On Building Intelligence into EagleEyes

James Gips

Computer Science Department
Boston College
Chestnut Hill, MA 02167
U.S.A.
gips@bc.edu

Abstract. EagleEyes is a system that allows the user to control the computer through electrodes placed on the head. For people without disabilities it takes 15 to 30 minutes to learn to control the cursor sufficiently to spell out a message with an onscreen keyboard. We currently are working with two dozen children with profound disabilities to teach them to use EagleEyes to control computer software for entertainment, communication, and education. We have had some dramatic successes.

1 The EagleEyes System

EagleEyes [4,5,6] is a technology that allows a person to control the computer through five electrodes placed on the head. An electrode is placed an inch above the right eye and another an inch below the right eye. Electrodes are placed at the temples, an inch to the left and right of the eyes. A fifth electrode is placed on the user's forehead or ear to serve as a reference ground. The leads from these electrodes are connected to two differential electrophysiological amplifiers, which amplify the signals by a factor of 10,000. The amplifier outputs are connected to a signal acquisition system for a Macintosh or Windows computer. Custom software interprets the two signals and translates them into cursor (mouse pointer) coordinates on the computer screen.

The difference between the voltages of the electrodes above and below the eye is used to control the vertical position of the cursor. The difference between the voltages of the electrodes to the left and right of the eyes is used to control the horizontal position of the cursor.

The dominant signal sensed through the electrodes is the EOG, or electrooculographic potential, which also is known as the ENG or electronystagmographic potential. The EOG / ENG has been investigated for over 70 years [21]. The EOG/ENG results from the variation in the standing potential between the retina and the cornea [16]. The signal corresponds to the angle of the eye relative to the head. Currently the major use of the EOG/ENG is in diagnosing vestibular and balance problems [3]. In the 1960's and 1970's people experimented with the EOG as a means of determining where people are looking [25]. Currently most approaches to sensing point of gaze use an infrared-sensitive camera or imaging system to visually track features of the eye and then a computer or

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some electronics to do the reverse geometry to determine where the user is looking [19,8]. Baluja and Pomerleau [1] have reported using a neural network to process ambient light video camera images of the eye to determine where the user is looking.

Using electrodes has its problems for tracking gaze. The EOG/ENG signal is a function of the angle of the eye in the head, so the signal can be affected by moving the eyes relative to the head or by moving the head relative to the eyes or by a combination of both. The signal picked up through the electrodes also can be affected by moving your eyelids [2], scrunching your eyes, moving your tongue, and by other facial movements both conscious and unconscious. (There also can be drifts in the signal caused by, for example, reactions between the skin and the electrodes, and interferences in the signal from various equipment and external anomalies. The signals involved are quite small, typically on the order of 100 microvolts.)

In the EagleEyes system we are not so much interested in the traditional tracking of eye movements as we are interested in enabling people to control the computer. For us the many ways the user can affect the signal is an advantage rather than a disadvantage. During initial training and skill development people experiment and arrive at their own optimal method of controlling the cursor. It's a semi-conscious skill like riding a bicycle or skiing. Some people move their head a lot. Some move their eyes. Some use their tongues. Many of the people we are working with have such profound disabilities. Whatever works is fine with us. Think of the brain as a neural net! People arrive at some optimal way of controlling the signal but it is not always quite clear how or what is going on.

Control of the computer through EOG also is being investigated in the EyeCon/Biomuse system [14] and by groups at Shinshu University in Japan [7] and the University of Vienna [22].

The EagleEyes system software allows us to run EagleEyes with most existing commercial software. Our system software runs in the background. Every 1/60th of a second it springs to life, senses the two values on the A/D converter, translates the values into screen coordinates, and saves them as the official mouse coordinates in the system. An option in the software allows a mouse click to be generated whenever the cursor remains within a settable small radius on the screen for a certain period of time. That is, the user can generate a click by holding the cursor at a spot on the screen for a certain fraction of a second. The software can run in the background with any well-behaved application. Thus, Macintosh or Windows software, whether commercial or custom-developed, can be run by eye control instead of mouse control.

