SOCIALLY ASSISTIVE ROBOT ENABLED HOME-BASED CARE FOR SUPPORTING PEOPLE WITH AUTISM

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Abstract

The growing number of people diagnosed with Autism Spectrum Disorder (ASD) is an issue of concern in Australia and many countries. In order to improve the engagement of people with ASD in a home-based environment, we implemented a 9 month Australian home-based care trial of socially assistive robot (Lucy) system to support two young adults with autism. The results provide empirical support that by marrying personhood (of people with ASD) with human-like communication modalities of Lucy, positive outcomes can be achieved in terms of engagement, productivity and efficacy as well as reciprocity of the people with ASD and reducing caring time.

Keywords: *socially assistive robot, autism, home-based care, person-centred and lifestyle centred service, positive engagement.*

Highlights:

- The first ever longitudinal trial (nine month trial with 2300 times of communication and over 152 hours of interaction) conducted in an Australian home-based environment.
- Design engaging ASD services with the implication of rich human-like communication modalities combining visual (PECS-based) interface, sound effects, intelligent emotive expressions and gestures with the gamification technique to enhance engagement.
- Reveal the impact of service personalization and novelty on human (with ASD) engagement and how to maintain the engagement through service personalization and novelty.
- Improve the sensory enrichment, efficacy and social interaction amongst autistic participants as well as between people with autism and their family.
- Provide the data-driven evidence for the potential of reducing the caring time and give respite to carers.
- Establish practical and theoretical implications of socially assistive robots to support people with autism in home-based care.

1 INTRODUCTION

The growing number of children diagnosed with Autism Spectrum Disorder (ASD) is an issue of concern both in Australia and the world. This concern is reflected in the 2008 resolution of the United Nations General Assembly for a World Autism Awareness Day (United-Nations-General-Assembly 2008). A 2006 report was the first study to estimate prevalence rates of children with ASD across Australia. The study made different estimates based on different data sources. Based on Centrelink data, the 2006 report estimated a prevalence rate of ASD of 62.5 per 10,000 (or one in 160) for 6-12 year old children. The 2012 Survey of Ageing, Disability and Carers showed an estimated 115,400 Australians (0.5%) had autism. This was a 79% increase on the 64,400 people estimated to have the condition in 2009 (Australian-Bureau-of-Statistics 2010).

Autism is a developmental disorder that encompasses a wide spectrum of impairments in social skills, communication and imagination. Most of current research focuses on the use of robots in the early diagnosis of autism (Campolo et al. 2008; Scassellati 2007), promoting self-initiated interaction (Feil-Seifer and Mataric' 2008; Robins et al. 2005), helping children with autism in turn-taking activities (Dautenhahn and Werry 2004), improving attention when engaging in activities (Duquette et al. 2008; Ravindra et al. 2009) and offering imitation therapy (Bird et al. 2007; Duquette et al. 2008). However, research on using socially assistive robots to improve the emotional wellbeing of the people with ASD, entertain and assist them in their daily basis has not been explored in the literature much. Emotional wellbeing is one of two aspects of personal well-being that can be measured in quantitative quality of life assessments (Deaton 2010) and is a critical part of a person to help them live gracefully and remain independent as well as integrated with society. The existing research on socially assistive robots and companion robots with limited human attributes constrains the range and level of emotional engagement with their human partners and their ability to influence emotional wellbeing in terms of developing reciprocal relationship and making them more productive and useful.

In order to enhance the emotional wellbeing of young people with ASD, we report on research conducted in families with people who have autism using a socially assistive robot called Lucy. The research makes the following contributions: a) designing lifestyle centred Lucy enabled services underpinned in the concept of personhood in people with autism (two young adults in the case study); b) integrating the delivery of lifestyle centred services with Lucy’s human-like communication attributes of voice, emotive expressions, head and body motion in dancing style to generate positive emotional engagement in person with autism and breaking technology barriers; c) providing flexible interaction modes with Lucy using voice, touch panel, mobile phone, and/or face involving cloud computing and computer vision techniques to meet disability needs and comfort requirements of person with autism. In this paper the two young adults have used touch panel for communication with the robot. Their carer and relatives have used mobile/smart phone for communication with the robot, and d) developing reciprocal relationship through 'a', 'b' and 'c' to make persons with autism more productive and useful (thus impacting on their overall emotional wellbeing), improve their positive engagement and social interaction in a home-based care environment as well as provide respite to their carers (e.g., parents) to reduce direct caring time. The longitudinal trial (of nine month) has been conducted with over 2300 times of communication and over 152 hours of interaction and the results demonstrates positive impacts of the socially assistive robot on engagement, efficacy, and social interaction, subject to service personalization and novelty.

The paper is organized as follows and uses a design science approach (Henver et al., 2004) to assess the use of a socially assistive robot for home-based care and support of people with autism. The next section outlines existing work in ASD, which is followed by specifications of the assistive robot (Lucy), theoretical foundations of robot service design, constructs used for the trial, data collection instruments, trial design and trial results or findings based on a case study of two young adults with autism. The trial results are then discussed in a separate discussion section which includes practical implications of the research as well as its limitations. Theoretical implications of research are also outlined followed by conclusions of the paper.

2 EXISTING WORK

Technologies such as computer technology (Bernard-Opitz et al. 2001; Liu et al. 2008; Moore et al. 2000), virtual reality (Conn et al. 2008; Lahiri et al. 2011; Welch et al. 2009) have been utilized for the purpose of creating a beneficial learning environment for children with ASD. Although robots have been suggested as tools to aid in the early diagnosis of autism (Campolo et al. 2008; Scassellati 2007), the majority of research focuses on developing robots and novel therapies that help alleviate symptoms in children that have been previously diagnosed (Bird et al. 2007; Duquette et al. 2008). The main intended role of a robot in autism therapy is to allow or encourage children to develop and employ social skills. Robots were designed to take part in numerous different interaction goals, such as improving self-initiated interactions, mediating turn-taking, assisting in emotion recognition, maintaining attention, evoking joint attention and eliciting imitation (Ricks and Colton 2010) as the deficits in the social and communicative skills of children with ASD.

In order to assist children with ASD in the use of facial expressions, and other social behaviours that regulate engagement, many studies adopted assistive robots with designed goals to elicit and maintain active engagement and attract attention of children with ASD through timed movement, social requests, and the display of desirable behaviours (Emi Miyamoto et al. 2005; Feil-Seifer and Mataric 2008; Ferrari et al. 2009; Kim et al. 2012; Kozima et al. 2007; Michaud and Caron 2002; Pioggia et al. 2007; ROBINS et al. 2004a; Stanton et al. 2008). These behaviours have been encouraged by having the robot react to the child's actions. Playing chase games with the child (Dautenhahn and Werry 2004) or blowing bubbles when the child presses a button on the robot (Feil-Seifer and Mataric' 2008) are examples of such activities. Other activities involve asking the child to identify the emotion a robot's face is displaying (Duquette et al. 2008; Pioggia et al. 2005), or to look in the direction the robot points (Ravindra et al. 2009). In some activities, the children directly interacts with the robot by themselves with a parent or clinician on hand to help encourage this interaction (Pioggia et al. 2005; Ravindra et al. 2009) while in other scenarios a therapist is involved and plays a more active part in the therapy (Kozima et al. 2005; Robins and Dautenhahn 2006).

Joint attention, the ability of demonstrating shared interest toward objects by pointing or using eye contact is another difficulty of children with autism. In many studies, children with ASD interacting with robots show spontaneous joint attention behaviours such as looking at an adult and back to the robot or pointing to the robot and looking at an adult with the intention of sharing some feature with that person (Feil-Seifer and Matarić 2009; Ferrari et al. 2009; Kerstin Dautenhahn et al. 2009; Kozima et al. 2005; Kozima et al. 2007; ROBINS et al. 2004a; Robins et al. 2009; Robins et al. 2005; Werry et al. 2001). In some studies, assistive robots are pre-programmed with behaviours that simulate attention from the robot’s perspective. For instance, Keepon (Kozima et al. 2007) can orient itself toward a user’s eyes and then toward an object in an apparent display of joint attention.

Other research focused on assisting children in imitation. Sometimes the imitation is structured, in that children are encouraged by adults or by the robot itself to imitate the robot’s actions (Bird et al. 2007; Duquette et al. 2008; Ferrari et al. 2009; Pioggia et al. 2008; Robins et al. 2004b; Robins et al. 2005). Other imitation occurs spontaneously and develops into a game, with the child imitating the robot’s behaviours and vice versa (Kozima et al. 2005; Kozima et al. 2007; Robins et al. 2009). These behaviours have been encouraged by having the robot react to the child's actions. Playing chase games with the child (Dautenhahn and Werry 2004) or blowing bubbles when the child presses a button on the robot (Feil-Seifer and Mataric' 2008) are examples of such activities.

Other studies focused on improving sharing and turn-taking ability of children with ASD. In these studies, children learn important life skills through social games involving turn-taking, so the ability to engage in these behaviours is important for development. Through their status as an explicit social presence, robots can elicit turn-taking with children who tend not to engage in such behaviour (Ferrari et al. 2009; Kerstin Dautenhahn et al. 2009; Kozima et al. 2007; Robins et al. 2005)

To the best of our knowledge, limited existing work has systematically studied the impact of socially assistive robot on elements of emotional wellbeing of the children with ASD, especially in the context of Australian home-based care. Our research is different from existing work in the following aspects: First, most of existing work focused on using robots as therapeutic or treatment tools to improve impaired skills of the children with autism. In this research, we focused on using social robots to enhance sensory enrichment (i.e., entertain them with singing and dancing), assist them in their daily basis (tell them weather for the day to assist in choosing suitable clothes or remind them about daily tasks). Second, research on therapeutic-assisted robots has gain popularity and has been conducted in short therapy sections or classroom environments. We conducted a longitudinal trial with young people with ASD in a home-based environment. To the best of our knowledge, this research is the first Australian home-based trial. In addition, Lucy used in the research trial has rich human-like functionality involving voice, gestures, emotion and combination of human attributes and can be personalized to preferences and lifestyles of people with ASD.

