Head-mounted Eye Tracker

Proposal for a design project for the School of Electrical and Computer Engineering

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1 Abstract

The goal of the project is to design and build a low-cost, light-weight, head-mounted eye tracker, which will enable tracking of a subjects focus of gaze within his/her field of vision. The head-mounted unit will consist of a forward-looking camera to record the subject's field of view, and a second camera to capture the position of the eyeball. Software running on a remote host will compute the position of the subject's gaze using the video feed from these two cameras.

The project will involve the design and implementation of the head-mounted unit, a mechanism to transfer the video to a host computer, and the associated video signal processing for calibration and to identify the gaze location. Automatic calibration of the unit to detect the position of the eyeballs is a desired feature. The unit is to be designed to be robust and light-weight, so that it can be used in a variety of situations, including use on infants and for outdoor use. It is also required to be significantly cheaper than existing units available in the market.

2 Introduction

An Eye Tracker is a device that identifies the focus of an individual's gaze within his/her field of vision. Eye trackers have been primarily used in research systems to investigate the visual behavior of individuals performing a variety of tasks. Knowing the user's point of gaze has significant potential to enhance current human-computer interfaces, given that eye movements can be used as an indicator of the attentional state of a user. [1] Users can explicitly control the interface though the use of eye movements. For example, eye typing has users look at keys on a virtual keyboard to type instead of manually depressing keys as on a traditional keyboard [2]. Such interfaces have been quite effective at helping users with movement disabilities interact with computers.

There are several kinds of eye-tracking devices available in the market. Almost all of them identify the gaze focus by detecting the position of the iris within the eye. Some of them require a controlled laboratory environment, complete with head restraints to effectively measure eyeball movement. Many systems use remote video cameras to identify the direction and focus of the subject's gaze. A third class of devices mount the sensors on the head of the subject, allowing the system to be potentially used in a wide variety of situations.

Most commercial systems are expensive, with even the cheapest ones costing a few thousand dollars. This has greatly handicapped the spread of this technology.

In this project, we aim to develop a head-mounted eye-tracker system that is significantly cheaper than a commercially available device. The Eye Tracker is aimed to be a light, mobile unit, that can be used in multiple situations, like on infants, or outdoors. The design of such a system throws up several challenges, which we have listed in the following sections.

The rest of this document is organized as follows.

- Section 3 formally specifies the technical requirements for the Eye Tracker system.
- Section 4 lists some of the issue and challenges that we foresee in developing the system.
- Section 5 describes the approach we propose to follow.
- Section 6 provides a conclusion.

3 Requirements

This section lists the requirements to be met by the Eye Tracker System.

3.1 System-level Requirements

[SYS-01]	The Eye Tracker System shall include a Head-Mounted Unit (HMU) that can be mounted on a subject's head. *Note: The requirements for the Head-Mounted Unit are listed in Section 3.2.*
[SYS-02]	The Eye Tracker System shall include a Base Station for video processing Note: *The requirements for the Base Station are listed in Section 3.3.*
[SYS-03]	The Eye Tracker System shall include a data transfer link from the HMU to the Base Station.
[SYS-04]	The Eye Tracker System shall include a Video Display unit to display the output in real-time.
[SYS-05]	The Eye Tracker System shall calibrate itself automatically. *[Note] 'Calibration' refers to the detection of the eye itself in relation to the face.*
[SYS-06]	The Eye Tracker system shall continuously perform the above calibration to compensate for any relative motion between the face and capture sub-system.
[SYS-07]	The Eye Tracker system shall take as input the field of view of a subject.
[SYS-08]	The Eye Tracker system shall output the focus of the subject's gaze.
[SYS-07]	The Eye Tracker system shall display the output with a maximum latency of 4s.
[SYS-08]	The Eye Tracker system shall measure the focus of the subject's gaze with an accuracy of 1 degree of visual angle.
[SYS-09]	The bill-of-materials for the Eye Tracker system shall not exceed $500.
[SYS-10]	The Eye Tracker system shall be designed to be used in an outdoor environment.

3.2 Head-Mounted Unit

[HMU-01]	The Head-Mounted Unit (HMU) shall capture the subject's field of view using a video capture device.
[HMU-02]	The HMU shall capture the subject's field of view at a frame-rate of at least 20 fps.
[HMU-03]	The HMU shall capture the subject's field of view with a minimum resolution of 720x480 pixels.
[HMU-04]	The HMU shall capture the focus of the subject's gaze within the subject's field of view.
[HMU-05]	The HMU shall capture the focus of the subject's gaze at a sampling-rate of at least 20 Hz.
[HMU-06]	The HMU shall transmit the video representing the field of view to the base station.
[HMU-07]	The HMU shall transmit the signals representing the subject's gaze to the base station.
[HMU-08]	The HMU shall not have any external physical connectors.
[HMU-09]	The HMU, excluding any batteries, shall weigh less than 1 kg.

3.3 Base Station

[BASE-01] The Base Station shall receive the video signal representing the subject's field of view from the HMU.

[BASE-02] The Base Station shall receive the signal representing the subject's gaze from the HMU.

