Technology and Disability 18 (2006) 167–171
IOS Press

Augmented environments for pediatric rehabilitation

Tom Chau[a,b,*], Ceilidh Eaton[c], Andrea Lamont[a], Heidi Schwellnus[a] and Cynthia Tam[a]
[a]*Bloorview Kids Rehab, Toronto, Canada*
[b]*Institute of Biomaterials and Biomedical Engineering, University of Toronto, Canada*
[c]*The Hospital for Sick Children, Toronto, Canada*

Abstract. Computer-mediated, augmented environments endow the real physical surroundings with additional properties or information. We present two augmented environment systems developed at the largest paediatric rehabilitation hospital in Canada. One enables children with motor impairments to create music while the other facilitates the relearning of community mobility skills in adolescents with acquired brain injury. We describe system features, results of preliminary studies with selected client populations and argue that further investigation of augmented environments as assistive technologies for paediatric rehabilitation is warranted.

Keywords: Intelligent systems, assistive technology for children

1. Introduction

In recent years, there has been considerable interest in the use of computer-mediated environments as assistive technologies for paediatric rehabilitation. Much of this interest has revolved around virtual reality systems, a type of computer-mediated environment that generates artificial environments within which the user interacts. While not necessarily immersive, virtual systems typically plunge the user into a virtual milieu where he or she can manipulate virtual objects. Some recent examples include role-playing virtual environments for adolescents with autism spectrum disorders [9], virtual reality play interventions [8,11] and spatial training [1] for children with cerebral palsy, multimodal environments for cognitive rehabilitation [3], a virtual maze for the assessment of spatial knowledge in teenagers with mobility impairments [14] and a virtual acoustic space for sensory rehabilitation of children with congenital blindness [5]. These environments have demonstrated potential to improve social participation and enhance specific motor skills in children, while maintaining interest and motivation [7]. Part of their appeal as an assistive technology lies in their unprecedented precision in controlling complex stimuli within a test environment [12], their ability to provide varying levels of environmental interaction [6], and the early evidence of skill transfer to real world tasks [15].

This paper focuses on a different type of computer-mediated environment for rehabilitation, known as augmented environments (AE). Unlike virtual environments, augmented environments do not simulate artificial surroundings, but rather *augment* the real physical environment with additional visual imagery, acoustic response, or other useful information or cues [4,13]. These augmentations may be encapsulated in the form of virtual objects within the real environment or as the endowment of additional properties upon real physical objects [10]. Figure 1 depicts the differentiation among real, virtual and augmented environments. Note that in the augmented environment one can have both real and virtual objects. While augmented environments have seldom been reported in the rehabilitation literature, we argue that they possess potentialities worthy of further exploration.

*Address for correspondence: Tom Chau, Bloorview Research Institute, 150 Kilgour Road, Toronto, Canada. Tel.: +1 416 425 6220 ext. 3515; Fax: +1 426 425 1634; E-mail: tom.chau@utoronto.ca.

ISSN 1055-4181/06/$17.00

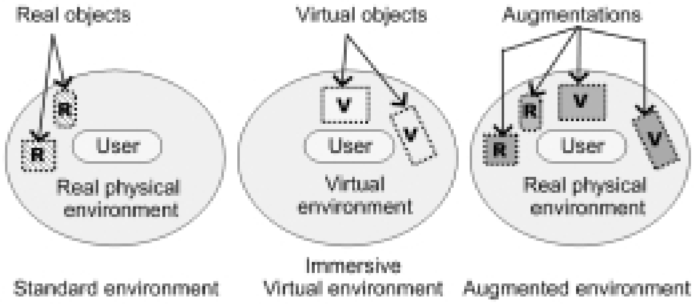

Fig. 1. Conceptual difference among real, virtual and augmented environments. The objects in the environments are labeled as R and V for real and virtual objects, respectively.

Particularly, in the next section, we introduce a novel augmented environment developed for paediatric rehabilitation. We then exemplify its specialization to two different areas of rehabilitation, namely, therapeutic music playing and topographical orientation training. We present some empirical results from small studies conducted at a rehabilitation hospital in Canada. The paper closes with remarks about the perceived potential of augmented environment systems in paediatric rehabilitation.

