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Control Strategies for a Robot for Interaction with Children with Autism Spectrum Disorder

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Abstract**—**Socially assistive robotic has become increasingly active and it is present in therapies of people affected for several neurobehavioral conditions, such as Autism Spectrum Disorder (ASD). In fact, robots have played a significant role for positive interaction with children with ASD, by stimulating their social and cognitive skills. This work introduces a mobile socially-assistive robot, which was built for interaction with children with ASD, using non-linear control techniques for this interaction.

Keywords**—**Socially assistive robotics, mobile robot, autonomous control, autism.

I. INTRODUCTION

A. Socially Assistive Robotics

SOCIALLY Assistive Robotics (SAR) focuses on assistance based on the social interaction, aiming at automating supervision, coaching, motivation and companionship aspects. This robotics field pursues to develop robots with physical embodiment in order to communicate and interact with users in a social and engaging manner, becoming an interdisciplinary and increasingly popular research area, which includes beside robotics, medicine, social and cognitive sciences, neuroscience, among others [1].

SAR comprises the intersection of assistive robotics and socially interactive robotics. On one hand, this kind of assistive robots provides assistance to a user, such as locomotion and rehabilitation. On the other hand, socially interactive robots communicate with a user through social and nonphysical interaction, as speech, gesture, and body movement [2]. SAR is capable of ensuring, increasing and improving human-robot interaction, and instances of individuals complied by this class of robots include stroke survivors, elderly and individuals with dementia, in addition to children with ASD [3].

Goals of an effective SAR system are: To establish a relationship with the user that leads toward intended therapeutic goals; provide a benefit to a caregiver by monitoring multiple aspects of the patient and providing ongoing quantitative assessments; and establish engagement and have the user enjoying interactions with the robot. Therefore, the usage of SAR is directed for application in a broad variety of settings, such as hospitals, schools, elderly-care facilities, and private homes [3].

B. SAR and ASD

SARs designed for interaction with children with ASD focus on development of their cognitive, behavioral and social abilities, aiding therapists and caretakers. The interaction of ASD children with robots is likely positive, because they are more predictable, simpler and easier to understand than humans [4], [5]. The robot designers aim to be useful in pedagogical treatments, through many functions that enable an optimistic interaction with these children, as well as calling their attention and stimulating them to get contact with the surrounding environment [6], [7].

SAR can have several shapes, being classified as anthropomorphic (resemble humans-humanoids), non-anthropomorphic (resemble animals or cartoon like-toys) and non-biomimetic (not resemble any biological species) [8].

Anthropomorphic or humanoids robots are used to interact with humans, trying to mimic some aspects, like playing soccer, dancing, speaking and playing instruments [4], [6], and [7]. An instance is the humanoid-robot KASPAR, which moves its head and arms, articulating gestures to interact with children with ASD, and has touch sensors in order to measure the tactile interaction between child and robot [5]. Another example is the humanoid-robot doll-ROBOTA, which performs a bodily interaction playing imitative games and other skills of social interaction, such as eye gaze, touch and joint attention [4].

A non-anthropomorphic robot example is PLEO, a dinosaur-robot designed to express emotions and attention, using body movements and simple vocalizations, triggering verbalization and interaction with another person [9].

Finally, an example of non-biomimetic robot is the creature-like robot KEEPON (a little yellow snowman), shaped to execute emotional and attention exchange with ASD children [10]. It is capable of aiding and encouraging them to perform interpersonal communication in a playful way and relaxed mood, stimulating children's social interactions with robots, peers, and caretakers [10], [11].

Some mobile robots have also been used in the interaction with ASD children, since they can be very interesting and attractive for them. An instance is Jumbo, an elephant robot, programmed to move toward the child and to stop at a distance from them. It moves head and trunk and has pictograms, used as a game [12]. Another robot is Roball, a spherical robot that

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navigates without getting stuck somewhere or falling. It has vocal messages and movements, like spinning, shaking or pushing [13]. Another example is Bobus, a mobile robot capable of detecting the presence of a child using pyroelectric sensors. It moves slowly closer to the child and plays music. During the interaction with ASD children, it is able to display light through LEDs and a small ventilator, coupled together in its body [12].

