A Testbed for intelligent Eye Research

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Abstract

The Eye-bed prototype introduces new ergonomic language scenarios. This paper focuses on developing a demonstration eye gesture language for intelligent user interface and computer control. Controls are integrated with a user model containing a history of previous interactions with the interface. Context recognition enables the Eye-Bed environment to continually adapt to suit the user's inferred and demonstrated preferences. Staring, gazing, glancing, blinking, etc… are part of person-to-person visual communication. By creating a computer interface language composed of exaggerated eye gestures, we create a multi-modal interface that is easy to learn, use, and remember.

1. Introduction

Computer human interfaces have long been applied to everyday situations. These interfaces are often trapped in a user-directed model, relying on the user to know and use a language to directly specify what she wants from the computer. More recently computers are finding their way into everyday things. These days our appliances seem to need to have their computers booted before they work. Cars, phones, record players even house locks come to a grinding halt when their computers don't work. We have been programming our thermostats, watches, and videotape recorders for so long that it seems reasonable to spend hours learning to use an MP3 music player that fits in your hand. They are about to get simpler.

At the very least hospital beds have some control for comfort, height, angle, and temperature. The bed area has another control to call an assistant. Usually each bed has a control for a television. How should we position ourselves optimally to watch a movie from bed? Automation of communication and media in bed could be very useful. The Media-Bed scenario adds new rich command and control integration opportunities to the computer human interface (Shelley, R., 2001).

If one integrated environmental controls, educational materials, and entertainment media into a bed interface how would a user communicate with it? Imagine imagery projected on the ceiling over a bed. [*Fig 2.*] Consider functions presented spatially as an integrated ecological user interface. This would require a person to select things on the spatial interface. Spatial selection has many dexterity problems. Historically the control theory issues and other obstacles of the components of Fitts and Steering laws (Hinckley, K. et al, 1994) have paled in comparison to the difficulty of learning command languages. We consider new languages that are trivial to learn and require low cognitive overhead to use. Through mimicry and extension of the social communication people employ nonverbally, we explore the realm of reduced consciousness communication.

Graphical interfaces are wonderful in that they allow a user to recognise something they might not have been able to remember otherwise, like a place in a file hierarchy. If they want an item they simply point at it to select it. Still, graphical interfaces have long been cumbersome and frustrating. People control 3D interfaces with analogue devices that change the rate and angle of motion as though the ultimate way to interact with a computer would be some sort of hovering gravity-independent helicopter. It is hard to learn to fly a helicopter. Many novice users of 3D interfaces have the constant feeling of listing dangerously as they walk into walls and can't stop the scenes from rotating.

A provocative area of user input design has been eye control. It has seemed like one of the ultimate interface approaches since the 1960s when the first rudimentary mechanical Perkinji trackers were demonstrated. Indeed psychologists and marketing people have used eye position to understand people's interests**.** (Yarbus, L. 1967). Unfortunately eye tracking utility has been stymied: the head moves; the eyes don't want to look at one thing; the tracking devices work in lab settings better than in an office; etc…. For the past 40 years, people have been improving eye-tracking technology using Electro-occulogram eye trackers, contact lenses, tracking infrared cameras and dual cameras to get to lightweight camera based systems. Dual camera systems like the Autostereoscopic user-computer interface (Pastoor, S., Skerjanc, R., 1997) and multiple multiplexed structured light source camera systems like the Blue Eyes™ system at IBM have become excellent tools (**BLUE EYES**). Unfortunately, these "better eye tracking systems" have made it even more obvious that the eye is not simply looking for interesting things that it wants to effect.

The eye is not a cursor control device. The eye notices movement in the periphery and has to attend to it vigilantly searching for danger. The eye is a guard dog; it has a job to do. Using eyes and trackers to move a cursor precisely is like using a security officer in a bank to show people the bathroom. The officer could do it but not as well as a concierge; at the same time the officer would risk being remiss in the primary security duties.

2. Eye motion as language

Large areas of the brain are devoted to interpreting visual input and controlling the eye (Carpenter, M., 1976). The sensitivity of the eye itself makes it a strange choice for a pointing device. The eye, after all, seeks to understand anything in its view. The area centralis is some 3 degrees wide; anything in this visual area is well known to the mind. One of the most difficult issues with eye-tracking scenarios is that the eye-tracking computer demands "eye contact". This is the very thing people are most used to devoting to scanning for safety, acknowledging other people, and to expressing their feelings non-verbally (Clark, H., Wilkes-Gibbs, D., 1986).

