Development of a Wearable Humidifier for the Eyes

by

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Dissertation submitted in partial fulfilment of
the requirements for the
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CERTIFICATION OF APPROVAL

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A project dissertation submitted to the

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Approved by,

(AP Dr Nor Hisham Hamid)

UNIVERSITI TEKNOLOGI PETRONAS

TRONOH, PERAK

May 2014

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.

NG KOK SHOON

ABSTRACT

Dry eye has become a common and chronic eye disease in the society especially in older adults. Dry eye symptoms are caused by insufficient amount of tears to lubricate and moisture the eye. People experiencing dry eye may feel irritated, scratchy, pain and redness of the eye. Dry and windy conditions, insufficient blinking and long term wear of contact lenses are among the main causes of dry eye symptoms. The most common supplement for natural tears production is the preservative-free artificial tears solution and eye drops. Problem arise when these conventional methods does not cure dry eye effectively as it is inconvenient for older people with constraint hand movement to apply the eye drop periodically in specific time period. Therefore, this project is carried out to understand the dry eye disease and to provide a better solution for the dry eye disease by developing a wearable eye humidifier to increase small area humidity level in proximity to the eye. The project development is breakdown into stages to design and develop the ultrasonic transducer, drive circuit, solenoid valve, Arduino microcontroller, timer circuit and water tank to be integrated into a working prototype model. The ultrasonic transducer converts water droplets into mist particles and the solenoid valve is used to control the flow of water. The Arduino microcontroller provides timing control for the humidification process. With the wearable eye humidifier prototype model, testing are carried out on three different session a day which is morning, afternoon and night to determine the suitable timing interval for the humidification process to take place. From the testing, the suitable timing interval for the humidification process is 1 hour 30 minutes interval in the afternoon session and 2 hours interval for the morning and night session. The wearable eye humidifier is able to increase small area humidity level in proximity to the eyes and thus provide a better solution for dry eye disease.

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CHAPTER 1

INTRODUCTION

1.1 BACKGROUND OF STUDY

Dry eye occurs when there are insufficient amount of tears to lubricate and moisture the eye. In medical term, dry eye is known as keratitis sicca, which means depletion in quantity and quality of tears on the surface of the eye. Keratoconjunctivitis sicca term means the dryness of the eye that affects the cornea and conjunctiva of the eye [1].

Tears are essential to maintain a good eye health. Each time the eyes blinked, tears are spread across the cornea, the front surface of the eye. Tears provide lubrication, clean the eye from foreign matters, moisturize the eye and provide clear vision. Tears are made up of three layers which are oil, water and mucus. The outer oily lipid layer is produced by meibomian glands which help to prevent evaporation of the water layer. The middle watery lacrimal layer is produced by lacrimal glands. The inner mucous layer is produced by goblet cells which function in spreading the tears evenly over the surface of the eye [2]. Dry eye symptoms may develop when the tears evaporate too quickly and are not evenly spread across the cornea due to the deficiencies of any of the three tear layers.

People experiencing dry eye may feel irritated, gritty, scratchy, pain and redness of the eye. Besides, the dry eye symptoms may include series of excess tears and series of very dry eye, blurred vision and also low tolerance of reading, facing the computer or any visual attention activities. Advanced dry eye may damage the cornea and caused impaired vision. Elderly people are more prone to dry eye, but nowadays dry eye can occur at any age [3]. According to National Eye Institute, nearly five million Americans aged 50 years and older are estimated to have dry eye [4]. Women are more likely to develop dry eye due to hormonal change during pregnancy and menopause.

Dry eye symptoms could be caused by effects of medications such as antidepressants, high blood pressure medicine and Parkinson's medicine, and also because of the dry and windy conditions. Air conditioning and dry heating system can make the eye feel dry. Insufficient blinking for a long period of time when facing the computer screen also caused dry eye. Long term contact lens wearers are also common victim of dry eye disease [5].

The main approaches used to reduce and treat dry eye are adding tears, conserving tears and increasing tears production. However, there are methods to reduce the dry eye symptoms including drinking plenty of water, blink regularly when starring at computer screen for long period, increase the level of humidity in the air at work and at home. People are also advised to wear sunglass outdoors and consume nutritional supplements containing fatty acid to decrease dry eye. The purpose of this study is to understand the dry eye disease and develop a personal eye humidifier to maintain the moisture of the eye in order to reduce the dry eye symptoms.

1.2 PROBLEM STATEMENT

Dry eye is a common and chronic disease, especially in older adults. In addition to the pain of dry eye, dry eye limits and decrease the performance of common visual-related activities, decrease work productivity, affects the quality of life and impact on mental and general health. Optometrist often prescribes treatment to maintain the health of the eye. The most common prescriptions are preservative-free artificial tear solutions and eye drops as supplement for natural tears production.

Problem arises when the available artificial tear solutions and eye drops are not able to solve the dry eye symptoms effectively. It is not easy and convenient for older adults with dry eye to apply the eye drops periodically according to specific period of time, especially those with constrained or weak hand movement. Besides, human nature tends to be lazy to apply eye drops continuously throughout the whole day and sometimes when people are busy; they will tend to forget the routine. On the other hand, children do not know how and when to apply the eye drops without the help from older adults.

1.3 OBJECTIVES

The objectives of this project are:

i. To study and understand the dry eye disease
ii. To review on different ways to humidify the human eye
iii. To develop a personal humidifier to increase small area humidity level in proximity to the eye
iv. To analyze and evaluate the characteristics of the humidifier

1.4 SCOPE OF STUDY

The project is performed to achieve the above objectives. The first objective of this project is to study and understand the dry eye disease. Research are done to gain understanding on the dry eye disease, tears production of human eye, causes of dry eye, symptoms of dry eye and also the available treatment for dry eye. By having a clearer understanding on the disease, a suitable treatment method which is the personal eye humidifier could be developed. Before the eye humidifier is developed, the second objective of this project is to review on different ways to humidify the eye. Researches are done to study on the different operating mechanisms of the conventional air humidifiers in the market to be used in the project.

The third objective of the project is to develop a personal humidifier to increase small area humidity level in proximity to the eye. An air humidifier model is build and tested to produce the mist for eye moisturize. Ideas and designs for the eye humidifier are then generated to select the best design for the project. The electronic circuit controller is designed to control the timing and amount of mist channeled to the eye for humidification. The final objective of the project is to analyze and evaluate the characteristic of the humidifier. Humidity tests will be conducted to investigate the relationship between the amount of mist sprayed and the humidity level of the eye. Based on the data collected from the testing, analysis and discussion can be made to determine the suitable timing and amount of mist for the eye humidification purpose. This project is feasible and relevance to be carried out within the given time frame.

CHAPTER 2

LITERATURE REVIEW

2.1 HUMIDIFICATION SYSTEM

Humidity is the amount of water vapor in the air. Water vapor is the gaseous state of water. There are three main measurements of humidity which are absolute humidity which is the water content in the air, relative humidity which is the measure of absolute humidity relative to the maximum for that temperature and specific humidity which is the ratio of water vapor to the total air content. Humidification is the process of adding moisture to the air. Based on the Indoor Air Quality (IQA) standards, the need for effective humidification control of both industrial and commercial indoor space have increased. According to the ASHRAE Standard 62-1989, relative humidity in habitable spaces should be maintained between 30% and 60% [6]. In today's world of technology, there are many different types of humidifier available to increase the humidity level. Among the popular humidifier systems are steam system, evaporative system, spray nozzle system and ultrasonic system [7].

Steam humidification system is also known as vaporizer, which boils water and release the steam to moisture into air. The process is done with an electronic heating element and an evaporation space [8]. This humidification method is the simplest and least expensive. However, the boiling of water requires huge amount of energy consumption and the heating element are noisy and dangerous. Evaporative humidification system operates by soaking the wick with water from the reservoir to provide large surface are to evaporate from. A fan is needed to draw air into the wick and help with water evaporation. The water evaporates based on relative humidity according to self-regulating principle, when the room humidity decrease, the water vapor increase [9]. However, this humidification system requires frequent replacement of the wick and the fan operation could be very noisy.

The spray nozzle humidifier system typically uses high pressure water or compressed air and water to force through a nozzle. Heating elements are also used to convert water to vapor. The size of the vapor varies according to the pressure variation. This humidification method is simple; however, it is not suitable for the personal eye humidifier project as it requires multiple nozzles and produce inconsistent amount and size of vapor. The ultrasonic humidification system converts water into fine mist particles by using piezoelectric resonators [10]. These resonators apply high frequency vibration energy in perpendicular direction to the surface of the resonators into the water to produce the mist particles. The fine mist particles are channeled out by fan for humidification. Ultrasonic humidifier is very quiet, produces constant fine mist particles and is able to achieve ideal humidity in a very short time [11]. However, it is advisable to use distilled water to prevent white dust.

Table 1: Comparison of Humidifier Systems

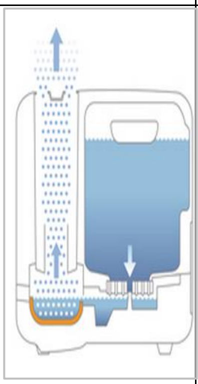
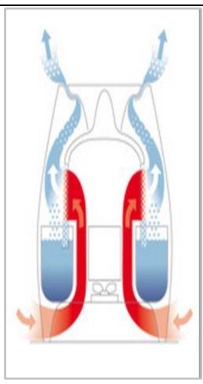
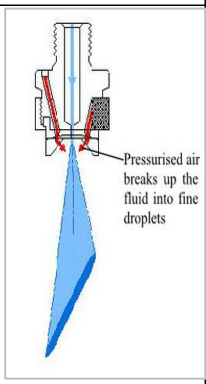
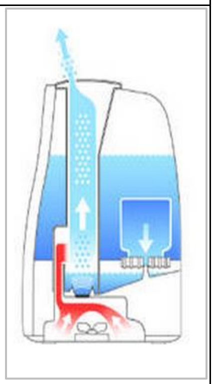
	Steam	Evaporative	Spray Nozzle	Ultrasonic
Figure	 Figure 1: Steam Humidifier [8]	 Figure 2: Evaporative Humidifier [9]	 Figure 3: Spray Nozzle Humidifier [7]	 Figure 4: Ultrasonic Humidifier [11]
Advantage	-Simple -Cheap	-Self regulating	-Simple	-Quiet -Produce fine mist particles - Efficient
Disadvantage	-High energy consumption -Noisy -Dangerous	-Frequent wick replacement - Noisy	-Inconsistent size and amount of vapor	-Require use of distilled water

Table 1 above shows the comparison of the humidifier systems. From the comparison, the ultrasonic humidifier system is the most suitable system for the personal eye humidifier. This is because it has a quiet operating system, produce fine mist particles and efficient in achieving ideal humidity which are important factors in the development are of eye humidifier.

2.2 PERSONAL HUMIDIFIER

Technological advancement of today’s world enables much chronic disease such as dry eye to be cured and prevented. Many personal humidifiers are available in the market, however only few are specifically for humidification of eye.

In 2003, Sharon Kleyne and Bio Logic Aqua Research announced the product, Nature’s Tears Eye Mist, the first ever personal, hand-held humidifier that releases 100% of fresh water mist around the eye [12]. This is to supplement the natural tear film water due to dry eye disease and dehydrating environment. This product however still requires manual hand movement to spray the fresh water mist around the eye. Kleyne discovered that eye discomfort or allergies are caused by the surface water loss of the tear film due to evaporation and other elements such as salt, lipids, antibodies and proteins are normally unaffected. Therefore, 100% of fresh water will be used for the personal eye humidifier project to cure and prevent dry eye disease. Figure 5 shows the Nature’s Tears Eye Mist.