C. MARIA

Mobile Autonomous Robot for Interaction with Autistics – MARIA is a previous anthropomorphic robot built at Federal University of Espirito Santo (UFES) to interact with ASD children, in order to stimulate social abilities, such as eye gaze, physical contact (touches), imitation and engagement with other humans [14]. This robot is equipped with a monitor and two speakers (that send images and sounds to attract the child's attention), a laser sensor (that detects the child's location), an onboard computer (that performs rules for interaction with the child), and a video camera (that captures images from her/his face). Moreover, it is 1.35 meters tall, composed of many colors and square shapes and its mobile activity is performed by a PIONEER 3 DX robot with three wheels (two driven wheels and a free wheel). Fig. 1 shows the robot MARIA.

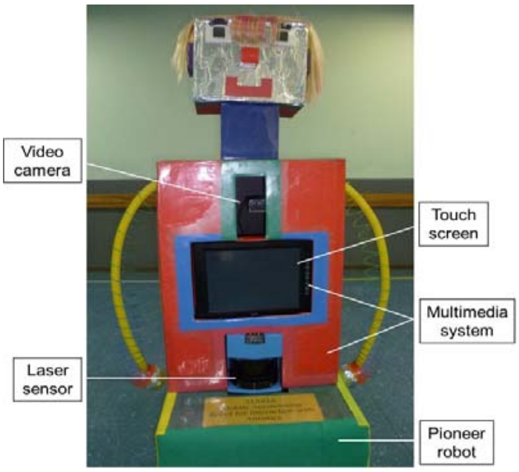

Fig. 1 Previous version of robot MARIA

Evaluating this prototype during the interaction with ASD children, we realized that the robot's colors, shapes and its humanoid features pleased and aroused the curiosity of children. Besides, the robot's ability of moving attracted the children's attention, increasing the child-robot interaction. This is probably relative to the fact ASD children are more attracted towards moving stuffs, choosing to play with interactive and robotic toys instead of passive toys [8]. However, the major limitation of MARIA is the lack of a fully autonomous movement, which would allow a wide interaction with children.

The aforementioned analysis corroborated to the development of a new robotic platform called New(N)-MARIA, a new playful and ludic robot, composed of the mobile robot Pioneer 3 DX and a 360° 2D Laser Scanner RPLidar coupled to an opening into the N-Maria structure in order to identify the child's position. Such devices are used to ensure the autonomous movement of N-MARIA as well as the interaction with ASD children. Then, the goal of this work is to introduce the new robot and its control system.

The following sections describe the strategies of control to autonomous locomotion that is used in the robot, as well as the algorithm that finds the child's location and the robot workspace. A procedure to evaluate the control and the results are also presented.

II. METHODS

A. Programming Environment

The programming language used for the control system implementation is C++ together with the ARIA library (Advanced Robot Interface for Applications), provided by Mobile Robots and SDK (software development kit) developed by Robopeak. The ARIA library allows the dynamic control of velocity, relative orientation and others parameters of movement of the robot, using high-level functions to access its internal and external sensors. Information about RPLidar sensor is acquired using SDK with some necessary modifications. The SDK main window is shown in Fig. 2 [15].

B. Odometer

This work involves a simple structuration of the test environment. For this, a free area is delimitated to robot works, named Workspace (Fig. 3). The robot should start at the center of the workspace heading in one of the axis directions. This workspace is an imaginary square whose limit is determined by odometry, ensuring the robot will not exceed the square boundary.

The information measured by the RPLidar and the robot position are processed to ignore people or objects out of the workspace. In Fig. 3, the robot is closer to the therapist than to the child, but the robot only interacts with the child because the therapist is not inside the workspace. This action is valid regardless the robot position. It is important to note that the environment is free of objects or obstacles.

The RPLidar measures distances up to 6 meters and scans about 360° around the robot. In order to ensure the detection of the child by the robot at any point of the workspace, we must consider that the diagonal of the square does not exceed 6 meters (1) (greater than the distance provided by RPLidar) (Fig. 4).

$$max \leq d \;\; for \;\; d = 6m \tag{1}$$

C. Controller

Any movement made by the robot should only occur after the detection of the child. So far, we are only considering a child into workspace of the robot, being obtained only her/his pose (position and orientation) by the RPLidar and enabling the approach by the robot.

