Adaptive Mouse-Replacement Interface Control Functions for Users with Disabilities

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Abstract. We discuss experiences employing a video-based mouse-replacement interface system, the Camera Mouse, at care facilities for individuals with severe motion impairments and propose adaptations of the system. Traditional approaches to assistive technology are often inflexible, requiring users to adapt their limited motions to the requirements of the system. Such systems may have static or difficult-to-change configurations that make it challenging for multiple users to share the same system or for users whose motion abilities slowly degenerate. As users fatigue, they may experience more limited motion ability or additional unintended motions. To address these challenges, we propose adaptive mouse-control functions to be used in our mouse-replacement system. These functions can be changed to adapt the technology to the needs of the user, rather than making the user adapt to the technology. We present observations of an individual with severe cerebral palsy using our system.

Keywords: Adaptive User Interfaces, Video-Based Interfaces, Camera Mouse.

1 Introduction

We present adaptive mouse control functions for use in video-based mouse replacement interface systems by people with severe motion disabilities. Our target user population is generally non-verbal and has some voluntary control of their head motion, but are unable to use traditional interface devices such as mice or trackballs. We track the user's head or facial feature positions to control mouse pointer movement on the screen. Head or facial feature positions may be detected by camera-based systems such as Camera Mouse [1, 4] or SINA [10], or by infrared head-trackers (e.g., [Boston University Computer Science Department Technical Report, February 2011.
1]). Motion of the head or tracked feature in the video frame is typically scaled by a constant factor and transferred to control the mouse pointer movement. This scaling factor enables configurable faster or slower mouse pointer motion.

Our experience with users showed that they were often not able to move their heads in all directions. This resulted in constricted motion of the mouse pointer when mouse pointer control functions with constant scale factors were used. With an adaptive function, the user is able to move the mouse pointer to all positions on the screen

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with head movements that are most comfortable. In this paper, we describe our experiences with various groups of individuals with motion impairments who present unique challenges to our assistive technology system. We then propose adaptive mouse control functions that address these challenges.

One way to address the problem of varying user movement abilities is to design adaptive user interfaces [5, 7]. Such interfaces can change their configuration to better suit the individual user. We previously proposed adaptive mappings [9] to solve this problem. This paper presents an extension of that work and includes a user study of the adaptive function system implemented within the Camera Mouse.

2 Interactions with Intended Users

The intended users of mouse substitution interfaces are people with severe physical disabilities. Mouse substitution interfaces are most beneficial to those who retain the ability to control their head movements, but do not have control of their extremities. We have been able to observe several distinct groups of people with such severe paralysis. Although each individual person may face their own challenges in terms of working with a computer-vision-based interaction system, some common challenges may be observed.

2.1 Adults with Degenerative Conditions

We visited a residential care facility in Dorchester, Massachusetts, called The Boston Home [3], several times in order to test and observe HCI systems such as the Camera Mouse. The residents of this facility were adults with Multiple Sclerosis (MS) and other progressive neurological diseases. The people we have met are generally adults who have spent much of their lives without disabilities. Some of them are very familiar with technology and are accustomed to working with computers. Some of these people have sufficient motor control so that they remain mobile, e.g., controlling a wheelchair, by interacting with a computer via a mouse or other input device. Residents with the ability to speak may use speech recognition software to control computer software and dictate emails. Due to the nature of degenerative diseases, the physical capabilities of the residents can change over time, presenting us with the challenge to develop and maintain assistive technology capable of adapting to changes in physical abilities of the user.

We observed several people interacting with the Camera Mouse and other HCI systems. We were particularly interested in each subject's range of motions and ability to repeat motions with their heads. Through these observations, we discovered that some of our assumptions about how people with severe motion impairments move and position their heads while interacting with video-based HCI systems did not apply to all users. For instance, one subject we observed had difficulty holding her head in an upright position. Another subject was able to turn her head further in one direction than the other direction.

Many people in The Boston Home care facility have some ability to speak, which makes speech recognition software a useful tool. This is often used in writing emails. It is notable that the software is set up so that users dictate their messages directly into the email program, thus granting them privacy (instead of dictating the message into a text-entry program that the care giver then cuts and pastes into an email program). Even when a person's speech becomes slurred, modern speech recognition software can adapt to allow this dictation to be relatively successful.

