Assistive robotics as therapy for autistic children

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Assistive robotics as therapy for autistic children

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***Abstract*—Assistive technology encompasses in its domain all rehabilitative tech, be it software or hardware, that works on improving quality of life for physically and mentally disabled people. Unlike creating assistive devices for people with physical disabilities, developing treatments for people with cognitive impairments is a very difficult task, due to the fact that cognitive disorders manifest differently from one group of people to another. One such specific group are children with Autism Spectrum Disorder (ASD). ASD is a condition that affects normal socio-emotional development in early childhood and causes difficulties with learning. One kind of treatment that has proven itself as particularly effective for young autistic children is robot-assisted therapy (RAT), which involves a robotic element – this can be robotic toys, robotic platforms, humanoid robots – with the purpose of making the learning process easier for these children. This paper elaborates on several different approaches for implementing robots in autism therapy, gives an overview on several RAT studies done in the world, and presents our work done in implementing a NAO humanoid robot in a research experiment with children on the autism spectrum.**

Keywords*—autism spectrum disorder, human-robot interaction, NAO humanoid robot, robot-assisted therapy, assistive robotics

I. Introduction

Autism represents a lifelong developmental disorder that manifests itself with a whole spectrum of cognitive impairments and a wide range of symptoms [1][2]. While it is not possible to create a generalized model containing an exact list of symptoms that would fit every autistic person in the world, there are some common indicators that apply for the majority of people diagnosed with this disorder.

Individuals who fall on the autism spectrum have an impaired way of perceiving the world, which means they sense, hear and see everything around them differently. They perceive other people differently due to their lessened or non-existent social skills, they sometimes develop certain repetitive actions and rituals, and they can be prone to some learning difficulties, particularly in early childhood.

This is not to say that an ASD diagnosis will automatically imply an intellectual disability (ID) diagnosis as well. Apart from their impaired social abilities, autistic people can still (on almost the same levels as neurotypical people) learn new skills, engage in hobbies, and they often show talents for mathematics, music, natural sciences, programming, etc.

What neurotypical people (parents and teachers in particular) perceive as difficulty with learning does not fall in the purview of ID, but stems from a different source. Autistic children owe their impaired learning skills not to a stunted intellect, but to the lack of well-developed socio-emotional abilities, which has negative effect on their behavior in the classroom by making it difficult for the autistic person to fit in with the rest of their peers and learn new skills [2].

The struggle to interpret and give social cues in casual, everyday interaction leads to the inability to handle one's own feelings as well as react to other people's emotions, and only increases the development of defensive rituals and repetitive behaviors as well. If we are undertaking a study to help autistic children with their learning issues, it is of great importance to firstly comprehend fully all possible symptoms children with ASD might demonstrate, as well as understand how they develop into learning problems.

The standard reference for diagnosis for years back has been DSM-5 criteria [3] for early autism diagnosis. DSM-5 categorizes the symptoms into two main groups:

A. Deficits in communication and social interaction:
   - A1. Deficits in socio-emotional reciprocity
   - A2. Deficits in non-verbal communication
   - A3. Deficits in forming and maintaining relationships

B. Occurrence of restricted, repetitive actions, interests and behaviors
   - B1. Stereotyped, repetitive speech, motor movements and/or use of objects
   - B2. Excessive adherence to routines and rituals as well as resistance to changes
   - B3. Highly restricted, fixated interests, abnormal in intensity or focus
   - B4. Hyper or hypo-reactivity to sensory input

Going by these criteria, defectologists have identified the following types of learning problems [1]:

- difficulties in paying attention to relevant cues and information, issues with attention span
- inability to properly express oneself via language
- difficulties with comprehending abstract thoughts and concepts
- social cognition impairment, inability to share and understand emotions, difficulties with imitation
- issues with planning, organizing and solving problems

Although seeming unconnected, these categories have an intertwined development in young autistic children. By being unable to process social cues from their peers and interact with them, autistic children find it difficult to express themselves properly, which in turn stunts the normal speech development. On the other hand, by having issues comprehending abstract thoughts and concepts, the autistic child might lose their attention in class quicker, and will have difficulties learning how to organize their time and develop problem-solving skills.

