# DESIGN OF MECHATRONIC SYSTEM FOR EYEBALL MOVEMENT

by

Syed Muhammad Afiq Bin Syed Othman

Dissertation submitted in partial fulfillment of
the requirement for the
Bachelor of Engineering (Hon)
(Mechanical Engineering)

MAY 2012

Universiti Teknologi PETRONAS
Bandar Seri Iskandar
31750 Tronoh
Perak Darul Ridzuan

CERTIFICATION OF APPROVAL

**Design of Mechatronic System for Eyeball Movement**

By

Syed Muhammad Afiq Bin Syed Othman

A project dissertation submitted to the
Mechanical Engineering Programme
Universiti Teknologi PETRONAS
In partial fulfillment of the requirement for the
BACHELOR OF ENGINEERING (Hons)
(MECHANICAL ENGINEERING)

Approved by,

______________________
Prof. Dr. T. Nagarajan

UNIVERSITI TEKNOLOGI PETRONAS
TRONOH, PERAK
May 2012

## CERTIFICATION OF ORIGINALITY

This is to certify that I am responsible for the work submitted in this project, that the original work is my own except as specified in the references and acknowledgements, and that the original work contained herein have not been undertaken or done by unspecified sources or persons.

SYED MUHAMMAD AFIQ BIN SYED OTHMAN

# ABSTRACT

Human eye is a potential medium to discover non-verbal communication. It can be done by observing the eye characteristics such as eye gaze and eye blinks activities. Eye movement and eye blink are the main parameters of the project where it can be used to relate with eye fatigue. The information on these parameters can be obtained by designing a prototype that using infrared oculography technique. This technique is based on the infrared light reflection on the iris. Infrared emitter projects infrared light toward eye and its reflection will be captured by the sensor. The signals from the sensor are transformed into line graph form in order to obtain the movement pattern for analysis process. By doing comparison on the data patterns due to different Visual Display Terminal (VDT) conditions, eye fatigue state can be set and known. In this project, the prototype is successfully fabricated and performed well in fake eye test. However, the prototype seems having problem with low infrared light intensity after the light has been reflected on the iris. But, there are some modifications that have been proposed in order to improve the performance and sensitivity of the prototype.

# ACKNOWLEDGEMENT

First and foremost, I would like to thanks to God for giving me the strength and inspiration in order to finish the project. I also grateful that I have been given the opportunity to do this final year project with Prof. Dr. T. Nagarajan, my supervisor who has guide and advise me throughout this learning process. All his brilliant ideas and time that he spent on the project is highly appreciated. Besides that, my utmost gratitude is extended to Victor Amirtham and my father for their invaluable help and support in order to complete the project.

# TABLE OF CONTENTS

# LIST OF FIGURE

# LIST OF TABLE

# CHAPTER 1
# INTRODUCTION

## 1.1 Background

Eye is one of the unique body parts of humans and animals. It is capable to express the condition or reaction of someone naturally. This kind of nonverbal communication can be revealed by understanding the eyeball movement patterns which help in the interpretation of the hidden message. The eye movement studies already started in the 1800s where it has been done by performing direct observation. Comparing to the latest technology, there are many means and options available to perform this field of studies. According to Goussard et al, "commonly, these ocular-motor functions are tested by studying the eye blinking, pupillary oscillation, accommodation, vergence and saccadic eye movement" (Goussard, Martin, & Lawrence, 1987). Since eyeball movements are quite small and fast, a good sensor is required to perform the detection task. Thus, infrared oculography technique is a good option for this project since it is contact free, small, non-intrusive, affordable and the light ray is invisible to the eyes (Castro, 2008). The movement of eyeball can be known by detecting infrared reflection on iris. The output signal from infrared electronic circuit will be transformed into line graphs where it can be compared in order to determine eye fatigue condition.

## 1.2 Problem Statement

Nowadays, many daily activities are requiring people to use computer and read lengthy of documents regularly. These scenarios will lead to huge workload to the eyes since the person need to concentrate to the screen or long texts for long period of time. Thus, eyes condition is started to change which indicates the current reaction of the person. From this point, a rough prediction can be made either the person eyes are in stress or fatigue condition by observing the eyeball movement and blinking patterns. In addition, this situation also can be related to visual display terminal (VDT) phenomena since "eye focal point always concentrated at the light-emitting screen, which can caused visual fatigue or other mental physical exhaustion" (Shi, Qu, Mi, & Chang, 2011). Besides that, viewing small objects or near objects, eye muscle contraction is continuing to increase the curvature of the lens which resulting visual fatigue and decreased the ability to regulate the eye vision (Goussard, Martin, & Lawrence, 1987). All the statements are related with eye fatigue which can be identified by studying on specific eye characteristic. Thus, a good prototype is required to detect eye fatigue condition in order to implement it to any application that needs this kind of interaction.

## 1.3 Objective & Scope of Study

The main objectives of the project are:

I. to design a mechatronic system which is capable to detect eye movement and eye blinking rate,
II. to fabricate the prototype based on the system that has been designed,
III. to identify the eyes fatigue state of a person in specific condition,

In this study, the project scope will be covered as below:

I. Design and fabricate the prototype components:
   - Electronic circuit box.
   - Infrared sensor eyeglass.
II. Create programming command in order to integrate between infrared electronic circuit and computer. This command also capable to convert electric signal into analog or digital reading.
III. Prototype testing on flat and sphere surface.
IV. Performing experiment on actual eye in various conditions.
V. Analyzed the pattern of eye movements and eye blinking.

## 1.4 Relevancy of the Project

The project of designing mechatronic system for eyeball movement is expected to be feasible along the project flow since:

I. The infrared (IR) system is easily available and affordable for the project budget.

II. Most of the equipment and tools are available in university laboratory and these facilities can be used during conducting experiment.

III. The project is to relate eye movement and eye blinking activity toward visual fatigue. It is not fully stress on the detail of the complex human eye condition.

IV. This project is safe to be conducted and not harmful to the prototype tester within suitable distance of infrared emitter, duration of testing and good practice of experiment handling since the prototype emit an infrared light that directly pointed to the eye. The hazard regarding on infrared light can be seen in Table 1.

Table 1: Eyes pathologies related to infrared wavelength (Castro, 2008)

| Spectral Region | Eye |
|---|---|
| Visible (400 - 780 nm) | Photochemical and thermal retinal injury |
| Infra-red A (780 - 1400 nm) | Cataract, retinal burn |
| Infra-red B (1.4 - 3.0 µm) | Aqueous flare, cataract corneal burn |
| Infra-red C (3.0 µm -1mm) | Corneal burn only |

According to Castro, the hazard related to infrared increases with decreasing distance between the beam source and the eye. But, this condition is valid until the distance is longer than the shortest focal length.

# CHAPTER 2
# LITERATURE REVIEW AND THEORY

## 2.1 Literature Review

Eye movement is a kind of nonverbal language which naturally portrayed the expression or condition of a person. Today, there are many researches have been done on the eye movement studies in order to reveal its' possible uses and values to science's world. Technically, eye movement can be categorized into two parts, namely saccades and target-holding movements (Yarbus, 1967). Saccades eye movements are fast which jumps from one fixation point to another meanwhile target-holding eye movements are smooth and resulting very stable image. However, eye movements can be simplify into vertical and horizontal movement which is easily be noticed by observing iris position. According to Selker et al, "the eye movement patterns also can be expended to include blink detection. By gathering both movement and blinking information, stress and fatigue state of the user eyes can be known" (Selker, Lockerd, & Martinez, 2001). Moreover, in eye fatigue characteristic, "blinking frequency and pupil diameter can be the preference parameter in retrieving data for eyes fatigue research in VDT condition" (Shi, Qu, Mi, & Chang, 2011). However, in a few researches, eyelid movement also has been set as the response parameter since it can reflect a person's fatigue level.

Referring to eye characteristic study, eye blinking has become one of the important parameter in providing extra information regarding on human condition. In scientific definition, eye blink is define as a closure that followed by an eye opening within one second. However, eye blinking can be categorized into two types which are voluntary and spontaneous eye blink. According to Quartz et al, the voluntary blinking takes only 0.2s, approximately half of the time taken compared to spontaneous blinking (Quartz, Stensmo, Makeig, & Sejnowski, 1995). Meanwhile, the most frequent movement of eyelid is spontaneous blinking. This movement takes about 10-30 movements per minute depending on the health and activities of a person. Comparing both types of blinks, the most useful for the study is the spontaneous blinking since it can indicate fatigue due to increase blinking rate while spending time on activities that required human sight.

By looking on latest sensor system, there are many developed methods of detecting eye movement which consist of various concepts and approaches. For eye movement detector, "the device should be capable for executing saccades within about 50-100ms with accuracy on the order of $1^o$, over the total angle of $60^o$-$90^o$" (Landolt, 2008). Thus, the sensor used must be highly sensitive to the movements of the eyeball in order to gain accurate data. In biomedical study," the detection is based on electro-ocular-graph (EOG) sensing. EOG is capable in detecting fast and rapid eye movement and the position of eye" (Gu, Meng, Cook, & Liu, 2002). EOG concept is good but it is applicable for horizontal eye movement only.