We learned from this experience that completing a task without assistance is rewarding for people with disabilities, when help is needed for so many other tasks. The small amount of privacy gained by dictating one's own email messages, even when speaking becomes difficult, is important in an environment where privacy is often not possible. Also important to note is the surprising level of usefulness of speech recognition technology even for people with limited speech abilities.

In 2008, the Camera Mouse was not used at The Boston Home due to staffing limitations. The Camera Mouse version available at the time required an assistant to be present throughout the computing session. The assistant would have to manually select the feature to be tracked on the user's face and reset the system if a loss of feature occurred during tracking. The Boston Home did not have the staff available to actively monitor users of the system and to help the system to recover if the tracking failed.

2.2 Adults with Stable Conditions

We have completed an extensive case study with an adult with Cerebral Palsy whose condition has been stable for a long period of time. This user has been especially helpful in facilitating our understanding of the challenges we face in developing human-computer interaction systems for people with severe motion impairments.

The participant of our study has developed his own method of communicating with others via subtle head movements. Because of the nature of his disability, he has some involuntary motions, specifically with his arms and head. When he uses the Camera Mouse, the involuntary head movements sometimes cause the mouse to move without his intention. This can be especially problematic when the participant tries to select a button on the screen by using the dwell time function of the mouse replacement system. We also observed that the participant has some difficulty moving his head precisely horizontally or vertically while using the Camera Mouse to control a mouse pointer.

2.3 Students and Small Children

The Boston College Campus School [2] provides education and therapy for students with multiple disabilities. The students we observed at the Campus School were familiar with various assistive technologies, including the current version of the Camera Mouse. The Camera Mouse system was originally developed for and tested with some of the students at the Campus School [1]. While the main goal at the Campus School is education, assistive technology is also being used as therapy to refine motor control as well as a tool to enable communication for nonverbal students.

The Campus School environment presents its own set of challenges and opportunities for developers of assistive technology. Some students have cognitive disabilities in addition to physical limitations. Some of the young children may be learning about their own motor control as they use the technology. When using the Camera Mouse, students may learn that their head movements correlate with the movements of the pointer on the screen. Some of the students at the school have Cerebral Palsy and their movement capabilities are unlikely to worsen over time. Some of the students have extremely limited motion abilities which severely restrict the direction and distances they are able to move the mouse pointer with the Camera Mouse.

2.4 Summary of Observations

By observing these diverse subjects, we have learned much about which assumptions about HCI systems for people with motion impairments can safely be made and which assumptions cannot. What had worked well in tests with able-bodied graduate-student subjects may not work well with people with disabilities. In one experiment, we had assumed that the users would hold their head upright while our computer-vision interface system looked at their eyes. We quickly learned that this was a reasonable assumption for able-bodied users of the interface, but not for users with severe motion disabilities. Some people with spastic cerebral palsy have involuntary movements of their head. Others, who did not have the strength to fully control movements of their head, often positioned their head at an angle.

3 Experiences with Users

In the traditional Camera Mouse, mouse motion is inferred from the apparent motion of the user's facial feature within the image plane of the camera. Specifically, the system assumes that if the user wants to move the mouse pointer directly to the left, then the tracked feature will move left in the image plane. However, our observations of users with disabilities have shown that they may not be able to comfortably hold their heads in a vertical position. This results in tilted head motion from side to side when the intended mouse control is horizontal. As a result the mouse cursor moves in a diagonal direction.

In two initial experiments, we recorded the mouse trajectories of an adult subject with cerebral palsy using the Camera Mouse. In the first experiment, circular targets appeared on the screen and the user was asked to move the mouse pointer to the highlighted target. Sometimes the user was able to position the mouse pointer near the target relatively quickly. Then he only needed to move the pointer a short distance horizontally or vertically to reach the destination. However, the recorded trajectories showed that he failed to make these short horizontal or vertical movements several times and instead moved the pointer in a diagonal direction, missing the intended target.

In a second experiment, we asked the user to move his head left and right while he was not directly controlling the mouse pointer. The aim of this experiment was to determine if his natural sideways motions, performed without the need to control the pointer, would differ from his motions when he intended to move the pointer (Fig. 1).

We observed that his natural horizontal head motion in general had a diagonal component to it. In addition, he altered this movement with an upwards motion when he neared the extremes of his left and right motions. This analysis of the user's motion trajectories suggests that the linear pointer control function of the traditional mouse-replacement interface, which uses constant scale factor, may not be best suited for this user and an adaptive approach should be tested (Fig. 2).