Figure 5: Nature's Tears Eye Mist [12]

Meanwhile in late 2007, Kelvin Chan invented a wearable self-contained personal humidifier as shown in Figure 6 to improve wearer's breathing air and to provide humidification for wearer's facial skin [13]. This invention uses conventional evaporative humidification system where ambient air is drawn into the device and flow through a water filled sponge. Once the air passed through the sponge, the mounted fan pulls the humidified air out to the users.

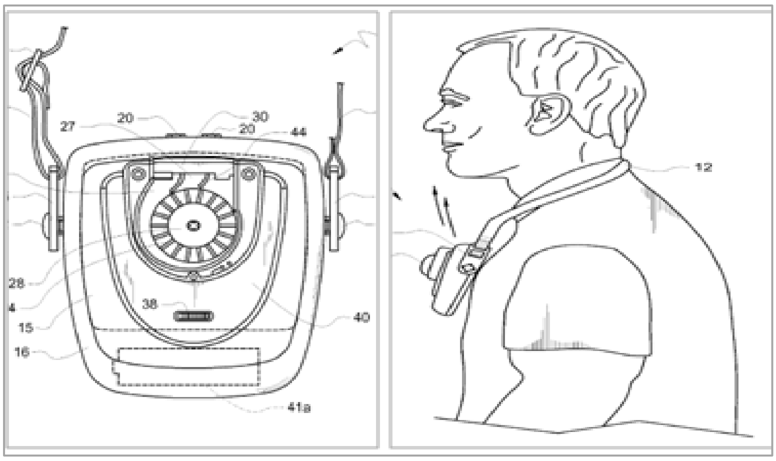


Figure 6: Wearable Self-Contained Personal Humidifier [13]

CHAPTER 3

METHODOLOGY

3.1 RESEARCH METHODOLOGY

Figure 7 below shows the research methodology for the project

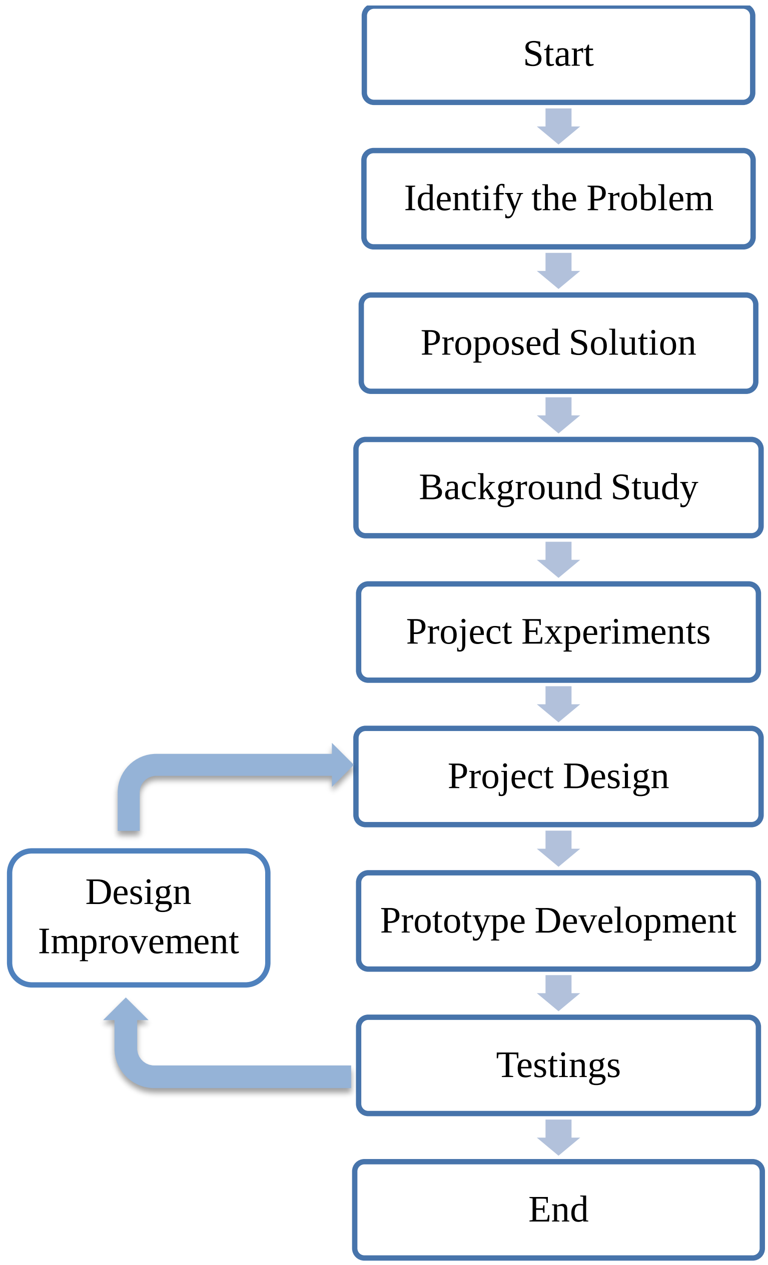


Figure 7: Research Methodology

3.2 PROJECT ACTIVITIES

Figure 8 below shows the project activities based on the research methodology above.

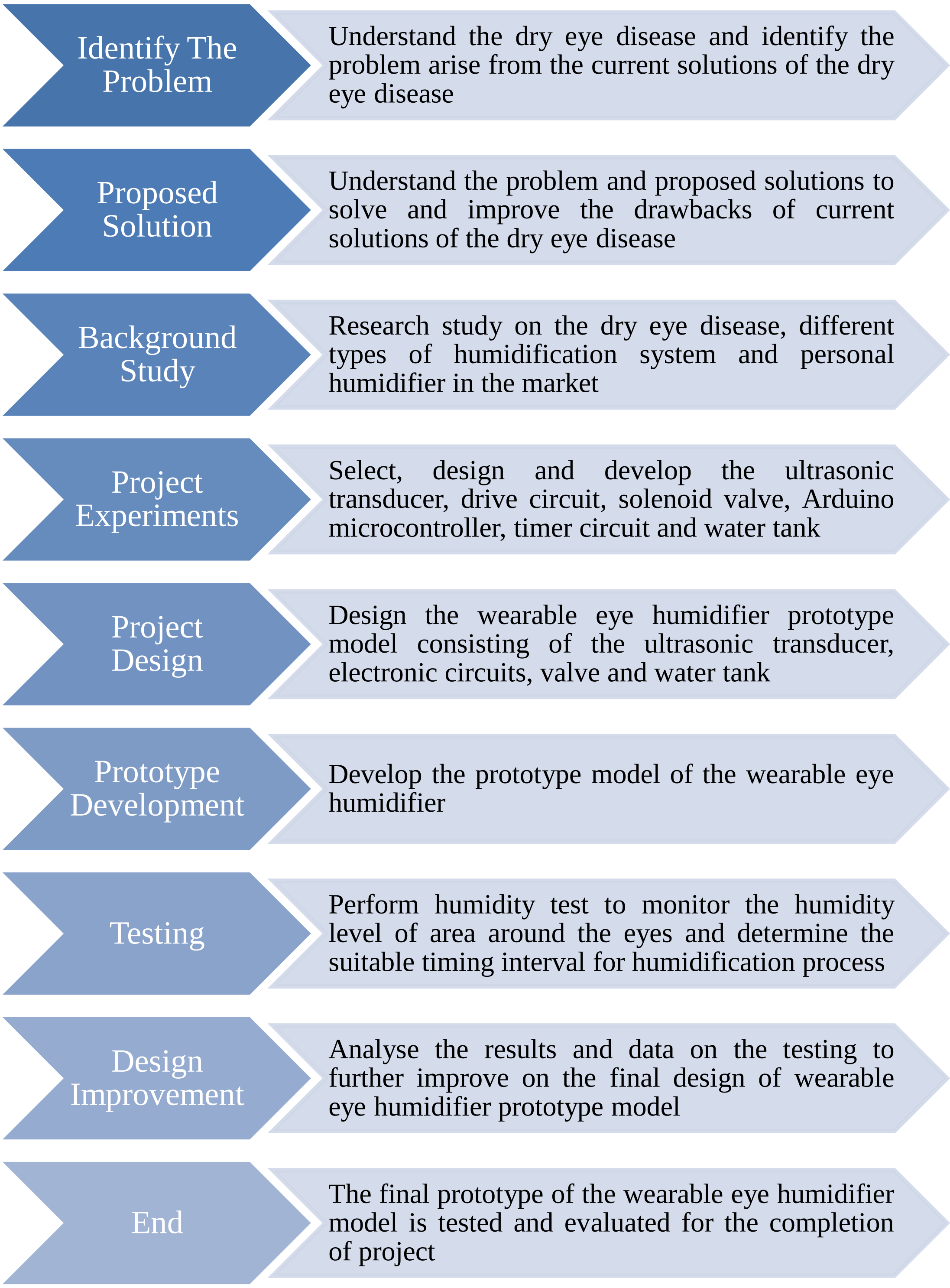


Figure 8: Project Activities

3.3 KEY MILESTONES

The key milestones in the project are divided into two aspects:

i. FYP Key Milestones
ii. Project Key Milestones

In FYP I, the FYP key milestones are the submission of extended proposal, proposal defense, submission of interim draft report and interim report. The first project key milestone is the literature review where a complete research study on the dry eye disease, air humidifier operating mechanism and personal humidifier was done. The next key milestones are the design of the portable ultrasonic humidifier and the development of the ultrasonic humidifier. The portable ultrasonic humidifier was designed and developed to produce water mist for humidification purpose.

In FYP II, the FYP key milestones are submission of progress report, pre-SEDEX, submission of dissertation (softbound) and technical paper, project viva and also the submission of dissertation (hardbound). As for the project key milestones, the Arduino microcontroller programming was developed to control the timing of the mist humidification. Next, the prototype of the wearable eye humidifier was designed and developed. Once the prototype is developed, the humidity tests are then performed to monitor the humidity level of area proximity to the eye and to determine the suitable timing interval for the humidification process. The next key milestones are the analysis of the data and results for design improvement on the final prototype of the project development.

3.4 GANTT-CHART

Table 2 and Table 3 below show the Gantt-Chart for the development of the project on both FYP 1 and FYP II.

Table 2: FYP I Gantt-Chart

Week number / Progress	FYP I													
	1	2	3	4	5	6	7	8	9	10	11	12	13	14
Topic Selection														
Background Study / Literature Review					🔴									
Submission of Extended Proposal						🟣								
Extended Study on Ultrasonic Humidifier														
Design of Portable Ultrasonic Humidifier								🔴						
Proposal Defence									🟣					
Development of Ultrasonic Humidifier												🔴		
Submission of Interim Draft Report													🟣	
Submission of Interim Report														🟣

🔴 : Key Milestone (Project)

🟣 : Key Milestone (FYP)

Table 3: FYP II Gantt-Chart

Week number / Progress	FYP II													
	1	2	3	4	5	6	7	8	9	10	11	12	13	14
Final Design of Eye Humidifier														
Arduino Microcontroller Programming			🔴											
Prototype Development					🔴									
Humidity Test on Eye Humidifier						🔴								
Submission of Progress Report							🟣							
Results and Data Analysis								🔴						
Design Improvement on Final Prototype										🔴				
Pre-SEDEX										🟣				
Submission of Draft Final Report											🟣			
Submission of Dissertation (Soft Bound)												🟣		
Submission of Technical Paper												🟣		
Project Viva													🟣	
Submission of Dissertation (Hard Bound)														🟣

🔴 : Key Milestone (Project)

🟣 : Key Milestone (FYP)

3.5 TOOLS AND SOFTWARE

Table 4 below shows the function of all the tools and software used in the development of the project.