3 DESIGN SCIENCE AS RESEARCH METHODOLOGY

Design science is of importance in a discipline oriented to the creation of successful artefacts. It provides a mental model for presenting and evaluating research in information system. Hevner et al. (Hevner et al. 2004) provided practice rules for conducting design science research in the information system discipline in the form of seven guidelines that describe characteristics of well carried out research. It involves a rigorous process to design artefacts to solve observed problems, to make research contributions, to evaluate the designs, and to communicate the results to appropriate audiences (Hevner et al. 2004). Such artefacts may include constructs, models, methods, instantiations (Hevner et al. 2004), social innovations (Aken) or new properties of technical, social, or informational resources (Järvinen 2007). The most important of these is that the research must produce an “artefact created to address a problem” (Hevner et al. 2004).

In this paper, we apply principles, practices, and procedures of design science as the methodology to carry out our research. The design science process in this paper is adapted from (Hevner et al. 2004) which includes six major steps: problem identification, establishing theoretical foundation for research rigor, design and development, demonstration, design evaluation, and communication of research results (Figure 1).

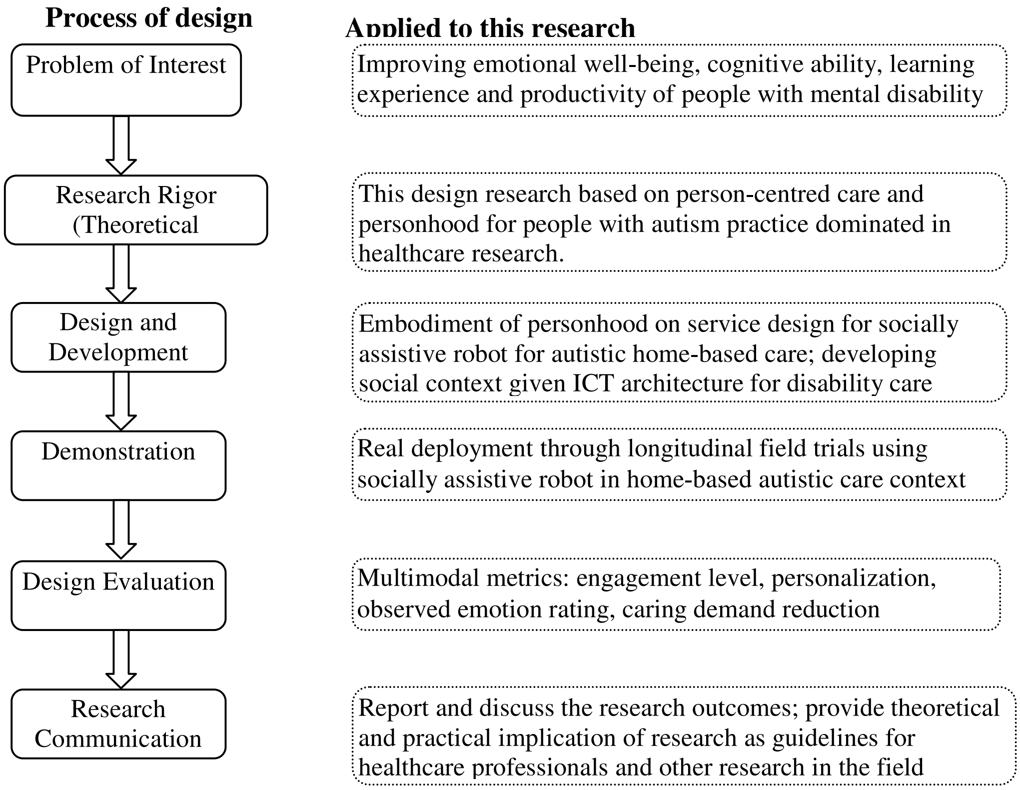


Figure 1. Design science research method applied to our

Problem and Motivation

The first process defines the specific research problem and justifies the value of a solution. The problem identification will be used to develop an effective artefactual solution (Hevner et al. 2004). In our paper, this process has already been addressed in the Introduction, with the problem being defined as embodying personhood in socially assistive robot service design to improve the emotional well-being, cognitive ability and learning experience of the people with autism in home-based care environment.

Research Rigor

Rigor addresses the way in which design is conducted. It requires the application of rigorous methods in both the construction and evaluation of the designed artefact (Hevner et al. 2004). In the second process, we employ personhood oriented service design as the theoretical foundation of our research (ref. Section

5), as health care researchers have shown the need for promoting person-centred care, self-identity and personhood for people with mental disabilities (Cohen-Mansfield et al. 2006; O'Connor et al. 2007).

Design and Development

The third phase, artefact development, is the heart of a design science project. Such artefacts are potentially constructs, models, methods, or instantiations (Hevner et al. 2004) or new properties of technical, social, or informational resources (Järvinen 2007). Conceptually, a design research artefact can be any designed object in which a research contribution is embedded in the design. The artefact at the core of this research is the development of the embodiment of personhood oriented service design in socially assistive robot for autistic care. The instantiation of the design artefact in this paper is the embodiment of personhood including subjective experience, interactive environment and home-based care context in socially assistive robot to support home-base autistic care. The robot services have been designed and developed to archive this embodiment (Section 6)

Demonstration

This process demonstrates the use of the artefact to solve one or more instances of the problem, which is to provide the support to autism care in this research. This could involve its use in experimentation, simulation, case study, proof, or other appropriate activity (Hevner et al. 2004). Hevner et al. provide a set of guidelines for design science research and identify five classes of methods for evaluating design artefacts. Our research uses a participatory case study to study the design artefact intensively through a real longitudinal deployment of the design artefact in the socially assistive robot in home-based care context (Section 7).

Design Evaluation

This process observes and measures how well the artefact supports a solution to the problem. The utility, quality, and efficacy of a design artefact must be rigorously demonstrated via well executed evaluation methods (Hevner et al. 2004). In this paper, we define several metrics and gather multimodal data sources for the evaluation process (Section 7).

Research communication

This process communicates the problem and its importance, the artefact, its novelty, the rigor of its design, and its efficacy and effectiveness to researchers and other relevant audiences, such as practicing professionals, when appropriate (Hevner et al. 2004). In this work, the problem of interest and its importance, the artefact design, its evaluation and theoretical and practical implication will be presented in details in next sections to research community and health care professionals (Section 8 and 9).

4 SPECIFICATIONS OF LUCY

Lucy as shown in Figure 1 is ~39 cm tall and weighs 6.5 kg. Lucy's human attributes include baby face like appearance, voice vocalization, face recognition, face registration and face tracking, facial expressions, gestures, body motion sensors, dance movements, touch sensors, emotion recognition and speech acoustics recognition.

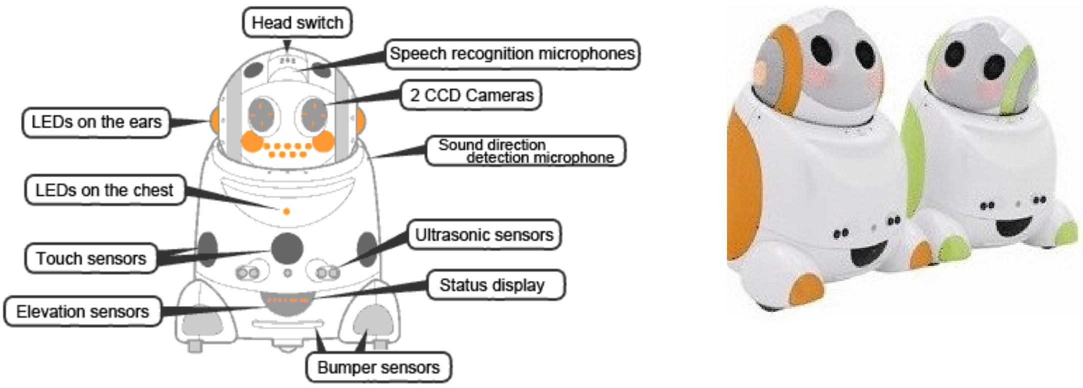


Figure 1. Lucy's specifications (left) and Emotive Expressions (right – orange color) with sibling Charlie

The field trials have been designed with the aim of evaluating the impacts of Lucy in the context of Australian home-based autism care. In this context the robot service design methodology is outlined next.

5 THEORETICAL FOUNDATIONS FOR ROBOT SERVICE DESIGN

Person-centred approaches have come to dominate the rhetoric associated with the design and delivery of residential, vocational, educational and recreational support for adults with intellectual disabilities. Recently, health care researchers have shown the need for promoting person-centred care, self-identity and personhood for people with mental disabilities (Cohen-Mansfield et al. 2006; Jean Tinney et al. 2007; O'Connor et al. 2007). Given the importance of pursuing this path, this research involves marrying personhood with Lucy's human-like communication modalities (e.g., voice, gestures, expressions, head and body movement), computer vision techniques (e.g., face recognition) and cloud computing based communication techniques (e.g., using tablet and touch pads to give instructions to Lucy) to realize a symbiotic robotic system.

Research in this area has indicated that negative consequences of autism can be mitigated by designing an approach towards care that respects and supports each individual's personhood (Cohen-Mansfield et al. 2006; O'Connor et al. 2007). Personhood has been defined as 'the standing or status that is bestowed upon one human being, by others, in the context of relationship and social being' (Flicker 1999). It includes three fundamental components, namely, interactional environment, subjective experience and social context. Figure 2 shows mapping of concepts related to these three components in Lucy.