[BASE-03] The Base Station shall process the signals received in BASE-01 and BASE-02 to identify the focus of gaze of the subject in his field of view.

[BASE-04] The Base Station shall identify the focus of gaze as a pixel location within the subject's field of view.

[BASE-05] The Base Station shall output a video signal showing the subject's gaze focus overlaid over the subject's field of view.

[BASE-06] The Base Station shall provide an option to store the output video signal to a file in the Base Station.

[BASE-07] The Base Station shall provide an option to store the gaze coordinates as a function of time in a text file.

3.4 Data Transfer Sub-system

[TXF-01] The Data Transfer Sub-system (DTSS) shall transmit the field of view video signal to the Base Station.

[TXF-02] The DTSS shall transmit the gaze focus signal to the Base Station.

[TXF-03] The DTSS shall provide a wireless interface between the HMU and the Base Station.

[TXF-04] The DTSS shall provide enough bandwidth to ensure error-free transmission of the field of view and gaze focus signals.

3.5 Video Output Sub-system

[VOUT-01] The Video Output Sub-system (VOSS) shall display the output video from the Base Station real-time.

[VOUT-02] The VOSS shall support the display of a video at a minimum frame rate of 20 fps.

[VOUT-03] The VOSS shall support the display of video with a minimum resolution of 720 x 480 pixels.

4 Issues to be addressed

Some of the major challenges that need to be addressed are given below.

1. The cost of eye-tracking systems

   Currently, a number of eye trackers are available on the market and their price range from approximately 5,000 to 40,000 US Dollars. The cost of an eye-tracking system can be split into two parts: the hardware cost, and the software cost.

   a) Hardware Costs: The hardware components of an eye-tracker include high frame-rate, infrared capable camera, camera lens, IR illumination circuitry and LEDs, and mechanical head-mounted parts. Since eye-tracking relies on tracking the corneal reflection, the camera resolution needs to be sufficiently high to get enough pixels on the eye region. Using a zoom lens that focuses on the eye will be a resolution. However, this would severely limit free head movement and increase the total cost. Also, there is a technical requirement on the accuracy of eye-tracker. A high frame-rate camera is needed, which would also increase the eye-tracking system cost.

   b) Software Costs: Notably, the bulk of the costs are associated with custom software implementations. These are sometimes integrated with specialized digital signal processors to obtain high-speed performance. Thus, reducing the software budget should also be taken into consideration.

2. The “invasiveness” of eye-tracking systems

   Although various eye-tracking technologies have been available for many years, (e.g.,Purkinje-reflection based, contact-lens based eye coil systems, electro-oculography;) [3], these techniques have all been primarily limited to the weight of their equipment. Some techniques require equipment such as special contact lenses, electrodes, chin rests, bite bars or other components that must be physically attached to the user. These invasive techniques can quickly become tiresome or uncomfortable for the user.

   Also, reliance on highly controlled environments can easily alter the results of the research. For example, in typical studies, participants view displays on a computer monitor while sitting in an office chair. However, outside the lab, people perceive the world as they move through it. Visual information is obtained, not imposed. People choose where to look freely.

   Thus, the invasiveness of eye-tracking system is an important issue to be addressed. An ideal eye-tracker would be completely non-invasive and unobtrusive.

3. Real-time eye tracking

   Given that eye movement can be an indicator of human’s intention, eye tracking has been primarily used in research and investigate the human-computer interfaces. For example, by adoption of eye-tracking technology, users can explicitly control the interface though the use of eye movements.

   This function requires that the system be real-time – that is, the processing should be completed as quickly as possible.

4. Accuracy

   A major issue in building low-cost head-mounted eye-tracking system is to achieve a certain degree of accuracy. The accuracy is affected by both video capture device, and the data processing software algorithm.