Table 4: Tools and Software

Tools/Software	Function
Ultrasonic Transducer	To convert water particles into mist particles for humidification process
Solenoid Valve	To control the flow of water
Arduino Microcontroller	To control the timing interval for the opening of the solenoid valve
Humidity Meter	To measure the humidity level
LT Spice Software	To design and analyze the drive circuit
Eagle Software	To design the circuit in PCB design
Arduino Programming Software	To program the Arduino microcontroller

CHAPTER 4

RESULTS AND DISCUSSION

4.1 PROJECT STAGES

The development of the wearable eye humidifier project is breakdown into stages in order to design and build a working prototype. In each stage, experiments and testing are performed in order to determine the most suitable materials and design for the project. Once completed, all the project stages will be integrated to develop a working prototype of the wearable eye humidifier. The breakdown stages of the project are as following:

i. Selection of Ultrasonic Transducer
ii. Ultrasonic Transducer Drive Circuit Design
iii. Selection of Solenoid Valve
iv. Arduino UNO Microcontroller Coding Design
v. Solenoid Valve Timer Circuit Design
vi. Water Tank and Drip System Design

4.1.1 Selection Of Ultrasonic Transducer

Ultrasonic transducer is the most important element of the project as it functions to convert water particles into mist particles for humidification process. Experiments are carried out to test different types of ultrasonic transducer to determine the resonant frequency of the ultrasonic transducer to change water particles into mist particles. Figure 9 shows the waveform generator and oscilloscope used in the experiment. The waveform generator is used to generate output waveform of different frequency and amplitude to be tested on the ultrasonic transducer while the oscilloscope is used to check the output waveform generated by the waveform generator. From the experiments, the ultrasonic transducer which is able to convert water particles into mist particles effectively will selected for project development.

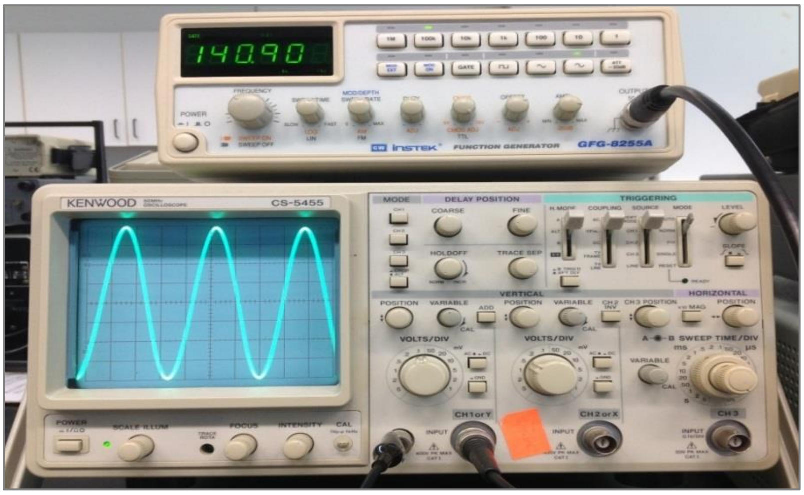
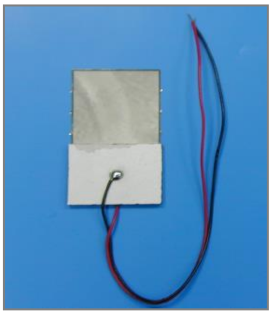


Figure 9: Waveform Generator and Oscilloscope

The experiments are performed with different types of ultrasonic transducer with different resonant frequency and the results are tabulated in Table 5.

Table 5: Ultrasonic Transducer Experiment Results

Types of Transducer	Ultrasonic Transducer 1	Ultrasonic Transducer 2	Ultrasonic Transducer 3
Figure	 Figure 10: Ultrasonic Transducer 1	 Figure 11: Ultrasonic Transducer 2	 Figure 12: Ultrasonic Transducer 3
Resonant Frequency	4 kHz	20 kHz	140 kHz
Amplitude	5 Vp-p	10 Vp-p	16 Vp-p
Results	No mist are produced	No mist are produced	Mist particles are produced

From the results, low frequency ultrasonic transducers 1 and 2 are not able to change water particles into mist particles. Therefore, in order to improve the result and to change water particles into mist particles, a higher frequency ultrasonic transducer 3 which is known as the ultrasonic atomizer transducer is used. With the resonant frequency and voltage amplitude of 140 kHz and 16Vp-p respectively, the ultrasonic transducer is able to converts water droplets into mist particles effectively. Figure 13 shows the mist particles produced by the ultrasonic transducer. Therefore, the ultrasonic atomizer transducer is selected to be used in the project development.

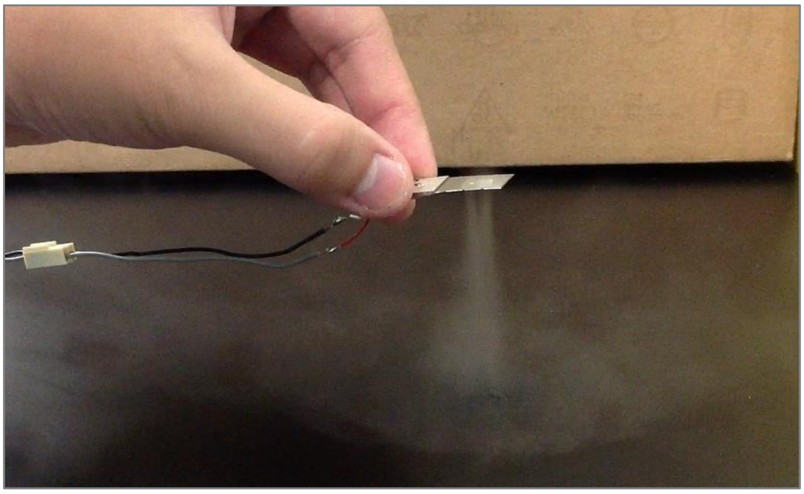


Figure 13: Ultrasonic Transducer Converts Water to Mist Particles

4.1.2 Ultrasonic Transducer Drive Circuit Design

From the experiments conducted, the resonant frequency and amplitude for the ultrasonic transducer to converts water droplets to mist particles are determined. The drive circuit has to be built to drive the ultrasonic atomizer transducer. The drive circuit of the transducer is first designed and simulated by using the LT Spice software to study the behavior of the circuit and to analyze the output of the circuit. Figure 14 shows the simulation of the drive circuit in LT Spice with input voltage (Vin) of 6V DC and the ultrasonic transducer represented by Load.

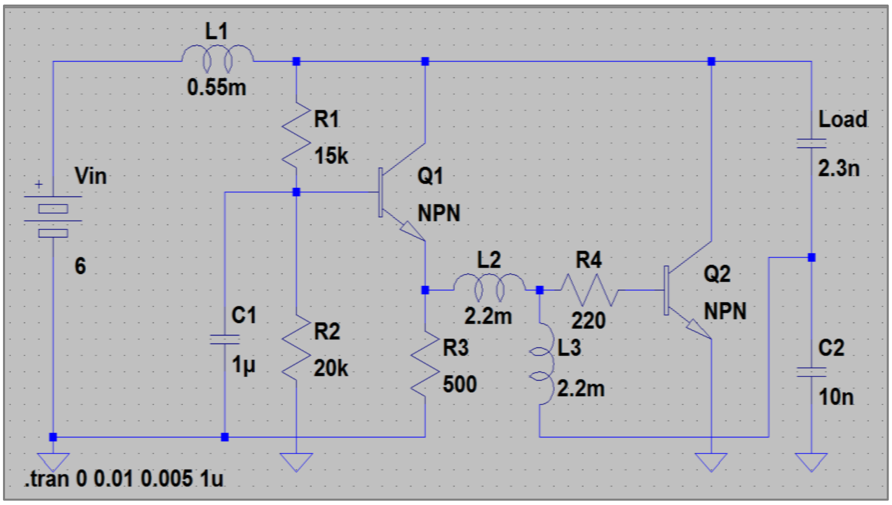


Figure 14: Ultrasonic Transducer Drive Circuit LT Spice Simulation

Figure 15 shows the output waveform generated from the drive circuit at the point of the Load which is the ultrasonic transducer. From the output waveform, the measured resonant frequency amplitude is 16 Vp-p. The resonant frequency of output waveform can be calculated from the period of the one complete oscillation by using the following formula:

$$F = \frac{1}{T} = \frac{1}{7\mu s} = 143\ kHz$$

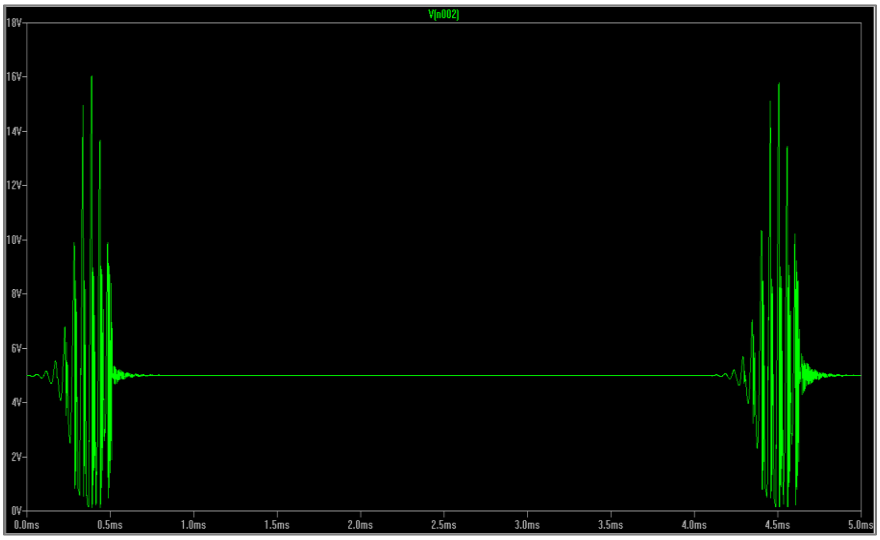


Figure 15: Output Waveform of Drive Circuit

From the LT Spice simulation of the drive circuit, the drive circuit is then build and tested by using breadboard connection. From the breadboard connection, the drive circuit is tested to check if it is able to produce the desired output for the ultrasonic transducer. Figure 16 below shows the breadboard connection of the drive circuit which is tested and able to drive the ultrasonic transducer.

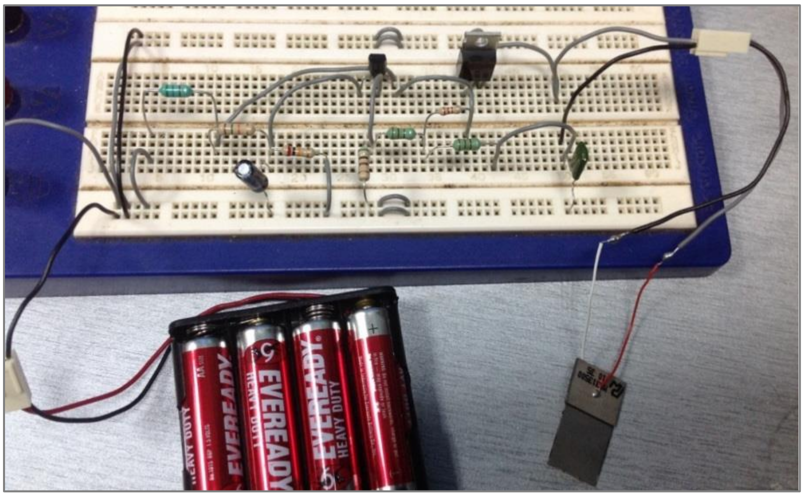


Figure 16: Breadboard Connection of Ultrasonic Transducer Drive Circuit

The drive circuit connection is then designed using the Eagle software to fabricate the circuit in PCB board connection. With the drive circuit in PCB board connection, the circuit is tested and checked again if it is able to produce desired output for the ultrasonic transducer. Figure 17 shows the PCB board connection of the drive circuit which is tested and able to drive the ultrasonic transducer.