On the other hands, infrared oculography method also has been applied to eye movement research. This method has been practiced by Selker et al in their Eye-R glass. Eye-R glass is used to detect eye fixation and interpret it during focusing on something in the immediate environment. Eye-R glass will record the interaction of user responds toward something that grabs user attention (Selker, Lockerd, & Martinez, 2001). Eye-R glass is designed as a wireless device that stores and transfers information based on user eyeball motion. This innovation is a good idea since it can help to detect eye gaze activity without any disturbance of wire and eye sight but it has the limitation on the memory storage. Due to its' wireless design, Eye-R glass can store about 30 ID's during eye movement recording activity. Based on its' system design, the infrared transmitting LED was selected with narrow angle of transmission between 17 and 20 degrees in order to assist directional intent of the user during transmission. Moreover, the circuit also contains an infrared receiver module which bidirectional communication of the system. The signal analysis coming from the eye's detector is achieved with a sample-and-hold circuit at a 60Hz rate and a PIC micro controller, which searches for patterns of fixation. However, this Eye-R glass project is mainly focus on human gaze but this method has the potential to go further research on more parameter of the eye.

For infrared oculography method, it is different from other methods since it is contact free, non-intrusive and cannot be influenced by other light sources. This technique commonly is used to capture horizontal eye movement but rarely used in vertical direction. Furthermore, infrared oculography is capable to reach spatial resolution which the smallest movement also can be detected. However this technique has shortcoming during eye blinks. Referring to Castro, "during horizontal and vertical measurement, blinks can be a problem, not only because the lids cover the surface of the eye, but also because the eye retracts slightly after the blink, altering the amount of light reflected for a short time" (Castro, 2008). Besides that, infrared oculography technique also very sensitive regarding the angle between the infrared emitter and sensors since the sensors only depends on the reflection infrared light that has been projected to iris.

Furthermore, visual fatigue in VDT case, it can be tracked by observing the performances of a subject in response to a target light slowly moving on the screen. The input and output of the system can be referred to target and eye position (Goussard, Martin, & Lawrence, 1987). If a person is capable to follow the movement of the target light is consider that the eyes in good condition. Otherwise, if the person find difficulty to perform the task is consider having visual fatigue. In Goussard et al research, they want to propose a method to derive an indicator according to the observation of the visual tracking system. The experiment is conducted by testing a person to observe on the CRT screen that shows random movement. The experiment is aid by using an infrared photoelectric device to the tester. In order to simplify the research, only one dimension signals is considered which refer to horizontal movement. As the research parameter, eye fatigued state is identified when a person does not perform smooth pursuit since the task difficulty causes him or her depend on saccadic movement to track the target. The experimental comparison between normal and fatigue eyes can be seen on Figure 1.

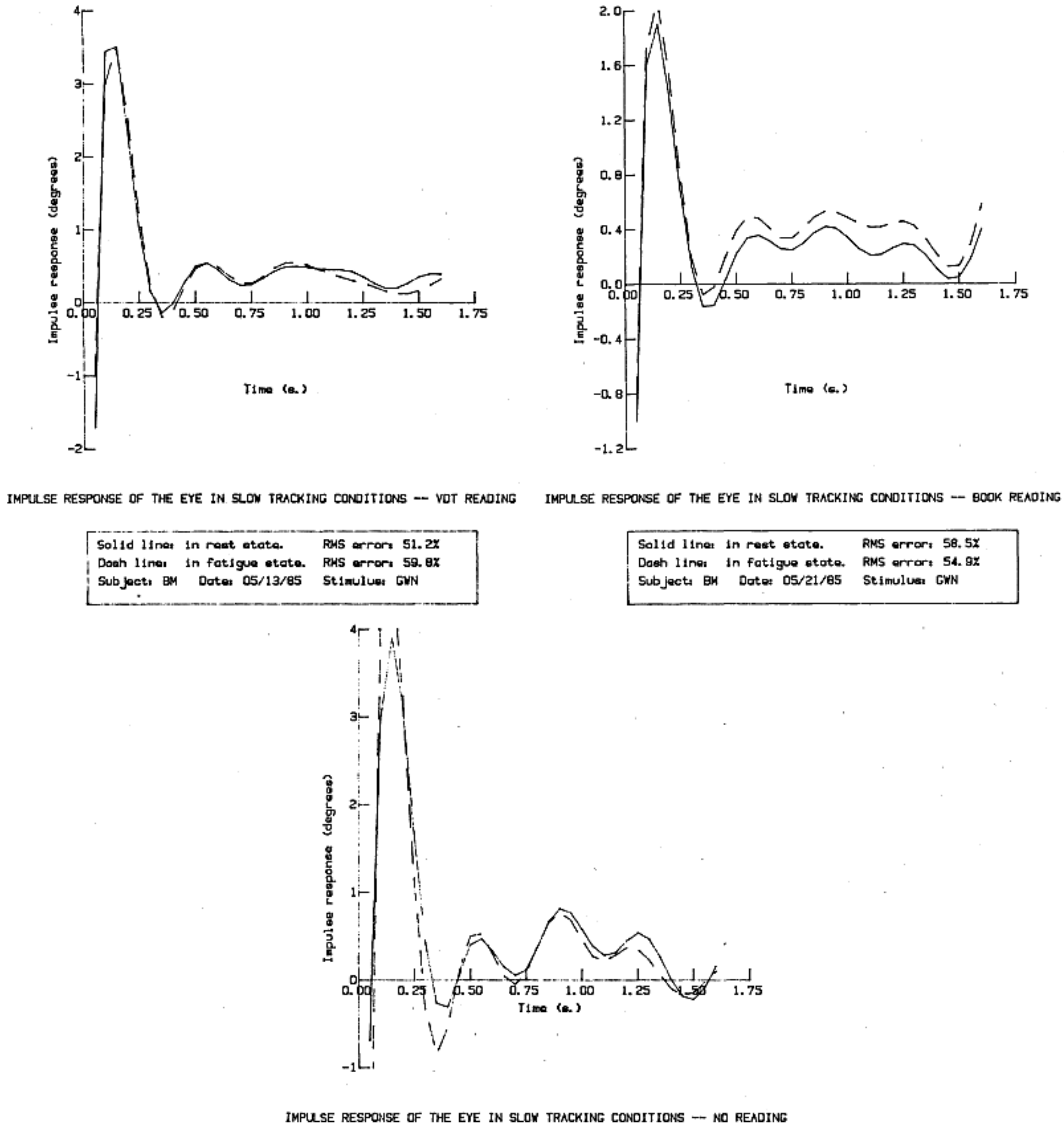


Figure 1: Model derived impulse responses (Goussard, 1987)

However, Goussard et al also stated that direct interpretation of tracking responses in terms of visual fatigue is very difficult and the quantization of fatigue levels through direct observation of the signals seems even more difficult.

According to Shi et al research on VDT, the fatigue detection has broad application prospects and realistic meaning in various fields. However, they just focus on blinking frequency and pupil diameter as their research parameter. By using smart eye 5.6 software, eye movement of the subject can be obtained. It uses the reflections of the IR flashes on the cornea to find the center of the eyes, it possible to measure head pose and eye state with great accuracy in real time, using video cameras. The experiment method is constructed by the tester in accordance with the requirements of VDT work operations to retrieve the electronic file to read the literature. From the experiment, Shi et al found that there was close relationship between the blink frequency and the intensity of physical fatigue. VDT worker's fatigue degree had been increased and the blink frequency and the pupil diameter had been decreased. Thus, the eye movement data showed significant difference under extreme mental pressure. Moreover, the eye movement parameters which are blink frequency and pupil diameter change as the elapse of time become decrease. Since the study is conducted by using smart eye 5.6 system, good accuracy of eye movement can be obtained and not disturbing the subject eye sight. However, the system apparatus is not suitable to attach on the tester body because it use two cameras in order to support the system requirement.

Based on the previous research that is related to the design of mechatronic system for eyeball movement project, there are many points that can be used as the reference or benchmark on this project. This information can help to improve and develop new idea for the betterment of the project.

## 2.2 Theory

Eyeball movement can be sensed by using infrared oculography technique. It consists of infrared emitter and infrared sensors. The sensors utilize the fact that the white of eye and the iris has the difference reflectance. When the infrared emitter is projected to the eye, the sensor will receive the reflecting light with different intensity. Thus, the location of iris can be found. In order to identify horizontal movement of eyeball, two sensors (left and right) are installed at the side of the emitter which is illustrated in Figure 2. In addition, one sensor is installed at the top of the infrared emitter in order to detect eye position at the center. If all infrared sensors cannot detect any infrared light once it is projected, it means eye blinking has been performed.

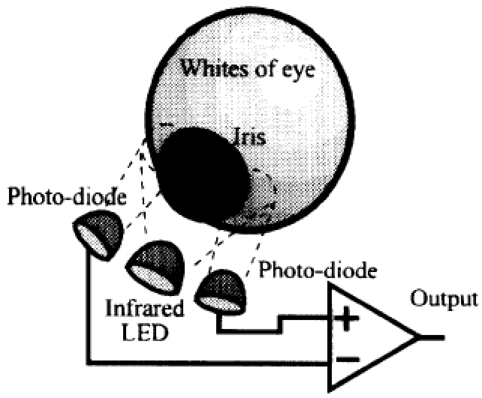


Figure 2: "Eye movement detector mechanism for horizontal direction" (Iwamoto, Katsumata, & Tanie, 1994)

Comparing to electrooculography (EOG) sensor, infrared sensor content less noise in the signal and it is good in studying micro-eye movements. But, "the main problem with infrared is that it only functions well with the eyes close from center which approximately about 10 degrees" (Timothy, 2011). The characteristic of infrared system are:

- Spatial resolution is about 0.1 degree.

- Temporal resolution is typically 100 Hz but greater resolutions are easily attainable.
- Vertical eye movement recording is possible.
- Setup is fast but calibration is necessary.
- Linearity is a major problem. The signal may actually reverse between; say +15 and +20 degrees.

