THERAPUETIC VERSUS PROSTHETIC ASSISTIVE TECHNOLOGIES: THE CASE OF AUTISM

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ABSTRACT

Assistive technologies can be divided into two broad categories: therapeutic and prosthetic. Therapeutic tools aim to help an individual deal with a disabilityor particular deficiency through teaching and intervention programmes. Prosthetic assistive technologies, on the other hand, supplement or replace natural abilities in which a person may have a disability. In this paper, we consider these two alternative approaches to rehabilitation for the case of autism. Autism is a spectrum of neuro-developmental disorders that is manifested in a triad of impairments: social interaction, communication, and repetitive behaviour or obsessive interests. The majority of assistive technologies for autism fall in the category of therapeutic. The lack of prosthetic technologies may be largely attributed to the fact that, to date, computers lack social and emotional intelligence, which are the skills that people diagnosed with autism need help with the most. We argue that the principal problem with therapeutic tools, namely the failure to generalize to real-world scenarios, provides the motivation for pursuing prosthetic technologies for autism. We summarize advances in two key technology areas, affective computing and wearable computing, which make the vision of prosthetic tools for autism a reality. In light of these advances, we present our own attempt at developing a prosthetic tool for autism: the emotional hearing aid. We conclude with a discussion of open questions that warrant future discussions and research.

KEYWORDS: Autism Spectrum Conditions, Mind-reading, Therapeutic technology, Prosthetic technology, Assistive technology, Emotion recognition

INTRODUCTION

The Technology-Related Assistance for Individuals with Disabilities Act of 1988 define assistive technologies as the range of products that are used to increase, maintain, or improve the functional capabilities of individuals with disabilities. These technologies can be divided into two broad categories: therapeutic and prosthetic. Therapeutic tools provide assistance in the form of teaching or therapy, with the aim of helping an individual deal with a disability or particular deficiency. Consider for instance, the case of cerebral motor disabilities such as Cerebral Palsy, a chronic condition affecting body movements and muscle coordination caused by damage to one or more specific areas of the brain. The variety of therapies that are used with people who have Cerebral Palsy include a physical therapist, an occupational therapist, and a speech-language pathologist. These aim to work with the person to help him or her improve posture, movement and communication. Prosthetic assistive technologies, on the other hand, supplement or replace the natural capacities in which a person may have a disability. Prosthetic technologies give people with various disabilities access to a wider range of resources and functions, and help them integrate better in the community. Various prosthetic systems are available for people with Cerebral Palsy, the applicability of which depends on the specificity of brain area damaged and the person's motor and intellectual abilities. These computer-based systems are based on a simple visual user interface, and often use haptic force feedback [29]. They enable a level of communication which considerably increases the person's autonomy. Hearing aids and other amplification devices for people with hearing problems are another example of prosthetic devices. Many factors affect the choice of whether therapeutic or prosthetic technologies are considered for a particular disability. This depends on the type of disability, its severity, a person's specific capabilities, and the affordability and social acceptability of the alternative technologies. It is also entirely possible that the two approaches be used to complement each other.

In this paper, we consider these two alternative approaches to rehabilitation for the case of autism. The consensus that early intervention methods can be very effective has motivated a wide range of therapeutic technologies and intervention programmes aimed at children diagnosed with Autistic Spectrum Disorders (ASD). These include computer-based educational software, virtual environments, and robotic platforms. Although these technologies have shown a general acceptance from children who have used them, there is little scientific evidence to show that these children are able to apply what they learn to real-world scenarios. The risk of failure to generalize suggests that the alternative approach of developing prosthetic, rather than therapeutic, technologies is worth pursuing. To date, there are no such tools for autism. This is mostly due to the fact that computers lack the social and emotional intelligence skills that are the ones that people diagnosed with autism need assistance with the most.

This paper surveys existing assistive technologies for autism and argues that with advances in two key technology areas—affective computing and wearable computing—there is a lot of potential for computer-based prosthetic tools. The paper proceeds as follows. The following section introduces ASD. The paper then summarizes existing intervention programmes and the factors along which they differ. A survey of existing therapeutic tools in light of these factors is presented next. The paper then draws attention to the lack of prosthetic tools in autism, and describes recent advances in affective computing and wearable computing. In light of these advances, the paper presents the emotional hearing aid, our own attempt at developing a prosthetic assistive tool for ASD. The paper concludes with a discussion of open questions and its implications for future research directions.

AUTISM SPECTRUM DISORDERS

Autism is a lifelong developmental disability that affects the way a person communicates and relates to people around them. It is a spectrum of neuro-developmental conditions, and hence is formally referred to as Autism Spectrum Disorders, or ASD. Classic autism lies on one extreme of this spectrum and typically involves associated learning difficulties, below average intelligence (IQ), and language delay. Asperger Syndrome and High-functioning Autism are two subtypes at the higher-end of the autistic spectrum, where individuals exhibit the same social interaction difficulties and restricted patterns of behaviour and interests seen in classic autism, but have an average or above average IQ. In Asperger Syndrome there is no general delay in language [6].

A Triad of Impairment

ASD is characterized by abnormalities in a triad of behavioural domains [1]:

- Social interaction
- Communication
- Repetitive behaviour and obsessive interests.

The abnormalities in social interaction are characterized by one or more of the following impairments: 1) an inability to regulate social interaction, 2) failure to develop peer relationships that involve a mutual sharing of interests, activities, and emotions, 3) a lack of empathy as shown by an impaired or deviant response to other people's emotions, and 4) a weak integration of social, emotional, and communicative behaviours. These abnormalities result in difficulties in forming social relationships, the inability to understand others' intentions, feelings and mental states, and difficulties in understanding gestures and facial expressions. In addition, people with autism usually show little reciprocal use of eye-contact and rarely get engaged in interactive games.

Impairments in communication are apparent through a delay in, or total lack of, development of spoken language that is not accompanied by an attempt to compensate through the use of gesture or mime as an alternative mode of communication. Often there is a relative failure to initiate or sustain conversational interchange. There is also a stereotyped and repetitive use of language or idiosyncratic use of words or phrases.

