Assistive Gaze-tracking Headset

Design Specification

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Problem Definition and Background

The eye-gaze tracking is implemented based on corneal reflection and image processing in recent years. Most of the systems require that a user fix the head position by using a chin rest so the motion of the head can be restricted or prevented [9]. For regular use, it is an unreasonable expectation that a user can keep his/her head completely still during the use of a computer. The flexibility to allow changing head orientation is crucial to using a computer naturally.

Gaze tracking for use as an assistive technology has been hampered by approaches which sacrifice head motion. This project focuses on the tracking of eye and head movement to determine where a person is looking. This gaze detection will be used to allow a user to comfortably interact with a computer by doing nothing more than looking at it. The goal is to implement a low cost assistive device prototype which helps people with disabilities to interact with a computer.

Preliminary Work / Design Alternatives

Eye tracking is a popular topic in the assistive industry. It can be a primary computer interface for disabled users who, due to an accident or disease, suffer from paralysis, with the exception of the eyes and head [1]. Various devices were designed to drive a power wheelchair or to control a mouse on a computer using eye movement. There are many commercially available systems to track eye movement based on different technologies. Currently, the most popular ones are image based optical tracking, infrared oculography and electrooculography (EOG) [4].

Infrared oculography uses a IR photodetector to measure reflected infrared light intensity based on the position of the pupil. It has a smaller tracking range in the vertical direction than the horizontal because of the eyelid. Furthermore, eyes retract slightly after a blink which alter the amount of light for a certain amount of time which makes real-time tracking a difficult task. EOG requires mounting electrodes on the skin and reading microvolt signals. An amplifier capable of making the signal useable increases cost, and the intrusiveness of electrodes makes it less preferable for daily use. The infrared detector and EOG based tracking methods also require user dependent calibration. The image based method is less intrusive and provides both horizontal and vertical resolution. However, all three methods mentioned above require head position and orientation to be stable after initial calibration. which is not user-friendly.

The decision matrix could be visualized as follows:

	Tracking Precision (4)	Ease of Use (4)	Safety (5)	Cost/ Availability(3)	Total
Infrared Oculographic Systems	Have very coarse angular motion resolution. Typically multiple degrees. 2	Requires IR Emitter and photodetector to be close to eye. Mounting issues. 4	High intensity infrared light can cause eye damage. 3	IR emitters and receivers are cheap. 5	54
EOG Systems	Reading surface muscle potentials near the eye can achieve sub degree precision. 5	User must attach electrodes to skin in appropriate places. Cumbersome 2	Requires human safe instrumentation amplifier. Shock hazard. 1	The cost of electrodes are generally high. Human safe instrumentation amplifiers very expensive. 1	36
Fixed Position Imaging Systems	Most of the pixels devoted to background image, difficult to achieve high angular resolution. 2	Requires little to no user intervention after initial calibrations. 5	Fixed position cameras pose little to no safety threat. 5	High resolution camera systems are usually very expensive and not available as standalone products. 2	59
Motion Compensated Infrared Image Tracking	Placing camera very close to eye with head mount ensures most of the imaging array is useful. 3.5	Head mount systems are portable and non-intrusive. 4	High intensity infrared light can cause eye damage. 3	Infrared components and low resolution cameras are cheap. 5	60

Selected Design Approach

Our project implements an affordable approach. We aim to develop a headset that accurately and noninvasively track gaze by capturing images of the eye while monitoring head movement to allow the user to comfortably turn their head within a reasonable reading range (<45°). This device, instead of positioned away from a user, will be mounted on the forehead. It will incorporate a widely available webcam and an Inertial Measurement Unit (IMU) containing an accelerometer, gyroscope, and magnetometer to calculate both eye movements relative to the eye sockets and head orientations. Because the camera will be mounted less than 5 cm away from one eye, pixel resolution requirements can be reduced. Human movements in general have limited bandwidth. To be more specific, human head movements are limited in both speed and angle [11], which reduces the requirements for IMU bandwidth. Commercial MEMS IMUs are suitable for our project because of the low cost and availability.

This project will utilize an open source IMU filter, *Madgwick filter*, to track head motion in real-time. This algorithm was used in various research in human movements such as gait characteristics [12]. Because the headset will send images to a host computer to do image processing, a separate microcontroller will be used to calculate head orientations and send results to the host computer to avoid the workload. Even though there are pre-made modules that are based on Arduino platform, we chose to use a Digital Signal Processing(DSP) microcontroller from Microchip Technology Inc because it has lower latency when sampling sensor data and calculating head orientations. We will measure the latency between acquiring sample data and the host computer processing it.

The testing for this project consists of multiple parts, covering both hardware and software. The API is expected to run into multiple issues. The image processing will definitely take some time to perfect. Every eye is different so it may take some time to find the correct methods to find the glint in the image and track it properly. The algorithm for interpreting the gaze angle based on head movements will also cause issues. Scaling the movements correctly will take some time and involve a good amount of trial and error.

Violent head movements will test to see how much force the sensor system can withstand and the bandwidth of the head tracking system. Experiments on different eye shapes, indoor lighting and blinking patterns will be conducted to fine tune the image processing algorithm. Because different eye colors may have different IR reflectivities, it will be tested to make the system as generic as possible. We will measure the bandwidth of gyroscope signals to verify our model of human movements in desktop computer use.

Gyroscopes have bias drift and the magnetometer should be calibrated away from any interferences such as computers or smart phones. Data on gyro drift rate will be collected and analysed to measure the effects of sensor calibration.

Using our developed prototype, we will test the accuracy of the system within certain time limits, such as over a minute and an hour. The data we will be characterising will be the outputted x,y positions from our software. Using this data, we will develop statistics for mean and variance. We will test with multiple users to see the effects of different eye shapes, eye colors, and other body parameters on tracking variance.

