The Eye Tracking System

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Executive Summary

This report is divided into several sections, reviewing Team B.I.T.'s plan to scope out, design, and finalize a product. There are various obstacles that have already been encountered, such as finding a cheap mini-camera that is still accurate, with a quality resolution and implementing a light-weight and unobtrusive headgear system.

Introduction

Professor Bibyk will work with Team B.I.T. to implement a low-cost Wireless Eye Tracking System. The Wireless Eye Tracking System will be used to assist people with disabilities and help children to learn languages. Team B.I.T. will design and implement a simplified and low-cost Eye Tracking system, which will allow a more marketable and accessible product to the public. The focus of the developed system will be away from elaborate hardware of the current eye tracking system, but instead toward clever DSP and other software algorithms.

Background

Team B.I.T. researched how the eye moves and how it is tracked, how image sensing and interlacing are used, grabbing frames from a video source, and current related systems at the Ohio State University.

Eye movements are typically divided into two categories: fixations and saccades. For eye tracking purposes, fixations are used to denote a starting point for all eye movements and saccades. Saccades are when the eye gaze moves to another position. An image sensor is a solid state device that takes an optical image and translates it into an electrical signal. An image sensor can be found in the design of any device that captures an image. An image sensor will be needed to implement the Wireless Eye Tracking System to capture the image of the eye. NTSC Transmission research was also thoroughly researched in order to remove the audio and color bandwidths from a signal coming from the camera. In an electronic device, a frame grabber can be used to capture individual still frame shots from a video source. This video source can either be an analog signal or a digital video stream. The individual video frames are usually captured in digital form before any processing is done. One advantage of more modern frame grabbers is the ability to capture multiple frames at once and compress these frames in real time.

The Center for Cognitive Science (CCS) and the Department of Logistics at The Ohio State University uses eye-tracking equipment similar to the system Team B.I.T. will be designing. A device called ASL is on the head that uses an infrared camera to observe the both the pupil and the reflection from the cornea, and transmits the data to a computer which processes the signal and displays the pupil tracking data. The Tobii is an advanced eye tracking system that includes a series of infrared cameras mounted into a specially fabricated PC monitor and a series of other sensors to track eye and head movement.

Requirements Analysis

The Wireless Eye Tracking System must consist of a head-mounted portion (headset), an interface to a PC, and PC software to configure and use the unit. The head-mounted portion of the system should be reasonably lightweight, enough so that a normally healthy person does not need to strain to hold the unit upright. The frame transmission rate of the unit should be adequate to enable the PC software to reliably track eye movement. Power consumption of the headset unit should be within ranges that can be produced by a battery pack that can be comfortably worn by the user.

Design Work

This system uses a TI CCD image sensor embedded in a commercially available webcam to observe the eye, and a TI-MSP430 microcontroller. The image sensor is primary used for optical light ranges, but can detect lower frequencies into the infrared region, which will aid greatly in tracking the pupil. The system will also use a TI EZ430-RF2500T target board to perform some signal processing and wirelessly transmit the data to a PC where software will further process the signal, track the pupil and display results.

Resources

Team B.I.T. consists of five team members: Rory Garand, Aaron Jackson, Nick Marquart, Lauren Sapharas, and Dustin Vorac. All members are Electrical and Computer Engineers at the Ohio State University, each with various specializations and engineering experience.

Schedule and Cost

The Wireless Eye Tracking system will be designed in the final months of the 2008 year and implemented in the beginning months of the 2009 year. The final product will be completed by March 2009 and it will be entered in the TI Design Contest. The Design Contest only allows a coupon budget of $200 so Team B.I.T will work to find affordable products within the given budget.

Design Review Discussion

Weekly meetings with Professor Bibyk and Drew helped keep Team B.I.T. on track and on schedule for implementing the Wireless Eye Tracking System. Each week concentrated on a specific issue and how to improve the design.

Report Structure

This report details all Background Research that was studied before implementing the Eye Tracking System, a Requirements Analysis which lists all required design tactics used in the implementation, a Design Approach which lists the hardware and software used, as well as Statement of Work, Resources, and Schedule and Cost sections.

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Introduction

Purpose

This document describes the planning, development, and implementation of an Eye Tracking System used to assist people with disabilities and teaching children to learn new languages. The selected hardware, software development, design planning and testing, system integration, and a final implementation design of the Eye Tracking System is detailed within this document. With the assistance of Professor Bibyk, the progress toward the final goal and the TI Design Project is shown throughout the document.

Problem Statement

Many people who live with paralysis have a difficult time with day to day tasks. While those with limited use of their limbs may be able to get by, those with full body paralysis have no such luck. Fortunately, most people still retain the ability to use their eyes unhindered. Therefore, tracking eyes has been suggested as a way for paralyzed people to continue interacting with the world. Even children, who are developing social skills or learning a language, interact through sight. If a child has a learning disability, tracking how their eyes react to learning methods allows teachers and researchers to successfully educate children.

Eye tracking is the process of tracing the movement in the eye to give vital information for research purposes. This technology can be applied to studying how pupils react to different situations, language development in children, applications for disabled persons, or detailed robotics and animatronics. Although the use of eye tracking has been seen as a great way to develop new technology, the expensive cost of the equipment that is needed to implement such a device is a major disadvantage. Traditional devices have so far been centered on sophisticated, expensive infrared sources or high resolution cameras.

By developing a simplified and low-cost system, eye tracking devices will become a far more marketable and accessible product to the general public. The focus of the developed system will be away from elaborate hardware of the current eye tracking system, but instead toward clever DSP and other software algorithms. Creating robust software to interface the system will also help less technical users to operate the system. The system will use a cheap black and white, or color camera pointing inwards toward the eye, mounted on a visor or other headgear device. The signal will then be processed by circuits and transmitted to a PC where it can be used for a wide variety of applications.

Scope

The project will focus on creating a simplified and low-cost and light weight Eye Tracking System with a wireless network. Furthermore, this report is limited to hardware and software performance of the device, and possible applications and does not include analysis of marketability specifics or performance of current systems in the market.

Background Research

Eye Movement

Eye movements are typically divided into two categories: fixations and saccades. Fixations occur when the eye gaze pauses in a certain position. For eye tracking purposes, fixations are used to denote a starting point for all eye movements and saccades. Saccades are when the eye gaze moves to another position. Humans alternate between fixations and saccades; this resulting series of fixations and saccades is a scanpath. Scanpaths are used to analyze cognitive intent, interest and importance.

The fovea provides the bulk of visual information. The periphery is less informative than the fovea. Figure 1 shows the fovea located in the macula region of the retina. The locations of the scanpaths during eye tracking signify the information that was processed. Fixations normally last for 200 ms when reading text and 350 ms when viewing a scene.