Fig. 1. A user conducted an experiment where he moved his head left and right. The exaggerated white line indicates the motion of his nose feature.

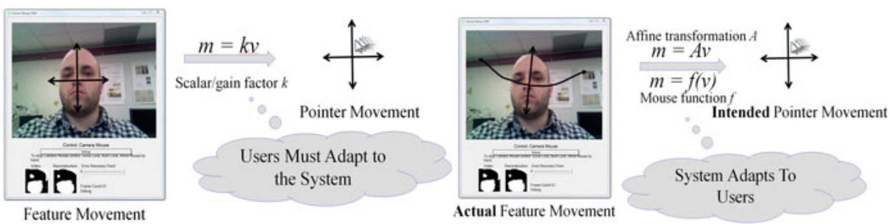

Fig. 2. Conceptual design of pointer movement functions. In a traditional mouse-replacement system, the mouse control function maps the facial feature motion linearly to the mouse pointer motion on the screen (left). In an adaptive system, the user's head motion is transformed into the intended mouse motion with a nonlinear function.

4 Mouse Mappings

We present a framework for modifying the pointer-movement control function of the traditional mouse-replacement system. In particular, we explored whether off-axis motion (i.e., motion that is not horizontal or vertical) can be compensated for. This would increase the usability of the interface for people who cannot easily move their heads in exactly horizontal or vertical directions. A seemingly straightforward solution to this problem would be to rotate the camera to the same angle as the user's head is tilted, or to provide the same functionality in software. However, our initial observations indicated that the users' motions were complex and required a more complicated analysis of the intended mouse motion. Based on our observation of users, we propose the functions shown in Figure 3 as alternatives to map facial feature movements into mouse pointer movements.

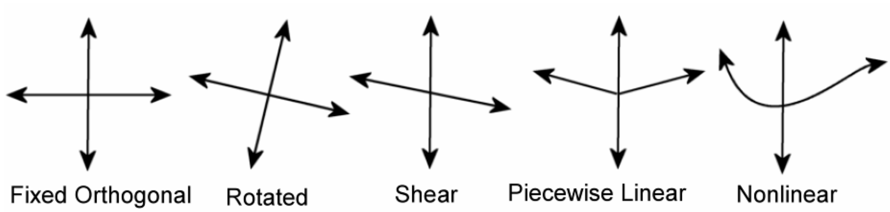

Fig. 3. Adaptive pointer-movement functions for mouse-replacement systems

In addition to alternative mappings based on movement in the image plane, we build upon work that explored a multi-camera system that analyzed motions of the user in three dimensions [8]. An experiment was conducted where users of the Camera Mouse system moved the pointer between targets while their motions were recorded with a multi-camera system. An analysis of feature trajectories shows motions in three dimensions (including towards or away from the camera) that are ignored by the traditional two-dimensional image-plane feature tracker.

The interface creates mouse motion in screen coordinates S. The two-dimensional system bases the movement on tracking a feature in image coordinates I, which is a projection of three-dimensional world coordinates W. The current approach relies on motions that are are aligned to the axes of the image coordinate system: $\delta S_x = K_x \times \delta I_x$, $\delta S_y = K_y \times \delta I_y$ for some constant gain factors K_x and K_y. The horizontal and vertical components of mouse motion in screen coordinate depend *only* on the corresponding horizontal and vertical components of feature movement in the image coordinates.

We previously proposed a generalized mapping to an affine transformation matrix A that allows both rotation and shear along with scaling [9]. Here, we propose mouse-pointer motion functions f that take into account additional information, such as both components of movement to create a tilted or rotated motion function $\delta S = f(K, \delta I)$, or the absolute coordinate of the screen pointer to create disjoint or curved response functions $\delta S = f(K, \delta I, S)$. If world coordinates can be estimated, they can be used to provide other response functions that take into account the user's motions in three-dimensions $\delta S = f(K, \delta W)$.

5 User Experiment

We invited the test subject mentioned above to participate in another experiment. Our previous analysis revealed that the user tended to tilt his head and that his motion had a diagonal component when he intended to move the mouse pointer simply horizontally. For an experiment with this user, we developed a pointer movement function that compensates for diagonal motion:

$$\delta Sx = fx(K, \delta I) = Kx \times \delta Ix \quad (1)$$

$$\delta Sy = fy(Ky, \delta I) = Ky \times (\delta Iy + D x \delta Ix) \quad (2)$$

$$D=\{-0.5,-0.25,0,0.25,0.5\}, \quad (3)$$

where the diagonal factor D in the pointer control function defines how much diagonal compensation will take place. This compensation causes the mouse pointer to move up or down by a factor relative to its horizontal motion. This function can therefore be used to compensate for diagonal head motion when horizontal mouse motion was intended. When D=0, the function reduces to the linear scaling function of non-adaptive traditional mouse-replace systems. For constant values other than 0, the function defines a shear function (see Fig. 3).