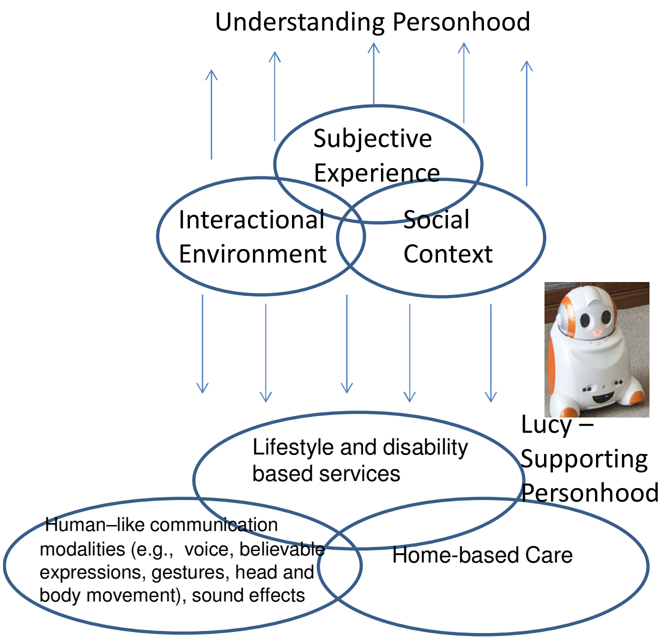


Figure 2. Lucy's service design methodology based on personhood

5.1 Modelling Subjective Experience in Lucy

The subjective experience in an autism care context involves design of services personalized around the lifestyle of the person with autism. These lifestyle based services which reflect their personhood are designed to engage and help them become more productive and useful. The need for engagement and usefulness is relevant in a home-based care environment where assistive technologies need to support the parents (carers) through partially or wholly independent interaction of Lucy with person with autism for limited periods. Based on our successful deployments of robots like Lucy in other domains (e.g., dementia) to support people with disability and mental health issues (Khosla and Chu 2013), we have modelled the subjective experience in the context of emotional well being of persons with autism. The five constructs related to emotional well being are sensory enrichment, social connectivity, productivity and usefulness, needs and comfort, and resilience.

5.2 Modelling Interactional Environment in Lucy

The embodiment of interactional environment in Lucy involves modelling of human characteristics like gesture, emotion and expressions, voice, motion and dancing and dialog adaptation. It involves integrating various services provided by Lucy with its communication modalities like voice, emotive expressions (e.g., blushing – Figure 3), head and body movements with different range, intensity and combination depending on service context so as to facilitate positive emotional engagement such as responding with positive expressions and actions (e.g., kissing the robot) and reciprocity (e.g., calling the robot by its name, responding to its recommendations).

Figure 3. Lucy blushing expressions

5.3 Modelling Home-based Care Context

Unlike in a supervised environment (e.g. in a school or community setting) in a home-based care context Lucy's services have to be delivered in a partially or wholly independent manner. Thus different users may prefer different interaction modes. In Figure 4 four interaction modes with Lucy are shown, namely, using voice, touch panel, smart phone or face i.e., face recognition)

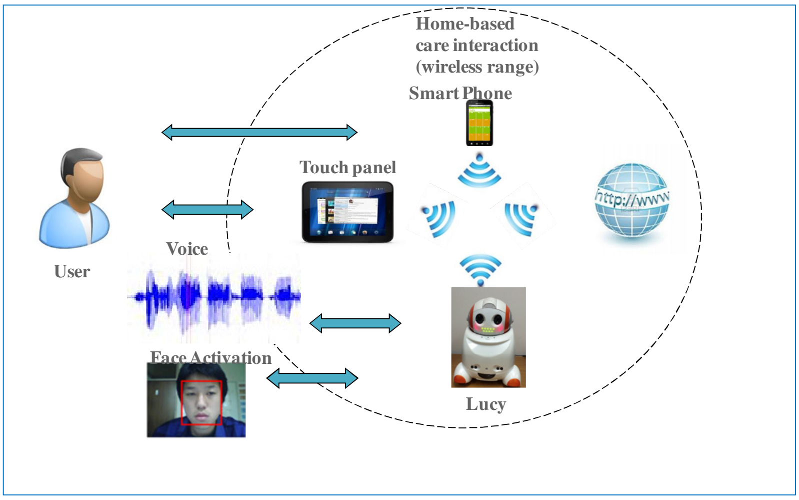


Figure 4. Lucy enabled home-based care trial environment

6 SERVICE DESIGN

This section presents service design and implementation for socially assistive robots to best support personhood of people with ASD by integrating human-like functionalities in service delivery, designing a human-robot communication modality suited people with autism, encouraging interaction through gamification, and supporting service personalisation and novelty.

6.1 Human-like functionality

Lucy used in the research has rich human-like functionality involving voice, gestures, emotion and combination of human attributes and can be personalized to preferences and lifestyles of people with ASD.

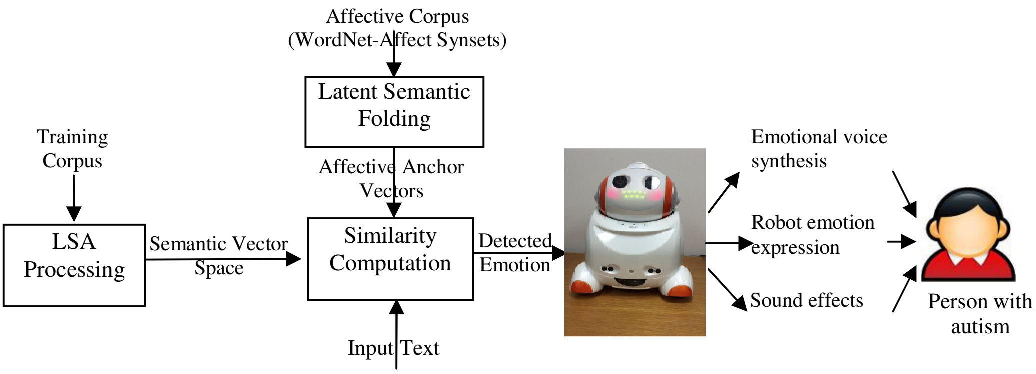


Figure 5. Delivery of human-like functionality evolving voice, emotive expression (emotion, gesture), and sound effect mediated by intelligent text emotion extraction.

In order to deliver such rich human-like features, Lucy is designed to be able to automatically extract the emotion from the text and perform according emotive expression (Figure 6), gesture (i.e., head and body movement), as shown in Figure 5.

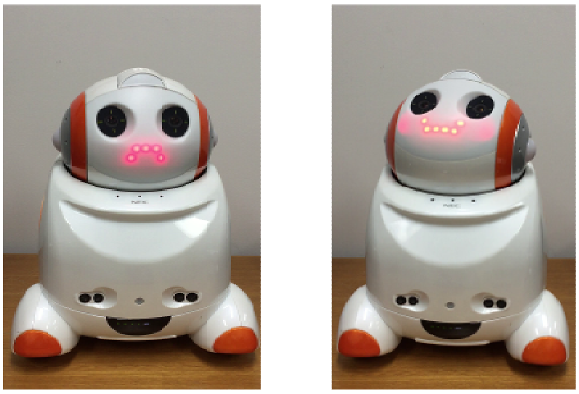


Figure 6. The robot expresses sad emotion (left) and happy emotion (right).

Let s be an input text and w_s an emotion label. Let e be a set of m possible emotion categories (excluding neutral) where $e = \{e_1, e_2, \ldots, e_m\}$. The objective is to label s with the best possible emotion label w_s , where $w_s \in \{e_1, e_2, \ldots, e_m, neutral\}$.

First, the semantic model was trained with BNC (British National Corpus) [1] using Latent Semantic Analysis (LSA) [2] to create the semantic vector space. Then, we extracted six synonym sets of affective words corresponding with the six emotions (anger, disgust, fear, joy, sadness, and surprise) from WordNet-Affect [3]. The effect synsets are then being folded into the semantic space using the folding-in technique [4] to form effective anchor vectors which represent six emotion categories in the semantic space.

Given input text which needs to identify its emotion, it can be represented by a vector in the LSA space formed by summing up the normalized LSA vectors of all the terms contained in it. Finally, the affect of the input text can be identified by computing the cosine similarity measure among the input vector and the affective anchor vectors. If similarity is defined between a given input text s, and an emotional class, e_j as $sim(s, e_j)$, the affect w_s of s is formally represented as follows:

$$w_s = \begin{cases} \arg\max\left(sim(s, e_j)\right) & if\ sim(s, e_j) \geq t \\ neutral & otherwise \end{cases}$$

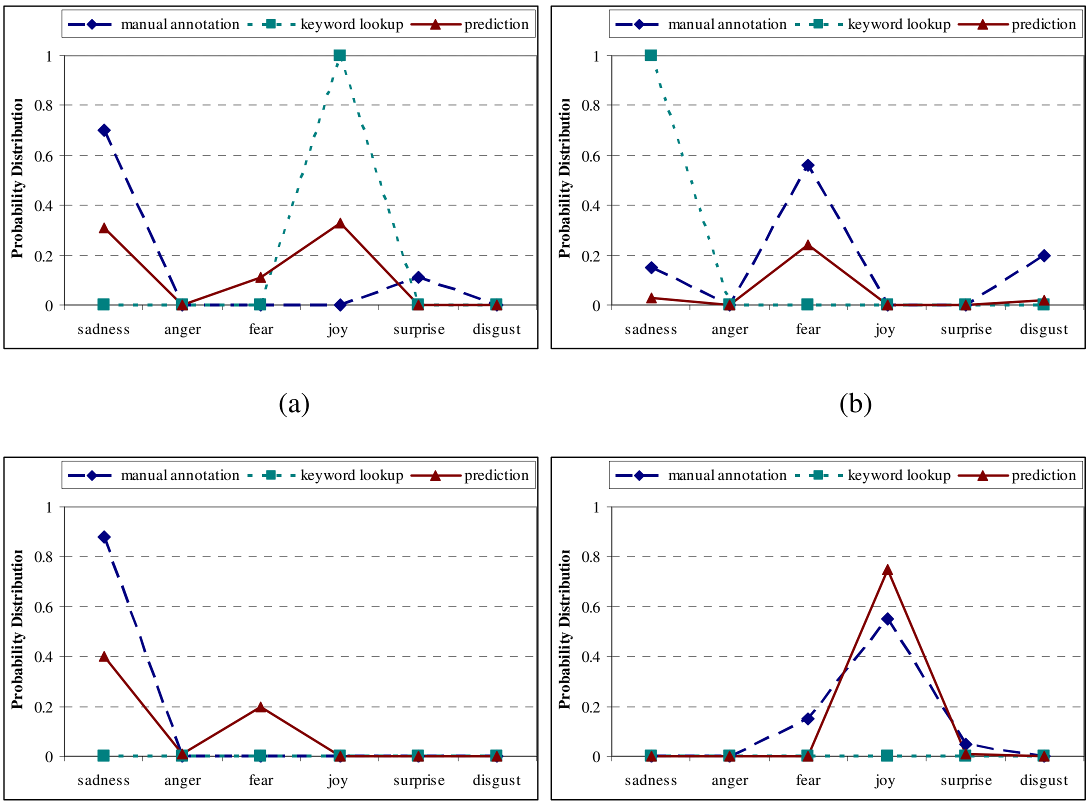
where $sim(s,e_j)$ is computed as cosine between the vector v_s of s and the affective anchor vector v_{e_j} of emotional class e_j:

$$sim(s,e_j) = \frac{v_s \cdot v_{e_j}}{\|v_s\| \cdot \|v_{e_j}\|}$$

To illustrate the classification of the above approach, Figures 7 show the probability distribution obtained across the six emotions for the following four text inputs (Table 1):

Table 1. Four input text E1-E4 for illustration

E1	She began to cry, and cried louder and louder and could not be comforted
E2	A mouse took a stroll through the deep dark wood
E3	The world's best-known woman bridge player, has died, writes Patrick Jourdain
E4	They were good friends, and one warm sunny morning, for no particular reason, they decided to go for a row in the bay



(a) (b) (c) (d)

Figure 7. Probability distribution across emotion for E1 (a), E2 (b), E3 (c) and E4 (d).