To make the learning process easier for autistic children, the teacher needs to present them with a minimal amount of information apart from the study materials, while at the same time strive to keep their attention. If the amount of sensory and social cues the autistic children receive – facial expressions, voice pitch and inflection, constant gesticulations, etc. – is kept to a minimum, the children will be able to absorb the study material with little difficulty.

Failing to achieve this successfully with human teachers only, pediatricians and defectologists have been teaming up with roboticists since the late 1990s, in an attempt to try and develop some form of assistive technology for autism therapy that will include robots as an outlet presenting the needed minimal amount of information.

II. Related work in robot-assisted autism therapy

The idea behind using robots as assistive technology for this kind of therapy is easy to follow – regardless whether in the use of toys or substitute teachers, robots present children with a far lesser amount of sensory and social cues, while at the same time being safe, friendly, non-threatening objects from which autistic children can benefit greatly while playing or learning [4][5].

Nowadays, the focus is on providing a suitable substitute for a teacher in the form of a humanoid robot, with the goal of making the learning process easier for the children. However, the earlier goals of the roboticists and defectologists were much simpler – simply eliciting a positive reaction to a robotic toy or platform was counted as something important, since it showed that the autistic children could cope with having a new presence and could respond to some commands from it.

The earlier work done with robotic assistive technology included some forms of mobile robotic toys, which tried to engage the children's interest while attempting to teach it something as well. The AuRoRA study [6] was the first notable example from this era, and it represented an effort to move away from the former unsuccessful attempts to include a robotic element in autism therapy, which were software-based and didn't succeed in keeping the children's attention [7]. The AuRoRA study included robotic platforms and dolls like Labo-1 [6] and Robota [8][9] which focused on involving the children in some low-level imitation games.

Other notable study from these early years is Sherbrooke's mobile robotic toys study [10] which used four types of robotic toys, each one engaging the children by some specific way of interaction – encouraging the child to follow a command from the robot, engaging the child in a physical play, starting an imitation game or assembling procedure, etc.

The success of these experiments was clearly noted as the children felt safe and comfortable, and after being in the toys' vicinity for a while they didn't even mind the presence of other people in the room. However, the limited number of actions provided by the robotic toys coupled with the lack of proper learning modules signified the need for more sophisticated robotic platforms for therapy. Since the early experiments with robotic dolls proved that autistic children feel at ease with humanoid robots, the next phase of assistive robotics was clear.

The more recent work in RAT deals almost exclusively with humanoid robots, something which was made even easier with their release for commercial use from 2010 onward. The wider choice of robots coupled with the availability of hardware for constructing one's own robotics platforms give roboticists and defectologists greater liberty when planning a RAT study. These opportunities provided for the development of many kinds of humanoid-based RAT.

There are several notable humanoid robots that are still used for therapy and that have marked great success – NAO, Kaspar, Troy, the Lego Mindstorm robots. The unique details in these studies are mostly the different approaches used, as well as the ending goals of the researchers. Several such opposites are:

- implementing a robot as a substitute teacher [11,12] **vs.** using the robot as a reward for successfully learning something with a human teacher [13]
- compiling sets of different exercises targeting several areas [11,12][14] **vs**. engaging in a continuous turn-taking imitation games [15,16]
- taking a generalized approach where the robot (either by itself or operated by a human) follows a strict set of modules without modifications [13][16] **vs.** taking the modular, individualized approach where the robot's actions are tailored to fit each of the children's specific needs [15][17]

Each of the approaches above come with their own merits and disadvantages, but ultimately the choice depends on the targeted learning difficulties and the vision of the defectologists. However, if there are no specific issues we wish to target, but rather the goal is to improve the learning and communication skills in general, there are several points that are important.

First, the robot should be used as a substitute teacher so that the child gets a feeling of consistency in the lessons, like in the studies in [11] and [12]. The other important thing is not to have a fixed set of exercises that will be performed without any changes, since every lesson should be adjusted according to the particular needs of the children. This modular approach is observed in [11], [15] and [17].

Approaching the RAT studies with these points taken is important for one other reason that sometimes goes unmentioned. Even for a trained human professional who's had years of medical expertise it can sometimes be very difficult to correctly anticipate the child's reaction to something or to adjust the learning modules. This makes it almost impossible to fully predict the children's reactions all beforehand and program a fixed set of exercises, which only goes to show the need for taking a modular approach and also having someone present who could monitor the robot and adjust the exercises.

