DESIGN OF ROBOT HEAD FOR EXPRESSION OF HUMAN EMOTION

GOH WEI JUN

A report in submitted in partial fulfilment of the requirement for the degree of Bachelor of Mechatronics Engineering (Hons)

Faculty of Electrical Engineering

UNIVERSITI TEKNIKAL MALAYSIA MELAKA

2013/2014

SUPERVISOR ENDORSEMENT

" I hereby declare that I have read through this report entitle "Design of Robot Head for Expression of Human Emotion" and found that it has comply the partial fulfilment for awarding the degree of Bachelor of Mechatronics Engineering (Hons)"

Signature :

Supervisor's Name :

Date :

STUDENT DECLARATION

I declare that this report entitle “Design of Robot Head for Expression of Human Emotion” is the result of my own research except as cited in the references. The report has not been accepted for any degree and is not concurrently submitted in candidature of any other degree.

Signature :

Student's Name :

Date :

ACKNOWLEDGEMENT

In preparing this report, I would like to highly appreciate my project supervisor, Dr.Fariz bin Ali@ Ibrahim. He had given me a lot of guidance on my project and provides me relevant information about robot head during my research. Dr.Fariz had also given me advice in the way to performs good presentation and lead me to write a good report. Dr.Fariz is a dedication supervisor that always cares and concerned about my working progress and always makes sure the task I had done was fulfil the requirement of this project.

Besides this, my sincere appreciation also extends to all my housemates who have provided assistance at various occasions. They shared me a lot of useful information regarding on the using of software such as Solidworks and Arduino software. They also gave me some advice regarding the construction of robot head in some occasions.

Finally, I would like to give a special thanks to all of the survey respondents. The conducted survey able to complete on time based on their cooperation and also sincere feedback. I am much grateful to all my family members which give me spiritual and financial support during this period.

ABSTRACT

Humanoid robot is a type of robot which is designed in human-form with the purpose to increase the quality of human life. The key features of humanoid robot are to perform human-like behaviours and to undergo effective interaction with human-operator. The purpose of this project is to develop an interactive robot head that able to express six basic human emotions based on Ekman's model. These six expressions are joy, sadness, anger, disgust, surprise and fear. The combination of action units based on different control points on robot head was proposed in this study. The new robot head is equipped with 11 degree of freedom for the movement of robot head in human like-way. Two surveys have been conducted to evaluate the suitability of robot head and facial expression designs in order to implement on the robot head. Arduino Mega has been used as the controller for the robot head system and it is integrated with IR remote keypad and LCD display. The remote keypad controller is designed for user to control the expression of robot head. It is synchronised with LCD display where the LCD able to display the name of emotion when particular button activated. This project focuses on the performance test of robot head in term of position accuracy and the result shows that the relative percentage error for each robot head parts is less than 20%. The survey that had been conducted for the facial expression recognition test obtained more than 70% recognition rate for each expression shown by the robot head. It can be concluded that this robot head system, is capable to improve the effectiveness of human-robot communication and possible for more advanced interaction development in the future.

ABSTRAK

Robot humanoid direkabentuk merupai bentuk manusia dengan tujuan untuk meningkatkan kualiti kehidupan manusia. Ciri-ciri utama robot humanoid adalah ia mampu mejalankan tingkahlaku seperti manusia dan menjalani interaksi yang berkesan dengan manusia. Tujuan projek ini adalah untuk membina kepala robot interaktif yang mampu memaparkan 6 emosi asas manusia berdasarkan model Ekman. Enam emosi ini adalah terdiri daripada kegembiraan, kesedihan, kemarahan, perasaan meluat, terkejut dan ketakutan. Gabungan unit tindakan berdasarkan kawalan unit yang berbeza pada kepala robot bagi setiap ekspresi muka telah dicadangkan dalam projek ini. Kepala robot ini dilengkapi dengan 11 darjah kebebasan untuk melaksanakan emosi yang berbeza seperti manusia. Dua kajian telah dijalankan dan penilaian telah dibuat untuk memilih reka bentuk kepala robot serta emosi muka yang paling sesuai untuk dibina pada kepala robot. Arduino Mega digunakan sebagai pengawal bagi sistem kepala robot ini dan ia berintegrasi dengan pengawal papan kekunci dan paparan LCD. Pengawal papan kekunci direka untuk mengawal pergerakan kepala robot berdasarkan kawalan pengguna. Pengawal papan kekunci ini disambung dengan paparan LCD untuk menunjukkan jenis ekspresi wajah. Projek ini menitikberatkan ujian prestasi robot dari segi ketepatan pergerakan dan keputusan menunjukkan ralat peratusan relatif untuk setiap bahagian kepala robot adalah kurang daripada 20%. Tinjauan pada kadar pengiktirafan untuk setiap pernyataan emosi menunjukkan lebih daripada 70% kadar pengiktirafan dapat diperolehi bagi setiap emosi yang ditunjukkan oleh kapala robot. Dengan menggunakan sistem robot ini, ia mampu meningkatkan keberkesanan komunikasi antara manusia dengan robot dan menambahkan kemungkinan pembangunan interaksi yang lebih maju pada masa akan datang.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

Page

LIST OF APPENDICES

CHAPTER 1

INTRODUCTION

1.1 Motivation

Autism spectrum disorder (ASD) is a life long developmental disability and it affects a person in multiple ways, where it can range from very mild to severe. Children with autism are characterized by impairments in three crucial areas of development which is communication, social and limited imagination. Autism spectrum disorder is reported to occur in all racial, ethnic, and socioeconomic background peoples.

There is no actual total number of autism children in Malaysia but the statistic showed by Department of Statistic Malaysia (2011), the total number of children aged from 0-14 was 7,784,600 [1]. According to Health Ministry statistics, it shows that one in every 600 children in Malaysia is autistic [2]. It is estimated that today there are 12,975 children in Malaysia are believed to have some form of autism spectrum disorders.

ASD has the fastest growing developmental disability rate with 10-17% annually [3]. The motivation for this project is to reduce the rates of autism with early therapies and intervention. Children with autism have face recognition deficits that cannot be attributed to overall cognitive abilities or task demands [4]. These children have difficulty with face identity after-effect and the ability to fix in memory faces that are unfamiliar. Thus, humanoid robot head with emotion express ability able to assist the children with ASD by continuously update on precise characteristic of human expression during the learning process.

1.2 Problem Statement

Through Mehrabian survey, 7% of information is transferred through spoken language while 38% transferred by paralanguage and 55% of transfer is due to facial expression [5]. This statistic indicates that facial expression is the major element in transferring information and this proposed robot head act as the mediator or the deliverer of the facial information to autism children.

Children with severe autism have significant difficulty to communicate or interact with other people. Most of the autism children are visual oriented and they need patient practice in the learning process. Humanoid robot head with emotion express ability able to solve this issue by provides autism children a learning platform on facial expression recognition. The ability of humanoid robot to perform a repetitive task to modelling human communication provides an effective and better therapy compared to human aided learning system. A report had stated that autism children paid more attention to the robot and followed its instruction to develop on their social skills [6]. Thus, the robot head proposed able to provide a proper learning system which are needed for autism children to recognize facial emotion so that they able to express their own feelings during interaction.

The effectiveness of a robot head to deliver the emotion is highly based on following criteria:

i. Type of robot head design and structure
ii. Degree of freedom of the robot head movement
iii. Amount and position of control point on the robot head
iv. Combination of action units on the robot head for each emotion
v. Recognition rate for each emotion express by robot head

For the robot head system, the selection of hardware components can influence the performance of the system. Arduino Mega has been chosen as the controller for the robot head system and it provides 54 digital I/O pins for connection.

The model of actuators are selected based on the specification of the robot head mechanisms which include the torque and speed needed for moving the mechanisms of robot head parts. The actuator chosen need to be high precision on positioning capabilities for the motion of the robot head. The measurement in term of angle and position distance for the robot head parts will be taken for accuracy performance test for each facial expression. The position of actuators in neutral expression has been taken as the reference point for the series of performance test.

1.3 Objectives

i. To design and construct a robot head that able to express human six basic emotions based on Ekman's model
ii. To design a keypad controller system for controlling robot head emotion expression and implement LCD display to show the name of emotion express by the robot head
iii. To analyze the performance of the robot head in term of position accuracy and obtain the recognition rate of each facial expression

1.4 Scopes

i. The construction of the robot head focuses on human head motion that consists of eyebrows, eyelid, eyeballs and lips. Each of this part able to move independently to express different emotion. Neck construction is not cover in this project.
ii. Appropriate control point on the robot head is determined to control the direction of movement of actuators. The actions units (AUs) are form by the combination of control point. The 6 basic emotion of Ekman's model covered in this project are joy, sadness, anger, disgust, fear and surprise. Working space of robot head is fixed (X-axis = 0.17m, Y-axis = 0.18m, Z-axis = 0.06m).

iii. This project covers the position accuracy test by repeating the motion of robot head parts which include eyeballs, eyebrows and lips.

iv. This project covers the facial expression recognition survey on 100 respondents through actual demonstration of the complete robot head structure. The expression of emotion on robot head appears randomly.

v. The motion of robot head is controlled by using Arduino Mega controller.

vi. A keypad controller is designed for user to control the emotion express on the robot head. The robot head shows the expression when a particular button on keypad controller is activate. Seven buttons are set up for six basic emotions while another one is for neutral emotion.

vii. A LCD display is designed to show the name of emotion on the robot head.

1.5 Outline of Dissertation

i. Chapter 1 describes the problem designate and goals to be achieved as well as range of this project covers.

ii. Chapter 2 describes the published information related to humanoid robot head in the way to perform human emotions and the performance indices used for expression evaluation.

iii. Chapter 3 describes the method designed to construct robot head parts and mechanism to express different emotion. This chapter also describes the method use to indicate the performance of robot head parts in terms of position accuracy and the facial expression recognition rate.

iv. Chapter 4 describes the findings obtained using statistical technique and also evaluation of the result obtained with proof.

v. Chapter 5 concludes the project findings and suggest on future research.

CHAPTER 2

LITERATURE REVIEW

2.1 Theory

2.1.1 Robot Head Design and Construction

Currently in the research of humanoid robot, the design and construction of the robot head become one of the determinant factors that will affect the effectiveness of communication between human and a robot. Different design of robot head portrait will produce different understandability for the user. Thus, to design an appearance concept of the robot head, we have to take consideration on two issues [7]:

i. How to design a face that can convey understandable expression, and
ii. How to make a friendly face and will not let user react adversely to it

Human has the best understanding on the expressions of human as this is a natural tendency as a human being. However, the robot head can be design in different form and configuration to achieve different purpose. The design and construction of robot head can be classified based on:

a) human-likeness, and
b) technical complexity of the robot head

The construction of robot head can be designed in human-like way or in a more technical head. The advantage of the human-like robot head (anthropomorphic) is that it can perform more realistic facial expression that would help in effective communication between a person and robot. Thus, it will increase the performance of the robot system and to perform a more adequate interaction to improve quality of human life.

On the other hand, a technical robot head (technomorphic) has no restriction on the design specification such as head size and shape. This robot head can be designed with other additional parts to increase the performance of the head. The time to construct a technical head is shorter as it does not cover the mechanical construction of the head in human manner.

The technical complexity is determined by the amount of sensors or actuators used in the mechanical construction of the robot head. The aim of this project is to develop a robot head with 11-DoFs which able to mimic human facial expression in a more natural way. The robot head parts constructed in this project are eyebrows, eyelid, eyeballs, and lips.

2.1.2 Ekman's Facial Action Coding System

Ekman's Facial Action Coding System (FACS) is a psychological knowledge introduced by Paul Ekman for generating facial expression on robot face [8]. Appropriate control regions are selected to generate adequate facial expression. In FACS psychology, Action Units (AUs) represent the movement of the muscle and it was divided into 44 basic components. The action units are formed by the combination of different control points and it is used for producing various facial expressions. The typical six basic expressions recognize in Ekman’s model are joy, sadness, anger, disgust, surprise and fear.

In this project, there are 10 AUs and two fixed units used to generate the six basic facial expressions as shown in Table 2.1 and Table 2.2. In order to perform the motion of these 10 AUs, 17 control points was selected and its direction of movement empirically on the facial skin are shown in Figure 2.1.

Table 2.1: Action unit on robot head

Action Unit	Appearance Changes	Control Point	
		Right	Left
A1	Outer brow raiser	C1	C4
A2	Inner brow raiser	C2	C3
A3	Outer brow lowered	C5	C8
A4	Inner brow lowered	C6	C7
A5	Upper lid raiser	C9	C10
A6	Eyeball left-right motion	C11	C12
A7	Eyeball up-down motion	C13	C14
A8	Upper lip raiser	C15	
A9	Lower lip raiser	C16	
A10	Lower lip lowered	C17	

Table 2.2: Fixed point on robot head

Fixed Unit	Position	Fixed Point	
		Right	Left
F1	Upper lip corner	C18	C19
F2	Lower lip corner	C20	C21

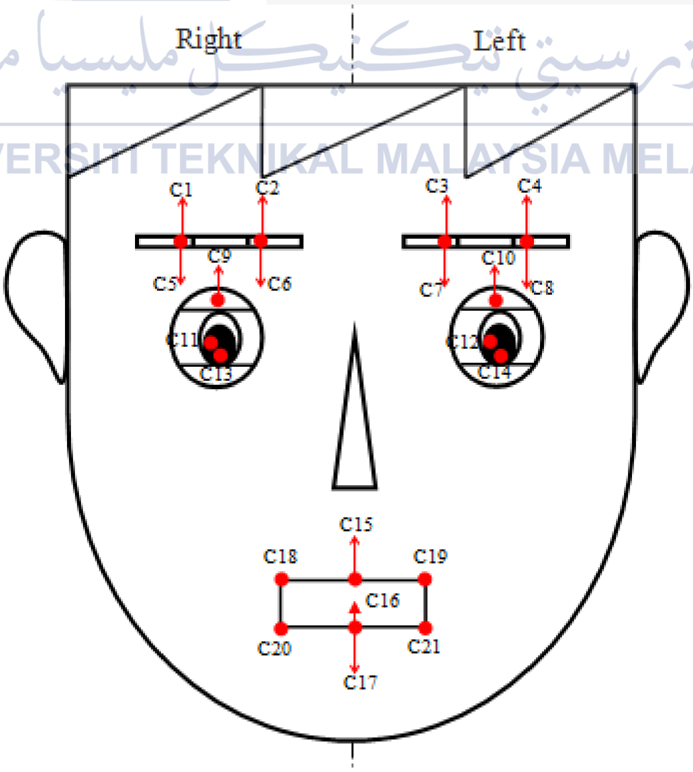
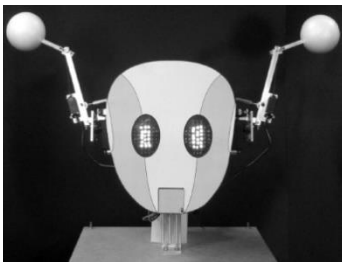


Figure 2.1: The position of control points and its moving direction

2.2 Research and Study

Table 2.3: Review for seven research papers

Element	**Paper 1**[9]	**Paper 2**[10]
Name of Robot	KOBIAN-R	Exaggerating Emotion Expresser
Type of Head	Human-like	Technical (insect character)
Proposed Method	-Include facial color on robot head and facial expression design based on computer graphic (CG) images	-No restriction on robot head design. Include arm-type antennae, emoticon eyes and exaggerating jaw and cheeks to express emotion
Type of Expression	Ekman's 6 basic expression (fear, disgust, joy, anger, surprise, sadness)	Ekman's 6 basic expression (fear, disgust, joy, anger, surprise, sadness)
Degree of Freedom	24-DoFs (8-DoFs for eyebrows, 5-DoFs for eyelids, 3-DoFs for eyes, 7-DoFs for lip, and 1-DoF for jaw)	13-DoFs (6-DoFs for antennae, 3-DoFs for jaw and cheeks, 3-DoFs for neck)
Type of Motor	DC motor & servo motor	DC motor
Type of Mechanism	Eyes-gimbals structure and metal ring turns around low friction PTFE sleeve Eyelids-wire driven mechanism with an ultrasonic motor Eyebrows-metal plate structure and CP driven by magnet through the cover Mouth-jaw joint	Arm-type antennae-lower link operate with two direct driven motor and upper link operate by a wire mechanism from a motor Emoticon eyes-made up of LED array (50 LEDs) and controlled by two FPGA microprocessors
Type of Controller	Computer	Bluetooth communication through computer
Dimension (mm)	150 x 214 x 181	N/A
Weight (kg)	1.7	N/A
Recognition Rate	Happiness – 71.5% Sadness – 73.1% Anger – 92.3% Surprise – 96.2% Fear – 19.2% Disgust – 57.7%	*Survey for the facial expression recognition rates was not conducted*
Design Overview		

Element	Paper 3[11]	Paper 4[7]	Paper 5[12]
Name of Robot	F & H robot	Flobi	SAYA
Type of Head	Human-like	Human-like	Human-like
Proposed Method	-Design and manufacture flexible face film with anti-cracking, anti-aging and anti-fading material -Implement the rope drive mechanism -Include the action of head to emphasize the emotion expression	-Design robot head with "baby face" appearance. -Display secondary emotion with four LEDs -Design hole-free lip with large motion range -Few parts of the robot head (hair, lips and eyebrows) is changeable	-Using McKibben type pneumatic actuators to control displacement of control point in facial skin -Using coil spring as head motion mechanism and implement new neck mechanism
Type of Expression	Ekman's 6 basic expression (fear, disgust, joy, anger, surprise, sadness), neutral and solemnity	5 basic expression (fear, joy, anger, surprise, sadness) and neutral	6 basic expression (fear, joy, anger, surprise, sadness, disgust) and calm
Degree of Freedom	14-DoFs (2-DoFs for eyeballs, 1-DoFs for eyebrow, 2-DoFs for lower jaw, 3-DoFs for neck, 6-DoFs for head)	18-DoFs (3-DoFs for eyes, 2-DoFs for eyebrows, 4-DoFs for eyelids, 3-DoFs for neck, 6-DoFs for mouth)	6-DoFs (2-DoFs for eyeballs, 1-DoFs for chin, 2-DoFs for mechanical frame, 1-DoF for eyelids)
Type of Motor	DC servo motor	DC motor	DC motor
Type of Mechanism	Face-non-metal rope drive mechanism	Individual part combined and attached to the core by using magnet	Facial skin-McKibben type pneumatic actuators Mechanical frame-oculomotor mechanism Neck-coil spring mechanism
Type of Controller	Computer and Intelligent Drive & Control Unit (IDCU)	AtmelXMega64 microprocessor and computer	Computer
Dimension (mm)	N/A	N/A	115 x 200 x 155
Weight (kg)	N/A	2.4	1.5
Recognition Rate	*Survey for the facial expression recognition rates was not conducted*	Happiness -83.3% Sadness -99.2% Anger –81.2% Surprise -54.5% Fear –33.4%	Happiness – 100% Sadness – 93% Anger – 86% Surprise – 100% Fear – 93% Disgust – 86%
Design Overview			

Element	**Paper 6**[13]	**Paper 7**[14]
Name of Robot	UKL Head	i-RoK
Type of Head	Human-like	Human-like
Proposed Method	-Simulate the silicon skin of the head and implement Ekman's action unit facial expression -Reduced the number of actuators and obtained trajectories in the emotion space -Implement face detection function on robot head	-Consider the general dimension of human head to design an anthropomorphic robotic head -Reduction of robot head weight for power consumption -Using rapid prototyping as manufacturing technique for robot head
Type of Expression	Ekman’s 6 basic expression (fear, disgust, joy, anger, surprise, sadness) and neutral	N/A
Degree of Freedom	N/A	8-DoFs (4-DoFs for neck, 3-DoFs or eye, 1-DoFs for lower jaw)
Type of Motor	DC motor & servo motor	RC servo motor and DC servo motor
Type of Mechanism	Face-wire mechanism driven by servo motor	-
Type of Controller	Computer	N/A
Dimension (mm)	N/A	151 x 187 x 187
Weight (kg)	N/A	4
Recognition Rate	N/A	N/A
Design Overview		

2.3 Summary of Review

Table 2.4: Advantages and disadvantages on seven research papers

	Advantages	Disadvantages
Paper 1 [9]	Recognition rates for each emotion (except fear emotion) were improved by 25% in average compare to Kobian robot. Small and light for mounted on bipedal walking robot.	The recognition rate of fear emotion is too low (19.2%).
Paper 2 [10]	Exaggerative motion improved the effectiveness of facial expression. More efficiently invoke a human emotional response. Useful in entertainment industry.	Unrealistic facial expressions decrease the performance of the system support human-robot interaction. No facial emotion recognition test was conducted.
Paper 3 [11]	High similarity of human face skin structure improves the accuracy of facial expression.	Facial expression performance of the robot head is low as the mechanism drive control with only 14-DoFs. No facial emotion recognition test was conducted.
Paper 4 [7]	Appearance of robot is friendly and widely accepted. It able to expresssecondary emotion more efficiently (e.g.: shame with red cheek).More natural expression is available through construction of hole-free lips. Appearance of the robot head is changeable to satisfied different condition.	Disgust expression is not available.
Paper 5 [12]	High similarities of the movement of human-like head motion are achieved.	Limited movable range of the head motion. The amount of respondents for the recognition rate test is less and the accuracy of the data is low.
Paper 6 [13]	The real time method for image based face detection provide basic ability for human-robot interaction	Unfamiliar robot head design
Paper 7 [14]	The major dimension and weight of human head is take into account for the design had made the appearance of robot head more human-like	Only neck and eye region construction. No emotional expression available.

