DEVELOPMENT OF A STINGRAY ROBOT

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This thesis is submitted as partial fulfillment of the requirements for the award of the Bachelor of Electrical Engineering (Electronics)

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JUNE, 2012

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Date : 24 MAY 2012

To my beloved mother and father

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ABSTRACT

This project involves the design and construct of biological inspired underwater robot that mimicking the stingray maneuverability. The robot will be design based on the shape of stingray, and has the abilities to swim like a stingray. There were three major parts in constructing the robot; mechanical design, electronic circuitry and software design. In the mechanical part, body frame and fins is design carefully in order to make the movement of the robot smooth underwater. 4 servo motors and DC motors are used to move the robot forward and downward (submerge). Flapping motion is performed by the servos rotation controlled by the PIC18F4550 microcontroller.

ABSTRAK

Projek in melibatkan rekabentuk dan pembinaan robot berasaskan biologi yang menyerupai pergerakan ikan pari. Robot ini direkabentuk berasaskan bentuk dan mempunyai kebolehan untuk bergerak seperti ikan pari. Terdapat 3 bahagian penting dalam membina robot ini; rekabentuk mekanikal, rekabentuk elektronik dan rekabentuk perisian. Bagi bahagian mekanikal, binkai badan dan sirip direkabentuk dengan teliti bagi memastikan pergerakan robot lancer di dalam air. 4 motor servo dan motor DC digunakan bagi menggerakkan robot kehadapan dan ke bawah (menyelam). Gerakan mengepak di lakukan oleh kawalan pusingan motor servo oleh pengawalmikro PIC18F4550.

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CHAPTER 1

INTRODUCTION

1.1 Introduction

In the deep ocean live many types of fishes with their own features and expertise. Movement and speed of these fishes is based on their shape and body part (fin) use to move in the water. The motion of fins or bodies can provide more flexible maneuverability. The robotic fish systems have wide-range of applications in many areas: marine sourcing, seabed charting, environmental assessments, monitoring, and sea exploring.

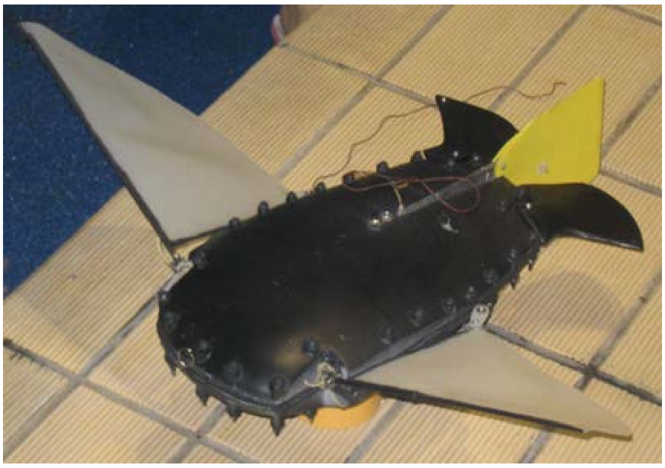


Figure 1.1: Example Of A Stingray Robot

1.2 Problem Statement

Similar to the conventional Autonomous Underwater Vehicles (AUVs), these robotic fishes is developed as a replacement for human. For the time being, human is required in order to explore in the deep sea. Diving into deep will expose human with high risk of danger - high water pressure and dangerous species. Human also can go underwater in certain amount of time due to certain limitation – oxygen and pressure. Also, some country explore and doing research underwater for military purpose. For all these reasons, an underwater vehicle is developing as a replacement for manpower.

1.3 Project Objectives

- To build a low cost robot that can move like stingray in the water.
- To design the mechanical and electrical structure and to construct a stingray robot.

1.4 Scope of Project

In order to achieve the objectives of the project, literature study on stingray’s characteristic which includes the fin motion, the stingray movement and shape are done. Research on the fin motion is investigated to get the detail on how the robot will go forward. The maneuver and shape of the stingray is also being investigated and studied. For electrical and mechanical part, the details are referred from the manufacturer references. With deep research and study, an electrical circuit is constructed to make sure the robot can maneuver autonomously and the robot body is designed to make sure it can operate underwater.

CHAPTER 2

LITERATURE REVIEW

2.1 Characteristic

‘Over the past two decades, the interests in robotic fishes have experienced an increasing trend. In addition to works from active and prominent groups in the international biomimetics community on bio-inspired aquatic robots, recent research and development works on fish robotics by the team in Nanyang Technological University (NTU) will be presented in the paper’ [1].

There‘re several type of swimming mode. This mode is classified by the shape of the fin. Figure 2.1 show the type of mode for fish. Rajiform mode is found in fish such as rays, skates, and mantas, whose swimming has been likened to the flight of birds. The amplitude of the undulations increases from the anterior part to the fin apex and then tapers again toward the posterior. Figure 2.2 show the manta ray locomotion. The fins may also be flapped up and down. Manta ray of cartilaginous fish is one kind of the largest fish in the ocean, whose swimming mode is Rajiform mode. When the movements of the two fins are same, the manta ray swims forward. When the movements of the two fins are different, the swimming direction will change. The swimming speed is usually slow, but the manta ray can swim at high speed and sometimes leaps out of the water. The rear two fifths of the body are used to control vertical movements and perform somersaults.

Flexible fin can be divided into two parts: the relatively rigid basal part which is the first third part nearest to the body and the relatively flexible distal part. When the basal part is moving upward, the distal part may point down under the resistance of water and vice versa. [2]. In Brower’s analysis, the profile of swimming motion is captured every 0.15 seconds. With 14 profiles captured in total, it is approximate that a total of 2.1 seconds is required to complete one flapping motion. Hence, the frequency of the flapping motion is approximately 0.5Hz [6].

