RoCA: A Humanoid Robotic Assistive Technology for Children with Autism

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\section*{ABSTRACT}
Current research suggests that autistic children are drawn to robots and are likely to benefit from robot mediated interventions. However, many autistic children from resource constrained environments have not benefited from robot enhanced therapy due to the high costs associated with the development and deployment of social robots. This paper presents the implementation of a novel low cost robotic assistive technology for children with autism to aid caregivers in their classroom activities. RoCA is a medium sized humanoid robot which has been equipped with motion, speech and interaction capabilities to encourage the children to learn through play.

\textbf{Keywords:} RoCA, autism, humanoid, Ghana, children.

\section*{1. INTRODUCTION}

Autism Spectrum Disorder is a complex disorder which causes communication delays, repetitive behaviours, sensory issues and social skills impairments in affected people [1]. Although there is no cure for autism, early interventions may be effective for some children and can lead to the improvement in their social and communication skills [2]. Research by Porayska-Pomsta et al. [3] and Goldsmith & LeBlan [4] indicate that children on the autism spectrum are easily drawn to technology because they are able to explore and use technology without risk of failure, judgement and ridicule [3][4]. Although technology plays a crucial role in autism therapy, the choice of intervention (for example phones, computers, robots) depends on factors such as level of expertise, cost, place of deployment and the characteristics of the children who would use the system. De la Cruz et al. [5] indicated that majority of the research on autism have focused on epidemiology and neuroscience with just quite a few targeting interventions for managing this disorder. This calls for an interdisciplinary approach to involve stakeholders from diverse fields in the design of technological interventions to ensure long-term effectiveness and acceptability [3].

\section*{2. LITERATURE REVIEW}

Developing technological interventions for autism therapy is not an easy task due to the multifaceted nature of the disorder. Technological interventions for autism often capitalize on the abilities and weaknesses of diagnosed children, and use them as a platform for introducing more challenging tasks. Bartolome & Zapirain [5] classified technological interventions for autism under four main divisions: virtual reality, dedicated applications, telehealth systems and robots. Virtual reality (VR), which refers to the use of computer graphics techniques to simulate the real world, has been identified as a potential tool in the therapy of children with autism [6]. According to Mitchell and Leonard [7], virtual environments (VE) could be suitable for autistic children because the user can control his or her level of participation and the VE can monitor a child’s mental state and behaviour in order customize the system to individual needs. Another category of technological systems in autism therapy are dedicated software applications. Most of these applications run on mobile phones, computers and personal digital assistants and aim at helping autistic children to improve their communication, social learning and imitation skills [5]. Lofland [8] indicates that mobile phones and computers can be useful tools in autism therapy because of their flexibility and portability. More so, individuals with autism may have difficulty with fine motor skills and as a result, writing by hand could be difficult. Therefore, using computers and mobile phones, they can easily express their thoughts by typing, hence reducing their frustrations in handwriting and drawing.

Often, children from low-income families, rural communities and ethnic minorities are at a higher risk of receiving late diagnosis for autism due to lack of
knowledge and trained personnel to manage the disorder [9]. Even in the urban areas, getting access to expert health care professionals in autism therapy could be difficult. In such instances, telehealth systems could come in handy to facilitate diagnosis and therapy for autism. Existing telehealth systems come in various designs and modes of operation such as a parent recording the activities of a child suspected to have autism and sending the video to a doctor for evaluation [10], systems for educating family members of autistic individuals [11][12][13] and real-time interaction between a medical practitioner and patient[13]. The use of telehealth in autism diagnosis and therapy has produced some successful results; however, it raises issues of concern such as diagnostic accuracy, cost effectiveness and evidence-based guidelines for telehealth applications [15]. The fourth category of technological interventions for autism therapy as identified by Bartolome & Zapirain [5] is robots. Past research indicates that robots promise to impact immensely in the therapeutic process, because autistic children easily familiarize and interact with robot companions than humans [16][18]. Robots can be used for repetitive tasks and can be programmed to behave in the same manner under the same set of conditions, making them good companions for autistic children who do not like sudden changes in their environment. Robots are being deployed as facilitators in teaching social communication, learning and imitation skills to autistic children [16][17][18][19]. Some robots which have been used in robot-mediated therapy for autistic children are Keepon[20] AIBO[21], Tito[22], PABI[23], KASPAR[24] and Nao[25]. A lot of these robots are still in the prototype phase of development and not available in the public domain. The few on the market, for example Nao and Milo cost $7,990 USD and $5,000 USD respectively [26]. For middle to low income countries, purchasing and deploying such robots for long term research and field use could be impractical due to the high associated costs. It is therefore not surprising that majority of the research on robot-enhanced therapy for autistic children have been undertaken in the Western World. In our research, we focused on investigating the potential applicability of robots in autism therapy in the African setting. The aim was to design and test a low cost humanoid robot for children with autism to aid in their therapy for the development and improvement of social abilities and communication skills.