In [9] a technical robot head has been introduced by including some additional parts such as arm type antenna, emoticon eyes and exaggerating jaw and cheek for better facial expression. This conceptual design of robot head increases the robot power of emotional expression. However, in comparison with the robot head discussed in [11] and [12], this type of robot head unable to perform realistic facial expression as human being, and thus decrease the effectiveness of human-robot communication.

Kobian-R robot in [9] consist the most degree of freedom for the movement of robot head which is 24-DoFs of movement in comparison with robot head in other papers. The amount of degree of freedom for the movement represents the moveable range of the parts on robot head. However, it does not represent the effectiveness of the facial expression for each emotion. This can be seen where the emotion happiness, sadness and fear of the robot head "Flobi" in [7] has the higher recognition rate compared to Kobian-R robot although it has only 18-DoFs of movement.

G.Wu et al. discussed on the type of material to manufacture face skin structure of the robot head where it has high similarity to human skin [11]. The flexible face film on the face able to emphasize on the muscle movement and resulted in higher accuracy of facial expression. In compared with the human-like skin structure applied in [12], SAYA robot head is cover with a soft urethane skin and attached together with McKibben type of pneumatic actuator provide a better movement of the skin as human muscle. This shows that the mechanisms to drive the skin structure also play an important role in order to perform a more realistic facial expression.

One of the obvious advantages of Flobi robot over other robot head design is that the appearance of the Flobi robot head is changeable depends on different situation [7]. Other than that, Flobi head appearance with a more comic-like human face provides an advantage of familiarity of human face and it able to provide more pleasant facial expression to be accepted by human being during interaction.

K.Berns et al. developed UKL robot head which can obtain the trajectories of emotion space through the implementation of face detection system [13]. This system enables real time face tracking where the robot head able to response adequately towards the emotion given by user. In [14], the construction of the robot head was just covered for neck and eye region. The dimension and weight of real human head was taken into account in i-RoK construction. This paper provides the head dimension for male and female to consider in robot head.

In summary, this project concentrates on the development of robot head design in a more friendly appearance. The appearance of the robot head is one of the main factors that influence the effectiveness of learning for the autism children. The robot head able to express six basic emotion (joy, sadness, anger, disgust, surprise and fear) under the control of users and the relative name of expression can be shown through LCD display. The design and mechanism of the robot head is discussed in next chapter.

CHAPTER 3

METHODOLOGY

This chapter is divided into three sections. In first section, it covers on the design consideration for the robot head. The conceptual design for robot head and the expression to be implemented on robot head is determined. The degree of freedom for the movement of robot head is also stated under this section. The second section is the mechanical construction of the robot head parts. The type of actuators, motion range and mechanism use for each robot head part are explained in details under this section. It is followed by the control system use for the robot head system in this project. The last section of this chapter will cover the setup for the experiment that carried along this project. It can be divided into two phases which are experiment before the construction of robot head and experiment after complete construction of robot head. The experiment that carried before construction of robot head are the integration test between software and actuators and also the selection of the servo motor based on its performance. The performance testing in term of accuracy of the robot head parts and recognition rate test for each expression are the experiment that carried after complete construction of the robot head.

The flow chart below indicates the process in order to complete the Final Year Project (FYP). The details of each phase were discussed in this chapter and the process flow for FYP1 was completed until the software simulation and the initial phase of hardware development which include the selection of actuators. In FYP 2 stage, the process started with hardware construction of robot head. The experiment starts to take place once the structure of robot head is completely constructed. The results for the experiment is analyzed to obtain the performance of the robot head system in perform different expression. The conclusion will be made to summarize the overall process and decide whether it meets the objectives of the project.

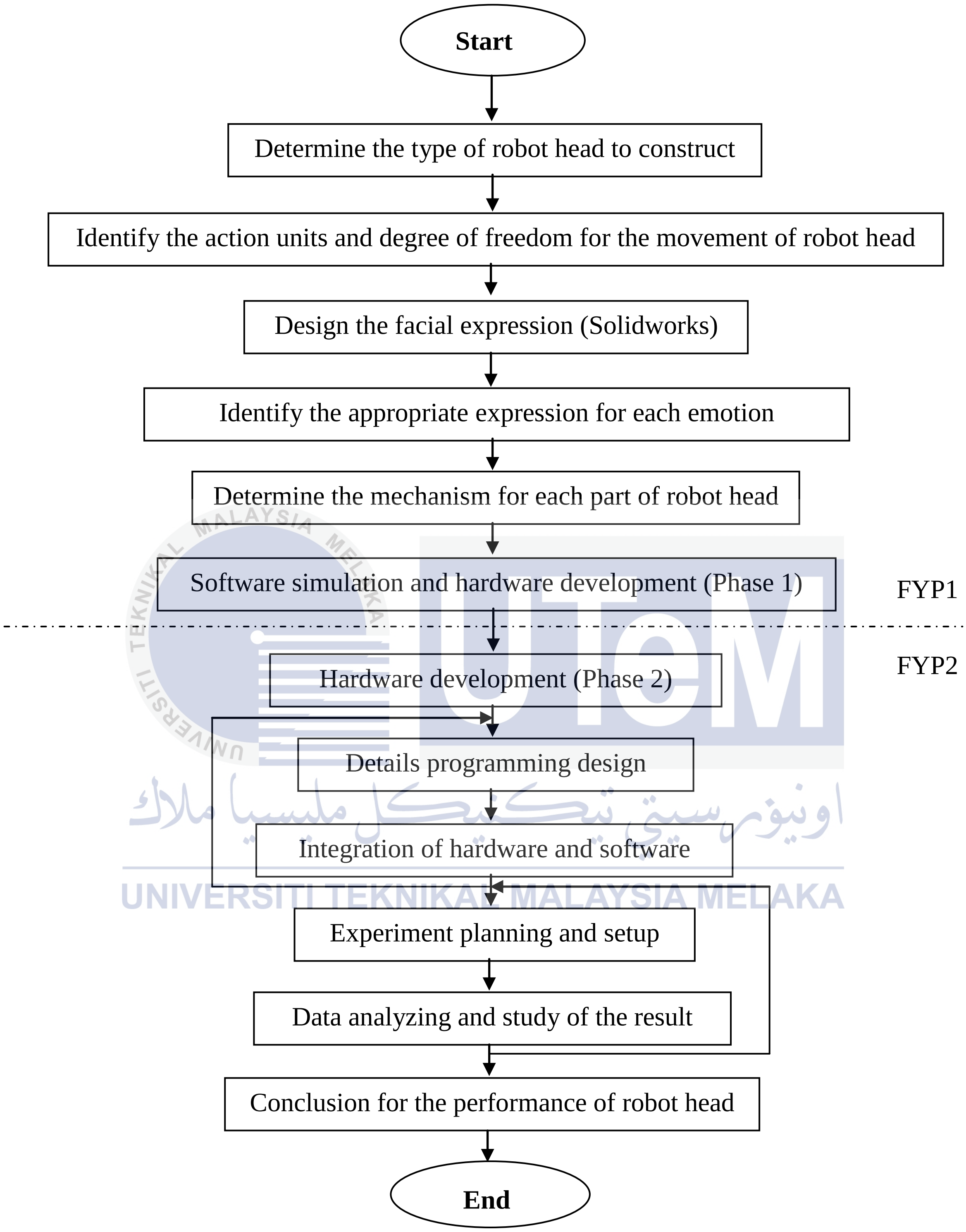


Figure 3.1: Flow chart for the process of Final Year Project

3.1 Design Consideration

3.1.1 Robot Head Conceptual Design

For the development of new robot head, a preliminary survey has been conducted to define the most appropriate robot head type to construct in the project. The designs of robot head are chosen based on the suitability for the learning purpose of autism children.

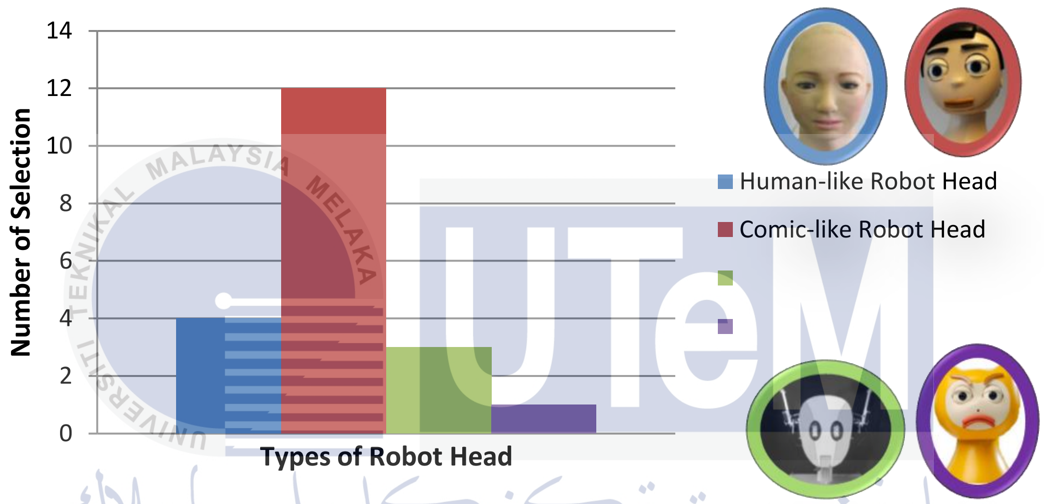


Figure 3.2: Selection of robot head type for the new robot head

This survey has been conducted in September 2013 and there are 20 subjects (16 Male and 4 Female) with average age of 23 participated. Result of this survey shows that the more comic-like human face obtain the most selection as the robot head design in due to its friendly appearance. There are 12 participants prefer comic-like robot head over other type of robot head design. They state that the friendly outlook for the robot head is the basic element and able to make to robot more easily accepted by the children. Therefore, the design of the new robot head is drawn based on the specification of comic-like robot head.

3.1.2 Degree of Freedom for Robot Head Movement

The designs of robot head are create based on the features on human head. It accommodates the parts such as eyebrows, eyelids, eyeball and lips. The effectiveness of the facial expression can be increase by improved the amount of similar features as human head. The motions perform by the robot head and its part can be achievable by human head. The degree of freedom for the movement of each robot head parts are being identified and considered in order to clarify the suitable mechanism to involve. The motion of robot head that consider in this design is the motion of eyebrows, eyelid, eyeballs and lips. The motion function and degree of freedom (DoF) of each part are listed in Table 3.1.

Table 3.1: Motion function and degree of freedom of human head

Part	Motion Function	Degree of Freedom	Joint
Eyebrows	It made up by aluminium foil. The length for the eyebrow is about 70mm and 10mm width. There are two control points in each eyebrow for it up and down movement.	4	Z-2-LR
Eyelid	It controls the open and close of eyes. Consist of upper lid motion with 90 °of movable range.	2	Pitch-Up Down
Eyeball	Eyeball is made up of a rigid sphere with the radius of 20mm. The eyeballs cover the left-right and up-down motion.	3	Pitch, Yaw-LR
Lips	It consists of upper lip and lower lip. The lips can be stretch, raised and lowered to form different shape under different emotion. There are total two control points for the lips where one for upper lip and one for lower lip. Two fixed point was set at the end of both upper and lower lip.	2	Z-LR

3.1.3 Facial Expression Design

The design of facial expression for 6 basic emotions is perform after the robot head conceptual design and degree of freedom for the movement of robot head was identified. In order to obtain the best representative of facial expression on robot head, twelve different designs of emotions have been created based on the DoFs configuration. The design of the facial expressions has been drawn by using Solidworks 3D drawing software.

Figure 3.3: Twelve sets of facial expression designs drawn by using Solidworks

A survey has been conducted based on these twelve sets of design. The purpose of this survey is to obtain the best representation of facial expression to implement on the robot head. The result for this facial expression design survey is shown in Chapter 4.

3.2 Mechanical Configuration

The robotic head in this research is design based on the major degree of freedom of human head. The actual degree of movement for the robot head parts such as eyeball, eyebrows, eyelid and lips are taken into consideration to avoid any mechanical constrain happens during construction of robot head. This robot head structure consists of 11-DoFs to express the facial expressions for 6 basic emotions. Construction for the robot head mechanisms is the most difficult part in the whole process of this project. The mechanism use for the parts on the robot head is important in order to perform a more understandable facial expression. Details of mechanism for each of the robot head parts are shown below:

3.2.1 Eyes

a) Eyeballs

The direction of eyes is useful in communication for the intention and attention. In order to perform a human-like eye movement, the robot eyes are design in three degree of freedom for its motion. The ideal animatronics movement of the eyes was using 3-axis gimbals system as shown in Figure 3.4. However, the gimbals system used in this project consists of only two axis of free movement which allows the eyes to move left and right, up and down simultaneously. For normal human eyes, it can rotate slightly about the direction of gaze. But in this case, this DoF is neglected as the pitch and yaw axes are sufficient to cover the visual space of robot. The eyeball for the robot has a diameter of 40mm and the distance separation between the two eyeballs is 20mm. The complete structure for one eye has weight of 250g including motors and the gimbals mechanism. Table 3.2 shows the details of mechanism for the eyeballs motion.

Table 3.2: Details of eyeballs mechanism

Part	Axis	Up/Right Degree	Down/Left Degree	Speed (deg/s)	Type of actuator	Type of mechanism
Eyeball	Pitch	15	60	600	4 micro servo motor HD1160A (2 on each side)	2-axis gimbals structure
	Yaw	30	30			

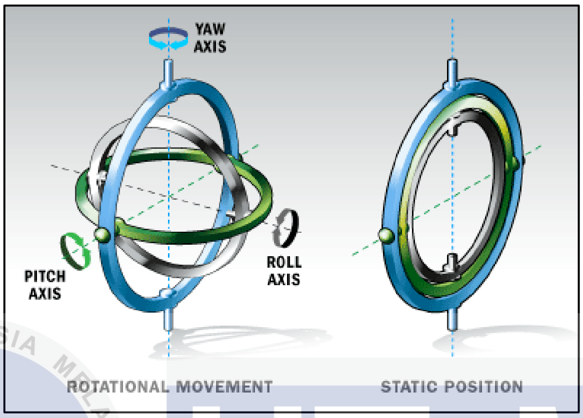


Figure 3.4: Gimbals system for eyeball movement

b) Eyelids

The project consist only the upper eyelid motion. It has two DoFs for the open and close motion. The open and close motion of the eyelid was control by a link mechanism using a SG90 micro servo motor. The linkage rotates based on the motor rotation in pitch direction (rotation about x-axis). The red arrows in the Figure 3.5 indicate the direction of motion for the eyelid.

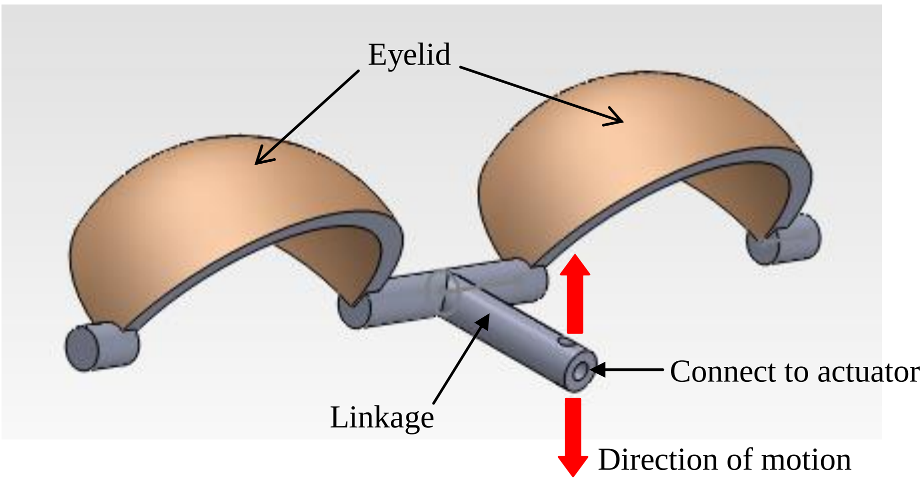


Figure 3.5: Mechanism of eyelid

Table 3.3: Details of eyelids mechanism

Part	Position	Upwards degree	Downwards degree	Type of actuator	Type of mechanism
Eyelids	Upper lid	90	0	1 micro servo motor SG90	Link mechanism

c) Eyebrows

The eyebrows on the robot head have four control points. One control points used to control inner eyebrow motion and another one to control the outer eyebrow motion. Each control point for the eyebrows is driven directly by the servo motor. The eyebrows have a limited motion in x-axis. The outer and inner eyebrow has a vertical motion range of ± 40°. The eyebrows are made with aluminium foil. The eyebrows have a length of 70mm and width of 10mm.

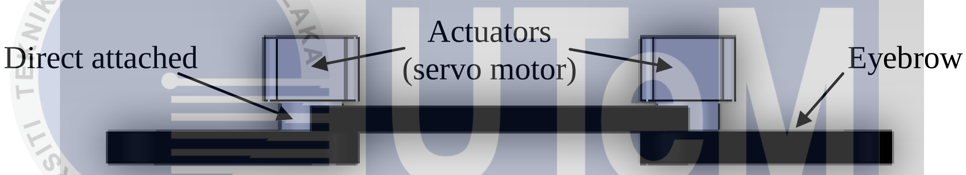


Figure 3.6: Mechanism of eyebrows

Figure 3.7: Control points (red dots) on eyebrows

Table 3.4: Details of eyebrows mechanism

Part	Position	Upwards angle (°)	Downwards angle (°)	Type of actuator	Type of mechanism
Eyebrows	Inner-brow	40	40	1 micro servo motor HD1160A	Direct attached on servo motors
	Outer-brow	40	40		

3.2.2 Mouth

This robot has 2-DoFs at the mouth (Z-axis motion at the centre of upper and lower lip). The lip changes it shaped and forms the expression through the combination of the upper lip and lower lip. The corner of the upper and lower lid consists of two fixed point to prevent the motion of lips at that parts. The control point is place at the centre of the upper lips and lower lips for it up and down motion. The servo motor was connected to the upper and lower lips through a short wire linkage which as shown in the Figure 3.8.

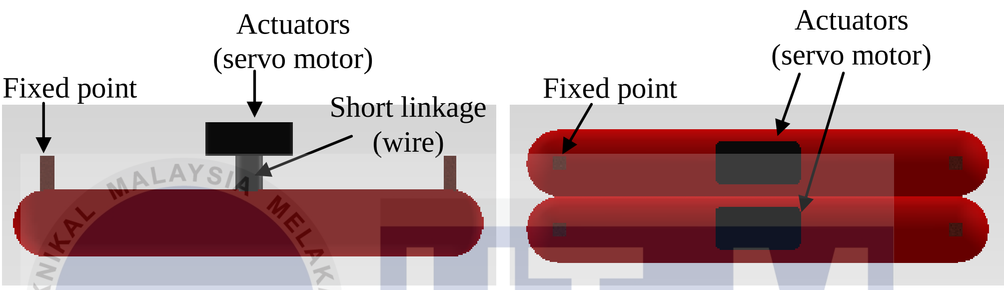


Figure 3.8: Top view and back view of lips mechanism

The lips have a similar structure as the eyebrows where it moulded with the silicone sealant. This flexible film structure enables the forming of different shape on the lips and it helps to increase the power of the facial expression.

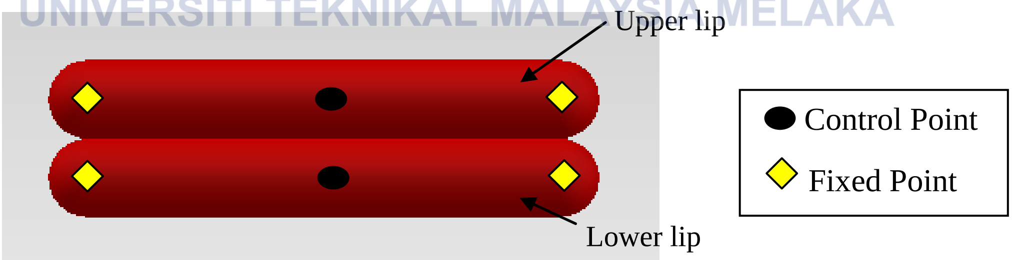


Figure 3.9: Front view of lips

Table 3.5: Details of mouth mechanism

Part	Position	Upwards distance (mm)	Downwards distance (mm)	Type of actuator	Type of mechanism
Mouth	Upper lid	10	-	2 C40R Hobby Servo Motor	Short linkage
	Lower lid	5	15		

3.2.3 Whole structure

The robot head have an overall dimension of 60 x 170 x 180 mm (width x length x height). The robot head is designed for a more comic-like outlook and this allows the dimension of the head is slightly varies from the normal human head. The weight of this robot head is about 1.2 kg.

The face structure is manufactured by using 3D rapid prototyping technique. The material used for printing the robot head is ABS plastic. This technique has the advantage over traditional manufacturing method where it requires shorter time in manufacture the head that consist of a more complex structure. However, the disadvantage of this 3D rapid prototyping was that it cost higher compared to manufactured traditional method. Therefore, the width of the robot head was shorten in the design as this part was not necessary in the robot head expression, and the price for manufactured the head can also be reduce.