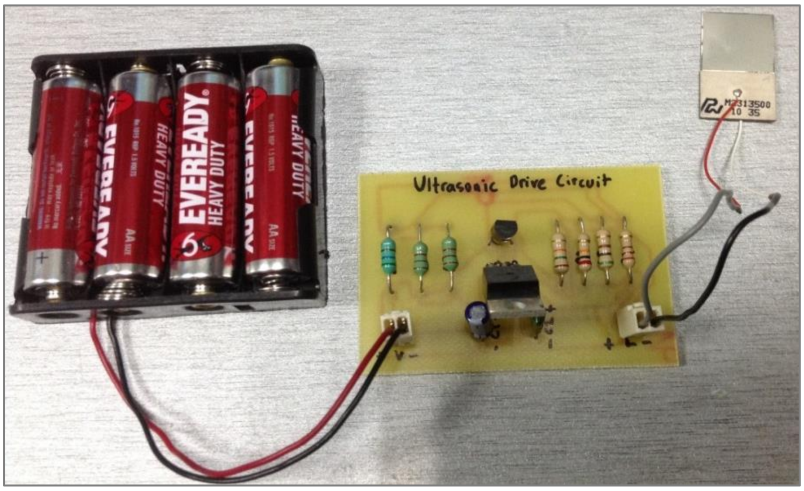


Figure 17: PCB Board Connection of Ultrasonic Transducer Drive Circuit

Further experiments are carried out to study the relationship between the amount of water channeled to the ultrasonic transducer and the amount of mist produced. As the number of water droplet channeled to the transducer increases, the amount of mist produced also increases. Figure 18 shows the graph representation of the amount of mist produced vs the amount of water droplet. The results of this experiments show that the amount of mist produced which is represented by scale (1=low mist produced and 5= high mist produced) is directly proportional to the amount of water droplet channeled to the transducer.

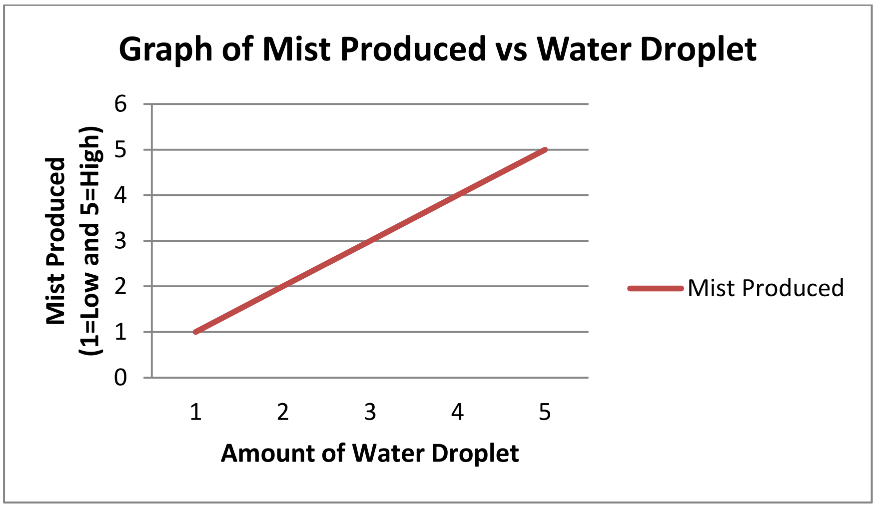


Figure 18: Graph of Mist Produced vs Water Droplet

4.1.3 Selection of Solenoid Valve

Solenoid valve are electromagnets that convert electrical energy to mechanical movement which is used to control the flow of water into the ultrasonic transducer. The opening and closing of the valve control the amount of water being channeled to the ultrasonic transducer. When the valve is open, water is allowed to flow through the valve to the ultrasonic transducer and when the valve is closed, the water is blocked thus prevent the flow of water. The solenoid valve is chosen based on several criteria such as input voltage, operation mode, weight and size. The selected solenoid valve for the project development is on 12V DC input voltage and normally closed mode. Normally closed means the valve is closed when no input voltage is supplied; when voltage is supplied, the valve will open to allow water to flow through the valve to the ultrasonic transducer.

For the project development, the solenoid valve is chosen to be small in size and light in weight to better suits the prototype of a wearable eye humidifier. Figure 19 shows the solenoid valve used in the development of the project.

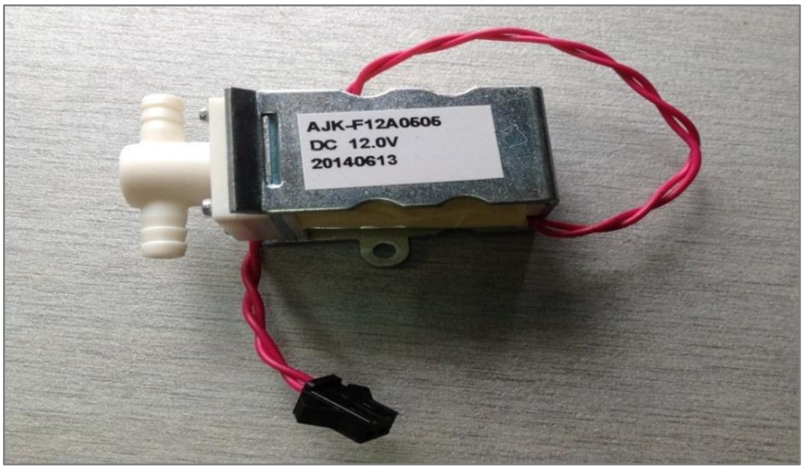


Figure 19: Solenoid Valve

4.1.4 Arduino UNO Microcontroller Coding Design

Arduino microcontroller used in the project development is Arduino UNO. It is used to provide timing control for the opening and closing of the solenoid valve. The programming design of the microcontroller allow the control of the amount of time for the valve to be open and also the amount of time delay before the next valve opening. Figure 20 shows the hardware of the Arduino microcontroller and Figure 21 shows the coding design of the solenoid valve timer.

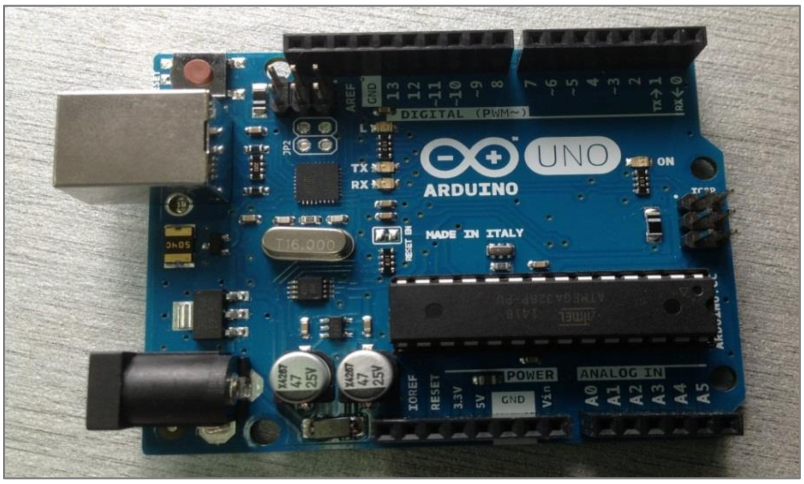


Figure 20: Arduino UNO Microcontroller

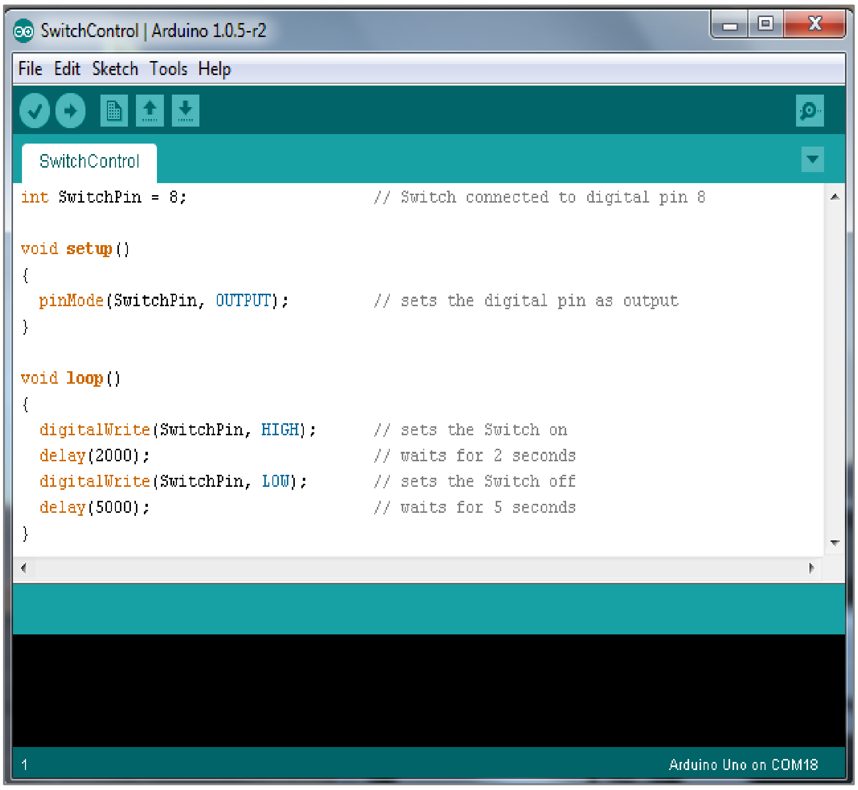


Figure 21: Solenoid Valve Timer Coding Design

The use of Arduino microcontroller allows the time of the valve opening to be varies according to the coding design. From Figure 21, the first delay represent the amount of time for the valve to be open and the second delay represent the amount of time delay before the next valve opening. Testing can be performed with different time variation to determine the suitable time range of the valve opening for humidification purpose.

4.1.5 Solenoid Valve Timer Circuit Design

The Arduino microcontroller has to be connected to a timer circuit to allow it to control the opening and closing of the solenoid valve. The solenoid valve timer circuit is designed by using a transistor (TIP 120) which acts as a switch to activate the solenoid valve. The timer circuit is first designed and builds on a breadboard connection to be tested with both the Arduino microcontroller and solenoid valve. Once the connection is tested, the timer circuit is built on a circuit board for more secure connection. The circuit is then tested again to make sure the connections are functioning correctly.

Figure 22 and Figure 23 shows both the solenoid valve timer circuit tested with Arduino microcontroller and solenoid valve on breadboard connection and circuit board connection respectively.