Interest Tracker (Maglio et al, 2000) lets people use generalized directional gaze to select information content by demonstrated interest, much as a person does when meeting a new acquaintance. This stands in contrast to the standard eye-tracking interface in which a user is asked to stare at a specific thing until it is selected: the physical difficulty of doing so; the social inappropriateness; and the uncomfortable feeling of the interface is significant. In contrast if the user is asked to look at the general area of an item to be selected these interface obstacles are diminished.

More recent work, demonstrated "Magic Pointing" (Shumin, Z. 1999), an approach that uses eye gaze to make a non-linear jump or "warp" a cursor to where the eye is looking on a screen. Subsequent GUI control is done through the standard cursor control device. It is quite easy to use eye tracking to identify areas of interest. Of value to interface design is the fact that the eye is a course output device and a fine input device. The most important notion however is that Interest Tracker and Magic Pointing take advantage of the fact that the eye wants to look in the area of interest. The syntax that the action of looking at a work area changes the spatial position of the cursor is a powerful one. Using a dwell time of just 0.3 seconds was more than adequate to allow a user to distinguish things they wanted to select. It was also found to be much faster than a mouse can select the same area (Maglio et al., 2000) Interest Tracker, introduced above, is a system that shows another simple and productive use of gaze interpretation. It augments a person's natural gaze at an area of interest with additional information or content of a similar nature.

Invision (Li, M.; Selker, T., 2001), takes this one step further, based on evidence that shows that the paths that people's eyes follow demonstrate what they are thinking (Yarbus, 1967). When people rapidly transit from one place to another they are more likely to be making a selection of a familiar item. When people's eyes move slowly around the field-of-view they are taking in information, and making decisions, but not selections.

The pattern based Invision interface made two contributions to eye tracking. It demonstrated that eye tracking accuracy could in many cases be improved by interpreting eye movement as the endpoints of the trajectory (i.e. knowing where the eye had moved from and too helps to understand user intent and focus). In the second, and more interesting case, the relationships between objects that the eye gazes at and the order that they are gazed at become the language that drives the computer. The system showed a set of objects representing the various sponsors of the Media Lab. As a person traversed them with their eyes, it used the path to notice their interests. As a person's eye went back and forth, between two things, the objects they were looking at moved closer to one another. In this way, as a user shows interest in a group of items the interface literally brings these items together. This has been explored as an interface for a kitchen as well (opening the refrigerator, oven, cabinets and dishwasher). These pieces of research all focus our attention on the information that comes out of an eye.

2.1.1. Gaze vs. Stare Detection:

The Eye-ARe Project took this further. Eye-aRe is a simple system that consists of a glasses mounted infrared LED and photodiode that detect reflected infrared light from the eye's cornea and sclarea. (Selker et al., 2001) A small PIC can detect when a person is gazing that their eyes roam around versus when they are staring their eyes stay relatively fixed. It is not hard to separate simple eye gaze intent. This approach can separate out intended versus unintended selection events. Even without a camera, Eye-ARe has successfully been used to send business card information when a user stares at (or is engaged in conversation with) another person, to bring up information about a display when a person looks at it, and detect closed and opened eyes and individual blink and wink signatures.

If the actions used to interact with a computer mimic the normal use of human eye gesture language, this synergy could assist user's learning and memory. Can such an eye gesture based language be the basis of an ecological interface? Can such a natural control language be integrated without being difficult to learn or generating confusion? Can reasoning, learning, and representation of intelligence be employed to give users more control?

Complex social dynamics are traceable to eye motion (Clark, 1986). These can be used to enhance human computer communication. Eye motion demonstrates a social gesture language. These are significantly easier to record than eye position. With this thesis we will describe the ways that eye gestures and task modeling have been experimented with in the Eye-Bed to reduce reliance on direct manipulation in the interface.

3. Media-Bed & Eye-Bed

The bed is a place where the average person will spend approximately one third of their life. Once made of plant fiber and then synthetic materials, we have now made the bed digital. The Media-Bed and Eye-Bed are a response to the challenges of integrating environmental, educational, and entertainment controls in a universal interface. The Media-Bed and Eye-Bed could simplify the controls of a hospital bed while adding new features that integrate these domains [good morning america].