6.2 Human-Robot Communication Interfaces for People with Autism

Individuals with autism exhibit deficits in the development of expressive communication (American Psychological Association, 1994). An estimated 50% of children diagnosed with autism fail to develop functional speech (Peeters & Gillberg, 1999). By definition children with autism spectrum disorders (ASD) experience difficulty understanding and using language. Accordingly, visual and picture-based strategies such as the Picture Exchange Communication System (PECS) show promise in ameliorating speech and language deficits. The PECS is a picture-based alternative communication method that is one of the most commonly used interventions for children with autism (Green et al., 2006). PECS was designed to teach individuals with little to no spoken language how to exchange picture cards for preferred items and activities.

Figure 8. (left) main touch interface, (right) book list interface: using the book's covers in the interface allows people with autism easily select right book by matching their books cover with the displaying picture.

Motivated by PECS, our touch interfaces have been designed as PECS-based communication interface by combining rich visual clues with text. For instance, Figure 8 shows the main touch interface (left image) and the book list interface (right image) designed for our trial participants (i.e., a couple with autism). Their reading book covers are utilized to design book list interface for them with the aim to assist them pick a book just as they did in their daily basis.

6.3 Engaging interaction with gamification

Gamification which is the use of game elements and game-design techniques in non-game contexts as diverse as education, information studies, human–computer interaction, and health (Seaborn and Fels 2015) as a meaningful concept and provide evidence of its effectiveness as a tool for motivating and engaging users in non-entertainment contexts, increase student motivation and engagement (Domínguez et al. 2013), encourage participation (Denny 2013; McDaniel et al. 2012).

In this research, the robot indicates the correct answer visually, by nodding its head, and audibly saying "*well done/very good job*". At the end of the quiz, people with autism being awarded tokens (i.e., golden stars) for correct answers, coupled with a favourite song being sung and danced by the robot. The robot rewards the human partner (i.e., person with autism) by singing them a favourite tune at the end of an activity (i.e., quiz, book reading) or when they win a (Bingo) game. The performance and accomplishment are monitored and reported to parents (carers) who then may applaud or reward their daughter/son's performance with actual gifts.

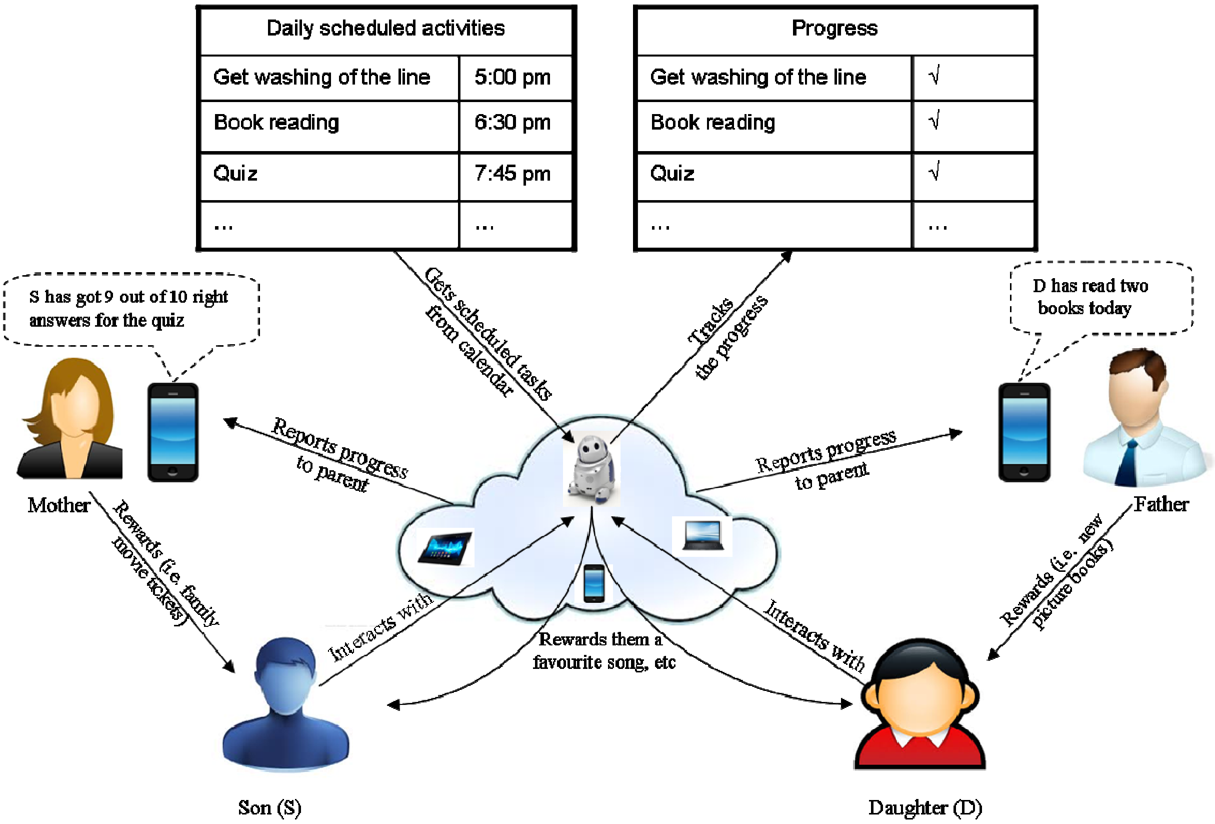


Figure 9. Implication of gamification in a longitudinal field trial with a family having two people with autism living with the parents.

Figure 9 illustrates the implication of gamification to our long-term field trial with a family having two young people with autism. The robot interacts with home devices such as laptop, touch panel and mobile device to form a private cloud. The robot gets the daily scheduled activities of the people with autism from their calendar (i.e. Google calendar which is updated by the parents online using their own computer device). The robot tracks the progress of the scheduled activities by the robot by monitoring the service interactions of people with autism (i.e. doing a quiz, listening to storytelling, etc). The robot rewards the people with autism for the accomplishment of each activity by singing and dancing them a favourite song.

Simultaneously, a report is sent to the parents's mobile devices through Skype/WhatsApp text messages. The parent might choose to reward their children progress or performance by actual gifts (i.e. movie tickets or picture books). The interaction between the people with autism and the robot will be monitored to track if the activity is accomplished by the human partner.

6.4 Service personalization and novelty

To maintain the sustainable benefits of the robot to people with autism over long-term care is one of crucial aim of our service design. The reality of our long-term trials with people with dementia and autism suggests that personalization and novelty are essential to keep the human partner engaged with the robot over longitudinal care. To facilitate this, we have designed robot services enabling family or carers of people with autism personalize the services according to individual preference through simple touch interface. This interface facilitates uploading service contents that suit their preference and maintains the service novelty. In other words, family or carers of people with autism can write their own stories and quizzes as well as upload their own music to sustain novelty and variety overtime to engage the person with autism under their care The robot will dynamically update the touch interface and speech vocabularies for the updated service as well as integrate emotive expressions, body movements, gestures and sound effects in the new song as well as in the text of the new story. The process of service updating is shown in Figure 10.

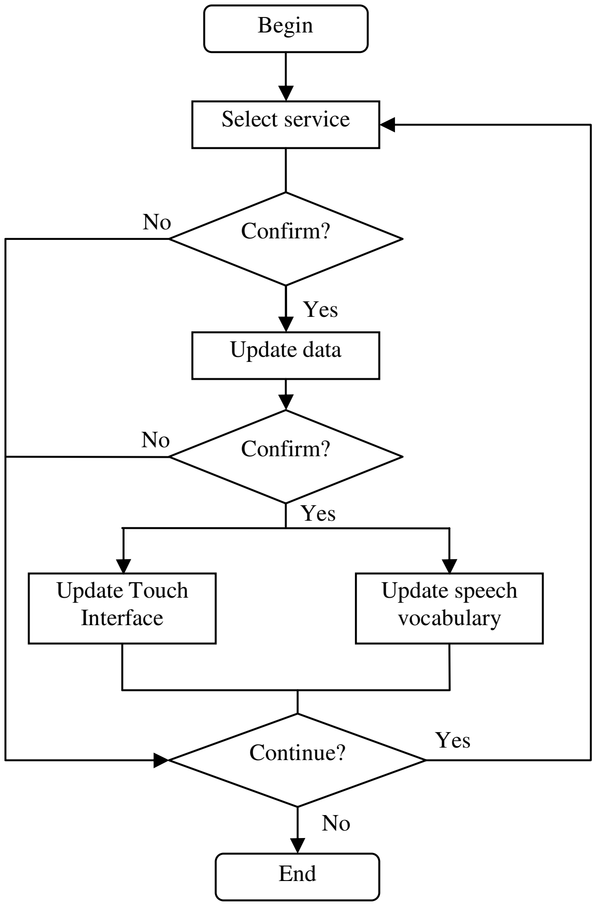


Figure 10. Flowchart of service personalization and sustaining novelty

7 CASE STUDY

Trial design is underpinned in a case study of two adults with autism in a Melbourne household in Australia. Figure 4 also shows the trial environment in the Melbourne household.