Other adaptive functions can be obtained by dynamically modifying the parameter D in Eqn. 2. We can define a piecewise linear function that moves the mouse pointer differently on the left and the right side of the screen. This can be accomplished with a negative D when the mouse pointer is on the left half of the screen, and positive on the right half. The non-linear response function is similarly obtained by varying D with the horizontal distance from the center of the screen.

As part of our experiment, we asked the participant to use a paint program and to move his head left and right while the program drew colored boxes under the mouse pointer (Fig. 4). We attempted four settings of the adaptive mouse function and observed the resulting mouse trajectories. With the constant setting of D=0.5, the user was more easily able to create a horizontal mouse motion compared to the control setting of D=0.

Once we settled on a setting for the adaptive mouse control function, we experimented with two additional user programs with this subject. In the first program, called MenuController [11], large buttons along the top of the screen are used to

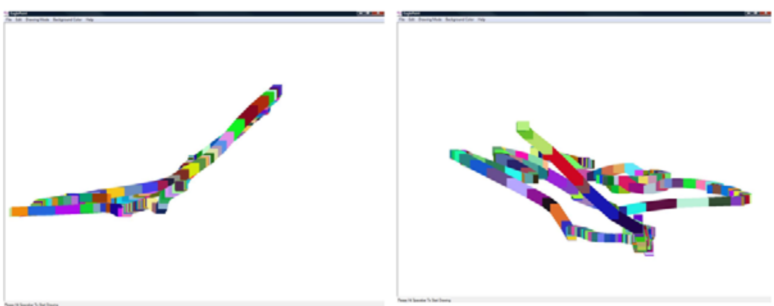

Fig. 4. Screen shots of two paintings made by the quadriplegic participant of our user experiment whose left and right head motion was interpreted by the Camera Mouse interface and controlled a paint program. Two versions of the Camera Mouse were used, a version with the traditional, non-adaptive mouse control function, i.e., D=0 (left) and a version with the adaptive mouse control function with D=0.5 (right). The non-adaptive mouse control function could not compensate for the significant diagonal motion in the mouse pointer that the user had not intended (left). The adaptive mouse control function compensated for some of the diagonal motion, producing a more horizontal mouse motion as the user had intended (right).

Fig. 5. Screen shot of the Camera Canvas photo editing program for people with motion disabilities

control window menu functions. The user had difficulty reaching these buttons at the end of this session. The user also used the Camera Canvas [6] program which has a configurable user interface with large buttons (Fig. 5). He was able to reach these buttons more easily. These last two experiments were near the end of the session and the subject was becoming fatigued.

Our experimental setup is shown in Fig.6. The user looks at a monitor while a web-cam and the Camera Mouse control the mouse pointer. We also recorded his motions with a two-camera thermal infrared system and a four-camera visible light system for future analysis.

6 Discussion and Future Direction

Adaptive pointer control functions can help users with limited motor control use mouse replacement interfaces. The ability to adapt the program to the user rather than requiring the user to adapt to the program is important for users who cannot move in certain ways or who become fatigued when moving in a way that is not comfortable to them. We suggest that adaptive interface systems are beneficial for users whose condition changes between sessions or even within sessions as they experience fatigue. Additionally, adaptive interfaces would be useful when different users at a care facility need to share the same system.

We plan to continue developing adaptive pointer control functions and extend our user study to additional individuals so that we can measure the efficacy of our methods. In addition, we have captured user sessions with a stereoscopic thermal infrared system, and a four-camera visible-light system for analysis of movement trajectories (Fig. 6). We plan to use this data to help develop mouse control functions that take into account the user's motion in three dimensions so that their intended mouse pointer movement can be better inferred.

Fig. 6. Experimental setup. The user is placed in front of a computer screen with a webcam capturing his motions to enable mouse pointer control. We simultaneously recorded his motions with a two-camera thermal infrared system and a high-speed four-camera visible-light system for future analysis.

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