Technical Report BU-CS-2008-025

Camera-based Interfaces and Assistive Software for People with Severe Motion Impairments

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Abstract Intelligent assistive technology can greatly improve the daily lives of people with severe paralysis, who have limited communication abilities. People with motion impairments often prefer camera-based communication interfaces, because these are customizable, comfortable, and do not require user-borne accessories that could draw attention to their disability. We present an overview of assistive software that we specifically designed for camera-based interfaces such as the Camera Mouse, which serves as a mouse-replacement input system. The applications include software for text-entry, web browsing, image editing, animation, and music therapy. Using this software, people with severe motion impairments can communicate with friends and family and have a medium to explore their creativity.

1 Introduction

Extreme paralysis can result from a traumatic brain injury, for example, due to a traffic accident, or from cerebral palsy, brainstem stroke or degenerative neurological diseases, such as Amyotrophic Lateral Sclerosis (ALS or "Lou Gehrig's disease") or Multiple Sclerosis (MS) (ALS Association, 2008; National Multiple Sclerosis Society, 2008). ALS is one of the most common neuromuscular diseases worldwide, and people of all races and ethnic backgrounds are affected, particularly people between 40 and 60 years of age. MS is an autoimmune condition that may cause numerous physical and mental symptoms and often progresses to physical and cognitive disability. Disease onset usually occurs in young adults. Each year, between one to two people per 100,000 develop ALS and between 2 and 150 people per 100,000 develop MS. Worldwide, degenerative neurological diseases affect millions of individuals.

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People with severe cerebral palsy or traumatic brain injury are generally nonverbal, people with ALS and MS may still retain the ability to speak but cannot rely on voice recognition systems once their speech has become slurred.

A study by Forrester Research (2003) for Microsoft Corporation presents statistics on the need and significance of accessible technology. It is estimated that about 17% (22.6 million) of computers users who suffer from severe impairments are very likely to benefit from accessible technology. It is also postulated that the need for accessibility devices may grow due to the increase in computer users above the age of 65 and the increase in the average age of computer users.

The estimates on numbers of computers users with severe disabilities suggest that intelligent interfaces and smart environments are urgently needed for a considerable fraction of our population. This report presents an overview of assistive software that we specifically designed for people with severe motion impairments. Readers interested in assistive software designed by other groups may refer to the recent literature discussion by Magee et al (2008) and Akram et al (2008).

2 The Camera Mouse and other camera-based interfaces

Advances in computer processing speed, camera technology, and computer vision methods have given rise to a new generation of assistive technologies that do not involve customized, expensive electro-mechanical devices (Brown, 1992), but instead are software based, facilitating human-computer interaction by interpreting video input. The "Camera Mouse" project, a joint effort between Boston University and Boston College, has been central in this development. The Camera Mouse is an interface system that tracks the computer user's movements with a video camera and translates them into the movements of the mouse pointer on the screen (Betke et al, 2002; Chau and Betke, 2005; Gips et al, 2001; Fagiani et al, 2002; Cloud et al, 2002). With the Camera Mouse interface, body features such as the user's nose, thumb, foot, eyebrow, or chin can be tracked. The interface can interpret the pointer dwell time as a left mouse click. The Camera Mouse can thus serve as a mouse-replacement input system. Its communication bandwidth has been studied by Akram et al (2008) who report throughput measurements obtained from subjects with and without disabilities. Subjects without disabilities performed movement tests on average 1.8 times slower with the Camera Mouse than with the standard hand-controlled mouse. Subjects with severe motion impairments performed the same movement tests on average 3.2 times slower than subjects without motion impairments who used the standard mouse.

The Camera Mouse software is currently available for free from `www.camera-mouse.org`. It is used by children and adults of all ages, see Fig. 1, in schools for children with physical or learning disabilities, long-term care facilities for people with advanced neurological diseases, hospitals, and private homes. The government of Northern Ireland, for example, installed the Camera Mouse in 26 schools. The first person who used the Camera Mouse regularly was a thirty-three month old girl with severe cerebral palsy (Fig. 1 top left). She cannot talk but can move her chin up and down a little and her head from side to side. She uses the Camera Mouse to play with educational games for children (Gips et al, 2001; Betke et al, 2002).

