Camera Mouse: A Brief History

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EagleEyes requires that five electrodes be placed on the user's head, which is intrusive. I wondered whether instead we could track eye movements with a video camera placed near the computer monitor. This would mean no more electrodes and no more amplifiers for the signals.

In 1999 I spoke with Margrit Betke, then a fellow faculty member in the Computer Science Department at Boston College, about working together to develop this system. Margrit is an expert in Computer Vision, developing computer programs to allow a computer to see using a video camera. We enlisted Peter Fleming, a very talented undergraduate, to work with us on the program. After Peter graduated, Chris Fagiani, also a very talented undergraduate, continued the work.

To begin, Margrit and Peter worked on the vision part. The idea was to first develop a program to track head movements using the video camera and then develop the second part that would find the eyes in the head in the video image. Within months they had the first part of the program, the head tracker, working. Click on a feature on the head and then as you move your head the computer tracks that feature. When I saw it and tried it I thought this would be valuable in and of itself. We could use this program for a head-controlled mouse pointer.

Back in 1999 computers were much less powerful than they are now. The computer was working at full capacity doing the head tracking in real time. We decided to use a second computer for the user. I adapted the EagleEyes program to be controlled on the user computer by the vision computer instead of by the signals from the EagleEyes hardware. By flipping a mechanical switch, or in some versions by pressing a special key like the NumLock key, control of the user computer would switch from the mouse to the vision computer and back.

The system worked remarkably well. It was much easier to use than EagleEyes. I thought about names like "EagleHead" and "EagleCam" for the system but decided on "Camera Mouse", using a camera as a mouse to control the mouse pointer. Since Camera Mouse behaved on the user computer like a standard mouse, it could be used with any Windows software.

This was back before USB webcams had been developed. We used a $1,000 Sony Pan-Tilt-Zoom camera and an internal video capture board in the vision computer. Plus, there was added equipment for the communications between the two computers. And, of course, there was an extra, high-powered vision computer. It cost over $5,000 for the original Camera Mouse setup plus a standard Windows 98 computer.

We contacted the BC Technology Office and set in motion a patent application. BC had an arrangement with Foley Hoag, a well-known downtown legal firm to do its patent work. We put in a lot of hours on patent applications but they never did bear fruit in actual patents.

We fairly quickly brought in people with disabilities to try the system and they responded well. We set up a system in the EagleEyes room in the Campus School. The population that would benefit from Camera Mouse is much broader than the population that would benefit from EagleEyes. EagleEyes is directed to people who are completely locked in except for voluntary eye movement. Camera Mouse is directed to people who have voluntary head movement, a much larger population.

Once the patent application was underway we could publicize the work. We followed the usual procedure in Computer Science, which is to present a quick preliminary paper at a conference and then prepare a longer and more complete paper for a journal. Conference papers usually have a four to six month lead time for submission. Journal papers, with rounds of revisions required by reviewers and editors, usually take a couple of years to be published. The conference paper (J. Gips, M. Betke, and P. Fleming, "The Camera Mouse: Preliminary Investigation of Automated Visual Tracking for Computer Access", *Proceedings of RESNA 2000*, Orlando, July 2000, RESNA Press, pp. 98-100.) is included after this narrative. The journal article (M. Betke, J. Gips, and P. Fleming, "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*, Vol.10, No. 1, 2002, pp. 1-10.) is available at my BC website.

In the journal article we describe initial testing of Camera Mouse. First we had 20 people without disabilities use Camera Mouse and a mouse to spell out "Boston College" three times each (order randomized) using an early version of the Midas Touch (midastouch.org) onscreen spelling board. The results are shown below in a Table from the journal paper.