Finally, restricted, repetitive, and stereotyped patterns of behaviour, interests, and activities are common in autism. Individuals with autism often show a preoccupation with one or more stereotyped and restricted patterns of interest that are abnormal in content or focus or intensity. They may also show a compulsive adherence to specific, non-functional routines or rituals, and have stereotyped and repetitive motor mannerisms that involve either hand or finger flapping or twisting.

Empathizing-Systemizing Theory of Autism

The empathizing-systemizing theory of autism [6] is one of the most prevalent theories that explain the triad of impairment in autism. It is an extended version of the mind-blindness theory of autism [3]. This view of autism, which is supported by evidence from psychological studies and more recently by studies of neuroscience, argues that people with ASD have deficits in the process of empathizing. The term "empathizing" encompasses two major elements. The first component is mind-reading, or theory-of-mind, which describes one's ability to attribute mental states to others by observing their behaviour. People with ASD appear to be specifically impaired in this ability, as reflected in tests of mental state attribution. Mind-reading is an important component of a broader set of abilities referred to as social intelligence [41, 50]. Through mind-reading we are able to link behaviour to mental states, and mental states to intentions [15, 47, 48]. This enables us to make sense of other people's behaviour and predict their future actions, and allows us to communicate effectively with other people [2, 25]. We monitor the nonverbal communication cues of a listener, determine his/her communicative intentions, decide whether or not the listener is engaged in the dialogue, and whether he/she understood the message. The second component, sympathizing, is closely related to and affected by the first component. Sympathizing is the ability to have an emotional reaction that is appropriate to other people's mental states. With deficits in the ability to empathize, people diagnosed along the autistic spectrum often have difficulties operating in the highly complex social environment in which we live and are, for the most part, unable to read or understand other people's emotions.

In parallel to the deficit in empathizing, people diagnosed with autistic spectrum conditions show intact or even superior "systemizing" abilities used in the analysis and construction of systems [6]. This ability to systemize explains in part the obsessive behaviour of people with ASD and their attention to detail. The fascination and obsession with machines, and in particular with the underlying rules and regularities that govern machines' operation, has been documented in many clinical descriptions of children with autism, such as in Baron-Cohen and Wheelwright [4] and Frith [17].

INTERVENTION PROGRAMMES

Despite difficulties in social interaction and communication, children diagnosed with ASD, particularly those with Asperger Syndrome seek interaction with other children [2, 17]. These attempts to integrate often fail because of a lack of understanding of nonverbal communication such as facial expressions. The general interest in social interaction provides the motivation for the many intervention programmes that have been proposed for ASD. These intervention programmes seek to teach children with ASD various social skills in one-to-one or in small group settings. I will particularly focus on those programmes that address the first of the triad of impairments—social interaction—drawing attention to the idealogy behind each programme.The programmes address one of the following areas of impairment:

- Social-perceptual understanding
- Social cognition
- Social commonsense

Social-perceptual Understanding

Social-perceptual understanding is the ability to detect and decode others' mental states based on immediately available, observable information. For example, one could attribute the mental state confused to a person given their facial expressions and/or tone of voice. As its name implies, this ability involves perceptual, or bottom-up processing of facial and other nonverbal stimuli. Programmes that are concerned with social-perceptual understanding explicitly teach children how to read emotional and mental states of people from facial and other nonverbal stimuli. Howlin et al [25] describe a number of emotion cards, which are schematic faces that portray different emotions, and are often used in classroom settings.

A less structured approach, especially suitable for use with children, involves emotional indexing of the child's surrounding environment [16]. Typically, the child's carer indexes the emotional content of situations as they arise, and suggests possible actions that can be taken by the child. For example "Oh, Mary got hurt. She is crying. Can you tell Mary, 'I am sorry'?" This approach to teaching emotions has reportedly improved the social competence of some children [16, 25]. In contrary to most other teaching approaches, social indexing works in the child's natural interaction environment reinforcing appropriate social behaviour in a spontaneous setting. Unfortunately, this method is not always available for the child, as it requires the physical presence of the carer, which in some cases, as in school settings, might be impractical. Also, unlike highly structured approaches, with this method it is almost impossible to recreate events once they have occurred. For example, using the above example, it is hard to get Mary to fall off her bike again in order to recreate her facial expressions and tears as she falls.

Social Cognition

Social cognition pertains to one’s ability to reason about mental states with the goal of explaining or predicting a person's actions. Examples include distinguishing jokes from lies, or predicting peoples' behaviour on the basis of false beliefs. While social-perceptual understanding relies principally on perceptual information that is available in the immediate and observable environment, reasoning about others' mental states to explain or predict action requires one to access knowledge about the person in question or their contextual circumstances. False belief tasks test a person's understanding that other people's thoughts can be different from one another and from reality. These tasks are the prototypical measure of social cognition.

Programmes that teach about mental state reasoning focus on joint attention, perspective-taking, understanding false beliefs and how to predict actions based on people’s behaviour and mental states. For example, LEGO© has been used to improving social competence [35] through encouraging close interaction and joint attention skills. The programme was evaluated based on the observation of subjects in unstructured situations with peers. Results revealed significant improvement on at 12 and 24 weeks of taking part in the programme.

Social Situations

The third class of intervention programmes are concerned with teaching child how to behave in a socially-appropriate manner in different contexts, such as how to stand in a queue, how to initiate conversation, and how to engage with people in conversation.

Social Stories by Carol Gray [21] are visual stories that are designed to improve children's understanding of various social situations and to teach them specific behaviours to use when interacting with others. A Social Story describes a situation, skill, or concept in terms of relevant social cues, perspectives, and common responses in a specifically defined style and format. For example, Most people eat dinner before dessert. This is a good idea or I will try to keep my seat belt fastened. This is very important. While Social Stories are typically written in the first person and are very simple, some are more detailed, are written in the third person, and are geared toward the abilities, interests, and vocabulary of older or higher-functioning individuals. Similar to Social Stories, Comic Strip Conversations [20] are used to teach children how to visually work through a problem situation and identify solutions.

Social indexing, like emotion indexing that is used in social-perceptual understanding, involves indexing the child's environment as different social scenarios arise.