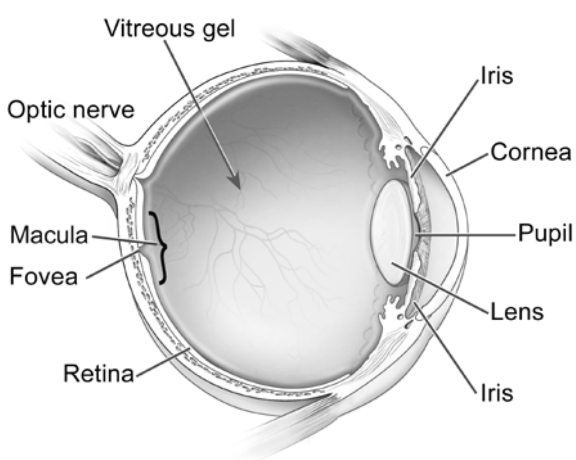


Figure 1: The Human Eye

Source: "The Human Eye: A Diagram" www.familyconnect.org

Eye Tracking Techniques

There are currently two types of eye tracking techniques that are used: Bright Pupil and Dark Pupil. Bright Pupil tracking creates a greater contrast between the iris and the pupil which allows for a more robust eye tracking. This greatly reduces any interference caused by eyelashes or other obscure features. Bright Pupil tracking additionally allows for tracking in lighting conditions, whether it is totally dark or very bright. This technique, however, is not effective for tracking outdoors. Dark Pupil tracking works to eliminate bright reflections. If the illumination source is offset from the path of the eye, then the pupil appears dark.

Image Sensors

An image sensor is a solid state device that takes an optical image and translates it into an electrical signal. An image sensor can be found in the design of any device that captures an image. One of the main uses of image sensors can be found in digital cameras. An image sensor is usually a Charge-Coupled Device (CCD) or a Complementary Metal-Oxide Semiconductor (CMOS). Both image sensors capture light using an array of small pixels on its surface and convert it into an electrical signal. The difference in these image sensors shows up in how they process the image.

A Charge-Coupled Device is an analog device that enables the transportation of analog signals. The transportation of the signals is done in successive stages with the use of capacitors. As the light is captured on the surface of the device, the capacitors collect an electrical charge that corresponds to the light intensity at that location. A CCD starts by taking the charges of the first row of the array and placing them on the read out register. Next they are put into an amplifier and then into an analog-to-digital converter. The analog-to-digital converter takes the electrical signal and converts it into a voltage. After the row has been converted, the read out register is deleted. One by one, each row of the array is transferred to the read out register and converted. Then the sequence of voltages is sampled, digitized, and stored. A block diagram of a CCD sensor used in a camera can be seen in Figure 2.

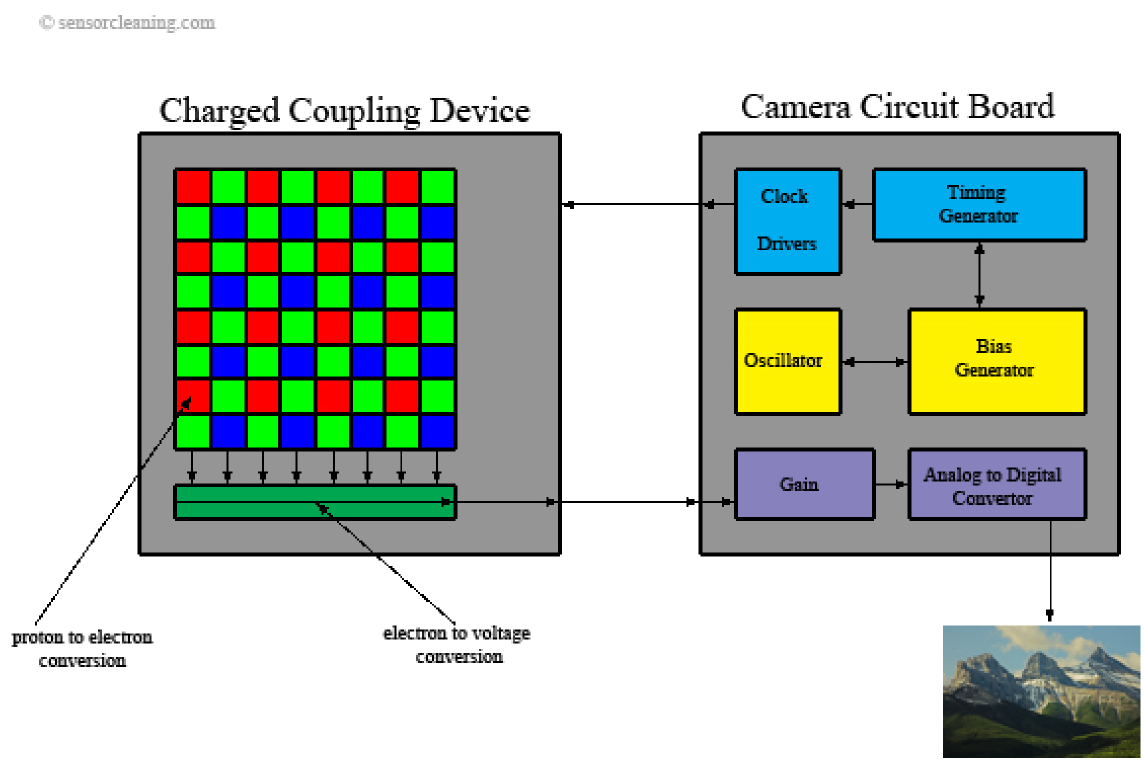


Figure 2: CCD Sensor

Source: "What is a Sensor?" www.sensorcleaning.com

A Complementary Metal-Oxide Semiconductor is an active pixel sensor that uses complimentary and symmetrical pairs of p-type and n-type metal oxide semiconductor field effect transistors (MOSFET) for logic functions. CMOS image sensors use multiple transistors to amplify and move the charge provided by incoming photons of light, enabling the pixels to be read individually. A CMOS device has several transistors at each pixel that amplify and convert each pixel into a digital signal. The signal is then stored. A block diagram for a CMOS sensor used in a digital camera can be seen in Figure 3.