III. Target group

Before starting to elaborate on our target group, an important point has to be made here. While researching related studies done with RAT we observed fairly quickly a drastic difference between the number of participants some of the abovementioned projects had, and the size of our own target group. Whereas we struggled to gather eight children (two of which did not continue with the classes), some of the projects had as much as 30-40 participants.

This gap is owed largely to the structure of our society, where even in this day and age there is still a social stigma present against disabled people. This discrimination extends to physical disabilities as well, but not as starkly as is it relating to mental disorders. In our non-inclusive society it's a challenge to organize projects that would work on helping autistic people, since due to people being stigmatized and uneducated on issues like these, autism in early childhood often goes unreported or unrecognized.

Another point here is the ratio of boys to girls that get diagnosed with autism. What almost every study on autism has noted is that boys outnumber girls from 2:1 to sometimes 9:1, depending on the age and the country of the study [18]. This, however, is not so much due to biological differences as it is due to social expectations. Early autism diagnosis symptoms are historically modeled after the way autism presents in boys and men. Autism in girls is harder to diagnose with these symptoms since girls are naturally encouraged to be more perceptive of the feelings of others and learn how to imitate other people and how to participate in social interaction regardless of whether they feel at ease with it or not. This is another point in criticism of the way society stigmatizes autistic individuals.

Of crucial importance to our study was the team of defectologists who helped us with our target group. The selection of candidates for this project was coordinated with the center for assistive technology in Skopje "Open the Windows". These were children who already had regular therapy classes at the center, and every single child had a defectologist responsible for it who monitored the classes and helped us with the needed modifications to the modules.

The initial target group for the experiment was eight young children on the autism spectrum, aged between seven and eleven years old, of which one was female and seven were males (falling neatly into the abovementioned ratios). Additionally, four of the subjects were without developed speech, and one was diagnosed with cerebral palsy (CP) as well.

While all of the subjects involved had had regular therapy lessons in the OtW center before, none of them had any previous contact with robots, be it in the form of humanoids, simpler robotic toys or platforms. Since one of the main symptoms present in autistic children is the aversion and fear of change, this was something we paid special attention to.

For this reason, the first meeting class for each of the children with the robot went under heightened supervision, and in the presence of the responsible defectologist and one or both of the parents. The parents' presence was of great importance on the off-chance that any of the children became greatly disturbed by the first interaction with the robot and was in need of calming down from familiar people.

IV. Our implementation

A. *Goals for the target group*

From the initial target group of eight children, six passed the preliminary meetings with the robot and continued with further classes in the experimental setting. These were the children who could interact with the robot without demonstrating difficulties with language barriers or without having an extreme level of fear and discomfort.

The goals for this narrower target group were defined with the defectologists that were responsible for the children. As we observed in section II, opting for a completely generalized, autonomous approach when working in therapy with this particular target group often yields unsatisfactory results. Autistic children are a challenging target group precisely because each child has unique needs and specific shortcomings. Because of this, we opted out for using the modular approach here, and tailored the classes individually according to each of the children's particularities.

As we explained above, the modular approach entailed beginning with a starting set of exercises that would follow the goals of improving social and learning abilities, but would then be adjusted for each child. The frequency of the modifications to the modules depended greatly on the severity of the child's reaction to the robot – a few of them required constant monitoring and modifications, while for some children just a slight change or removal of a module was made at the beginning and then the child was left on its own to interact with the robot.

B. *Technology*

Deciding on using a humanoid robot as the best one to motivate development of social skills for autistic children, we selected the NAO humanoid robot. NAO has already been proven to be a robot suitable for autism therapy [19], fulfilling all the requirements for autism therapy robot – having a compact, sturdy, robust body; being the size, shape and having the approximate movements of a human toddler; having a clean design with plain colors with emphasis on the head and hands; as well as being the right balance between being too mechanic and too human-like, thus presenting an engaging humanoid platform.

Since we were following the modular approach and we didn't need a higher level of AI programmed for the NAO, the modules were all programmed in Choreographe, Aldebaran's program for NAO. In order to implement NAO's speech commands in Macedonian, we used human recorded voice which we later modified in Audacity to provide it with a robotic tinge so it sounds more authentic and interesting for the children. A sidenote here – in the first class with the children we used regular, unmodified human voice in NAO, and when compared to the later robotic voice, we noted a significant raise of interest in the children for whom the robotic voice was much more engaging.