3. ROBOT DEVELOPMENT PROCESS

RoCA has been developed by a team of researchers at the Department of Computer Science, Kwame Nkrumah University of Science and Technology in Ghana. The robot development process underwent diverse stages ranging from requirements elicitation, selection of appropriate software and hardware to the development process.

3.1 Requirements Elicitation

The two elicitation techniques utilized to gather the requirements for the design of robot were direct observations and interviews. The main author spent time at some autism centers in Ghana to familiarize herself with the children and their day-to-day activities. The visits also afforded the opportunity to observe the children and their teachers in their daily teaching sessions and to collect data which proved useful in the design and construction of the robot. Open-ended questions were presented to various stakeholders (teachers, psychologists, parents and other caregivers) in the autism centers during one-on-one interview sessions. The requirements elicitation phase ended with the establishment of formal requirements specifications for the social robot RoCA. Based on the accrued requirements, the structure of the robot was decided on as a naturalistic embodied humanoid because biologically inspired robots are usually appealing to humans and able to blend into the environment quite easily. Appropriate construction materials and software were then selected to serve as building blocks for the robot development and control.

3.2 Software Approach

The brain of RoCA is an EZ-B v4/2, EZ-B v4/2 is a wifi robot controller which can be manipulated via a computer or mobile phone. This robot controller is more powerful and faster than Arduino. With the EZ-B v4/2, most of the controlling programs reside on a computer instead of the microcontroller. Therefore, the robot can be programmed to execute complex tasks without much focus on storage limitations. EZ-B v4/2 has 3 PC ports, 3 UARTs, 24 multi-use servo/digital/serial ports and 8 analog ports. Two Integrated Development Environments (IDE), EZBuilder and Visual Studio 2017 were used as platforms to program the EZ-B v4/2 using Ez-Script and C#. The minimum system requirements needed to be able to install EZ-Builder are: Windows 8.1 minimum, Intel Pentium or AMD 64 or 32 Bit, 1.8 GHz CPU, 6 GB RAM and 200 MB free drive space.

3.3 Robot Design and Development

RoCA is a full body 1210mm tall humanoid robot running on two 32-bit ARM Cortex processors. It has been equipped with EZ-B v4/2 Wi-fi robot controller, 16V DC battery, loudspeakers, microphones, a wireless camera and customizable multicoloured LED lights to provide visual appeal to the children. The body of RoCA is made from polystyrene, a light weight, rigid but moldable
material with the ability to maintain stability. The physical structure of RoCA, which is easy to assemble and disassemble, is composed of a humanlike head, a neck, upper body with two arms and lower body containing wheels and continuous rotation servos at the base to drive the robot. Each arm of the robot consists of a shoulder with 1 degree of freedom (DoF). In consultations with experts, the robot has been designed to look simple in order to appeal to the children on the autism spectrum who could become overwhelmed with too many details and mechanical components. The development of RoCA has been a collaborative effort of the researchers and caregivers of children with autism; as a result, the robot is easy to use, program, assemble and disassemble. End users of this robot who are most likely to be non-IT inclined can control the robot when given adequate training. In conformance with standard autism therapy sessions, the robot provides rewards by saying “good job” when tasks are done correctly and also provides reinforcement when a child is not able to perform a task.