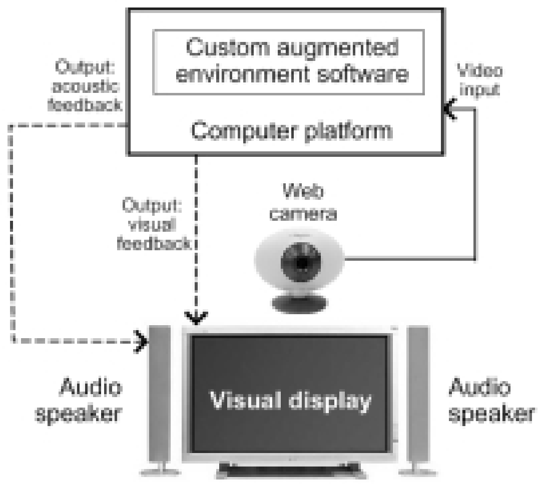

Fig. 2. Main components of augmented environment system for paediatric rehabilitation.

2. The augmented environment system

The main components of the augmented environment system are depicted in Fig. 2. The computer receives input about the environment and the user's activities through a USB web camera. The received images are processed by custom software within the computer. Movement detection, tracking and filtering are deployed as necessitated by the particular application. When the perceived user activities meet certain criteria, such as intersection with a virtual object, the software sends out appropriate visual and acoustic feedback which is presented to the user via a large screen visual display and audio speakers.

3. An augmented environment for music playing

The virtual music instrument is a realization of the above augmented environment that addresses issues of physical access. It allows children with poor motor control such as in cerebral palsy (CP) or those with hypotonia such as in spinal muscular atrophy (SMA) type 2, to make music via bodily movements, both as a structured educational activity and an unstructured play activity. As portrayed in Fig. 3, the assistive technology consists of the components outlined above. In this particular realization, the child sees an image of him or herself on the visual display, superimposed with coloured circles representing different musical notes. These circles are the virtual objects or augmentations within the real environment. When the child interacts with one of these virtual notes, through movement of fingers, hands, arms, head or body, the note becomes transparent on the visual display and the appropriate tone is sounded in the likeness of a selected music instrument. The technology is non-contact in that the child does not need to touch any physical devices, but simply moves through the surrounding space.

The virtual objects, i.e. notes, can be completely configured by a therapist or parent for each individual child and piece of music. The colour, volume, timbre, tone, spatial position, size and multiplicity of the virtual notes are adjustable. Additionally, the sensitivity of each note to movement and on and off dwell times

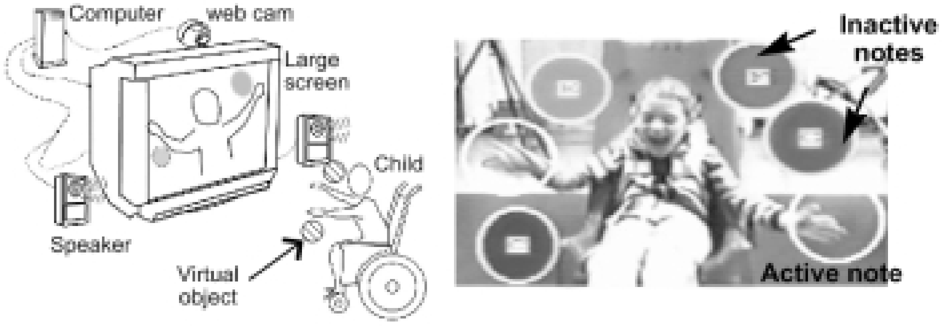

Fig. 3. Left panel: Components of the virtual music instrument. Note that the virtual notes are completely configurable. Right panel: A child with cerebral palsy playing with the virtual music instrument.

can be individually adjusted. These dwell and sensitivity variables allow the technology to filter out sporadic involuntary movements, and accommodate both fast and slow movements simultaneously. The configurable position and size of the activation regions facilitates successful activation regardless of one's range-of-motion or location of bodily control site. For each virtual note, the volume of the auditory feedback increases as more of the note's area is activated. Notes can be held for different temporal values by sustained movement within the region of activation. Hence, this augmented environment not only provides access to musical tones, but also offers control of volume and timing of the feedback, much akin to a conventional instrument.