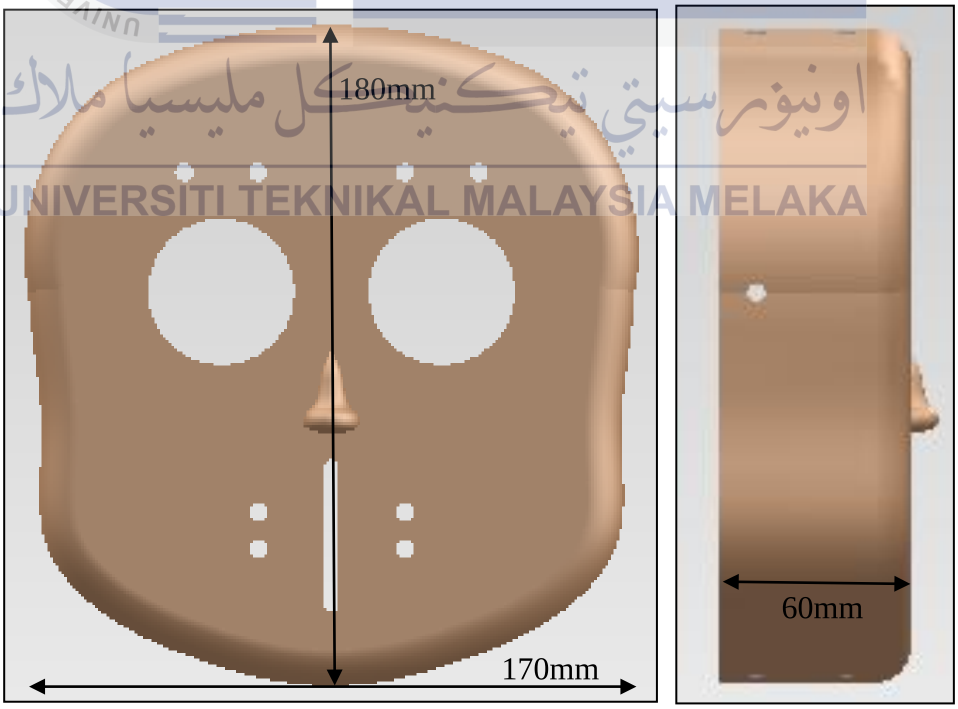


Figure 3.10: Front view and side view of robot head structure

3.3 Control System

The control system of robot head consists of Computer and Arduino Mega controller which act as the control station for robot head system. There are two inputs for the robot head system. First input is from the design coding, where the coding or program is created and loaded into the database of the controller. Another input obtains through the activation of the IR remote keypad from user control. The keypad controller will send an in-line signal to Arduino controller and the controller will process the signal before sent the related output command to the actuators. The outputs that can receive by the user are the motion of robot head where different expression can be perform. The LCD display also able to show the name of emotion when particular expression is shown.

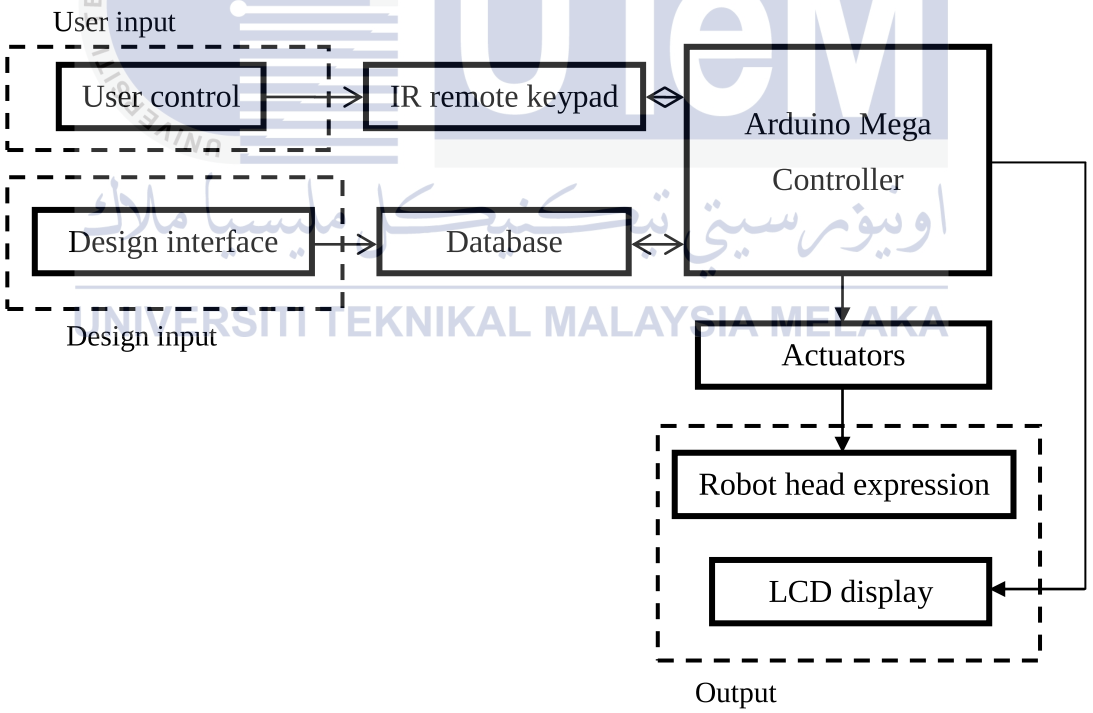


Figure 3.11: Block diagram for the control of robot head expression

Figure 3.12: Arduino Mega and LCD display (16x2)

Figure 3.13: IR remote keypad with serial code for each button

The actuators are activated when the IR keypad controller was pressed with relative to its facial expression selection. The location of each actuator placed is shown in Figure 3.13 and the details of control position are show in Table 3.6. There are total seven facial expressions can be select on the keypad controller which included neutral expression.

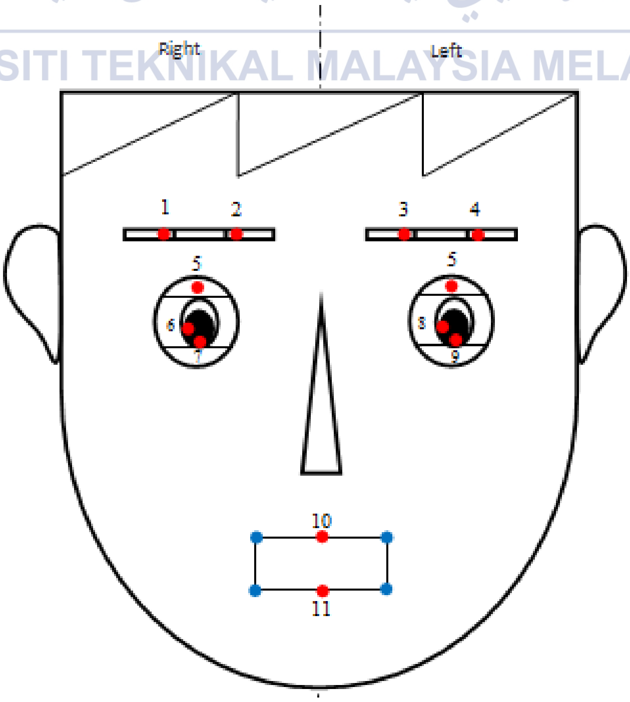


Figure 3.14: Location of actuators on robot head

Table 3.6: Details of control position for each actuator

Actuator	Types	Control Position	Signal Pin
1	HD1160A	Right eyebrow outer part	30
2	HD1160A	Right eyebrow inner part	31
3	HD1160A	Left eyebrow inner part	28
4	HD1160A	Left eyebrow outer part	29
5	SG90	Upper eyelid motion	34
6	HD1160A	Right eyeball left-right motion	24
7	HD1160A	Right eyeball up-down motion	25
8	HD1160A	Left eyeball left-right motion	22
9	HD1160A	Left eyeball up-down motion	23
10	C40R Hobby	Upper lip motion	38
11	C40R Hobby	Lower lip motion	39

The LCD display will show the name of the expression when the related button was pressed for each expression. Table 3.7 summarize the button configuration for each expression by using IR remote keypad.

Table 3.7: IR remote button configuration and LCD display for each expression

Button	Function/Position	LCD Display
POWER	Initialize/Reset	IM EMOTION ROBOT
0	Neutral	NEUTRAL
1	Joy	HAPPY
2	Sadness	SAD
3	Anger	ANGRY
4	Disgust	DISGUST
5	Surprise	SURPRISE
6	Fear	FEAR

3.4 Expressions in Ekman's Model

For the construction of robot head in this project, it just covers on 6 basic expressions discovered in Ekman's model. These six emotions are joy, sadness, anger, disgust, fear and surprise.

Table 3.8: Six emotional expression group for Ekman’s model and OCC model

Ekman's Model [8]	**OCC Model** [15]
Joy	Happy-for, Gloating, Joy, Pride, Admiration, Love, Hope, Satisfaction, Relief, Gratification, Gratitude
Sadness	Resentment, Pity, Distress, Shame, Remorse
Anger	Anger, Reproach, Hate
Surprise	Surprise
Fear	Fear, Fear-confirmed
Disgust	Disgust

Table 3.8 above shows the emotional group for Ekman's model and OCC model. OCC model is a model of emotion which widely uses to states the strength of an emotion which depends on the events, agents or objects in the environment of the agent that exhibits the emotion [15]. Only Ekman's model of emotion are implement on the robot head as it was sufficient for the robot to perform an interactive human-robot interaction. Beside this, autism children need more direct forward learning system for face emotion recognition where complicated facial expression as stated in OCC model will increase the difficulty of the understanding for the emotion.

3.5 Experiment Setup

3.5.1 Controller and Component Integration Test

In the early stage, the simulation of servo motor and LCD display are carried out by using Arduino controller. The connection and programming for both of these components are being studied and the hardware experiment was conducted during the process. Arduino Mega is the controller for this robot head system. Arduino Mega controller used ATmega 2560 as it processor which include 16 MHz clock speed, 8KB of SRAM, 4KB of EEPROM and 256KB of flash memory for storing code. It consists of 54 digital I/O pins and support native USB transfer. Arduino Mega controller is chosen over Arduino Uno Rev3 controller due to its amount of I/O port. In this project, 11 actuators (servo motors) are used to control the movement of robot head, and with include the port using for LCD display and IR remote keypad, it needs more than 24 ports. Therefore, Arduino Mega was chosen as the controller in this project.

Beside this, LCD display (16x2) with yellow backlight was chosen to show the name of emotion express by robot head. This type of LCD display able to display 16 x 2 characters of words and was more convenient to setup compare to 7-segment display. The simulation at this stage was to control the position of servo motor and show the name of emotion through LCD display. Following was the components using in the experiment:

i. Arduino Mega with ATmega 2560 processor
ii. Micro servo motor HD 1160A
iii. LCD display (16x2)
iv. 5mm LED (Red, Yellow and Green)
v. Tactile push switch
vi. 10kΩ variable resistor (Pot)
vii. 100uF capacitor
viii. 470Ω resistor
ix. Half-size breadboard

3.5.2 Servo Motor Selection and Accuracy Test

In order to minimize the cost used for the construction of this robot head, a selection has to be made on the actuators used. Currently, there are three different model of servo motor available for use in this final year project which provided by lecturer. These three types of servo motors are SG90 micro servo, HD1160A micro servo and C40R RC hobby servo.

Figure 3.15: SG90 micro servo, HD 1160A micro servo and C40R RC hobby servo

Table 3.9: Specification of three different model of servo motor

Specifications	SG 90 Micro Servo	HD 1160A Micro Servo	C40R RC Hobby Servo
Dimension, L x W x H	22 x 11.5 x 27mm	29 x 11.7 x 29.6mm	40.2 x 19.8 x 36mm
Weight, g	9	16	38
Torque, kg/cm	1.2	2.7	6
Operation Speed, s/deg	0.12/60	0.12/60	0.14/60

This experiment was conducted to test on the accuracy of these three models of servo motor. The objective of this experiment was to obtain the performance of the actuators and decide which model of actuator that able to provide a more reliable and accurate angle value for the motion of robot head in express the emotion. This experiment covers the servo motor motion angle test from 0° to 180°. The mean, error and relative percent error are calculated to analyze which type of servo motor have a better accuracy and more suitable for the use in robot head construction.

3.5.3 Performance Test (Position Accuracy)

During the construction phase of robot head, there are many factors that will affect the performance of robot head such as the arrangement of actuators and the type of mechanism use to support or connect the actuators. In order to obtain an optimized performance of the robot head, several experiments need to be carry out to analyze the position accuracy for each robot head parts in perform the expression.

At this stage, four accuracy tests were carried on three different parts of robot head, which are eyebrows, eyeballs and lips. The robot head parts were tested for the ability to move in its allowable range of position. For the eyeballs, the test was done separately for left-right motion and up-down motion. The accuracy test for the lips also performs separately for upper lip and lower lip. Total of 15 samples are taken in each test. The mean, error value and relative percent error were calculated to compare the output reading with desired value.

The method use for the position measurement is very important to ensure the reliability of the value obtain. In this case, the value of initial position for the robot head parts is recorded before the experiment start. The reading of initial position is taken as the reference in the experiment. Measuring tools such as protractor and ruler are used to obtain the angle value or distance of the robot head parts. Parallax error need to be avoided during the process of recording data in order to make sure the value taken was accurate and does not offset. IR keypad remote was used to control the activation of each actuator for the movement of the robot head parts.

The purpose of this experiment was to analyze the ability of the robot head parts such as eyeballs, eyelid, eyebrows and lips in perform the expression of emotions. The range of angle or distance for the motion of robot head parts are re-identified after the analysing of each data. The effectiveness of the facial expression for the robot head can be achieved through the accurate motion of each moving parts.

3.5.3.1 Eyebrows Accuracy Test

For the eyebrows accuracy test, there are total eight position was tested which is from -40 ° until 40 ° with 10 ° per increment. The reading of angle for the position of 4 different parts on eyebrows (L1, L2, R1 and R2) was recorded. Figure below show the connection of the eyebrows with servo motor:

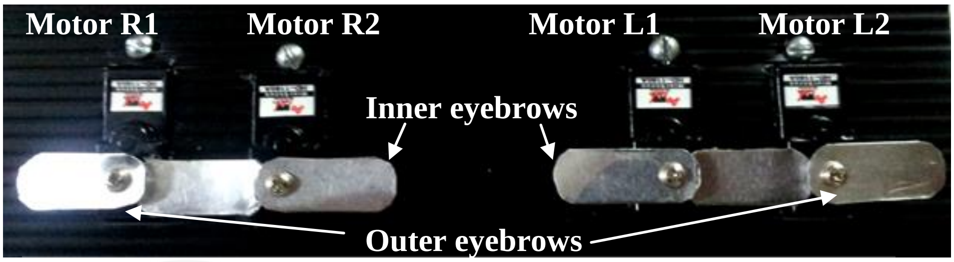


Figure 3.16: Servo motor connection for eyebrows

Table 3.10: Pins configuration for eyebrows

Component/Part	Pin
Motor R1 signal	30
Motor R2 signal	31
Motor L1 signal	28
Motor L2 signal	29
IR remote signal	60
Power pin	5V
Ground pin	Gnd

Table 3.11: Range of motion for eyebrows

	L1 (°)	L2 (°)	R1 (°)	R2 (°)
Range (Angles)	40 to -40	40 to -40	40 to -40	40 to -40

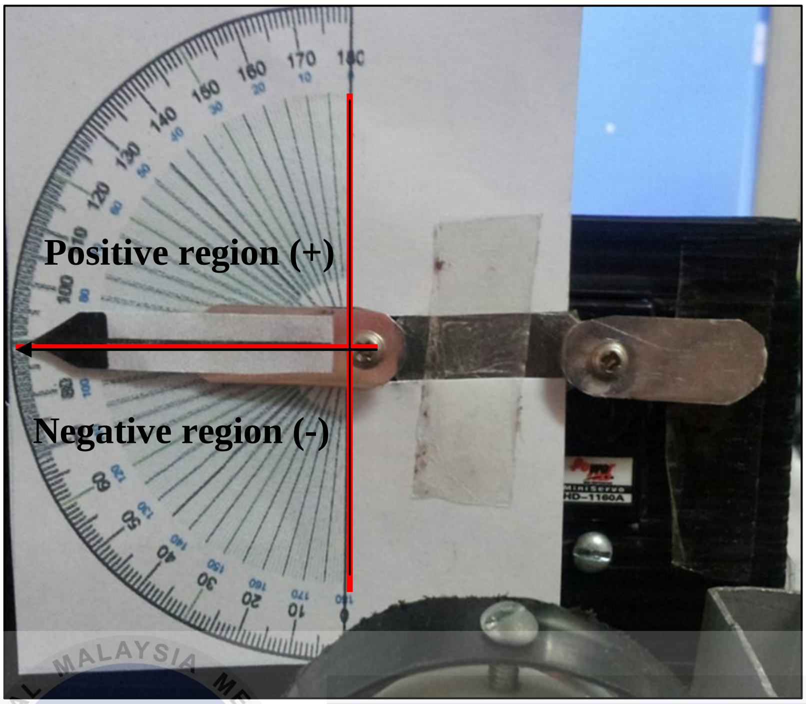


Figure 3.17: Nominal position for eyebrow part L1 and R1

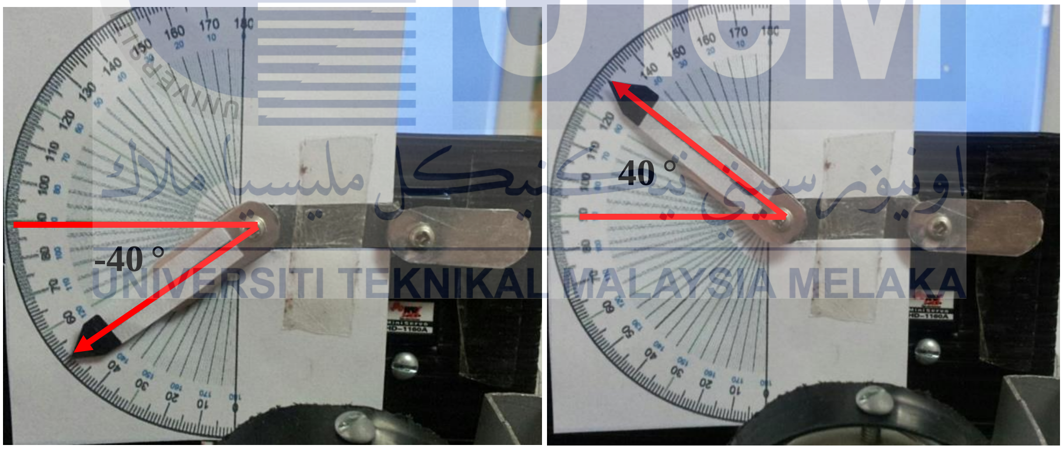


Figure 3.18: Maximum and minimum range of motion for eyebrow part L1 and R1

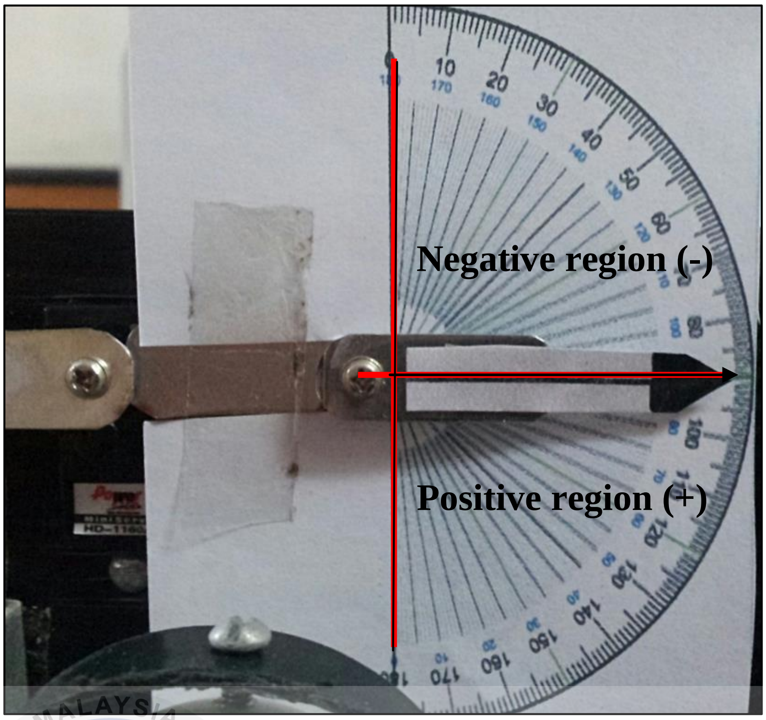


Figure 3.19: Nominal position for eyebrow part L2 and R2

Figure 3.20: Maximum and minimum range of motion for eyebrow part L2 and R2

Formula used in experiment:

$$\text{Mean} = \frac{\text{Sum of value for 15 samples}}{15}$$

$$\text{Error} = \left| \frac{\text{Nominal value} - \text{Mean value}}{2} \right|$$

$$\text{Relative Percent Error (RPE)} = \left| \frac{\text{measured value} - \text{true value}}{\text{true value}} \text{x}100\% \right|$$

3.5.3.2 Eyeballs Accuracy Test

There are two accuracy test was done on the motion of eyeballs. One is for the left-right motion while another one is for the up-down motion. For the left-right motion test, the angle that covers was from -30 ° to 30 ° with 10 ° per increment. For the up-down motion accuracy test, it starts from -60 ° to 20 ° with also 10 ° for each increment. Motor left back (LB) and right back (RB) control the left-right motion of eyeballs while motor left front (LF) and right front (RF) control the up-down motion. Figure below show the connection of servo motor to the eyeballs:

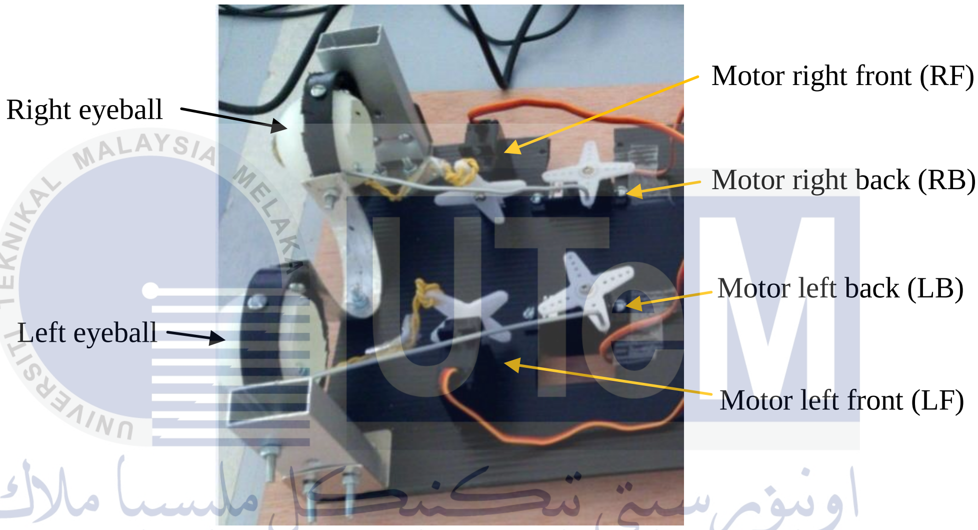


Figure 3.21: Servo motor connection for eyeballs

Table 3.12: Pin declaration for eyeballs

Component/Part	**Pin**
Motor RB signal	23
Motor LB signal	22
Motor RF signal	25
Motor LF signal	24
IR remote signal	60
Power pin	5V
Ground pin	Gnd

Table 3.13: Range of motion for eyeballs

	LB (°)	**RB (°)**	**LF (°)**	**RF (°)**
Range (Angles)	-30 to 30	-30 to 30	-60 to 20	-60 to 20

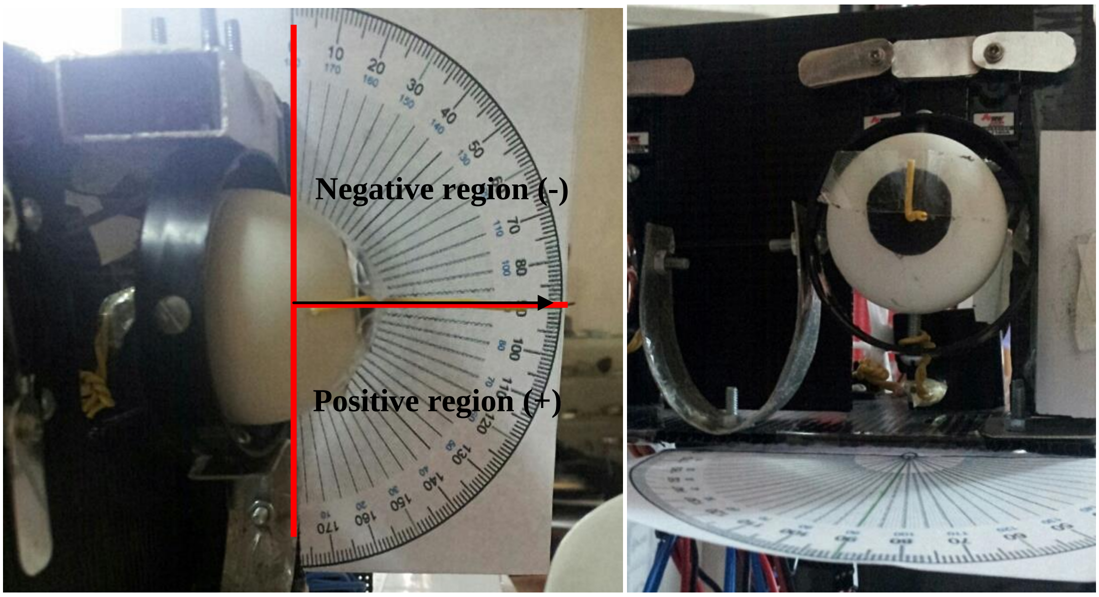


Figure 3.22: Top view and front view of eyeball at nominal position

Figure 3.23: Top view and front view of eyeball at maximum left position

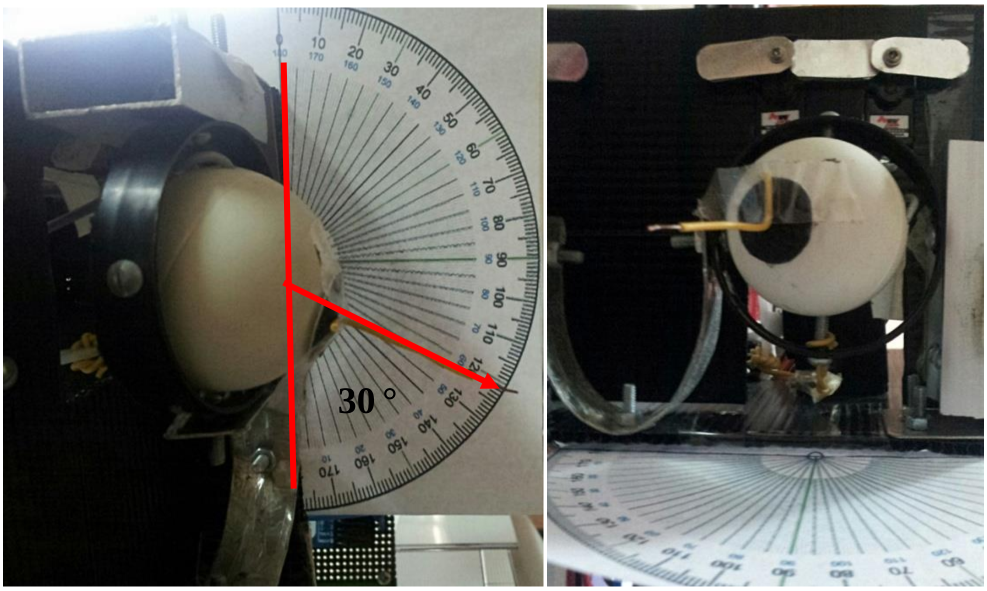


Figure 3.24: Top view and front view of eyeball at maximum right position

Figure 3.25: Side view of eyeball for up-down motion accuracy test

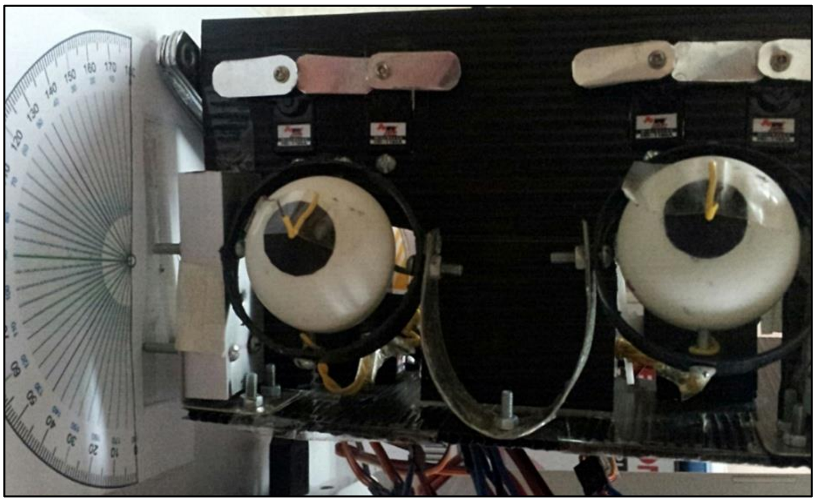


Figure 3.26: Front view of eyeball for up motion

Figure 3.27: Front view of eyeball for down position

Formula used in experiment:

$$\text{Mean} = \frac{\text{Sum of value for 15 samples}}{15}$$

$$\text{Error} = \left| \frac{\text{Nominal value} - \text{Mean value}}{2} \right|$$

$$\text{Relative Percent Error (RPE)} = \left| \frac{\text{measured value} - \text{true value}}{\text{true value}} \times 100\% \right|$$

3.5.3.3 Lips Accuracy Test

Accuracy test has been performed on upper lip and lower lip separately. The position of upper lip is tested from 0 to 1cm with 0.2cm increment in each test while for the lower lip is from 0.6cm to -1.6cm. The test was repeated for 15 times and each reading was recorded in a table.

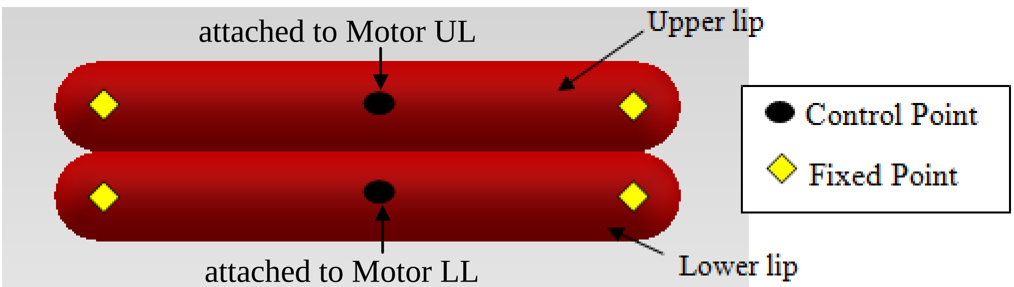


Figure 3.28: Servo motor connection for lips

Table 3.14: Pin declaration for lips

Component/Part	**Pin**
Motor UL signal	38
Motor LL signal	39
IR remote signal	60
Power pin	5V
Ground pin	Gnd

Table 3.15: Range of motion for lips

	UL	**LL**
Range (Distance)	0 to 1cm	0.6 to -1.6cm

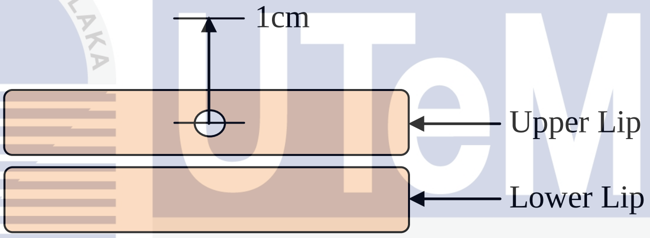


Figure 3.29: Range of motion for upper lip

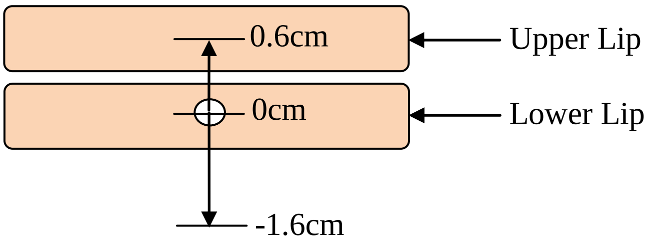


Figure 3.30: Range of motion for lower lip

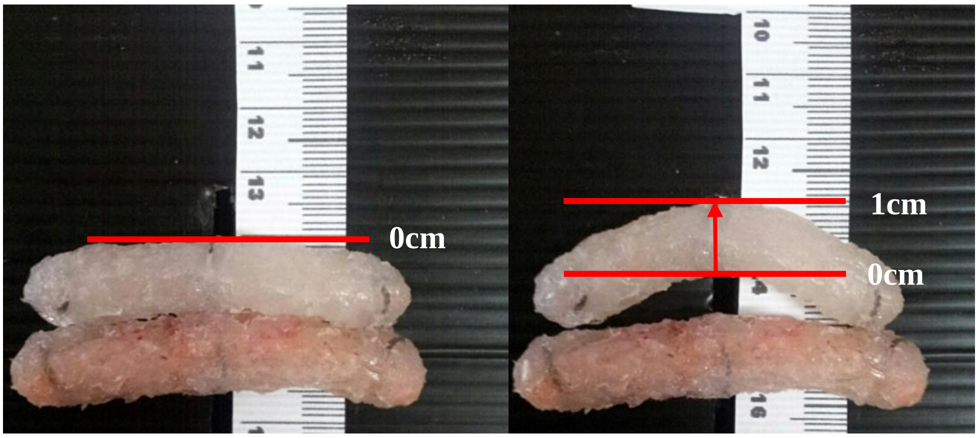


Figure 3.31: Initial position and maximum position for the upper lip

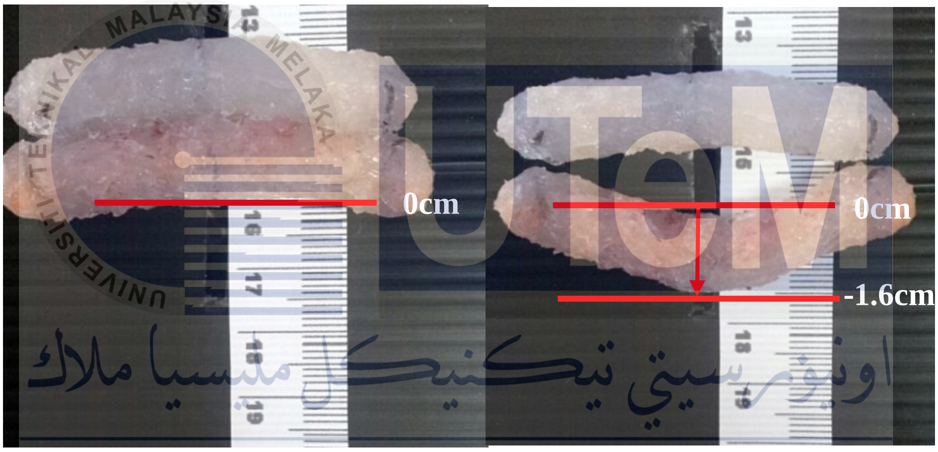


Figure 3.32: Initial position and maximum down position for the lower lip

3.5.4 Expression Recognition Test

After the complete construction of the robot head, a troubleshooting process was carried out based on the output result. This troubleshooting process is performed on the parts which have the obtained value that highly varied from the desired value. This process includes reduction of the allowable moving range for the robot head parts in order to achieve higher accuracy for each moving position. The robot head need to be able to perform and express the six basic expressions correctly with high recognition rate. Thus, a test was conducted on 100 children (average age 5 years old) from Tzu Chi Foundation (Melaka) to obtain the recognition rate of each emotion express by the robot head. The expression of robot head was shown randomly to the respondents. LCD display is excluded during the test to prevent the respondents from knowing the exact name of the emotion express by robot head.

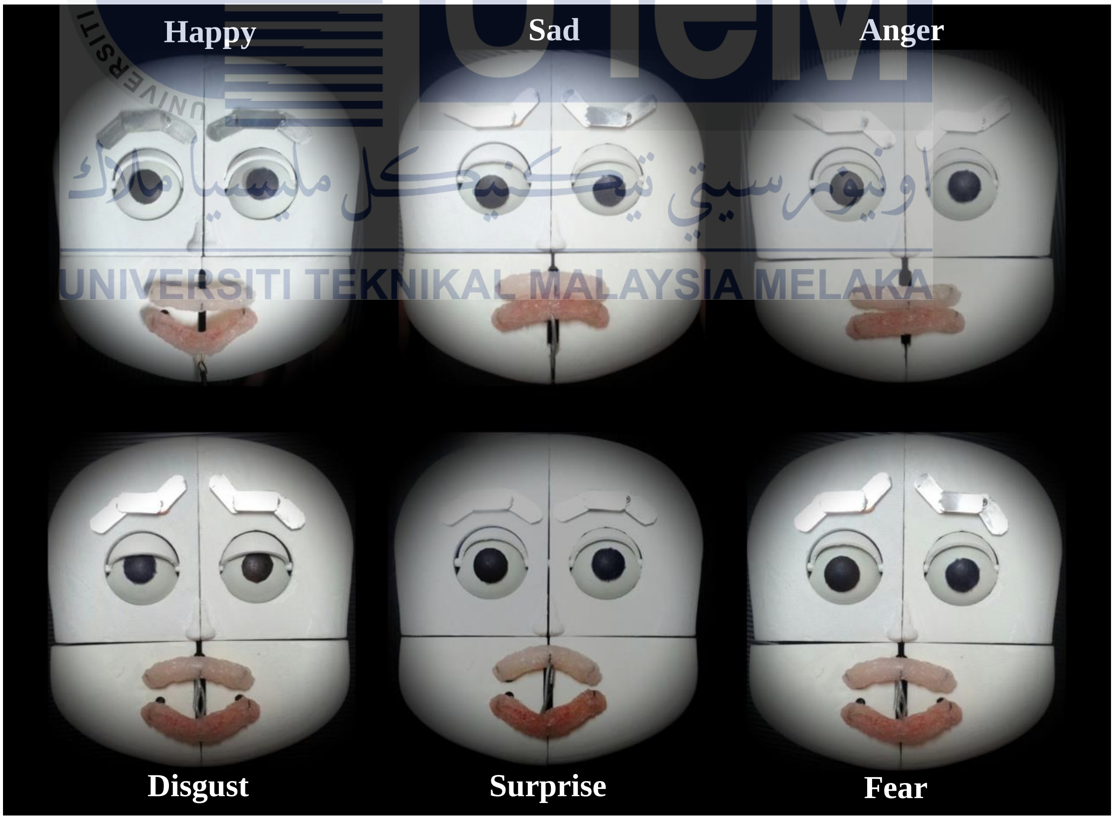


Figure 3.33: Six basic expressions shown by robot head after complete construction

CHAPTER 4

RESULT AND DISCUSSION

This chapter covers the result of the experiments which had been design in previous chapter. The experiment data are summarized in a table and the mean value, error and relative percent error for the data are calculated. The result of the experiment is then being evaluated and analyzed. The discussion for each experiment is written based on the proof at the end of this section.

4.1 Facial Expression Design Survey

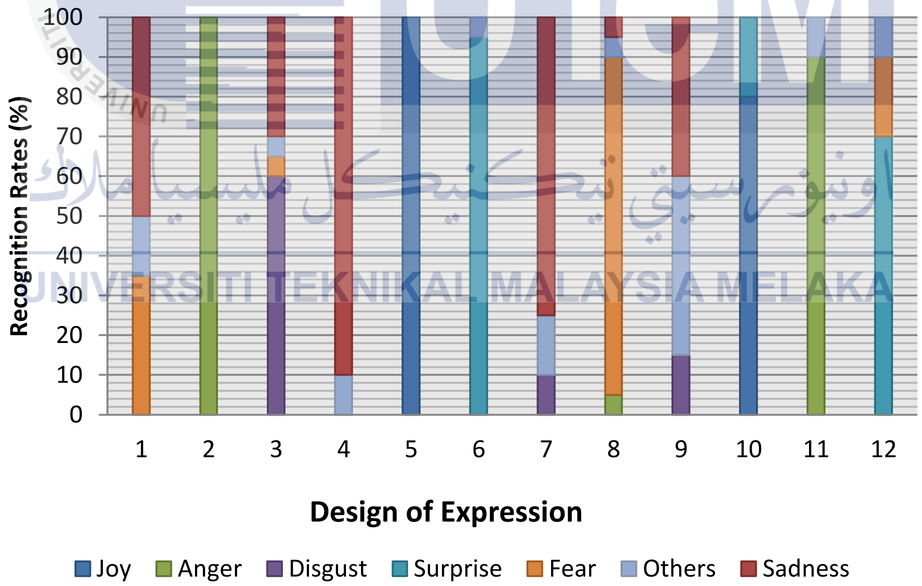


Figure 4.1: Recognition rates for each facial expression design

This experiment was conducted in October 2013 and it involved 20 respondents (16 Male, 4 Female) with average age of 23. Based on the survey, we obtained that Design 5 have the full recognition from the respondents as joy expression.

This design is taken directly as the expression to implement on the robot head. Design 4 (90%) was chosen over Design 7 (75%) as the sad expression. There is some mixing of disgust expression in the Design 7 which cause the power of sad expression lowered. Design 2 was highly recognize by the survey participants for anger expression. It received fully recognition from the respondents and thus it was selected as the design for anger expression.