In accordance with our approach, greater focus was put on the adjustability and flexibility of the modules, so the amount of sensor information processed from NAO was kept to a minimum. The only input data being read was from NAO's tactile sensors on the top of its head.

C. *Experimental setting*

To minimize the amount of new information presented to the children (apart from NAO itself), we decided on holding the classes in the center where the children had their standard rehabilitative classes. Each child had the exercises in their usual room, accompanied by their defectologist, and at the beginning by one or both parents as well, with the goal of providing the children with a familiar and safe environment, and to downplay the possibly frightening effect of the new classes with NAO.

Since tactile contact plays a great role for autistic children when communicating, NAO had to be in a stable position so as not to risk any damage being done to the hardware or the children getting startled if the robot suddenly fell over or was pushed. NAO was seated on top of the table in the room, facing the humans, and the child sat on a chair or stood in front of NAO, with the rest of the people present standing behind the child. The classes spanned over eight weeks and took place during the standard timeslots for therapy the children had, taking up either the first or last 10-15 minutes from their normally scheduled classes.

In accordance with the learning and social difficulties the children had, we developed eight module targeting the general requirements set up by the defectologists. These modules consisted of exercises for improving communication and interactions skills, exercises concerned with the concepts of body awareness and possession, exercises for improving spatial awareness and orientation and exercises for improving the understanding of colors. The modules were designed so as to include all of the most important features needed for autism therapy – turn taking when interacting, imitation games, physical exercises, tactile elements, introducing new concepts via easily understandable commands, and focus on learning proper interaction protocols.

The other important thing (apart from including all the necessary features in the modules) was to keep the children relaxed and engaged, and we achieved that by the combination of equipping NAO with a friendly voice, making use of his eye LEDs to mark successfully completing a module, and implementing childish happy reactions as feedback.

V. RESULTS AND DISCUSSION

Giving a precise evaluation of the results in any project or study concerned with RAT is always a challenging task, as the results are more often of a qualitative instead of quantitative nature, and this is most evident in the studies and projects that focus on children with ASD. The factors considered for evaluating success were: the time each child took to perform the set of exercises and the amount of modifications of the modules during the entire experiment.

It's important to note that the full names of the children who participated in our study will be protected for ethical reasons, owing to the sensitive nature of this research. As the results are discussed below, each child will be referred to by his/hers initials.

Out of the initial eight subjects, two did not make it past the first introductory classes with NAO. T.N.'s main issue was the language obstacle, since he didn't speak Macedonian, and as such couldn't understand the commands NAO gave him. Even though we modified the exercises by either having NAO gesticulate more clearly, or by having his mother translate NAO's commands, it still wasn't enough to breach the language obstacle.

On the other side, I.A. had no problem with understanding NAO, but he wasn't able to overcome the initial fear he had from the robot. We attempted making some modifications in the four exercises that had the NAO perform pronounced movements, since that provoked greatest discomfort in I.A. Unfortunately, modifying or removing those modules still didn't change the effect NAO had on him, so he dropped out of the experiment as well.

For the rest of the participants a histogram of the times they took to perform the complete set of exercises during the first proper class with NAO and during their last are given in Fig. 1 and Fig. 2, respectively. The histogram bins represent intervals of time given in minutes expressing the abovementioned duration. A comparison of the times each child took to perform the set of exercises on the first and on the last class is shown on Fig. 3.

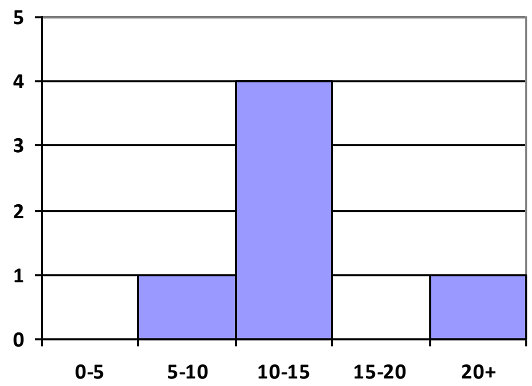

Fig. 1. First class with NAO, histogram of the children's performance evaluated in amount of time (in minutes) for exercise completion.