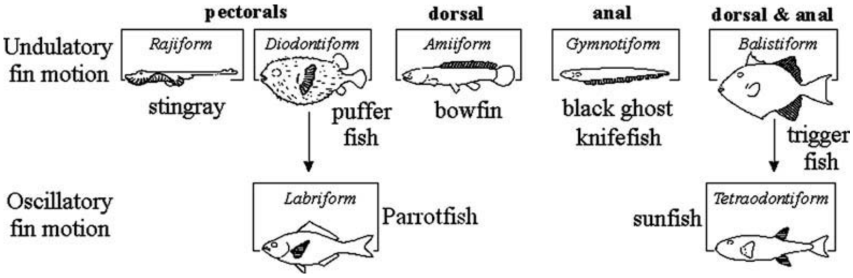


Figure 2.1: Scheme of Median and/or Paired Fin Locomotion

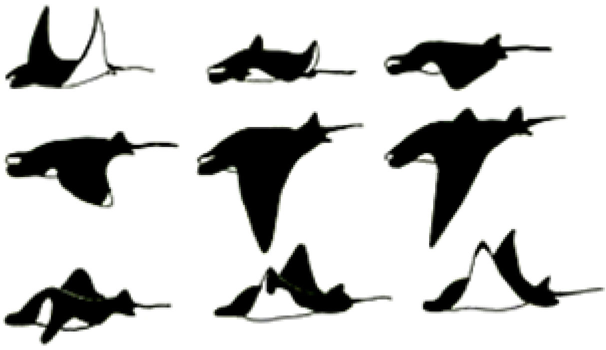


Figure 2.2: Klausewitz's Illustration of Manta Ray Locomotion

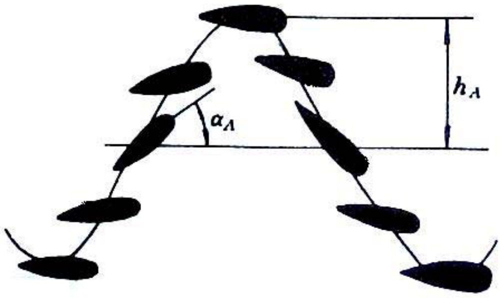


Figure 2.3: The Simplified Model of Fin Motion

2.2 Robot Development

Research and development in the area of fish robot has become popular in recent years. Fish have high efficiency, maneuverability, and lower noise than most of the current marine robots. The robotic fish is a combination of bio-mechanic and engineering technology.

2.2.1 A micro biomimetic manta ray robot fish actuated by SMA

A micro biomimetic manta ray robot fish actuated by SMA by Zhenlong Wang, Yangwei Wang, Jian Li, Guanrong Hang is an example of robot that use SMA (shape memory alloy). This method is easy to use, low-cost, light-weight and no noise compare to motors. SMA also has low operational voltage and long life but low in efficiency. This type of material has widely use in robotic field. Many robots use this material as wing, grip, robot hand, deformable robot, lobster robot, and robot fish.

SMA is a material that actuated by electric current. When heated from low temperature martensite to high temperature austenite, SMAs will return to their predetermined shape and produce the activation, which is known as reverse transformation. When cooled from austenite to martensite, SMAs undergo a martensite transformation and will return to their initial state by bias stress. The SMA operational frequency can be increased to over 2 Hz, which is high enough to simulate the bending movements of the fin.

The prototype of the robot is 243 mm in length (with a 110 mm caudal fin), 220 mm in width (with a 67 mm body), 66 mm in height and 354 g in weigh. Latex membrane (0.2 mm thick) is use as the fin surface. TiNi (50.2 at.% Ni) SMA wires with 0.2 mm diameter are employed. In biomimetic fin 1 and 2, the length of every SMA wires is 70 mm. The elastic substrate of biomimetic fin 1 and 2 is made of polyvinyl chloride (PVC) sheet with a thickness of 0.25 mm. Comparing with biomimetic fin, flexible fin does not include the SMA. The structure of the biomimetic fin is shown in Figure 2.5. A 11.1 V, 1500 mAh, 12 C Lithium polymer rechargeable battery is used as the robot power source. 111.8 g balance weight is placed under the power source to stabilize the robot underwater. With this balance weight, the robot can float in the water with a very small part of the dorsal cover out of water. With more balance weight of 2.3 g, the robot would submerge into the water completely. A design of low net buoyancy would make it convenient for the appending of static diving systems such as ballast tanks or dynamic diving systems such as fins. Figure 2.4 shows the design of the robot.

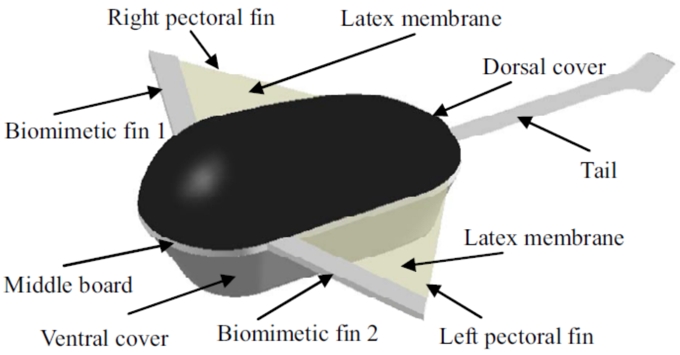


Figure 2.4: Micro Robot Design

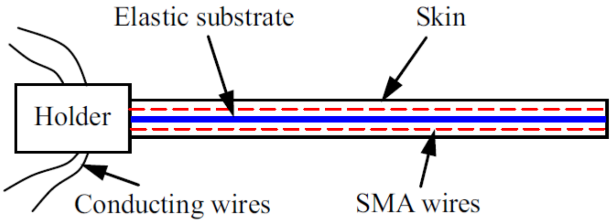


Figure 2.5: The Structure of Biomimetic Fin

Radio frequency remote control module is used for robot control employed. The control module is based on a PIC16F877A MCU. MOSFET is connected to prevent overheat that can damage the SMA. High current (up to 9 A at 28 V) used by the SMA to actuate can cause overheat. Figure 2.6 shows the architecture of the control system. Pulse generated by the microcontroller is applied to the SMA (fin ray) and the sequence of the pulse is shown in Figure 2.7. The pulse sequence 1 is for upward flap of the fin while the other is for downward flap with the width of t_{on} = 80ms while t_{int} = 700ms. The speed and the amplitude of the robot can be increase by increasing the pulse width. The robot turning motion is occurred when only a single fin is flapping while the other remains static. The turning angle can be change by adjusting the flapping amplitude and frequency [2].