Choice of programme

Besides the differences in focus and objectives, the above intervention programmes differ with respect to other several factors. The first factor is the amount of structure in the programme. Highly-structured methods, such as Gray's Social Stories, use carefully planned teaching material deployed in a relatively controlled environment, while social and emotion indexing are less structured. The methods also differ in the setting in which the teaching takes place. These range from being hypothetical, such as methods used in classrooms, to being naturalistic such as that used in LEGO© therapy [35]. In addition, the programmes are targeted at different ASD subtypes, which are reflected in the complexity level of the teaching material in terms of cognitive and language requirements.

THERAPEUTIC TECHNOLOGIES FOR AUTISM

Computer-based technologies are particularly suitable for use in therapeutic contexts since they are well accepted by individuals ASD. Indeed many children with ASD have demonstrated that they can learn through these technologies [40]. Computers are also an ideal resource to join a child's "attention tunnel". External events can be more easily ignored when focusing on a computer screen as the area of concentration is limited to the bounds of the screen. The small area of focus might explain why some people with autism can tolerate higher sensory input via a computer than they can tolerate elsewhere. In addition, computers offer a context-free environment in which many people with autism feel comfortable. Finally, computers are predictable and, are therefore, controllable. They enable errors to be made safely, encouraging children to use non-verbal or verbal expression.

Therapeutic tools for autism include educational software, virtual environments, and the use of robotics. These technologies differ with respect to the class of social interaction skills they address, the degree with which they are structured, whether or not they operate in the child's natural environment, and the extent with which they are interactive. Table 1 compares existing technologies along these factors. The table also indicates if children who have used a particular tool have been able to generalize to scenarios similar to the ones they have been exposed to while using that tool.

Educational Software

Fun with Feelings [18] (Figure 1) is a commercial software product that aims to teach children about the basic emotions (happy, sad, angry, afraid, surprised, and disgusted). Using a series of games, the children are taught the facial expressions and sounds associated with each of the basic emotions, and the situational factors that give rise to them. Each emotion is broken down into several small pieces that are built in stages into an image of that emotion for the child. While general reviews of the software indicate that it is popular among autistic children, to the best of our knowledge, there are no scientific studies that evaluate whether children who have used this software show an improvement in reading emotions.

Figure 1 Fun with feelings

Bubble Dialogue [51] is a role playing computer program in which pairs of users collaborate to develop a narrative. Typically this is either two children or a child and adult pair. The software allows users to represent characters' thoughts as well as their speech, which therefore allows participants, through their characters, to reveal thoughts and views that might otherwise be hidden and very difficult to access. This also encourages the child to consider what the other character (as well as their own) is thinking or feeling as well as saying. It therefore encourages perspective-taking, an area which is lacking in autism.

Early empirical work using the program found that children who are normally reluctant to role play are willing to do so when using the program. There is also evidence that children readily identify with the characters they portray, thus allowing the program to be used as a diagnostic and methodological tool, in addition to its role in helping children develop communication and literacy skills through developing Bubble Dialogue narratives.

Mental state simulator [19] is a software that uses formal AI reasoning to teach children diagnosed with High Functioning Autism about mental state concepts and representations. The simulator was tested with two children over the span of a year. Their ability to reason about different mental states was tested before they started using the program, and after a year of use. The results show an overall improvement in both children with reasoning about deception, pretend play, and the expressions of surprise, sorrow and happiness. They were also able to understand jokes and to a lesser extent infer intentions of others. It is worth pointing out that the two children were also attending other therapeutic sessions along with using the mental state simulator. It is therefore unclear whether the marked improvement can be entirely attributed to using the software. In addition, two cases is a rather limited test-set, making it hard to draw conclusions about its success in helping these children learn about emotions beyond the hypothetical scenarios presented in the program.

Figure 2: Screen capture from the emotions library from The Mind Reading DVD [5]

The “Mind-reading DVD” [5] (Figure 2) provides a comprehensive resource for helping individuals diagnosed along the autism spectrum recognize the facial expressions of emotions. It is an interactive guide to learning about emotions, with a library of over 400 emotion concepts and many games. The DVD was developed by a team of psychologists led by Professor Simon Baron-Cohen at the Autism Research Centre at the University of Cambridge, working closely with a London multi-media production company. The emotions library of the DVD provides a corpus of audio and video clips portraying 412 emotion concepts. Each emotion is captured through six audio and video clips, and is also explained through six stories to give a flavour of the kinds of contexts that give rise to that emotion. The games zone encourages informal learning about emotions in a less structured setting. The games tackle a number of contexts for reading emotions including a school, an office and a marketplace.

A number of studies are underway to evaluate the effectiveness of the Mind Reading DVD as a tool for teaching children with autism about emotions. The preliminary results are as follows: children who have used the DVD to learn about emotions perform relatively well on the standardized “Reading the Mind in the Eyes” test compared to other children with similar autism conditions, but who have not seen the DVD. However, both groups fail to correctly identify the feelings and emotions of characters in film excerpts (compared to a control group). This suggests that, even though the DVD has in fact helped these children learn about emotions, the videos were sufficiently different from real-world facial stimuli that the children failed to generalize. It is worth noting, however, that to correctly identify the emotions of the characters in the film excerpts, it was necessary to integrate multiple modalities, beyond the face, and even other context cues. For instance, in one of the films, a little girl dressed in ragged clothes is shown sitting by a staircase. The camera then zooms out to show lots of other children marching happily in to a ballroom. The little girl is evidently upset and feeling lonely. To answer this question correctly one had to integrate all this information meaningfully. The integration of different modalities and the subject of context are not explicitly taught in the DVD; rather, it focuses on cues in the face or intonations in the voice.

Virtual Environments

A Virtual Environment (VE) is a computer-generated, 3D environment that aims to surround, or immerse the user so that he or she becomes part of the experience in a simulated environment [12], and potentially allowing the transfer of skills from the virtual to the real world. There are several levels of VE, the most sophisticated of which is called immersion. In this version the user wears a which tracks the person’s movement and uses that to reposition the user's location in the scene. The application of virtual environments to autism has several advantages. It can be used to rehearse problematic real-life situations and simulate different scenarios in a safe learning environment in which the individual may make mistakes which might be physically or socially hazardous in the real world. In addition, the environment can be altered gradually to teach generalization and cross-recognition.