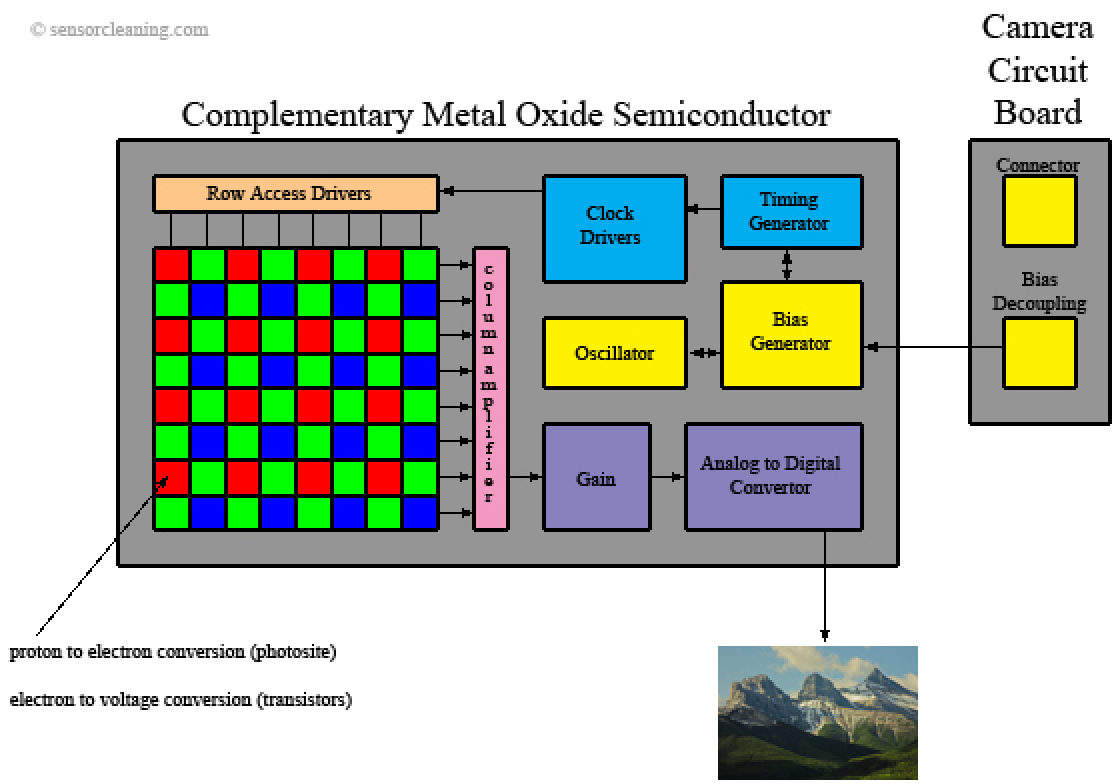


Figure 3: CMOS Sensor

Source: "What is a Sensor?" www.sensorcleaning.com

Until recently, implementation of items such as digital cameras was dominated by CCD image sensors. With the modern development of CMOS technology, the use of CCD image sensors has seen a large decrease. Some of the reasons for this decrease include cost and power consumption. A CMOS wafer is much cheaper to produce than a CCD wafer, which makes the use of CMOS image sensors in a system very inexpensive. A CMOS image sensor also uses much less power than that of a CCD image sensor.

The Department of Linguistics

The Department of Linguistics at The Ohio State University uses eye tracking in its Psycholinguistics Lab to conduct research experiments. These research experiments investigate psychological and neurobiological factors that enable humans to acquire, use and comprehend language. A majority of the research done involves studies of children's ability to learn language. The lab uses two different eye tracking systems in their research. This equipment includes the ASL 6000 and the Tobii 1750.

The Center for Cognitive Science

The Center for Cognitive Science (CCS) at The Ohio State University uses eye-tracking equipment similar to the system Team B.I.T. will be designing. The CCS conducts experiments aimed at how people read and how their movements relate to their perception of the world around them. To achieve this, the CSS implements two different systems designed by ASL and Tobii.

ASL System

The ASL (Applied Science Laboratory) is a device worn on the head that uses an infrared camera to observe the both the pupil and the reflection from the cornea, and transmits the data to a computer which processes the signal and displays the pupil tracking data. The user wears the ASL and the device tracks the movement of the pupil as the user interacts with real world objects that can be touched or moved, as well as monitor-based visual tasks, such as reading text or observing images. A color camera is used to record the movement of the eye and displays the images on a monitor where the eye movement can be examined.

The ASL tracks the orientation of the head via sensors and the subject's distance from the PC monitor via magnetic sensors, one mounted on the ASL, and the other three feet behind the subject for additional precision. The ASL is fairly precise, but can become unreliable over time if not calibrated properly. Correct calibration can take up to 15 minutes, which further complicates usage of the device. This system is similar to the one Team B.I.T. will design, but will require less calibration, will be cheaper and potentially more accurate.

Tobii System

The Tobii is an advanced eye tracking system that includes a series of infrared cameras mounted into a specially fabricated PC monitor and a series of other sensors to track eye and head movement. The Tobii system processes images of the subjects face and eyes, as well as the reflection in the eyes. These images are used to estimate the 3D position in space of each eye and the target of the eye gaze.

The Tobii does not require the subject to wear any equipment and the calibration is much faster and far more accurate than the ASL. While accurate, the Tobii system is incredibly expensive and not practical as a marketable consumer product or medical device. Additionally, this system is limited to computer monitor based experiments as opposed to also tracking the interaction with real world objects. The technical complexity of this system is well beyond the scope of this project.

NTSC Transmissions

National Television System Committee (NTSC) is a standard format for analog video signals. NTSC is most often used for television broadcast, but is also used for consumer video recording devices. The color signal is frequency multiplexed into luminance (Y), hue (U), and saturation (V) components. The Y component is the grayscale video data, and the U and V components together for the chromas, or color component. Figure 4 shows the frequency spectrum of the NTSC standard.