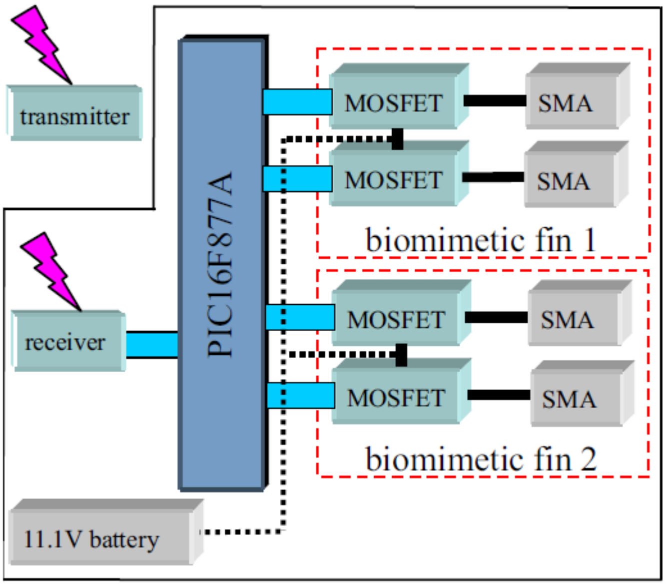


Figure 2.6: Control System Design

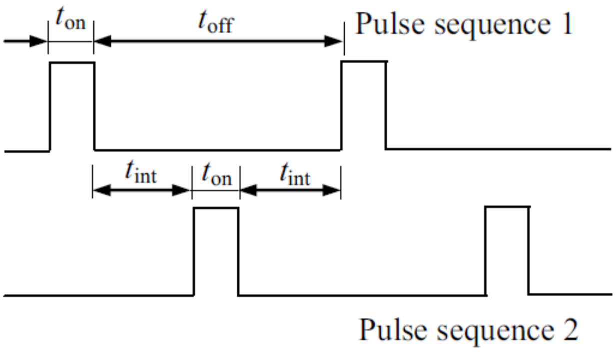


Figure 2.7: Pulse Sequence for Single Fin

2.2.2 Development of a Rajiform Swimming Robot using Ionic Polymer Artificial Muscles

Mimetic Control Research Center, Japan has developed a robot using Ionic Polymer - Metal Composite (IPMC) method as their robot element. The IMPC consists of an ion-exchange membrane whose surface is plated by thin rare metal layers. When voltage is applied across the electrodes, the hydrated cations move toward the anode. This water movement causes the swelling of the anode side of the ionic polymer therefore the bending moment is generated. The structure of the IMPC is shown in Figure 2.8. The IMPC is made from Nafion N-117 membrane (DuPont) through five times gold plating process. The size of the each IPMC is 5[mm] × 50[mm]. Thickness is about 0.2 [mm]. They used Na+ ion as its counter ion because IPMC doped Na+ exhibits quick response.

Eight IPMCs which is clamped by the acrylic support with copper electrodes is used for the fin ray. A thin polyethylene film is used as the fin surface. The IPMCs were put into the slit of the film as shown in Figure 2.9. The thickness of the film is about 12[μm], which does not inhibit the motion. The entire size of the fin is about 75[mm] × 45[mm]. This robot use a microcontroller system called *C-CHIP* whose size is only 30[mm] × 40[mm]. It has been developed at Bio-Mimetic Control Research Center, RIKEN and Aichi Institute of Technology.

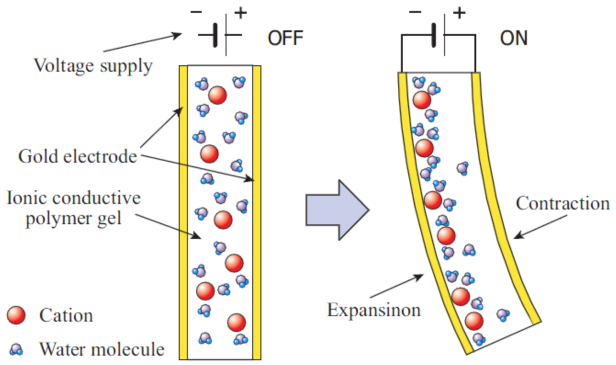


Figure 2.8: Illustrations of the Deformation Mechanics of IPMC

A linear amplifier using two transistors and an OP amp is used to prevent plating damage cause by unnecessary current. This current is the result of water electrolysis causes by high voltage. Because the electrical impedance of IPMC is capacitive, lower current flows during driving at lower frequencies. Taking these into account, an estimation of the flowing current of an IPMC is at most a few hundreds milliamperes. The amplifier maximum output current and voltage is about ±500mA and ±2.5V respectively [3].

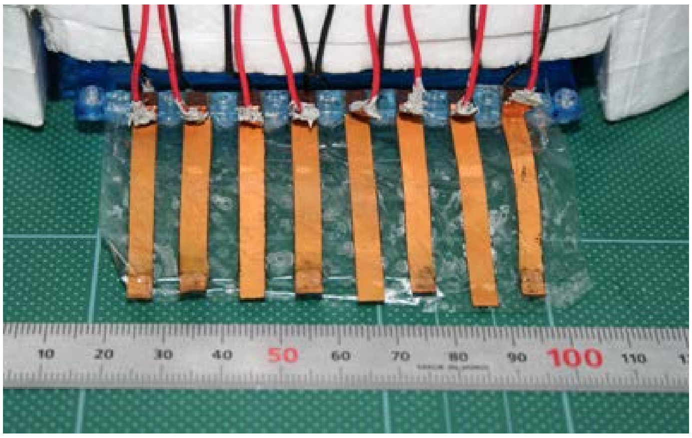


Figure 2.9: Developed Fins with Eight IPMCs

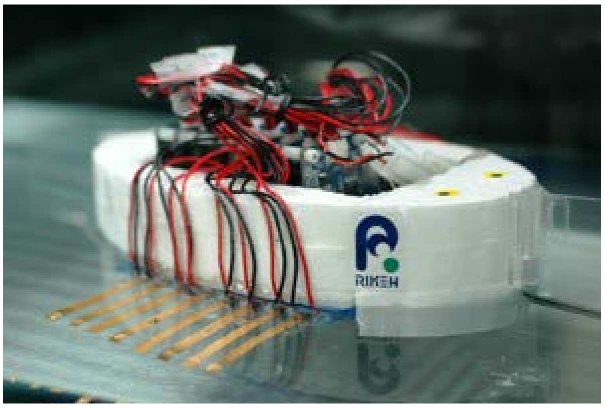
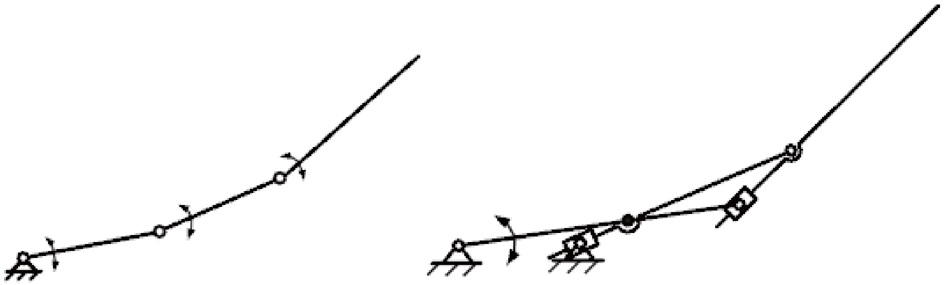


Figure 2.10: The Robot Overview

2.2.3 Design and Optimization of a Robotic Fish Mimicking Cow-nosed Ray

Licheng Zheng, Shusheng Bi, Yueri Cai, and Chuanmeng Niu has Design and Optimize a Robotic Fish Mimicking Cow-nosed Ray. The robot use 6 servo motors, 3 motors on each side of fin to move the robot. The robot is designed similar to cow-nosed ray in nature. Mould made of plexiglass is manufactured for flexible pectoral fins. Mechanism with three revolution joints as shown in Figure 2.11(a) can be used as a fin ray based on the locomotion. The joint require 3 actuating motors which make the fin ray heavy and difficult to control. To overcome this disadvantage, a rocker-slide mechanism as shown in Figure 2.11(b) is designed which use only one motor. All the link rods are made of duralumin except the distal rod, which is made of carbon fiber to provide elasticity.