Strickland [56] presents several games that teach children diagnosed with autism about a range of social situations. StreetGame and FireSafetyGame allow children to practice correct street safety procedures, and what to do in the case of fire. In a study of two children with mild to moderate degrees of autism, Strickland et al. [57] found that they accepted the VR equipment (headset), and responded to the computer-generated world by verbally labeling the names and colours of objects. Both children consistently tracked moving objects in a scene, with both eyes, head, and body turning.

Cheng et al. [11] develop and evaluate an interactive virtual environment to improve emotion understanding amongst children with Autistic Spectrum Disorders. Their environment focuses on teaching the three types of emotions identified by Howlin et al. [25]. These are situation-based emotions, or that are concerned with how particular situationa make people feel, desire-based emotions that are caused by a person’s desire being fullfilled or not, and belief-based emotion that are caused by the beliefs of people and whether they agree or conflict with reality.

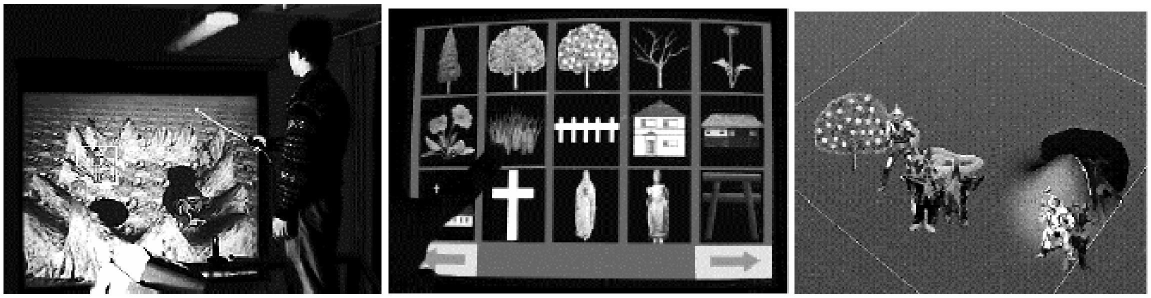

Figure 3 The virtual sand box [23]. (left) The appearance of the virtual sand box; (middle) the touch panel displayed for selection of figures; (right) landscape created by a male of age 12, who is mildly autistic.

The virtual sand box [23] enable children to interact in a virtual setting modelled around real-life social scenarios. The sand play technique is a psychotherapy technique that has been used to diagnose and treat people with ASD and other developmental conditions. autism. Patients are asked to play with a sand box; modelling real-world scenes and context using sand and placing figures such as people and animals in these scenes. These created landscapes are then carefully analyzed by therapists to identify the patients' psychological and psychiatrical problems. The virtual sand box is a virtual simluation of this environment. The virtual sand box was evaluated for diagnosis. Further studies are needed to evaluate its effectiveness as a therapeutic tool.

Kidtalk [10] is a therapist-moderated online chatting environment, where children work through common social situations, such as going to the movies, or going to a party, by chatting online. The interaction is broken down into stages or scenes which provide social context and goals for the children to achieve. It is built on group social skills therapy, which is used to teach children pivotal social skills, increase their sense of affiliation with others, and improve self-esteem. Group social skills therapy, is inacessible to many because of geographic, economic and other factors. This online environment makes the therapy more accessible. An evaluation of this project is currently underway.

Virtual environments present a richer setup for children to explore different social scenarios compared with educational or training software. However, like with educational software, more studies are needed to investigate if learning experiences through these virtual environments generalize to other real-world environments.

Robotics

In addition to computer-based technologies, several therapeutic tools are based on the use of robots. Contrary to people's social behaviour which can be very subtle and widely unpredictable, the use of robots allows for a simplified, safe, predictable and reliable environment where the complexity of interaction can be controlled and gradually increased. It is also more realistic and engaging than interacting with a screen.

The AURORA project [13, 59] investigates the suitability of different robotic platforms, as an interactive toy that can engage children in a therapeutically relevant environment. Different embodiments of this toy have been investigated, including the mobile robot Labo-1, and a small humanoid doll (see Figure 4). The aim is to encourage pro-active social behaviours towards the robot, elicit robot-child eye contact, and teach the child the basics of turn-taking and interaction games. The robot can also be used as an object of shared attention, encouraging interaction with peers and adults.

Figure 4: Range of robotic platforms that have been developed for the AURORA project

Werry et al. [59] and Robins et al. [53, 54], have demonstrated the ability of a mobile robot to provide a focus of attention and shared attention where the robot's role as a mediator became apparent in child-teacher interactions, child-investigator interactions and child-child interactions. Their findings so far suggest that children with autism pay more attention to a mobile robot than to a non-robotic toy. Long-term interactions with children show an increase of therapeutically relevant behaviours such as imitation. The authors emphasize that even though their findings are encouraging, caution is needed in the interpretation of the data: positive long-term effects of robots on children with autism still need to be demonstrated.

The Affective Social Quotient project [7] consists of short digital videos that embody one of several basic emotions and a set of physical dolls linked by infrared to the system. The system knows which dolls correspond to which clips, so that the child can explore emotional situations by picking up dolls with certain emotions, or the system can prompt the child to pick up dolls that go with certain clips.

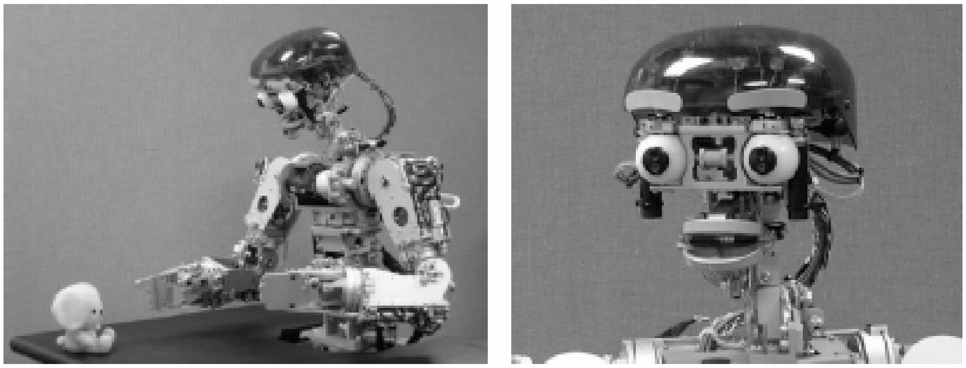

Figure 5 Infanoid, the upper-torso infant robot, and its expressive active vision head. From Kozima and Yano [33].