2 Current Systems

We currently have seven EagleEyes systems, three in our laboratories, one in the Campus School, one in a satellite facility at the Reeds Collaborative in Middleboro, Mass., and personal systems in the homes of a 13 year old boy and a 15 year old boy, each of whom have spastic quadriplegic cerebral palsy. The

Campus School is a day-time educational facility for 42 students, aged three to twenty-two, who are non-verbal and have multiple impairments. It is part of the School of Education at Boston College and is located on the main university campus. The EagleEyes facility at the Campus School is reserved for full-time Campus School students in the morning and for visitors and other students with disabilities from the greater Boston area in the afternoon. Because of increasing demand, we recently opened up the facility in Middleboro, about an hour south of Boston, to provide access to EagleEyes to children in the area. EagleEyes facilities at other locations are under discussion.

The personal systems were installed in the homes of two young men who have no voluntary control of muscles below the neck, have no reliable "switch sites," and cannot speak. Both have learned to use EagleEyes well enough to spell out messages. Both use EagleEyes every day for cognitive academic activities in their school programs; they are able to use EagleEyes to do their homework [13,15,20].

3 Using EagleEyes

The EagleEyes system mainly tracks the EOG, which is proportional to the angle of the eye in the head. Learning to use the EagleEyes system is an acquired skill.

A person without disabilities usually requires 15 to 30 minutes to learn to use the system and to become proficient enough to spell out her name using a keyboard displayed on a screen. For a new user we usually explain that the system is measuring mainly the angle of the eye in the head and that the cursor can be moved either by holding the head constant and moving her eyes or by fixing her eyes on a spot in the screen and by moving her head or by some combination of the two. New users practice moving a cursor on a blank screen and then play a simple video game we have developed for training.

In one study we taught twelve undergraduates (mean age: 20) and ten faculty and staff (mean age: 58) to use EagleEyes. Subjects had no previous experience with EagleEyes. Each session lasted one hour. By the end of the session all but one of the subjects were proficient enough to shoot down 9 or 10 out of 10 aliens in the video game we use for training. Eleven out of twelve undergraduates and eight out of ten faculty and staff became proficient enough to spell out the message "hello eagle eyes" through the electrodes with an average of under one error per subject.

For people with severe disabilities it can take anywhere from 15 minutes to many months to acquire the control skill to run the system. First of all, the children need to understand that they are controlling the cursor on the screen by moving their eyes. Children who are completely paralyzed from birth are not used to physically controlling anything, much less the cursor on the screen with their eyes. Once the children understand the cause and effect of moving the cursor with their eyes, we help them develop their control skills by having them run various commercial and custom-made software. For example, one program allows them to "paint" with their eyes. Wherever the child moves the cursor colored lines are drawn. At the end of the session we print out the eye paintings on a color printer and give them to their parents to hang up on the refrigerator or to put in a frame on the wall. The children use video games for practice and also multimedia programs we have developed that allow the user to select one of four digitized video clips to be played by looking at one of four opening frames of the clips presented in quadrants on the screen.

At the invitation of the California Pacific Medical Center in San Francisco we recently tried EagleEyes with ten people with ALS (Lou Gehrig's disease). In a 60 to 90 minute session six learned to use the system well enough to hit at least 9 out of 10 aliens in our training video game. Five learned to use EagleEyes well enough to spell out messages. One gentleman with advanced ALS spelled out the message "there is no way to the end of the journey but to travel the road that leads to it".

4 The Human-Computer Interface

A major challenge has been the design of the human-computer interface. That is, given the capabilities of people to move their eyes and head to control the signal and given the physical characteristics of the EagleEyes system, the amplifiers and so forth, how should the software be designed so that it is easy for people to use? Jacob [10,11] points out important potential benefits and problems of using eye movements to control computers. For example, he discusses the "Midas Touch problem":

> *At first, it is empowering to be able simply to look at what you want and have it happen, rather than having to look at it (as you would anyway) and then point and click it with the mouse or otherwise issue a command. Before long, though, it becomes like the Midas Touch. Everywhere you look, another command is activated; you cannot look anywhere without issuing a command. The challenge in building a useful eye tracker interface is to avoid the Midas Touch problem.*
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> Jacob ([10] page 156)

Generally the software we use with EagleEyes is controllable by large buttons or clickable areas. The basic issue is accuracy and control. With EagleEyes, the user can move the cursor with fair accuracy and can issue a single mouse click by briefly holding the cursor at a spot.