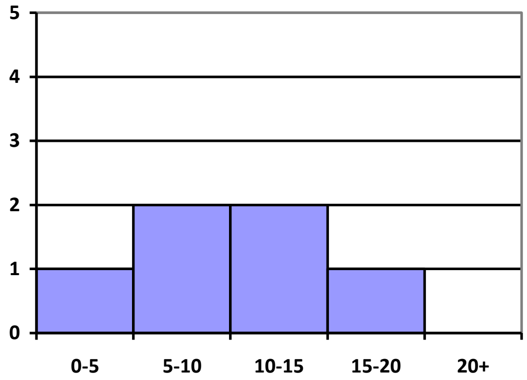

Fig. 2. Last class with NAO, histogram of the children's performance evaluated in amount of time (in minutes) for exercise completion.

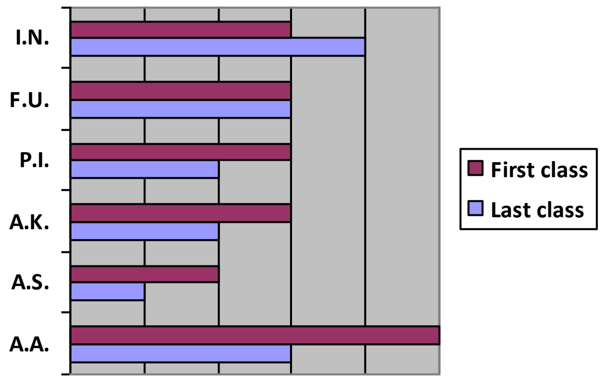

Fig. 3. Comparison of the first and last class performance for each child.

One positive outcome, which can be observed in Fig. 1 and Fig. 2, was the decreased time in the exercises duration on the last class compared to the time on the first class. On the first class most of the children needed 10-15 minutes to complete the exercise set, but on the last class one half of the children ended the exercises in less than 10 minutes. As it is observable from Fig. 3, with five out of the six children we noted a decrease in the time it took for them to finish the set of exercises. Beside decrease in time, another positive outcome was the children`s decreased fear from the robot and increased curiosity and drive for interaction.

An additional aspect of the experiment was the amount of modifications done to the exercises. With all of the six children, the modifications made to the exercises were less noticeable, and most of them were done directly on the spot (with one notable exception being A.K, who didn't need any modules changed).

A.A. required the most modifications on account of him having CP, so the three exercises focusing on body movements were partially altered (more precisely, A.A. had loss of mobility in his left arm, so the exercises which demanded arm movement were removed while the rest were left in).

With A.S. and P.I. there were only some minor alterations in simply lowering or increasing the number of repetitions per module respectively, as A.S. executed the exercises successfully on her first try, but with more repetitions got distracted by NAO's robotic voice and ignored the commands in favor of hearing NAO speak over and over again. On the other hand, P.I. was the exact opposite and could only focus on what NAO was telling him to do after several attempts.

Finally, F.U. and I.N. also finished the set of modules successfully with only some modifications required, but the disparity between that and their increasing set durations is owed to their changeable attitude to NAO – F.U. to the end didn't develop a genuine interest for the robot and as such wasn't motivated to play with it and do the modules faster, whereas I.N. was susceptible to very changeable moods – some days he was eager to do the exercises and others he didn't want to go anywhere near NAO.

VI. Conclusion

In this paper, our project is elaborated and the results obtained demonstrate the challenging process of working with autistic children. When embarking on an RAT project with this target group, it is very important to have a flexible view for the desired outcome. The unpredictable behaviors and mood swings characteristic for autistic children, coupled with the fact that we lack proper understanding about what is interesting for them and what might elicit fear or discomfort can present a real obstacle if we work with fixed goals.

However, that is not to say that projects and experimental studies of this kind should be neglected just because the target group can pose some challenges and difficulties. Even on a smaller-scale project of just eight weeks, our results still show that this kind of therapy can provide us with good results and indeed we observed that the children show progress in their learning.

The modular approach we used and the perseverance of every person involved in this project, participants and supervisors alike, resulted in a successful study. From the children that went on to receive the full span of the lessons, we had a 83% rate of success in terms of decreasing the time needed for completing the lessons, and we learned a lot about the issues of each child as well as how we can quickly adjust the exercises to their needs. This is what marked our experiment as a successful one, and what will hopefully motivate other researchers as well to partake in and further develop the area of assistive robotics, slowly leading up to eradicating the stigmatization in our society.

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