In conclusion, this infrared oculography technique is suitable for the prototype and capable to perform the designed task well.

Based on the designed system flow shows in Figure 3, infrared light is directly projected to the eye and the infrared sensor will capture the signal. Then, infrared electronic circuit transfers the electric signal to Arduino Leonardo board. This board will convert the raw signal to analog or digital signal and send it to computer by using specific programming command. These analog or digital signals will be displayed on the screen through Arduino interface application. Then, the result can be directly transferred to Microsoft Excel in order to transform it into line graph for further analysis activity.

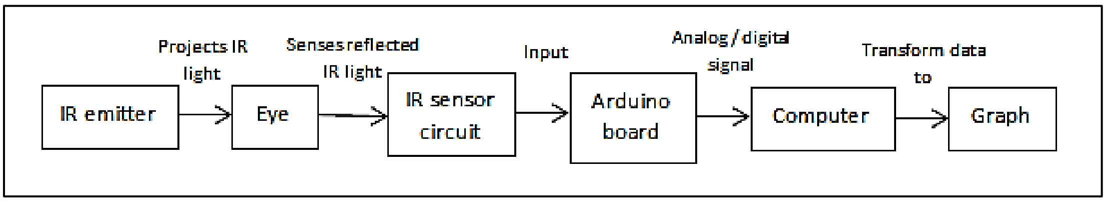


Figure 3: System flow of the eyeball movement detector.

# CHAPTER 3
# METHODOLOGY / PROJECT WORK

## 3.1 Project Activity

At the initiation stage of the project, it is important to search and review some literatures or paperwork that are related to the project which is regarding on the design of mechatronic system for eyeball movement. These literature reviews are essential to structure the project flow and a few modifications can be made in order to gain better result. Furthermore, these previous research can be set as initial datum or benchmark to improve the study on that particular field.

In eye movement study, it is important to have the prototype first before proceed to any testing or experiment activities. Proper design concept needs to be produced due to comply with research objectives. In addition, the designed prototype must be realistic to fabricate, easy to be attached to the subject, safe to be used and also reduce the amount of sight blockage due to the sensor stand size. Finally, the most suitable design concept will be selected for fabricating process.

Then, testing and experiment activities can be conducted by using the designed prototype. The result data which regards to eye movement and eye blinks will be analyzed and relate the pattern to eye fatigue. For simpler view of the project flow, all detail activities can be referred to process flow chart and Gantt chart of the research on Figure 4, Table 2 and Table 3.

### 3.1.1 Process Flow Chart

All the project stages of FYP 1 and FYP 2 are shown in Figure 4.

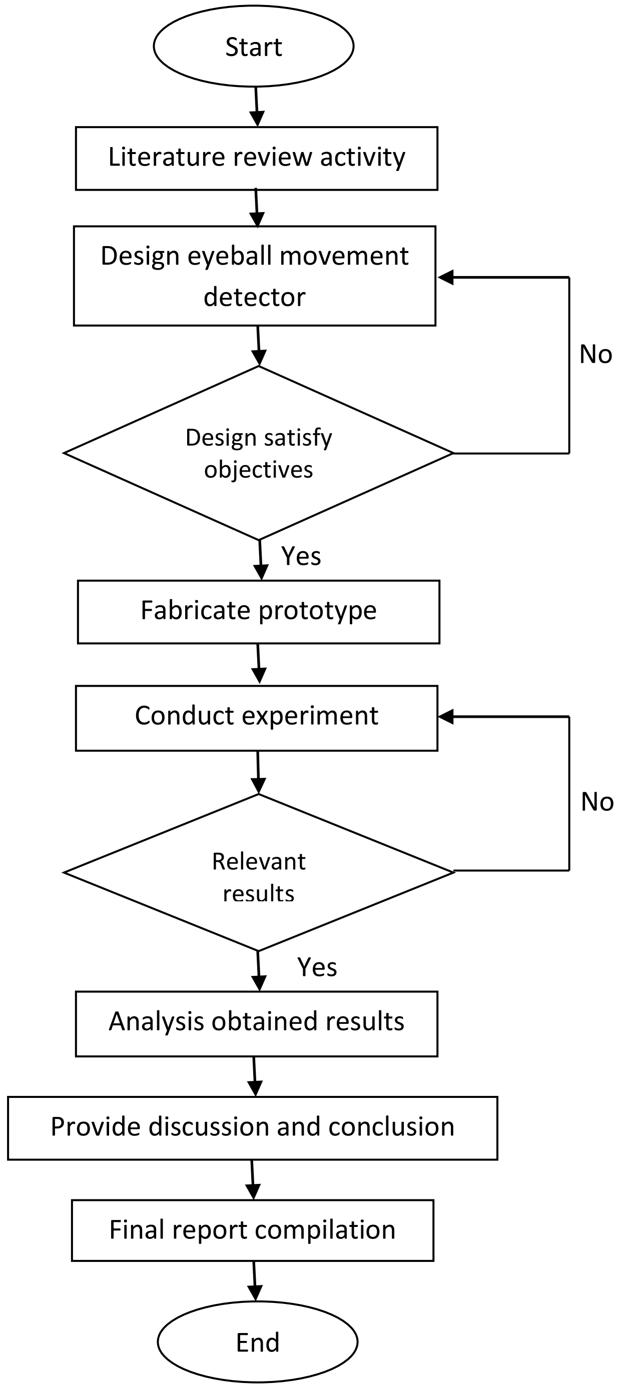


Figure 4: Process flow chat of the project.

### 3.1.2 Gantt Chart

These Gantt charts show the activities that will be performed during the project period. All the activities have been given specific time frame in order to indicate the project is more manageable and avoid any delay in its' activities. In addition, the project key milestone indicates important day during the project period.

For FYP 1, most of the activities are based on research paper and focusing on the literature review of the project. Furthermore, this period also used to produce concept designs of the prototype before one of it will be chosen to proceed with fabrication process. The detail activities of FYP 1 can be referred to Table 2.

Table 2: Gantt chart and key milestone for Final Year Project 1

| No. | Activities / Week | 1 | 2 | 3 | 4 | 5 | 6 | 7 | | 8 | 9 | 10 | 11 | 12 | 13 | 14 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | Project topic selection | ■ | ■ | | | | | | Mid-semester break | | | | | | | |
| 2 | Preliminary research work | | ■ | ■ | ■ | ■ | | | | | | | | | | |
| 3 | Extended Proposal defense submission | | | | | | ● | | | | | | | | | |
| 4 | Proposal Defense | | | | | | | | | ■ | ■ | | | | | |
| 5 | Design prototype | | | | | | | | | | | ■ | ■ | | | |
| 6 | Purchasing prototype components | | | | | | | | | | | | | ■ | | |
| 7 | Interim draft report submission | | | | | | | | | | | | | | ● | |
| 8 | Interim report submission | | | | | | | | | | | | | | | ● |

● - key milestone ■ - Process

For FYP 2, the project activities continue for prototype fabrication and performing experiment. The components that need to be fabricated are infrared sensor eyeglass and its' electronic circuit box. For experiment part, it has been divided into flat surface testing, fake eye testing and actual eye testing. The result of the experiment will be analyzed and documented in final report. The detail activities of FYP 1 can be referred to Table 3.

Table 3: Gantt chart and key milestone for Final Year Project 2

| No. | Activities / Week | 1 | 2 | 3 | 4 | 5 | 6 | 7 | | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | Fabricate prototype | ■ | ■ | ■ | ■ | ■ | ■ | ■ | Mid-semester break | | | | | | | | |
| 2 | Perform experiment | | | | | | | | | ■ | | | | | | | |
| 3 | Analysis experiment result | | | | | | | | | | ■ | ■ | | | | | |
| 4 | Progress report submission | | | | | | | | | ● | | | | | | | |
| 5 | Provide experiment discussion and conclusion | | | | | | | | | | | ■ | ■ | | | | |
| 6 | Prepare final report | | | | | | | | | ■ | ■ | ■ | ■ | ■ | ■ | | |
| 7 | Pre - EDX | | | | | | | | | | | | ● | | | | |
| 8 | Draft report submission | | | | | | | | | | | | | ● | | | |
| 9 | Dissertation submission | | | | | | | | | | | | | | ● | | |
| 10 | Technical paper submission | | | | | | | | | | | | | | ● | | |
| 11 | Oral Presentation | | | | | | | | | | | | | | | ● | |
| 12 | Project Dissertation submission | | | | | | | | | | | | | | | | ● |

● - key milestone ■ - Process

### 3.2 Concept Design of the Prototype

Components like infrared system, plastic eyeglass, wire and sockets is available in market and affordable to purchase. However, the sensor stand must be custom made and it must suit with infrared system and the eyeglass. The suitable material for the sensor stand is an aluminum sheet. The aluminum sheet should be thin, approximately 1mm thick. It must be flexible (can adjust the structure), light weight and easy to fabricate. The selected sensor stand design can be seen in Figure 5.