We have experimented with using voluntary blinks instead of dwell time to cause a mouse click. We have written software to detect voluntary blinks versus involuntary blinks. We have found voluntary blinks to be slower and less accurate than dwell time in making selections. (When a person blinks there is a large spike in the vertical EOG. It takes some time for the vertical signal to recover.) With a third pair of electrodes and another amplifier and signal channel we have devised software to detect winks of the left and right eye. Undergraduates can learn to blink quickly twice in succession for a double click or that winking the left eye causes the left mouse button to be depressed until the next wink. This is not very natural. The more fundamental problem with this general approach for us is that we have found that the children and young adults we are working with cannot voluntarily blink or wink their eyes!

We have adapted EagleEyes to use with the now standard wimp (Window-/Icon/Mouse) interface but it does not seem quite right for our users. We are groping towards a better interface to use with EagleEyes. Nielsen [17] and Jacob et al. [12] provide interesting discussions of trends for next generation user interfaces, including some possible future roles of eye tracking devices.

We have experimented with two forms of continuous movement through a virtual space with EagleEyes.

One form is the movement through a virtual visual space. For example, EagleEyes works with classic commercial video games where you (your character) move around through a simulated world. A favorite with some of our older male users is to run commercial flight simulator game programs strictly through the electrodes of EagleEyes. Of course you use your eyes to gather information and your eye movements can be involuntary. It's easy for your plane to spin out of control when using a simulator with your eyes, perhaps even more so than with a mouse or joystick.

A second interesting form of continuous movement through a virtual space is to use EagleEyes with a real-time musical composition program. Here the space is auditory. The music that emerges from the computer depends on the cursor location. Normally the user composes by moving a mouse or joystick; the music changes in real-time. With EagleEyes, the user composes by moving his eyes. Since EagleEyes works equally well with eyes closed, you can sit back in your easy chair with your headphones on, close your eyes and relax, and compose music by moving your eyes and head.

A basic trend in human/computer interfaces has been a continuing shortening of the feedback time between human and computer. In the bad old days of punched cards and batch jobs the feedback time was measured in hours or days. Now the feedback time is measured in seconds. Still, there should be a way to shorten it even more by eliminating the voluntary motions of moving the hand to move the mouse and click the button. Shortening the feedback time seems to lead to increased realism and better interfaces.

5 Controlling Mobile Devices

A student project allows a commercial remote-controlled toy car to be controlled through EagleEyes. Basically the idea is to look left and the car moves left, look up and the car moves forward, etc. This is a big hit with children who have never been able to control a physical device.

In recent work [24] EagleEyes was used to control the Wheelesley robotic wheelchair [23]. A robotic wheelchair has sensors and an internal computer so it can automatically avoid running into obstacles and walls. (See the several papers in this volume.) With EagleEyes the driver looks up to move the wheelchair forward. The driver looks left to move the wheelchair to the left. And so on. This can be considered a real-life extension of the use of EagleEyes to move through virtual visual spaces. Since the driver is using the eyes to take in information as well as to steer the wheelchair, this takes a certain concentration. The sensors and the internal computer can do most of the work of controlling the chair and keeping it out of trouble. The driver is needed mostly at decision points, for example at hallway intersections or when turns are needed in open spaces. We demonstrated this highly experimental system at the American Association for Artificial Intelligence '97 national conference in Providence, RI. Work is continuing on improving the interface and the control methods. The goal is to create a wheelchair system that people with profound disabilities can use, people who have no chance at becoming competent drivers of conventional powered wheelchairs.

6 Custom Software

We have developed several types of applications software to use with the system – communications software, educational software, entertainment software [5].