We engaged in discussions with computer users at The Boston Home (2008), a not-for-profit specialized care residence for adults with progressive neurological diseases, to learn about their most urgent computing needs. Patients with advanced muscular dystrophy and multiple sclerosis revealed that their primary interest was assistive software that would enable them to have access to communication and information, i.e., text entry, email, and web browsing (Akram et al, 2008).

We have developed an application mediator system (Akram et al, 2006) for Camera Mouse users that helps users navigate between different activities such as browsing the Web, posting email, or designing art work (Fig. 2). Users with disabilities reported that they appreciated the holistic experience of this system.

Fig. 1 Camera Mouse users: a young child with cerebral palsy, a man with amyotrophic lateral sclerosis, a woman with multiple sclerosis, and a woman with cerebral palsy.

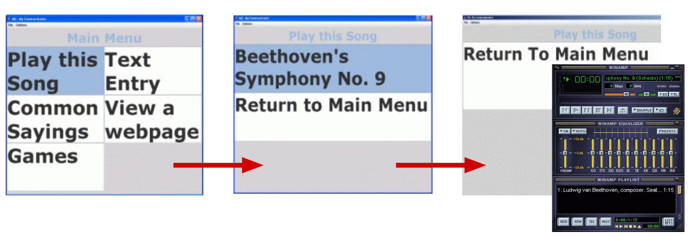

Fig. 2 The Application Mediator enables users to navigate from the main menu through the “Play this Song” submenu to launch a commercial music player that automatically begins playing the selected song (Figure courtesy of Akram et al (2006)).

Various techniques have been developed by the computer-vision research community to detect and track people without disabilities and analyze their gestures (Sclaroff et al, 2005). To tackle these difficult tasks, shape, appearance, and motion models of the user's body, in particular, for the head and face (Waber et al, 2005) and the hands and fingers (Wang et al, 2008; Crampton and Betke, 2003) have been developed. We have focused on methods to interpret movements of the user's eyes (Magee et al, 2004; Shugrina et al, 2006; Betke et al, 2000), eyebrows (Grauman et al, 2003; Lombardi and Betke, 2002), mouth (Shugrina et al, 2006) and head (Waber et al, 2005) as communication messages. We also developed a system that allows people to design their own gestures, for example, single-stroke movement patterns they can make by moving their nose tip, and match these gestures to a desired set of commands that control the computer (Betke et al, 2006).

3 Text entry and web browsing

Text entry programs enable Camera Mouse users to select one letter at a time using on-screen keyboards (Fig. 3, top) or groups of letters and then letters within the selected group (Fig. 3, bottom). Our designs (Betke et al, 2002; Cloud et al, 2002) address the "Midas Touch" problem – not everything that the mouse pointer touches should be activated (Jacob, 1995). We reserved certain regions on the screen as rest areas (e.g., the green fields in Fig. 3, top) where a dwelling pointer does not activate a command. We have also developed a "web mediator," a program that allows people with disabilities to browse the web in an effective and efficient fashion (Waber et al, 2006). Selection of a small text link in a web page displayed by a traditional browser may be particularly difficult for users who experience tremors or other unintentional movements that prevent them from holding the mouse pointer still. Our solution therefore changes the display of a web page so that the size of links is increased and links are grouped so that the user can first select a group and then scroll through individual links within that group.