At Bloorview Kids Rehab, the Canadian rehabilitation centre where the AE was developed, we have used the virtual music instrument in music education, occupational therapy and music therapy, with over 50 children between the ages of 3 and 12, the majority with either spastic cerebral palsy (quadriplegia), or a neuromuscular condition such as spinal or peroneal muscular atrophy. While most children access the device using the upper extremities, head, finger, foot and torso have also been employed by some children. The visual display has also ranged from a large screen television used by most children to a video image projected on the ceiling for those who need to use the device in a supine position due to poor trunk control.

In a pilot music education study consisting of 6 weekly sessions with 6 primary school children (aged 4.4 ± 1.3 years) with either CP or SMA, the technology engaged children for significantly ($p = 0.05$) increasing durations of free play, between first and last sessions. The sessional mean was 18 ± 10.4 minutes of free play. Additionally, interaction with the technology required on average significantly ($p < 0.05$) fewer physical (5.4 ± 2.8), demonstration (7.4 ± 5.2) and hand-over-hand cues (14.7 ± 6) than verbal (72.4 ± 9.6) cues per 25 minute session. This finding implies that the technology is liberating in the sense of minimizing physical dependency on the caregiver while playing music. In terms of task complexity, all children started with only simple cause and effect activation knowledge. By the last session, all children could do a matched spatial activation task (i.e., locating a virtual object in a space) while two-thirds were facile with matched colour activation tasks (i.e., associating colour with spatial location of the virtual object). This result suggests that the augmented environment may promote the development of targeted visuo-perceptual and motor planning skills.

Future development of this assistive technology will include the automatic initial placement of notes around a child based on demonstrated range-of-motion.

4. Augmented environment for community mobility rehabilitation

Using a client-centred approach that involved input from and pilot testing with 15 adolescents with acquired brain injury, we have developed a second augmented environment, specifically for the rehabilitation of community mobility skills in adolescents living with the effects of acquired brain injury. In this case, the augmented environment addresses difficulty with judgments relating to topographical orientation, personal safety, personal preference, and money management. To this end, the AE creates a sequence of scenes, each representing a decision point along a community outing to a local shopping complex. Each scene contains several virtual objects, representing different decision alternatives. Figure 4 depicts a sample scene sequence. For example, Fig. 4(b) is a scene portraying the choice