(a) (b)

Figure 2.11: (a) Mechanism with three revolution joints. (b) Two stage rocker-slide mechanism. Where arrows are need actuators.

The pectoral fin of cow-nosed ray is approximate to a triangle, so the joint number is different for different fin rays. There are 2, 3, 1 joints for the fin rays from front to back respectively, as shown in Figure 2.12.

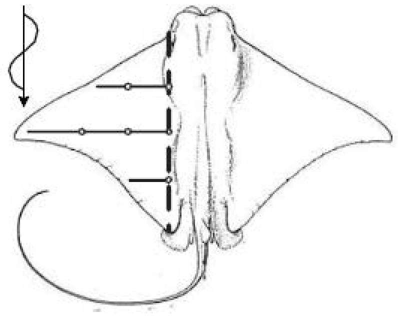


Figure 2.12: Fin's Joint Structure

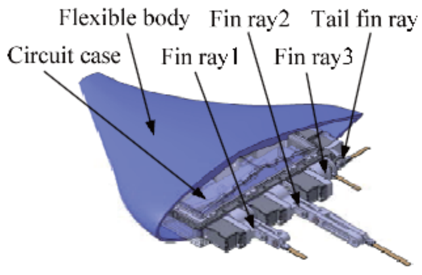


Figure 2.13: Fin Structure

In order to prevent the electrical devices from damage, flexible skin made of silicon rubber is used because of its waterproof ability. Moreover, the major components, like servo motors and circuits, are also designed to be waterproof. Thus the damage can be avoided even if the flexible skin fails to be waterproof. Servo motors are sealed by glyd rings, seal covers and the base parts [4].

2.2.4 Better Endurance and Load Capacity an Improved Design of ROMAN-II

Chunlin Zhou, Kin-Huat Low from School of Mechanical and Aerospace Engineering, Nanyang Technological University have design a manta ray robot called Roman-II. Roman-II is an improved design of Roman-I. Roman-I have too many joint and linkage on the ray which requires much energy to drive. This will significantly reduce the swimming efficiency. Elastic material is used on Roman-II to introduce compliance capability in the fin motion. A fin membrane in silicon rubber sheet is us as the fin surface resulting motion control becomes less complex and consumption of energy could also be reduced. Figure 2.14 shows Roman-II mechanical design

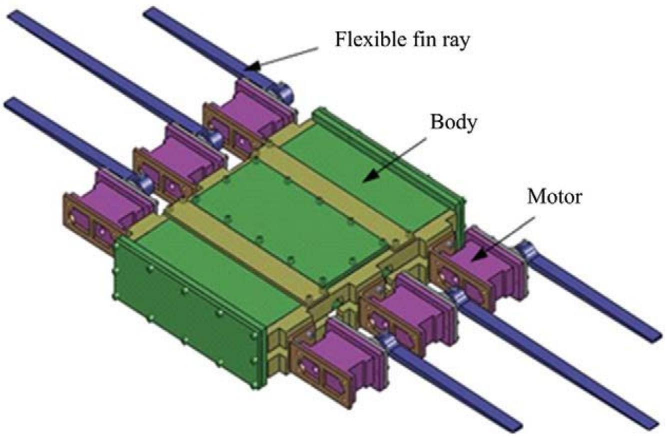


Figure 2.14: Roman-II Mechanical Design

The flapping of Roman-II fins of upstroke only takes about half time of down stroke for one full flapping cycle. Figure 2.15 show the harmonic gait of fin flapping. This robot also can perform a turning motion by generating bigger thrust on one side of flapping fin. By doing this, the robot will turn towards another side. The thrust control can be achieved by reducing the oscillation frequency and/or amplitude. The pivot turning occurs when fin on one side is performing forward swimming, whereas the fin in another side is performing backward swimming. During gliding motion, the robot in the present work makes use of small changes in its buoyancy together with the help of two sided fins to convert vertical motion to horizontal [6]. Figure 2.16 shows the fin position for gliding motion.

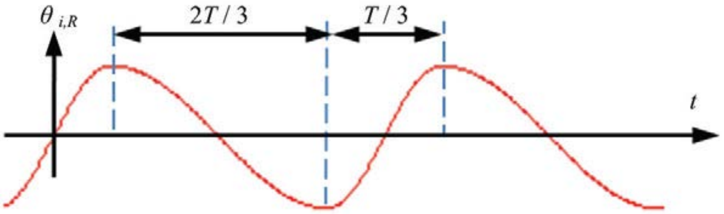
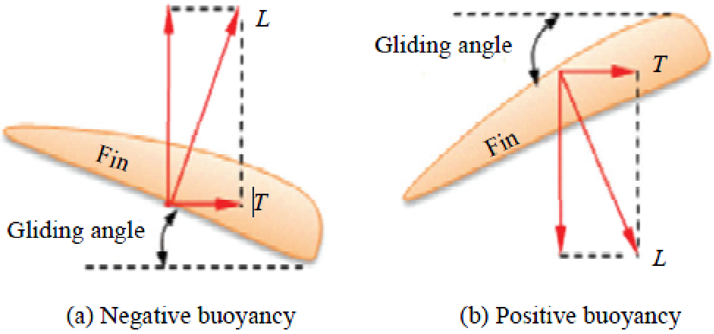


Figure 2.15: Control signals for a fin ray



(a) Negative buoyancy (b) Positive buoyancy

Figure 2.16: Fin Position for Gliding Motion

2.3 Buoyancy System

Archimedes stated that “any object, wholly or partially immersed in a fluid, is buoyed up by a force equal to the weight of the fluid displaced by the object’. When an object submerged in the fluid, experiences greater pressure at the bottom is greater than at the top. An object tends to sink when its density is greater than the fluid in which it is submerged and afloat if the object less dense than the fluid. As for fish, their gas bladder has flexible walls that contract or expand according to the surrounding pressure. The bladder has a gas gland that can introduce oxygen to the bladder to increase its volume and thus increase buoyancy. To reduce buoyancy, gases are released from the bladder into the blood stream and then expelled into the water via the gills [11]. Buoyancy system for underwater vehicle or robotic fish is the main criteria in developing fully functional robot.

