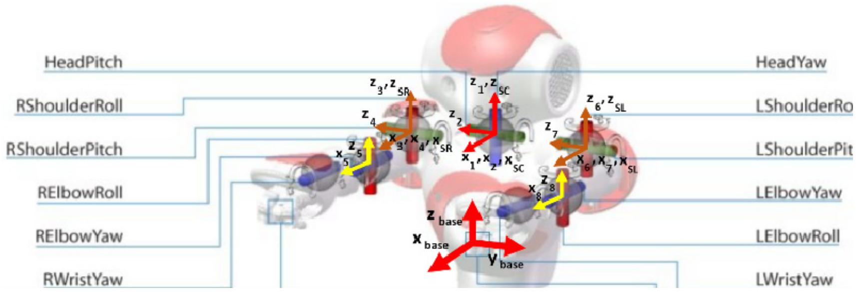


Fig. 3. NAO kinematic chains and upper body joints

For the homogenous transformation matrix ${}^{i-1}_{i}T$, the corresponding Denavit-Hartenberg (DH) parameters of NAO are given in Table 1.

$$ {}^{i-1}_{i}T = \begin{bmatrix} \cos\theta_i & -\sin\theta_i & 0 & a_{i-1} \\ \sin\theta_i.\cos\alpha_{i-1} & \cos\theta_i.\cos\alpha_{i-1} & -\sin\alpha_{i-1} & -\sin\alpha_{i-1}.d_i \\ \sin\theta_i.\sin\alpha_{i-1} & \cos\theta_i.\sin\alpha_{i-1} & \cos\alpha_{i-1} & \cos\alpha_{i-1}.d_i \\ 0 & 0 & 0 & 1 \end{bmatrix} \quad (1) $$

Table 1. DH Parameters for Head, Right-Hand and Left-Hand of the NAO Robot

	α_{i-1}	a_{i-1}	θ_i	d_i
1	0	0	θ_1	0
2	$\pi/2$	0	$-\theta_2$	0
3	0	0	θ_3	0
4	$\pi/2$	0	$-\theta_4$	0
5	$-\pi/2$	$L_{RightArm}$	θ_5	0
6	0	0	θ_6	0
7	$\pi/2$	0	$-\theta_7$	0
8	$-\pi/2$	$L_{LeftArm}$	θ_8	0

We can combine DH transformation matrices of the corresponding joints to find the Head, Right Wrist, and Left Wrist positions of NAO:

$$^{ShoulderCenter}_{Head}T = {}^{SC}_{1}T \cdot {}^{1}_{2}T \quad (2)$$

$$^{ShoulderRight}_{ElbowRight}T = {}^{SR}_{3}T \cdot {}^{3}_{4}T \cdot {}^{4}_{5}T \quad (3)$$

$$^{ShoulderLeft}_{ElbowLeft}T = {}^{SL}_{6}T \cdot {}^{6}_{7}T \cdot {}^{7}_{8}T \quad (4)$$

$$^{SR}_{WristRight}P = {}^{ShoulderRight}_{ElbowRight}T \cdot [L_{RightForehead}, 0, 0, 1]^T \quad (5)$$

$$^{SL}_{WristLeft}P = {}^{ShoulderLeft}_{ElbowLeft}T \cdot [L_{LeftForehead}, 0, 0, 1]^T \quad (6)$$

The inverse kinematics for the considered eight joints is presented in Table. 2. Now, the robots are capable of imitating the patients through the data retrieved by the Microsoft Kinect sensor. Kinect's data sampling rate is 32 frames per second. The (x,y,z) coordinates of 20 points of the user's body are accessible in each data sampling. The accuracy of the imitation process is elaborated in detail in the Results section.

Table 2. Inverse kinematics for the Head, Right Hand and Left Hand of the NAO Robot

HeadYaw:	$\theta_1 = a\tan 2(H\_SC_y, H\_SC_x)$
HeadPitch:	$\theta_2 = a\tan 2(\sqrt{H\_SC_x^{\,2} + H\_SC_y^{\,2}}, H\_SC_z)$
RSh_Pitch:	$\theta_3 = -a\tan 2(E\_SR_z, \sqrt{E\_SR_x^{\,2} + E\_SR_y^{\,2}})$
RShoulderRoll:	$\theta_4 = a\tan 2(E\_SR_y, E\_SR_x)$
RElbowPitch:	$\theta_5 = \pi - a\cos(\frac{\vec{R}_{Arm} \cdot \vec{R}_{Forehand}}{\lvert\vec{R}_{Arm}\rvert \lvert\vec{R}_{Forehand}\rvert})$
LSh_Pitch:	$\theta_6 = -a\tan 2(E\_SL_z, \sqrt{E\_SL_x^{\,2} + E\_SL_y^{\,2}})$
LShoulderRoll:	$\theta_7 = a\tan 2(E\_SL_y, E\_SL_x)$
LElbowPitch:	$\theta_8 = a\cos(\frac{\vec{L}_{Arm} \cdot \vec{L}_{Forehand}}{\lvert\vec{L}_{Arm}\rvert \lvert\vec{L}_{Forehand}\rvert}) - \pi$

3.2 Teleoperating NAO using haptic phantom-omni

Operating a humanoid robot is not an easy task for patients and therapists. Empowering autistic children to move the robot joints arbitrarily causes the children to show creative social behaviors. This may also help them get involved in triadic Child-Robot-Therapist and Child-Robot-Child interactions. To reach this goal, we have used a 6-DOFs haptic manipulator (see Fig. 4) manufactured by The Sensable Technologies PHANTOM, as an interface between users and our humanoid robots. The first three DOFs of this device are active while joints 4-6 are passive. The haptic device makes it possible for users to touch or manipulate virtual objects, and it can apply force feedback on the user's hand.