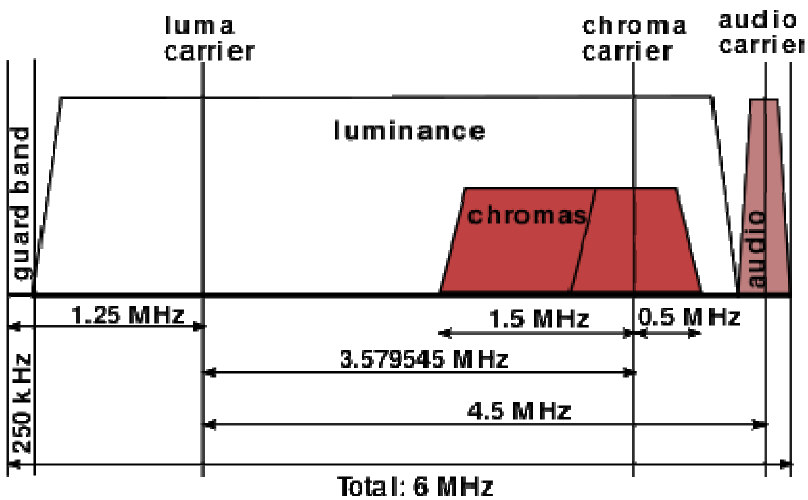


Figure 4: NTSC Transmission Spectrum

Source: "NTSC" www.en.wikipedia.org/wiki/NTSC

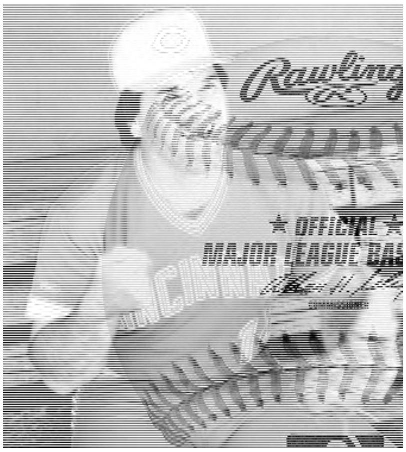
The luminance is an AM-modulated signal where its values denote grayscale values. The frames from the CCD are split into horizontal lines and interlaced. Interlacing involves alternating lines of data. The camera used by Team B.I.T. employs 2:1 interlacing where for a frame of data, the odd lines correspond to the n^{th} image and the even lines belong to the n^{th}-1 image. Thus, to capture a single frame of complete data, two frames must be captured. NTSC also specifies what voltage levels, held for a pre-determined time, when a new line starts, and when a new frame starts. NTSC also specifies a frame rate of 29.95 frames per second.

Team B.I.T. uses bandpass filter to isolate frequencies around the luma carrier seen in Figure 4. The bandwidth of the filter will be adjusted so that it is wide enough data is recovered to reliably reconstruct a signal while also narrow enough so the sampling frequency specified by the Nyquist theorem ($f_{sampling} = 2 * Bandwidth$) is lower than the maximum sampling rate of the A-D converter on the MSP430.

To demonstrate the principles of interlacing and how an image will be reconstructed, two MATLAB scripts were created. The first script, *NTSC_demo_makeframes.m*, included in Appendix A, reads in two images, interlaces them in a 2:1 ratio, then saves the data as a JPG file. First, MATLAB reads in an image using the **imread()** command which stores it as an AxBx3 matrix where A and B are the pixel dimensions of the image, and the third dimension contains the luminance and chrominance data. The process that Team B.I.T. will use to filter the chrominance data can be simulated in MATLAB by taking only the first index of the third dimension. The resulting matrix has the same number of elements as pixels of the image, but only contains the luminance data. Next, a loop interlaces the two images yielding two arrays that each contain the information for one half of two different frames. These interlaced frames are stored as .JPG files to be used by the second MATLAB script. Figure 5 shows the original image alongside with the “filtered” version containing only the luminance data. Figure 6 shows the two interlaced frames. It should be noted that parts of the original images were cut-off so that they would have the same pixel dimensions and could be properly interlaced.

Figure 5: Original images (left); Luminance component used for interlacing (right).

The second MATLAB script, included in Appendix B and called *NTSC_demo_makeImages.m*, takes the .JPG frame data created in *NTSC_demo_makeframes.m* and de-interlaces them into their original images. The script reads in the data using the **imread()** function and uses a loop to undo the interlacing. This de-interlacing is an important process that Team B.I.T. will have to employ in order to reconstruct the NTSC frames. Figure 6 shows the two interlaced frames that *NTSC_demo_makeImages.m* reads in. The resulting de-interlaced images look identical to the images on the right side of Figure 5.



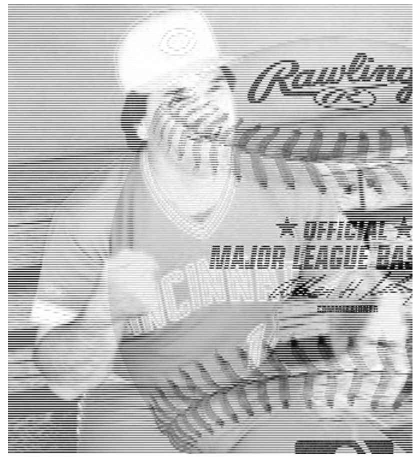


Figure 6: Two Interlaced Frames

The two images appear identical; however each contains the even lines for one image, and the odd lines for the other image. In practice, the frame would contain data for the n^{th} image and the $n^{th}+1$ image, thus having two interlaced frames would have complete data for one complete image and two halves to two different images. In this case, two frames yielded two complete images.

Frame Grabber

In an electronic device, a frame grabber can be used to capture individual still frame shots from a video source. This video source can either be an analog signal or a digital video stream. The individual video frames are usually captured in digital form before any processing is done. After a video frame has been captured in digital form, the information can be displayed, stored or transmitted in raw or compressed digital form. One advantage of more modern frame grabbers is the ability to capture multiple frames at once and compress these frames in real time.

On the market, there are multiple types of frame grabbers available. These frame grabbers vary in function, ability, and types of input information. These types include analog frame grabbers, digital frame grabbers and frame grabbers that can accept both analog and digital signals as inputs.

Both analog and digital frame grabbers have memory, a bus interface and general I/O registers. The memory in a frame grabber is used to store the images from each individual frame. The bus interface is used to gain access to the data stored in memory or the data being put into the frame grabber. The general I/O registers in a frame grabber are used for triggering image acquisition or controlling external equipment.

An analog frame grabber accepts analog video signals. These analog video signals are then processed and sent to its analog-to-digital converter. Now that the signal is in its digital form, it can be displayed, stored or transmitted. This device has a circuit to recover the horizontal and vertical synchronization pulses from the input and an NTSC/SECAM/PAL decoder. A digital frame grabber accepts digital video streams. Since these video streams are already in digital form, it does not cause for decoding before the signal can be processed.

For the implementation of an eye tracking device, an analog frame grabber would be idea. The camera outputs a NTSC analog signal, which will be sent to the input of the analog frame grabber. The frame grabber would then grab individual frames to be processed. From there, the frame would be displayed and stored into memory. During processing, software would track the eye.

Requirements Analysis

The system must consist of a head-mounted portion (headset), an interface to a PC, and PC software to configure and use the unit. The physical interface between the headset and PC must be wireless, in order to lend the system mobility. This can be accomplished though any wireless transmission medium, including radio frequency transmission, our choice in this system. As such, the radio frequency transmitters must conform to FFC specifications and limitations. The PC software must be compatible with common PC operating systems and hardware.

The headset portion of the unit should be lightweight enough to feel comfortable to the average user. For our purposes, "average user" refers to a person of typical physical strength and stature. We can accomplish this by mounting the camera and processing/transmitting units on a piece of headgear, even something as simple as a baseball cap. The power supply that powers the unit can be worn as a belt-mounted unit, due to its likely significant weight. The interface between the head-mounted unit and PC can be powered by either the power supply worn by the user, or the PCs own power supply, or both, depending on the implementation of the system.