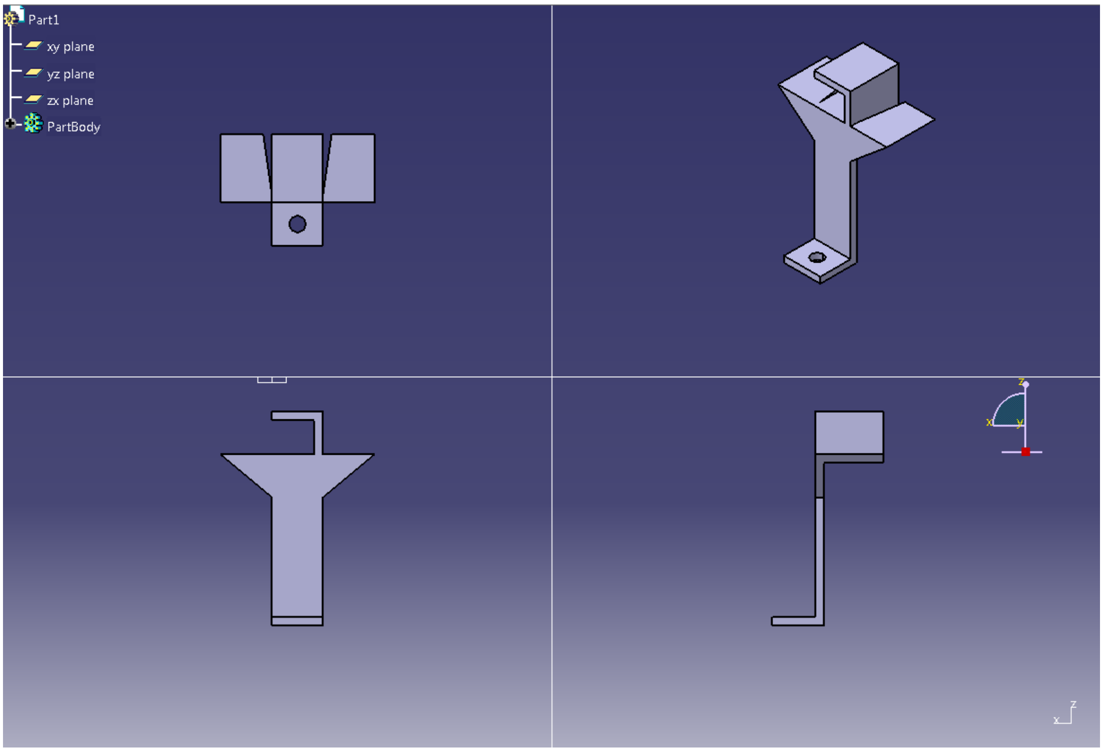


Figure 5: Chosen sensor stand design.

Based on the design concept, the sensor stand must able to support three infrared sensors and one infrared emitter. In addition, the designed sensor stand also depends on the eyeglass shape and eye position of the subject since it will affect the position of infrared sensors. The sensor stand is attached to the thick frame eyeglass as illustrated in figure 6.

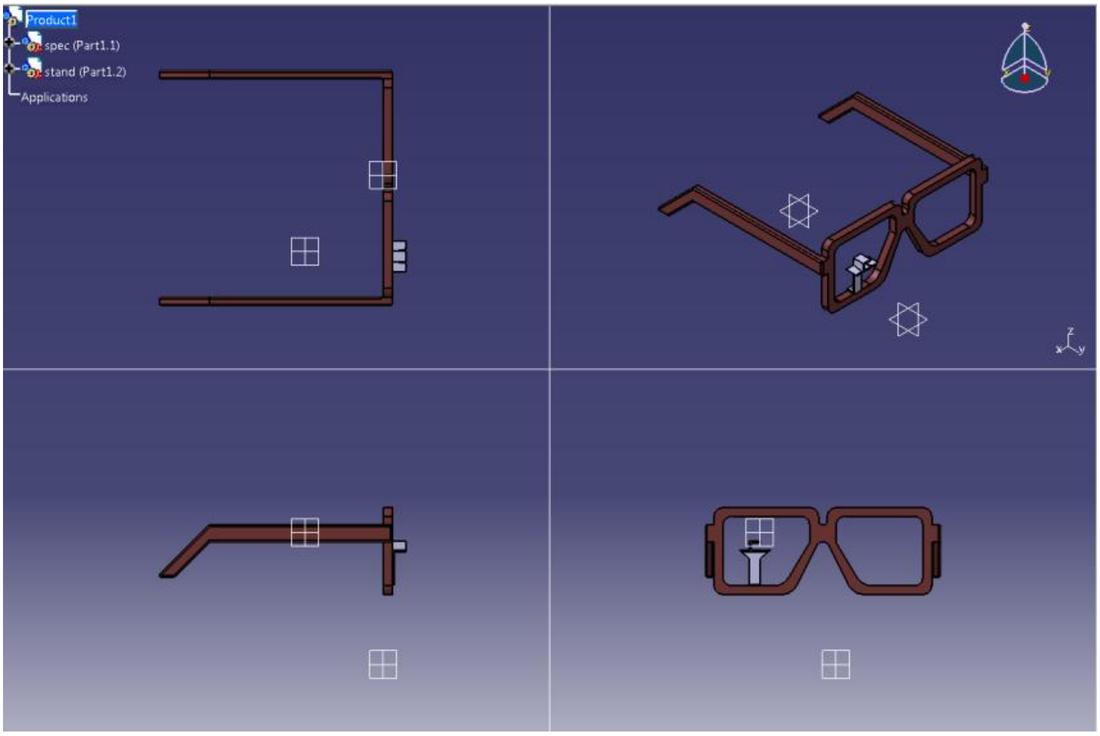


Figure 6: Sensor stand is attached to eyeglass.

Basically, humans have various shapes of head and face. These unique attribute causing inconstant of pupil location for each of different person as illustrated in Figure7. Thus, the sensor holder must be made from flexible material in order to alter the shape easily. Due to simplify the design, only a person has been chosen to perform the experiment and his or her head and face shape are been consider in designing the infrared sensor eyeglass.

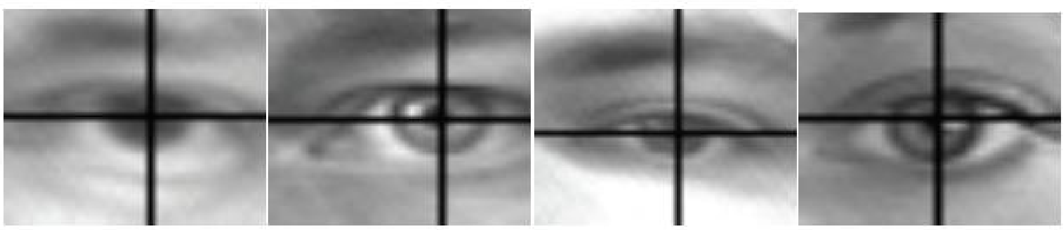

Figure 7: Different pupil location and eye opening for every person.

### 3.3 Research Parameter Identification

Referring to the project objectives, this project must relate the eye movement and eye blinks to visual fatigue. For these parameters, it is easily to be indicated by observing the output signal of the infrared sensors. The information of the designed parameter can be referred to Figure 8 and Table 4.

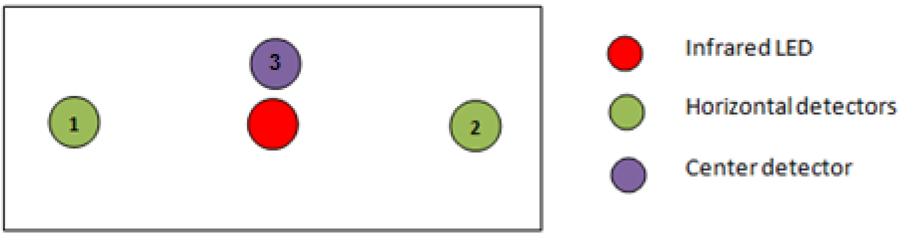


Figure 8: Infrared emitter and sensors positioning.

The distance between infrared emitter and each horizontal detector is 6mm but for center detector, it will be positioned as close as possible on the top of the emitter. The angle of sensor is about $10^{o}$ toward the infrared emitter.

Table 4: Summarize of infrared sensor detection.

| Condition / Sensor | A | B | C | D |
|---|---|---|---|---|
| 1 | Y | N | Y | N |
| 2 | N | Y | Y | N |
| 3 | Y/N | Y/N | Y | N |
| Eye Movement | Left | Right | Center | Blinking |

Y = detect movement

N = no detection

For eye fatigue parameter in this project, it is based on the Shi et al and Goussard et al research on VDT. The parameter is set to relate on the blinking rate and the response of eye movement. According to Shi et al, the fatigue degree of someone had been increased when the blinking frequency had been decreased. So, during experiment, it is important to identify eye blinking activity and record it for every situation given. On the other hand, Goussard et al said that eye fatigued state is identified when a person does not perform smooth pursuit since the task difficulty causes him or her depend on saccadic movement to track the target. In conclusion, eye fatigue can be noticed when blinking frequency decrease and the response of eyes movement is slow.

## 3.4 Project Procedure

Since the project consists of many parts such as mechanical, electronic and also programming, thus, the procedure can be categorized as below:

- Infrared electronic circuit assembly,
- Infrared reflection test,
- Construct programming command,
- Experiment on fake eye,
- Experiment on actual human eye.

The final result of the project is determined by producing line graph from the spreadsheet which consists of analog and digital reading. The data regarding on eye movement and eye blinks will be focused in the result since both of it are the main parameters of the study.

### 3.4.1 Infrared Electronic Circuit Assembly

The objective of this activity is to produce an electronic circuit that consists of three infrared sensors, an infrared emitter and three LEDs to indicate signal from sensors. The electronic circuit is designed to switch on the LED when there is no detection of infrared light. Meanwhile, the LED will be switched off when infrared light is detected. The circuit has been modified from the actual circuit in the COGECO website (Paisley, 2010). The procedure of the electronic circuit assembly as below:

1. Electronic components such as IR emitter, IR sensors, resistor, IC and stripboard are prepared to be assembled.
2. All the components are connected as Figure 9.