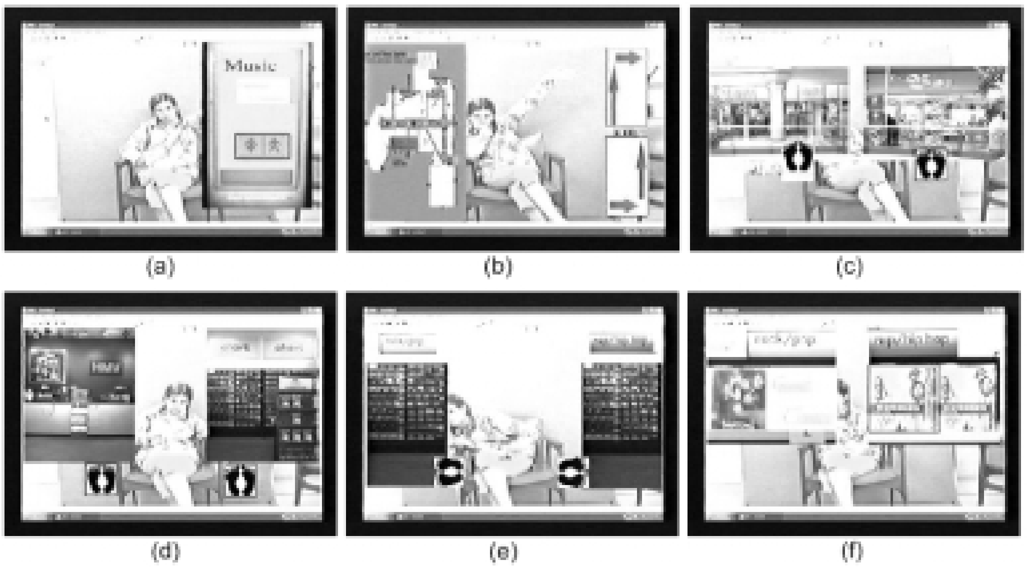

Fig. 4. Example of scene sequence in shopping mall trip. Here the user has selected to buy a CD from a music store. All subsequent decisions must be consistent with this activity selection. The scenes are: (a) Upper level mall directory; (b) Navigating the mall to the music store; (c) Store selection on target path; (d) Navigating within music store to new releases section; (e) Choosing type of music; (f) Choosing a specific artist.

between two different paths within the upper level of the shopping mall. Once the correct choice is made at a given scene, the user would then proceed to the next scene, i.e. Fig. 4(c), representing the next decision along the way. Oftentimes, the correct choice is the one which is logically consistent with the previous selections.

Similar to the virtual instrument, the user interacts with the virtual objects simply by pointing or gesturing in the desired direction of navigation. However, the feedback provided upon activation of the virtual object can be more varied. Visual feedback in the form of a text message may be presented to the user, such as, “Good choice” or “Try again”. Alternatively, the chosen object may move or rotate as appropriate. An auditory message or an appropriate sound effect may also be played. For example, if the user chooses to go through the turnstile the wrong way, the sound of someone grunting is played.

In addition, realistic background sounds may further augment the environment, to modulate the level of cognitive distractions. For example, at a busy intersection scene where the user needs to decide when it is safe to cross the street (red light versus green light), one can selectively add sounds of vehicular traffic, birds chirping, and a dog barking to raise or lower the level of distractions.

With this augmented environment we conducted a 10-week study with 7 adolescent inpatients aged 15.7 ± 2.5 years, all with moderate to severe acquired brain injuries. In addition to their regular therapy, participants engaged in up to three nominally 20-minute training sessions per week with the augmented environment. Mediated by an occupational therapist or a child life specialist, each session consisted of a sequence of real-life scenarios encountered on an outing from the rehabilitation hospital to the local shopping mall. Common to every session were the scenes relating to travel from the hospital to the shopping mall via the public transit system. Once they reached the mall, the individuals could choose different sequences of activities among sessions, for example, buying clothes versus buying a hamburger.

Over the training period, the average time per decision across the group decreased significantly ($p = 0.0053$) from 35.6 ± 6.4 seconds at the initial session to 25.6 ± 2.5 seconds by the final session. The error rate also decreased significantly ($p = 0.0495$) dropping from over 5% to less than 1% between first and last sessions. All participants progressed from simple dichotomous decisions (e.g., stairs versus escalator) to multiple choice selections at the mall where they chose among various activities, products and food items.

The experimental group was compared to an age-matched control group of 7 adolescents with similar brain injury severities who only received conventional physical and occupational therapy related to community mobility and topographical orientation. We found that despite the additional training received through the use of the augmented environment, there were no significant differences between the two groups on physical ($p = 0.32$) and cognitive ($p = 0.61$) scores on the community mobility assessment measure [2]. In fact, the failure rate on the safety component of the measure was the same in both groups. The lack of differences in this preliminary study may be due to the limited duration and intensity of the augmented environment interactions. It is also likely that the real world challenges were far greater than those presented in the simple augmented environment. This suggests that the augmented environment could be further developed into a wearable system, whereby real-time augmentations relating to orientation or environmental cues could be relayed to the user during an actual community outing.

Nonetheless, participants found it easy to interact with the augmented environment, grasping the visuospatial relationships among virtual objects and the causality of their movements within a few minutes. Our study suggests that augmented environments can be easily tailored for training specific community mobility tasks and that participants seem to be engaged by the practical relevance of the tasks, the natural movement-based interface and the realism of the visual and auditory feedback. We plan to conduct future research comparing community mobility training via a wearable augmented environment system and conventional training via therapist accompaniment, both during actual outing community outings.