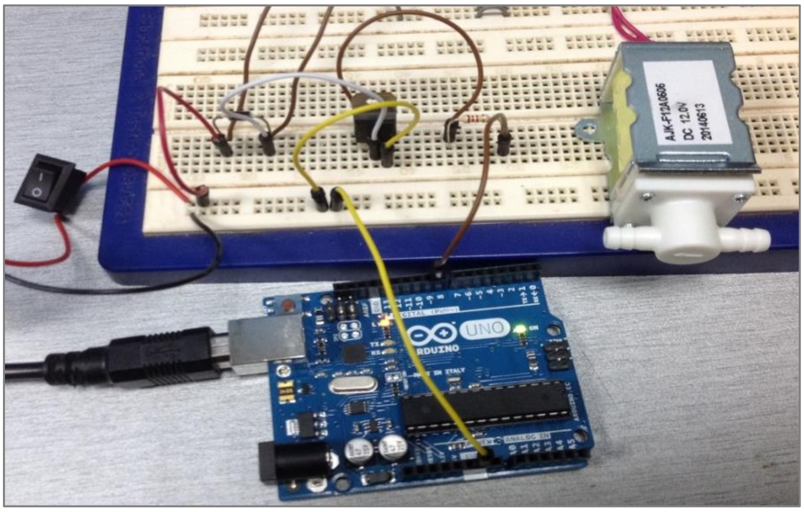


Figure 22: Solenoid Valve Timer Circuit on Breadboard Connection

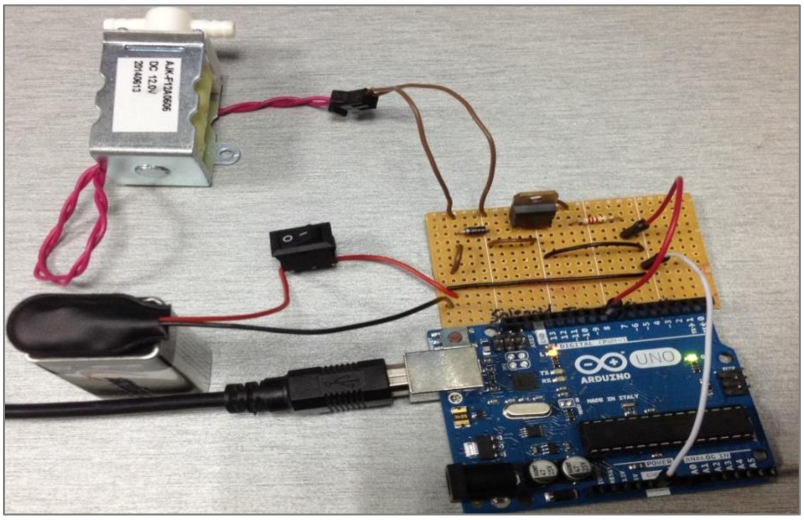


Figure 23: Solenoid Valve Timer Circuit on Circuit Board Connection

The timer circuit is tested and is able to control the opening time of the solenoid valve and also the time delay for the next valve opening. This allows the flow of water to the ultrasonic transducer to be control for the development of the project. Further testing is performed throughout the project development in order to determine the most suitable time for the humidification process to take place.

4.1.6 Water Tank and Drip System Design

Normal distilled water is used for the eye humidification purpose. This water has to be channeled to the ultrasonic transducer for the humidification process to take place. Therefore, a small water storage tank has to be designed with a drip system for the water to be stored and channeled to the ultrasonic transducer. The water storage tank operates by the gravitational force principle where it is placed above the ultrasonic transducer. By using the gravitational force, the water in the storage tank will flow from the tank through the drip tube. The drip tube is then connected to the solenoid valve to control the flow of the water to the ultrasonic transducer for humidification purposes. Figure 24 shows the water storage tank connected to the solenoid valve for the project development.

Figure 24: Water Storage Tank Connected to Solenoid Valve

4.2 PROTOTYPE DEVELOPMENT

The prototype of the wearable eye humidifier is developed by integrating the ultrasonic transducer, drive circuit, solenoid valve, Arduino microcontroller, timer circuit and water tank developed in the project stages. The prototype is designed by using a head strap to hold all the components together and to be wearable. Figure 25 shows the wearable eye humidifier prototype on a model head mannequin.

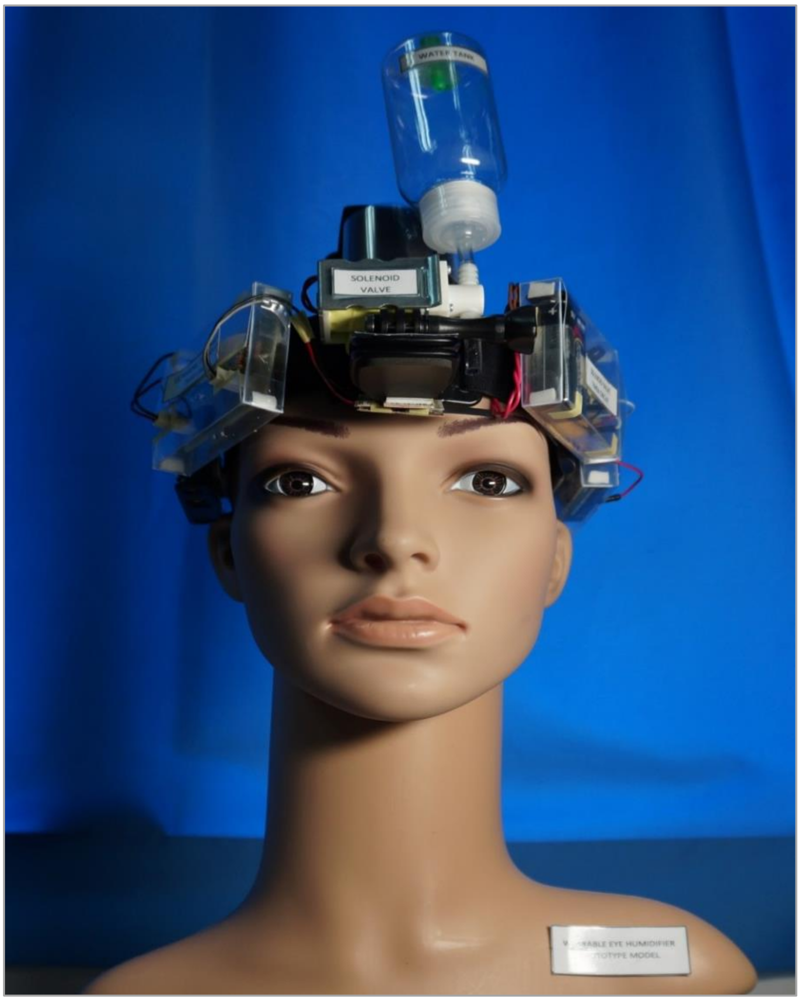


Figure 25: Wearable Eye Humidifier Prototype Model

The prototype model of the wearable eye humidifier is tested to make sure it is functioning according to the project design. The wearable eye humidifier is able to convert water droplets into mist particles according to the programmed time for humidification process on the area around the eyes.

The water tank, solenoid valve and the ultrasonic transducer are placed at the front of the wearable eye humidifier prototype model. The water tank is connected with the solenoid valve to control the flow of water droplets to the ultrasonic transducer which converts water droplets into mist particles. The ultrasonic transducer is position above the eye in order to channel the mist particles and provide humidification to the area around the eye.

On the right side of the prototype, the ultrasonic transducer is connected with the drive circuit and the power source. The drive circuit drives the ultrasonic transducer for humidification process to take place. On the left side of the prototype, the solenoid valve is connected with the timer circuit and the Arduino microcontroller. The Arduino microcontroller and the timer circuit provide timing control for the opening of the valve and the interval for the next valve opening for the humidification process to take place. Figure 26, Figure 27 and Figure 28 shows the front view, right side view and left side view of the prototype model respectively.

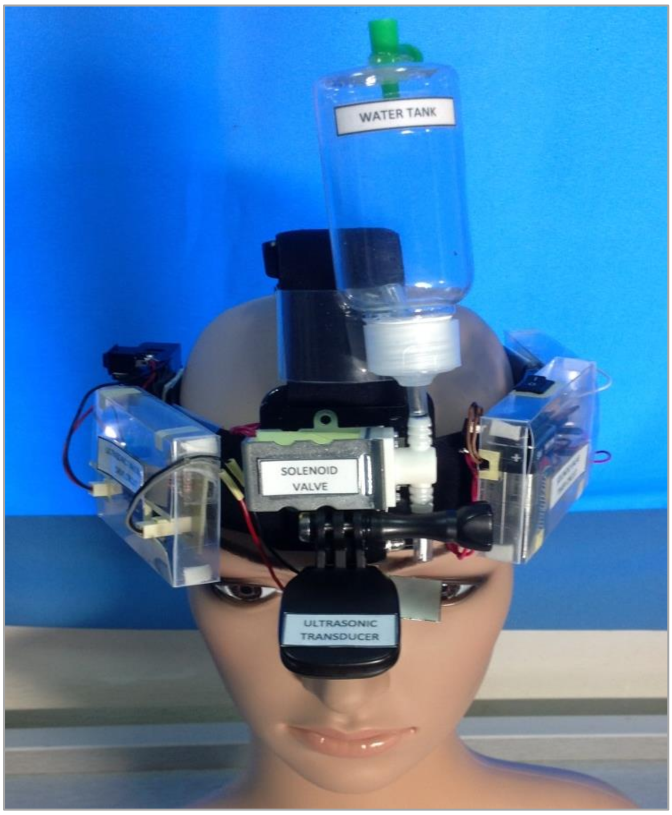


Figure 26: Front View of Prototype Model

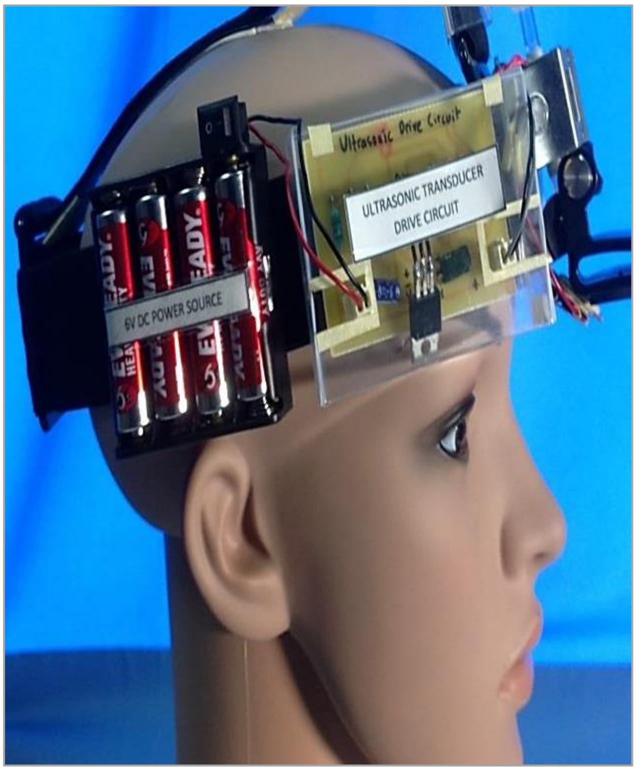


Figure 27: Right Side View of Prototype Model

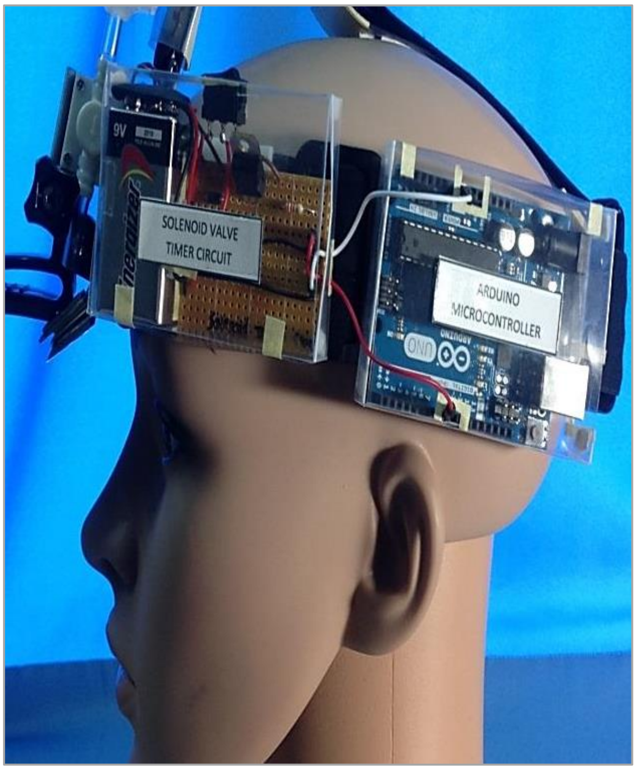


Figure 28: Left Side View of Prototype Model

4.3 EXPERIMENTS AND TESTING

The wearable eye humidifier prototype model is successfully developed and is able to provide humidification process to the area around the eyes. Humidity test is performed by using the humidity meter to measure the humidity level of the area proximity to the eyes. The timing for the humidification process is critical as the eyes will feel discomfort when the condition is too dry or too wet. Therefore, several experiments and testing are carried out to determine the most suitable timing for the humidification process to take place.