Table 3 shows the mapping between subjective experience and emotional wellbeing constructs (Health, 2010) and corresponding lifestyle based services designed to be delivered by Lucy to two persons with autism in a Melbourne household in the state of Victoria in Australia. The parents have an adult Daughter (D) aged 23 and Son (S) aged 25 who have autism. The parents expect that Lucy (social robot) would help to make their daughter more productive by supporting them with household chores and enable their son to improve his hygiene habits. In the process it will also help to provide them some respite.

The lifestyle based services for D and S include Lucy singing and dancing to their favourite songs, Lucy reading books selected by them, playing hygiene habit based quiz as well as providing reminders to them. The next section will elaborate on how these services have been designed.

Table 3. Mapping between Lucy's five constructs and services

Subjective Experience and Emotional Wellbeing construct	**Lucy's services**
Positive Emotional Engagement through Sensory Enrichment	• Sing and dance • Interactive storytelling • Reading news
Social Connectivity	• Playing game (e.g., Bingo) • Phone calls • Lucy enabled social connectivity using smart phone
Needs and Comfort	• Flexible communication modes (e.g., voice commands, touch panel based commands to robot)
Resilient, Productive and Usefulness	• Quiz , playing game, reminder, telling weather, interactive storytelling

7.1 Positive emotional engagement, sensory enrichment

The functional model parameters for modelling positive engagement and reciprocal relationship are based on design and delivery of personalised services underpinned in the lifestyle choices of the person involved. These include music and songs, news and stories personalised to their taste and positive episodic experiences, social needs, and family history, As shown in Table 1 services shortlisted for trial are singing and dancing, interactive storytelling, and reading news, playing bingo, making phone call and Skype.

7.2 Productivity and Usefulness

The ability to play a meaningful and productive role in their daily life can be important to the emotional wellbeing (Health, 2010). Being able to engage and contribute to themselves and family makes them feel useful. In this context quiz and reminder based services have been designed for persons with autism. The quiz includes questions to improve their basic knowledge and toilet hygiene, make them productive in their daily living. The reminder is used to help them participate in family chores productively.

7.3 Interaction modes with Lucy

Flexible communication modes are considered as an important component for enabling Lucy to personalize care for people with autism (given their physical abilities and mental faculties). At home, mother, daughter and son can communicate with Lucy using voice and smart phone (mother) and touch panel (daughter and son) respectively. The touch panel is provided with graphical buttons for various services. The design of the touch panel facilitates perceptual processing (rather than cognitive processing) for ease of use. The various communication modes are enabled through cloud based computing, computer vision and speech recognition techniques.

The data collected from trial involves: Lucy's video recording of interaction of users participating in activities and validation of video data with feedback with activity pattern log files in Lucy and interview with parents. The various sources of data collection facilitate content validity of measurement of emotional engagement, reciprocity and productivity (Lynn 1986).

A Case Study - Daughter (D)

D is a 23 years old young lady with autism who lives in Australia. She lacks self-confidence, has limited social skills and has difficulty holding short conversations. As her mother has put it "Melissa is a young lady who needs a structured environment to engage her in activities that stimulate and motivate her. Without activities that engage her she will engage in obsessive compulsive behaviours." Her parents want her to be more productive at home rather than simply watching TV programs for most of the day. She has a very short attention span and lacks motivation to learn. She would like her to be more productive and help out in household chores and also improve her hygiene habits so that her mother can get proper sleep at night. Existing technological devices like iPad cannot engage her for long.

Lucy (social robot) has been deployed in D's home for a period of 9 months. During this time, D has taken initiative and engaged with Lucy independently. She maintains eye contact with Lucy without hesitation.

She has developed a reciprocal relationship with Lucy in this period. Lucy reminds D to take clothes off the line and rewards her by singing and dancing to her favourite songs. D has played Bingo (number game) with Lucy to improve eye and had coordination skills. Lucy has done several quizzes with D related to her toilet hygiene.

Figure 11 (a and b). D is enjoying the music played by Lucy. (b) S (her bother) is excitedly looking at photo (sent remotely by their sister) projected on a screen by robot Lucy © SBS Insight

Her mother reported that now her concentration span increased because of multi-modal sensory enrichment provided by Lucy. Once Lucy was brought back to research centre for upgrade, on its return to D’s home her mother reported “Melissa was delighted to see Lucy on the table. To my surprise she gave her a kiss. I wish I had got a photo of this it was very cute.” D particularly enjoyed emotive expressions and gestures synchronized with various dancing themes.

In order to leverage the reciprocal relationship between Lucy and D, her parents can also send messages from their smart phones to Lucy for broadcasting to D. D’s mother had this to say “I sent D a message [asking] could she please come and turn the light on. D was in the lounge room watching TV. And she did. Next time I will do the same but will get her to put the kettle on as well. I think we can build up to her making me a cup of coffee then turning the light on. All a bit of fun but we can build on this.” Her mother had this to say after nine months of deployment of Lucy in their home: “Melissa's concentration span has improved over this period. I guess it is difficult to know what has contributed to this but no doubt the engagement with Lucy has certainly helped. The music (see Figure 11) and in more recent time the talking stories have improved Melissa's ability to sit and listen.” (see figure 12).

Figure 12. D and S are jointly listening to a story narrated by Lucy

Melissa has also increased her verbal vocabulary. Some of these can be directly attributed to Lucy who constantly repeated these words.

The Bingo game is a wonderful addition (Figure 13). The modified bingo game has provided an activity we can play as a family. There are not too many games we can sit around the table and play. D has really surprised me with her ability to play this game with actually less assistance than S (D’s older brother who also has autism). S does not seem to have the same enthusiasm for it. We started with numbers 1 to 20 which D and S have mastered reasonably quickly. We have now increased the range of numbers to 30. It is important to constantly provide new challenges for both D and S but not make the challenges so great that the skill is too difficult or they will lose enthusiasm.

Figure 13. D and S playing Bingo with their mother ©SBS Insight

Since introducing a chocolate frog for the Bingo winner D's concentration has improved greatly while playing the game, especially when she won a number of them. D even came out with a new word, "Ge-day". It will be interesting to see if she plans to use this greeting away from Lucy.

The calendar reminders are great to have, especially in the afternoon, to remind D and S to assist with a few household chores. These chores include emptying the dishwasher and getting the washing off the line. D's mother indicated, "On Wednesday, we have a carer from 3pm to 6pm. Lucy reminds our carer, D and S of the chores that need to be completed. As neither their father nor I are home until 6pm, having Lucy was helpful. Lucy had been working without issues well over the last 3 months or so. Until then, it was at times a little frustrating with Internet drop-out. This issue has prevented greater involvement from our carer. But these things take time and patience. Our carer, Catherine, is now using Lucy for the talking stories and to play Bingo and has even been confident enough to teach a fill in carer how to use Lucy."

Analysis:

The ability of Lucy to improve the subjective experience of D in her daily life through singing and dancing to her favourite songs, playing games like bingo and interactive storytelling have not only provided her sensory enrichment but also made her more productive and cooperative at home. The rich human-like interactional abilities of Lucy delivered in embodied form differentiate it from other screen based technological devices by positively engaging D for longer periods of time and developing reciprocal relationship with D in terms of rewarding her for household chores. The rich sensory enrichment provided to D through singing and dancing motivates her to interact with Lucy in learning activities like interactive storytelling and playing Bingo. Playing Bingo with Lucy is also a family-oriented activity which brings family together.

In a home-based care context, the above interactional activities with Lucy provide diversion therapy to D and can also help to mitigate stress situations. The engagement with Lucy which lasts anywhere between 20 minutes to 1 hour on a typical day help to provide respite to her parents. The encouraging results of the ongoing trial with D also point in the right direction of using the personhood model to design services in Lucy.

Case Study - Son (S)

S is a 25 year old young adult who has different autistic traits compared to D. S likes to interact with technological devices. The main concern about S is about his toileting and personal hygiene. Also, his parents would like him to be motivated to learn.

Figure 14. (a) S positively engaged with Lucy in interactive storytelling and (b) S pointing to the horse in the book based on Lucy's creation of sound effects of a horse © SBS Insight

Figure 14a shows coordination between Lucy telling the story and S reading the book. Figure 14b, on the other hand, depicts comprehension by S that the sound effect being made by Lucy is that of a horse as pointed out by S in the book. S's mother had this to say "While I am writing this, S's father took him outside for a bit of fresh air but S has come back inside and grabbed the books and put Lucy back into the reading program. Way to go team."

Playing quiz with Lucy has positive impact on mental activity and sense of usefulness to the persons with autism. As shown in Table 4, the quiz consists of 10 questions written by D's and S' parents that aim at helping them to learn or memorize some basic knowledge or daily routines. The number of correct answers in each try is recorded, as shown in figure 10. All the participants used touch panel to provide answers to Lucy. Lucy provided the correct answers and the feedback to the users on the number of questions with correct answers and offered a consistent encouragement (i.e., “Very well done”, “Well done, you absolutely can do better next time”, etc.) regardless of how good the results are. As evidenced by the feedback from the parents and health care workers, the quiz activity provided a sense of usefulness to the participants.

Table 4. A sample quiz written by the carers (parents) of the participants

Question	Choices
What kind of animal is Tilly?	1. Cat; 2. Elephant; 3. <u>Dog</u>
Mandy has a job as a?	1. Truck driver; 2. Gardner; 3. <u>Teacher</u>
What colour is dad's shirt?	1. Red; 2. Green; 3. <u>Black</u>
Before I go to bed at night I need to?	1. Say goodnight to mum and dad; 2. Remember to clean my teeth; 3. <u>Both clean my teeth and say good night</u>
When I have been to the toilet the next thing I need to do is?	1. <u>Push the toilet button;</u> 2. Turn of the light; 3. Wash my hands
When I have been to the toilet and I have pushed the toilet button I then need to?	1. Turn off the light; 2. <u>Wash my hands;</u> 3. Dry my hands on the towel
What colour is the sky?	1. Yellow; 2. Green; 3. <u>Blue</u>
When I have been to the toilet and I have pushed the button and washed my hands, then I need to?	1. Leave the bathroom; 2. <u>Dry my hands;</u> 3 turn off the light
What time does Peter, the taxi driver, come during the week?	1. <u>Eight O'clock;</u> 2. Ten O'clock; 3. Six O'clock
When I have been to the toilet and I have pushed the button. Then I have washed and dried my hands, then I need to?	1. Turn off the light; 2. Leave

The log data shows that through prompting and vocalizing the right answers to the D and S, they can learn basic knowledge which helps them in their daily life (Figure 15). One of the parents’ commented that their son remembered to “turn off the lights” and “wash hands” before leaving the toilet.