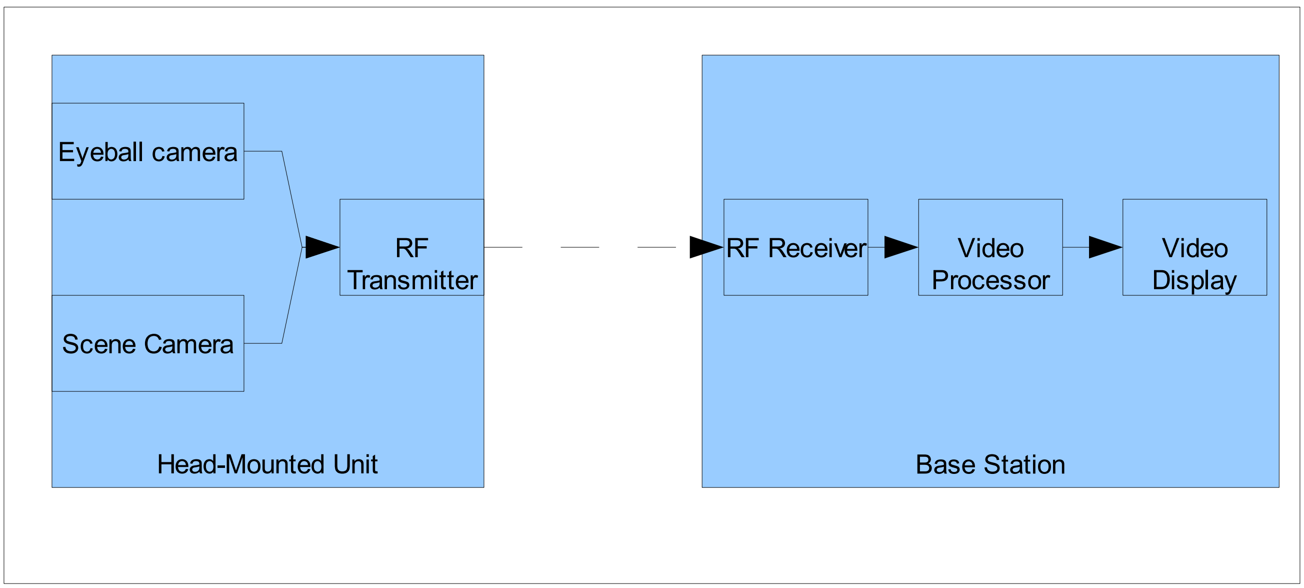
   In the video capture aspect, the accuracy of point of gaze estimates during eye movements can be quite poor. This loss of accuracy is due to the motion blur induced by the long CCD integration times. At the same time, we need to improve the accuracy by adopting a high resolution camera. As a result, a tradeoff between cost, equipment weight, and accuracy has to be considered.

In the data processing phase, tradeoff between real-time performance and accuracy is needed, since improvement of accuracy means large quantity of computation, which would greatly affect the real-time feature. Thus, high-performance software with a good algorithm to analyze the eye-tracking data is needed.

5 Approach and Expected Results

5.1 System Design Overview

The system design focuses on meeting the formal requirements specified in Section X, and in addressing the challenges listed in Section Y. A block diagram of the proposed system is given below:



Drawing 1: Eye Tracker System Overview

5.2 Addressing challenges

Our approach to address some of the challenges listed above is given below.

1. Cost:

   We plan to mitigate cost through two strategies:

   1. Use commercial, of-the-shelf units for the various sub-systems shown in Drawing 1 , including a PC as the Base Station, so that complex software can be run relatively cheaply.
   2. For software, use software available in-house, or as open-source components. A possible candidate for the eye tracking software is OpenCV; Matlab implementations are available for download.

2. Real-time eye tracking
   We are considering the use of a real-time eye-tracking package known as cvEyeTracker, that is capable of tracking eye movements at over 20 frames per second, besides of the off-line matlab software. The cvEyeTracker software is written in C++, and it uses Intel's OpenCV libraries in conjunction with cvHAL to process captured video. The algorithm used in this application is relatively simple to afford it speed. Consequently, it is also likely the eye movement measures are less accurate than that obtained with the off-line analysis described above.

3. Accuracy
   As mentioned in section 4, the accuracy of the eye-tracking system is a combination of two parts: one is the video capture accuracy, while the other is the video data processing accuracy.

   1. As mentioned above, during the capture, the motion blur will result in the loss of accuracy. Fortunately, eye movements are very rapid lasting on the order of 10 milliseconds while fixations are much longer (hundreds of milliseconds). Thus only a small percentage of the captured images show the eye in motion and for many of these frames, the motion blur is small enough that an accuracy estimate of the point of gaze can still be obtained. The use of readily available, yet more expensive, cameras capable of flexible integration times, higher sensitivity and higher frame rates would eliminate this problem.

   2. Accuracy in software can be greatly increased if the video can be analyzed offline. The large quantity of computation would definitely reduce the real-time performance. The best way to combine the accuracy and real-time is to adopt a multi-scale method in image processing. Thus, we implement an open source software written in Matlab, which operates approximately one frame per second, besides the cvEyeTracker.

   Finally, we expected to get a head-mounted eye tracker capable of an accuracy of approximately one degree of visual angle.

6 Project Plan

We have defined the following milestones and responsibilities for this project.

Phase	Milestones	Target End Date	Owner
1 : Evaluation	Evaluation of available eye-tracking software – cvEyeTracker	February 1, 2011	Zelan, Anil
2 : Core Software	Offline software for analysis of eye movement, and correlation with scene video	March 15, 2011	Zelan
3 : Core Hardware	Development of Head-mounted unit	March 15, 2011	Anil
4: Integration	Development of video transmitter and receiver hardware	April 1, 2011	Anil
	Development of video transmitter/receiver software	April 1, 2011	Zelan
	Development of display system – Hardware and software	April 15, 2011	Anil, Zelan
5: System tests	Complete system test	April 30, 2011	Anil, Zelan

7 Conclusion

In conclusion, we propose to develop a Head-Mounted Eye Tracker to facilitate research using eye focus findings. A significant aspect of the project is to keep the cost to a minimum, while achieving high performance. The use of off-the-shelf hardware components, along with open-source or in-house software is planned to keep the costs down. The requirements for the system have been formally defined.