Adapting a humanoid robot for use with children with profound and multiple disabilities

P J Standen[1], D J Brown[2], J Hedgecock[3], J Roscoe[4], M J Galvez Trigo[5], E Elgajiji[6]

[1,3,4]Division of Rehabilitation and Ageing, School of Medicine, University of Nottingham, Nottingham, UK

[2,5,6]Interactive Systems Research Group, School of Science & Technology, Nottingham Trent University, Nottingham, UK

p.standen@nottingham.ac.uk, david.brown@ntu.ac.uk, [3]*mzyjh1@nottingham.ac.uk,* [4]*mzyjr@nopttingham.ac.uk, msegtrigo@gmail.com, eelgajiji@umit.edu.ly*

[1]*www.nottingham.ac.uk,* [2]*www.ntu.ac.uk*

ABSTRACT

With all the developments in IT for people with disabilities, few interventions have been designed for people with profound and multiple disabilities as there is little incentive for companies to design and manufacture technology purely for a group of consumers without much buying power. A possible solution is therefore to identify mainstream technology that, with adaptation, could serve the purposes required by those with profound and multiple disabilities. Because of its ability to engage the attention of young children with autism, the role of a humanoid robot was investigated. After viewing a demonstration, teachers of pupils with profound and multiple disabilities described actions they wished the robot to make in order to help nominated pupils to achieve learning objectives. They proposed a much wider range of suggestions for using the robot than it could currently provide. Adaptations they required fell into two groups: either increasing the methods through which the robot could be controlled or increasing the range of behaviours that the robot emitted. These were met in a variety of ways but most would require a degree of programming expertise above that possessed by most schoolteachers.

1. INTRODUCTION

With all the developments in IT for people with disabilities, it is disappointing that few interventions have been designed for people with profound and multiple disabilities. A recent systematic review (Kagohara et al, 2013) on the use of iPods, iPod Touch and iPads in teaching programs for people with developmental disabilities noted an absence of studies on individuals with profound and multiple disabilities. Their explanation for this was that this group presents unique challenges with respect to the design of technology-based interventions, a major one being their lack of sufficient motor control to activate the device and software.

There have been some attempts to circumvent this problem of motor control. An extensive body of work by Lancioni (see for example Lancioni et al, 2008) has demonstrated there is a way for almost anyone to activate a microswitch. The most common way is to use a push switch, which is activated by applying pressure to a large button. However they can also be triggered by pressure sensors on the armrest of a wheelchair, by chin or eyelid movement (Lancioni et al, 2005) or by vocalisation (Lancioni et al, 2001). This then allows the user to exert environmental control, activate a piece of equipment which may produce speech on their behalf, or begin a pleasurable stimulus for the user such as playing a piece of music.

There have also been attempts to capture gesture or body movements using infrared sensor-based systems to enable those with multiple disabilities to control multimedia (Brooks, 2011). A more recent development that can allow a profoundly disabled person to interact with their environment has been enabled by the appearance of low cost headsets that enable gamers to interact with games using their own brain activity (Welton et al, in press). Although microswitches can be activated in relatively effortless ways, operating them may still be a challenge to someone with poor postural control and low muscle tone. One teacher in an earlier study (Hedgecock, 2013) commented that, for children with severe physical disabilities, even

maintaining their position requires considerable effort. If you are then asking them to learn a new response, an exceptionally attractive reward is going to be necessary.

There is little incentive for companies to design and manufacture technology purely for a group of consumers without much buying power and it has been argued that those with disabilities are reluctant to adopt technology that is designed specifically for them. Reasons for this include the stigma associated with assistive devices as they are believed to be a visible sign that emphasises the difference between them and others and the absence of abilities (Parette and Scherer, 2004). A possible solution is therefore to identify mainstream technology that, with adaptation, could serve the purposes required by those with profound and multiple disabilities. Studies with children with autism (e.g. Werry and Dautenhahn, 1999, Salter et al, 2008, Dautenhahn and Billard, 2002, Robins et al, 2005) found that robots possess qualities that would make them a promising candidate for employment with children with profound and multiple disabilities. Robins et al (2005) report that, unlike interactions with human beings, "interactions with robots can provide a simplified, safe, predictable and reliable environment where the complexity of interaction can be controlled and gradually increased" (p 108). In addition, Robins et al also found from behavioural observations that "children with autism directed significantly more eye gaze and attention towards the robot, supporting the hypothesis that the robot represents a salient object suitable for encouraging interaction".