In many robot development, air or gas is use to reduce the density of robot. The buoyancy system of Roman-I is using air bladder for that purpose. When the air bladder expand, the water in cylindrical ballast is expels out. But the developer found that the system is not effective as problems occur when operating the robot underwater. The problems are when the pressure in the air bladder as at certain value, the bladder cannot become larger. The air pump will not work well due to the vacuum in the water tight container. As the robot dives, the water compresses the bladder, which then increases the burden of the air pump. Instead of using air pump, the water pump is used to overcome these problems. This improved system is implemented on Roman-II with additional water pressure sensor to detect the depth, closed-loop buoyancy control and depth control [6]. Figure 2.17 shows buoyancy system for Roman-I and Roman-II.

A knife fish robot build by Nanyang Technology University use a buoyancy system based on the fish system. An opened end tank with 2 pistons that retract and extend using lead screws is use for the system as shown in Figure 2.18. In order to maintain the robot horizontal angel the piston on both sides is adjusted. If the right side of the buoyancy tank is higher than the left side, the piston on the right side will retract and this will bring the buoyancy tank to a horizontal angle. In the case that the right piston is fully retracted, the left piston will extend and again bring the buoyancy tube to a horizontal angle [11].

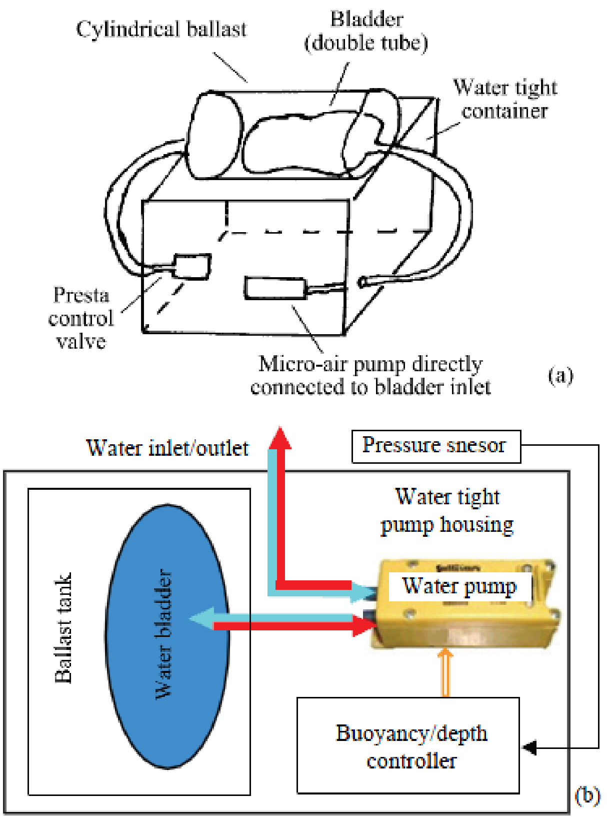


Figure 2.17: Buoyancy System for (a) Roman-I and (b) Roman-II

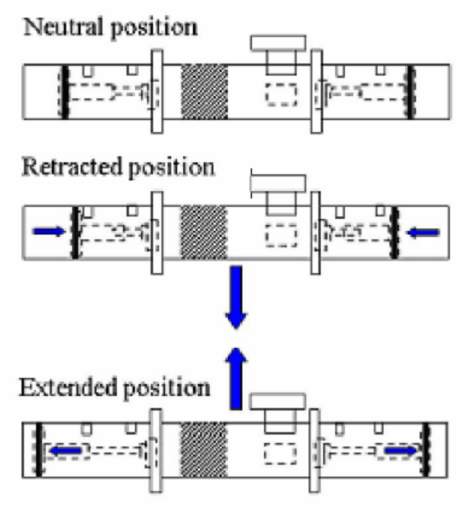


Figure 2.18: Knife Fish Robot Buoyancy System

CHAPTER 3

DESIGN & STRUCTURE

3.1 Electrical Design

There are several device and parts that will be use to move the stingray. The devices are servo motors, microcontroller and the body part. These devices and part is connected and assembled in order to develop this project. Figure 3.1 shows the circuit block diagram for this project

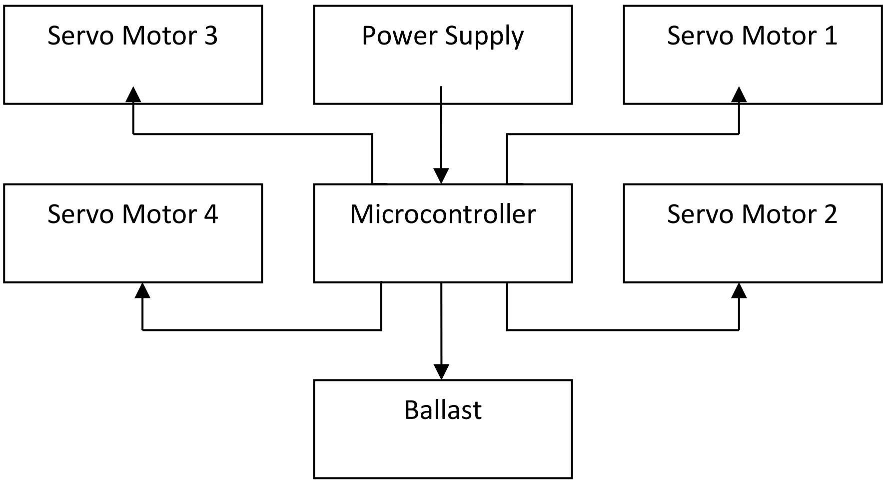


Figure 3.1: Circuit Block Diagram

3.1.1 Servo Motors

Inside a typical servo contains a small motor and gearbox to do the work, a potentiometer to measure the position of the output shaft, and an electronic circuit that controls the motor to make the output gear move to the desired position. This shaft can be positioned to specific angular positions by sending the servo a coded signal. When a pulse is sent to the servo, the control board calculates which way the shaft should rotate in order to reach the corresponding position.

Servos interpret pulse widths (PWM) as position. To move the servo shaft, repetition of PWM is required. Pulse width range is approximately between 0.5ms to 2.5ms. For some type of servo, the pulse width range is approximately between 1.0ms to 2.0ms. Figure 3.2 shoes the servo position for each PWM.