Prior to the experiments and testing, a set of one week relative humidity level data are taken from the Malaysian Meteorological Department to determine the average relative humidity level in the morning, afternoon and night. The average relative humidity is taken as the reference humidity level in the experiments.

Table 6: Relative Humidity Data from Malaysian Meteorological Department

Day	Date	Relative Humidity (%)		
		Morning	Afternoon	Night
Monday	28/07/2014	78	53	66
Tuesday	29/07/2014	80	71	87
Wednesday	30/07/2014	88	66	86
Thursday	31/07/2014	85	60	65
Friday	01/08/2014	77	59	63
Saturday	02/08/2014	77	46	58
Sunday	03/08/2014	76	69	70
Average		80	60	70

Table 6 above shows the one week relative humidity data from 28th July 2014 to 3rd August 2014. The average relative humidity for morning, afternoon and night sessions are 80%, 60% and 70% respectively.

The relative humidity data from the Malaysian Meteorological Department shows that the relative humidity differs in the morning, afternoon and night due to the temperature and weather condition. The data of the morning session are taken from time 06:00 to time 12:00 with an average temperature of 26 ℃; the data of the afternoon session are taken from time 12:00 to time 18:00 with an average temperature of 33 ℃ and the data of night session are taken from time 18:00 to time 00:00 with an average temperature of 28 ℃.

The experiments are carried out on three different sessions in a day which is in the morning, in the afternoon and at night to determine the most suitable timing for the humidification process to take place. The time intervals for the experiments are set to be 30 minutes, 1 hour, 1 hour and 30 minutes and 2 hour interval. On each time intervals, the humidity level is measured and compare with the reference humidity level to determine the most suitable interval for humidification process.

4.3.1 Morning Session

i. 30 Minutes Interval

Table 7: Humidity Level on 30 Minutes Interval (Morning)

Time (hour)	Humidity Level (%)
0	78
0.5	83
1.0	85
1.5	89
2.0	91

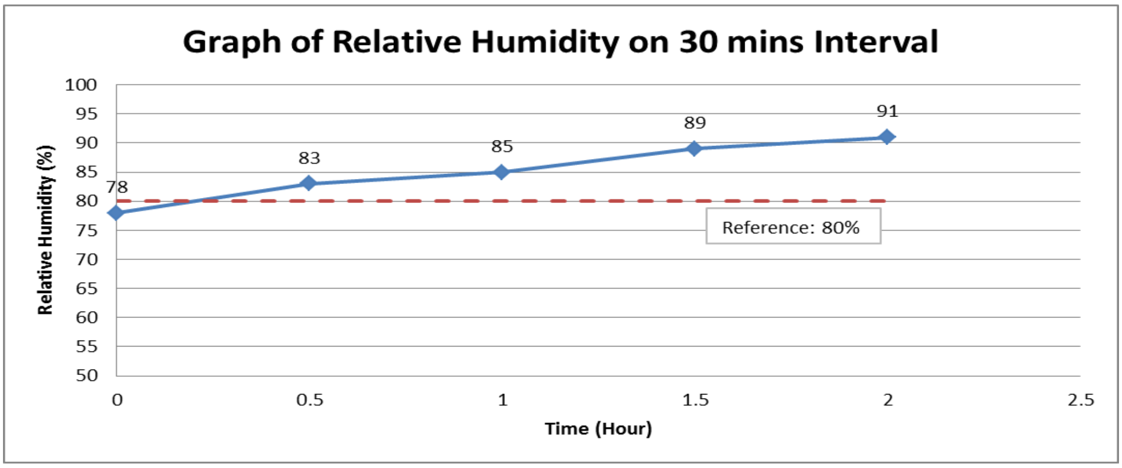


Figure 29: Relative Humidity Graph on 30 Minutes Interval (Morning)

ii. 1 Hour Interval

Table 8: Humidity Level on 1 Hour Interval (Morning)

Time (hour)	Humidity Level (%)
0	78
1.0	82
2.0	86
3.0	87
4.0	87

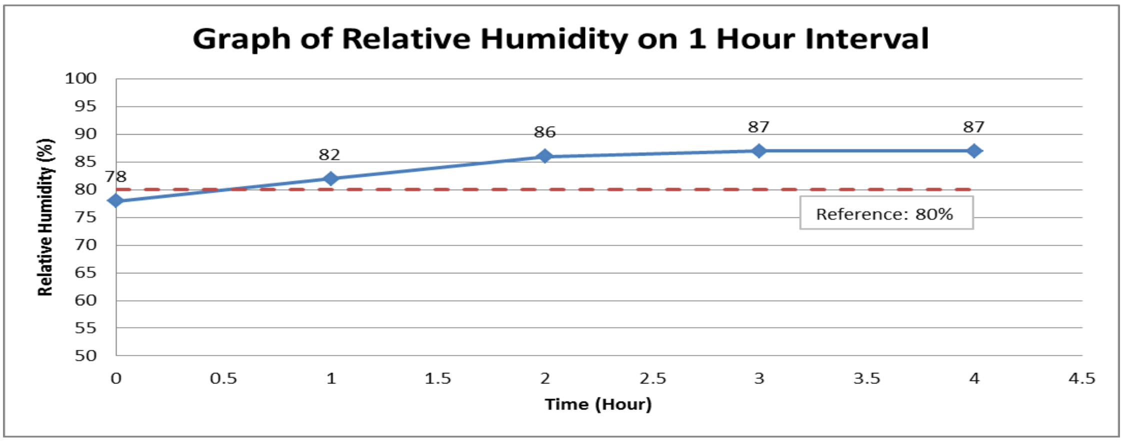


Figure 30: Relative Humidity Graph on 1 Hour Interval (Morning)

iii. 1 Hour 30 Minutes Interval

Table 9: Humidity Level on 1 Hour 30 Minutes Interval (Morning)

Time (hour)	Humidity Level (%)
0	77
1.5	80
3.0	82
4.5	85
6.0	86

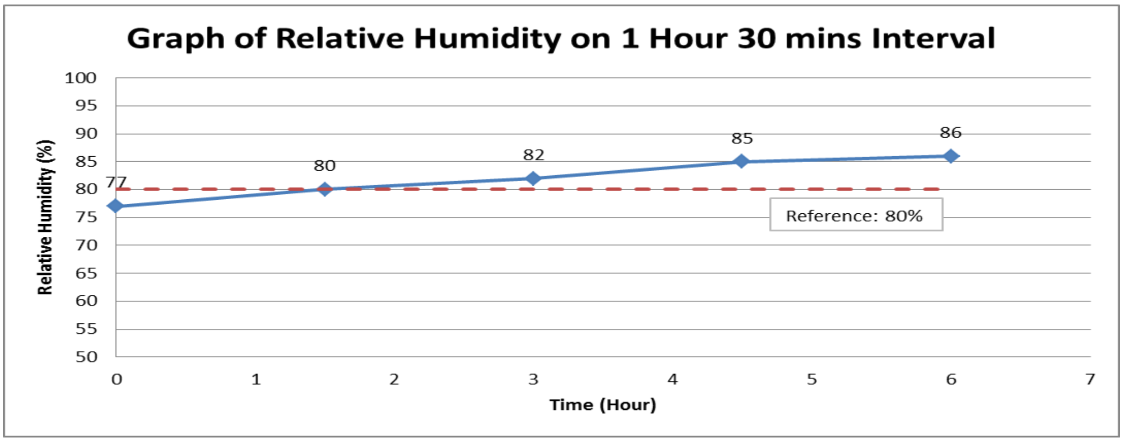


Figure 31: Relative Humidity Graph on 1 Hour 30 Minutes Interval (Morning)

iv. 2 Hours Interval

Table 10: Humidity Level on 2 Hours Interval (Morning)

Time (hour)	Humidity Level (%)
0	77
2.0	79
4.0	81
6.0	81
8.0	82

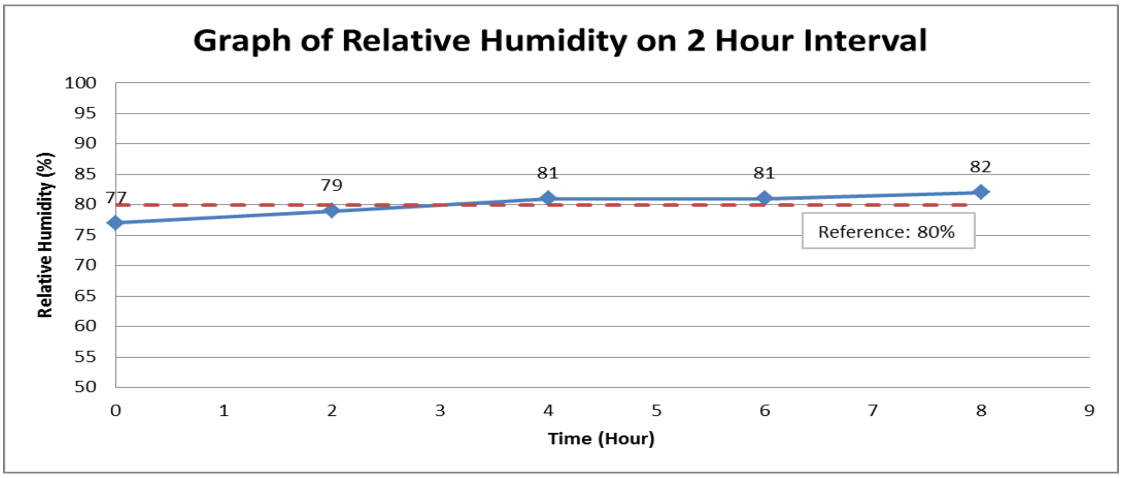


Figure 32: Relative Humidity Graph on 2 Hours Interval (Morning)

For the results in the morning session, the relative humidity graph of each time intervals are shown in Figure 29, Figure 30, Figure 31 and Figure 32 respectively. On time intervals of 30 minutes, 1 hour and 1 hour 30 minutes, the relative humidity increases above the reference humidity level of 80%. These conditions make the area proximity to the eyes feel wet and humid which are not suitable for the eyes. On time interval of 2 hours, the relative humidity increases and maintain on the reference humidity level. This condition is able to provide a suitable humidification for the eyes. Thus, in the morning, the most suitable timing interval for the humidification process is 2 hours.