This latter quality was echoed in an exploratory study (Ibrani, Allen, Brown, Sherkat, and Stewart, 2011) of eight children with either autism, Downs syndrome or severe learning disabilities working with a mobile robotic platform. Klein et al. (2011) showed that working with a robot increased "playfulness", and therefore engagement, in two out of the three young children with developmental disabilities in their study. They describe how engaging children in this way could encourage the development of functional skills. According to Iovannone *et al*. (2003) engagement is "the single best predictor" of learning for children with intellectual disabilities. Discussing children with complex needs, Carpenter (2011) writes that "Sustainable learning can occur only when there is meaningful engagement. The process of engagement is a journey which connects a child and their environment (including people, ideas, materials and concepts) to enable learning and achievement" (p35). For teachers of children with profound and multiple disabilities, achieving their engagement is a big challenge and they have to work hard to attract and maintain a child's attention before trying to teach something. The robot is eye-catching and attractive, novel, responsive, non-demanding, safe and predictable and, if the robot is doing the teaching, is the child's focus more likely to be where it needs to be in order for the learning to take place?

Two recent small scale studies (Hedgecock 2013, Roscoe 2014) investigated the suitability of a humanoid robot to support the learning of pupils with profound and multiple disabilities. Both studies found that engagement rated by teachers using the SSAT Engagement Scale (The Special Schools and Academies Trust, 2011) was significantly higher with the robot than in the classroom. At the beginning of both studies, teachers were asked to identify pupils they thought might benefit from working with the robot, learning objectives they thought the robot would help the pupil achieve and how the robot might help them do this. The teachers proposed many more possible uses for the robot than it could perform in order to provide personalised interventions for individual pupils. Therefore the aims of the current paper are to describe the uses the teachers identified for the robot and how the robot was adapted to enable it to fulfill these roles.

2. METHODS

2.1   Participants

Eleven members of teaching staff from a school in Nottingham with around 150 pupils with severe, profound or complex learning and/or physical disabilities nominated one or two pupils to work with. There were no exclusion criteria for the pupils other than parents not consenting. The 13 boys (age range 5 to 18 years) and 3 girls (age range 11 to 20 years) were some of those with the most complex needs. Most had minimal communication skills and little understanding of words relying on body language, signs and symbols or verbal cues and were described as having a short attention span and being easily distracted. Several had a diagnosis of cerebral palsy but most had delayed fine and gross motor development with low muscle strength, some being reliant on wheelchairs or walkers and some having involuntary movements. Sensory impairments were common, five had epilepsy and one was tube fed and suffering from recurrent chest and urinary tract infections.

2.2   The robot

The robot used in this project was a NAO NextGen (Model H25, Version 4) humanoid robot, which is commercially available from robotics manufacturer Aldebaran Robotics. NAO is manufactured with a wide

range of behaviours, including walking, standing up and sitting down, dancing, and recognising speech, sounds and objects as well as producing speech from text and playing sound files. These behaviours can all be programmed into the robot using Choregraphe, a user-friendly graphical interface that allows users to control the robot wirelessly from a laptop or desktop computer and create sequences of behaviours.