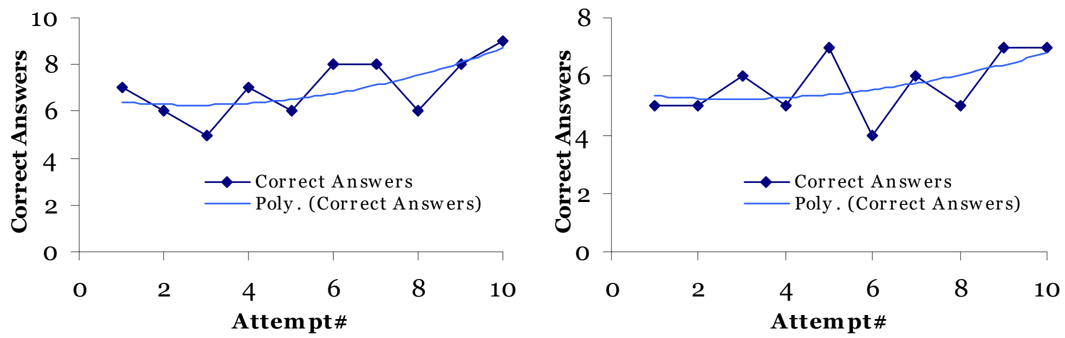


Figure 15. The number of correct answers of S (left) and D (right)

Figure 16. (a) S took quiz with Lucy and (b) washed hands based on quiz on hygiene with Lucy

D's and S's mother had this to say, "By creating a fun short quiz with a high success rate so as to engage either D or S in a learning activity we are hoping these skills are then transferred to actual activity. We have seen a degree of success with S who was transferring a toilet schedule to the actual activity." (see figure 16)

7.4 Activity Patterns

In this section we corroborate the qualitative comments made by the parents with actual activity patterns of D and S as logged by Lucy in nine months of deployment. By socially engaging the people with autism with Lucy through familiar activities which they are doing in their daily life, we are able to break technology barriers and encourage acceptance of Lucy. This has led people to interact and reciprocate to Lucy on a one-to-one basis. The statistics of the log activity data (figure 17) recorded during the trials show that the participants maintain high frequency of interactions with Lucy.

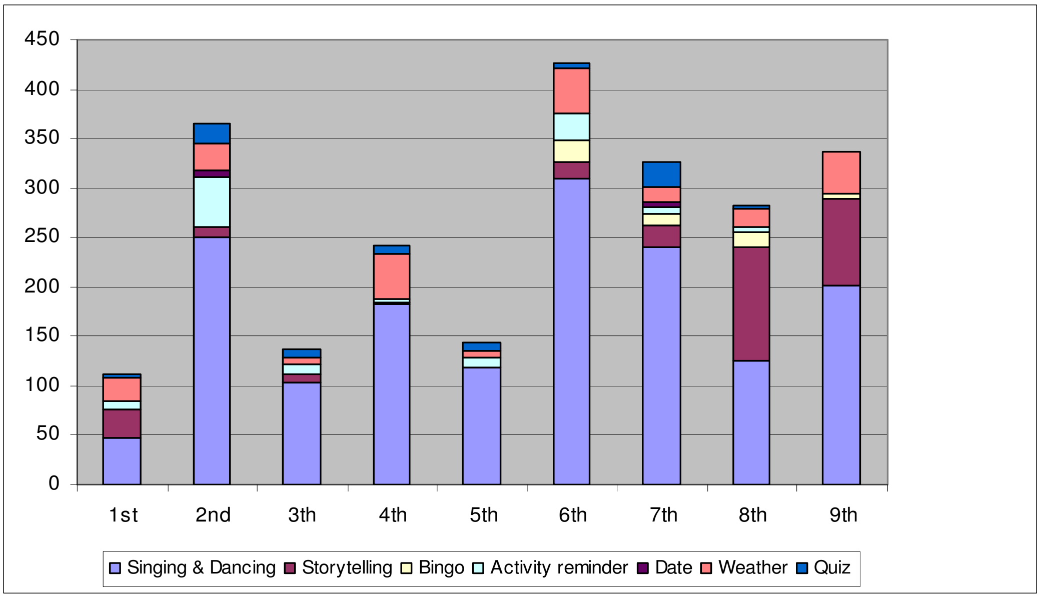


Figure 17. Frequency of interaction with Lucy

At the time of writing this paper the updates can now be done by D and S's parents that is very liberating for them. Also, the variation can be due to family going on holidays. Additionally, one-to-one activities like Lucy reminding D and S about their calendar of activities for the day are other services that have been used by them to make them more resilient. The calendar services are delivered by Lucy automatically (i.e. not initiated by D or S) and they are not recorded per day. Their frequency will depend upon the actual calendar for a day and will vary each day and month. Furthermore, by integrating the favourite songs and books of the trial participants into service design allows Lucy to deliver personalized care to D and S.

7.5 Impacts of personalization and service novelty to user engagement

One of the challenges of a longitudinal trial is to maintain active engagement of the human partner with the robot. In order to study the impact of service novelty on engagement, we statistically analyse the frequency and duration of interaction (Figures 18 and 19) between the participants and the robot and use it as an indicator for need of service update. The correlation between service update and the interaction indicators was measured.

At the beginning, the robot was introduced to family with limited personalization and service contents (i.e., only 25 general kid songs). In addition, the storytelling was delivered using narrative voice with limited robot emotive expression, sound effect and background music. This results in the low frequency of interactions (111 interactions) in the first month. We are aware that the low frequency of interaction may effect by the new introduction of the robot in their home environment.

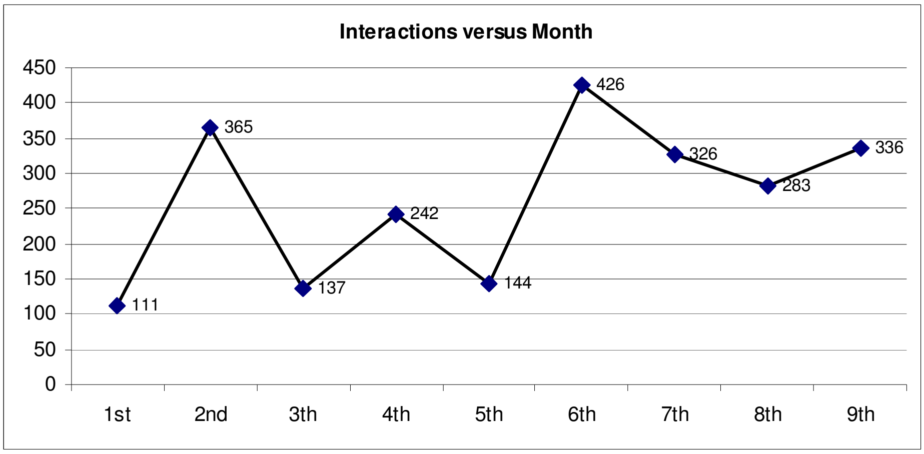


Figure 18. Impact of service novelty to frequency of interaction

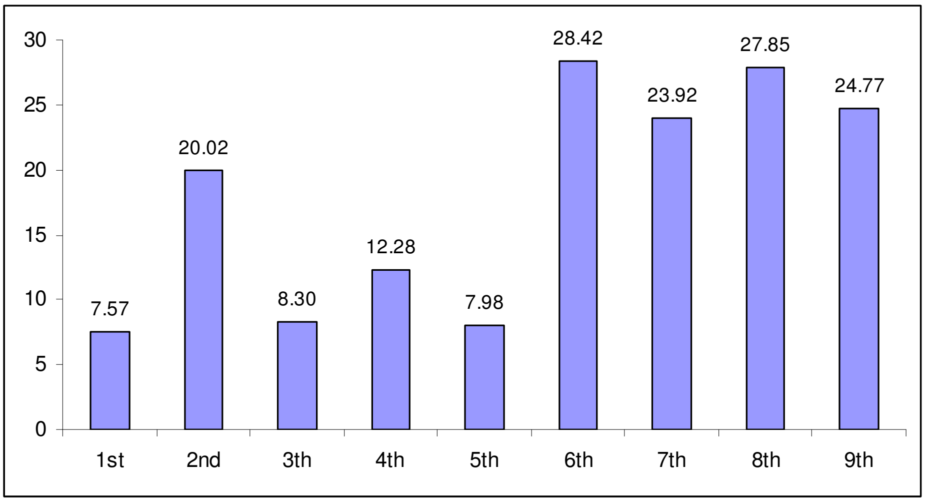


Figure 19. Impact of service novelty to duration of interaction

The first service update is executed at the beginning of second month. In this update, we collect some favourite music albums from the carers (i.e., parents) and picture books which they love. The books were narrated and the emotive expression were embedded into the storytelling manually. This contributes to the high engagement (363 interactions) in the second month, thus no update was conducted in the third month.

The next update was performed at the beginning of the fourth month with the introduction of a more rich human-like storytelling combining robot emotive expressions facilitated by our intelligent text emotion extraction, gestures, sound effects with voice.

At the beginning of the sixth month, Bingo game is installed for the trial, but adapted for the number from 1 to 30, to enhance the cognitive skill of the participants. Also, an updating service has been provided to the family which allows them to update the service contents (i.e., songs, books and quizzes) themselves. The communication interfaces are adaptively updated with new data. The parents can even write and upload their own stories, quizzes and music anytime without need of contacting the researcher team. This allows the carers to update their service more frequently. The frequency of interactions of the consecutive months (6^{th} to 9^{th}) indicates that engagement is enhanced compared with at least monthly updates in the previous months, highlighting the need of service novelty in the longitudinal trial to maintain human engagement.