5. Closing remarks

A fundamental goal of augmenting one's environment is to re-establish a balance among individual functional ability, demands of the occupational task at-hand and physical requirements of the environment. This goal philosophically resonates with the World Health Organization's biopsychosocial model of disablement, where context plays a pivotal role in defining health and function. In this framework, modulating the environment, for example via an augmented environment system, is arguably more important than "changing" the individual. We have presented two different augmented environments for paediatric rehabilitation. While our studies have involved a small number of children and youth with disabilities to date, the flexibility, simple access alternative, multimedia appeal, and task-specific customizability of augmented environments suggest that their potential as an assistive technology should be further explored.

References

[1] T. Akhutina, N. Foreman, A. Krichevets, L. Matikka, V. Narhi, N. Pylaeva and J. Vahakuopos, Improving spatial functioning in children with cerebral palsy using computerized and traditional game tasks, *Disability and Rehabilitation* **25**(24) (2003), 1361–1371.

[2] K. Brewer, T. Geisler, K. Moody and V. Wright, A community mobility assessment for adolescents with an aquired brain injury, *Physiotherapy Canada* **50**(2) (1998), 118–122.

[3] A. Camurri and P. Ferrentino, Interactive environments for music and multimedia, *Multimedia Systems* **7**(1) (1999), 32–47.

[4] A. Fuhrmann, G. Hesina, F. Faure and M. Gervautz, Occlusion in collaborative augmented environments, *Computers & Graphics-UK* **23**(6) (1999), 809–819.

[5] J.L. Gonzalez-Mora, A. Rodriguez-Hernandez, L.F. Rodriguez-Ramos, L. Diaz-Soco and N. Sosa, Development of a new space perception system for blind people, based on the creation of a virtual acoustic space, *Engineering Applications of Bio-inspired Artificial Neural Networks, Lecture Notes in Computer Science* **1607** (1999), 321–330.

[6] M.A. Grealy and D. Heffernan, The rehabilitation of brain injured children: the case for including phsyical exercise and virtual reality, *Pediatric Rehabilitation* **4**(2) (2001), 41–49.

[7] J. McComas, J. Pivik and M. Laflamme, Current uses of virtual reality for children with disabilities, in: *Virtual Environments in Clinical Psychology and Neuroscience: Methods and Techniques in Advanced Patient-Therapist Interaction*, G. Riva, B.K. Wiederhold and E. Molinari, eds, IOS Press, Amsterdam, The Netherlands, 1998, pp. 161–169.

[8] S. Miller and D. Reid, Doing play: competency, control and expression, *Cyberpsychology and Behavior* **6**(6) (2003), 623–632.

[9] S. Parsons, P. Mitchell and A. Leonard, The use and understanding of virtual environments by adolescents with autisic spectrum disorders, *Journal of Autism and Developmental Disorders* **34**(4) (2004), 449–466.

[10] H. Regenbrecht, G. Baratoff and M. Wagner, A tangible ar desktop environment, *Computers & Graphics* **25**(5) (2001), 755–763.

[11] D. Reid, A model of playfulness and flow in virtual reality interactions, *Presence-Teleoperators and Virtual Environments* **13**(4) (2004), 451–462.

[12] A.A. Rizzo, J.G. Buckwalter, T. Bowerly, C. van der Zaag, L. Humphrey, U. Neumann, C. Chua, C. Kyriakakis, A. Van Rooyen and D. Sisemore, The virtual classroom: a virtual reality environment for the assessment and rehabilitation of attention deficits, *Cyberpsychology and Behavior* **3**(3) (2000), 483–499.

[13] L. Rosenblum, Virtual and augmented reality 2020, *IEEE Computer Graphics and Applications* **20**(1) (2000), 38–39.

[14] D. Stanton, P.N. Wilson and N. Foreman, Effects of early mobility on shortcut performance in asimulated maze, *Behavioural Brain Research* **136**(1) (2002), 61–66.

[15] P.N. Wilson, N. Foreman and D. Stanton, Virtual reality, disability and rehabilitation, *Disability and Rehabilitation*, **19**(6) (1997), 213–220.