The cost of the unit must be in a range reasonable for consumer adoption. Parts costs are estimated to be $200, and since labor to build and program the unit are minimal (students work for free), the total cost of the unit should be limited to about $200. This puts the unit well within consumer price ranges, and would make the unit easy to purchase for the average user, or in bulk for larger organizations. Since the system will be a wireless, mobile unit, power consumption of the head-mounted must be kept to a minimum, such that the entire system can be powered without requiring external, wired power sources.

Parts for the unit are required to be purchased from Texas Instruments. This includes microcontrollers, cameras and/or image sensors, RF transmitters, and image processing ICs.

Parts can be obtained from other sources, but will raise the $200 price on the system, as parts not purchased from TI are not covered in the development teams TI coupon budget of $200.

Design Work

Team B.I.T. proposes that a system can be developed to track one's pupil and be used as a marketable product for general consumers, but more specifically towards medical applications. The system can use this data to manipulate a cursor on the user's PC. This system uses a Color CCD image sensor embedded in a commercially available webcam to observe the eye, and a TI-MSP430 microcontroller.

System Design

The image sensor is primary used for optical light ranges, but can detect lower frequencies into the infrared region, which will aid greatly in tracking the pupil. The system also uses a TI EZ430-RF2500T target board to perform some signal processing and wirelessly transmit the data to a PC where software will further process the signal, track the pupil and display results.

In the system, the camera gets image directly from the eye. The system uses a frame grabber to capture frame-by-frame images from the camera. The frame grabber converts the analog output of the camera image into a digital signal through its USB output. This implementation also uses the EZ430-RF2500T target board to wirelessly transmit this data to a PC. Once the data is in the PC, software will be used to process the signal, track the pupil and display the results. Figure 5 shows the block diagram for the system, which will be constructed similarly to the ASL with the hardware strapped to the head.

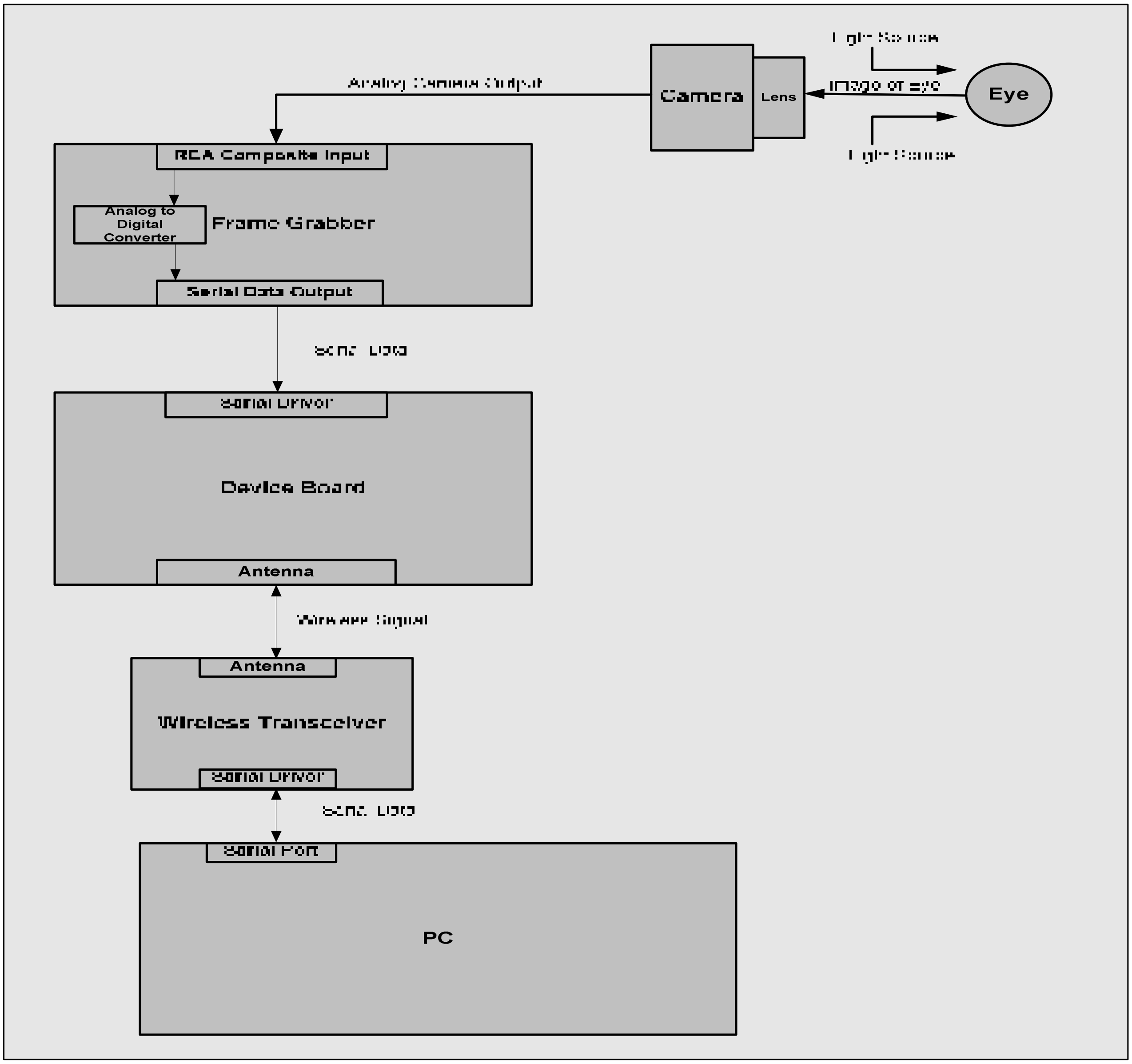


Figure 7: System Block Diagram

Team B.I.T.'s design is more aesthetically built into a baseball hat. The camera is attached to the hat with a screw and bolt, which will allow the system the ability to be adjusted to focus on the eye. The brim of the hat will be trimmed down to let light shine on the eye to increase the visibility of the image. Figure 9 shows the mounted device.

Figure 8: Mounted Eye Tracking Device

Power Requirements

A battery pack will be used in this project to supply power to the portable eye tracking equipment. Ten AA batteries will deliver the total 15 Volts required by the electronic devices. The camera needs 12 Volts DC and the microcontroller needs 3.3 Volts DC to operate. A DC/DC converter can simultaneously split the total voltage to the specified amounts, as well as provide a constant signal. Due to limitations with standard dry cell batteries, power can dwindle as the charge decreases. In this system, the voltage supply will always stay within range while the DC/DC converter is in place. Figure 6 shows the detailed specifications of wiring the camera wirelessly to power and connecting its signal via composite video to the MSP430 microcontroller.