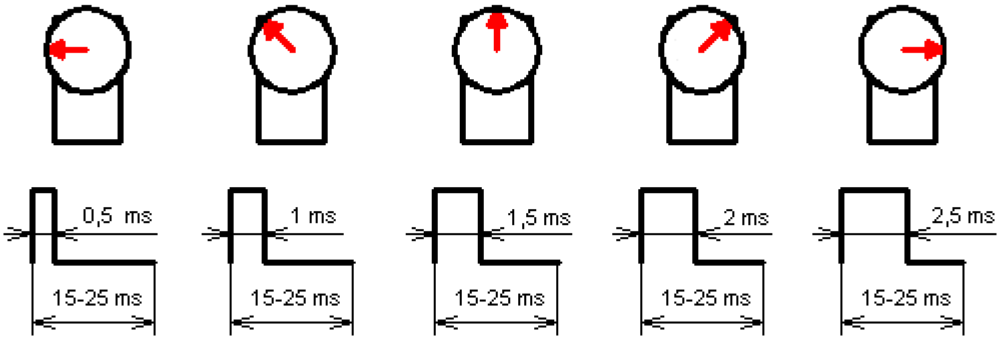


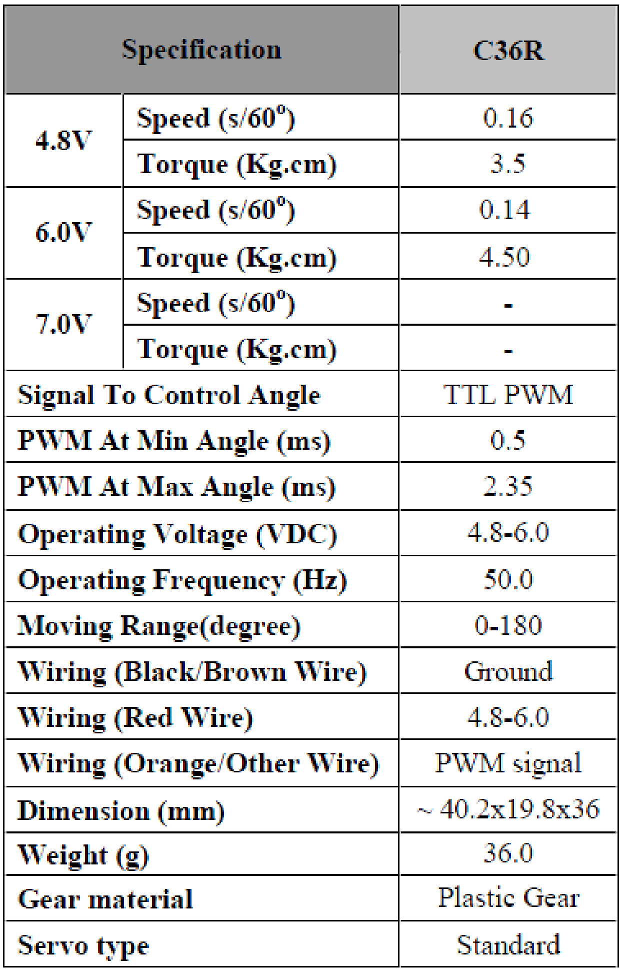
Figure 3.2: PWM And Servo Position

3.1.1.1 Cytron C36R Servo Motor and Holder

For this project, Cytron's C36R servo motors with holders are being used. In order to reduce the servo speed (for downstroke), 5V relay is used. Darlington transistor array IC (ULN2003A) is used to increase current from output of PIC18F4550 to energize the relay's coil. Figure 3.3 to Figure 3.6 shows the Cytron C36R servo details and circuit connection.

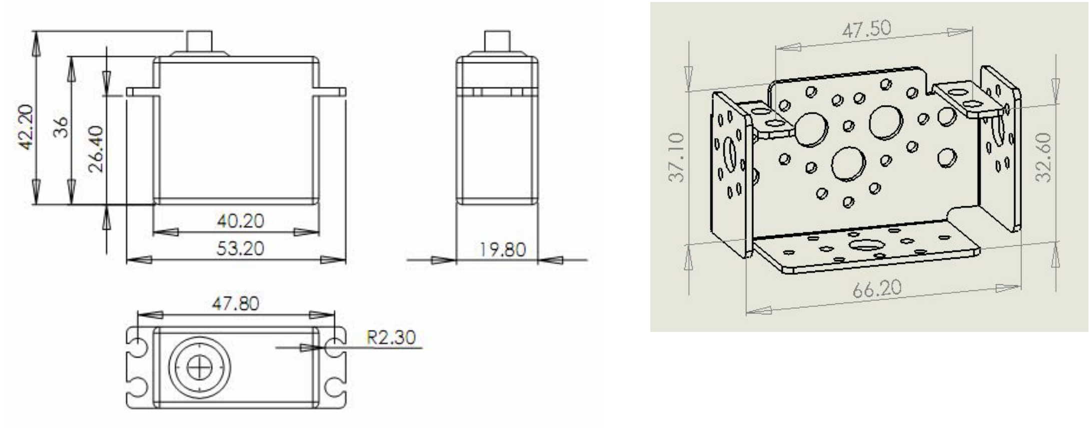
(a) (b)

Figure 3.3 (a) C36R and (b) Wire Connection



Specification		C36R
4.8V	Speed (s/60°)	0.16
	Torque (Kg.cm)	3.5
6.0V	Speed (s/60°)	0.14
	Torque (Kg.cm)	4.50
7.0V	Speed (s/60°)	-
	Torque (Kg.cm)	-
Signal To Control Angle		TTL PWM
PWM At Min Angle (ms)		0.5
PWM At Max Angle (ms)		2.35
Operating Voltage (VDC)		4.8-6.0
Operating Frequency (Hz)		50.0
Moving Range(degree)		0-180
Wiring (Black/Brown Wire)		Ground
Wiring (Red Wire)		4.8-6.0
Wiring (Orange/Other Wire)		PWM signal
Dimension (mm)		~ 40.2x19.8x36
Weight (g)		36.0
Gear material		Plastic Gear
Servo type		Standard

Table 3.1 C36R Specification



(a) (b)