Among these six chosen facial expression design, the Design 3 was selected as the design for the disgust expression and it has the lowest rate of recognition where it consist only 60%. The Design 3 has partially mixing expression in sadness (30%), fear (5%) and others expression (5%). However, this design is taken for the robot head construction as there are no others design has the higher recognition rate for the disgust expression. To improve the power of this disgust expression, the mechanism and material use to construct the lips need to be more flexible. Design 6 obtained 95% of recognition for surprise expression and this design was selected to apply on the robot head. For the fear expression, participants able to recognize it from Design 8 and it obtained 85% of selection rate. In conclude, only the design with higher recognition rate for each emotion was chosen to implement on the robot head. Further construction of the robot head was based on this design and the robot head configuration are determined by the mechanism and material used. The overall recognition rate for the facial expression design survey is shown in the table below:

Table 4.1: Overall recognition rate (%) for each design of facial expression

	Joy	Sadness	Anger	Disgust	Surprise	Fear	Others	Note (Selection)
1	0	50	0	0	0	35	15	-
2	0	0	100	0	0	0	0	Anger
3	0	30	0	60	0	5	5	Disgust
4	0	90	0	0	0	0	10	Sadness
5	100	0	0	0	0	0	0	Joy
6	0	0	0	0	95	0	5	Surprise
7	0	75	0	10	0	0	15	-
8	0	5	5	0	0	85	5	Fear
9	0	40	0	15	0	0	45	-
10	80	0	0	0	20	0	0	-
11	0	0	90	0	0	0	10	-
12	0	0	0	0	70	20	10	-

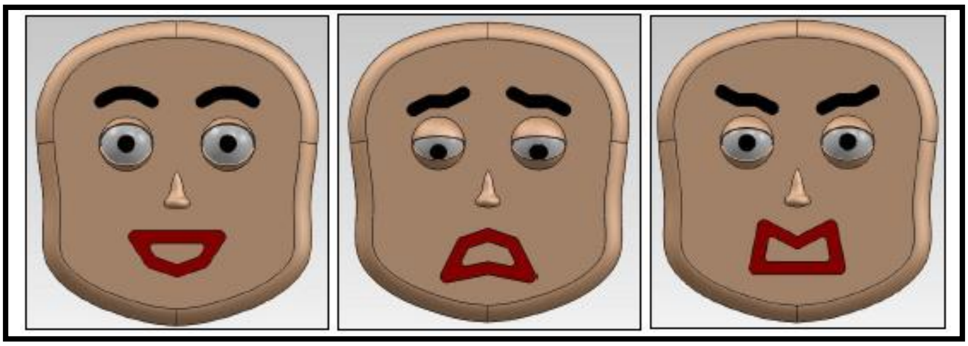


Figure 4.2: Facial expression of joy, sadness and anger (from left to right)

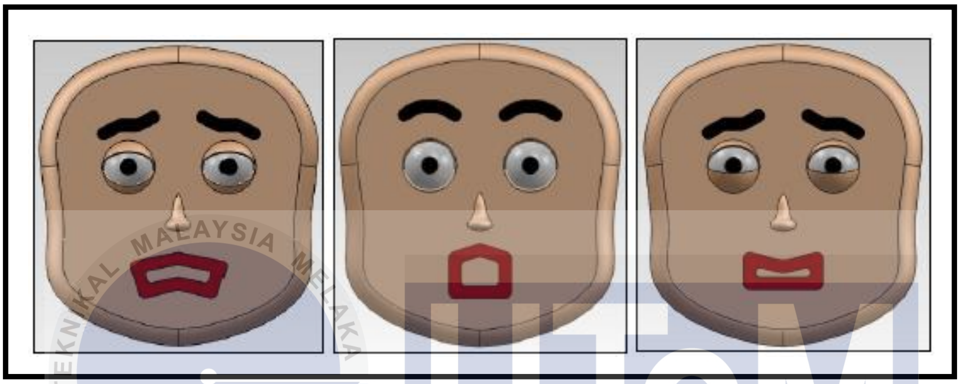


Figure 4.3: Facial expression of disgust, surprise and fear (from left to right)

4.2 Motion Combination of Action Units

In this model of robot head, 10 AUs are formed to perform six basic expressions on robot head. There are total 17 control points were define in this model and the correspond action units of the control point is shown in Table 2.1. The combination of different control point is used to form the six basic expressions and the result of the combination design of expression is shown in Table 4.4.

Table 4.2: Intensity scoring for the motion of each Au

Intensity Scoring	
A	Trace
B	Slight
C	Marked or Pronounced
D	Severe or Extreme
E	Maximum

Table 4.3: Direction of movement for AUs

Direction	
W	Up
X	Down
Y	Left
Z	Right

Table 4.4: Combination of AUs to form each expression

Facial Expression	Action Units
Joy	A3*E*+A4*E*+A5*C*+A10*E*
Sadness	A1*E*+A2*E*+A5*B*+A7*X*+A8*E*+A9*E*
Anger	A1*E*+A4*E*+A5*D*
Disgust	A2*E*+A3*E*+A5*B*+A8*C*+A10*C*
Surprise	A3*E*+A4*E*+A5*E*+A8*E*+A10*E*
Fear	A2*E*+A3*E*+A5*C*+A7*W*+A8*D*+A10*D*

Key: A1 until A10 represents the action unit based on Table 2.1 while the alphabet behind represent the intensity scoring or moving direction

4.3 Controller and Components Integration Test

Table 4.6: Result for the controller and components integration test

Push Switch 1	Push Switch 2	LED	Servo Motor Angle (°)	LCD Display
LOW	LOW	ORANGE	0	NEUTRAL
HIGH	LOW	GREEN	30	HAPPY
LOW	HIGH	RED	-50	SAD

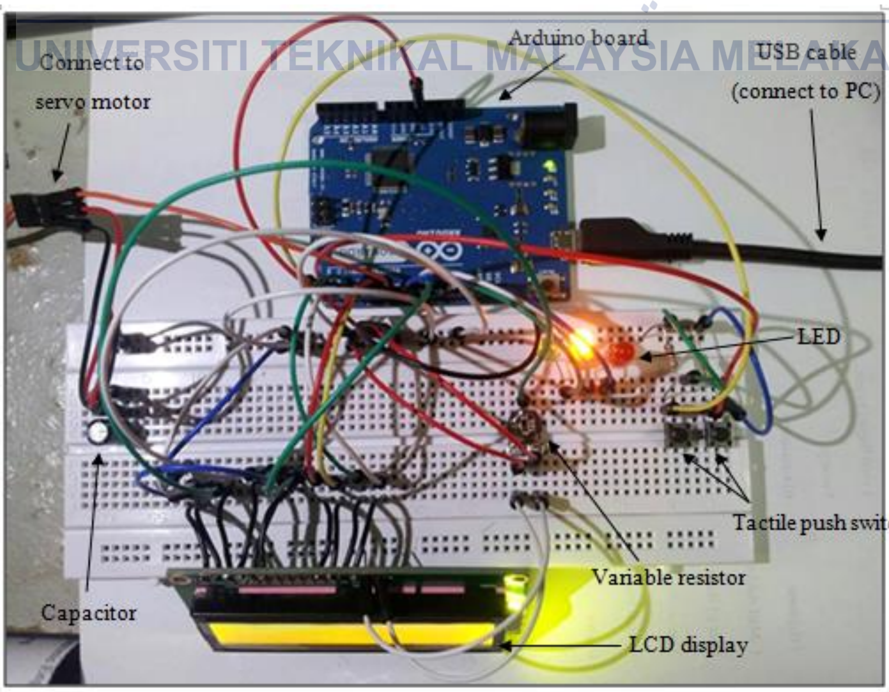


Figure 4.4: Connection of hardware simulation

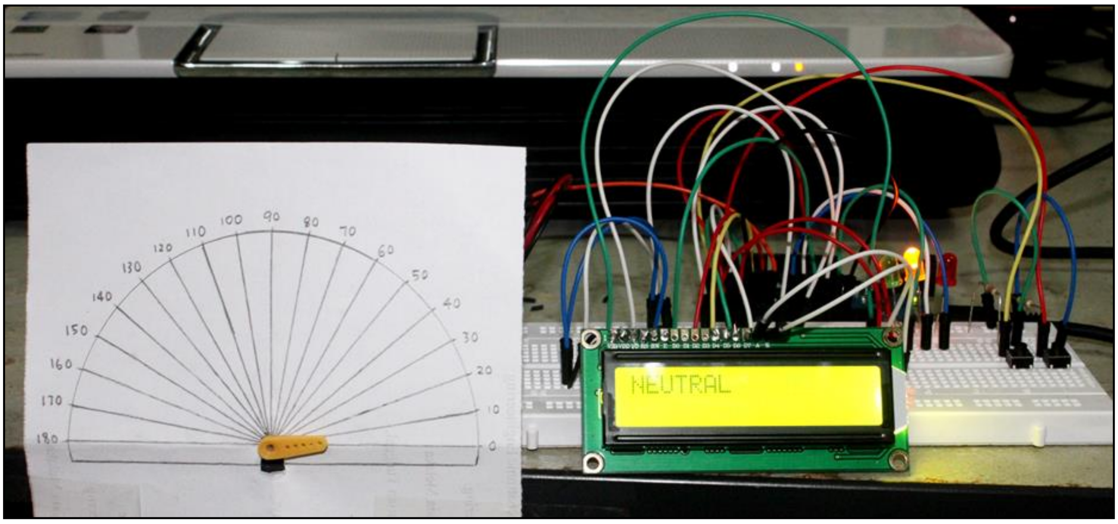


Figure 4.5: Position of servo motor and display on LCD during initial stage

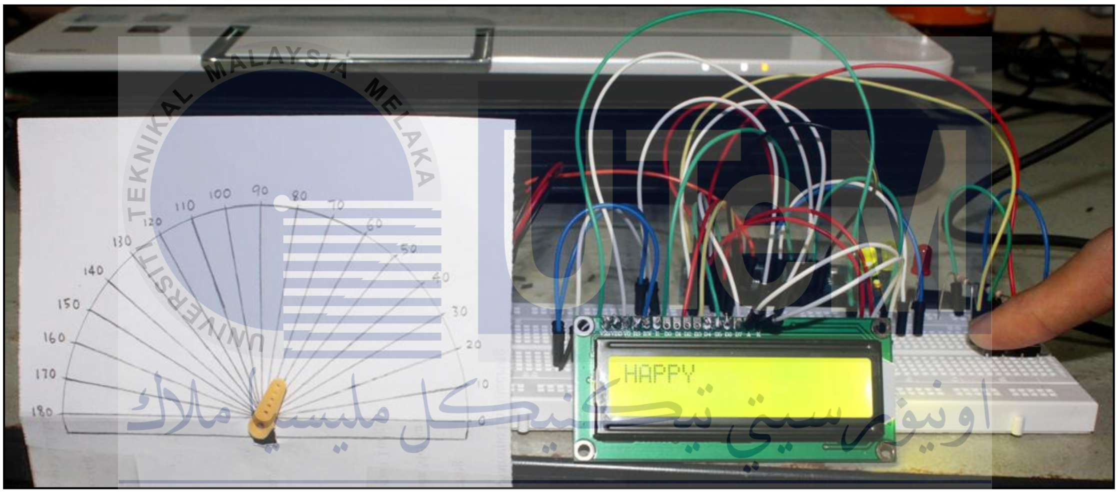


Figure 4.6: Position of servo motor and display on LCD when switch 1 trigger

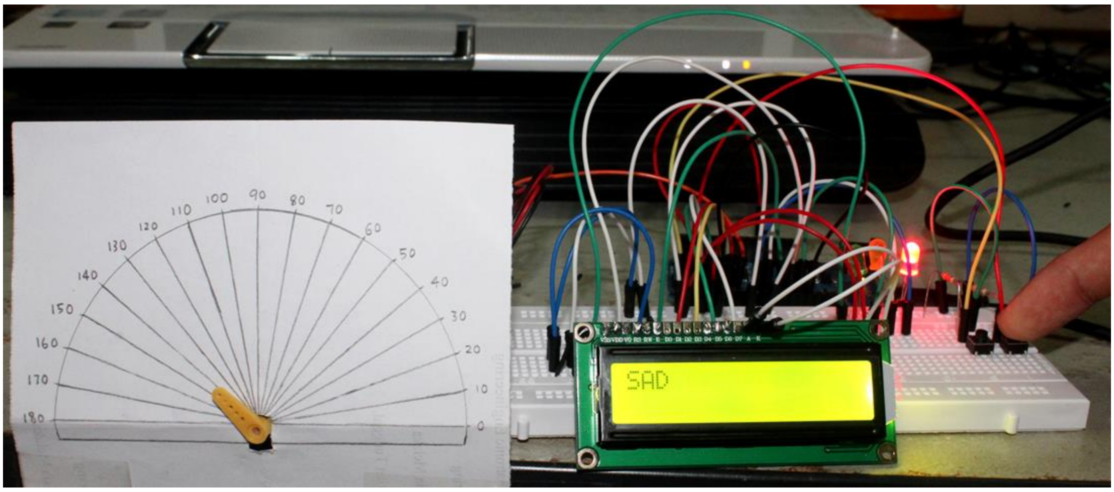


Figure 4.7: Position of servo motor and display on LCD when switch 2 trigger

The experiment carried at FYP1 stage with the purpose to control the movement of servo motor and display character on LCD display by using Arduino controller. Two tactile push switches was set up and act as input switch for the system. Switch 1 and 2 was connected to pin 0 and pin 1 respectively.

```
#include <LiquidCrystal.h>
#include <Servo.h>

Servo servo_0;
LiquidCrystal lcd(12,11,5,4,3,2);
const int buttonPin = 0;
const int buttonPin2 = 1;
const int ledPin =  13;
const int ledPin2 =  8;
const int ledPin3 =  9;
servo_0.attach(6);
```

Figure 4.8: Declaration of program in Arduino simulation coding

Liquid crystal library and servo library was added in the program to declare the command use for LCD display and servo motor as shown in Figure 4.15. LED light used to indicates the process of the system and it was connected to pin 8 (Red), 9 (Orange) and 13(Green). Signal pin of servo motor HD 1800A was connected to analog pin 6 to receive PWM signal. Initially, both switch was at LOW condition and yellow LED is light up to indicate this process. LCD display show 'NEUTRAL' and the servo motor at 0 ° position. When switch 1 is trigger, servo motor rotates to 30 ° and the LCD display shows the 'HAPPY' character. The LED green colour was light up at this condition. When the switch 1 is released, the whole system will return to its initial condition. When switch 2 is push, the red LED is light up and servo motor rotates to -50 °. The LCD was display 'SAD' to indicates the activation of different switch (expression selection). The angle of 0 °, 30 ° and -50 ° was chosen in the experiment as it is the angle for the eyeball part on robot head to move to centre or towards left and right side.

The drawback for this integration test was that it unable to hold the circuit while the push to on switch activated. The system will return to its initial condition when the switch is released. The movement for robot head require the system or actuator to hold at particular condition and position for each of the expression of emotion. The system only require to return to its original position (neutral position) when a button for neutral expression is trigger.

Beside this, this integration test using different servo motor angle to differ the expression shown. For further real robot head system, 11 actuators are needed to connect to the Arduino controller and the movement of each servo motor is depends on the combination of action units.

4.4 Servo Motor Selection and Accuracy Test

Table 4.7: Result for the accuracy test experiment for HD1160A micro servo

Angle, °	Sample			Mean	Error	Relative Percent Error (%) $= \left\lvert \frac{measured\ value - true\ value}{true\ value} \text{x}100\% \right\rvert$
	1	2	3			
0	0	0	0	0	0	0
10	10	10	10	10	0	0
20	20	20	20	20	0	0
30	30	30	30	30	0	0
40	40	40	40	40	0	0
50	50	50	50	50	0	0
60	60	60	60	60	0	0
70	70	70	70	70	0	0
80	80	80	80	80	0	0
90	90	90	90	90	0	0
100	100	98	100	99.33	0.67	0.67
110	109	110	108	109	1	0.91
120	118	119	118	118.33	1.67	1.39
130	127	127	128	127.33	2.67	2.05
140	136	138	136	136.67	3.33	2.38
150	145	144	146	145	5	3.33
160	155	155	153	154.33	5.67	3.54
170	165	163	162	163.33	6.67	3.92
180	172	171	173	172	8	4.44

Table 4.8: Result for the accuracy test experiment for SG90 micro servo

Angle, °	Sample			Mean	Error	Relative Percent Error (%) $= \left\| \frac{measured\ value - true\ value}{true\ value} \text{x}100\% \right\|$
	1	2	3			
0	0	0	0	0	0	0
10	10	10	10	10	0	0
20	20	20	20	20	0	0
30	30	30	30	30	0	0
40	40	40	40	40	0	0
50	50	50	50	50	0	0
60	60	60	60	60	0	0
70	70	70	70	70	0	0
80	80	79	80	79.67	0.33	0.41
90	89	89	89	89	1	1.11
100	99	99	98	98.67	1.33	1.33
110	109	108	107	108	2	1.81
120	117	116	117	116.67	3.33	2.78
130	127	125	125	125.67	4.33	3.33
140	135	134	134	134.33	5.67	4.05
150	144	144	143	143.67	6.33	4.22
160	152	153	153	152.67	7.33	4.58
170	163	162	162	162.33	7.67	4.51
180	171	172	171	171.33	8.67	4.81

Table 4.9: Result for the accuracy test experiment for C40R RC Hobby Servo

Angle, °	Sample			Mean	Error	Relative Percent Error (%) $= \left\lvert \frac{measured\ value - true\ value}{true\ value} \text{x}100\% \right\rvert$
	1	2	3			
0	0	0	0	0	0	0
10	10	10	10	10	0	0
20	20	20	20	20	0	0
30	30	30	30	30	0	0
40	40	40	40	40	0	0
50	50	50	50	50	0	0
60	60	60	60	60	0	0
70	69	69	70	69.33	0.67	0.96
80	79	78	79	78.67	1.33	1.66
90	88	88	89	88.33	1.67	1.85
100	97	96	97	96.67	3.33	3.33
110	108	105	105	106	4	3.63
120	115	113	113	113.67	6.33	5.28
130	124	122	124	123.33	6.67	5.13
140	132	131	131	131.33	8.67	6.19
150	140	142	139	140.33	9.67	6.45
160	150	148	149	149	11	6.88
170	158	158	156	157.33	12.67	7.45
180	166	165	167	166	14	7.77

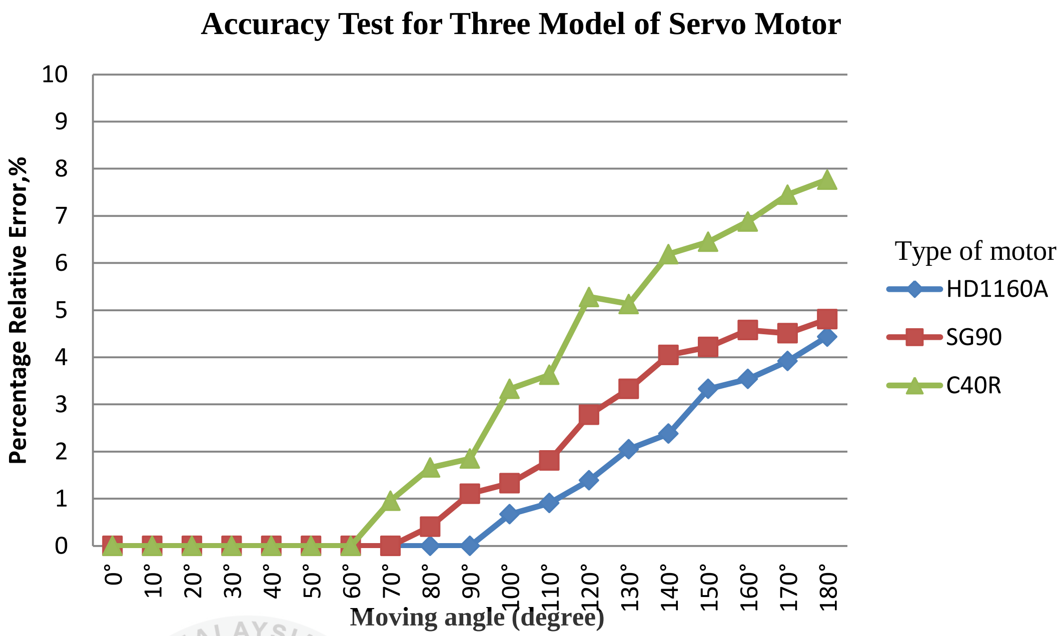


Figure 4.9: Percentage relative error for three model of servo motor

The graph above shows the percentage of relative error for three models of servo motors, which are HD1160A micro servo, SG90 micro servo and C40R RC hobby servo. This experiment covered the motion of the servo motor from 0° to 180°. From the result obtain, we can observe that HD1800A micro servo had a better accuracy in the angle of motion where it only start to varied from it desired value at the angle of 100°. The relative percentage error for this model of servo motor increase in a slower rate compare to other two models of servo motor. The percentage of relative error at 180° for this motor was 4.44% where it was 0.37% lower than SG90 micro servo and 3.33% lower than C40R RC hobby servo.

For SG90 micro servo, the angle value starts to deviate from the desired value at 80°. The maximum of percentage of relative error occurs at 180° with 4.81%. The error of the angle value at 180° is 8.67°. For C40R RC hobby servo, it has the lowest accuracy of angle motion compared to other two types of motor. The motor starts to produce error at 70°. The maximum percentage of relative error for this motor is 7.77% and it occurs at 180°.

Among these three models of servo motor, HD1160A micro servo provides more precise motion especially in the range from 0 ° until 90 °. It is also the most suitable actuators to use for the high angle motion which more than 90 °. This can be applied at the eyes part (eyeballs and eyebrows) of robot head where it requires higher accuracy of motion. While for the SG90 micro servo, although it has slightly lower accuracy compared to HD1160A, however it still able to produce an accurate angle value in the range of 0 ° to 70 °. This motor suitable to implement at the eyelid part as the motion of lips is not more than 70 ° and it able to provide a high accuracy of robot head expression. The C40R RC hobby servo only produces accurate angle value at 60 ° and below. This motor suitable to use at the lips part due to that the lips only required short range of motion. Beside of this, C40R have higher torque compare to other two model of motor and it is more suitable to drive the lips mechanism which made up by using silicone sealant material.

This experiment provide a series of results that ease the selection of servo motor to be implement on the robot head without purchase new motors.. This can also reduce the budget of the project for purchasing more actuators where one normal servo motor may cost for about RM40. The full performance of the robot head was highly depends on the combination of actuators with the mechanism which uses to form the expression on robot head.