3.4 Features of RoCA

1. Communication and robot control: The robot has an integrated wifi and an embedded webservice which enables remote control via a computer or a mobile phone.
2. Movement: The robot is able to raise both left and right hands up and down as well as turn neck left, right, up and down. Degrees of freedom (DoF): Head – 2, left arm -1, right arm – 1.
3. Speech functionalities
   a. Voice output: The robot outputs sound with the aid of inbuilt speakers. Pre-recorded sounds can be played by the robot. The robot can output speech in real time when a person speaks directly into the microphone of the computer or the mobile phone being used to control the robot.
   b. Speech processing
      Through speech recognition functionality, the robot can be controlled by giving voice commands. Selected words or phrases picked up by the microphone can be analysed by the robot and the appropriate action(s) can be performed by the robot. RoCA can produce human voice through a speech synthesis module where words or phrases typed into the computer used to control the robot can be read out by the robot.
4. Colour detection: The robot is equipped with a camera that has been configured to detect multiple colours.
5. Video streaming and live capturing of events: The robot’s camera can record its environment and send live video streams over wifi to a remote computer.
6. Modes of control

The robot can be controlled in two modes: Autonomous and Wizard-of-Oz (WoZ). In the WoZ mode, the care giver of the child can manually operate the robot and control the various modalities such as sound, movement and lighting. The caregiver can also select the various lessons to be delivered by the robot, repeat lessons or stop lessons when necessary. When put in autonomous mode, the robot can perform a pre-specified script which can include a combination of modalities such as movement, music and academic lessons. The robot has been equipped with a SingleShot Emotion Detector (a deep learning model developed by the authors) which can predict the affective states of the children and decide on the appropriate activity to perform in order to sustain the interest of the children. In this mode, the robot always seeks the consent of the caregiver by means of a message prompt on the screen of the controlling interface before changing lessons.

3.5 Non-functional specifications

1. Appearance: The robot is visually appealing to the children. The colours, lights and materials used in building the robot are user-friendly.
2. Safety, Security and Usability: The software controlling the robot has been programmed to provide a safe and conducive environment for the children and their care givers. Also, authentication schemes are provided so that the robot can only be controlled by authorized persons. The interface for controlling the robot is easy to use.
3. Energy: The robot has been developed with electronic components which provide efficient use of power supply and generate very little heat.

3.6 Interaction scenarios specification

The choice of scenario media (text, images, videos or live interaction) could influence the responses of people towards robots [27]. Robots which enact scenarios familiar to people are likely to gain acceptance as compared to those which portray arbitrary behaviours. A user-centered approach was adopted to engage teachers of the autistic children in the co-creation of activities for child-robot interaction sessions. Scenarios presented by the robot have been streamlined to encompass activities from their academic lessons and their play sessions. Fig. 1, Fig. 2 and Fig 3 show the front, back and various motion capabilities of RoCA.
3.7 Software Interface for Robot Control

RoCA was programmed using two IDEs: Ez-Builder and Microsoft Visual Studio 2017 using the EZScript and C# programming languages respectively. The multi-tab custom interface for the robot which contains the motion, lessons, exercises, emotion detection and fuzzy inference engine modules were developed in C#. Fig 4 shows a screenshot of the custom robot control interface.
4. DISCUSSION

In the participatory design approach adopted in the robot development process, the stakeholders were actively involved in the requirement elicitation, design, identification of interaction scenarios and evaluation of the low cost robot. This approach addresses a gap in autism research where social robots have been designed and developed for the children instead of being co-designed with them. The contributions of the stakeholders gathered from the interviews and group discussions were influential in shaping the robot development process. For a domain like autism management, the choice of hardware and software for a technological system is very crucial due to the fact that some of the children are likely to exhibit very aggressive behaviours. The body of this prototype of RoCA was carved out of polystyrene foam because it is low cost and less fragile. RoCA already been used in a series of research activities involving some Ghanian autistic children and the results suggest that the robot appeals to the children and the children interact well with it. More longitudinal studies have to be conducted to investigate the effects of robot assisted teaching on long term gains and engagement levels of the children.

5. CONCLUSION

Many autistic children from resource constrained environments have not been able to benefit from robot mediated interventions which have proven to be quite effective in some countries. This paper presents RoCA, a low cost humanoid robotic assistive technology for children with autism. The robot is simple but provides various multimedia and academic interaction modules to engage the children. In future, extended trials would be conducted with Ghanaian children on the autism spectrum to ascertain the long-term benefits of robot mediated interventions.

REFERENCES