4.3.2 Afternoon Session

i. 30 Minutes Interval

Table 11: Humidity Level on 30 Minutes Interval (Afternoon)

Time (hour)	Humidity Level (%)
0	57
0.5	61
1.0	65
1.5	68
2.0	70

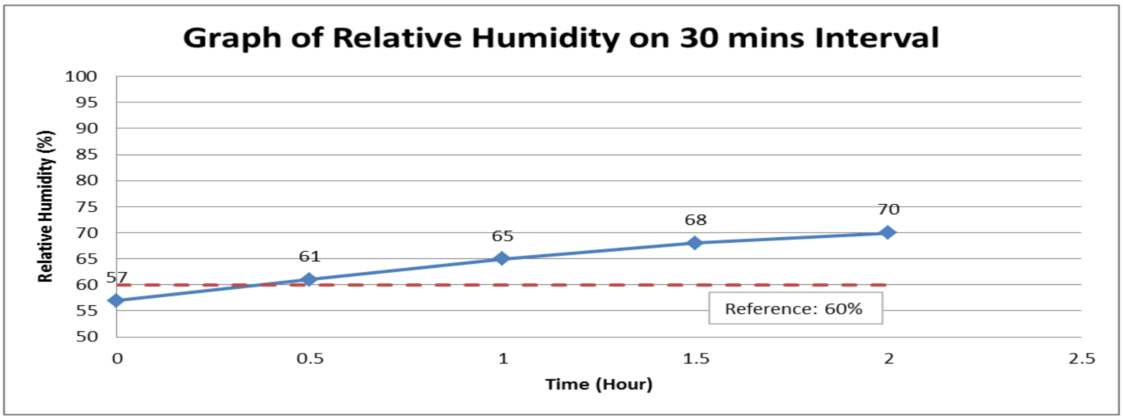


Figure 33: Relative Humidity Graph on 30 Minutes Interval (Afternoon)

ii. 1 Hour Interval

Table 12: Humidity Level on 1 Hour Interval (Afternoon)

Time (hour)	Humidity Level (%)
0	58
1.0	60
2.0	63
3.0	65
4.0	66

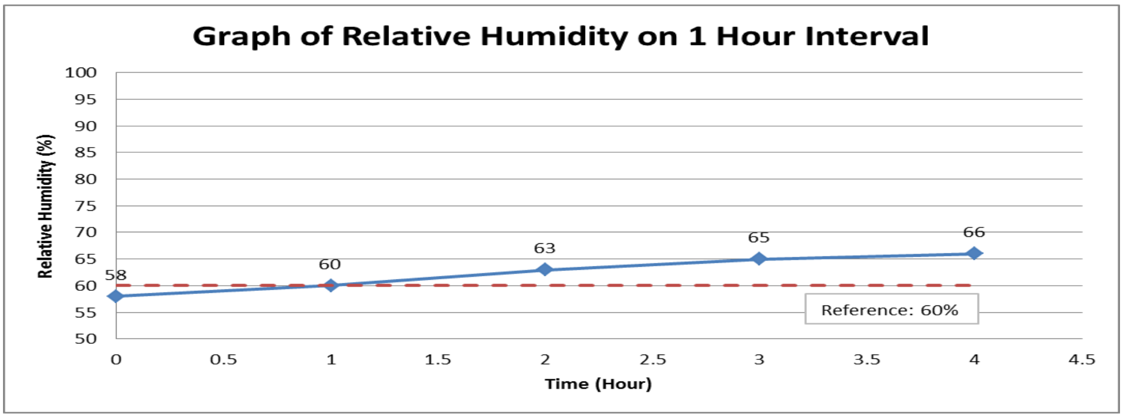


Figure 34: Relative Humidity Graph on 1 Hour Interval (Afternoon)

iii. 1 Hour 30 Minutes Interval

Table 13: Humidity Level on 1 Hour 30 Minutes Interval (Afternoon)

Time (hour)	Humidity Level (%)
0	58
1.5	59
3.0	61
4.5	62
6.0	62

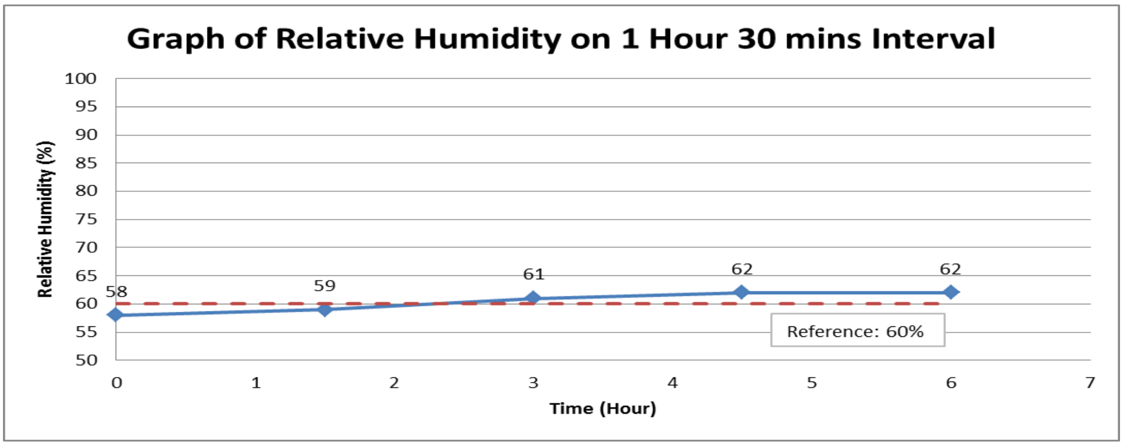


Figure 35: Relative Humidity Graph on 1 Hour 30 Minutes Interval (Afternoon)

iv. 2 Hours Interval

Table 14: Humidity Level on 2 Hours Interval (Afternoon)

Time (hour)	Humidity Level (%)
0	57
2.0	57
4.0	58
6.0	57
8.0	57

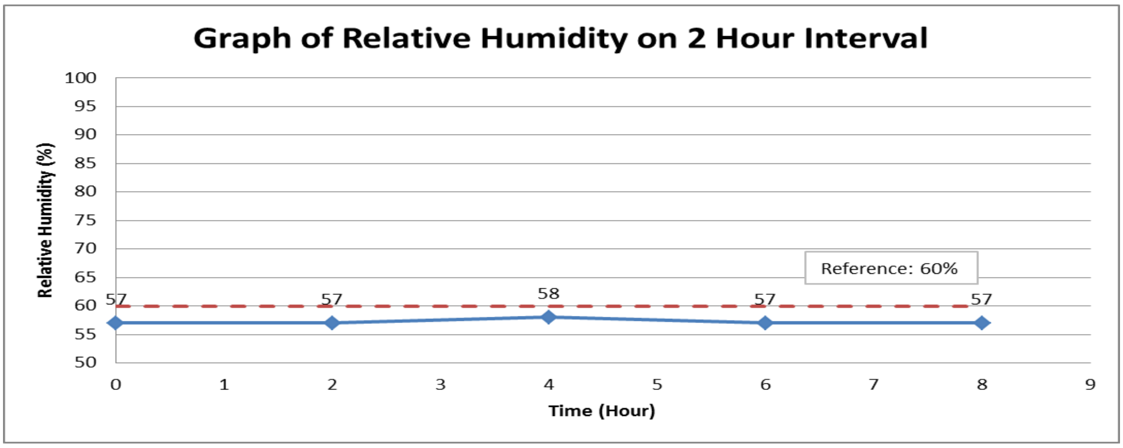


Figure 36: Relative Humidity Graph on 2 Hours Interval (Afternoon)

For the results in the afternoon session, the relative humidity graph of each time intervals are shown in Figure 33, Figure 34, Figure 35 and Figure 36 respectively. On time intervals of 30 minutes and 1 hour, the relative humidity increases above the reference humidity level of 60%. These conditions make the area proximity to the eyes feel wet and humid which are not suitable for the eyes. On time interval of 1 hour 30 minutes, the relative humidity increases and maintain on the reference humidity level. This condition is able to provide a suitable humidification for the eyes. However, on time interval of 2 hours, the relative humidity does not increases and falls below the reference humidity level. This condition make the eye feel dry and uncomfortable. Therefore, in the afternoon, the most suitable timing interval for the humidification process is 1 hour 30 minutes.

4.3.3 Night Session

i. 30 Minutes Interval

Table 15: Humidity Level on 30 Minutes Interval (Night)

Time (hour)	Humidity Level (%)
0	70
0.5	72
1.0	76
1.5	78
2.0	81

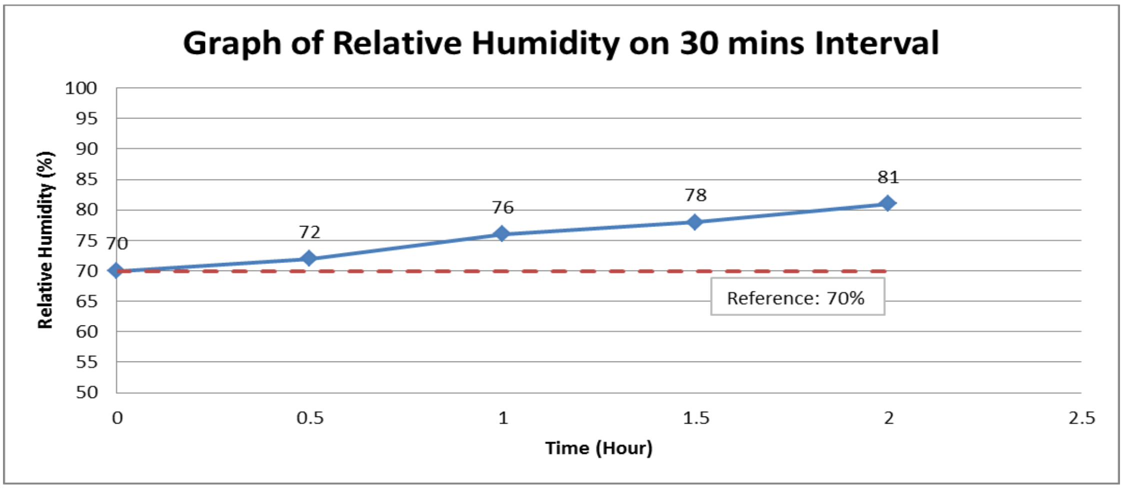


Figure 37: Relative Humidity Graph on 30 Minutes Interval (Night)

ii. 1 Hour Interval

Table 16: Humidity Level on 1 Hour Interval (Night)

Time (hour)	Humidity Level (%)
0	69
1.0	71
2.0	73
3.0	76
4.0	78

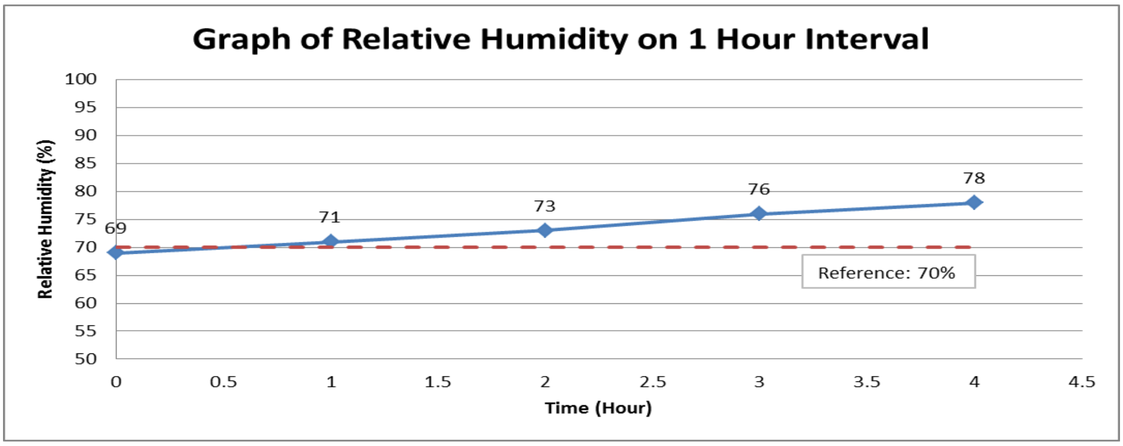


Figure 38: Relative Humidity Graph on 1 Hour Interval (Night)

iii. 1 Hour 30 Minutes Interval

Table 17: Humidity Level on 1 Hour 30 Minutes Interval (Night)