4.5 Eyebrows Accuracy Test

Table 4.10: Accuracy test for eyebrow part L1

Angle (°)	Sample														
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
-40	-40	-40	-40	-40	-40	-39	-40	-40	-40	-40	-40	-40	-39	-40	-39
-30	-30	-29	-30	-30	-30	-29	-29	-30	-29	-30	-30	-30	-30	-29	-30
-20	-20	-20	-20	-19	-20	-20	-19	-20	-20	-20	-19	-20	-19	-20	-20
-10	-10	-10	-10	-10	-10	-10	-10	-9	-10	-10	-10	-10	-10	-10	-10
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
10	10	10	9	10	10	10	10	10	9	10	10	10	10	10	10
20	19	19	20	20	20	20	20	19	20	20	20	20	19	20	20
30	30	29	30	30	30	30	29	30	30	30	30	29	30	30	29
40	40	40	40	40	40	40	39	39	40	40	40	39	40	40	40

Table 4.11: Mean value, error and RPE for accuracy test eyebrow part L1

Angle (°)	Mean (°)	Error (°)	RPE (%)
-40	-39.80	0.20	0.50
-30	-29.67	0.33	1.10
-20	-19.73	0.27	1.35
-10	-9.93	0.07	0.70
0	0	0	0
10	9.87	0.13	1.30
20	19.73	0.27	1.35
30	29.73	0.27	0.90
40	39.80	0.20	0.50

Table 4.12: Accuracy test for eyebrow part L2

Angle (°)	Sample														
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
-40	-39	-40	-40	-40	-39	-40	-39	-40	-40	-39	-40	-39	-40	-39	-40
-30	-29	-30	-30	-28	-29	-30	-30	-30	-30	-29	-30	-30	-29	-30	-30
-20	-20	-19	-19	-20	-20	-19	-19	-19	-20	-20	-20	-19	-20	-19	-20
-10	-10	-9	-10	-10	-10	-10	-10	-10	-9	-10	-9	-10	-10	-10	-10
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
10	10	10	10	10	10	9	10	9	10	10	10	10	9	10	10
20	20	19	20	20	20	20	19	19	19	19	20	19	20	20	20
30	29	30	29	30	30	30	30	29	30	29	30	29	30	29	29
40	40	39	40	40	40	40	39	39	40	40	40	40	39	40	40

Table 4.13: Mean value, error and RPE for accuracy test eyebrow part L2

Angle (°)	Mean (°)	Error (°)	RPE (%)
-40	-39.60	0.40	1.00
-30	-29.60	0.40	1.33
-20	-19.53	0.47	2.35
-10	-9.80	0.20	2.00
0	0	0	0
10	9.80	0.20	2.00
20	19.60	0.40	2.00
30	29.53	0.47	1.57
40	39.73	0.27	0.68

Table 4.14: Accuracy test for eyebrow part R1

Angle (°)	Sample														
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
-40	-40	-39	-40	-40	-40	-40	-40	-40	-40	-40	-40	-40	-40	-40	-40
-30	-30	-30	-30	-30	-29	-30	-29	-30	-29	-30	-30	-30	-30	-30	-30
-20	-19	-20	-20	-19	-20	-20	-20	-20	-20	-19	-20	-20	-20	-20	-19
-10	-10	-10	-10	-10	-10	-10	-10	-10	-10	-10	-9	-10	-10	-10	-10
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
10	10	10	10	10	10	10	10	9	10	10	10	10	10	10	9
20	20	19	20	20	19	20	20	20	20	19	20	20	20	19	20
30	29	30	30	30	30	30	30	29	30	30	29	30	29	29	30
40	40	39	39	40	40	40	40	40	40	40	39	40	40	40	40

Table 4.15: Mean value, error and RPE for accuracy test eyebrow part R1

Angle (°)	Mean (°)	Error (°)	RPE (%)
-40	-39.93	0.07	0.18
-30	-29.80	0.20	0.67
-20	-19.73	0.27	1.35
-10	-9.93	0.07	0.70
0	0	0	0
10	9.87	0.13	1.30
20	19.73	0.27	1.35
30	29.67	0.33	1.10
40	39.80	0.20	0.50

Table 4.16: Accuracy test for eyebrow part R2

Angle (°)	Sample														
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
-40	-40	-40	-40	-39	-40	-40	-40	-40	-39	-40	-40	-39	-40	-40	-40
-30	-30	-30	-30	-30	-30	-29	-30	-30	-30	-30	-29	-30	-30	-30	-29
-20	-20	-20	-20	-20	-20	-20	-20	-20	-20	-19	-20	-20	-19	-19	-20
-10	-10	-10	-10	-10	-10	-10	-9	-10	-10	-10	-10	-10	-10	-10	-10
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
10	10	10	10	10	10	9	10	10	10	9	10	10	10	10	10
20	20	19	20	20	20	20	19	20	20	20	20	19	20	19	19
30	30	30	30	30	30	28	30	29	30	30	29	30	30	29	30
40	39	40	40	40	39	39	40	40	40	40	40	40	39	40	40

Table 4.17: Mean value, error and RPE for accuracy test eyebrow part R2

Angle (°)	Mean (°)	Error (°)	RPE (%)
-40	-39.80	0.20	0.50
-30	-29.80	0.20	0.67
-20	-19.80	0.20	1.00
-10	-9.93	0.07	0.70
0	0	0	0
10	9.87	0.13	1.30
20	19.67	0.33	1.65
30	29.67	0.33	1.10
40	39.73	0.27	0.68

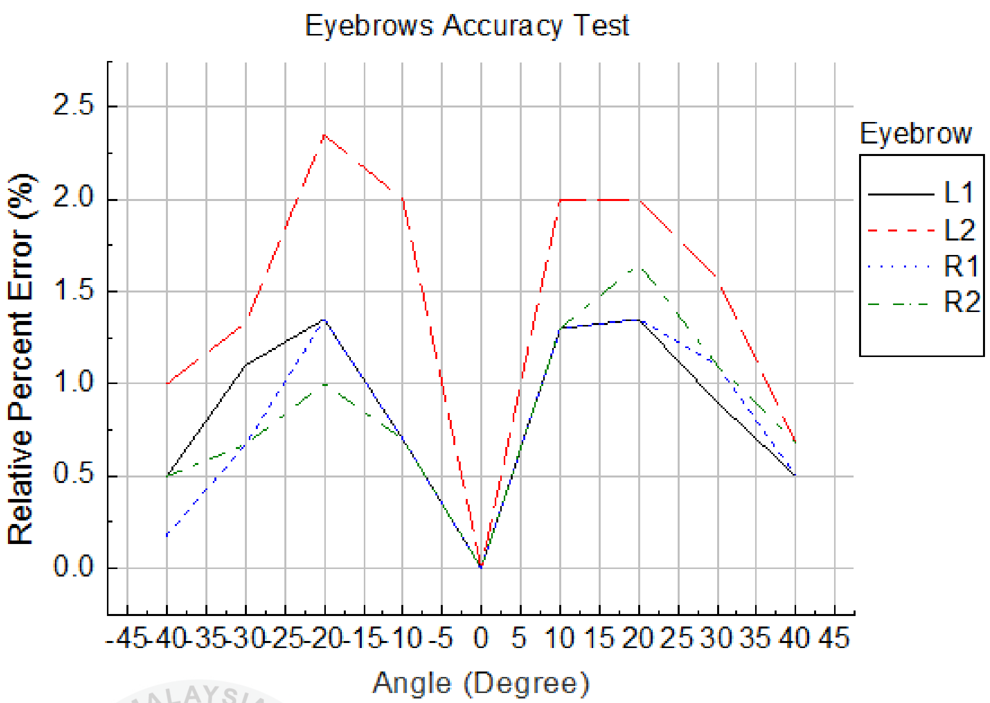


Figure 4.10: Graph of eyebrows accuracy test

The graph above shows the relationship between the relative percent error and the angle motion of eyeballs which tested on 4 parts of eyebrows (L1, L2, R1, R2). L1 and L2 was the par from left eyebrow while R1 and R2 represent two part of right eyebrow. The allowable range of motion (angles) for each part on the eyebrow was from -40 ° to 40 °. From the result, we can observe that eyebrow L2 have a relative high percentage of RPE in compare with other three part of eyebrow. The highest RPE for L2 was occurs at -20 ° with the amount of 2.35% of error. For three other parts, L1, R1 and R2, their highest RPE was only 1.35%, 1.35% and 1.65% respectively. This indicates that eyebrow with the part L2 was not so accurate in its positioning and it was due to the improper direct attached of the servo motor to the eyebrow. One servo motor has been attached to each part of the eyebrow and the motion of the motor was directly drive the motion of eyebrow. From the graph, we also can observe that at -40 ° and 40 °, eyebrow have the relative low RPE by compare with the position in the range of -35 ° to 5 ° and 5 ° to 35 °. At -40 °, eyebrow part L1, L2, R1 and R2 have the RPE of 0.5%, 1%, 0.18% and 0.5% respectively. While at 40 °, the RPE for L1 was 0.5%, 0.68% for L2, 0.5% for R1 and 0.68% for R2. When the motor drive the eyebrow part to its maximum angle (-40 ° and 40 °), the position (angle) was more nearer to its actual position.

The overall RPE for eyebrows was below 2.5% and it was considered as an accurate motion for this parts. The mechanism used (direct attach method) of the servo motor to the eyebrows was the main factor that lead to the accuracy of the motion. Servo motor has a precise angle of motion and this allows eyebrows to perform repeat movement accurately in different position.

4.6 Eyeballs Accuracy Test

4.6.1 Eyeballs Left-Right Motion Accuracy Test

Table 4.18: Accuracy test for left-right motion of left eyeball

Angle (°)	Sample														
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
-30	-28	-28	-29	-27	-29	-28	-28	-27	-28	-28	-28	-29	-28	-28	-29
-20	-19	-20	-19	-20	-19	-19	-19	-19	-20	-19	-18	-20	-20	-19	-19
-10	-10	-10	-10	-9	-10	-9	-10	-9	-10	-9	-10	-10	-10	-10	-9
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
10	9	10	10	10	10	9	10	10	10	10	10	10	10	9	10
20	18	20	18	19	19	19	20	19	19	20	19	19	18	20	18
30	28	29	28	28	28	28	27	27	28	29	27	28	28	28	28

Table 4.19: Mean value, error and RPE for left eyebrow left-right motion accuracy test

Angle (°)	Mean (°)	Error (°)	RPE (%)
-30	-28.13	1.87	6.23
-20	-19.27	0.73	3.65
-10	-9.67	0.33	3.30
0	0	0	0
10	9.80	0.20	2.00
20	19	1.00	5.00
30	27.93	2.07	6.90

Table 4.20: Accuracy test for left-right motion of right eyeball

Angle (°)	Sample														
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
-30	-29	-29	-28	-29	-28	-29	-28	-29	-29	-29	-29	-29	-29	-28	-29
-20	-19	-19	-19	-19	-20	-20	-20	-19	-19	-20	-19	-19	-19	-20	-19
-10	-10	-10	-9	-10	-9	-9	-10	-9	-10	-10	-10	-10	-10	-9	-10
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
10	9	9	9	10	10	9	10	10	10	9	10	10	9	10	10
20	18	19	18	18	19	19	18	19	19	18	19	18	19	17	19
30	28	27	27	28	27	29	27	28	27	27	28	27	28	28	28

Table 4.21: Mean value, error and RPE for right eyebrow left-right motion accuracy test

Angle (°)	Mean (°)	Error (°)	RPE (%)
-30	-28.73	1.27	4.23
-20	-19.33	0.67	3.35
-10	-9.67	0.33	3.30
0	0	0	0
10	9.60	0.40	4.00
20	18.47	1.53	7.65
30	27.6	2.40	8.00

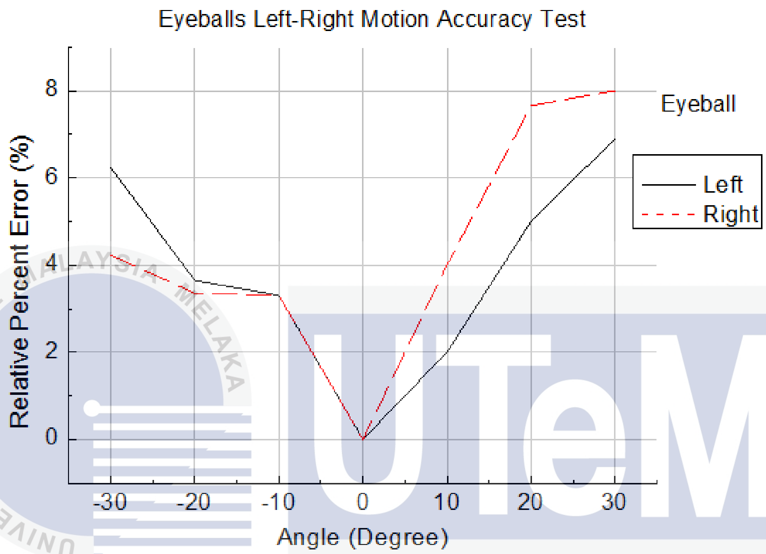


Figure 4.11: Graph of the eyeballs left-right motion accuracy test

The graph above shows the relationship between relative percent errors of the left right motion of eyeballs with its motion angle. The left-right movable range of angle for eyeballs was -30 ° to 30 °. Eyeballs was moved to left from the angle of 0 ° to -30 ° while moved to right from the angle of 0 ° to 30 °. From the graph we can observe that left eyeball have 6.9% of RPE compare to only 4.23% for right eyeball at 30 °. This indicates that left eyeball have a more accurate angle motion when it turn to the left side compare to right eyeball. While at angle 30 °, right eyeball have 1.10% RPE higher compare to left eyeball. This shows that right eyeball have a more accurate positioning in moving to right side with compare to left eyeball. Both side of the eyeball was connected to a steel wire which acts as linkage to connect the eyeballs with the servo motor. When the servo motor is moved to drive the eyeballs in left right motion, there was some lost for the motion accuracy due to the collision between the wire and the eyeballs. The overall RPE for the eyeballs in left right motion was below 10%.

4.6.2 Eyeballs Up-Down Motion Accuracy Test

Table 4.22: Accuracy test for up-down motion of left eyeball

Angle (°)	Sample														
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
-60	-57	-58	-58	-58	-57	-58	-58	-57	-58	-57	-57	-57	-58	-58	-58
-50	-49	-48	-48	-49	-49	-48	-49	-48	-49	-48	-49	-49	-49	-48	-48
-40	-39	-39	-40	-39	-39	-39	-40	-38	-38	-38	-40	-38	-38	-39	-38
-30	-29	-29	-29	-30	-29	-30	-29	-30	-29	-30	-29	-30	-29	-29	-30
-20	-20	-20	-20	-19	-19	-20	-20	-20	-19	-19	-20	-19	-19	-20	-19
-10	-10	-10	-9	-10	-10	-9	-10	-9	-10	-10	-10	-10	-10	-9	-10
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
10	9	8	9	9	9	8	9	8	9	8	8	8	9	9	9
20	16	15	17	16	16	15	16	17	16	16	16	15	16	16	17

Table 4.23: Mean value, error and RPE for left eyebrow up-down motion accuracy test

Angle (°)	Mean (°)	Error (°)	RPE (%)
-60	-57.6	2.40	4.00
-50	-48.53	1.47	2.94
-40	-38.80	1.20	3.00
-30	-29.4	0.60	2.00
-20	-19.53	0.47	2.35
-10	-9.73	0.27	2.70
0	0	0	0
10	8.60	1.40	14.00
20	16	4.00	20.00

Table 4.24: Accuracy test for up-down motion of left eyeball

Angle (°)	Sample														
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
-60	-58	-57	-58	-56	-56	-57	-56	-56	-57	-57	-56	-57	-56	-58	-57
-50	-48	-48	-49	-48	-47	-49	-47	-48	-49	-48	-48	-48	-47	-48	-48
-40	-39	-38	-38	-38	-39	-37	-38	-37	-39	-38	-38	-39	-38	-38	-39
-30	-29	-28	-27	-28	-27	-28	-27	-28	-28	-29	-29	-29	-28	-29	-29
-20	-19	-19	-18	-20	-20	-19	-19	-19	-20	-19	-20	-19	-20	-20	-19
-10	-10	-10	-10	-10	-10	-10	-10	-10	-10	-10	-9	-10	-10	-10	-9
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
10	9	9	9	9	9	8	9	10	9	9	9	10	9	10	9
20	17	14	16	16	15	16	16	15	16	17	15	16	15	15	16

Table 4.25: Mean value, error and RPE for right eyebrow up-down motion accuracy test

Angle (°)	Mean (°)	Error (°)	RPE (%)
-60	-56.80	3.20	5.33
-50	-48	2.00	4.00
-40	-38.2	1.80	4.50
-30	-28.20	1.80	6.00
-20	-19.33	0.67	3.35
-10	-9.87	0.13	1.30
0	0	0	0
10	9.13	0.87	8.70
20	15.67	4.33	21.65

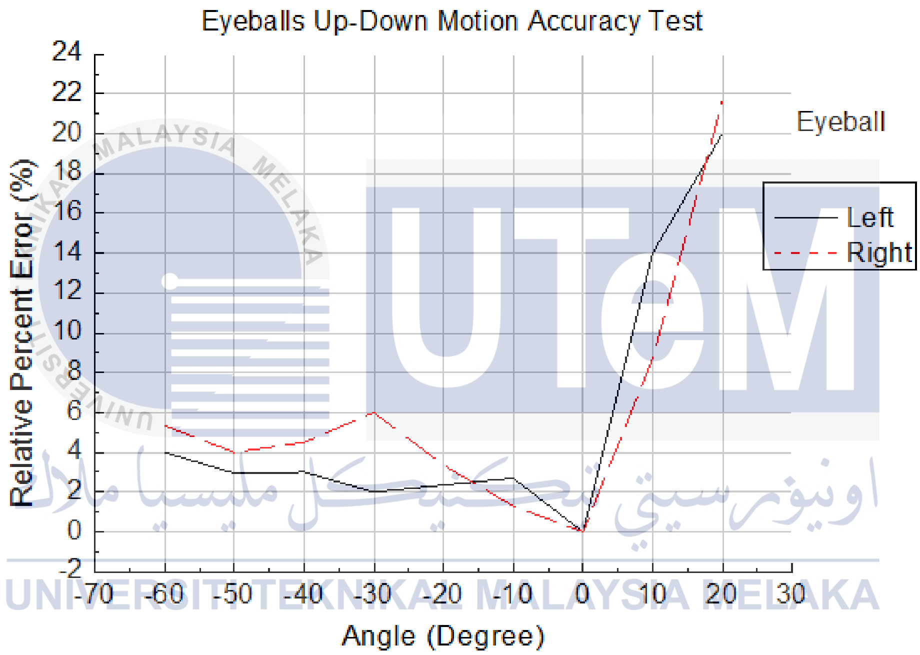


Figure 4.12: Graph for the eyeballs up-down motion accuracy test

The graph above shows the relationship of relative percent error for the up-down motion of eyeballs. The up-down movable range of angle for eyeballs was from -60 ° to 20 °. Eyeballs was move down from the angle 0 ° to -60 ° while move up from 0 ° to 20 °. From the graph, we can observe that the RPE for the left and right eyeball to move in down position was much lower compare to move in up position. The highest RPE for left eyeball in down position was 4% while for right eyeball was 6%. There are only 2% of RPE different for left and right eyeball. For the motion of eyeballs in up position, the RPE strive over 20% where for left eyeball was 20% while right eyeball was 21.65%.