4 Image editing

We developed CAMERA CANVAS, an image editing software package for users with motion impairments who cannot move their hands but can move their heads (Kim et al, 2008). CAMERA CANVAS works specifically with the Camera Mouse as the mouse-substitute input system. Users can manipulate images through various head movements, tracked by the Camera Mouse. The system is also fully usable with traditional mouse or touch-pad input. We studied the solutions for image editing and content creation found in commercial software to design a system that provides many of the same functionalities, such as cropping subimages and pasting them into other images, zooming, rotating, adjusting the image brightness or contrast, and

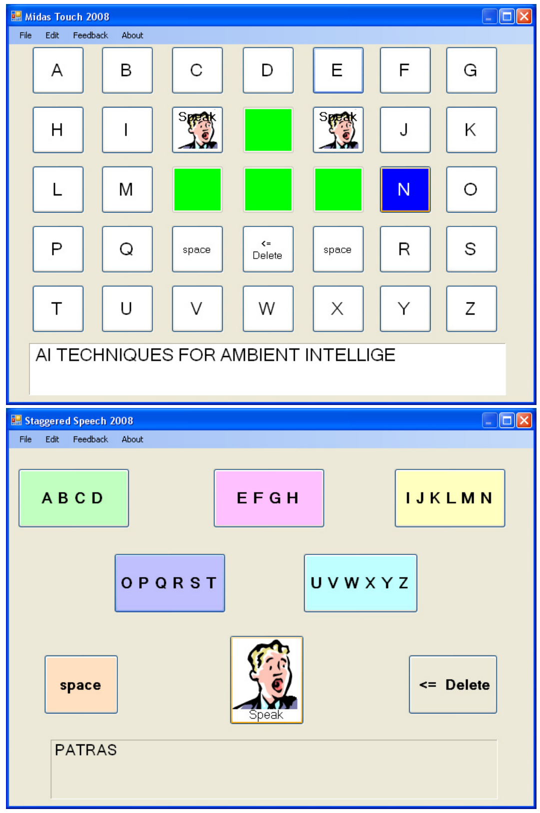

Fig. 3 Two text-entry programs: MIDAS TOUCH (top) and STAGGERED SPEECH (bottom).

drawing with a colored pen, see Fig. 4. Preliminary experiments with 20 subjects without disabilities, each testing CAMERA CANVAS with the Camera Mouse as the input mechanism, showed that users found the software easy to understand and operate. The time for a subject to complete various image editing tasks correlated with the subject's age and self-declared level of computer knowledge. For example, in one of our experiments, we asked the 20 users to test the move and crop tools with the image shown in Fig.5. It took the users 3:43 minutes on average to finish the task with a standard deviation of 2:42 minutes.

5 Animation

Animation software provides people with severe disabilities a medium to explore their creativity and imagination. Our ANIMATE! software allows people with disabilities to create video animations of an anthropomorphic figure, see Fig. 6. Com-

Fig. 4 The CAMERA CANVAS image editing tool. The user scrolls through the menu bar on the left by moving the mouse pointer up or down. To select a task, the pointer must dwell on the gray icon in the center of the bar. Top: Image rotation. The user selected to rotate the image 45 degrees counterclockwise (CW) on the second menu bar. Bottom: Copy Interface. The user selected the portion of the image to copy represented as a translucent blue rectangle. To change the position and size of the rectangle, the user moves the upper left and lower right corner of the rectangle, respectively. The movement is initiated by placing the mouse pointer onto one of the white-red arrows (Figure courtesy of Kim et al (2008)).

puter users with motion impairments who cannot control the movement of their own hands and feet can use ANIMATE! to control the hands and feet of the figure. By guiding how the arm, leg, torso, and head segments of the figure should move from frame to frame, they can, for example, choreograph a dance for the figure. The program has large buttons for functions such as open, new, save, play, next frame, previous frame, and rotate.