Overall, the results indicate that there is a strong relationship between service personalization and novelty and the level of engagement of the human partner to the robot.

7.6 Potential to reduction on time demand of caring

Home-based care for people with autism places substantial financial and time pressures on primary caregivers (Australian Bureau of Statistics 2008; Edwards et al. 2008; Hill and Thomson 2007). Crowe and Florez (2006) reported that on average mothers of children with disabilities were spending an additional 13.1 h per week in child care activities than mothers of children without disabilities.

The additional time demands of caring may lead mothers to restrict time that previously was available for other activities including paid employment, time with their spouse, time with other children, hobbies, recreation, or sleep. It has the potential to adversely affect the psychological adjustment and the quality of life of mothers. There is strong evidence that mothers of children with developmental disabilities, such as autism spectrum disorders and intellectual disabilities have higher rates of mental health problems than other mothers in the community (Bailey et al. 2007; Singer 2006).

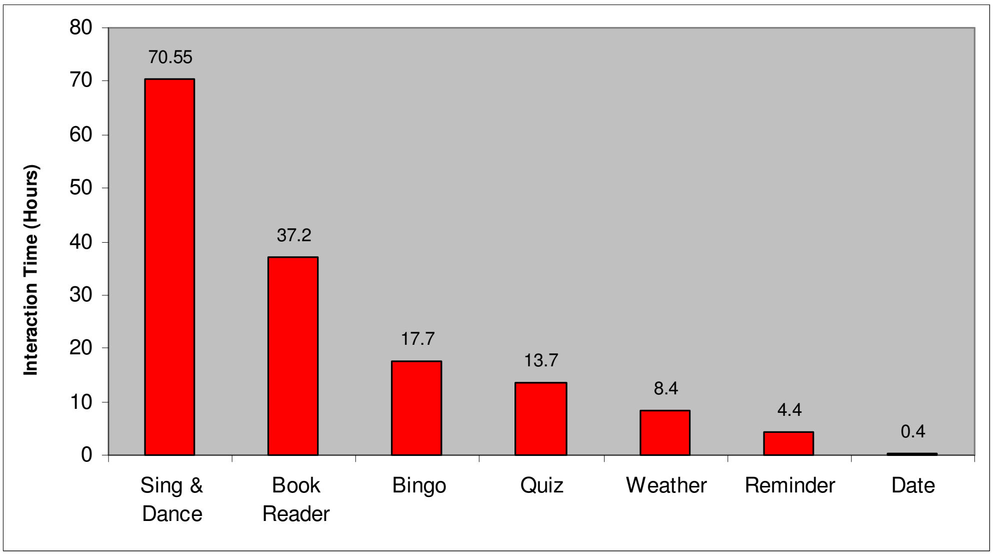


Figure 20. Time duration of interaction for each service.

The duration of interaction for a specific service is calculated as the time interval the participants spent using that service, and is computed from the time that service started until the robot finished performing that service.

The duration of interaction for each service is shown in Figure 20. In total, the participants have spent 152 hours interacting with the robot. Except Bingo (about 37 hours) which is a group activity that required the participation of carers, the other services (about 115 hours) did not require the presence of the carers, thus have the potential to reduce caring time for the carers. Hence, the use of the robot, Lucy, provided the carers some break time to participate in other tasks or chores.

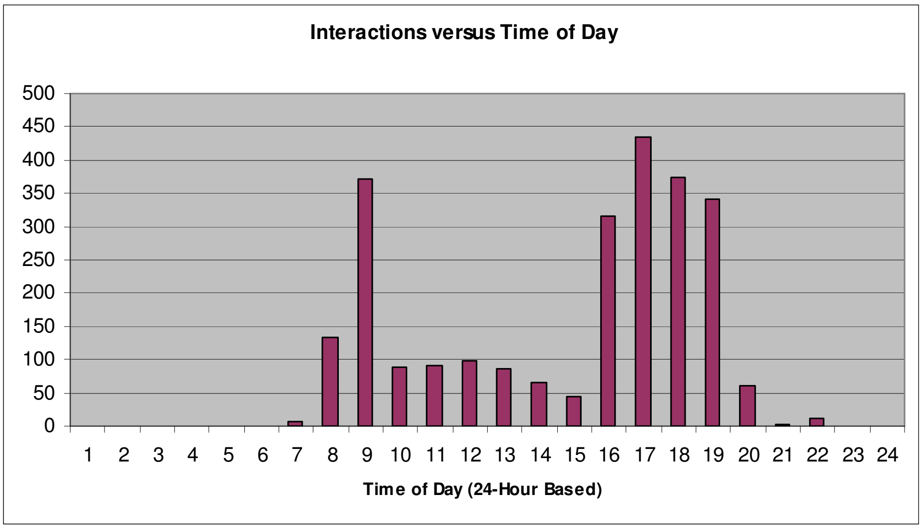


Figure 21. Statistics of interaction versus time of the day.

The statistics of interaction in a 24-hour period is shown in Figure 21. This statistics provide complementary information for implementing time-based personalization which the robot initiates the interaction or service based on the historical interactional time. The statistics also give carers (parents) useful information to schedule their caring time better where the interaction between people with autism and the robot is less likely to take place.

7.7 Encourage social interaction

The trial also demonstrates that the robot can be utilized as a communicating mediator amongst people with autism as well as between people with autism and their family.

First, the robot is a proxy for the communication between people with autism and their remote family members, by facilitating the message, photo and video sharing from other family members to people with autism. The carer (mother) commented that "Mandy (the sister) is in Indonesia at the moment and has sent some messages via Lucy the Robot. Melissa (the daughter) was sitting on the couch at that time and the look of delight when the random message came on was priceless".

Figure 22. S looked at his sister's photo which was sent remotely by his sister and projected to the computer's screen by the robot (left), then he turned to D (both have autism) to share their happy moment (right) © SBS Insight

Figure 22 illustrates the precious moment of the autistic participants when receiving their sister's photo which she sent to them via the robot directly from her mobile. S looked and pointed at the photo (left figure) and then turned to his sister to share his happiness with her while still pointing at the photo (right figure). This figure also demonstrates the potential of robot Lucy to encourage social interaction between people with autism.

The statistics in Figure 20 show that D and S have been involved in the Bingo game for more than 17 hours within a four month period (from sixth month – when Bingo was installed – to ninth month) with their family (father, or mother or both). It has contributed to the social engagement between participants with autism and their family.

The trial also reveals the potential of the robot in facilitating the indirect communication between the family and people with autism. To this point, the mother commented, "I worked last night and generally have a sleep after tea before going to work. I usually set my alarm to get up. On doing so I sent Melissa a message could she please come and turn the light on. MC was in the lounge room watch TV. And she did. Next time I will do the same but will get her to put the kettle on as well."

7.8 Observed emotion ratings

Video recordings were activated automatically by the robot using its eye cameras whenever the interaction was detected. Mood states of the participants were assessed for each interaction using the Observed Emotion Rating Scale (Lawton, Van Haitsma, & Klapper, 1999). A member of the research team trained two research assistants not involved in the facilitation or control of the intervention to analyse the videos using the emotional rating scale measures. To be more specific, each video was analysed and the emotional state of the participant was classified as general alertness, pleasure, or displeasure (anger, anxiety/fear, or sadness). The observed emotional states are summarised in Table 5.

Table 5. Observed emotional states

Pleasure					Displeasure														General alertness						
					Anger					Anxiety				Sadness										
Smiling	Singing	Kissing (robot)	Flapping	…	Physical aggression	Yelling	Cursing	Making distancing gesture	…	Shrieking	Hand wringing	Wincing/grimacing	…	Crying	Frowning	Head turn down	…	Participating in task	Maintaining eye contact	Yes following object or person	Responding by moving or saying	Turing body	Moving toward person or object	…

Pleasure = OR (1,0,0,1,0)=1

Alertness = OR (1,1,0,0,0,0,0)=1

1	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0

Anxiety = OR (0,1,0,0)=1

Figure 23. Samples of data input and emotion state outputs

For each video, the emotional response of the participant was annotated as a string of binary values which value ‘1’ annotated to an emotional sign if that sign is detected. Finally, the emotional state was annotated if at least one of its signs occurred (annotated with value ‘1’). For instance, the first data input in Figure 23 means that the emotional signs smiling, flapping, participating and eye contact have occurred in the input video. Accordingly, this data entry was annotated with both pleasure and alertness since at least one sign of those two emotional states has appeared in the input video. Similarly, the second data entry is annotated with anxiety since one of its signs has the value ‘1’.

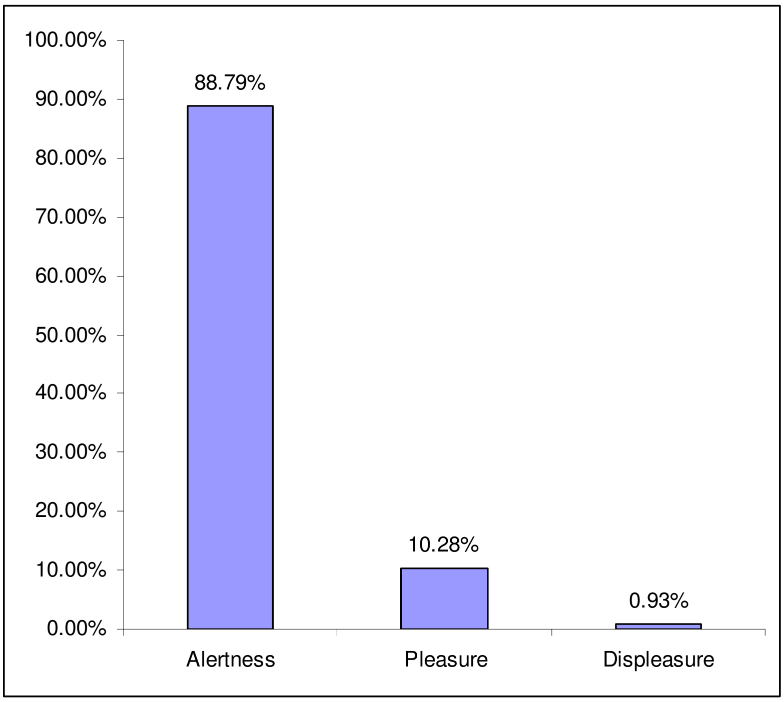


Figure 24. Statistics of emotional response analysis

The statistics of all data entries input by the annotators are summarized in the Figure 24. The results show that the alertness rate is over 88% which indicates the high reaction or engagement rate of the trial participants with the robot, and about 10% of the reaction are pleasure evolving smiling, touching or kissing actions. Only about 1% of the reactions are classified as displeasure (most were observed as anxiety).