TABLE II
TIMING COMPARISON BETWEEN STANDARD MOUSE AND CAMERA MOUSE USAGE. SAMPLE MEAN AND STANDARD DEVIATION σ OF THE LENGTHS OF THREE COMMUNICATION TESTS WITH THE SPELLING-BOARD INTERFACE PERFORMED BY 20 HEALTHY SUBJECTS

	Spelling Board Experiments					
	Regular Mouse			Camera Mouse		
	Mean Time Including Mouse Clicks	Mean Time Excluding Mouse Clicks	σ	Mean Time Including Mouse Clicks	Mean Time Excluding Mouse Clicks	σ
Test 1	15.29 s	14.59 s	2.88 s	28.67 s	21.67 s	3.58 s
Test 2	12.48 s	11.78 s	2.23 s	26.67 s	19.67 s	3.32 s
Test 3	11.90 s	11.20 s	1.55 s	25.24 s	18.24 s	2.70 s

Camera Mouse took twice as long as the regular mouse. But still, all users were able to complete the task and spell out the message with Camera Mouse, which was very encouraging.

Then we describe testing Camera Mouse with a dozen people with disabilities. Here is a summary of the results, again from the journal paper.

TABLE III
SUMMARY OF RESULTS FOR THE FIRST DOZEN PEOPLE WITH DISABILITIES TO TRY THE CAMERA MOUSE

Age	Gender	Condition	Results	Continuing to Use ?
2	M	Cerebral Palsy	Obtaining a system for home.	Yes
3	F	Cerebral Palsy	First regular user with home system.	Yes
6	F	Cerebral Palsy	Spelled name. Obtaining a home system.	Yes
8	M	Cerebral Palsy	Spells naughty words and laughs.	Yes
11	M	Cerebral Palsy	Obtaining a home system.	Yes
14	M	Cerebral Palsy	Spells words. Obtaining a home system.	Yes
15	M	Cerebral Palsy	Close, but could not control reliably.	No
19	M	Cerebral Palsy	Does not have sufficient muscle control.	No
23	M	Traumatic Brain Injury	Does not have sufficient muscle control.	No
31	M	Traumatic Brain Injury	Spelled "TAKE OFF DAD."	Yes
37	M	Cerebral Palsy	Spelled "MERRY CHRISTMAS."	Yes
58	M	Cerebral Palsy	Spells, explores internet on home system.	Yes

Here is one of the first users of the system, the three-year old young lady with Cerebral Palsy from the table above.

Fig. 3. The Camera Mouse user playing with educational software. The video camera is placed underneath the user computer's monitor.

Here are two quotes from her mom:

> We are a family of four. What makes us different is that we have a daughter who is three and has cerebral palsy. The best thing that Camera Mouse has given us, is watching both of our daughters sharing and playing at something that brings them so much joy

> and giggles. That is an experience that should not be missed by other families.
>
> Camera Mouse has given her a way to communicate her thoughts, it gives the school that she is attending a way to adapt the curriculum so that she can participate in a REGULAR preschool, it puts her in a situation where people can see her ABILITIES rather than her disabilities. When she uses the Camera Mouse, she is alert, attentive and responsive. She controls the mouse with her chin and plays with educational software.

At the request of users we began providing systems for homes and schools. The parents or school would sign a licensing agreement with BC. We would send them a list of the equipment they needed to purchase from various vendors. As mentioned above, this would total around $5,000 in addition to a Windows 98 computer. Much of this $5,000 was for the high-powered vision computer. They would purchase the equipment. We would provide instructions and the existing Camera Mouse software for free. Or, sometimes we would send a student to construct and install the Camera Mouse system and instruct the purchaser on how to use it.

As $100 USB cameras appeared and computers became more powerful I envisioned a very low cost system that used a webcam with no other hardware and ran completely on one computer. Jon Gips, my son, developed a “radical proof of concept” program using an early USB camera.

We began to explore ways to develop a professional level USB camera based Camera Mouse and get it out of the lab and onto the computers of people who could use it. I spoke with Steve Erickson of the BC Technology Office about various approaches. We decided to try to commercialize the software.

After various dead-ends I came into contact with a group of people at the IC^2 Institute at The University of Texas at Austin who were interested in exploring forming a company to develop and commercialize Camera Mouse. They flew up to Boston to meet with me and try Camera Mouse and talk with current users and the BC Technology Licensing office. They decided to proceed. They formed a company Camera Mouse, Inc. I was a 7% owner. They negotiated a licensing agreement with BC. They hired a professional software developer and put up a website at cameramouse.com and began selling a USB webcam based version of the software. Initial price was $495 per copy then lowered to $395 per copy. The program worked well. They did sell some copies but not enough to break even. The company folded and BC revoked the license.