Figure 3.4: (a) C36R and (b) Holder Dimension Drawing

Figure 3.5: Servo Holder

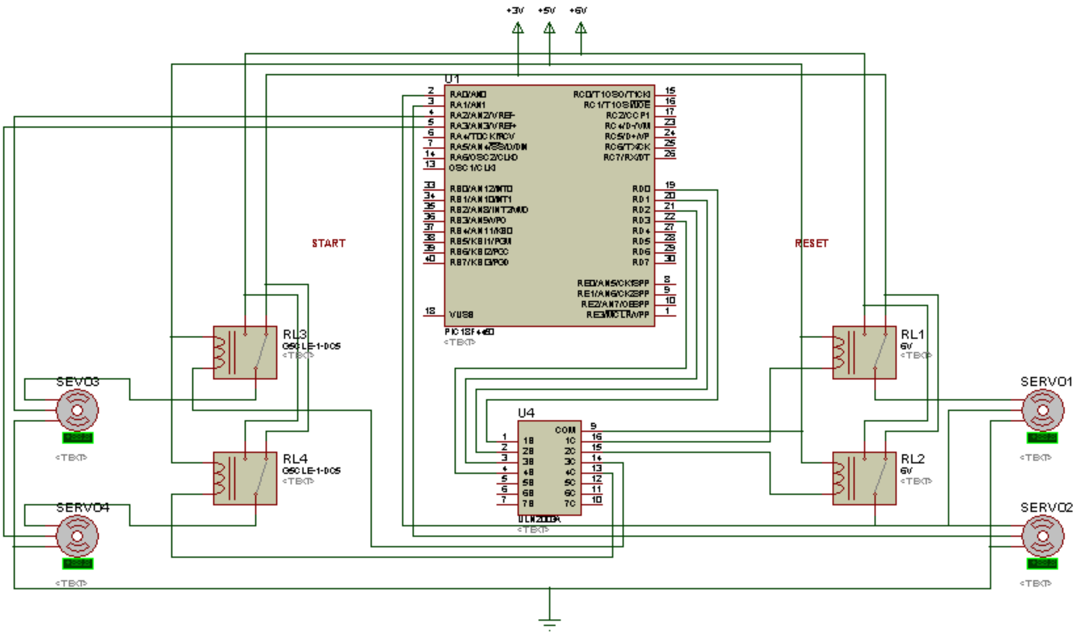
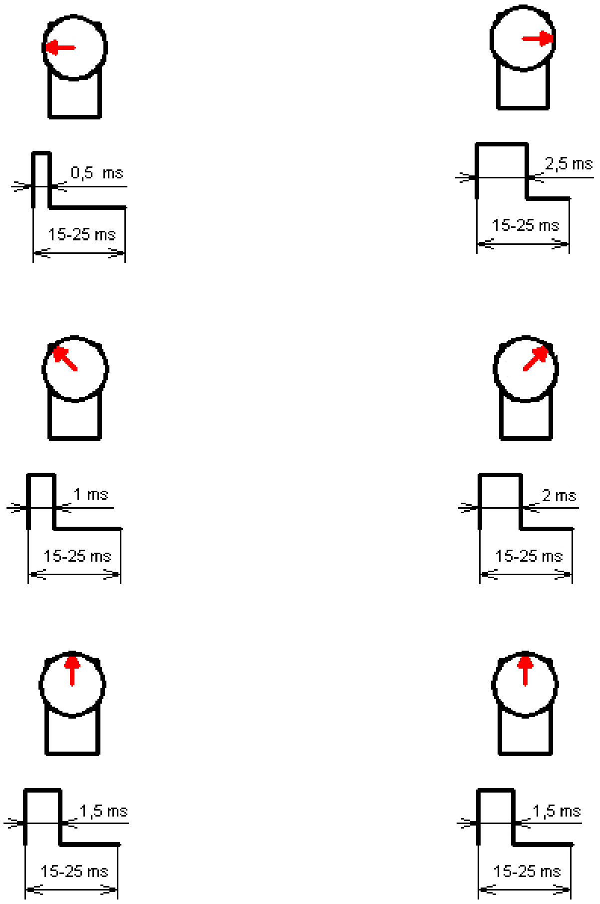


Figure 3.6: Connections Between Servo And Microcontroller

3.1.1.2 Reversing servo direction

In order to make the robot move forward, the servo that control the flapping of one side of fin needs to rotated in opposite direction of the other side of servo. Thus, a reverse signal is required. For this reason, Turnigy Servo Signal Reverser is used for servos located at left sided of robot (that control the left fins). Figure 3.7 shows the details of Turnigy Servo Signal Reverser and Figure 3.8 shows differences before and after using Turnigy Servo Signal Reverser.

Figure 3.7: Turnigy Servo Signal Reverser



(a) (b)

Figure 3.8: (a) Actual and (b) Reverse Servo Signal and Position

3.1.2 Microcontroller Unit

The MCU main circuit consists of a crystal, reset switch, and 5 volts supply from voltage regulator. The microcontroller will send the signal to the devices connected based on the program. Servo motors will be connected to this device directly to the I/O port of the microcontroller. Figure 3.9 shows the circuit diagram for microcontroller unit The microcontroller will generate the pulse for the servo motors to operate. The buoyancy system for this project is also controlled by the microcontroller. Figure 3.10 shows the PIC18F4550 pin details

3.1.2.1 PIC18F4550

For this project, PIC18F4550 (40-Pin PDIP) is used. The microcontroller is programmed by using the CCS C Compiler software. 4MHz crystal is connected to the OSC1 and OSC2 pins to establish oscillation. The pin is assigned as below:

PIN	ASSIGNMENT	DESCRIPTION
B0	START	Start button
C0	SERVO 1	Send PWM signal to servo 1
C1	SERVO 2	Send PWM signal to servo 2
C4	SERVO 3	Send PWM signal to servo 3
C5	SERVO 4	Send PWM signal to servo 4
D0	SIGNAL 1	Send signal to activate relay 1
D1	SIGNAL 2	Send signal to activate relay 2
D2	SIGNAL 3	Send signal to activate relay 3
D3	SIGNAL 4	Send signal to activate relay 4
E3/MCLR	RESET	Reset button