The Media-Bed and Eye-Bed are part of a growing body of language based interface development. (Selker, T.; Burleson, W., 2000) The thesis is that replacing explicit spatial selection with a language-based interaction may provide interfaces that are easy to learn, use, and remember. One novel control approach in this direction has been the use of eye tracking. The social language of the eye (i.e. "wink, wink…. Know what I mean" as said again and again in … Monty Python's Holy Grail) can be used as a natural easily understood language. In the Bed projects we overlay and map expected characterized ocular responses such as stare, gaze, wink, etc… with a language to communicate interface intentions between the user and the computer.

The Media-Bed and Eye-Bed are a computer systems that recognizes and remembers what a person is doing in bed to provide useful information and environmental modifications. They "listens" to many information channels to enhance the semantics of a language. The Eye-Bed extends language recognition of the Media-Bed to include eye-tracking semantics: blinking, winking, staring, and gazing. Both create a user model which includes time stamps, interface states, knowledge of the position and sound of the user, in additon to the traditional direct user input channel.

The Media-Bed and Eye-Bed are a place for us to experiment with new scenarios for using a computer in our live. They are also a place to experiment with new multi-modal input devices. For example, eye tracking in a bed has advantages. The person's head is supported and can be stabilized. This naturally reduces the difficulty of finding and tracking the eye position. The bed consists of an integrated multimedia personal computer and video projector. It runs a Macromedia Director movie projected onto the ceiling above a standard bed. This projection creates a virtual world that provides the user with a space for interaction and reactive input.

3.1. Prototype Scenario

A person is lying in bed. Many simple activities can be computer-facilitated making lying in bed more pleasurable and productive. A scene appears, projected on the ceiling above the user's head (Figure 2). It is a scene of rolling hills dotted with icons: an e-mail kiosk, a TV satellite dish, a juke box, a person reading in a lawn chair, a newspaper stand, the moon and stars, and the sun. Each of these icons can move the user into another part of the world depending on his needs and wishes at the time. We have experimented with different renditions of physical world imagery or so-called "ecological interfaces". Ecological interfaces have been shown to improve speed and accuracy of selection over two-dimensional interfaces when users are familiar with them (**Dryer et al, 19??).**

Pointing and selecting it, the kiosk enlarges to fill the screen, bringing the user into another space. A smaller rendition of the rolling hills at the top of the screen points to the original main screen where the user came from. The user can similarly watch TV, read the newspaper or read an online book while lying on their back in bed. The display is projected upward to cover the ceiling above the bed. When reading something or watching TV or a movie, the user no longer has to prop themselves up with their arms or find a comfortable position to sit in. If the user has back or neck problems, this is especially important.

Once the user has finished reading e-mail selecting the hills at the top of the screen returns them to the initial selection screen. It's time to go to sleep, so the user moves to the moon and stars, a soothing song begines to play and a sunset that gradually darkens to reveal the night sky is projected. The bed can subtly and playfully encourage or persuade a person to go to sleep at an hour that they should by shifting to this mode as well. (Fogg, B., 1998) Selecting the moon presents the outlines of constellations. As the user explores the night sky, the names of the constellations and planets appear. Selecting a planet brings up its path and other information. This is an example of how the system can function in an educational and informational role as well. As the user falls a sleep (their eyes close and they move less), the bed recognizes the hour, and sets sunrise wake up music to accommodate the user's sleep patterns. The bed has learned how long it's occupant likes to sleep by monitoring the use patterns of the alarm clock. Since the bed has access to the user's calendar, it knows the user will not miss any appointments by waking up at eleven o'clock. In the morning, the sun rises on the ceiling, accompanied by morning music. The room is gradually lit up by the sunlight, and the day's schedule is presented for review along with e-mail and newspaper customized to the user's interests and preferences. In this scenarios the user is able to enjoy the activities that they normally enjoy with the media selection assistance from the computer.

Selection of functions on the Media-Bed selection of items on the ceiling was originally accomplished with a Polhemous 6-degree of freedom system in a ball. The position of the ball controlled a ball-shaped cursor on the landscape imagery of the ceiling interface. The ball used a bed based coordinate system to control a cursor on the screen. It was tiresome to hold it in exactly the right position on the bed to activate the functions . The Gyromouse™ did not require the person's hand to go to a specific place in the air or on the bed to use spatial control. The TrackPoint™ in a custom built handle and a TrackPoint keyboard were much easier to use allowing hands to rest on the device. The next step in evaluating the Media Bed interface was to add an eye tracker. The newer Eye-Bed system uses the eye-tracker, positioned in a lamp mounted to the headboard, to control the system.