Kozima and Yano [33] investigate the possibilities of using Infanoid, a baby humanoid robot shown in Figure 5, in autism therapy. The objective is to help children with ASD establish a mapping between the feelings and actions of the robot, and their own feelings and actions. Similar to the AURORA project, they propose engaging the child in imitation play, gradually introducing the complexity of the interaction.

In summary, the above technologies are mostly remedial tools aimed at providing a learning environment to teach children the fundamentals of social behaviour. They do not provide assistance to individuals with autism beyond that gained through teaching. In addition, as they do not operate in a natural human-human interaction environment, they risk failing to generalize [25].

PROSTHETIC TECHNOLOGIES IN AUTISM

The risk to generalize is a limiting factor in therapeutic tools, serious enough to warrant the investigation of alternative remedial tools, namely prosthetic ones. There are several documented cases in which prosthetic technologies, similar to those used with people with cerebral palsy, have been used to assist non-verbal autistic people or those experiencing difficulties in expressing themselves verbally. These assistive devices build on the advanced visual skills reported by people with ASD, and use a combination of drawings and picture cards similar to the communication cards already used by a number of autistic people to communicate with their entourage.

Apart from these few cases, there are almost no assistive tools that are designed to assist, rather than teach, people diagnosed with autism. This is mainly because, to date, computers have a lack of social or emotion intelligence skills, which is the area in which people with ASD need the most help. We argue that this is bound to change as computer technologies become emotion-aware and socially-adept, as computers move from being limited to a desktop environment to being integrated in various wearable devices. These advances, combined with real-time algorithms for machine vision provide the foundation of building technologies that augment the capacities of people with ASD.

Affective Computing

Affective computing is a relatively new field of computing that relates to, arises from, or deliberately influences emotions [43]. The field draws its inspiration from the increasing literature that emphasizes the interplay of emotion and reason. These findings have led to a new understanding of the human brain, in which it is no longer considered as a purely cognitive information processing system; instead it is seen as a system in which affective and cognitive functions are inextricably integrated with one another [34]. Accordingly, researchers in affective computing argue that an accurate model of the user would have to incorporate the affective as well as the cognitive processes that drive the user's reasoning and actions.

Figure 6 Affect sensing technologies: (left to right) The Expression Glasses [55], the Galvactivator [44], the Pressure Mouse [49]

Since the inception of this field, a number of researchers have charged ahead with building machines that have affective abilities. In particular, there has been significant progress on the affect-sensing front. The Expression-Glasses [55], the Galvactivator [44], and the pressure mouse [49] are just a few examples of the different approaches that have been implemented to detect emotion from nonverbal cues. Open research problems include making these affect-sensing systems more robust to variations in interaction contexts, applying them to spontaneous human-computer and human-human interaction contexts, and building more intelligence in the systems with regards to the range of mental states that are sensed. From the point of view of applications, systems that adapt their responses based on the emotional state of the user include the learning companion [32], the computer that detects and responds to user frustration [30], educational games [8], and telemedicine [36].

As these challenges are addressed over time, information about a user's mental state will become as readily available to computer applications as are keyboard, mouse, speech and video input today. Interaction designers will have at their disposal a powerful new tool that will open up intriguing possibilities for assistive tools that are especially targeted at people with affective disability.

Wearable Computers

There has been an increasing surge of interest in developing wearable devices with the goal of applying them in applications of augmented reality and perceptual interfaces, especially vision-based interfaces. In augmented reality, computer-generated images are superimposed over a user's view of the physical world. When combined with a mobile computer, augmented reality can also be experienced in an outdoor environment. Perceptual interfaces are technologies that have perceptive capabilities built in them, vision being one of them. Vision-based interfaces perform a range of tasks including people recognition, identity recognition, gesture recognotion, facial expression for emotion recognition, and object detection and video surveillence.

Figure 7 The evolution of Tinmith backpack designs at 2001, 2002 and 2004, Piekarski *et al* [45].

One example of a wearable computer is the Outdoor Tinmith backpack, developed at the Wearable Computer Lab, University of South Australia, which investigates mobile outdoor augmented reality [45]. The core of the backpack is a polycarbonate box mounted onto a baby carrying harness, which makes it both comfortable and reasonably lightweight. Plastic Velcro is used to permit simple reconfiguration of devices and provides a cable routing infrastructure. USB is embedded into the devices to remove the need for legacy interfaces, and provides a compact power and data distribution mechanism. In addition, specialised video overlay units and FPGAs are used to perform CPU intensive tasks with minimal power consumption and faster performance.

Figure 8 Mobile user interface used in Kolsch et al [31]. All hardware components aside from display, camera, and microphone are in the backpack.

Kolsh et al [31] present a hand gesture recognition system that can be used in mobile computing environments. The system, shown in Figure 8Figure 9, uses the Outdoor Tinmith Backpack Computer. Only the head-worn devices are exposed, everything else is carried in a small backpack. Their vision system is fast and robust to variations in lighting conditions and dynamic background.

Besides wearable head displays, a range of wearable digital camcorders are available. For high-end applications, Point Grey Research [46] manufacture several designs, which have been used mostly for research purposes and other specialized applications. In the consumer market, Deja View, Inc. [14] have recently introduced an inch long digital camcorder which is small enough to clip onto a pair of eyeglasses and record video onto flash memory, shown in Figure 9.

Figure 9 Wearable digtal camcorder by Deja View Inc

In assistive technology, wearable devices have been proposed to assist those with cognitive impairments, such as traumatic brain injury and dementia. For example, COACH (Cognitive Orthosis for Assisting activities in Home) [39] aims to develop automated computer vision systems to assist patients . Such systems would be able to non-invasively monitor the patient, stepping in to provide help in the form of verbal or visual prompts when necessary.