Minimum Standard for Project Completion

We had to take into account the time constraint which meant that our goals had to be reasonable for the allotted time. We were advised that our goals were too ambitious to achieve in the four months. This meant that some of those goals had to be cut in favor of spending more time on the reasonable goals. One of the goals that we chose to remove was allowing the user complete freedom of movement of the head. We do not have time to implement the methods that will track every possible head position. Instead, we have decided to focus on eye tracking and limited head rotation.

Our advisor has suggested that at minimum our project should be able to detect where a user is looking on the computer screen by just using the eyes. This will consist of having multiple large letters displayed on the screen and having the program track which letter the user is looking at. As a minimum criteria, we hope to not only meet this but surpass it greatly.

Non-Technical Constraints/Issues

Economically, we were restrained to a budget of below $300. Although our budget fell below our maximum allowance, if we chose to it could have been several times higher. The extra expense could have allowed for the purchase of higher quality and more precise sensors. The lower end budget was also a self imposed constraint decided by the group. An additional goal that we set for ourselves was to create a product that could be affordable to consumers and not just research labs. Thus far, our per unit cost is well below $100, not including retail markups.

As a whole, we believe the project has a negligible impact on the environment. The hardware component leverages existing CMOS and polycarbonate production technologies. Due to polycarbonate's shatter resistance, the design does include non-renewable and non-environmentally friendly materials. We chose electronics which meet Restriction of Hazardous Substances Directive (ROHS). We hope the choice to use USB, a common computer interface, will improve retention time. As a major contribution to e-waste is upgrading old technology, we hope that our design will remain useful and that our potential consumers understand the long-term purchase value of our product. In addition, the market for eye tracking devices is currently very small compared to the market for consumer electronics like TVs and laptops. We expect that our project will make up a very small constituency of the total amount of electronic waste.

The ethical, health, and safety constraints were taken into account when finding the specifications for the headgear. Our main concern was about how safe shining an IR laser on the human eye for extended amounts of time were. Due to recommendations from other researchers in the field, a low powered LED was chosen. Although it is unlikely that even prolonged exposure will cause anything more than discomfort, we decided to put an eight hour max use limit on the final product.

When designing the project, we found no constraints that could be caused by political or social concerns. As of now there are no current political or social issues that center around the process of eye or head movement tracking.

Preliminary Results

At this current stage, the software has yet to be tested with detecting and tracking eye movements. The eye tracking part of the software using Java and OpenCV has shown promising results through testing on other images. The program interfaces well with the PSEye camera that will be used in the final design. A concern that was brought up when testing with the camera was the delay on the image tracking. As of now, when capturing images with the PSEye, the program has a latency of around 200mS at 60fps. Additional latency has been noticed but not measured when the software attempts to detect objects. The future plans to help resolve the latency is to write additional code to help the computer grab frames at a faster rate by directly accessing the USB bus. The deletion of the parts of the code used for debugging will also help improve the speed of the software.

The graphical software interface has been partially completed to allow for calibration of the sensor information. It also displays useful debug data that will be hidden from the user for demonstration. Lack of useful test data for verification has made further design difficult. We expect to generate some useable test data so that partial debugging can be done without full system integration.

The communication between the micro-controller and IMU sensor was tested at 200 samples per second for accelerometer and gyro and 50 samples per second for the magnetometer. We expect to increase the transfer rate with further optimizations. Because of the complications with I2C handshaking, the implementation of the filter has been delayed. At the end of this weekend, the pitch, roll and yaw angle calculations will be implemented and we expect to begin tuning the filter. The communication between the micro-controller and the PC was established and used in debugging.

Project Revisions

Schedule Revision:

Week	**Shalin Modi**	**Kevin Chau**	**Tianyang Chen**	**David Arisumi**
February 27	Work on test program for David to visually show eye position in the program.	Assist Shalin with getting a functional calibration testbed for David. Generate test Data for David & Shalin.	Implement the filter on the micro-controller	Finalize work on Image Tracking section of the code and prepare it for testing on eye movements using the camera and IR filter. Attempt to implement code to speed up frame grabbing data.
March 4	Add statistics metrics to testbench program.	Assist Tianyang and David as necessary. Verify that we meet minimum design specs. Collect data and demo system as-is to advisor.	Implement the filter on the micro-controller	Begin writing algorithms for translating head vector data into xy coordinates. Correct any problems discovered while testing eye tracking.
March 11	Ensure all minimum design spec features are implemented and functional. If not, complete ASAP.	Verify completion of calibration utilities. Verify critical aspects of sensor platform work.	Test head orientation	Continue work on head tracking section of the code. Also create a main and begin on having all sections on the code communicate with each other.

March 18	Minimum specs complete. See if tab switching can be completed within time.	Complete final hardware packaging. Assemble hardware and assist Tianyang.	Test head orientation tracking and optimize filter	Begin final algorithm for combining eye tracking data with head motion data.
March 25	Work on demo gui program. Add additional GUI features if necessary.	Assist all with system integration and testing.	Test head orientation tracking and tune the filter for optimal performance	Finish program. Begin Group testing. Debug and improve algorithms as needed.
April 1	Programs should enter release candidate status. Program features are locked in.	Collect system measurements. Analyze data. Generate performance specification.	Debug/Work on Poster	Debug/Work on Poster
April 8	Debug/Finish software features/ Work on Poster	Debug/Work on Poster	Debug/Work on Poster	Debug/ Work on Poster
April 15	Finalize everything	Finalize everything	Finalize everything	Finalize everything

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