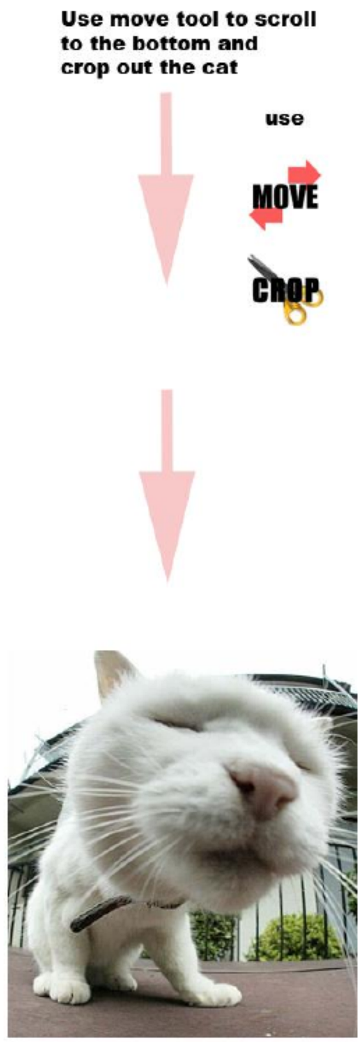

Fig. 5 Test interface for the move function of the image editing tool CAMERA CANVAS (Figure courtesy of Kim et al (2008)).

6 Games

Many users whose motion abilities are severely limited enjoy playing computer games that require them to be active and to move. Usually these games have to be

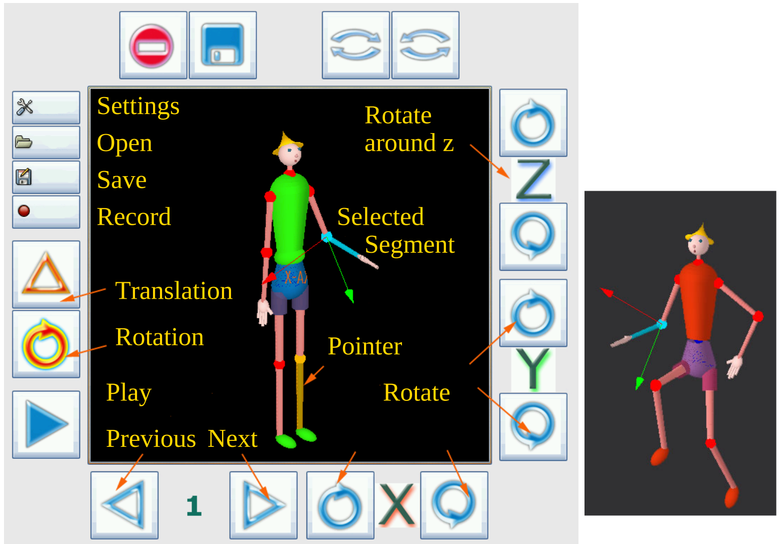

Fig. 6 ANIMATE! – a program that enables people with disabilities to create video animations of an anthropomorphic figure. **Left:** ANIMATE!'s interface has large selection buttons suitable for Camera Mouse use. **Right:** A video frame of a dancing animation created with ANIMATE!

tailored to work with the user's assistive device, e.g., the Camera Mouse interface, since the effective movement resolution of the device is typically not sufficient to allow the users to operate the graphical user interfaces of standard commercial applications. Examples of gaming software suitable for Camera Mouse use are ALIENS (Fig. 7), SLIME VOLLEYBALL (Fig. 8) and BLOCKESCAPE (Fig. 9). In addition to serving as entertainment platforms that are craved by our user population, these games have also been useful tools for us to test the efficacy and user acceptance of our camera-based interfaces (Betke et al, 2002; Magee et al, 2004, 2008). Preliminary experiments with the BLOCKESCAPE game (Magee et al, 2008) showed that some users with severe motion impairments were able to navigate the moving block through the gaps of the moving walls successfully. The game ALIENS is easier to play and is very popular with our users with cerebral palsy.