Despite these significant advances, mobile wearable systems have not seen the level of maturity, in terms of robustness, speed, and accuracy required for real-world applications. Moreover, the designs are too bulky and heavy to be used. Notwithstanding these hurdles, wearable computers promise to extend the use of computers beyond the traditional desktop environment to more natural contexts and interaction scenarios.

The Emotional Hearing Aid

The emotional hearing aid, which was first introduced in el Kaliouby and Robinson [26], is a portable assistive computer-based technology designed to help children with Asperger Syndrome read and react to the facial expressions of people they interact with in real-life situations. In a sense, this tool is analogous to a hearing aid, which allows people with hearing problems to communicate with the rest of the world. The main modules of the emotional hearing aid are modelled around the emotional indexing approach, described earlier in this paper. The idea is that the tool is responsible for indexing the emotions of the people the child interacts with, by analyzing the facial expressions of surrounding people, inferring their mental states and communicating that back to the child.

The emotional hearing aid implements the two principal elements which constitute one’s ability to empathize with others: mind-reading and sympathizing. The first component is an automated mind-reading system that infers the mental states of people by analysing their facial expressions. The system combines top-down predictions of mental state models (Dynamic Bayesian Networks) with bottom-up vision-based processing of the face to recognize both cognitive and affective mental states in real-time video. A technical description of the implementation of the automated mind-reading system can be found in el Kaliouby and Robinson [27, 28]. The second component is the reaction advisor, which suggests appropriate reactions for the child to take based on the inferences made by the mind-reading system. Currently, this component is implemented as a rule-based system which takes into account important factors such as the persistence, intensity, and confidence of a mental state inference.

So far, we have evaluated the automated mind-reading system on posed videos from the Mind Reading DVD [5]. Even though the results compares favourably to that of human performance on a similar recognition task, the recognition accuracy (77.4 %) is generally not sufficient for use with a real-time application such as the emotional hearing aid. After all, if users are going to depend on the tool for advice on how to react to other people, the reliability of the system in terms of recognition rate needs to be higher, while the false positive rate needs to be lower.

It is possible to extend the function of the emotional hearing aid to incorporate information about the context in which an interaction occurs. This information can be integrated in the inference process along with the video input to boost the reliability of the results. A simple implementation of location-context would entail defining several profiles which reflect the various situations the child can be in, such as “in school”, or “in playground”. The contexts would have to be explicitly selected, but as the tool gets more sophisticated, more detailed profile information would be deduced automatically by the system.

In theory, the users of the emotional hearing aid would benefit from the integration of context and other modalities in the system since many people diagnosed with Asperger Syndrome have problems integrating mental state concepts from facial expression into wider contexts (e.g., previous encounters with a person or an environment). The integration of context and other modalities within the emotional hearing aid, and a study of its effect on recognition accuracy, is a research direction worth pursuing.

Challenges

Admittedly, the emotional hearing aid is an ambitious project and it is no where near being available for use outside of lab settings. Developing and verifying the tool presents a number of challenges which span different research areas.

First, the reliable, real-time, automated inference of a wide range of mental states, including the complex ones, from facial expressions in video continues to challenge the state-of-the-art methods in machine vision and machine learning.

Second, the rules that govern how people read other people's mind from nonverbal cues and how they react accordingly (mind-reading and sympathizing) continue to challenge researchers in the behavioural sciences. From an engineering point of view, this means that there is no "rule-book" to follow when automating these processes. Instead, statistical machine learning and data-driven approaches have to be combined with the limited domain knowledge that is available to encode the automated system's functions. Future directions include the re-implementation of the reaction advisor using partially observed Markov decision processes [24], so that the utility of the actions is also learnt from data rather than hard-coded as in the current rule-based implementation.

Third, there is the issue of generalization. Will the system be able to encode the common sense knowledge that complements mind-reading and other social processes such that the suggested reactions of the system are indeed useful?

The emotional hearing aid has the potential to offer children at the high-functioning end of the autism spectrum more opportunities to engage in natural social interactions, beyond the hypothetical scenarios used in a teaching environment. The tool is designed to provide assistance even when the child’s carer is not available and ensures that events are accessible even after their occurrence for discussion and learning purposes. Whether or not this will be the case will only be answered as a more complete prototype of the system is developed and tested with the potential users of this technology.

OPEN QUESTIONS AND CONCLUSION

Technical challenges aside, developing a prosthetic tool for people diagnosed with ASD raises a number of concerns. The first of these pertains to the usability of such tools. One theory of autism, the weak central coherence theory [9] argues that the majority of people are able to establish the gestalt, context or gist of a problem, a skill which involves top-down or global processing and integrating information in context. People with ASD show impairment in these functions, with their processing seemingly devoid of high-level meaning. This may mean that people with ASD might find a tool like the emotional hearing aid cognitively overloading.

Another concern addresses whether people with ASD, in fact, need assistive, especially prosthetic ones at all. People with ASD have an extraordinary ability to focus on a subject, and "think" in unique ways. This gives them the potential for profound original thought. Autistic emotions can also be looked as another advantage: people with ASD are good at separating their feeling from their thinking, and can stay calm and rational in situations where neurotypical persons are paralyzed by fear or panic. Using prosthetic technologies that mimic the social functions of neurotypical may not be what people with ASD really want or need. Nonetheless, the world in which we live is a highly social one, and the capacities for social interaction and communication are impaired to varying degrees in people with ASD, resulting in a general inability to interact successfully with others.

In conclusion, this paper has shown that with emotional and social intelligence skills being integrated with wearable, vision-based technologies, there is an opportunity for developing assistive prosthetic tools for people with ASD. These technologies can be used in tandem with therapeutic tools. Whether or not prosthetic technologies like the emotional hearing aid will benefit people with ASD in the way it is intended will only become apparent as new technologies emerge and proper user studies conducted to evaluate each of these concerns.

References

1. APA (1994). DSM-IV Diagnostic and Statistical Manual of Mental Disorders, 4th Edition. Washington DC: American Psychiatric Association.

2. Attwood, T. (1998) Asperger's Syndrome: A Guide for Parents and Professionals, Philadelphia: Jessica Kingsley Publishers.