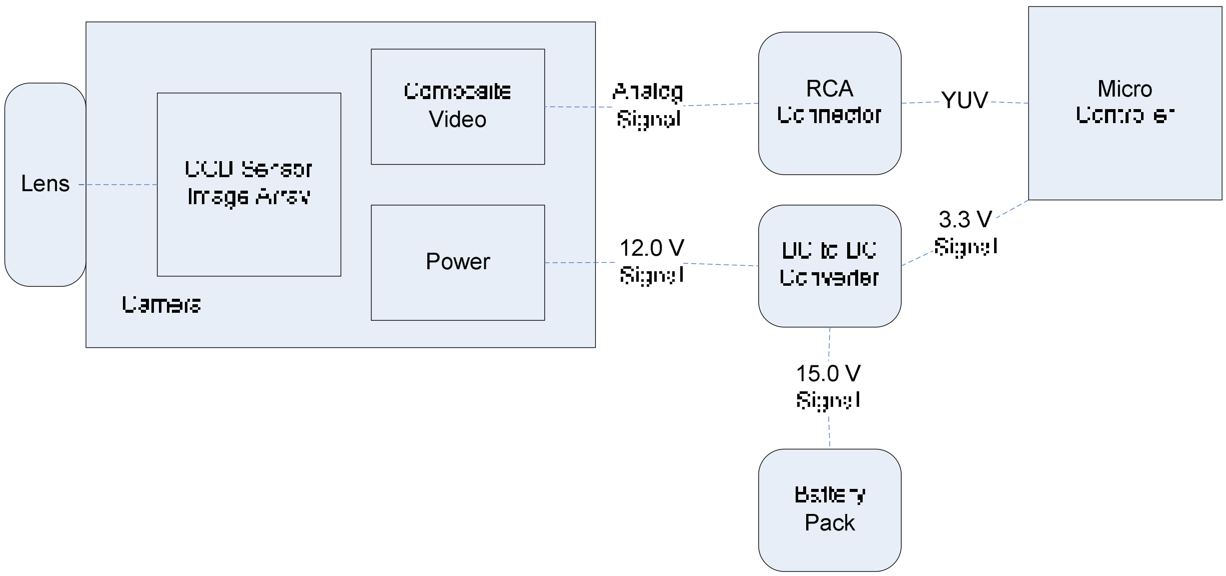


Figure 9: Power Requirements Block Diagram

Structural and Physical Descriptions for Hardware and Software

Camera Specifications

The 380 Line CCD camera is a light weight and small in size with a high resolution and consumes low power. The System uses a Color CCD 380 Line Camera which is powered with 12 VDC at 100 mA. It also has both video and audio composite output plugs. The Camera specifications are described below in Table 1.

Model:	380
Imager:	Color CCD
Sensor Format:	1/4" Sony
Video Format:	NTSC
Resolution:	380 TV Lines
Scanning System	2:1 Interlace (NTSC)
Neutral Density Filter:	210
Lens:	3.6mm f/2.0, 90 degree FOV
Video Output:	1 Vp-p, 75 Ohms
Electronic Shutter Speed:	1/60 to 1/100,000 sec
Supply Voltage:	12VDC

Power Consumption Max:	100 mA
Chip Set:	Sony
S/N Ratio:	Greater than 50dB
Audio	Yes
Sync System:	Internal Sync
Weight:	1.5 oz
Size	36mm (W) x 36mm (H) x 33mm (D)
Cable Length - Standard	4 feet

Table 1: Camera Specifications

Source: "380 Line CCD Camera" www.wirelessvideocameras.net

DC/DC Converter Specifications

Figure 7 shows a step-up switching regulator utilizing the TL3577. The regulator produces an output voltage higher than the input voltage. The TL3577 turns its switch on and off at a fixed frequency of 100 kHz, thus storing energy in the inductor (L). When the NPN switch is on, the inductor current is charged at a rate of VIN/L. When the switch is off, the voltage at the SWITCH terminal of the inductor rises above VIN, discharging the stored current through the output diode (D) into the output capacitor at a rate of (VOUT – VIN)/L.

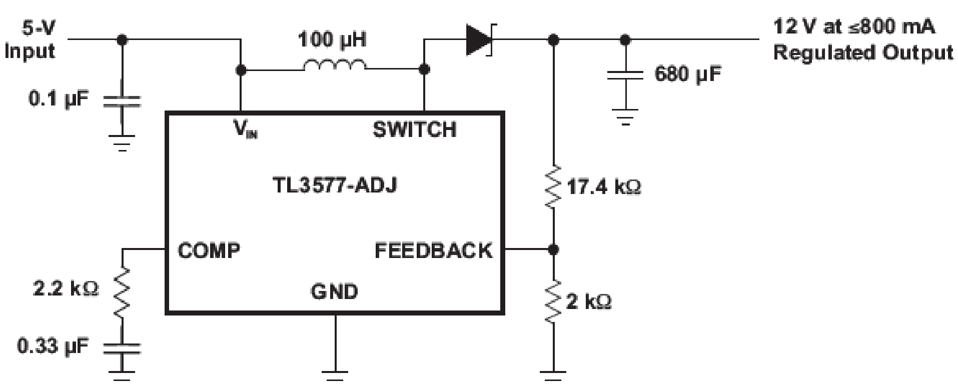


Figure 10: Boost Converter Circuit Design

Figure 8 describes the pin assignments of the TL3577 Boost Converter.

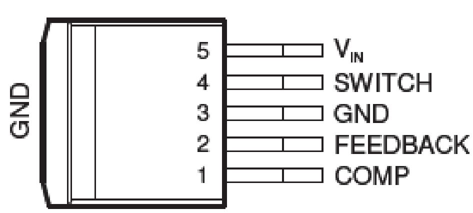


Figure 11: Boost Converter Pin Assignments

The specifications for the TL3577 12V Boost Converter are described below in Table 3.

Iout(Max)	3 A
Duty Cycle(Max)	84%
Vin(Min)	3 V
Vin(Max)	40 V
Vout(Min)	3.6 V
Vout(Max)	60 V

Table 2: TL3577 12 V Boost Converter Specs

Microcontroller Software

The microcontroller software consists of two different programs running in parallel on two MSP430F2274 microprocessors. Each processor is included in an evaluation module, together with a CC2500 2.4GHz RF transceiver, which is used as a communication link between the two processors. One processor will run software that samples the digital serial data from the fram grabber connected to the camera, temporarily buffers this data in order to obtain two entire frames from the frame grabber, and will then push these frames over the wireless link to the partner MSP430. The software on this MSP430 will re-buffer the two frames, de-interlace the images if required, and compress the image so it can be passed to the PC within a baud rate of 256Mbaud/sec. The baud rate limit is a function of the PC serial port, as well as the limited speed of the evaluation module's UART.