In communications software, we have developed a classic "spell 'n speak" keyboard program. We have found the typing speed using EagleEyes with a full on-screen keyboard to be about one character every 2.5 seconds for short (three or four word) messages. The accuracy required for a 30 character keyboard is too great for the children with disabilities with whom we are working. We have worked on perhaps a dozen iterations of a two-level system, where the user first selects a group of letters and then selects a letter from the group. We also have worked with various augmented communication systems, like Boardmaker and Speaking Dynamically, where the user looks at icons and the computer speaks words or phrases that correspond to the icons. Most children with profound disabilities are taught to look up for "Yes" and down for "No". One of the first communications programs we usually try with a child is a program that asks a question (typed in ahead of time by a parent or teacher) and then says "Yes" for the child if the child moves the cursor up and "No" if the child moves the cursor down. Once this skill is mastered we can move on to a spelling program that allows the user to select a letter by looking up for "Yes" and down for "No" in response to questions like "Is the letter in the group ABCD?"

We have developed several types of educational software. One often-used program administers multiple choice tests via eye control. The question is placed in the center and four choices are placed off in the corners (or in a + pattern). This program is being used every day by the two teenagers with EagleEyes systems in their homes.

All of this software works with a traditional mouse as well as with EagleEyes. It simply is designed to be controlled with large buttons and single clicks and to be as easy to use and transparent as possible. The content is designed to be useful or amusing for the children and young adults with whom we work.

7 Intelligence

Currently the intelligence in the EagleEyes system resides in the user. We provide tools and feedback, but it is up to the user to learn how to control the electrical potentials that are sensed by the electrodes on his or her face. The guiding principle in the design of the EagleEyes hardware and software has been KISS – Keep It Simple, Stupid.

The EagleEyes system and processing is as simple and transparent as possible. The system is self-centering. The only initial calibration we do is to adjust the gain on each channel and that is only on systems that are used by multiple people. On systems in children's homes, there are no initial calibrations or adjustments necessary as the gain settings usually are appropriate from one session of a single user to the next. During the processing either we use the raw signals to control the mouse pointer or we do some simple exponential smoothing on the signals, at the choice of the user.

A question for us is how we might build intelligence into the EagleEyes system itself, for example into the "mouse" drivers. EagleEyes is an interface between the user and an application program on the screen. We might have EagleEyes more aware of the application program or more aware of the user or both.

EagleEyes is designed to work with any application program. One approach to making it aware of the application program might be for it to examine the screen, decide what might be the points of interest (for example buttons or, more generally, locations of color discontinuities), and then try to determine if the user is trying to reach one of those points. The program might attempt to assist the user in moving the cursor to those points and perhaps in issuing a mouse click there.

EagleEyes receives signals from electrodes placed around the eyes: these correspond primarily to the angle of the eye in the head and are affected by eye movements.

Human eye movements have been studied for many years and much is known about them [25,18]. When scanning a visual scene or a computer screen or reading text the eyes often engage in "jump and rest" behavior. A saccadic eye movement is a rapid ballistic movement by which we voluntarily change fixation from one point to another. A saccadic eye movement can take from 30 to 120 milliseconds. Between saccadic eye movements the eyes often are relatively still as they fixate on an area of the screen for approximately 250 milliseconds (100 to 500 milliseconds) and take in the information in that area. We could attempt to have the EagleEyes driver make use of the characteristics of human eye movements in moving the cursor. For example, the driver might use the ballistic characteristics of saccadic movements in better predicting where the user wants to move the cursor on the screen.

Are these feasible? Would these efforts do more harm than good? The concern is that the control of the cursor might become more complex and unpredictable so the user might have more difficulty learning to control the cursor through EagleEyes. Eye movement is not the only source for the signal we are sensing. By our efforts we might make EagleEyes more difficult to use rather than easier to use.

We have been working to make the user better able to control the signal. We have been working to make and find applications software that is especially EagleEyes-friendly. Whether our users would benefit from an attempt to build intelligence into the EagleEyes software itself is an important open question for us.

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