7 Music therapy

People with motion impairments may experience a strong therapeutic benefit from playing music. Unfortunately, their movement abilities are often too limited for them to play traditional music instruments. We developed a camera-based human-computer interface called MUSIC MAKER to provide such people with a means to make music while performing therapeutic exercises (Gorman et al, 2005, 2007). MUSIC MAKER uses computer vision tools to convert the movements of a person's

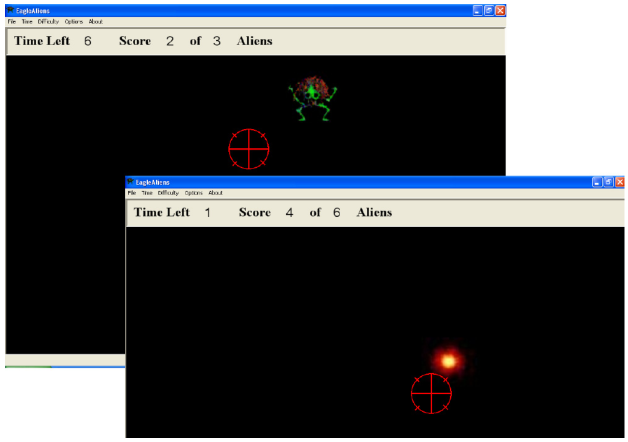

Fig. 7 ALIENS: The Camera Mouse user controls the mouse pointer (red) and tries to catch aliens (green) that appear in random locations on the screen for brief moments. If the user is successful in catching an alien, the game mimics a loud explosion.

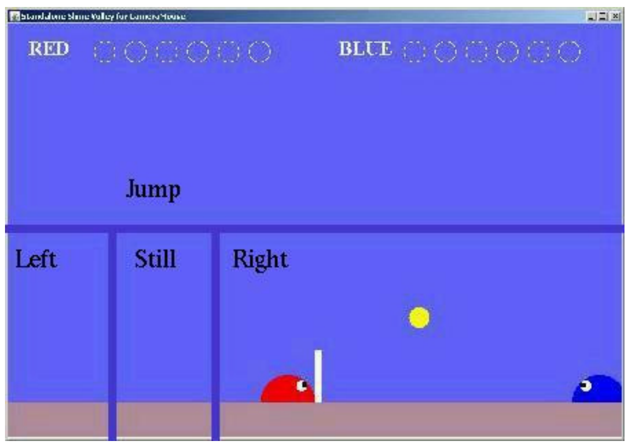

Fig. 8 SLIME VOLLEYBALL: The players take turns hitting the ball (yellow) so that it flies across the net (white). A player wins if the ball lands in the opposite player's court (brown). In our version, the Camera Mouse user (red player) plays against the computer (blue player) by moving his or her body feature (e.g., nose tip). The Camera Mouse interface converts the user's movement into mouse pointer movement on the screen. The user can move the pointer into one of four screen regions and thereby control the red player to move left or right, keep still, or jump up.

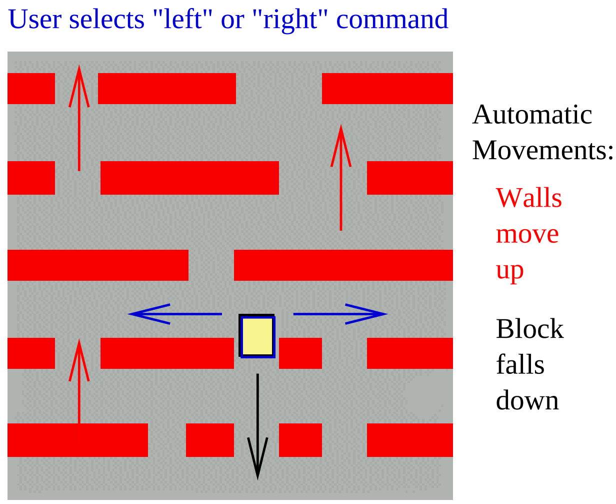

Fig. 9 The BLOCKESCAPE game: As the yellow block falls toward the bottom of the screen, the player tries to navigate it through the wholes in the red walls, which automatically move upward, by initiating "move block left" and "move block right" commands.

body part, for example, a finger, fist, or foot, into musical and visual feedback. The user shown in Fig. 10, for example, is performing a hand-opening-and-closing exercise and receives visual feedback on a projection screen. Music is playing during the exercise and is interrupted whenever the user is not moving her fingers at a certain minimal speed. By analyzing the motion pattern and trajectory that a body part follows during an exercise, MUSIC MAKER provides a quantitative tool for monitoring a person's recovery process and assessing therapeutic outcomes.

