**eyeCU Eye Tracking System**

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**Abstract**

The aim of our project is to design and implement a low-cost human computer interface such that a computer responds to movements of the user’s eyes. The focus of this system is to enable individuals with limited mobility to easily interact with technology. Currently, there are many eye tracking devices available; however, the price of these commercially available systems is around $30,000. By developing a low-cost eye tracking system, we can make the device a more accessible product for the general public. The system design employs head-mounted unit with an infrared video camera to capture the position as well as the motion of the user’s gaze. Due to its great potential, this project provides a great learning opportunity for students.

**Introduction**

The objective of our project is to develop an eye tracking system for a human-computer interface assistive. The eye tracking system is an assistive technology named eyeCU, the project will use visual feedback from the human eye to move a cursor across the display of a computer. This project fulfills the requirements of the Electrical, Computer, and Energy Engineering Capstone course requirement for the University of Colorado at Boulder, which is needed to receive an undergraduate degree in this field. Development for eyeCU will be conducted in the Electrical, Computer, and Energy Engineering Capstone laboratory. Supervising the project is our faculty sponsor, Tom Brown. Additionally, three graduate level TA’s will be supervising research along with Sam Siewert, senior instructor. This project is intended to provide a computer mouse alternative for those with limited mobility.

**Background**

Many individuals with paralysis have difficulty with daily tasks, especially individuals with full body paralysis. For those who still maintain the ability to use their eyes unhindered, there is the possibility of using eye tracking as a means of interaction with the world. Eye tracking is the process of tracing the movement of the eyes in order to control a computer cursor.

Currently, there are many eye tracking devices available; however, the price of these commercially available systems is around $30,000. By developing a low-cost eye tracking system, we can make the device a more accessible product for the general public. Unlike common eye tracking methods, this project will be done through clever image processing on a microcontroller as opposed to a desktop computer. This would make our device available to any user. Finally, we plan to make this system a wearable device for portability and ease of use.

There are two types of eye tracking techniques commonly practiced: Bright Pupil and Dark Pupil. Bright pupil tracking employs the use of infrared (IR) illumination of the eye to create greater contrast between the pupil and the iris In this configuration, the eye tracking robustness and accuracy is significantly improved; however, this technique is not effective in outdoor lighting due to interference from Ultraviolet light. The Dark Pupil technique does not require IR lighting; however, the algorithms for tracking pupils in this configuration are much more complex.

This project will require background knowledge in embedded systems, digital signal processing, power electronics, real time embedded systems, biomedical engineering, and some knowledge in optical electronics. Additionally, Sam Siewert, one of the Capstone faculty who has extensive knowledge of real-time embedded system will be available for support.

**Methods**

The hardware for our system consists of three main components as shown by Figure 1. First, we have a main board that is responsible for the digital signal processing (DSP). Second, we have a daughter board that connects to the main board via headers. The daughter board will contain the camera interface and a direct memory access controller (DMA controller). The final main piece of hardware is the board that connects to the computer. This third board will communicate with the main board by wireless.

Figure 1: eyeCU Functional Block Diagram

The main board consists of the Beagle Bone development board. This board utilizes the ARM Cortex A8 which features a clock speed of 500-750 MHz and an optimized floating point unit on chip. These features make it ideal for our DSP. This board will communicate with the computer interface board using wireless at 2.4 GHz provided by the XBEE from Sparkfun.

The daughter board will be a custom board designed by the team. It will consist of all the circuitry that is required to interface to the camera. The selected camera will capture images of the eye and communicate via DMA with the main board to transfer the image data to be processed by the ARM Cortex. Choosing to do DMA will allow us to use specialized hardware to handle the memory access, and keep the main board from using clock cycles on low lever processing. The board will feature a Stellaris ARM Cortex M3 which may be used as a preprocessor for the images.

The computer interface board is fairly simple. It will have a MSP430 that will accept data from the main board using a paired XBEE. It will then send commands over USB to the computer. These commands will be received by custom software running on the host computer that will move the cursor accordingly.

The software side of our project is responsible for the tracking the user’s gaze and generating the corresponding cursor movement. This task is broken down into calibration stage where the user’s tendencies are measured, the pupil detection algorithm where the pupil is tracked to find direction of gaze, and finally the computer controller software.

The calibration stage is performed before the device is ready for use. During the calibration process, critical user-specific information is collected to be used for the pupil detection algorithm. First, the center position of the pupil is noted in order to provide a reference point to which the position of the pupil during use can be compared to determine an appropriate direction of cursor movement. Next, a region of interest will be determined in order to decide how far the user’s gaze must drift from the center position for the device to react. Finally, the device will collect information about the skin tone and eye to eyelid ratio of the user to determine if the user is blinking.

As discussed previously, the direction of the gaze is determined based on the movement of the pupil. Our assumption is the direction of the gaze corresponds directly to pupil moving in that direction. Hence the DSP algorithm in our project will be geared towards detecting the centroid of the pupil To develop our algorithm, we will take advantage of the characteristics of human pupil, such as its elliptical shape and dark color. From the result of our calibration stage, we can determine a window in each frame that requires processing and throw away any unwanted parts of the image. At the first level of our algorithm, we will throw away pixels that are not dark enough (also known as thresholding) to restrict the part of the image to be processing to detect the pupil. We will also explore noise removal and other background elimination techniques such as image subtraction to further restrict our search window. Since the pixels of the image that meet the threshold requirement likely form contiguous regions, we suspect that the largest contiguous region is the pupil. Thus our algorithm will find the largest contiguous region, and the center, which corresponds to the center position of the pupil. Note that our algorithm must also avoid capturing false pupil (i.e. when the user has their eyes closed). To do so, we will utilize the fact that the pupil that our algorithm captures must be elliptical.