8 DISCUSSION, PRACTICAL IMPLICATIONS AND LIMITATIONS

The experience of positive emotions is an important component of emotional wellbeing. However, autism may impede the ability of a person to pursue pleasurable moments and young people with autism may have limited opportunity to engage in meaningful activities and, in particular, activities that are focused on a positive emotional response in a home-based environment. This research demonstrates that social robots like Lucy with human-like characteristics that involve voice, gestures, emotion and their combination with personalized services (i.e., quizzes, favourite songs, books) can be used in home-based environments to provide sensory enrichment and generate sustainable social engagement among young people with ASD. In addition, the results of this study indicate that human-like characteristics in combination with personalized service design facilitate the acceptability of Lucy among young people with autism; D and S accepted the daily prompts of Lucy which allow them to become more productive and useful. Lucy can also be used as a learning tool to help D and S with ASD learn basic skills which are then potentially transferred to actual activity. In this study Lucy has helped S to improve his hygiene habits.

This research also reveals the importance of personalization and novelty to human engagement in longitudinal care. To be more specific, the service contents need to be personalized to each individual preference and they need to be updated over time to maintain the engagement of human partners with the socially assistive robots in the longitudinal care. As evidenced during the trial service personalisation has led to spike in use of Lucy's services. D and S's parents can write their own stories and quizzes which can be uploaded on Lucy to sustain novelty of engagement and to improve the social and learning skills. This ability of Lucy to automatically integrate voice, emotive expressions, sound effects, head and body movement and deliver new services in a engaging manner has been liberating for the parents of people with ASD. In the future, a network of Lucys will be trialled for supporting people with autism and increasing the range and variety of services.

Thus the work provides important support for the idea that beside the role of diagnosis and treatment for people with autism as studied in existing work, robots like Lucy may be used in home-based environments to assist young people with ASD to be more productive and useful as well as provide some respite to the carers (i.e., parents). The acceptability and non- judgemental nature of interaction of Lucy with D and S has allowed their parents to use Lucy as a means of making D more productive at home and getting household chores done by getting Lucy to vocalise messages/reminders sent from their smart phones to S and D in an engaging manner (see attached video).. The parents along with D and S play Bingo with Lucy as a family bonding exercise (see attached video). Lucy's ability to communicate with other pervasive devices like smart phones and tablets has also created opportunities for using gamification as a technique for rewarding D and S.

This research was limited primarily by the sample size. The success of this field trial has led us to deploy social robots to support more people with autism in more home-based environments. This work has not considered aspects related to diagnosis of autistic behaviour in people with autism which will be the focus of future work. We are also working on increasing the duration of interaction between the person with autism and the social robot in a 24 hour day.

9 THEORETICAL IMPLICATIONS OF WORK

One of the primary challenges in this research has been how to engage people with autistic traits (i.e., who have a limited concentration span) over a sustained period of time. In this research, two adults with autism have interacted with Lucy for more than 150 hours over a period of nine months. From a theoretical standpoint, the social innovation has been achieved through integration of three design dimensions, namely, comprehension of people and society, ICT, and computing and engineering as shown in Figure 25. These three dimensions have been translated into a multi-layer design architecture shown in Figure 26.

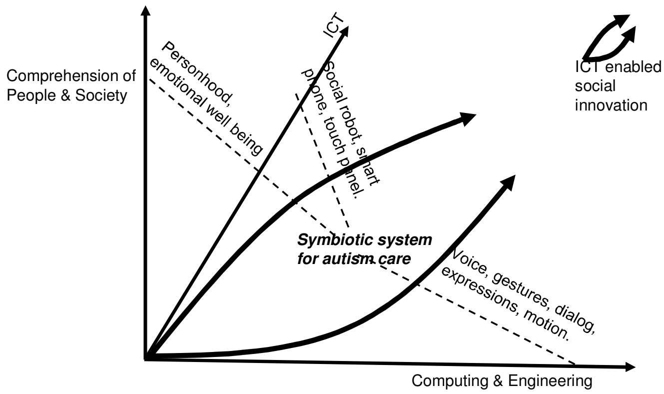


Figure 25. Symbiotic system for autism care

An important challenge in this research has been to engage, enable and empower people with autism. This research represents integration along

Embedded in Lucy's architecture are five layers as shown in Figure 26. At the base level, the interactional components related to personhood and socially assistive robotics (e.g., empathy, adaptation (Tapus et al. 2007)) involve design and development of network-centric human communication tools, like voice and emotion dimension recognition, face recognition and tracking, gesture and motion, dialog modelling, and adaption techniques. This is the bottom layer in Figure 26.

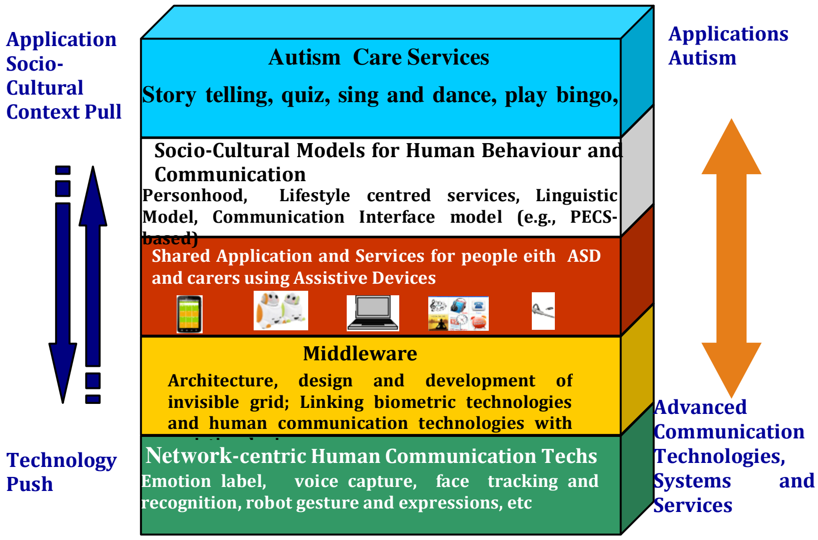


Fig 26 Five Layers of Lucy's Architecture

In this layer, human-like communication modalities like voice vocalisation and recognition, face tracking and recognition, Lucy's emotive gestures, head and body movements head and body facial expression analysis and changes in emotion dimension labels in a continuous manner as expressed by people in real care environments. Unlike prevalent emotion recognition technologies which use stereotypical facial expression benchmarks of happy, sad, angry (Lang 1995; Picard 2000), Lucy monitors the changes in the facial features which indicate transition into a negative or positive emotion state along the emotion (affect) dimension. The application of this component has not been reported in this paper.

The middleware layer includes software programs which provide the interface for communication between Lucy and other assistive devices like smart phone, touch panel, and applications of Lucy. Lucy's wireless network connectivity allows it to be integrated with other devices and cloud computing infrastructures, thus seamlessly becoming a part of a unified communication network and Internet of Things. It is designed for a network of Lucy to coordinate activities in a home based environment function together with other devices. The shared intelligence layer supports development and execution of services distributed on various devices like Lucy (e.g., gesture, expressions, emotion recognition and motion (dance), service personalisation, speech vocalization.), touch panel (e.g., quiz execution in conjunction with Lucy), laptop (e.g., speech recognition), remote communication between human communication tools (e.g., on PC or touch panel). A remote server is also used for upload/downloads data onto and from Lucy, respectively.

The socio-cultural layer includes psychological and linguistic models of human behaviour and communication depending upon the social context. In terms of residential aged care trials, the socio-cultural layer models the subjective experience of the residents in terms of group and one-to-one services with Lucy. Socially assistive robots need to be designed in a social context. Within the social context the robot enabled services for the human partner need to be underpinned in concept of personhood to enable engagement and reciprocity. Secondly, the human-robot interface should be believable for breaking technology barrier and to facilitate a long term meaningful reciprocal relationship between assistive robot and young people with autism. This aspect has clear implications for design of interactional environment and human-like communication modalities, and ornamental design of the robot (e.g., two young adults with autism and their family think Lucy looks cute with its baby face, etc.) to enable its productive use. Lucy, in this context provides a rich range of communication modalities to create believable expressions for services delivered by it. It also operates as friendly interactive hub for integrating all pervasive devices in the home.

Finally, the application layer focuses on design and development of personalised services derived from the social context layer using human-like communication modalities. This integration of social design with technology design provides seamless basis for social interaction and breaks technology barriers. The ability of the application layer to enhance and adapt the personalised services facilitate novelty and sustainable social engagement.

10 CONCLUSION

In this paper, we have reported the outcomes on the first ever longitudinal home-based field trial of social robot (Lucy) with young people with autism in Australia. The paper adopts a design science approach by embodying the concept of personhood in Lucy and delivering personalised services with a rich variety of human-like communication modalities meaningful positive changes in daily lives of young adults with autism in a real home-based care environment. Multiple sources of collection of data including interviews, and logging of actual activity or interaction patterns have been used to enhance the content validity of measurement of emotional engagement, reciprocity and productivity constructs related to emotional wellbeing and subjective experience of the person with autism. The work also represents social innovation in the area of socially-assistive robot enabled home-based care through long term (9 months) engagement of two young adults with autism. The trial in the 9 month period has provided hope and respite to the parents. In future, we are adding new services and enhancing existing ones. Lucy has successfully eliminated the barriers of use of technology by people with autism, and more importantly has had a positive impact on their productivity and usefulness, contributing to enhance their quality of life.

Theoretically, the work also represents a step forward in human-computer interaction for addressing social issues by employing a multi-dimensional design approach based on integration of social perspective like personhood and emotional well being with cutting edge technology design involving socially assistive robots with human-like communication modalities.

11 ACKNOWLEDGEMENT

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