PC Software

The PC-connected MSP430 will communicate with a serial port on the PC through the USB interface of the MSP evaluation module's UART. This two-way link will allow a PC interface to receive camera frames from the buffered copies in the MSP430's memory, and process them on the much faster PC CPU. This software will reconstruct the camera's frame, and calculate the center of the eye in the picture. Controls for the system, such as image transmission timing, sampling rate, or other variables can be adjusted in this software and communicated to the system through the serial port.

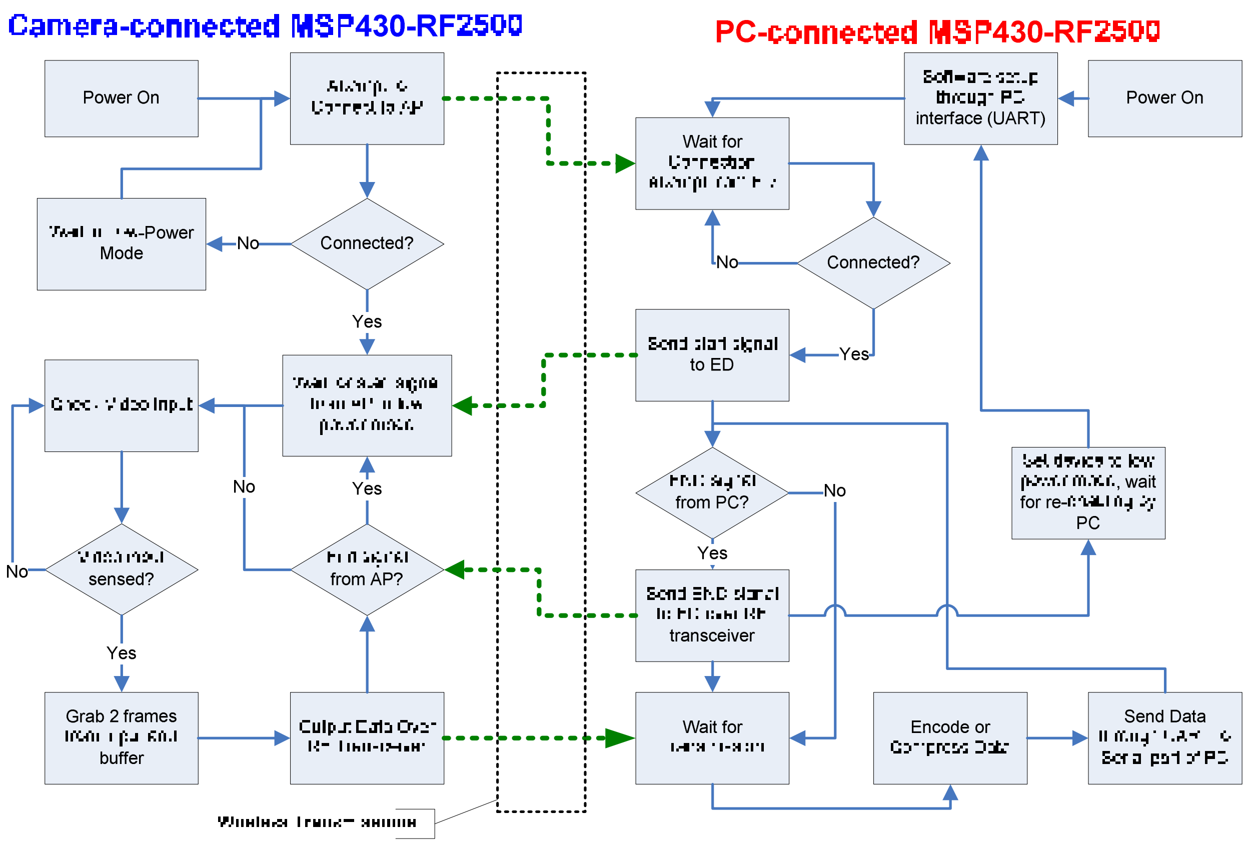


Figure 12: Software Flow Chart

Report of Work

Team B.I.T. spent the months of Autumn Quarter researching Eye Tracking System Background information, as well as visiting current systems at the Ohio State University. After thorough background research was accomplished, the design process began. The Eye Tracking System groundwork was proposed for how the project will move forward for implementation.

Team B.I.T. divided its members into subgroups, consisting of different specifications and specializations: Microcontroller Work, Camera Work, Wireless Components, Power Management, and further Research. Dustin and Aaron focused on programming the microcontroller, Nick focused on camera work and using MATLAB to produce signals, Lauren focused on wireless components, and Rory focused on power management.

Resources

Personnel

Team B.I.T. consists of five electrical engineers with various skills necessary to accomplish the proposed task. Each member has experience in distinctive areas which will aid in completing the goal of an Eye Tracking System.

Rory Garand has experience with various programming languages such as C++ and assembly languages. Rory focuses on computer hardware components and logic design in his studies at Ohio State University. He also has internship experience in control systems. Rory will specialize in power management for the Eye Tracking System. (Please note: Rory graduated in March 2009 but contributed greatly to the group, especially specializing in the power area)

Aaron Jackson is currently a senior at The Ohio State University college of Electrical and Computer engineering with an Electrical Engineering specialization. Aaron has a main concentration in computers and a secondary concentration in both Power and Communications. He has participated in undergraduate research in the area of Robotics. Aaron will specialize in working with the MSP430 microcontroller for the Eye Tracking System.

Nick Marquart is a fifth year senior at The Ohio State University who is majoring in Electrical and Computer Engineering with a focus in Electromagnetics and Digital Signal Processing. Nick has competed in the Fundamentals of Engineering for Honors Nanotechnology competition and has work experience as a co-op. Nick will specialize working with the camera signals for the Eye Tracking System.

Lauren Sapharas is an Electrical and Computer Engineer at the Ohio State University. Lauren focuses on digital logic, circuit design, and computer software and has experience working with different programming languages including Java, C++, VHDL, and various types of assembly languages. She has internship experience working with networking. Lauren will specialize in working with wireless components for the Eye Tracking System.

Dustin Vorac is a fifth-year undergraduate in Electrical and Computer Engineering, focusing primarily on Programming and Digital Logic Design. He has completed OSU's microprogramming and microcontroller coursework, including associated labs. Dustin has work experience as a programming intern and writing desktop applications in .NET. Dustin will specialize in working with the MSP430 microcontroller for the Eye Tracking System.

Facilities and Equipment

The facilities used for the Eye Tracking Project include computer labs in Caldwell Laboratory for programming purposes, Caldwell Labs 239 for group meeting purposes and discussions with

Professor Bibyk. The Cognitive Science Center and Linguistics Department at the Ohio State University were used for research and background information purposes.