8 Conclusion

This technical report gave an overview of assistive software designed at Boston University and Boston College to serve non-verbal people with severe motion impairments. Among the camera-based interfaces we have proposed, the Camera Mouse is most popular and successful as a mouse-replacement input system for use with text-entry, web-browsing, image-editing, animation, and gaming software. We also described MUSIC MAKER, an intelligent camera-based interface for rehabilitation therapy.

Smart environments are needed that automatically learn the optimal interface parameters for users whose movement abilities decrease over time. Our future work will focus on intelligent interfaces that adapt to the changing computing needs of people with degenerative neurological diseases.

Fig. 10 MUSIC MAKER: A camera-based music making tool for rehabilitation. The user obtains visual and auditory feedback based on the analysis the motion pattern of her hand (Figure courtesy of Gorman et al (2005)).

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References

Akram W, Tiberii L, Betke M (2006) A customizable camera-based human computer interaction system allowing people with disabilities autonomous hands free navigation of multiple computing tasks. In: Stephanidis C, Pieper M (eds) Universal Access in Ambient Intelligence Environments – 9th International ERCIM Workshop ”User Interfaces For All” UI4ALL 2006, Königswinter, Germany, September 2006, Revised Papers. LNCS 4397, Springer-Verlag, pp 28–42

Akram W, Tiberii L, Betke M (2008) Designing and evaluating video-based interfaces for users with motion impairments. Universal Access in the Information Society In review

ALS Association (2008) ALS Association. http://www.alsa.org/

Betke M, Mullally WJ, Magee J (2000) Active detection of eye scleras in real time. In: Proceedings of the IEEE Workshop on Human Modeling, Analysis and Synthesis, Hilton Head Island, SC

Betke M, Gips J, Fleming P (2002) The Camera Mouse: Visual tracking of body features to provide computer access for people with severe disabilities. IEEE Transactions on Neural Systems and Rehabilitation Engineering 10(1):1–10

Betke M, Gusyatin O, Urinson M (2006) SymbolDesign: A user-centered method to design pen-based interfaces and extend the functionality of pointer input devices. Universal Access in the Information Society 4(3):223–236

Boston Home (2008) The Boston Home, a specialized care residence for adults with advanced multiple sclerosis and other progressive neurological diseases. http://thebostonhome.org/

Brown C (1992) Assistive technology computers and persons with disabilities. Communications of the ACM 35(5):36–45

Chau M, Betke M (2005) Real time eye tracking and blink detection with USB cameras. Tech. Rep. 2005-012, Computer Science Department, Boston University, http://www.cs.bu.edu/techreports/pdf/2005-012-blink-detection.pdf

Cloud RL, Betke M, Gips J (2002) Experiments with a camera-based human-computer interface system. In: 7th ERCIM Workshop on User Interfaces for All, Paris, France, pp 103–110

Crampton S, Betke M (2003) Counting fingers in real time: A webcam-based human-computer interface with game applications. In: Proceedings of the Conference on Universal Access in Human-Computer Interaction (UA-HCI), Crete, Greece, pp 1357–1361

Fagiani C, Betke M, Gips J (2002) Evaluation of tracking methods for human-computer interaction. In: IEEE Workshop on Applications in Computer Vision, Orlando, Florida, pp 121–126

Forrester Research (2003) The Aging of the US Population and Its Impact on Computer Use. A Research Report commissioned by Microsoft Corporation. http://www.microsoft.com/ enable/research/computerusers.aspx