The RPE error for the eyeballs move in up position is significantly higher compare to move in down position. This is mainly due to mechanism used where the wire linkage that connect the eyeballs to the servo motor was in pull condition when moving the eyeballs in down while the wire linkage was in push condition when moving the eyeballs up. Push condition may cause the wire to bend and thus it cause large error during the accuracy test for the up motion of eyeballs. In order to eliminate the large RPE in the motion for eyeballs in up position, the maximum position for the eyeballs had limit to only 15 ° but not 20 ° at first. The reason for set the upper limit position for the eyeballs at 15 ° was to make sure the overall RPE is below 20%

4.7 Lips Accuracy Test

Table 4.26: Accuracy test for upper lip

Distance (cm)	Sample														
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0.2	0.1	0.1	0.1	0.2	0.1	0.1	0.2	0.1	0.1	0.1	0.2	0.1	0.1	0.2	0.1
0.4	0.4	0.3	0.3	0.4	0.3	0.3	0.3	0.3	0.4	0.4	0.3	0.3	0.4	0.3	0.4
0.6	0.6	0.6	0.7	0.6	0.5	0.7	0.6	0.5	0.5	0.6	0.7	0.6	0.6	0.7	0.7
0.8	0.8	0.9	0.8	0.8	0.8	0.7	0.8	0.7	0.8	0.7	0.8	0.8	0.8	0.7	0.9
1.0	1.0	1.0	1.0	1.1	1.0	1.0	1.1	1.0	0.9	1.0	1.0	1.1	1.0	1.0	1.0

Table 4.27: Mean value, error and RPE for upper lip accuracy test

Distance (cm)	Mean (cm)	Error (cm)	RPE (%)
0	0	0	0
0.2	0.127	0.027	13.500
0.4	0.340	0.060	15.000
0.6	0.613	0.013	2.167
0.8	0.787	0.013	1.667
1.0	1.013	0.013	1.300

Table 4.28: Accuracy test for lower lip

Distance (cm)	Sample														
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
0.6	0.4	0.5	0.5	0.5	0.5	0.4	0.5	0.4	0.4	0.5	0.5	0.5	0.5	0.4	0.5
0.4	0.4	0.4	0.3	0.4	0.4	0.3	0.4	0.3	0.3	0.3	0.4	0.3	0.4	0.4	0.3
0.2	0.2	0.1	0.2	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.2	0.1	0.1
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
-0.2	-0.1	-0.1	-0.1	-0.2	-0.1	-0.1	-0.2	-0.1	-0.1	-0.1	-0.1	-0.2	-0.1	-0.1	-0.1
-0.4	-0.3	-0.3	-0.4	-0.3	-0.4	-0.4	-0.3	-0.4	-0.3	-0.4	-0.4	-0.3	-0.3	-0.3	-0.4
-0.6	-0.5	-0.6	-0.6	-0.6	-0.5	-0.5	-0.5	-0.5	-0.5	-0.6	-0.5	-0.5	-0.6	-0.5	-0.5
-0.8	-0.8	-0.8	-0.7	-0.7	-0.8	-0.8	-0.8	-0.7	-0.8	-0.7	-0.7	-0.7	-0.8	-0.7	-0.7
-1.0	-1.0	-1.0	-1.0	-1.0	-0.9	-1.0	-1.0	-1.0	-1.0	-0.9	-1.0	-1.0	-0.9	-0.9	-1.0
-1.2	-1.2	-1.2	-1.1	-1.2	-1.1	-1.2	-1.2	-1.2	-1.2	-1.2	-1.2	-1.2	-1.1	-1.2	-1.2
-1.4	-1.4	-1.4	-1.4	-1.4	-1.4	-1.4	-1.4	-1.4	-1.3	-1.4	-1.3	-1.4	-1.4	-1.4	-1.4
-1.6	-1.6	-1.5	-1.6	-1.6	-1.5	-1.5	-1.5	-1.5	-1.5	-1.5	-1.6	-1.5	-1.5	-1.5	-1.5

Table 4.29: Mean value, error and RPE for lower lip accuracy test

Distance (cm)	Mean (cm)	Error (cm)	RPE (%)
0.6	0.467	0.133	22.167
0.4	0.353	0.047	11.750
0.2	0.12	0.020	10.000
0	0	0	0
-0.2	0.12	0.020	10.000
-0.4	0.346	0.054	13.500
-0.6	0.533	0.067	11.167
-0.8	0.747	0.053	6.625
-1.0	0.973	0.027	2.700
-1.2	1.180	0.020	1.667
-1.4	1.387	0.013	0.952
-1.6	1.527	0.073	4.583

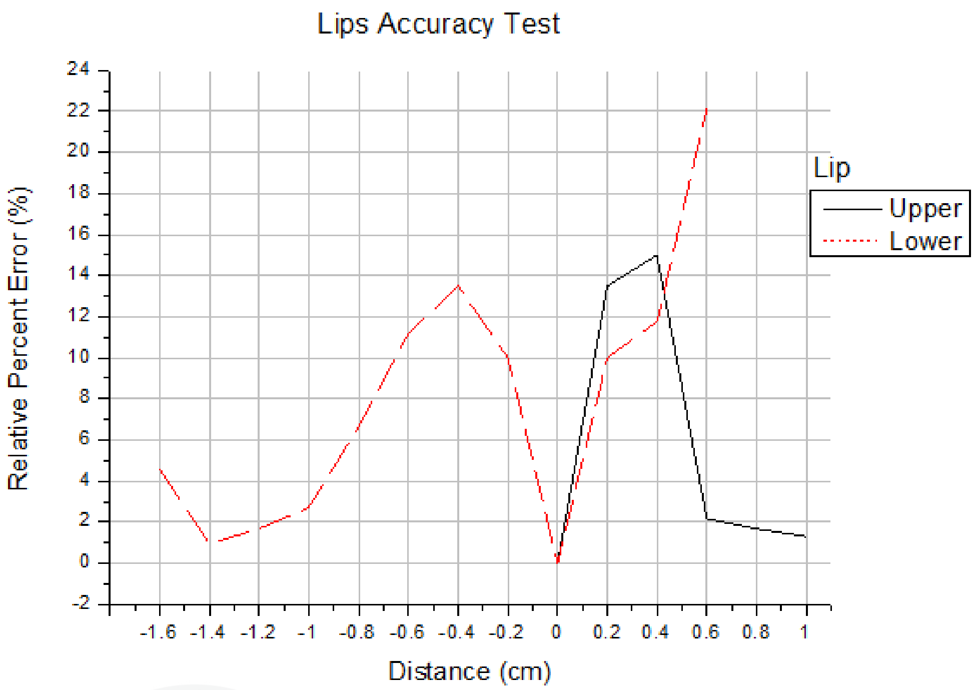


Figure 4.13: Graph of the lips accuracy test

The graph above shows the relationship between the relative percent errors of the lips motion with its moving distance. The accuracy test for the lip was separate into two parts which is upper lip test and lower lip test. For upper lip test, the allowable moving distance for the lip is from 0cm to 1cm while for lower lip test, the allowable moving distance is from 0.6cm to -1.6cm. In the upper lip test, we can observe that the maximum RPE occurs at 0.4cm with 15% while the lowest RPE was at 1cm which is only 1.3%. This indicates that the upper lip have a higher accuracy when it was stretched to the maximum position (1cm). This is important the express of anger and surprise emotion where both of this expression require a full extension of upper lip. While for the lower lip test, we can observe that the higher RPE was occurs at 0.6cm with 22.167%. At 0.6cm, the lower lip was stretched maximum to the upper position. The motion of the lower lips to upper position was limited by the arrangement of the lips. The maximum position for lower lip to move upwards was decided to limit at 0.5cm in order to keep the RPE below 20%. The lower lip is designed to move in up position as it able to strengthen the sad expression. Beside this, the lowest RPE for the motion of lower lip occurs at -1cm. The lower lip able to performs an accurate motion when it was fully stretched down 1cm from its original position. This able to increase the recognition rates for the expression such for happy and surprise emotion which required the full stretching of lower lip in down position.

4.8 Expression Recognition Test

Table 4.30: Recognition rate for expression recognition test

Actual Expression	Selection Expression from Respondent							Recognition Rate (%)
	Joy	Sadness	Anger	Disgust	Surprise	Fear	Others	
Joy	100	-	-	-	-	-	-	100
Sadness	-	95	-	5	-	-	-	95
Anger	-	-	84	10	-	-	6	84
Disgust	-	-	-	71	-	18	11	71
Surprise	-	-	-	-	100	-	-	100
Fear	-	7	-	17	-	73	3	73

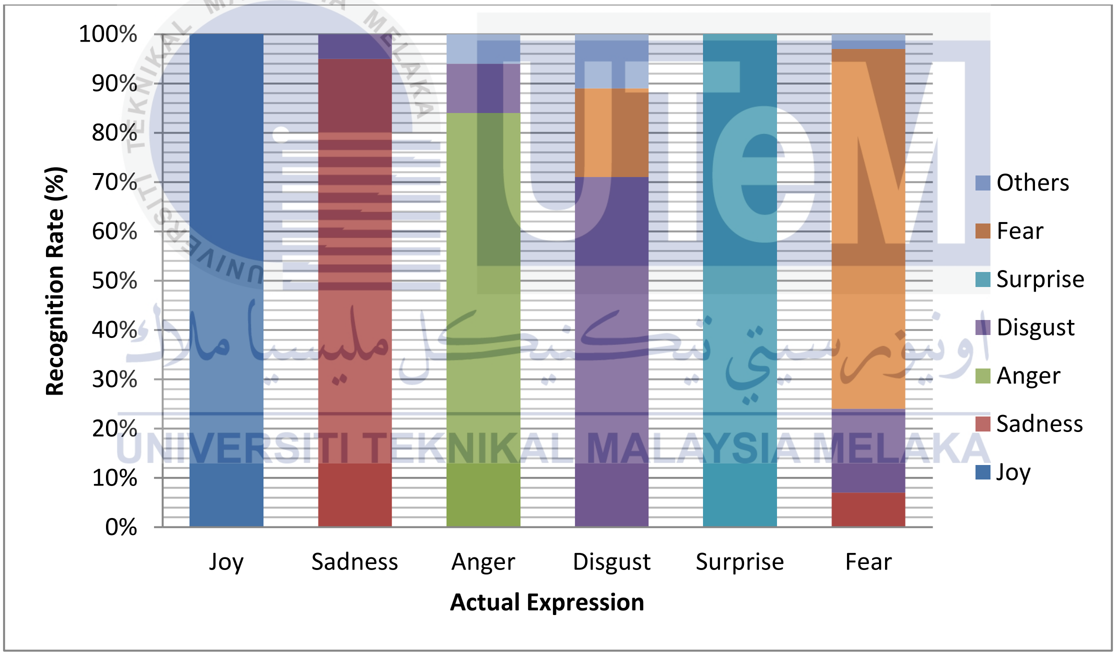


Figure 4.14: Recognition rate for each robot head expression

The bar chart above indicates the expression recognition rates for six basic emotion that the robot head able to perform. These six basic emotions are joy, sadness, anger, disgust, surprise and fear. Among this six expressions, joy and surprise emotion have the higher recognition rate where both of this emotion obtained 100% recognition from the 100 respondents. This shows that the combination of action units used in this two expressions are suitable and effective.

For joy expression, the decisive motion of robot head part was on its lips motion where the lower lip was moving downwards to form the expression. While for surprise expression, the eyelid was fully open and both the upper and lower lip was also fully extend to its maximum position. The emotion sadness comprised 95% of recognition rate which is also one of the expressions that received high recognition. The eyeballs and eyelid moved downwards and both upper lip and lower was moved upwards to perform this expression. This expression gives a slightly mixing of disgust expression for the respondents (5%). For anger expression, it received 84% of recognition from the respondents and where another 10% respondents stated it as disgust emotion and 6% from other expression. The upper lip was moved upward to perform anger expression and this slightly affects the recognition rate of the expression due to mixing of disgust expression. The recognition rate for fear expression was slightly higher than disgust expression where it obtained 73% of effective recognition compared to only 71% for disgust expression. These two emotions have low power of expression ability on robot head compared to other four expressions. The upper lip and lower lip was open slightly for this two expressions and for fear expression, it was strengthen with the wider open of angle for the eyelid. The overall expression recognition rate on the robot head are above 70% and this effective expression ability able to provide a good and reliable learning system for autism children.

CHAPTER 5

CONCLUSION AND RECOMMENDATION

The conclusion for overall Final Year Project can be generalized as follow:

i. The robot head able to perform 6 basic expression (joy, sadness, anger, disgust, surprise and happy) through the combination of 10 action units and two fixed units. The robot head made up of eyeballs, eyelid, eyebrows, and lips which are the major elements of a normal human head. The robot head face was fabricated by using 3D prototyping method. (Objective 1)

ii. The comic-like face is chosen as the outlook appearance for the robot head. It provides a more friendly looks to the user and more easily accepted by the children.

iii. The robot head consist of 11 degrees of freedom for the movement and it used 11 actuators to driven the mechanism of robot head parts.

iv. The implementation of IR remote keypad and LCD display system was introduced in this project. For each expression select by the user through keypad controller, the LCD display able to show that particular name of emotion. There are total seven buttons are set and it represent activation of seven different expressions (neutral, joy, sadness, anger, disgust, surprise and fear). (Objective 2)

v. The performance testing for the position accuracy of the robot head parts (eyeballs, eyebrows, eyelid and lips) are conducted. The result shows that the relative position error for each robot head parts was less than 20% and thus robot head able to perform the emotion effectively. The survey on the recognition rate for each emotion expression was conducted individually to 100 respondents. The overall recognition rate obtained for the six emotions express by robot head was more than 70%.

There are some recommendations on the future work regarding this project:

i. The four fixed point on the upper and lower lip can change to action unit and this able to increase the power of expression ability on robot head.

ii. A control point and action unit can add in for the nose part. This action unit enable the extension and contraction of the robot nose and this can lead to the increase of expression ability especially for disgust and fear emotion.

iii. The mechanism used in eyeballs can replace with half shaft U-joint where it able to provides a more stable push-pull motion for eyeballs.

iv. The robot head can be further construct by add in some additional features such as hair. On top of the robot head was provided with some hole with the purpose for other parts to fix in. The robot face and lips can also paint with appropriate colour to improve the human likeness of the robot head.

REFERENCES

[1] "Health Facts 2012", Departments of Statistic Malaysia, Malaysia, 2012, pp. 3-4.

[2] "Arts Centre for Autistic Kids", New Straits Times, 2012 [Online]. Available: http://www.nst.com.my/latest/arts-centre-for-autistic-kids-1.155159

[3] "Prevalence of Autism Spectrum Disorders", Department of Health and Human Services, Centres for Disease Control and Prevention. Morbidity and Mortality Weekly Report, United States, 2012.

[4] A. Klin, S. Sparrow, A.Bildt, V. Cicchetti, J. Cohen, and R. Volkmar, "A Normed Study of Face Recognition in Autism and Related Disorders", Journal of Autism and Developmental Disorders, Vol. 29, No. 6, 1999.

[5] A. Mehrabian, "Communication without Words", Psychology Today, Vol.2, No. 4, 1968.

[6] T.Bekele, U.Lahiri, R. Swanson, A. Crittendon, E. Warren and N. Sarkar, "A Step Towards Developing Adaptive Robot-Mediated Intervention Architecture (ARIA) for Children With Autism", Neural Systems and Rehabilitation Engineering, IEEE Transactions on , vol.21, no.2, pp.289,299, 2013.

[7] I. Lütkebohle, F. Hegel, S. Schulz, M. Hackel, B. Wrede, S.Wachsmuth and G. Sagerer, "The Bielefeld Anthropomorphic Robot Head 'Flobi'", IEEE International Conference on Robotics and Automation, Anchorage, Alaska, 2010.

[8] P. Ekman and W.V. Friesen, "The Facial Action Coding System", Consulting Psychologists Press, 1978.

[9] T. Kishi, T. Otani, N. Endo, P. Kryczka, K. Hashimoto, K. Nakata, A. Takanishi. Development of Expressive Robotic Head for Bipedal Humanoid Robot. IEEE International Conference on Intelligent Robots and Systems, Vilamoura, Algarve, Portugal, October 2012.

[10] H. Song, Y.-M.Kim, J.-C.Park, C. H. Kim, and D.-S. Kwon, "Design of a robot head for emotional expression: EEEX," in RO-MAN 2008-The 17th IEEE International Symposium on Robot and Human Interactive Communication, 2008, pp. 207–212.

[11] G. Wu, Q. M. Meng, Y. Wang, "Development of the humanoid head portrait robot system with flexible face and expression", Proceedings of the 2004 IEEE International Conference on Robotics and Biomimetics, pp. 718-723.

[12] T. Hashimoto, S. Hiramatsu, T. Tsuji and H. Kobayashi, "Development of the Face Robot SAYA for Rich Facial Expressions", Proceeding of SICE-ICASE International Joint Conference 2006, 2006, pp.5423-5428.

[13] K.Berns, T.Braum, "Design concept of a human-like robot head," Humanoid Robots, 2005 5th IEEE-RAS International Conference on , vol., no., pp.32,37, 5-5 Dec. 2005.

[14] O. Olcucuoglu, A.B.Koku, E.I. Konukseven, "i-RoK: A human like robotic head", Humanoid Robots, 2007 7th IEEE-RAS International Conference on , vol., no., pp.442,446, 2007.

[15] L. Huangfu, W. Mao, D. Zeng, L. Wang, "OCC model-based emotion extraction from online reviews," Intelligence and Security Informatics (ISI), 2013 IEEE International Conference on , vol., no., pp.116,121, 4-7 June 2013.

APPENDICES

Appendix A

Project Planning (Gantt Chart)

	2013															2014																			
Month	September			October				November				December				January				February				March				April				May			
Project Activities	1	2	3	4	5	6	7	8	9	10	11	12	13	14	-	-	-	-	-	-	-	1	2	3	4	5	6	7	8	9	10	11	12	13	14
Project Title Registration	■	■						Mid Semester Break							Study Week	Final Exam Week	Semester Break												Mid Semester Break						
Project Research		■	■	■	■	■	■		■	■	■	■	■	■																					
Preparation Proposal		■	■	■	■	■	■		■																										
Component Selection (Phase 1)				■	■	■																													
Data Collection					■	■	■																												
Software Design						■	■																												
Study LCD display						■																													
Study Servo Motor							■																												
Study Arduino Controller									■																										
Software Simulation							■		■	■																									
Hardware Development											■	■	■	■								■	■	■	■	■	■	■							
Component Selection (Phase 2)											■	■	■	■																					
Integrate Hardware & Software													■	■								■	■	■	■	■	■	■		■	■	■	■	■	
Performance Testing																											■	■		■	■	■	■	■	
Performance Analysis																											■	■		■	■	■	■	■	
Troubleshooting																											■	■		■	■	■	■	■	
Final Report Draft																						■	■	■	■	■	■	■							
Thesis Writing																														■	■	■	■	■	■
Report Submission										■				■																					■
FYP Presentation										■																									■
Discussion		■	■	■	■	■	■		■	■	■	■	■	■								■	■	■	■	■	■	■		■	■	■	■	■	■

Appendix B

Details of Project Activities:

i. Project Title Registration
   - Propose and register FYP title with lecturer
   - Submit title registration form and declaration form

ii. Project research
   - Findings on related article, journal and website about project
   - Keywords during searching : 'robot head', 'facial expression'
   - Study on the 6 basic expression, facial control units and action units, mechanism of robot head

iii. Preparation Proposal
   - Prepare a draft project proposal regarding FYP 1
   - The proposal include: Introduction (Motivation, Problem Statement, Objective, Scope), Literature Review, Methodology, Early Result and Discussion, and Conclusion

iv. Component Selection (Phase 1)
   - Arduino controller selection (amount of I/O pins, etc)
   - Servo motor selection (torque and speed identification)
   - LCD display selection
   - Keypad controller selection

v. Data Collection
   - Type of robot head
   - Best design of robot facial expression
   - 20 participants are involve in each survey

vi. Software Design
   - Using Solidworks software to design 6 basic robot head expression
   - The part that must include in the design is eyebrows, eyelid, eyeballs, and lips

vii. Study LCD display

- Study about the connection of LCD display (16 x 2)
- Study about the programming coding for the display by using Arduino
- The words to display on LCD are: 'Happy', 'Sad', 'Angry', 'Disgust', 'Surprise' and 'Fear'

viii. Study on Servo Motor

- Study about the way servo motor operate
- Study about the connection and programming coding to operate servo motor

ix. Study on Arduino Controller

- Study about the communication and interfacing by using Arduino
- Design simple coding for Arduino simulation

x. Software Simulation

- Carry out simulation of project by using Proteus software
- The simulation will include: Arduino controller, LCD display, Keypad controller and Actuators (servo motors)
- Basic programming are design by using Arduino software

xi. Hardware development

- Start to construct robot head with the sequence of: eyes, mouth, and head
- Actuator and type of mechanism to used are included for the construction of head

xii. Component Selection (Phase 2)

- Mechanism for each part of robot head will be selected at this stage
- The material to build the robot head and the internal structure of the robot head

xiii. Integrate Hardware and Software

- Implement programming coding with the robot head hardware
- Design a complete programming flow for 6 different expression
- LCD display and keypad controller must be involve in the design

xiv. Performance Testing

- Accuracy test for robot head parts are carry out
- The result will record down for further analysis
- Recognition rate for the facial expression also will be determine through the survey (conduct on 100 respondents)

xv. Performance Analysis

- Analyse the performance testing (accuracy test and recognition rate)
- Related graph is drawn for discussion

xvi. Troubleshooting

- Hardware and software troubleshooting is carry out simultaneously to obtain optimum performance for robot head

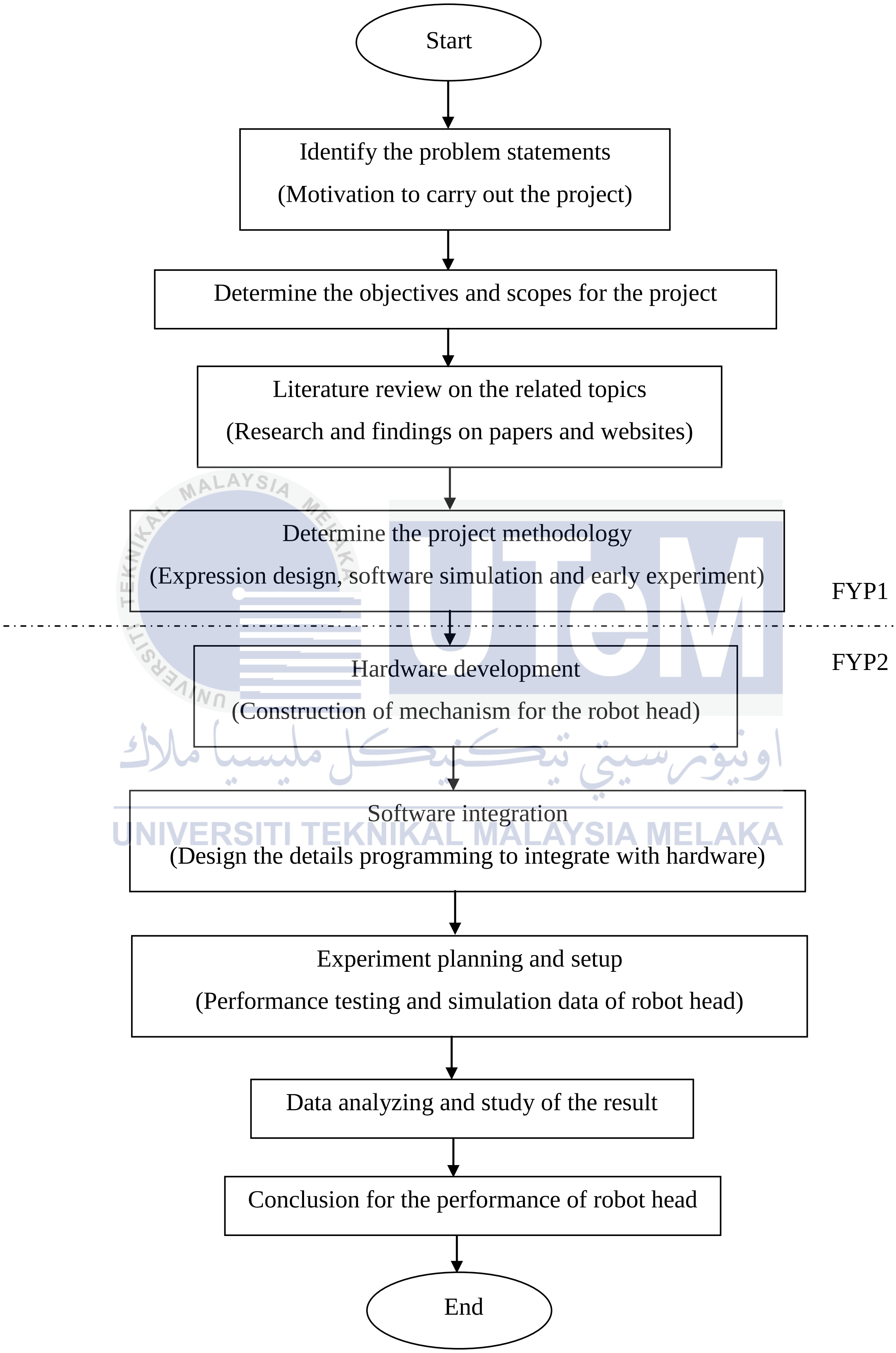
xvii. Final Report Draft

- Briefly write down the important information regarding whole FYP project

xviii. Thesis Writing

- Details writing on the FYP report which must include: Abstract, Introduction, Literature Review, Methodology, Results and Discussion, Conclusion, References, etc.