Schedule and Cost

Schedule

Beginning in September 2008, Team B.I.T. researched and developed design work for a Wireless Eye Tracking System. Designing and researching through December 2008, final design ideas came together and Team B.I.T. began researching possible T.I. parts to order. After receiving various hardware and software packages, Team B.I.T. began programming and building a individual pieces of the Eye Tracking Device. Ending in June 2009, Team B.I.T. submitted a final design report and individual sections of the physical device to Professor Bibyk and applied to the T.I. Design Contest. Table 4 shows specific tasks completed by the team throughout the design year.

Quarter 1	
Days	**Task Completed**
1-15	Brainstorm
16-25	Discuss Problem Statement
26	Submit Proposals to Professor Bibyk
27-34	Research Eye Movements, Image Sensors, and Eye Tracking Techniques
35-40	Research Ohio State University's Center for Cognitive Science
40-45	Research Ohio State University's Department of Linguistics
50	Visit Department of Linguistic's Eye Tracking Device
51-55	Discuss Improvements on Current Systems
60-65	Initial Design Plan
66-67	Discuss Options and Possible T.I. parts
68-72	Build Initial System Block Diagram
73	Submit Rough Documentation Report to Professor Bibyk
73	Presentation of Initial Design Plan, received many improvement ideas
Quarter 2	
Days	**Task Completed**
1-2	Facility Set-up and Familiarization
3	Order T.I. Parts
4-10	Begin Start Up Work

11-15	Improve System Block Diagram
16-20	Research Power Management and NTSC
21-24	Begin MATLAB programming
25	Receive T.I. Parts and CCD Camera
26	Reseach Camera Specs and Operation
27-35	Begin Learning Microcontroller Software
36-45	Begin Programming Microcontroller and Continue Programming NTSC in MATLAB
46	Midterm Presentation for more Design Ideas/ Improvements
50-60	Continue Programming and Improving Design
61-64	Integrate CCD Camera into Baseball Hat
65-70	System Integration and Testing
71	Power Management Testing
72	Final Presentation
Quarter 3	
Days	**Task Completed**
1-5	Create Software Flow Chart
6-20	Continue Programming and Improving Design
21-30	Research Frame Grabber and other Power Ideas
31-35	Test Baud Rate Limitations and Time Specifications
36-45	Update and Improve System Documentation
46-60	Final Software Testing, Compiling, and Documentation
70	Submit Final Documentation and System to Professor Bibyk

Table 3: Team Schedule

Cost

The Eye Tracking System includes the following equipment and cost described in Table 5.

Equipment	Cost
Color CCD 380 Line Camera	$0
Visual Studios, MATLAB, and Software Applications	$0
(2) MSP430 2.4 GHz Wireless Target Board / $49.00 each	$98.00
Shipping and Handling	$6.03
(1) TL3577 12V Boost Converter	$6.28
Miscellaneous (solder, tools, etc…)	$20
TOTAL	**$130.31**

Table 4: Equipment Costs

TI will supply a $200 coupon budget. The proposed system's objective is to be a low-cost system so the final product will cost less than $200 to implement. The final cost was $130.31. Team B.I.T. received a used camera from Professor Bibyk for no cost to assist in lowering the total cost of the system.

Design Review Discussion

Weekly meetings with Professor Bibyk and Drew helped keep Team B.I.T. on track and on schedule for implementing the Wireless Eye Tracking System. Each week concentrated on a specific issue and how to improve the design.

The first quarter primarily concentrated on finalizing the design parts and ordering everything while still working on updating documentation and designing the system. Once the parts were ordered and shipped, programming the microcontroller and learning the software was the first task. Team B.I.T. was divided into subgroups to accomplish multiple goals at once.

The second quarter concentrated on updating the design specifications and working on midterm presentations to Professor Bibyk and Drew. Each member of the team focused on their specialties, but primarily worked on getting the microcontroller to do something and figuring out the specifications of the camera and power management requirements. In order to test the power management of the camera, Team B.I.T. hooked the camera via composite video to a television. MATLAB was used in generating a "test" camera signal.

The final quarter focused on programming the microcontroller and editing the NTSC MATLAB programming. After the individual pieces were beginning to improve and build on each other, Team B.I.T began testing more system integration processes as well as researching ways to improve the design, such as a frame grabber or different power management ideas. Updating all of the documentation was a main concern as well after the initial design plan was drastically changed. In order to communicate ideas better, many block diagrams were created to show software flow implementation as well as system integration.

Conclusion

Team B.I.T. will design and construct a low-cost system for tracking a user's eye movement. The Wireless Eye Tracking System will be used to assist people with disabilities, help children to learn languages and prove to be a cheap consumer product. The Wireless Eye Tracking System uses cheap components, primarily from Texas Instruments and extensive software developed by Team B.I.T. to drive the cost down. The final cost for all components is $130.31.

Team B.I.T. experienced many problems while implementing and designing the Eye Tracking System such as streaming data from the MSP430 microcontroller I/O ports and managing various voltage levels and preserving a common ground. Decoding streaming video was by far the most difficult task while requiring streaming in real-time, learning the sampling rate and bandwidth, interlacing, and decoding the actual signal. Getting a hold of a frame grabber was nearly impossible to test different improvement ideas, for all frame grabbers that were compatible with the system were very expensive and would hinder the coupon budget and would not follow the initial problem statement of being a low-cost consumer product. Ideally, a frame grabber would work well in the Eye Tracking System in order to be more efficient.

Appendix A

```
% NTSC_demo_makeframes.m
clear

% Generating sample frames
pic = imread('baseball.jpg');
pic2 = imread('pete_rose.jpg');

pic_me = pic(1:374,1:336,1);
pic_pete = pic2(1:374,:,1);

%imshow(pic_me)
%figure()
%imshow(pic_pete)

frame1 = uint8(zeros(374,336));
frame2 = uint8(zeros(374,336));

% This loop interlaces the 2 images into 2 frames (2:1 interlacing)
for i = 1:374
    if mod(i,2) ~= 0
        frame1(i,:) = pic_me(i,:);
        frame2(i,:) = pic_pete(i,:);
    else
        frame1(i,:) = pic_pete(i,:);
        frame2(i,:) = pic_me(i,:);
    end
end

imshow(frame1)
figure()
imshow(frame2)

imwrite(frame1,'frame1.jpg');
imwrite(frame2,'frame2.jpg');
```

Appendix B

```
% NTSC_demo_makeImages.m
clear

frame1 = imread('frame1.jpg');
frame2 = imread('frame2.jpg');

%imshow(frame1)
%figure()
%imshow(frame2)

pic1 = uint8(zeros(374,336));
pic2 = uint8(zeros(374,336));

for i = 1:374
    if mod(i,2) ~= 0
        pic1(i,:) = frame1(i,:);
        pic2(i,:) = frame2(i,:);
    else
        pic1(i,:) = frame2(i,:);
        pic2(i,:) = frame1(i,:);
    end
end

imshow(pic1)
figure()
imshow(pic2)
```