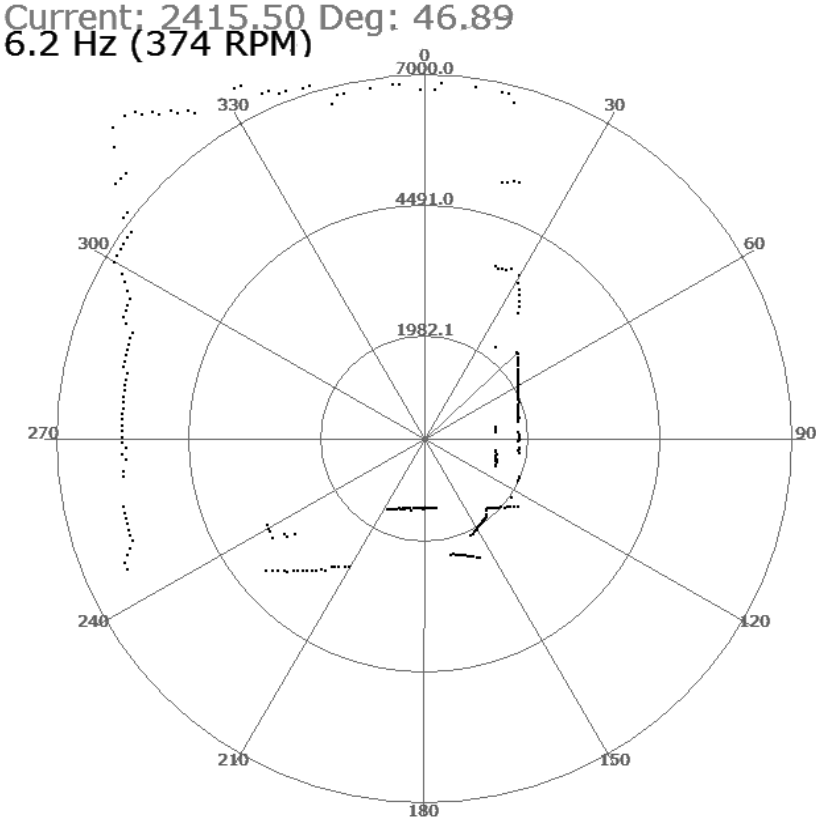
Current: 2415.50 Deg: 46.89
6.2 Hz (374 RPM)

Fig. 2 Main window of RPLidar, showing measurements from 360°

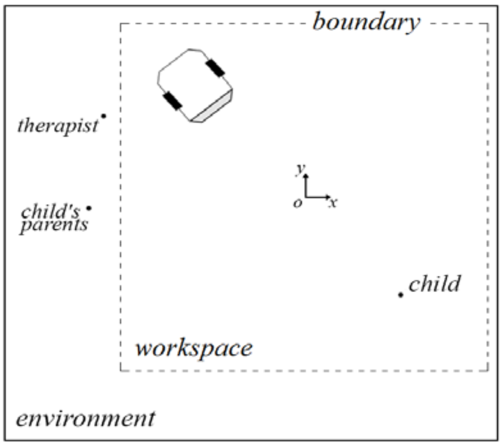

Fig. 3 Robot interaction workspace

The next step of this work is to make possible to distinguish a child from an adult, so preventing the robot from executing unnecessary movements, as the child's first contact with the robot is normally accompanied by a therapist or even their parents. This way, the N-MARIA will be able to interact only with children.

Once the robot has established where the child is located, and considering the control action defined by [16], given by (2), where the orientation and the position are adjusted jointly (Fig. 5), the robot moves towards the child in a shorter period in a position control performed after the orientation control (ungrouped control). On the other hand, if the robot does not need to move toward the child, the usage of an ungrouped control allows the robot to gain time in the trajectory as well as greater energy autonomy, when compared to the control proposed by [16].