Appendix C


Start
Identify the problem statements
(Motivation to carry out the project)
Determine the objectives and scopes for the project
Literature review on the related topics
(Research and findings on papers and websites)
Determine the project methodology
(Expression design, software simulation and early experiment)
FYP1
FYP2
Hardware development
(Construction of mechanism for the robot head)
Software integration
(Design the details programming to integrate with hardware)
Experiment planning and setup
(Performance testing and simulation data of robot head)
Data analyzing and study of the result
Conclusion for the performance of robot head
End

Appendix D

Coding for Controller and Components Integration Test

```
#include <LiquidCrystal.h>
#include <Servo.h>

Servo servo_0;
LiquidCrystallcd(12,11,5,4,3,2);
constintbuttonPin = 0;
constint buttonPin2 = 1;
constintledPin =  13;
constint ledPin2 =  8;
constint ledPin3 =  9;
intbuttonState = 0;
int buttonState2 = 0;

void setup()
{lcd.begin(16,2);
lcd.clear();
pinMode(buttonPin, INPUT);
pinMode(buttonPin2, INPUT);
pinMode(ledPin, OUTPUT);
pinMode(ledPin2, OUTPUT);
pinMode(ledPin3, OUTPUT);
  servo_0.attach(6);           }

void loop()
{buttonState = digitalRead(buttonPin);
  buttonState2 = digitalRead(buttonPin2);

if (buttonState == HIGH && buttonState2 == LOW)
  {
  servo_0.write(60);
digitalWrite(ledPin, HIGH);
digitalWrite(ledPin2, LOW);
digitalWrite(ledPin3, LOW);
lcd.print("HAPPY");
delay(200);
lcd.clear();  }
```

```
else if (buttonState2 == HIGH &&buttonState == LOW)
  {
  servo_0.write(140);
digitalWrite(ledPin2, HIGH);
digitalWrite(ledPin, LOW);
digitalWrite(ledPin3, LOW);
lcd.print("SAD");
delay(200);
lcd.clear();
  }

else
  {
 servo_0.write(0);
digitalWrite(ledPin, LOW);
digitalWrite(ledPin2, LOW);
digitalWrite(ledPin3, HIGH);
lcd.print("NEUTRAL");
delay(200);
lcd.clear();   }}
```

Appendix E

Coding for Eyeballs and Eyebrows Accuract Test

```
#include <IRremote.h>
#include <Servo.h>

//IRremote code
unsigned long ValueON = 0xFFA25D;
unsigned long ValueMute = 0xFFe21d;
unsigned long ValueMinus = 0xFFA857;
unsigned long ValuePlus = 0xFF906F;
unsigned long Value0 = 0xFF6897;
unsigned long Value1 = 0xFF30CF;
unsigned long Value2 = 0xFF18E7;
unsigned long Value3 = 0xFF7A85;
unsigned long Value4 = 0xFF10EF;
unsigned long Value5 = 0xFF38C7;
unsigned long Value6 = 0xFF5AA5;
unsigned long Value7 = 0xFF42BD;
unsigned long Value8 = 0xFF4AB5;

Servo servo_1;
Servo servo_2;
Servo servo_3;
Servo servo_4;
Servo servo_5;//Left EB Left
Servo servo_6;//Left EB Right
Servo servo_7;//Right EB Left
Servo servo_8;//Right EB Right

int RECV_PIN = 9;
IRrecv irrecv(RECV_PIN);
decode_results results;

void setup()
{  Serial.begin(9600);
  irrecv.enableIRIn();
  pinMode(led_pin, OUTPUT);

  //Servo Pin
  servo_1.attach(5); //Ball Left Back
  servo_2.attach(10);//Ball Right Back
  servo_3.attach(4);// Ball Left Front
  servo_4.attach(11);// Ball Right Front
  servo_5.attach(2);//Brow Left Left
```

```
  servo_6.attach(3);// Brow Left Right
  servo_7.attach(12);//Brow Right LEft
  servo_8.attach(13);//Brow Right Right

  //Servo initial angle
  servo_1.write(105);
  servo_2.write(20);
  servo_3.write(80);
  servo_4.write(90);  }

void loop() {
  if (irrecv.decode(&results)) {
    Serial.println(results.value, HEX);
    irrecv.resume(); }

    //NEUTRAL
    if (results.value == Value0) {
      digitalWrite(led_pin,HIGH);
      servo_1.write(105);//LB ball
      servo_2.write(20);//RB ball
      servo_3.write(80);//LF ball
      servo_4.write(90);//RF ball
      servo_5.write(75);//LL brow
      servo_6.write(115);//LR brow
      servo_7.write(65);//RL brow
      servo_8.write(105);//RR brow    }

     //HAPPY
    if (results.value == Value1) {
      digitalWrite(led_pin,HIGH);
       servo_1.write(105);
       servo_2.write(20);
       servo_3.write(80);
       servo_4.write(90);
       servo_5.write(115);//LL brow
       servo_6.write(80);//LR brow
       servo_7.write(105);//RL brow
       servo_8.write(70);//RR brow    }

     //SAD
    if (results.value == Value2) {
      digitalWrite(led_pin,HIGH);
        servo_1.write(105);
        servo_2.write(20);
        servo_3.write(20);//LF
        servo_4.write(130);
        servo_5.write(115);//LL brow
        servo_6.write(150);//LR brow
        servo_7.write(30);//RL brow
        servo_8.write(70);//RR brow//RF    }
```

```
 //ANGER
if (results.value == Value3) {
  digitalWrite(led_pin,HIGH);
  servo_1.write(105);
  servo_2.write(20);
  servo_3.write(80);
  servo_4.write(90);
  servo_5.write(40);//LL brow
  servo_6.write(80);//LR brow
  servo_7.write(105);//RL brow
  servo_8.write(150);//RR brow}

 //DISGUST
if (results.value == Value4) {
  digitalWrite(led_pin,HIGH);
  servo_1.write(105);
  servo_2.write(20);
  servo_3.write(80);
  servo_4.write(90);
  servo_5.write(115);//LL brow
  servo_6.write(150);//LR brow
  servo_7.write(30);//RL brow
  servo_8.write(70);//RR brow    }

//SURPRISE
 if (results.value == Value5) {
  digitalWrite(led_pin,HIGH);
  servo_1.write(105);
  servo_2.write(20);
  servo_3.write(100);//LF
  servo_4.write(40);//RF
  servo_5.write(115);//LL brow
  servo_6.write(80);//LR brow
  servo_7.write(105);//RL brow
  servo_8.write(70);//RR brow    }

 //FEAR
 if (results.value == Value6) {
  digitalWrite(led_pin,HIGH);
  servo_1.write(105);
  servo_2.write(20);
  servo_3.write(80);
  servo_4.write(90);
  servo_5.write(115);//LL brow
  servo_6.write(150);//LR brow
  servo_7.write(30);//RL brow
  servo_8.write(70);//RR brow    }}
```

Appendix F

Coding for Lips Accuracy Test

```
#include <LiquidCrystal.h>
#include <IRremote.h>
#include <Servo.h>
LiquidCrystal lcd(14,15,16,17,18,19);

//IRremote code
unsigned long ValueON = 0xFFA25D;
unsigned long ValueMute = 0xFFe21d;
unsigned long ValueMinus = 0xFFA857;
unsigned long ValuePlus = 0xFF906F;
unsigned long Value0 = 0xFF6897;
unsigned long Value1 = 0xFF30CF;
unsigned long Value2 = 0xFF18E7;
unsigned long Value3 = 0xFF7A85;
unsigned long Value4 = 0xFF10EF;
unsigned long Value5 = 0xFF38C7;
unsigned long Value6 = 0xFF5AA5;
unsigned long Value7 = 0xFF42BD;
unsigned long Value8 = 0xFF4AB5;

int RECV_PIN = 2;
IRrecv irrecv(RECV_PIN);
decode_results results;

void setup()
{    Serial.begin(9600);
  irrecv.enableIRIn();
  servo_9.attach(3); //Mouth Up
  servo_10.attach(4);//Mouth Down

  //Servo initial angle
  servo_9.write(70);
  servo_10.write(160);
  lcd.begin(16,1);
  lcd.clear();
  lcd.print("IM EMOTION ROBOT");}

void loop()
{   if (irrecv.decode(&results)) {
    Serial.println(results.value, HEX);
    irrecv.resume(); }
```

```
 //BEGIN
if (results.value == ValueON) {
  lcd.print("IM EMOTION ROBOT");
  servo_9.write(70);
  servo_10.write(160);    }

 //NEUTRAL
if (results.value == Value0) {
  lcd.print("NEUTRAL         ");
  servo_9.write(70);
  servo_10.write(160);    }

//HAPPY
if (results.value == Value1) {
  lcd.print("HAPPY           ");
  servo_9.write(5);
  servo_10.write(140);    }

 //SAD
if (results.value == Value2) {
  lcd.print("SAD             ");
  servo_9.write(130);
  servo_10.write(80);    }

 //ANGER
if (results.value == Value3) {
  lcd.print("ANGRY           ");
  servo_9.write(90);
  servo_10.write(80);    }

 //DISGUST
if (results.value == Value4) {
  lcd.print("DISGUST         ");
  servo_9.write(40);
  servo_10.write(120);    }

//SURPRISE
 if (results.value == Value5) {
  lcd.print("SURPRISE        ");
  servo_9.write(5);
  servo_10.write(80); }

 //FEAR
 if (results.value == Value6) {
  lcd.print("FEAR            ");
  servo_9.write(30);
  servo_10.write(120);     }
```

Appendix G

Complete Coding for Robot Head System

```
#include <LiquidCrystal.h>
#include <IRremote.h>
#include <Servo.h>

LiquidCrystal lcd(58,59,54,55,56,57);

//IRremote button code declaration
unsigned long ValueON = 0xFFA25D;
unsigned long ValueMute = 0xFFe21d;
unsigned long ValueMinus = 0xFFA857;
unsigned long ValuePlus = 0xFF906F;
unsigned long Value0 = 0xFF6897;
unsigned long Value1 = 0xFF30CF;
unsigned long Value2 = 0xFF18E7;
unsigned long Value3 = 0xFF7A85;
unsigned long Value4 = 0xFF10EF;
unsigned long Value5 = 0xFF38C7;
unsigned long Value6 = 0xFF5AA5;
unsigned long Value7 = 0xFF42BD;
unsigned long Value8 = 0xFF4AB5;

//Motor declaration
Servo servo_1;// Eyeball left (left right)
Servo servo_2;// Eyeball right (left right)
Servo servo_3;// Eyeball left (up down)
Servo servo_4;// Eyeball right (up down)
Servo servo_5;// Eyebrow left inner (L1)
Servo servo_6;// Eyebrow left outer (L2)
Servo servo_7;// Eyebrow right outer (R1)
Servo servo_8;// Eyebrow right inner (R2)
Servo servo_9;// Eyelid
Servo servo_10;// Upper lip
Servo servo_11;// Lower lip

//LED Pin
int led_pin = 1;

int RECV_PIN = 60;
IRrecv irrecv(RECV_PIN);
decode_results results;
```

```
void setup()
{
  Serial.begin(9600);
  irrecv.enableIRIn();
  pinMode(led_pin, OUTPUT);

  //Servo motor pin declaration
  servo_1.attach(22); //Eyeball left (left right)
  servo_2.attach(23);//Eyeball right (left right)
  servo_3.attach(24);// Eyeball left (up down)
  servo_4.attach(25);//Eyeball right (up down)
  servo_5.attach(28);//Eyebrow left inner (L1)
  servo_6.attach(29);// Eyebrow left outer (L2)
  servo_7.attach(30);//Eyebrow right outer (R1)
  servo_8.attach(31);//Eyebrow right inner (R2)
  servo_9.attach(34);//Eyelid
  servo_10.attach(38);//Upper lip
  servo_11.attach(39);//Lower lip

  //Servo motor initial angle
  servo_1.write(40);//Eyeball left (left right)
  servo_2.write(160);//Eyeball right (left right)
  servo_3.write(50);// Eyeball left (up down)
  servo_4.write(110);//Eyeball right (up down)
  servo_5.write(90);//Eyebrow left inner (L1)
  servo_6.write(90);// Eyebrow left outer (L2)
  servo_7.write(90);//Eyebrow right outer (R1)
  servo_8.write(90);//Eyebrow right inner (R2)
  servo_9.write(100);//Eyelid
  servo_10.write(180);//Upper lip
  servo_11.write(50);//Lower lip

  lcd.begin(16,1);
  lcd.clear();
  lcd.print("IM EMOTION ROBOT");
  }

void loop() {
  if (irrecv.decode(&results)) {
    Serial.println(results.value, HEX);
    irrecv.resume(); }

    //BEGIN
    if (results.value == ValueON) {
      lcd.print("IM EMOTION ROBOT");
      servo_1.write(105);//Eyeball left (left right)
      servo_2.write(160);//Eyeball right (left right)
      servo_3.write(50);// Eyeball left (up down)
      servo_4.write(110);//Eyeball right (up down)
      servo_5.write(90);//Eyebrow left inner (L1)
```

```
  servo_6.write(90);// Eyebrow left outer (L2)
  servo_7.write(90);//Eyebrow right outer (R1)
  servo_8.write(90);//Eyebrow right inner (R2)
  servo_9.write(100);//Eyelid
  servo_10.write(180);//Upper lip
  servo_11.write(50);//Lower lip
}

//NEUTRAL
if (results.value == Value0) {
  lcd.print("NEUTRAL        ");
  digitalWrite(led_pin,HIGH);
  servo_1.write(105);//Eyeball left (left right)
  servo_2.write(160);//Eyeball right (left right)
  servo_3.write(50);// Eyeball left (up down)
  servo_4.write(110);//Eyeball right (up down)
  servo_5.write(90);//Eyebrow left inner (L1)
  servo_6.write(90);// Eyebrow left outer (L2)
  servo_7.write(90);//Eyebrow right outer (R1)
  servo_8.write(90);//Eyebrow right inner (R2)
  servo_9.write(100);//Eyelid
  servo_10.write(180);//Upper lip
  servo_11.write(50);//Lower lip
}

 //HAPPY
if (results.value == Value1) {
  lcd.print("HAPPY          ");
  digitalWrite(led_pin,HIGH);
  servo_1.write(105);//Eyeball left (left right)
  servo_2.write(160);//Eyeball right (left right)
  servo_3.write(50);// Eyeball left (up down)
  servo_4.write(110);//Eyeball right (up down)
  servo_5.write(50);//Eyebrow left inner (L1)
  servo_6.write(160);// Eyebrow left outer (L2)
  servo_7.write(130);//Eyebrow right outer (R1)
  servo_8.write(50);//Eyebrow right inner (R2)
  servo_9.write(130);//Eyelid
  servo_10.write(170);//Upper lip
  servo_11.write(20);//Lower lip
}

 //SAD
if (results.value == Value2) {
  lcd.print("SAD            ");
  digitalWrite(led_pin,HIGH);
  servo_1.write(105);//Eyeball left (left right)
  servo_2.write(160);//Eyeball right (left right)
  servo_3.write(20);// Eyeball left (up down)
  servo_4.write(150);//Eyeball right (up down)
```

```
  servo_5.write(130);//Eyebrow left inner (L1)
  servo_6.write(50);// Eyebrow left outer (L2)
  servo_7.write(50);//Eyebrow right outer (R1)
  servo_8.write(130);//Eyebrow right inner (R2)
  servo_9.write(50);//Eyelid
  servo_10.write(160);//Upper lip
  servo_11.write(70);//Lower lip
}

 //ANGER
if (results.value == Value3) {
  lcd.print("ANGRY           ");
  digitalWrite(led_pin,HIGH);
  servo_1.write(105);//Eyeball left (left right)
  servo_2.write(160);//Eyeball right (left right)
  servo_3.write(50);// Eyeball left (up down)
  servo_4.write(110);//Eyeball right (up down)
  servo_5.write(150);//Eyebrow left inner (L1)
  servo_6.write(160);// Eyebrow left outer (L2)
  servo_7.write(50);//Eyebrow right outer (R1)
  servo_8.write(50);//Eyebrow right inner (R2)
  servo_9.write(150);//Eyelid
  servo_10.write(180);//Upper lip
  servo_11.write(55);//Lower lip
}

 //DISGUST
if (results.value == Value4) {
  lcd.print("DISGUST         ");
  digitalWrite(led_pin,HIGH);
  servo_1.write(105);//Eyeball left (left right)
  servo_2.write(160);//Eyeball right (left right)
  servo_3.write(70);// Eyeball left (up down)
  servo_4.write(90);//Eyeball right (up down)
  servo_5.write(50);//Eyebrow left inner (L1)
  servo_6.write(50);// Eyebrow left outer (L2)
  servo_7.write(130);//Eyebrow right outer (R1)
  servo_8.write(130);//Eyebrow right inner (R2)
  servo_9.write(50);//Eyelid
  servo_10.write(160);//Upper lip
  servo_11.write(30);//Lower lip
}

//SURPRISE
 if (results.value == Value5) {
  lcd.print("SURPRISE        ");
  digitalWrite(led_pin,HIGH);
  servo_1.write(105);//Eyeball left (left right)
  servo_2.write(160);//Eyeball right (left right)
  servo_3.write(50);// Eyeball left (up down)
```

```
 servo_4.write(110);//Eyeball right (up down)
 servo_5.write(50);//Eyebrow left inner (L1)
 servo_6.write(150);// Eyebrow left outer (L2)
 servo_7.write(130);//Eyebrow right outer (R1)
 servo_8.write(50);//Eyebrow right inner (R2)
 servo_9.write(150);//Eyelid
 servo_10.write(140);//Upper lip
 servo_11.write(20);//Lower lip
}

//FEAR
if (results.value == Value6) {
 lcd.print("FEAR            ");
 digitalWrite(led_pin,HIGH);
 servo_1.write(105);//Eyeball left (left right)
 servo_2.write(160);//Eyeball right (left right)
 servo_3.write(40);// Eyeball left (up down)
 servo_4.write(150);//Eyeball right (up down)
 servo_5.write(50);//Eyebrow left inner (L1)
 servo_6.write(50);// Eyebrow left outer (L2)
 servo_7.write(130);//Eyebrow right outer (R1)
 servo_8.write(130);//Eyebrow right inner (R2)
 servo_9.write(110);//Eyelid
 servo_10.write(160);//Upper lip
 servo_11.write(30);//Lower lip
}
}
```

Appendix H

Solution Manual for Using Robot Head

A. Coding Design

1. To add servo motor port into controller, refer to "Motor declaration".
2. To change the port number or pin of servo motor, refer to "Servo motor pin declaration".
3. To set or change the initial angle of servo motor, refer to "Servo motor initial angle".
4. To change the name for LCD to display, edit *lcd.print ("**name**").*
5. For add or remove of IR remote button, change *if (results.value== **button**)*. The ***button*** name may refer to "IR remote button code declaration".
6. To change the angle position of servo motor after activation, change the relative servo motor angle value *servo_**X**.write **(angle)*** under the *void loop* for the activation of particular button.

B. Robot head manual control

1. Powered the Arduino controller via the USB connection or with an external power supply in the range of 7-12 volts.
2. Press power sign button on IR remote keypad to initialize position of the robot head parts.
3. Eight buttons are set to perform the expression on robot head:

   Button ON = Initialize or Start
   Button 0 = neutral expression
   Button 1 = joy expression
   Button 2 = sadness expression
   Button 3 = anger expression
   Button 4 = disgust expression
   Button 5 = surprise expression
   Button 6 = fear expression
4. Remove or switch of the power supply for Arduino controller when robot head not in used.