Margrit accepted a faculty position in the Computer Science Department at Boston University. Her group at Boston University continued working on Camera Mouse and interesting variations. See cameramouse.bu.edu for a description of their work.

After the demise of Camera Mouse Inc., I continued to receive inquiries about Camera Mouse. We decided to develop a new version of Camera Mouse and make it available for free. Under contract from Boston College, Donald Green engineered and implemented a new Camera Mouse. Don is a friend and former student who had worked on EagleEyes as an undergraduate. He has worked for various companies as a professional software engineer and programmer, and has his own software consulting company. I am responsible for the external design and functional specs for the system. I design the user interface and what features are included in the program and what the program is supposed to do, how it is supposed to behave. I also am responsible for the documentation and much of the testing. Don is completely responsible for everything under the hood, the internal design and architecture of the program and the implementation of all the code. I've never looked at the code.

We brought out Camera Mouse 2007 in June 2007 at cameramouse.org. In 2007 we had 3,000 downloads. We release maybe three new versions of the program each year, usually with minor fixes and feature upgrades. Of course, Microsoft keeps bringing out new versions of Windows so we needed to update the program for Vista and Windows 7 and Windows 8 and Windows 8.1 and Windows 10. We make use of the OpenCV vision library and need to make revisions in Camera Mouse to incorporate improvements in OpenCV. In 2008 we brought out Camera Mouse 2008 and had over 30,000 downloads. At various times since then Don was assisted by Matt McGowan, also a former BC student, and Christine Hsu Nason.

The original cameramouse.org website was of my own (terrible) design. In 2009 and 2010 Sophia Yen, a friend and former student who now is a high level consultant for a major consulting firm, kindly volunteered to take a strategic and tactical look at Camera Mouse so we could put it on a stable long term course and help as many people as we could. Sophia made crucial recommendations, including that we hire an outside firm to develop a professional looking website and brochure and that we launch a worldwide mail / email effort targeted at places like the North India Cerebral Palsy Association in the Punjab to let them know about the free Camera Mouse program to seed growth. We hired Cuie & Co., a two-person firm in South Africa, for the one-time design and implementation of the website and brochure for around $2,500 if I am not mistaken. We continue to use the design at cameramouse.org. I maintain and change the website within their design. I had student assistants comb through the web to create a mail / email list and then send out either paper brochures or pdfs.

Where do we get the money to pay for this? Camera Mouse is part of the EagleEyes Project at Boston College so we use money in the BC EagleEyes Project budget. Also, funds contributed to the EagleEyes Project by alumni and friends and the Mitsubishi Electric Research Lab in Cambridge and the Mitsubishi Electric America Foundation and others. Really, Camera Mouse, like EagleEyes, is a labor of love and we run it on a shoestring budget.

We did a complete redesign and rewrite of the program for Camera Mouse 2012.

As of July 2016 we have had over 3,100,000 downloads of Camera Mouse! The current version is Camera Mouse 2016. Don and I are discussing Camera Mouse 2017.

Camera Mouse is completely free to download. There is no advertising or gimmicks in the website, installer, or program. We try to make it as easy as possible to download, install, and use. At the beginning there was a registration page so I could find out where the downloads were going and collect email addresses. But I found that half the people left at the registration page even if registration was completely optional. So no registration.

My name and email address are listed on cameramouse.org with the request that any questions be sent to me. I provide all technical support. I respond to emails within 24 hours. I track down any problems, with Don's help as needed. We try to make the program as high quality and functional and easy to understand as possible. I receive one or two emails a week about Camera Mouse. Many praise the system. Some offer suggestions for improvements. A few report problems. All are most welcome. We endeavor to support Camera Mouse on Windows systems from XP to the present, which even Microsoft doesn't do, promptly with a very personal and caring touch.

We are fortunate that the Opportunity Foundation of America in Salt Lake City supports Camera Mouse in addition to EagleEyes.