Fig. 4. Haptic Phantom-Omni Robots and its 3 active and 3 passive DOFs

Autistic children or others can move the haptic device's pen in 3D space and use it as a remote controller to enjoy playing with the humanoid robot. The θ_1, θ_2, θ_3, and θ_5 values recorded by Phantom-Omni encoders are assigned to Head-Yaw, Head-Pitch, Right-Shoulder-Roll, and Right-Elbow-Pitch joints of NAO, respectively. Similar to the previous subsection, the data have been sent via wireless to NAO in order to have real time position tracking.

3.3 Teleoperating NAO using Haptic Phantom-Omni

Delayed development of joint attention, is one of the central disorders in individuals with autism. Utilizing humanoid robots is expected to improve low- and high-level joint attention behaviors such as eye contact, showing, pointing, and gaze shifting through different therapies. So far, programming of the robots to have behavioral-verbal interactions with the patients, as well as, their preparation to take part in different therapeutic situations has been completed. The robots have been programmed using the robots' speech, movement, and facial expressions capabilities, to implement a number of different therapeutic sessions to improve joint attention and imitation of autistic children. To exemplify, they are capable of waving, saying hello and goodbye, one-leg balance in order for the autistic children to imitate the action, pointing to different pictures and asking the autistic child to do the same, expressing happiness for a gift or to encourage the children, or sadness during clinical interventions. Moreover, they can provide verbal reinforcement based on the effectiveness of the responses given by the autistic child. They also teach different colors by changing the color of the LEDs in the robot's eyes and body while introducing the color, and playing music for children while dancing (see Fig. 5). Reinforcement and rewards (i.e. smile, hugs, etc.) are given for the performance of any of the joint attention skills. Having the robot and the therapist imitate the child while the child is involved in a game is considered an effective way to establish joint attention opportunities.

Fig. 5. NAO and Alice robots in autism treatment process (teaching colors, pointing to a picture, one-leg balance, waving, and smiling)

4. Results and Discussion

In this section, the experimental results of teleoperating NAO using Microsoft Kinect sensor is described. We have provided a C# code to save and process the joints' positions data gathered by Kinect. The goal is to have NAO imitate human upper body movements. Accordingly, the key points necessary for this purpose are Head, Center Shoulder, both Right and Left Shoulders, Elbows, and Wrists. Using inverse kinematics equations presented in Table. 2, the equivalent joint angles of NAO are calculated and sent wirelessly to the robot. Fortunately, the sampling rate of Kinect is adequate for good imitation. The lowest acceptable value for fraction of maximum speed of robot actuators is limited by imitation time delays. The upper limit is restricted by jerk increase in robot actions. It is experimentally found that these two requirements were met when this fraction was set to 0.8. Kinect data are noisy and the absolute position error of a fixed point may be more than 10 centimeters. Therefore, the data are filtered in order to smooth out short-term fluctuations through two methods: a) simple moving average of the previous 10 data, and b) 4^{th} order low-pass Butterworth filter with a cutoff frequency of 6 Hz.

As a case study, a person stood in 2 meters in front of the Kinect and moved his hands and head. The whole process took 113.4 seconds and included: movement of hands in arbitrary directions, elbows' flexion, drawing a circle and a square clockwise and counter-clockwise, and left/right and up/down head movements. In Figure 6, four