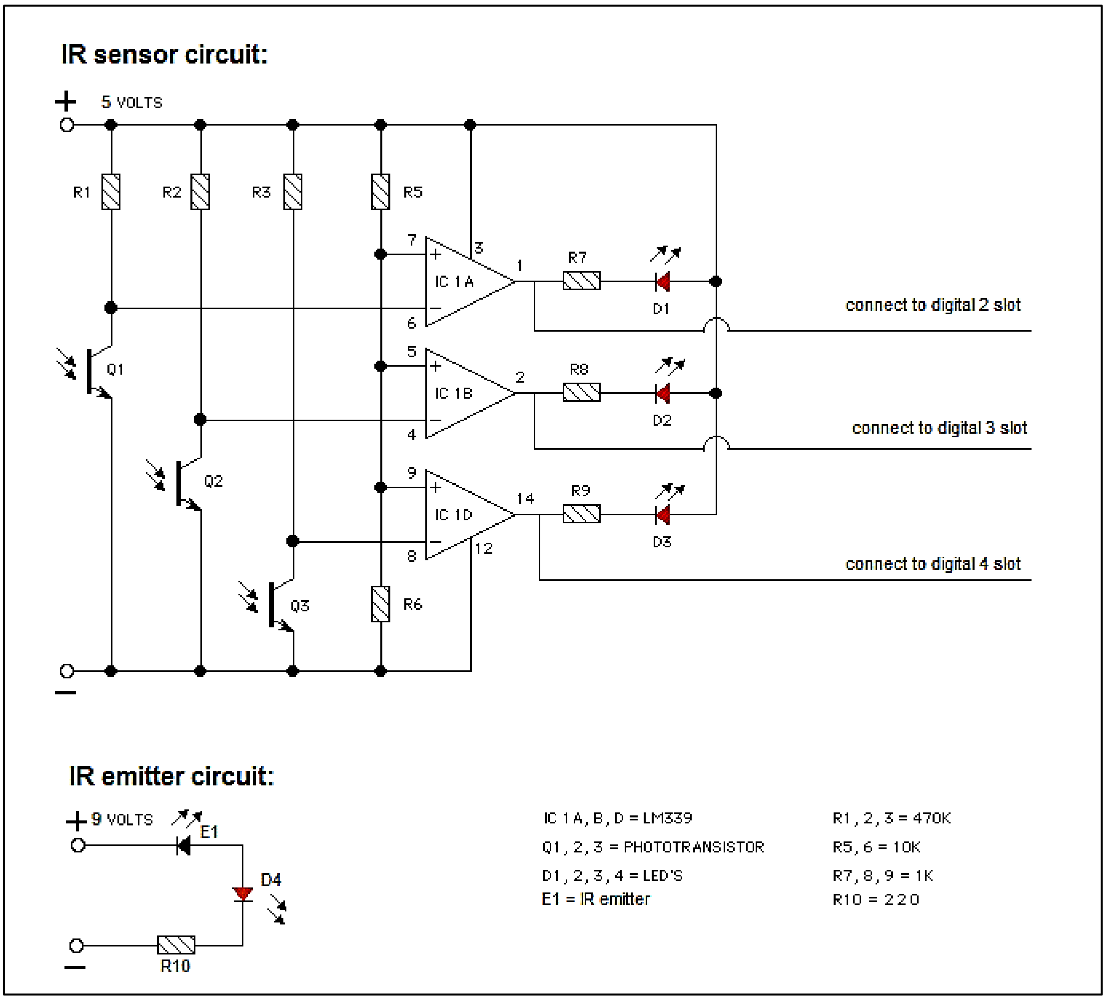


Figure 9: Infrared electronic circuit diagram.

3. The IR sensor circuit is connected to Arduino board and both sensor and emitter circuits are switched on.
4. Each IR sensors are tested in order to know its' functionality condition.
5. The result of each sensor is recorded.

### 3.4.2 Infrared Reflection Test

The objective of this test is to identify the reflection length that can be received by infrared sensor after infrared light has been projected to a flat dark glossy surface. The procedure of the test can be followed as below:

1. Infrared electronic circuit is switched on.
2. An IR emitter is used to project infrared light to a flat dark glossy screen and a sensor is used to detect the reflected light. The components configuration is illustrated as Figure 10.

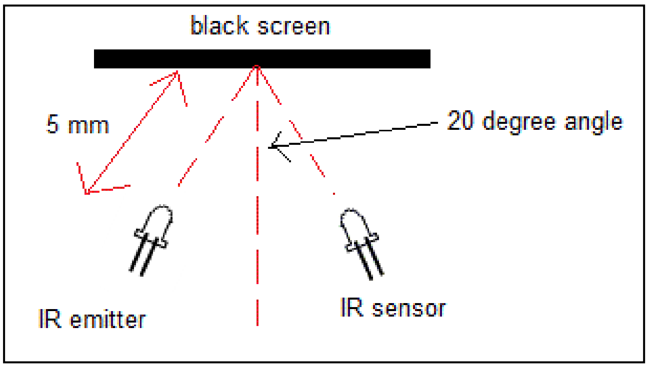


Figure 10: IR reflection test configuration.

3. The distance between the IR sensor and screen are changed with increment of 5mm.
4. The respond of IR sensor is recorded by observing its LED.

### 3.4.3 Construct Programming Command

The purpose of constructing programming command is to give order to Arduino board during receiving signal from infrared electronic circuit. Arduino board will transformed the signal to analog or digital reading and displayed it on the screen. The procedure can be seen as following:

1. Arduino application software is started by using laptop.
2. The command is inserted as below:
   - Command for analog reading:

```
/*
  AnalogReadSerial
  Reads an analog input on pin 0,1,2 and prints the result to the serial monitor.
  Attach the signal wires from IR circuit to pin A0, A1,and A2.
*/
// the setup routine runs once when you press reset:
void setup() {
  // initialize serial communication at 9600 bits per second:
  Serial.begin(9600);
}
// the loop routine runs over and over again forever:
void loop() {
  // read the input on analog pin 0:
  int sensorValue0 = analogRead(A0);
  int sensorValue1 = analogRead(A1);
  int sensorValue2 = analogRead(A2);
  // print out the value you read:
  Serial.print(sensorValue0);
  Serial.print("     ");
  Serial.print(sensorValue1);
  Serial.print("     ");
  Serial.println(sensorValue2);
  delay(360);        // delay in between reads for stability
}
```

   - Command for digital reading:

```
/*
  DigitalReadSerial
 Reads a digital input on pin 2,3 and 4
 Prints the result to the serial monitor
*/
// digital pin 2,3,4 have sensors attached to it. Give it a name:
int sensor2 = 2;
int sensor3 = 3;
int sensor4 = 4;
// the setup routine runs once when you press reset:
void setup() {
  // initialize serial communication at 9600 bits per second:
  Serial.begin(9600);
  // make the sensor's pin an input:
  pinMode(sensor2, INPUT);
  pinMode(sensor3, INPUT);
  pinMode(sensor4, INPUT);
}
// the loop routine runs over and over again forever:
void loop() {
  // read the input pin:
  int SensorState2 = digitalRead(sensor2);
  int SensorState3 = digitalRead(sensor3);
  int SensorState4 = digitalRead(sensor4);
  // print out the state of the button:
  Serial.print(SensorState2);
  Serial.print("     ");
  Serial.print(SensorState3);
  Serial.print("     ");
  Serial.println(SensorState4);
  delay(360);        // delay in between reads for stability
}
```

3. The command is verified in order to make sure the programming is correct.
4. The command is uploaded to Arduino board.
5. The serial monitor application is clicked in order to observe the reading.
6. The IR sensors are tested to verify its' condition.
7. The result is saved into Microsoft Excel and line graph is plotted.

### 3.4.4 Experiment on Fake Eye

The objective of this experiment is to demonstrate the prototype concept due to reflection on sphere shaped surface which is almost similar to the shape of actual human eye. Besides that, the accuracy of sensor position angle also can be known by observing the experiment result. The experiment procedure as follows:

1. Faked eye is prepared by applying a small, dark, glossy and circle shaped sticker to a Ping-Pong ball.
2. The Ping-Pong ball is positioned 15mm straightly from the infrared emitter.
3. The infrared electronic circuit is switch on and connected to computer.
4. Data recording is started.
5. The fake eye is rotated into horizontal plane.
6. The fake eye is blocked by a piece of paper for a few times to illustrate eye blinks.
7. Analog and digital data is transfer to Microsoft Excel and transform it into line graph.

### 3.4.5 Experiment on actual human eye

The objective of this experiment is to collect information of eye movement and eye blinks due to visual fatigue case. The experiment is performed by same person for two different situations in specific period of time. The experiment is based on VDT condition where the tester has to read lengthy text on computer screen before and after performing high visual concentration activity.

**Condition A:**

1. The subject must be freed from performing any activities that require high visual concentration within 2 hours.
2. The prototype is set to a subject.
3. The prototype position is adjusted so that it fit to the subject eye.
4. The electronic circuit box is switched on and connected to computer.
5. Let the person read a document on the computer screen for 10 minutes.
6. The analog reading on Arduino interface is transfer to Microsoft Excel in order to plot line graph.
7. The graph patterns are analyzed due to eye movement and eye blinks.
8. Step 1-7 is repeated by applying digital reading.

* The experiment is conducted in short period of time in order to minimize as low as possible any hazard toward the subject eye.