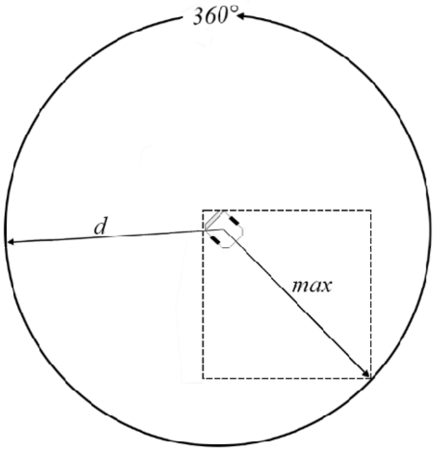

Fig. 4 Limitation of RPLidar 360° scanner and square diagonal of workspace

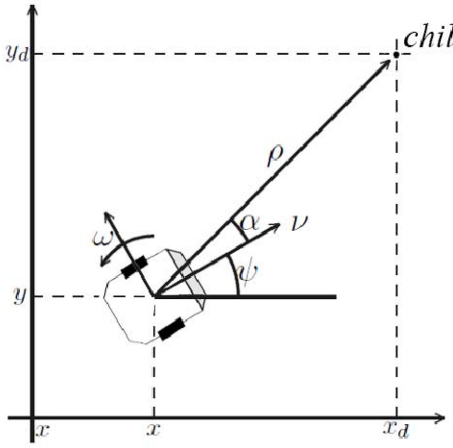

Fig. 5 Coordinates system for final position controller

$$\nu = \nu_{\max}\tanh\rho\cos\alpha$$
$$\omega = k\omega\alpha + \nu_{\max}\frac{\tanh\rho}{\rho}\sin\alpha\cos\alpha \qquad (2)$$

where ν is linear velocity; $\nu_{\max}$ is the maximum linear velocity; ρ is distance between robot and child; α is angle between robot orientation and child; ω is angular velocity; k is controller gain.

1. Orientation Controller

After the detection of the child by the RPLidar, the error between the robot's orientation (ψ) and the child's position is calculated and defined by the angle α (Fig. 5). The control action (3), proposed by [17], acts only on the robot's orientation correcting the orientation error; thus, that action corrects the angular error α positioning the robot in front of child.

$$\omega = \omega_{\max}\tanh\tilde{\psi} \text{ for } \tilde{\psi} = \psi_d - \psi \text{ , } \psi = \psi_d \to t = \infty \qquad (3)$$

where $\omega_{\max}$ is the maximum angular velocity; $\tilde{\psi}$ is orientation error.

Applying (3) in the Lyapunov candidate function (4), it is possible to verify that the system is asymptotically stable, since the candidate function (4) is definite positive and its derivate function is negative definite (5).

$$V(\tilde{\psi}) = \frac{\tilde{\psi}^2}{2} \qquad (4)$$

$$\dot{V}(\tilde{\psi}) = -\omega_{\max}\tilde{\psi}\tanh\tilde{\psi} < 0 \text{ for } \omega_{\max} > 0 \qquad (5)$$

2. Position Controller

In case the child detected, the position controller is started. This controller is governed by the control action (2) modified[1], given by (6), where the parameter ρ is the distance measured by the RPLidar. Besides, a limit distance of 35 cm was determined so that the robot stops in relation to the child, ensuring safety and allowing that other forms of interaction and analyses occur.

$$\nu = \nu_{\max}\tanh\rho \qquad (6)$$

Applying (6) in the candidate function of Lyapunov (7), we notice that the system is asymptotically stable, as shown by (7) and (8).

$$V(\rho) = \frac{\rho^2}{2} \qquad (7)$$

$$\dot{V}(\rho) = -\nu_{\max}\rho\tanh\rho < 0 \text{ for } \nu_{\max} > 0 \qquad (8)$$

D. Procedure

The test-structure is composed of the robot MARIA without the ludic shape and with the RPLidar sensor, as shown in Fig. 6.

Firstly, a workspace of 1.5 m x 1.5 m for the experiment with the robot was delimitated. Thus, the robot could identify the child just inside this bounded area, as well as interact with her/him. Subsequently, specific points were marked on the workspace for the child's location (highlighted by letters). These points define the path of the child that will be followed by the robot, as shown in Fig. 7.

Fig. 6 Mobile robot (Pioneer 3DX) and RPLIDAR (black disc on top) as part of the N-MARIA structure

A volunteer participated of this pilot test, initially stopped at the start position "a", displacing to the positions "b", "c" and "d" (Fig. 7). The RPLidar identified the volunteer's position, and the robot moved towards her, and stopped at a distance of about 35 cm, then the volunteer moved to next position while the robot waited for the volunteer stop. It is noticeable that when the robot perceived movement that it stopped and waited to move safely.