Fig 1 shows three of the sections of the control screen of Choregraphe with annotations labelling the various features. The central Flow Diagram Panel initially appears blank for the user to create a sequence of behaviours by dragging and dropping behaviours from the box library on the left. The behaviours that the robot comes with will appear in here. A Behaviour box represents a behaviour, or sequence of behaviours and double-clicking on the box reveals another flow diagram panel, of the smaller behaviours making up one single behaviour. For behaviours that the robot comes with, these will have been written by the manufacturer. However, new behaviours can be added to the robot's repertoire by creating new behaviour boxes grouping together a series of preprogrammed behaviours. Additionally, new behaviours can be written from scratch using computer programming languages recognised by NAO such as C, C++, Java, MATLAB, Urbi, .NET and Python. On the right hand side of the screen is the Robot View Panel which will show a real-time simulation of the behaviour currently being played.
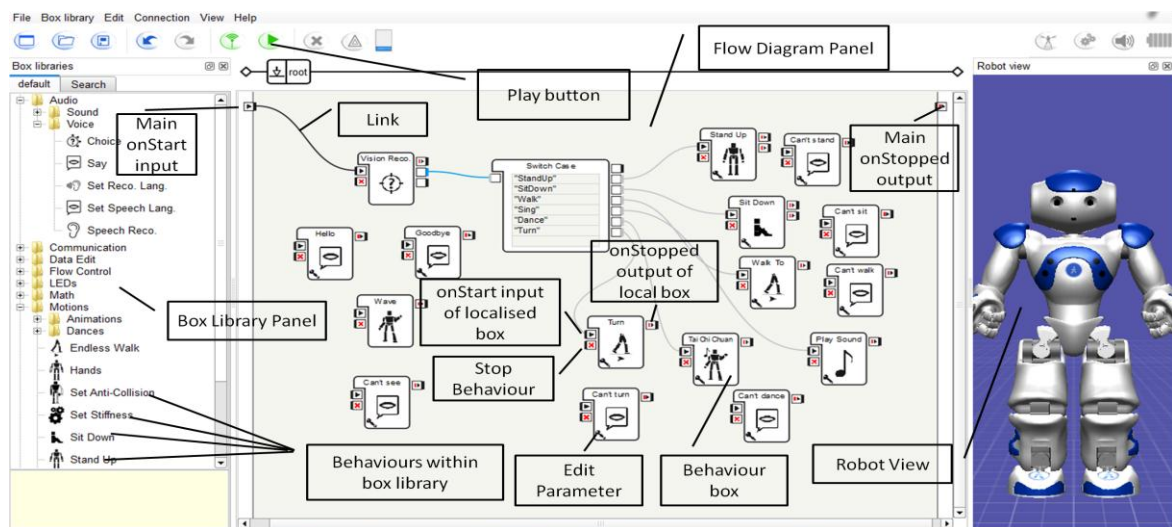
Figure 1. *Three of the sections of the control screen of Choregraphe. For explanation see text.*

2.3   Procedure

Teachers were recruited from those that attended a demonstration of the robot at the school given by the research team. In individual meetings with a member of the research team they identified one or two pupils whom they thought would benefit from working with the robot. Discussions were held with the teachers to devise an appropriate learning objective for the pupil to achieve in the sessions and how the robot might be used to achieve this. Some of the actions required were already available in the robot's repertoire but those that were not had to be created in other ways before the final format of the sessions could be individually designed for the pupils, focussing on their interests and learning style, to help them achieve their learning objective.

3. RESULTS

The results are in two parts: first of all a taxonomy of what the teachers wanted the robot to do and secondly how changes were programmed into the robot to enable it to fulfill these requests.

3.1   What did teachers want the robot to do?

3.1.1 To produce a behaviour that acted as a reinforcer. When working with this group of pupils teachers tend to use behaviourist techniques more than with other groups of pupils and their requests relied heavily on the concept of reinforcement ie behaviour which is reinforced tends to be repeated (i.e. strengthened); behaviour which is not reinforced tends to die out or be extinguished (i.e. weakened). Teachers identified reinforcers that could be provided by the robot which could broadly be grouped into two categories: behaviours that were appealing or enjoyable in their own right and would act as a reward for completing a goal, or behaviours that allowed the pupil to either achieve a learning objective. Although not primarily

intended as a reward, the pupils may still have found it rewarding to complete the activity with the help of the robot or feel empowered by the control which the robot allows them.

Behaviours that were appealing to the pupil or enjoyable in their own right. Examples of these were mostly dancing and playing music. When the pupil makes a response that the teacher requires, this reinforces the link between, at the simplest level, seeing a switch and pressing it, then pressing one with particular symbol. This was initially the case for pupil S2 who the teacher wanted to learn to press a microswitch to learn the association between cause and effect. The robot would reward with a song or dance, phrases like "Well done", "great job", "awesome" or the clapping/cheering app from the robot appstore http://www.robotappstore.com . This basic model could be elaborated on in the following ways:

- *shaping*: another goal for S2 was to make voice commands to control the robot (eg "stand", "sit") but initially the robot was programmed to respond not just to these commands but also to approximations of them (ie "stand up", "get up"). If her utterances were not clear enough, the robot was to respond in a rewarding or encouraging way but to indicate that this was not quite the way the utterance should be (eg "sorry I didn't hear you", "I am an old robot, you have to speak clearly").