3. Baron-Cohen, S. (1995) Mindblindness: An Essay on Autism and Theory of Mind. MIT Press

4. Baron-Cohen, S., Wheelwright, S. (1999) Obsessions in Children with Autism or Asperger Syndrome: A Content Aanalysis in terms of Core Domains of Cognition. British Journal of Psychiatry, 175, 484-490

5. Baron-Cohen, S., Golan, O., Wheelwright, S., Hill, J. (2004) Mind-reading: The Interactive Guide to Emotions, London: Jessica Kingsley Publishers (www.jkp.com/mindreading)

6. Baron-Cohen, S., Wheelwright, S., Lawson, J., Griffin, R., Hill, J. (2004) The Exact Mind: Empathising and Systemising in Autism Spectrum Conditions. In Goswami, U, (ed) Handbook of Cognitive Development, pages 491-508. Blackwell: Oxford

7. Blocher, K. (1999) Affective Social Quotient (ASQ): Teaching Emotion Recognition with Interactive Media and Wireless Expressive Toys. S.M. thesis, MIT, Cambridge, MA

8. Bunt, A., Conati, C.(2003) Probabilistic Student Modelling to Improve Exploratory Behaviour. Journal of User Modeling and User-Adapted Interaction, 13:269–309

9. Burnette, C., Mundy, P., Meyer, J., Sutton, S., Vaughan, A., Charak, D. (2005) Weak Central Coherence and Its Relations to Theory of Mind and Anxiety in Autism. Journal of Autism and Developmental Disorders, vol. 35, no. 1, pp. 63-73

10. Cheng, L., Kimberly, G., Orlich, F. (2003) KidTalk: Online Therapy for Asperger's Syndrome. Technical Report, Social Computing Group, Microsoft Research

11. Cheng, Y., Moore, D., McGrath, P. (2002) Virtual Learning Environments for Children with Autism. In 6th Human Centred Technology Postgraduate Workshop

12. Cromby, J., Standen, P., and Brown, D. (1996) Successful Transfer to the Real World of Skills Practised in a Virtual Environment by Students with Severe Learning Difficulties In Proceedings of 1st European Conference on Disability, Virtual Reality and Associated Technologies Pages 103-107

13. Dautenhahn, K., Billard, A. (2002) Games Children with Autism Can Play with Robota, a Humanoid Robotic Doll. Proceedings of the 1st Cambridge Workshop on Universal Access and Assistive Technology [CWUAAT] In: S. Keates, PJ. Clarkson, PM. Langdon and P. Robinson (Eds.) Universal Access and Assistive Technology, Springer-Verlag (London), 179-190

14. Deja View Inc, http://www.mydejaview.com/ (Last accessed 18/03/2005)

15. Dennett D.C. The Intentional Stance. Cambridge, MA: MIT Press, 1989

16. Fling, E. (2000) Eating an Artichoke: A Mother's Perspective on Asperger Syndrome. Jessica Kingsley Publishers

17. Frith, U. (eds) (1991) Autism and Apserger Syndrome, Cambridge University Press

18. Fun with feelings (2004) http://www.digisoftdirect.com/products/funwithfeelings.html (Last accessed 17/03/2005)

19. Galitsky, B.(2003) Using mental simulator for emotional rehabilitation of autistic patients. FLAIRS – 03, 166-171.

20. Gray, C. (2004) Comic Strip Conversations. Future Horizons Incorporated.

21. Gray, C., White, A.B. (Eds) (2002) My Social Stories Book. Jessica Kingsley Publishers.

22. Goldman, A., Sripada, C.S. (in press) Simulationist models of face-based emotion recognition. Cognition.

23. Hirose, M., Kijima, R., Shirakawa K, Nihei K (1997) Development of a Virtual Sand Box: An Application of Virtual Environment for Psychological Treatment. In: G. Riva (Eds.) Virtual Reality in Neuro-Psycho-Physiology: Cognitive, Clinical and Methodological Issues in Assessment and Treatment, IOS Press

24. Hoey, J., Little J. (2004) Decision Theoretic Modeling of Human Facial Displays. In Proceedings of European Conference on Computer Vision.

25. Howlin, P., Baron-Cohen, S., Hadwin, J. (1999) Teaching Children with Autism to Mind-read: A Practical Guide for Teachers and Parents. John Wiley and Sons

26. el Kaliouby R., Robinson P. (2003) The Emotional Hearing Aid: An Assistive Tool for Autism. In the Proceedings of the 10th International Conference on Human-Computer Interaction (HCII): Universal Access in HCI, volume 4, pages 68-72.

27. el Kaliouby R., Robinson, P. (2004) Real-Time Inference of Complex Mental States from Facial Expressions and Head Gestures. In the IEEE International Workshop on Real Time Computer Vision for Human Computer Interaction at CVPR.

28. el Kaliouby R., Robinson, P. (2004) Mind-Reading Machines: Automated Inference of Cognitive Mental States from Video. In Proceedings of IEEE Conference on Systems, Man and Cybernetics, The Hague, Netherlands.

29. Keates, S., Clarkson, P.J., Robinson, P. (2002) Understanding how to Improve the Accessibility of Computers through Cursor Control Studies. Proceedings of ACM CHI 2002, pages 766-767

30. Klein, J., Moon, Y., Picard, R.W. (2000) This Computer Responds to User Frustration: Theory, Design, and Results. Interacting with Computers, 14(2):119–140, 2000

31. Kölsch, M., Turk, M., Höllerer, T. (2004) Vision-Based Interfaces for Mobility. Intl. Conference on Mobile and Ubiquitous Systems (MobiQuitous)

32. Kort, B., Reilly, R., Picard, R.W. (2001) An Affective Model of Interplay Between Emotions and Learning: Reengineering Educational Pedagogy Building a Learning Companion. In Proceedings of IEEE International Conference on Advanced Learning Technologies, pages 43–46, 2001

33. Kozima, H., Yano, H. (2001) Designing a Robot for Contingency-detection Game. Working Notes Workshop Robotic & Virtual Interactive Systems in Autism Therapy. University of Hertfordshire, Technical Report No 364