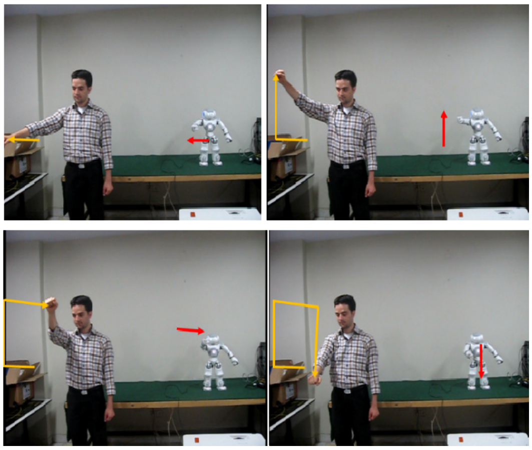


Fig. 6. Snapshots of drawing a square by the user

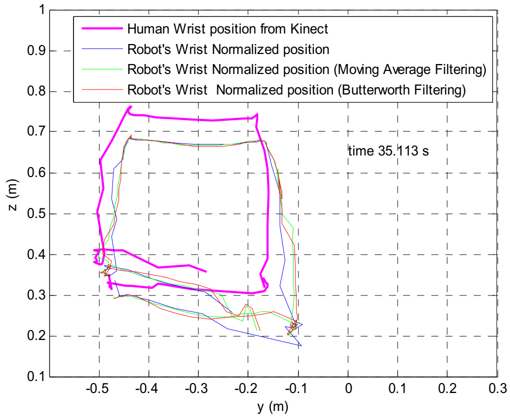


Fig. 7. Right wrist positions while drawing a square for four situations

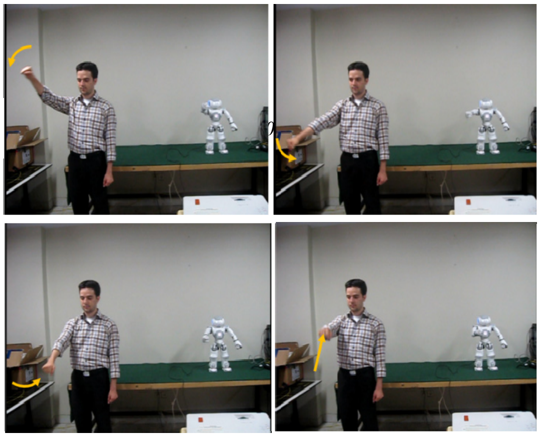
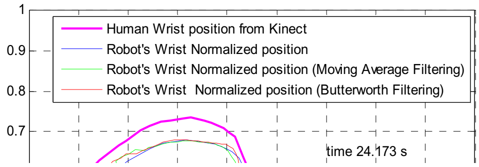


Fig. 9. Snapshots of drawing a circle by the user



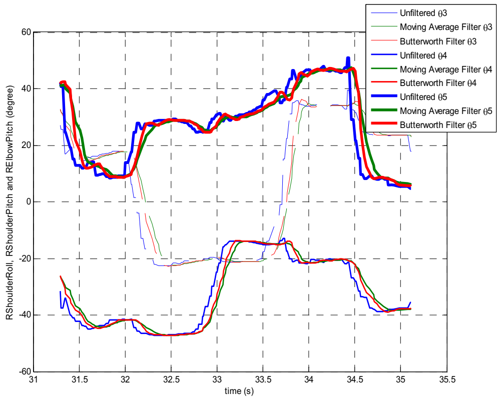


Fig. 8. Right hand's DOF's vs time during drawing a square in unfiltered and filtered situations

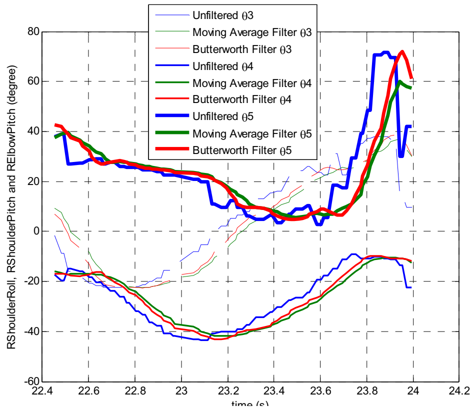


Fig. 11. Right hand's DOF's vs time during drawing a circle process in unfiltered and filtered situations

snapshots of the process of drawing a square by the person are shown. Figure 7 depicts NAO's right wrist position in three situations unfiltered, applying moving average, and Butterworth filters to a person's right hand angle signals in a y-z plane. Figure 8 shows the right hand's angles versus time during the process of drawing a square. This part starts from t=31.3 (s) and lasts to t=35.1 (s). Figures 6-8 shows that NAO is able to imitate the person very well. The imitation accuracy is satisfactory for the clinical intervention sessions and therapeutic design. Although, usage of moving average or Butterworth filters decreases the imitation accuracy and slightly increase its time delay, filtering the angles' data makes the robot's movements much smoother and more reliable; and the robot's joints and body experience lower accelerations and jerks. The robot's imitation delay time is less than 0.4 sec. in the unfiltered and filtered angles' data. Figures 9-11 show the circle drawing movement's snapshots and right wrist position graphs.

5. Conclusion

In this paper, three main objectives were described. Teleoperating NAO using Microsoft Kinect was the first and the main goal of this article. Results showed that the imitation processes are acceptable based on good NAO movement quality and low imitation time delay. Similar to this but easier, NAO can also be teleoperated using a haptic robot as a remote controller. The same procedure can be used on the Alice robot. Finally, it was shown that real time humanoid robot imitation of a person and vice versa is possible. Using the robots' speech, movement and facial expressions capabilities, we designed different appropriate therapeutic scenarios to improve joint attention and imitation of autistic children. Clinical interventions are currently underway, and it is anticipated that the autistic children treated with this technology will enjoy faster improvement regarding making eye contact, initiating and responding to joint attention, imitation, and dyadic/triadic interactions. Moreover, a proper database associated with robotic assisted autistic treatment will be collected for comparative studies with conventional/traditional methods.

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