Through the construction of user model profiles, the Media-Bed and Eye-Bed can learn to suit the user's wishes by understanding what they are interested in seeing, doing, and listening to. The boom box and media presenting applications in the bed do this explicitly. A hiking boot icon when selected kicks the juke box or media player indicating to the user that the system will try to change what media to present. The system changes the current media and updates the model of what to try in the future. It uses artificial intelligence to record actions and reactions of the user to build a model of what kind of information and media will be useful in which situations.

The Eye-Bed version augments the positional syntax of a cursor on a GUI with a language of few simple eye gestures to make an even more interesting interaction scenario. This is done through a paradigm of *relaxed eye tracking.* The Eye-Bed version develops a contextual knowledge of the situation. It uses the "eyes shut" condition to know when a person is asleep or not wanting to see imagery anymore. "Eyes open" to tell the bed that a person need not hear the loud version of the alarm clock, "excessive blinking" or "nervous eyes" to change the station of the radio or TV, and "gazing" into a sparse ecological interface to select interface icons. The eye position itself and the way that a person is looking at something can determine what should be done. If the eye isn't wandering and there is only one nearby object of interest the selection is obvious. Using this multi-modal and contextually aware approach we have enhanced the user interface in the Media bed.

3.1.1. Nervous Eyes Want Change

Work with Eye-aRe and the work of many other researchers have shown that it is easy to recognize rapid blinking as a sign of dissatisfaction. In the Eye-Bed we integrate rapid blinking as the syntactic way to say you are not satisfied with the current interactions. For example, we used rapid blinking to change the channel on the radio and video, in a similar manner to the boot kicking the player. Since this action is similar to the natural way of communicating dissatisfaction, people are able to remember the action and accomplish it with ease.

3.1.2. Open Eyes

It is extremely easy to know when an eye is open or closed. Eyes open presumes the person is not asleep and is thus the syntax for telling the bed to activate wake-up imagery of a sunrise and turning off the loud alarm if the time is morning or if the user generally wakes up at that time of day. Likewise if a person is not in bed the wake up alarm is not needed. An eye projected on the ceiling shows the eye open and labels the status "open". This projected eye is part of the feedback to the user that the eye tracking is on and working.

3.1.3. Eyes Closed

Missing pupils is the syntax for putting the system into a sleep mode. Of course, a person need not watch TV or other things when they are asleep so it can fadeout these media. The Eye-Bed system puts up a black screen with "Zzzzzzz…" written across it when a person closes their eyes for several seconds.

3.1.4. Stare

Attention is a fundamental communication act. When a person looks at something intently we call it staring. In the Eye-Bed we use dwell time to activate a spatial icon. Eye-aRe demonstrates that staring at a toy dog is an obvious way to make it respond with a bark; staring at a TV is an obvious way to demonstrate interest in the TV show. Therefore staring in the Eye-Bed is used to select and activate media.

3.1.5. Gaze

When a person looks around we could say they are gazing. In the Eye-Bed the eye moving around without staying anywhere is interpreted as lack of focus on the bed interface. The system shows the interpretation on the ceiling display eye indicator.

The eye gesture syntax described in this section is small. The simple language of eye states has been enough to drive the entire Eye-Bed demonstration.

3.2. Discussion

Typical spatial interfaces use a spatial inclusion syntax. **(ref selker apel**). The control moves an indicator or cursor to within the boundaries of a spatial object or icon to associate syntax to it. The eye gesture language is an augmented visual language in which some eye gestures have global consequence while others act as parameters of a selection device just as mouse buttons on a mouse are parameters to the graphical object that the cursor associates it with. The Eye-Bed eye gesture language has made it possible for people to control the entire Media-Bed interface using only their eye gestures.

In using a gesture-based interface it usually becomes difficult to teach and use the gestures. This system's use of natural eye gestures, which people do anyway, makes using the bed almost as natural as a social interaction. One goal of creating "natural interfaces" is to create interfaces that use the actions that people are familiar with and relate them to actions the system might expect of users. This can be achieved by copying the actions of people. Studying perceptual and physiological actions and capabilities of people is important as well. It has been shown that in many situations people treat computers as they do people (Reeves, B.; Nass, C., 1986). This paper and these uses of eye input demonstrate how the higher order behavioural and social psychological areas can be used as a motivating approach for interface design. By carefully studying these fields exciting taxonomies of natural behaviour can be found. Once found these can become a basis for more natural, social, and gesture-based interaction languages with the computer. Our goal is developing interaction languages that are amalgamations of typical human actions with appropriate computer augmentation to assistance people in what they want to do.