**Condition B:**

1. The subject has been performing any activities that require high visual concentration approximately within 2 hours.
2. The prototype is set to a subject.
3. The prototype position is adjusted so that it fit to the subject eye.
4. The electronic circuit box is switched on and connected to computer.
5. Let the person read a document on the computer screen for 10 minutes.
6. The analog reading on Arduino interface is transfer to Microsoft Excel in order to plot line graph.
7. The graph patterns are analyzed due to eye movement and eye blinks.
8. Step 1-7 is repeated by applying digital reading.

* The experiment is conducted in short period of time in order to minimize as low as possible any hazard toward the subject eye.

# CHAPTETR 4
# RESULT AND DISCUSSION

## 4.1 Result and Finding

All the project methodology that has been explained in section 3.4 has its own individual finding and result. The purpose of the activities is to ensure that the project is in the correct path which is follow the idea that has been planned. The result and finding of each project procedure as following:

- **Infrared Electronic Circuit Assembly**

  The electronic components have been assembled on the stripboard. The infrared electronic circuit can be seen in Figure 11.

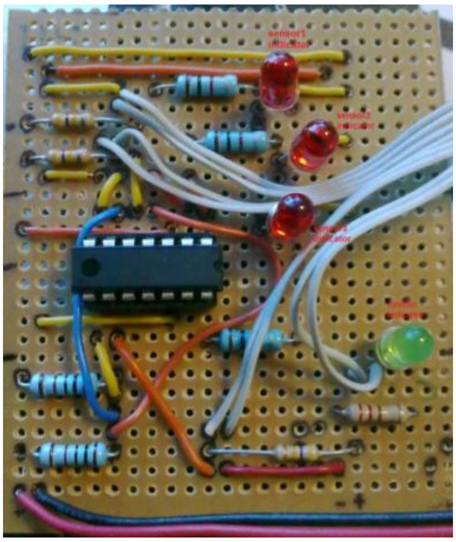

Figure 11: Assembled infrared electronic circuit.

For infrared sensors testing, all of it in a good condition and able to receive infrared light within 90mm of length. Each infrared sensor is able to switch off its individual LED during receiving infrared light.

The infrared electronic circuit is connected to Arduino board in order to read the signal. Then, the data from Arduino board is transferred to computer via USB cable. The components which consist of infrared electronic circuit and Arduino board are known as electronic circuit box (can be seen in figure 12). The electronic circuit box is connected to IR sensor eyeglass via 9 pin serial port.

Figure 12: electronic circuit box and IR sensor eyeglass.

- **Infrared Reflection Test**

The test has been done in 20 degree of reflection angle into the flat, dark and glossy screen. The test result can be seen in Table 5.

Table 5: Reflection length result.

| Length (mm) | Observation on LED |
|---|---|
| 5 | Off |
| 10 | Off |
| 15 | Off |
| 20 | Off |
| 25 | Blinking |
| 30 | On |

Referring to the result, it indicates that the reflection of infrared light is good until 25mm of distance. Thus, the IR sensors have to position less than 25mm to the eye in order to gain clear signal during experiment on actual human eye.

- **Construct Programming Command**

The command is successfully verified and uploaded to the Arduino board. The result which is the display on the serial monitor can be seen in Figure 13 and Figure 14.

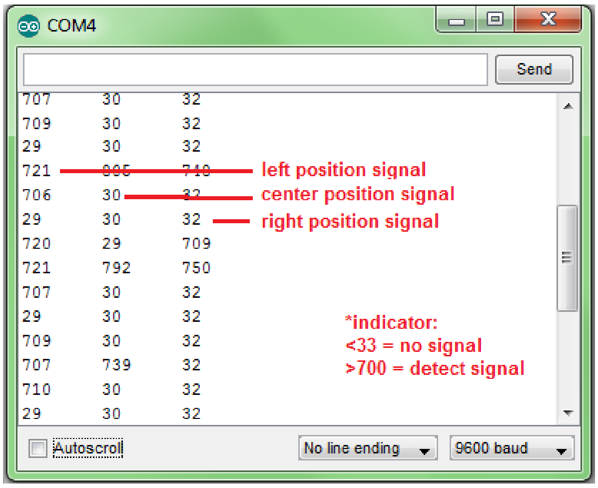


Figure 13: Analog reading of the testing result.

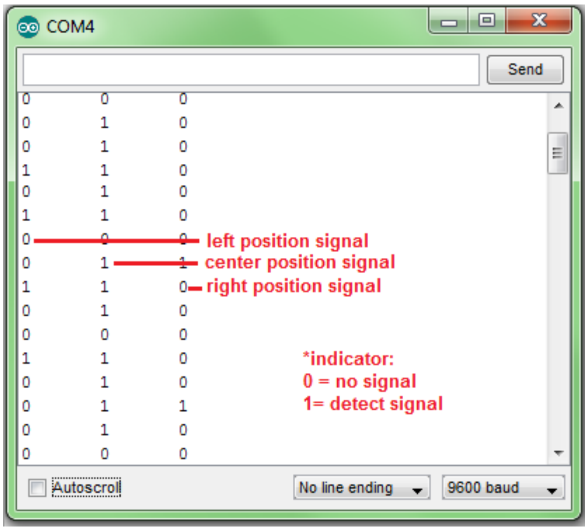


Figure 14: Digital reading of the testing result.

From the serial monitor display, there are three rows of number. Each row represents each sensor that has been installed which is left, center and right sensor. For analog reading, the reading range is from 27 to 830. The reading which is more than 700 indicates signal detection whereas the reading below 40 means no detection at all. Meanwhile for digital reading, the reading only shows number 0 and 1 only. Number 0 indicates no signal meanwhile number 1 indicates signal has been received.

- **Experiment on Fake Eye**

Regarding on fake eye test, the prototype is performed well due to artificial eye movement and eye blinking activities. The obtained result is almost similar with the expected result which has been stated in Table 4 (section 3.3). Thus, this result shows that positioning of the infrared sensors is proven correct. In this experiment, four readings are taken within a second in order to obtain accurate result. The result graph can be seen in Figure 15, 16, 17, 18 and 19.

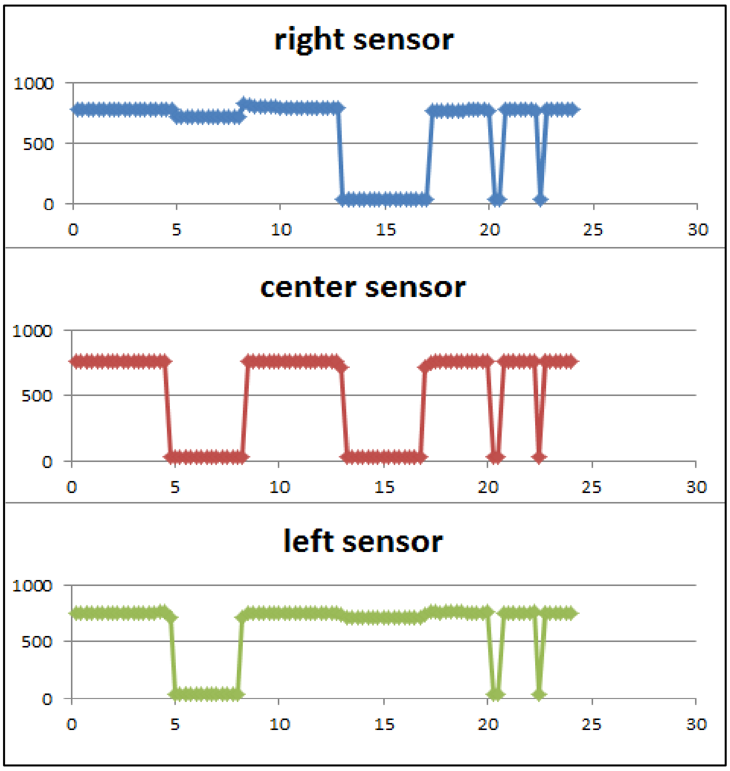


Figure 15: Individual line graph for each sensor in analog reading.

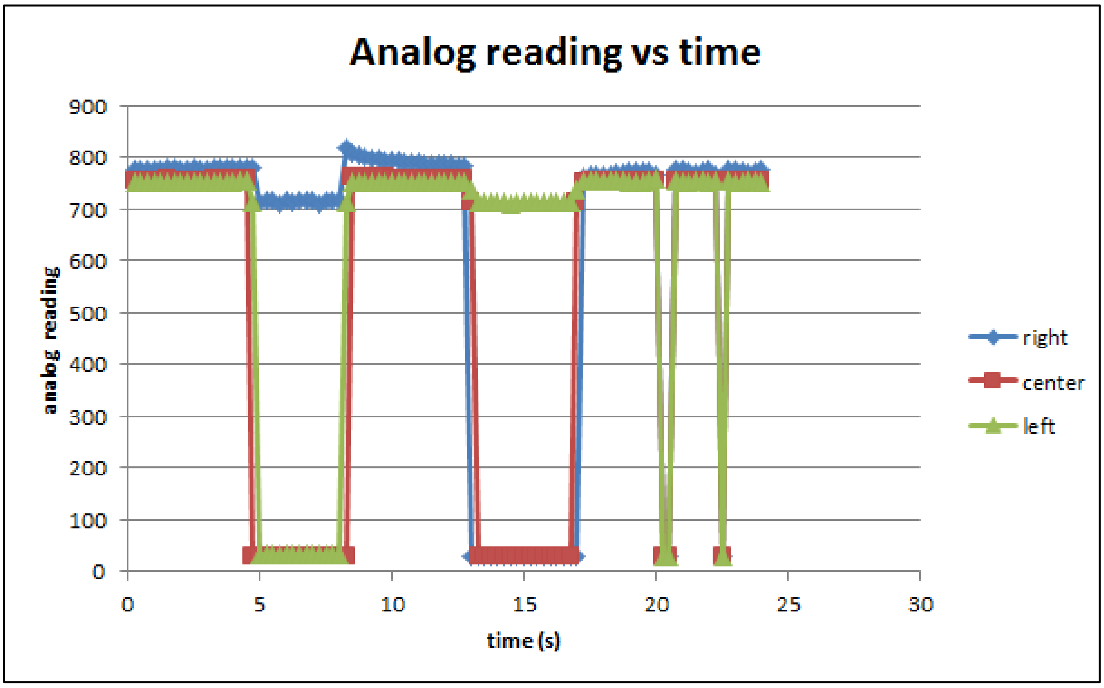


Figure 16: Line graph compilation of all sensors in analog reading.