Gips J, Betke M, DiMattia PA (2001) Early experiences using visual tracking for computer access by people with profound physical disabilities. In: Stephanidis C (ed) Universal Acccess In HCI: Towards an Information Society for All, Volume 3, Proceedings of the 1st International Conference on Universal Access in Human-Computer Interaction (UA-HCI), Lawrence Erlbaum Associates, Mahwah, NJ, pp 914–918

Gorman M, Betke M, Saltzman E, Lahav A (2005) Musicmaker – a camera-based music making tool for physical rehabilitation. Tech. Rep. BUCS-2005-032, Boston University

Gorman M, Lahav A, Saltzman E, Betke M (2007) A camera-based music making tool for physical rehabilitation. Computer Music Journal 31(2):39–53

Grauman K, Betke M, Lombardi J, Gips J, Bradski GR (2003) Communication via eye blinks and eyebrow raises: Video-based human-computer interfaces. International Journal Universal Access in the Information Society 2(4):359–373

Jacob RJK (1995) Eye tracking in advanced interface design. In: Barfield W, Furness TA (eds) Virtual Environments and Advanced Interface Design, Oxford University Press, pp 258–288

Kim WB, Kwan C, Fedyuk I, Betke M (2008) Camera canvas: Image editor for people with severe disabilities. Tech. Rep. 2008-010, Computer Science Department, Boston University, http://www.cs.bu.edu/techreports/pdf/2008-010-camera-canvas.pdf

Lombardi J, Betke M (2002) A camera-based eyebrow tracker for hands-free computer control via a binary switch. In: 7th ERCIM Workshop on User Interfaces for All, Paris, France, pp 199–200

Magee JJ, Scott MR, Waber BN, Betke M (2004) Eyekeys: A real-time vision interface based on gaze detection from a low-grade video camera. In: IEEE Workshop on Real-Time Vision for Human-Computer Interaction (RTV4HCI), IEEE Computer Society, Washington, D.C., 8 pp. A revised version appeared under the title “A Real-Time Vision Interface Based on Gaze Detection – EyeKeys.” In B. Kisacanin, V. Pavlovic, and T. S. Huang, editors, *Real-Time Vision for Human-Computer Interaction,* 2005, pages 141–157, Springer-Verlag.

Magee JJ, Betke M, Gips J, Scott MR, Waber BN (2008) A human-computer interface using symmetry between eyes to detect gaze direction. Transactions on Systems, Man, and Cybernetics, Part A: Systems and Humans 38(6):1–14

National Multiple Sclerosis Society (2008) National Multiple Sclerosis Society. http://www.nationalmssociety. org/

Sclaroff S, Betke M, Kollios G, Alon J, Athitsos V, Li R, Magee J, Tian T (2005) Tracking, analysis, recognition of human gestures in video. In: Proceedings of the 8th International Conference on Document Analysis and Recognition, Seoul, Korea, invited paper.

Shugrina M, Betke M, Collomosse J (2006) Empathic painting: Interactive stylization through observed emotional state. In: Proceedings of the 4th International Symposium on Non-Photorealistic Animation and Rendering (NPAR 2006), Annecy, France, 8 pp.

Waber B, Magee JJ, Betke M (2006) Web mediators for accessible browsing. In: Stephanidis C, Pieper M (eds) Universal Access in Ambient Intelligence Environments – 9th International ERCIM Workshop ”User Interfaces For All” UI4ALL 2006, Königswinter, Germany, September 2006, Revised Papers. LNCS 4397, Springer-Verlag, pp 447–466

Waber BN, Magee JJ, Betke M (2005) Fast head tilt detection for human-computer interaction. In: Proceedings of the ICCV Workshop on Human Computer Interaction, Lecture Notes in Computer Science, Springer Verlag, Beijing, China, 10 pp.

Wang J, Athitsos V, Sclaroff S, Betke M (2008) Detecting objects of variable shape structure with hidden state shape models. IEEE Transactions on Pattern Analysis and Machine Intelligence 30(3):477–492