3.3. Status

3.3.1. Media Bed

The Media-Bed is a Macromedia Director program running on a computer. The Media-Bed with physical inputs has been demonstrated to hundreds of people at the MIT Media Lab; the opening of Media Lab Europe in Dublin, Ireland; and at the AAAI Fall 2000 workshop in Falmouth, MA. We are surprised at how relaxing it is to lie down to demonstrate the night time and wake up scenarios. Within days of it working people were approaching us to form marketing alliances. We have used the media Bed and its display as a place to work and find that it is quite relaxing.

3.3.2. User Model

All of the selection scenarios are enhanced by the creation of the user model. The simplest user model is that a person whose eyes are closed need not be shown imagery. Currently we consider a person whose eyes are closed to be asleep.

The user models in the radio and TV are the most sophisticated. These models notice what time of day it is, what has been playing and how long a user listens or watches it as a basis for appreciation. If a user likes the music then similar music continues to play. Of course we have found that some people don't like to hear the same music over and over again. Refining the heuristics for this is a current goal. The eye tracking approach has allowed us to simulate nervousness or detect actual nervousness as the way to tell the media generator that it should attempt to find other media to play. If a person is not paying any attention to anything near the media player and has not recently turned it on, these analyses of nervousness most likely are not about the media

3.3.3. Eye-Bed

An early version of the Eye-Bed was demonstrated on Good Morning April 10 2001 (Shelley, R. 2001). The Eye-Bed is the Media-Bed with another computer running the eye gesture recognition software. Mike Li wrote a Java version of the Eye-Bed software. It was replaced with a C version written by Jessica Scott that requires much less of the Ethernet communication for its interpretations. The New version has a much better ability to interpret eye gestures. Further, the new version includes the eye indicator on the ceiling bed display.

The Eye-Bed eye gesture based interface has been demonstrated dozens of times at the MIT Media Lab. The ability to control it with less than a minute of instruction amazes everyone. The impressive thing about Eye-Bed is that people enjoy using it and don’t need much instruction. The system is so easy to use that we often have visitors demonstrate the eye-gesture based interface to one another. The real value of this interface is the ease with which we can recognize the gestures of eyes closed, open, gaze, stare, blink, and nervous blinking.

The current system has limitations. Text entry has not been satisfactorily resolved. There are good and bad times to use the system. So far the system is designed for a single user and does quite well at integrating the many controls of the previously discussed hospital bed. However the system does not make any accommodation for the social or sexual activities that take place in bed in fact at this point many users think that the current features are too intrusive. They are appalled at the thought of email intruding into their bedroom and literally “hanging over their heads”.

3.4. Future Work

The interface is effective enough for us to sleep with it on and beneficial enough for us to enjoy it when we are awake. The goal of demonstrating the limits of time and fidelity of eye gesture are central to our future work. The integration and evaluation of new eye gestures and other physiologically natural gestures is central to the context aware stance of the research group that this work takes place in. Understanding what social cues are for and how to make them reliable within a graphical interface system continues to be exciting. We will extend the language that we have developed to include other forms of implicit communications such as facial gestures. The question as to whether a serious formal theory will aid in this endeavour stands before us.

Discussions in bed, on the phone, or in person will be augmented by pervasive access to information. The nature of this information will also rely upon user models. For example, a four-year old who wants to know what bears eat, is looking for a different answer than what a college biology major with the same question is looking for. We will continue to explore the integration of health monitoring and feedback systems. Sound sensing and acoustical feedback will be used to monitor sleep apnoea and snoring. The Media-Bed and Eye-Bed has moved into educational areas, starting with astronomy. We will soon move on to other contextually appropriate topics. Especially interesting is the context of looking up such as in auto mechanics, marine biology, meteorology, ornithology, and rainforest canopy sciences. This work will also be extended into the realms of fun, play, and creativity by implementing games and motivational activities.

4. Conclusion

The appropriate use of interface techniques should be the focus of the Computer Human Interface field. Unfortunately as industry develops new interface techniques and scenarios designers bring untested ideas into the market. In this paper we attempt to show that a well-understood language of a few eye gestures can simplify the use of the eyes as a control for user interfaces. We further use an ecological interface to simplify teaching control of the user interface. In doing so we create a system that is natural and ease for people to learn, use, and remember. The goal of developing improved user interactions will continue to require us to invent new scenarios and test where and how they can be applied.

5. Acknowledgements

We thank the MIT Media Lab for supporting this work; Jesse Pavel for the Polhemus to Director Interface; Kim May and Ian May for the hand held track point.

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