The output of the DSP software is a series of control codes which will be transmitted to the computer. There are two classes of control codes: calibration codes and cursor movement codes. An example of a calibration code would indicate that the computer should display an image at which the user should direct his gaze. Cursor movement codes will be interpreted by the computer to perform actions like “move cursor right” and “stop cursor movement”.    
 Each control code will be placed into a queue and processed by the computer software. The computer software will be written in the python programming language to encourage cross platform compatibility on machines that run different operating systems. The software runs in the background and continuously receives commands from the computer module at a rate of about 30 times per second. The commands are then interpreted and the indicated action is performed.­

Since the project utilizes an IR LED to illuminate the eye of a human subject in order to test proof of concept for the tracking algorithm, the project requires approval from the Institutional Review Board (IRB) These subjects will be volunteers from the members of the eyeCU team. We have already written and submitted the necessary forms for IRB approval.

**Division of Labor**

To successfully complete this project by the end of the semester, tasks are divided equally among members of the group. Specific tasks are assigned based on the experience as well as expertise of the individual. The following table displays the overall breakdown of labor among the group members. Furthermore, each task has a primary and secondary member in order to provide support.

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| Tasks | Armeen Taeb | Nick Bertrand | Arielle Blum | Mike Mozingo | Khashi Xiong |
| Computer Applications | Secondary | Primary |  |  |  |
| Lighting | Primary | Secondary |  |  |  |
| DSP | Primary | Secondary |  |  |  |
| Code Optimization | Secondary | Primary |  |  |  |
| Camera Module |  |  | Primary | Secondary |  |
| Wireless Communication |  |  | Secondary |  | Primary |
| Physical Setup |  |  | Secondary |  | Primary |
| Firmware/Drivers |  |  | Primary | Secondary |  |
| Power |  |  |  | Secondary | Primary |
| PCB Layout |  |  |  | Primary | Secondary |

Table 1: Division of Labor

**Time Schedule**

**Regular Events**: Weekly meetings among team members on Mondays at 6:00 pm and weekly progress reports submitted to Tom Brown, Sam Siewart, and TAs.

**Major Deadlines:**

* **Preliminary Design Review – 01/31/2012:** Present initial project idea to instructors, TAs, and fellow colligates
* **Critical Design Review – 02/28/2012:** Present design and construction plans of final prototype. Begin major construction and implementation of software.
* **Milestone 1 – 03/20/2012:** First milestone
* **Milestone 2 – 04/10/2012:** Second milestone
* **Capstone Design Expo – 05/03/2012:** Completed prototype with all necessary materials and documentation presented to instructors, TAs, fellow colligates, and general public.

A Gantt chart can be found in the appendix of this document detailing the step-by-step outline of the project including dates for the beginning and completion of each major phase.

**Budget**

The following table details the components which constitute the budget of eyeCU.

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| --- | --- | --- | --- |
| **Item Name / Description** | **Unit Price** | **Quantity** | **Total Amount** |
| BeagleBone MCU Dev Board | $89.00 | 2 | $178.00 |
| CMOS Camera | $9.00 | 2 | $18.00 |
| NVSRAM 4Mbits (External Memory) | $81.71 | 2 | $163.42 |
| Wireless Transceiver | $22.95 | 2 | $45.90 |
| XBee USB Explorer | $24.95 | 1 | $24.95 |
| PCB Fabrication 4-Layer | $66.00 | 3 | $198.0 |
| PCB Fabrication 2-Layer | $33.00 | 3 | $99.00 |
| Expo Presentation Poster | $50 | 1 | $50.00 |
| Eyeglasses Frame | $5.99 | 1 | $5.99 |
| USB mini smd connector | $1.25 | 2 | $2.50 |
| Ethernet connector | $1.95 | 1 | $1.95 |
| FIFO Buffer | $12.00 | 2 | $24.00 |
| Microcontroller 8051 | $4.05 | 2 | $4.05 |
| Package of Zip Ties | $5.99 | 1 | $5.99 |
| Programmable Logic Chip (CPLD) | $1.29 | 4 | $5.16 |
| micro SD Socket for Transflash | $3.95 | 1 | $3.95 |
| micro SD Card Reader | $4.95 | 1 | $4.95 |
| Flash Memory micro SD 4GB | $19.95 | 2 | $39.90 |
| Tantalum Capacitor | $0.95 | 10 | $9.50 |
| Resistor | $0.40 | 20 | $8.00 |
| Voltage Regulator | $1.50 | 5 | $7.50 |
| Battery 3.3V | $2.95 | 2 | $5.90 |
| JTAG Programmer | $55.00 | 1 | $55.00 |
| ARM Cortex A8 MCU | $25.38 | 2 | $50.76 |
|  |  | Total $ | 1012.37 |

**Reference Section**

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**[2]** Guestrin, E.D.; Eizenman, M.; , "General theory of remote gaze estimation using the pupil center and corneal reflections," *Biomedical Engineering, IEEE Transactions on* , vol.53, no.6, pp.1124-1133, June 2006

**[3]** International Commission on Non-Ionizing Radiation Protection (ICNIRP), “Guidelines on Limits of Exposure to Broad-Band Incoherent Optical Radiation (0.38 to 3*μ*m),” *Health Physics* 73(3), 539–554 (1997).

**[4]** International Commission on Non-Ionizing Radiation Protection (ICNIRP), “Light-Emitting Diodes (LEDS) and Laser Diodes: Implications for Hazard Assessment,” *Health Physics* 77(2), 744–752 (2000).

**[5]** T. J. T. P. van den Berg and H. Spekreijse. Near infared light absorption in the human eye media. Vision Research, 37:249-253, January 1999.

**Appendix**