Last summer I hired Erin O'Keefe, an outstanding student who had just completed her freshman year during which she took two of my courses, as a student assistant to serve as Camera Mouse Social Media Director. Erin has developed a Camera Mouse Facebook page at facebook.com/cameramouse . Please visit and contribute. Erin also is developing an Instagram page and a YouTube channel. You can see some Camera Mouse videos at cameramouse.org/videos.

With between 500 and 1,000 downloads each day, Camera Mouse has helped many people. It has helped people with Cerebral Palsy, Traumatic Brain Injury, Stroke, Spinal Cord Injuries, Multiple Sclerosis, ALS, Repetitive Stress Injury. How do I know? From emails I receive and from postings on the web. Samples of some of the emails and postings are given later in the book. Below is the initial conference paper on Camera Mouse.

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THE CAMERA MOUSE: PRELIMINARY INVESTIGATION OF AUTOMATED VISUAL TRACKING FOR COMPUTER ACCESS

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ABSTRACT

A system has been developed that uses a camera to visually track the tip of the nose or the tip of a finger or some other selected feature of the body and moves the mouse pointer on the screen accordingly. People without disabilities quickly learn to use the system to spell out messages or play games. People with severe cerebral palsy have tried the system with some initial success. Our goal is to provide computer access to people who are quadriplegic and cannot speak by developing computer vision systems.

BACKGROUND

People who are quadriplegic and nonverbal, for example from cerebral palsy or traumatic brain injury or stroke, have limited motions they can make voluntarily. Some people can move their heads. Some can blink or wink voluntarily. Some can move the eyes or tongue. Family, friends, and other care providers usually detect these motions visually.

Many computer access methods have been developed to help people who are quadriplegic and nonverbal: external switches, devices to detect small muscle movements or eye blinks, head pointers, infrared or near infrared camera based systems to detect eye movements, electrode based systems to measure the angle of the eye in the head, even systems to detect features in EEG. These have helped many people access the computer and have made tremendous improvements in their lives. Still, there are many people with no reliable means to access the computer. We are interested in developing computer vision systems (1) that work under normal lighting to provide computer access to people who are quadriplegic and nonverbal.

STATEMENT OF THE PROBLEM

Develop a system that uses a camera to visually track a feature on a person's face, for example the tip of the nose, and use the movement of the tracked feature to directly control the mouse pointer on a computer.

THE SYSTEM

The system involves two computers: the vision computer, which does the visual tracking, and the user's computer, which runs a special driver and any application software the user wishes to use.

The Vision Computer

The vision computer is a 550 MHz Windows NT machine with a Matrox Meteor-II video capture board. The vision computer receives 30 frames per second from a Sony EVI-D30 camera mounted above or below the monitor of the user's computer. The image used is of size 320 by 240 pixels. The image sequence from the camera is displayed in a window on the vision computer by the visual tracking program.

Initially the operator uses the camera remote control to adjust the pan-tilt-zoom of the camera so that the person's face is centered in the image. The operator uses the mouse to click on a feature in the image to be tracked, perhaps the tip of the user's nose. The vision computer draws a green 15 by 15 pixel square centered on the point clicked and outputs the coordinates of the center of the square. These will be used for the mouse coordinates by the user's computer.

Thirty times per second the vision computer receives a new image from the camera and decides which 15 by 15 square subimage is closest to the previous selected square. The vision computer program examines 400 15 by 15 trial square subimages around the location of the previously selected square. The program calculates the normalized correlation coefficient $r(s,t)$ for the selected subimage s from the previous frame with each trial subimage t in the current frame

$$r(s,t) = \frac{A\sum s(x,y)t(x,y) - \sum s(x,y)\sum t(x,y)}{\sigma_s \sigma_t}$$

where A is the number of pixels in the subimage, namely 225, and

$$\sigma_s = \sqrt{A\sum s(x,y)^2 - \left(\sum s(x,y)\right)^2} \quad \text{and} \quad \sigma_t = \sqrt{A\sum t(x,y)^2 - \left(\sum t(x,y)\right)^2}$$

The trial subimage with the highest normalized correlation coefficient in the current frame is selected. The coordinates of the center of this subimage are sent to the user computer. The process is repeated for each frame.

If the program completely loses the desired feature the operator can intervene and click on the feature in the image and that will become the center of the new selected subimage.