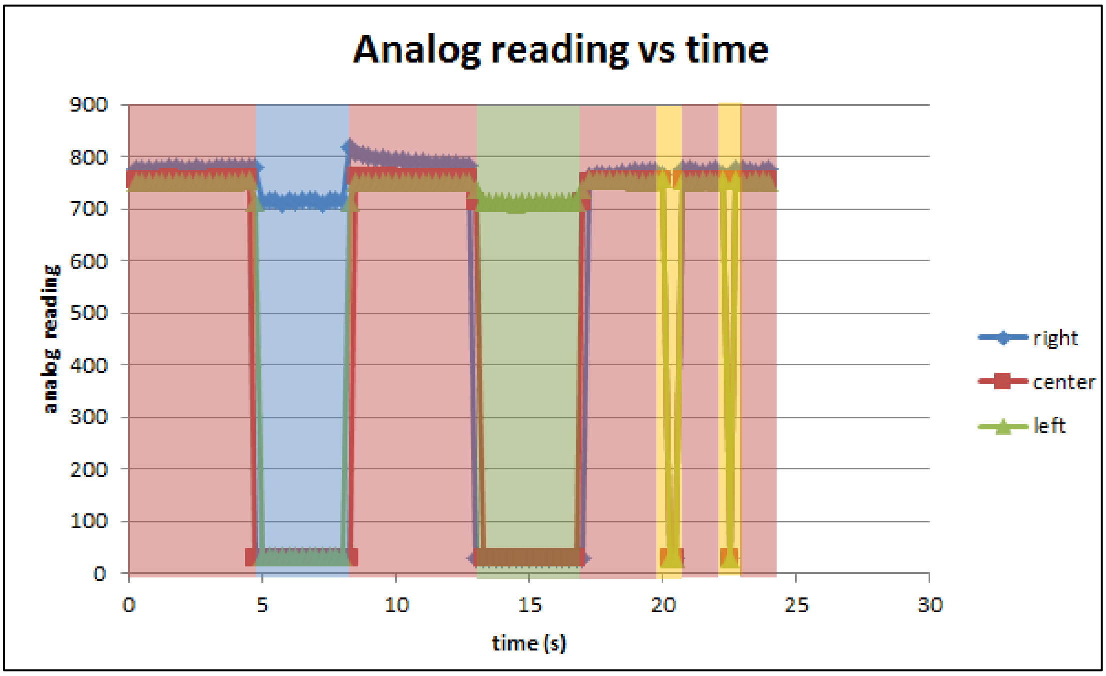


Figure 17: Analyzed line graph in analog reading.

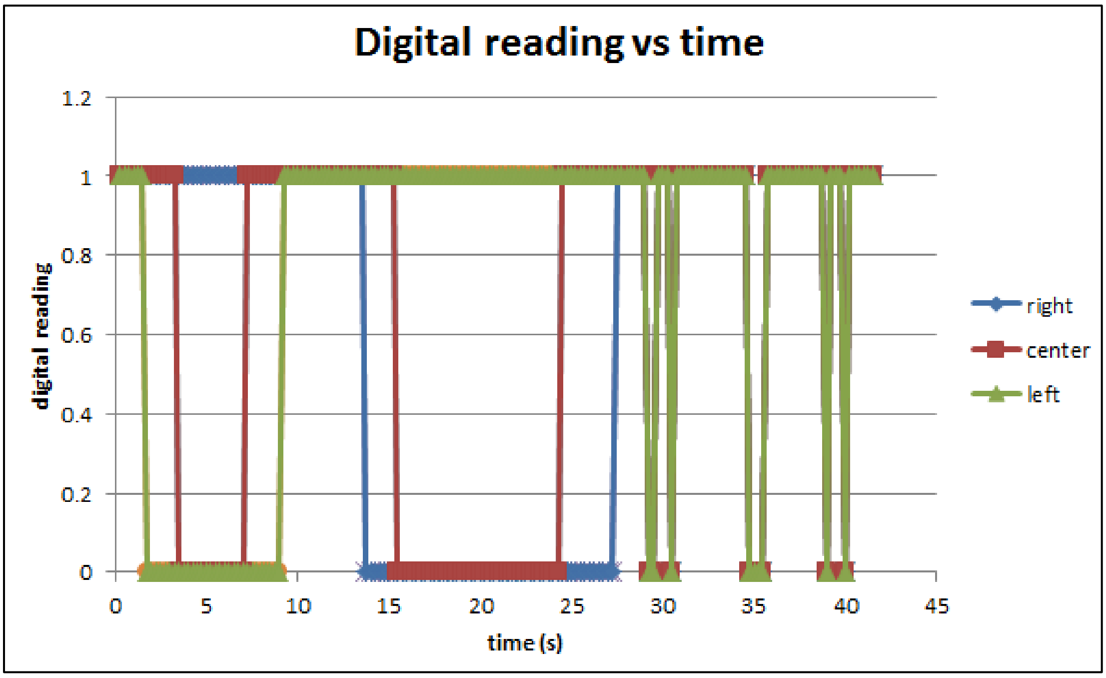


Figure 18: Line graph compilation of all sensors in digital reading.

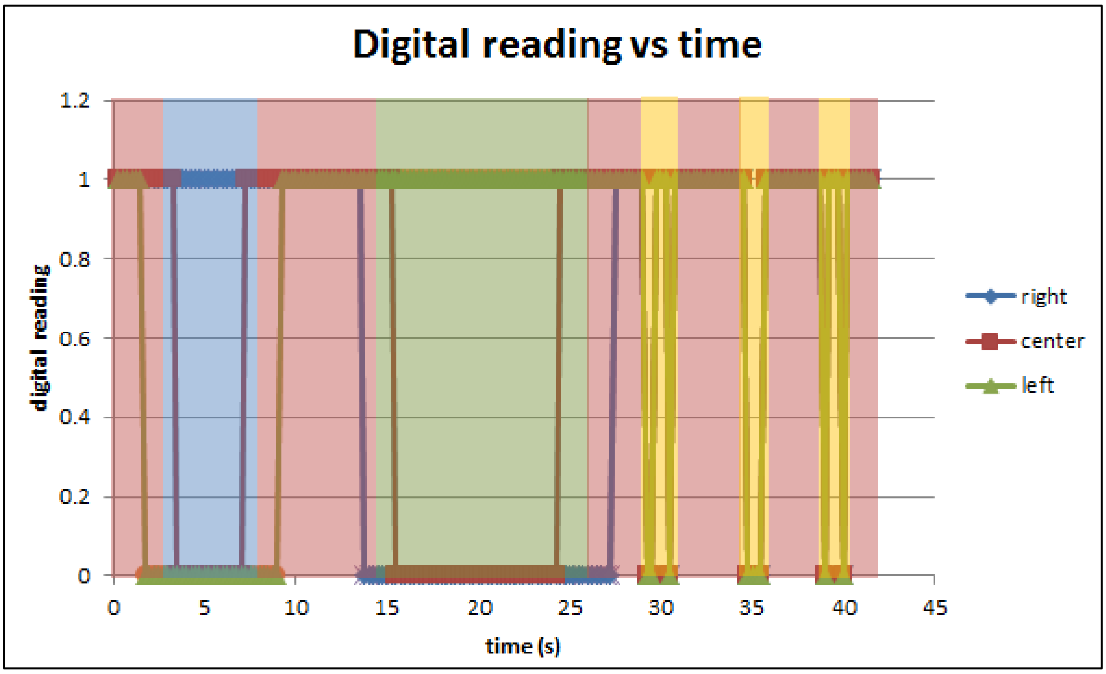


Figure 19: Analyzed line graph in digital reading.

From these line graphs, there are three colors of lines which are blue, red and green. Each of these colors represents right, center and left sensor respectively. The individual line graph (Figure 15) seem simpler compared to the line graph compilation. But, an individual line graph is useless without any support from other individual line graph since eye movement and eye blinks detection require integration between these three infrared sensors. Thus, the line graph compilation is providing more useful information even though it seems more complicated and hard to analyze. Based on analyzed line graph (Figure 17 and 19), there is highlight section which is in blue, red, green and yellow color. These colors represent detection in right position, center position, left position and eye blinks respectively. For example, based on analyzed line graph in digital reading (Figure 19), the result shows that the fake eye in center position during the beginning of the test. Then, it has been rotated to right position for a few seconds before it went back to the center position. The fake eyeball is positioned to the left at 15 to 25 second. Then, eye blink has been performed during 30, 35 and 39 second.

- **Experiment on Actual Human Eye**

Meanwhile for experiment on actual eye, the result is not really impressive since no detection obtained either in digital or analog reading which can be seen in Figure 20. This problem is suspected came from low reflected infrared light intensity after reflection on iris. Thus, infrared sensor cannot detect any signal due to infrared light intensity below the sensor requirement. Thus, modification is required to solve the suspected problem.