34. LeDoux, J.E. (1996) The Emotional Brain. New York: Simon & Schuster

35. LeGoff, D. (2004) Use of LEGO© as a Therapeutic Medium for Improving Social Competence. Journal of Autism and Developmental Disorders, 34 (5), 557-571

36. Lisetti, C., Nasoza, F., Ozyera, O., LeRougeb, C., Alvarezc, K. (2003) Developing Multimodal Intelligent Affective Interfaces for Tele-home Health Care. International Journal of Human-Computer Studies, 59

37. MacKenzie, I.S. (1995) Virtual Environments and Advanced Interface Design, chapter Input Devices and Interaction Techniques for Advanced Computing, pages 437–470. Oxford, UK: Oxford University Press

38. Meltzoff, A. (2004) Handbook of Childhood Cognitive Development, chapter Imitation as a Mechanism of Social Cognition: Origins of Empathy, Theory of Mind, and the Representation of Action, pages 6–25. Oxford: Blackwell Publishers

39. Mihailidis, A., LoPresti, E.F. (in-review). Cognitive Assistive Technology. In M. Akay (Ed.), Wiley Encyclopaedia of Biomedical Engineering. Hoboken, NJ: John Wiley & Sons, Ltd, Submitted August, 2003.

40. Moore, D., McGrath, .P, Thorpe, J. (2000) Computer-Aided Learning for People with Autism-a Framework for Research and Development. Innovations in Education and Training International, 37, 3, 218-228

41. O' Connell, S. (1998) Mindreading: How we learn to love and lie. Arrow Books

42. Pantic, M., Rothkrantz, L. (2001) Automatic Analysis of Facial Expressions: The State of the Art. IEEE Transactions on Pattern Analysis and Machine Intelligence, 22:1424–1445

43. Picard, R.W. (1997) Affective Computing. Cambridge, Massachusetts: MIT Press

44. Picard, R.W, Scheirer, J. (2001) The Galvactivator: A Glove that Senses and Communicates Skin Conductivity. In Proceedings from the 9th International Conference on Human-Computer Interaction, pages 91–101

45. Piekarski, W., Smith, R., and Thomas, B. H. (2004) Designing Backpacks for High Fidelity Mobile Outdoor Augmented Reality. In 3rd Int'l Symposium on Mixed and Augmented Reality.

46. Point Grey Research. http://www.ptgrey.com/ (last accessed 18/03/2005)

47. Premack, D., Woodruff, G. (1978) Does the Chimpanzee have a Theory of Mind? Behavioural and Brain Sciences, 4: 515-526

48. Phillips, A.T, Wellman, H.M. (2002) Infant's Ability to Connect Gaze and Expression to Intentional Actions. Cognition, 85:53-78

49. Qi, Y., Picard, R.W. (2002) Context-sensitive Bayesian Classifiers and Application to Mouse Pressure Pattern Classification. In Proceedings of the International Conference on Pattern Recognition (ICPR)

50. Realo, A., Allik, J., Nlvak, A., Valk, R., Ruus, T., Schmidt, M., and Eilola, T. (2003) Mind-Reading Ability: Beliefs and Performance. Journal of Research in Personality, 37(5):420–445

51. Rajendran, G., Mitchell, P. (2000) Computer Mediated Interaction in Asperger's syndrome: The Bubble Dialogue Program. Computers and Education, 35, 189-207

52. Robins, B., Dautenhahn, K., Dubowski, J. (2004) Investigating Autistic Children's Attitudes Towards Strangers with the Theatrical Robot - A New Experimental Paradigm in Human-Robot Interaction Studies. In Proceedings of the IEEE Ro-man 2004, 13th IEEE International Workshop on Robot and Human Interactive Communication

53. Robins, B., Dickerson, P., Stribling, P., Dautenhahn, K. (2004) Robot-Mediated Joint Attention in Children with Autism: A Case Study in Robot-Human Interaction. Interaction Studies: Social Behaviour and Communication in Biological and Artficial Systems 5:2, in press

54. Robins, B., Dautenhahn, K., Boekhorst, R., Billard, A. (2004) Effects of Repeated Exposure to a Humanoid Robot on Children with Autism. In S. Keates, J. Clarkson, P. Langdon and P. Robinson (Eds.) Designing a More Inclusive World, Springer Verlag, London, pp. 225-236

55. Scheirer, J., Fernandez, R., Picard, R.W. (1999) Expression Glasses: A Wearable Device for Facial Expression Recognition. In Proceedings of the CHI ’99 extended abstracts on Human factors in computing systems, pages 262–263, 1999

56. Strickland, D. (1996) A Virtual Reality Application with Autistic Children, Presence: Teleoperators and Virtual Environments 5(3), 319-329

57. Strickland, D., Marcus, L., Mesibov, G., Hogan, K. (1996) Two Case Studies Using Virtual Reality as a Learning Tool for Autistic Children. The Journal of Autism and Developmental Disorders, 26(6)

58. Turk, M., Kolsch, M. (2004) Emerging Topics in Computer Vision, chapter Perceptual Interfaces. Prentice Hall PTR

59. Werry, I., Dautenhahn, K., Ogden, B., Harwin, W. (2001) Can Social Interaction Skills Be Taught by a Social Agent? The Role of a Robotic Mediator in Autism Therapy. Proceedings CT2001, The Fourth International Conference on Cognitive Technology: Springer Verlag, Lecture Notes in Computer Science, sub series Lecture Notes in Artificial Intelligence

Table 1: Comparison of therapuetic tools for autism. 1: social-perceptual, 2: social-cognitive, 3: social commonsense / social situations, 4: structured, 5: natural environment or not, 6: immersive environment, 7: generalization has been tested.

Therapeutic tool	1	2	3	4	5	6	7
Fun with feelings [18]	●			●			
Bubble Dialogue [51]		●		●			
Mental state simulator [19]	●			●			●
Mind Reading [5]	●			●			●
StreetGame, FireSafetyGame [56]			●	●		●	
Virtual Sandbox [34]			●	●		●	
Virtual Learning Environment [11]							
Kidstalk [10]	●			●			●
AURORA [13]			●	●		●	
Affective Social Quotient [7]	●			`●			
Infanoid [33]		●		●			