- *providing cues*: Verbal utterances from the robot encouraged S7 to use only one hand to trigger the micro-switches

- *inhibiting a response:* For TN, the robot was meant to only respond if the switch were pressed once thus discouraging him from perseverating. For one pupil (S4) the robot was meant to remind him not to be violent as he had a tendency to react in this way.

- *offering choice:* Presenting the pupil with 2 or more switches, with each triggering a different stimulus was planned for teaching the making of choices. By pressing the switch, it was hoped that the pupil would learn that one switch (with a particular symbol or colour) would trigger a stimulus she preferred to the other. The pupil (ST) would then, hopefully, be able to consistently choose the switch triggering the stimulus she preferred, even when the switches were moved around.

Getting the robot to do something to achieve a learning objective. This reinforces the link between pupil action and robot action purely through contingency. However it has the additional benefits of facilitating learning through "action by proxy" rather than through abstract concepts (eg for TH to improve his sense of direction by learning the concepts of "forwards", "backwards", "left" and "right"). This also has the advantage of demonstrating spatial awareness without too much physical activity for someone who may have very limited opportunities for movement. A related example was where S8 learnt to use a joystick similar to that of his electric wheelchair by using it to direct the robot. A different type of learning objective that could be achieved with this application of the robot was exemplified by KW learning the meaning of symbols by showing them to the robot and seeing it respond appropriately. The next stage for KW was to recognise that there must be an order to some actions (e.g. the robot cannot dance when sitting down) and then to put together sequences of up to 4 events taking this into account. While these uses of a reinforcer are described as having no intrinsic reward and differentiated from the first group, it is highly likely that, for someone who has little control over their environment, these behaviours are rewarding in addition to being instrumental in achieving a learning objective.

3.1.2 Robot gives commands. For several of the pupils their learning objectives were either purely to follow commands (eg the robot asked S6 to pick up, throw and pass ball) but could be to help in communication skills (eg ST to repeat what the robot says, thus learning turn taking, see Fig. 2). Similarly, the robot could demonstrate one of S5's physiotherapy exercises encouraging her to touch her ear with her hand prior to pressing the micro-switches. While a human could issue all of these commands, teachers felt that the engaging and consistent nature of the robot might provide a stronger stimulus.

3.2   How to get the robot to fulfil these roles?

3.2.1 Analysing the requirements highlighted that the first problems was enabling the pupil to control the robot. Four of the robot's channels were investigated for their potential route of control:

- Visual recognition. The learning objective for KW (described above) was to learn the meaning of symbols by showing them to the robot and seeing it respond appropriately. For pupils in wheelchairs it was problematic to position the robot and pupil where the robot could see the symbol being presented.

- Auditory recognition. This was utilised with for example, S1 where the teacher's goal was to improve verbal communication. However, the auditory recognition was not advanced enough to consistently recognise the pupil's voices or the auditory output from a hand held computer used by one of the pupils to vocalise words. In these cases the researcher had to resort to using the Wizard of Oz technique.

- Tactile and pressure sensors. The robot has nine tactile and eight pressure sensors at different sites and can be programmed to respond when these are stimulated. However, either pupils were unable to reach these (for example if they were in a wheelchair) or the teacher thought that the pupil's motor control would not enable them to touch the robot with the right level of force.
- Wireless control was already there via the computer but this was only suitable for the researcher or teacher to control the robot. If not using visual or auditory communication, pupils needed a more user friendly way to control the robot. For TH, who was independently mobile, his learning objective was to gain an appreciation of left and right by correctly steering the robot from a start point to an end point. A simple solution was achieved using a smartphone's (Samsung Galaxy Note II) accelerometer as a steering wheel enabled by an app for the phone, and a server for the computer, available from http://www.robotappstore.com.

Figure 2. *ST repeating back to the robot the utterance it has just emitted.*

The majority of pupils were already switch users or their teacher wished them to acquire this skill. One (S8) wanted to learn to use a joystick so that he could control his electric wheelchair with a joystick. In order to allow a switch or joystick to control the robot, Pygame, a cross platform set of Python modules designed for writing video games was used. Pygame is built over a library that allows the use of a high-level programming language like Python in order to structure a program that could be used with several input devices. Next, a piece of Python code was written to produce a virtual server that could act as a bridge between the robot and any input device the pupil required such as Jellybean switches or a joystick. In this way, executing the program corresponding to the server and running the appropriate behaviour in Choregraphe it was possible to control the robot wirelessly with different input devices.