The User's Computer

The user's computer is a Windows 98 machine running a special driver program in the background. The driver program takes the coordinates sent from the vision computer, fits them to the current screen resolution, and then substitutes them for the mouse coordinates in the system. The driver program is based on software developed for the EagleEyes system (2), an electrodes based system that allows for control of the mouse by changing the angle of the eyes in the head.

Any commercial or custom software can be run on the user's computer. The visual tracker acts as the mouse. The NumLock key is used to switch from the regular mouse to the visual tracker and back. The user moves the mouse pointer by moving his head (nose) or finger in space.

The driver program contains adjustments for horizontal and vertical "gain." High gain causes small movements of the head to move the mouse pointer greater distances, though with less accuracy. Adjusting the gain is similar to adjusting the zoom on the camera, but not identical.

Many programs require mouse clicks to select items on the screen. The driver program can be set to generate mouse clicks based on "dwell time." With this feature, if the user keeps the mouse pointer within, typically, a 30 pixel radius for, typically, 0.5 second a mouse click is generated by the driver and received by the application program.

RESULTS

The tracking program works extremely well. The program tracks a person's nose for many minutes without adjustment or intervention. No lighting changes were made in the lab, which has standard overhead fluorescent bulbs. Occasionally the selected subimage creeps along the user's face, for example up and down the nose as the user moves his head. This is hardly noticeable by the user as the movement of the mouse pointer still corresponds closely to the movement of the head.

The Camera Mouse

A person without disabilities has good control very quickly. A person can sit down and spell out a message on an onscreen keyboard after just a minute of practice. Using 0.5 seconds dwell time spelling proceeds at approximately 2 seconds per character, 1.5 seconds to move the pointer to the square with the character and 0.5 seconds to dwell there to select it. People spell out entire messages without intervention by the operator.

We have tried the system with three teenagers with severe disabilities. Two of the teenagers used to have no head control but have had a baclofen pump implanted in the past year to reduce muscle spasticity. They now have some head control and are able to move the cursor around but not yet reliably. One teenager is able to move the cursor at will by moving her head.

We have been working with Rick Hoyt, who was born with severe cerebral palsy. Rick has some voluntary head movement, especially to the left. He and his brother developed an easy to use and increasingly popular spelling system based on just a "yes" movement. We have implemented the spelling system in a computer program (3). When combined with this tracker, messages can be spelled out just by small head movements to the left or right using the Hoyt spelling method.

DISCUSSION

Our current system does not use the tracking history. The subimages in the new frame are compared only to the selected subimage in the previous frame and not, for example, to the original subimage. We plan to investigate methods that would compare the current subimages with past selected subimages, for example using recursive least squares filters or Kalman filters (4).

We are just beginning clinical work with the tracking system. We will invite more people with severe disabilities to try the system. People for whom the system seems appropriate will continue working with it so that we can help them better access the computer and also so we can try to optimize the performance of the system. We will work with Rick Hoyt so he can use the tracking system to spell out messages on the computer using his own spelling method.

Our larger plan is to develop systems to visually recognize the facial movements – head movements, blinks and winks, tongue movements, eye movements (5) – that people with quadriplegia can make so we can provide computer access to as many people as possible. We hope the visual tracker is interesting and useful in itself and a first step in this larger project.

REFERENCES

1. Essa IA, "Computers Seeing People." AI Magazine, Summer 1999, 69-82.
2. DiMattia P, Curran FX, and Gips J, EagleEyes: Emancipating the Intellect of Learners with Severe Disabilities. Edwin Mellen Press, in press. See also http://www.bc.edu/eagleeyes
3. Gips J and Gips J, "A Computer Program Based on Rick Hoyt's Spelling Method for People with Profound Special Needs." Submitted.
4. Haykin S, Adaptive Filter Theory, 3rd edition. Prentice Hall, 1995.
5. Betke M and Kawai J, "Gaze Detection via Self-Organizing Gray-Scale Units." Proceedings of The International Workshop on Recognition, Analysis, and Tracking of Faces and Gestures. IEEE Press, 1999, 70-76. See http://oak.bc.edu/~betke/research-group/default.html

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