Time (hour)	Humidity Level (%)
0	70
1.5	72
3.0	74
4.5	74
6.0	75

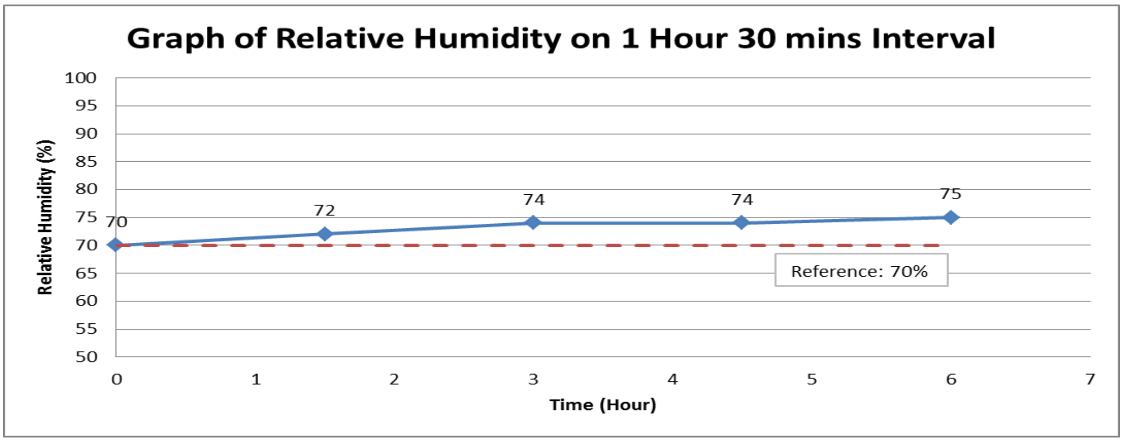


Figure 39: Relative Humidity Graph on 1 Hour 30 Minutes Interval (Night)

iv. 2 Hours Interval

Table 18: Humidity Level on 2 Hours Interval (Night)

Time (hour)	Humidity Level (%)
0	69
2.0	71
4.0	71
6.0	72
8.0	72

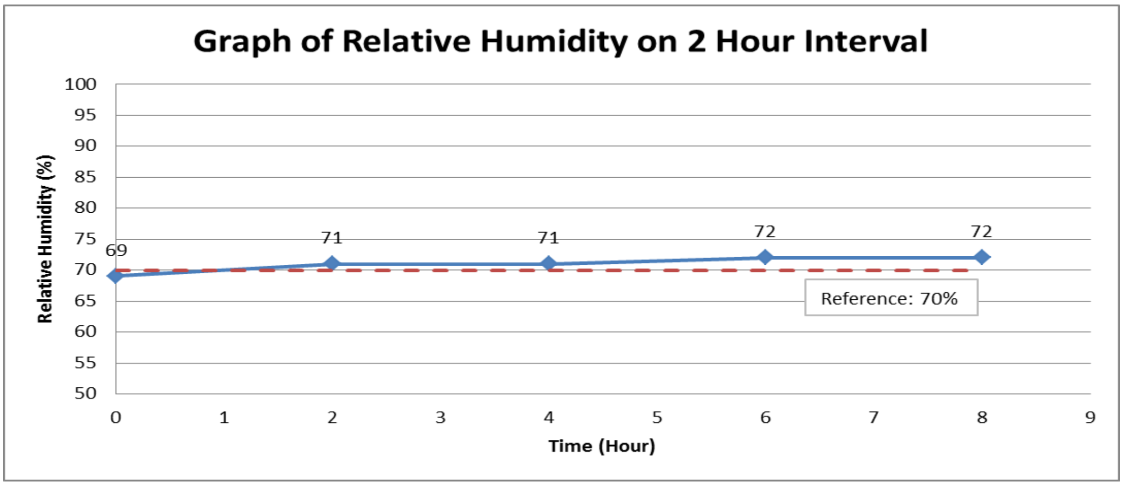


Figure 40: Relative Humidity Graph on 2 Hours Interval (Night)

For the results in the night session, the relative humidity graph of each time intervals are shown in Figure 37, Figure 38, Figure 39 and Figure 40 respectively. On time intervals of 30 minutes, 1 hour and 1 hour 30 minutes, the relative humidity increases above the reference humidity level of 70%. These conditions make the area proximity to the eyes feel wet and humid which are not suitable for the eyes. On time interval of 2 hours, the relative humidity increases and maintain on the reference humidity level. This condition is able to provide a suitable humidification for the eyes. Thus, at night, the most suitable timing interval for the humidification process is 2 hours.

The data of the experiments are further analyzed to determine the changes in humidity level after all four time intervals and also the changes in humidity level after two hours which is shown in Figure 41 and Figure 42 respectively.

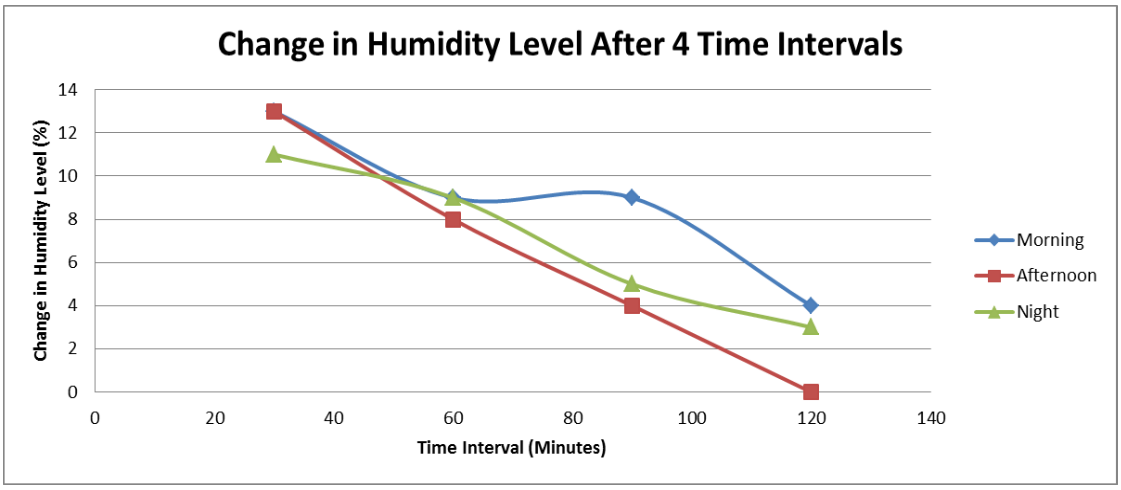


Figure 41: Change in Humidity Level after 4 Time Intervals Graph

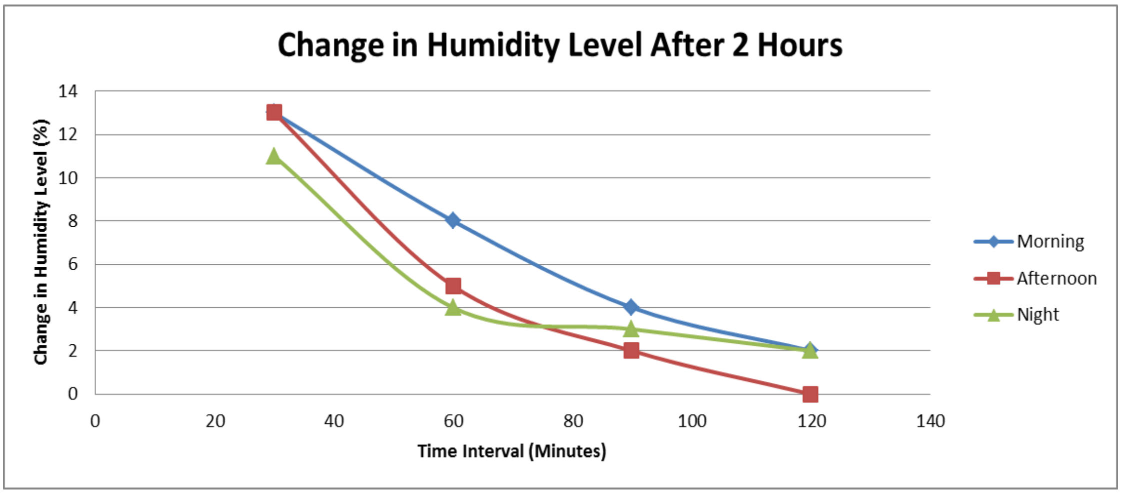


Figure 42: Change in Humidity Level after 2 Hours Graph

The experiments show that the changes in humidity level differ according to different time sessions of the day. This allows us to determine the timing interval and number of humidification process needed to increase the humidity level. As the weather is hot and dry in the afternoon, the humidity level is lower compared to the morning and night session, thus a more frequent humidification interval is required. As the weather in the morning and at night is cold, the humidity level is higher compared to the afternoon session, thus a less frequent humidification interval is required.

4.4 FUTURE WORK

The development of the wearable eye humidifier is successful with the integration of the ultrasonic transducer, drive circuit, solenoid valve, Arduino microcontroller, timer circuit and water tank into a working prototype model. The prototype model is tested and is able to increase the humidity level of area proximity to the eyes. The prototype model is developed to show the concept and ideas of the wearable eye humidifier which is a new invention to provide a better solution to the dry eye disease.

In future, the wearable eye humidifier prototype model can be further developed into a simpler and better design for commercialization purposes. With the suitable timing interval for the humidification process determined, the Arduino microcontroller and timer circuit can be replaced by a simpler and cheaper 555 timer circuit. A smaller design of the solenoid valve and water tank could be introduced to simplify the design of the wearable eye humidifier. Figure 43 shows the future concept design for the wearable eye humidifier where all the electronic circuits and valves are downsized and integrated in an eyewear design.

Figure 43: Future Concept Design of Wearable Eye Humidifier

CHAPTER 5

CONCLUSION AND RECOMMENDATIONS

The development of the wearable eye humidifier project is successful with the completion of the final prototype model. The objectives of the project are achieved where thorough study on the dry eye disease and different humidification systems are made prior to the development of the wearable eye humidifier. The prototype model of the wearable eye humidifier is tested and is able to increase the humidity level of area proximity to the eyes. The prototype model is developed to show the concept and ideas of the wearable eye humidifier which is a new invention to provide a better solution to the dry eye disease.

The project is breakdown into stages for the design and development of the ultrasonic transducer, drive circuit, solenoid valve, Arduino microcontroller, timer circuit and water tank. All the project stages are then integrated together to develop a working prototype model of the wearable eye humidifier. The humidity test is performed on the prototype model to monitor the humidity level of the area proximity to the eyes. Experiments and testing are also performed to determine suitable timing interval for the humidification process to take place. The data and findings from the experiments and testing are analyzed to improve the final prototype model of the project.

In future, once complete research has been done on the wearable eye humidifier project, several recommendations and improvement could be implemented on the project. The wearable eye humidifier prototype model can be further developed into a simpler and better design for commercialization purposes. With extended studies and research, the normal distilled water used in the wearable eye humidifier can be replaced by vitamins and supplements to improve the health of the eyes.

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