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[1] In (2), the angle α refers to the error between the robot's orientation and the child's position. Since the position controller only acts after the orientation controller, the angle α can be considered zero, what implies in $\cos\alpha = 1$.

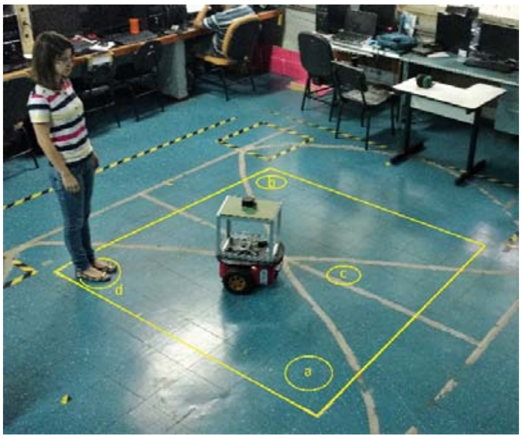

Fig. 7 Robot moving from point "c" to the goal (point "d") during the pilot test

III. RESULTS AND DISCUSSION

This work introduced the robot N-MARIA, which has an RPLidar device that enables detection of 360° samples. Thus, despite of the child is behind of the robot, the RPLidar is able to detect her/him, turn and move towards her/him, up to a safe distance from her/him.

The path performed by the robot was recorded by odometry after, moving through the positions 1, 2, 3, 4 and 5, as shown in Fig. 8.

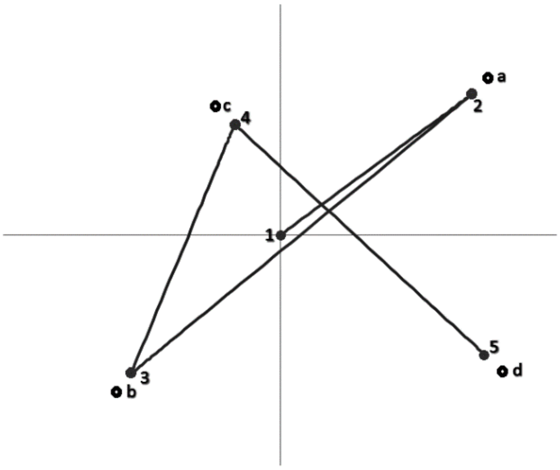

Fig. 8 Path followed by the robot, moving through the locations 1, 2, 3, 4 and 5

The locations a, b, c and d correspond to the child's locations, and the robot should stop at 35 cm in front of her/him. The error measured between the locations where the robot should supposedly stop (theoretical position) and where it actually stopped (real position) is shown in Fig. 9.

Taking into account the distances of each path performed by the robot, the average error was 1.5% and the greatest error was not more than 2.5%. Thinking about the application proposed in this work, this error should not affect the right robot operation, since it can be insignificant. As it can be seen in Fig. 9, the error at location b is almost zero.

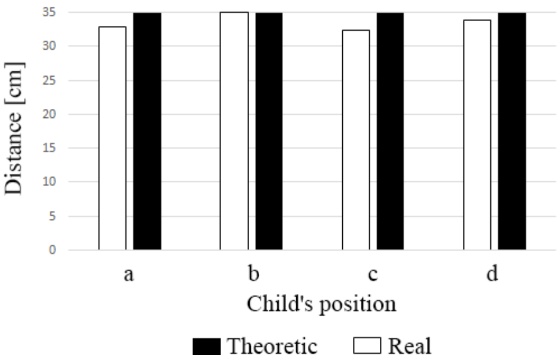

Fig. 9 Final position error

IV. CONCLUSIONS

In the literature, experimental tests demonstrated that children with ASD are interested by the movements of robots, enjoying interacting with them. The movement enables a more attractive interaction, being interesting as a potential therapeutic tool to an additional intervention on the rehabilitation process, as well as, on the development of necessary social skills of children [12].

The control system here proposed was satisfactory, since the laser sensor allows the identification of the child's location in 360° and a safe movement performed by the mobile robot, featured by a well defined path and an error close to zero.

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