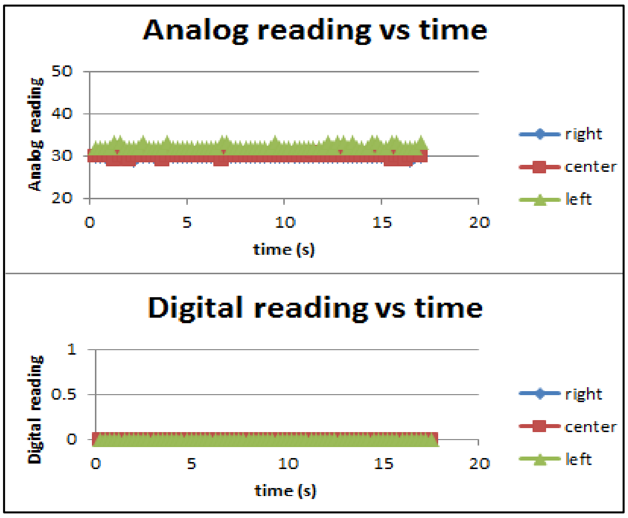


Figure 20: Experiment result on actual human eye.

## 4.2 Discussion

Based on the experience of handling the project, there are some important points that need to be focused. These points are essential in order to improve project performance. During the infrared electronic circuit assembly activity, there is a situation where infrared emitter and sensors become less efficient. This problem happens when the infrared sensors only can detect projected infrared light in very short distance. The root cause of the problem is come from soldering activity of the emitter and sensors. The heat from soldering activity can damage the emitter and sensors since these electronic components are sensitive with high temperature. Thus, new type of connector has been chosen to replace soldering method.

Besides that, the infrared electronic circuit also has some difficulty regarding on the power supply. Since this circuit consists of two parts which are IR emitter circuit and IR sensor circuit, both of it requires different voltage to operate. For sensor circuit, it is only require 5V to operate the sensor system. This amount of voltage can be supplied from the Arduino board. The reason of choosing 5V is to ensure that the digital signal can be performed since Arduino board will indicate 0 signal if the detected voltage less than 5V and 1 signal if the detected voltage is more than 5V. Meanwhile, for the emitter circuit, the voltage that needs to supply is 9V. The relevancy of the decision is to increase infrared light projection length. The projection length of 9V is greater compared to 5V. Thus, 9V of power supply is suitable for the emitter circuit.

Based on the reflection test, it is understandable that infrared sensors are required to have correct reflection angle. According to Castro, this angle is really sensitive in order to gain accurate result. Moreover, after infrared light has been reflected, the projection distance become shorter than actual where 90mm of projection length will become 25mm only. Thus, the infrared emitter and sensors need to be positioned close to the subject eye and the distance must be less than 25mm. In addition, the reason not to use powerful infrared emitter for the prototype is to minimize as low as possible the infrared hazard toward human eyes and it is safe to be used on during experiment. The detail hazard regarding on infrared projection toward human eyes can be referred in section 1.4.

Regarding on the experiment activities, positive result is obtained for the experiment on fake eye. But, when the prototype is tested on actual human eye, no detection is gained due to low reflected infrared light intensity problem. The infrared light loss huge amount of its intensity during reflection on iris. Besides that, the angle of reflection on actual eye become complicated since the flat iris is located behind the convex lens. Thus, the reflection angle is more difficult compared to any flat or sphere surfaces. By having correct angle position of the sensor, better infrared light intensity can be captured and the clearer signal can be gained. The illustration of light reflection on eye can be referred to Figure 21.

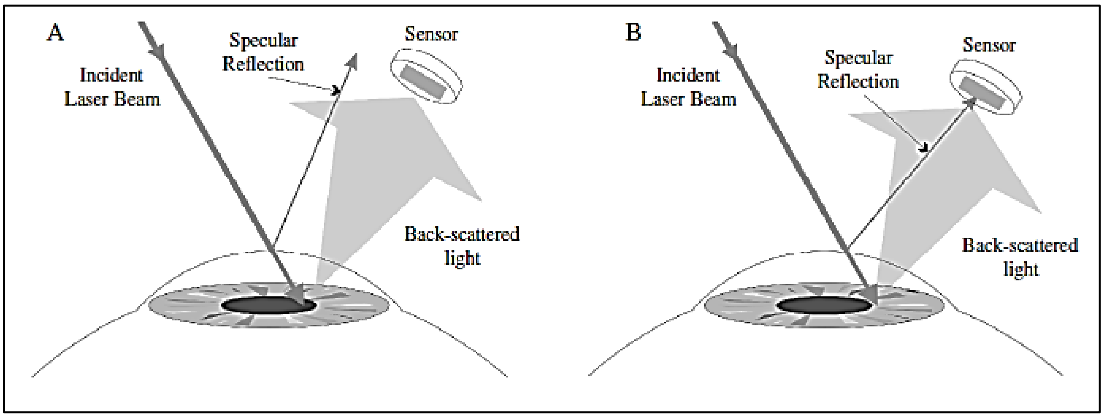


Figure 21: Diagram demonstrating (A) how specular reflection occurs and (B) how certain angles of incidence cause specular reflection to directly impose on a sensor (Irie, Wilson, & Jones, 2002)

# CHAPTETR 5
# CONCLUSION AND RECOMMENDATION

## 5.1 Conclusion

The design and fabrication of the prototype by using infrared oculography method has been achieved. But it still requires a few modifications in order to fit with very sensitive eye movement and eye blink detection. The detail study on infrared reflection angle and reflected infrared light intensity are to be focused. By having correct mechanism of eye movement and eye blink detection, this prototype is potential to be expended to other fields such as medical, psychology or any application that requires this kind of interaction within a system.

## 5.2 Recommendation for Future Work

In order to overcome low infrared light intensity problem, amplifier system can be applied to the infrared sensor in order to amplify weak signal. Thus, small changes of movement is potentially be detected by the sensor. Moreover, the amplifier system should be installed with filter system due to reduce threshold problem.

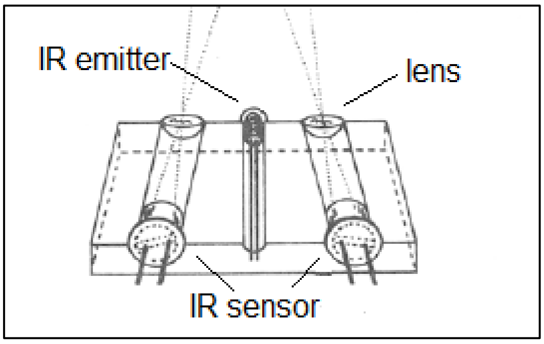


Figure 22: Applying lens to infrared sensor (Young, 1975).

Regarding on infrared light reflection angle, it can be improved by performing detail study on the reflection characteristic. Furthermore, proper structure of sensor stand also helps to obtain accurate angle easily. Due to reduce the difficulty to find very accurate reflection angle, a small lens can be applied in front of the sensors (Young, 1975) in order to concentrate more infrared light intensity toward the sensor. The position of the lens can be referred at Figure 22.

# REFERENCES

Castro, F. L. (2008). Class I Infrared Eye Blinking Detector. *Sensors and Actuators A: Physical*, 388-394.

Goussard, Y., Martin, B., & Lawrence, S. (1987). A New Quantitative Indicator of Visual Fatigue. *BIOMEDICAL ENGINEERING, VOL. BME-34, NO. 1,*, 23-29.

Gu, J., Meng, M., Cook, A., & Liu, P. X. (2002). Using Biomedical Signal to Detect Natural Eye Movement and to Control Artificial Ocular Implant. *IFAC Publications*, 307-311.

Irie, K., Wilson, B. A., & Jones, R. D. (2002). A laser-based eye-tracking system. *Behavior Research Methods, Instruments, & Computers*, 561-572.

Iwamoto, K., Katsumata, S., & Tanie, K. (1994). An Eye Movement Tracking Type Head Mounted Display for Virtual Reality System: Evaluation Experiments of a Proto-type System. *IEEE International Conference* (pp. 13-18). Texas: Systems, Man, and Cybernetics.

Landolt, O. (2008, January 15). *Visual sensors using eye movements.* Retrieved February 28, 2012, from Koch Lab publications: http://papers.klab.caltech.edu/271/

Paisley, R. (2010, March 7). *Basic Visible and Infrared Light Detectors*. Retrieved May 20, 2012, from COGECO: http://home.cogeco.ca/~rpaisley4/PhotoDetectors.html

Quartz, S. R., Stensmo, M., Makeig, M. S., & Sejnowski, T. J. (1995). *Eye Blink Rate as a Practical Predictor for Vigilance.* San Diego: Society for Neuroscience.

Selker, T., Lockerd, A., & Martinez, J. (2001). Eye-R, a Glasses-Mounted Eye Motion Detection Interface. *Interactive Posters*, 179-180.

Shi, X., Qu, X., Mi, W., & Chang, D. (2011). Study on index of visual fatigue of VDT work. *IEEE International Conference* (pp. 9-12). Wuhan: Computing, Control and Industrial Engineering (CCIE).

Timothy, C. H. (2011, December 13). *Eye Movement Recording Devices*. Retrieved April 23, 2012, from dizziness-and-balance.com: http://www.dizziness-and-balance.com/practice/eyemove.html

Yarbus, A. (1967). *Movements of The Eyes.* New York: Plenum Press.

Young, L. R. (1975). METHODS & DESIGNS: Survey of eye movement recording methods. *Behavior Research Methods & Instrumentation*, 397-429.