3.2.2 How to get the robot to produce the responses the teacher required.

- Some responses were programmed in already (eg a tai chi dance, the text to speech function which could provide encouragement or cues such as "well done"; "I can't walk when I'm sitting down. I need to stand up first".)
- Some routines were freely available for download from the internet (eg Gangnam Style was downloaded free from youtube and the Macarena dance downloaded free from http://www.robotappstore.com).
- A pupil's favourite piece of music could be found on youtube and made into an audio only file with YouTube converter (http://www.youtube-mp3.org/). Then using an online tool for creating personalised ringtones allowed the song to be cut into the right length making sure that the track starts and ends at an appropriate time. Explicit lyrics were also cut out at this stage!
- More complex behaviours such as kicking a football, were first of all broken down into components and either created from box behaviours already available for the robot or script was written in Python and then included as a box behaviour in Choregraphe.

4. DISCUSSION

When the teachers attended the demonstration of the robot, although a wide range of possibilities were demonstrated, they produced an even wider range of suggestions for using the robot than it could currently provide. The actions they required the robot to make could conveniently be described in behaviourist terms ie

the robot would provide reinforcement. However, the wider role they required the robot to take can be seen in terms of the social approach to learning advocated by Wood et al (1976) and also Vygotsky (1987). For young children Vygotsky emphasised the importance of a more experienced adult to mediate their attempts to learn something new. Wood et al used the term "scaffolding" to describe the support given to the less experienced learner and the idea of a scaffold underlines the importance of something temporary that can be removed once learning has taken place. More recently Feuerstein (2006) coined the term "Mediated Learning Experience" to refer to the way in which stimuli experienced in the environment are transformed by a mediating agent, usually a parent, teacher, sibling, or other intentioned person in the life of the learner. Seen this way, the robot is taking on the role of the agent of the experienced person. It has to be emphasised that this role is only possible because of the ability of the robot to engage the pupils (Hedgecock, 2013, Roscoe, 2014), as without engagement there is no opportunity to expose the pupil to the link between their actions and that of the robot.

While initial studies have shown it to be engaging, if schools are going to invest in such an expensive piece of equipment they need to know it has the flexibility to support a wide range of their teaching requirements. Adaptations they required fell into two groups: either increasing the methods through which the robot could be controlled or increasing the range of behaviours that the robot emitted.

In terms of methods through which the robot could be controlled, currently the auditory recognition is not sophisticated enough to be used to meet the learning objectives identified by the teachers. Visual capacity was appropriate for symbols if the pupils could be enabled to position the symbol in a way that the robot could pick up. For pupils in wheelchairs this was difficult unless the robot was on a table in front of them but then this restricted the space the robot had to operate in. The most successful adaptation was enabling the robot to be controlled by a switch. A specific solution to this was found but in order to allow the use of a range of control devices (eg tablet, X box, steering wheel) a more universal solution is required.

One of the authors (MJGT) is currently developing an application for mobile devices that will allow them to remotely operate different robots. It will also allow the teachers to launch prebuilt behaviours or build new ones combining them to meet the learning objectives for each pupil. This would be done directly from a tablet PC or mobile phone, bypassing the requirement for a computer running Choregraphe or being connected to the Internet. Initially the application will be designed and tested with the NAO robot used in this study and tablet PCs running the Android operating system. The next step will be to adapt it for use with different robots and operating systems (such as iOS or Windows Phone). This application will also include a set of games or activities based on findings from this study and earlier work that will aim to help the development and learning skills of children with intellectual disabilities via interaction with the robot.

5. CONCLUSIONS

The humanoid robot used in this study possessed the qualities teachers required to engage pupils with profound and multiple disabilities: it was eye-catching and attractive, novel, responsive, non-demanding, safe and predictable. Teachers came up with a much wider range of suggestions for using the robot than it could currently provide and adaptations they required fell into two groups: either increasing the methods through which the robot could be controlled or increasing the range of behaviours that the robot emitted. These can be met but require a degree of programming expertise above that possessed by most school teachers.

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