Table 3.2: Pin Assigment

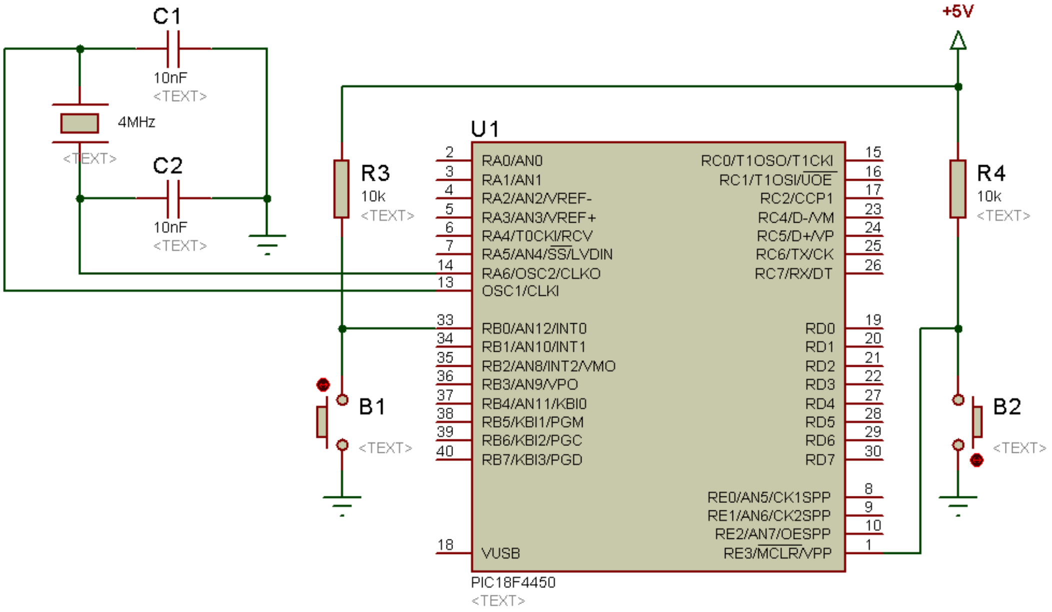


Figure 3.9: Microcontroller Unit

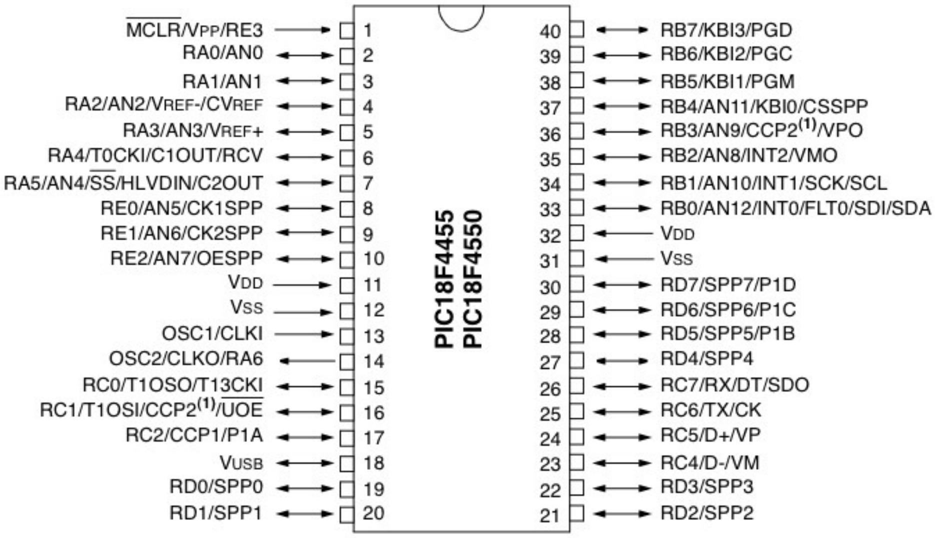


Figure 3.10: PIC18F4550 Pin Details

3.1.3 Power Supply Unit

Powermaxx rechargeable LiPo is used battery in this project. This battery produced 11.1V 2200mah and is used to supply power to servos and control unit. Figure 3.13 shows the picture of Powermaxx LiPo battery.

Figure 3.13: Powermaxx LiPo Battery

3.1.3.1 +5V Voltage Regulator

IC 7805 is used to generate 5V DC supply. This supply is connected to pin 11 and 32 of the PIC18F4550 and the switches (START and RESET). The capacitor is connected to increase the stability of the oscillator. Figure 3.12 shows the circuit diagram of +5V voltage regulator.

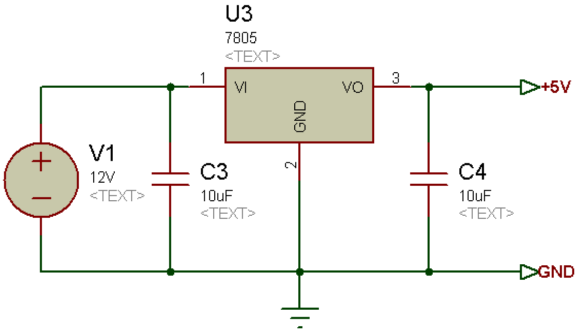


Figure 3.12: +5V Voltage Regulator

3.1.3.2 +6V High Current Voltage Regulator (With Short Circuit Protection)

Due to multiple usage of servo and load, more than 1A supply is needed. Thus, TIP42C transistor is used in this circuit as a pass transistor to increase the current capabilities. To increase the stability of the oscillator, capacitor is connected. 6V DC voltage is generated by the IC 7806 and being reduced to 3V by using the potentiometer. 6V voltage will rotate the servo at maximum speed while 3V at lower speed to perform different flapping speed of the robot fins (downstroke). These 2 voltages will be supply to servo through 5V relay. Figure 3.13shows the circuit diagram for +6V high current voltage regulator (with short circuit protection).

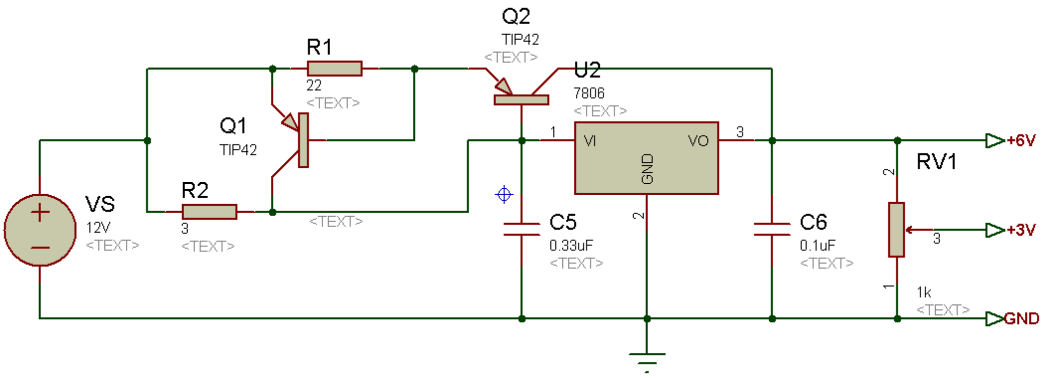


Figure 3.13: +6V High Current Voltage Regulator (With Short Circuit Protection)

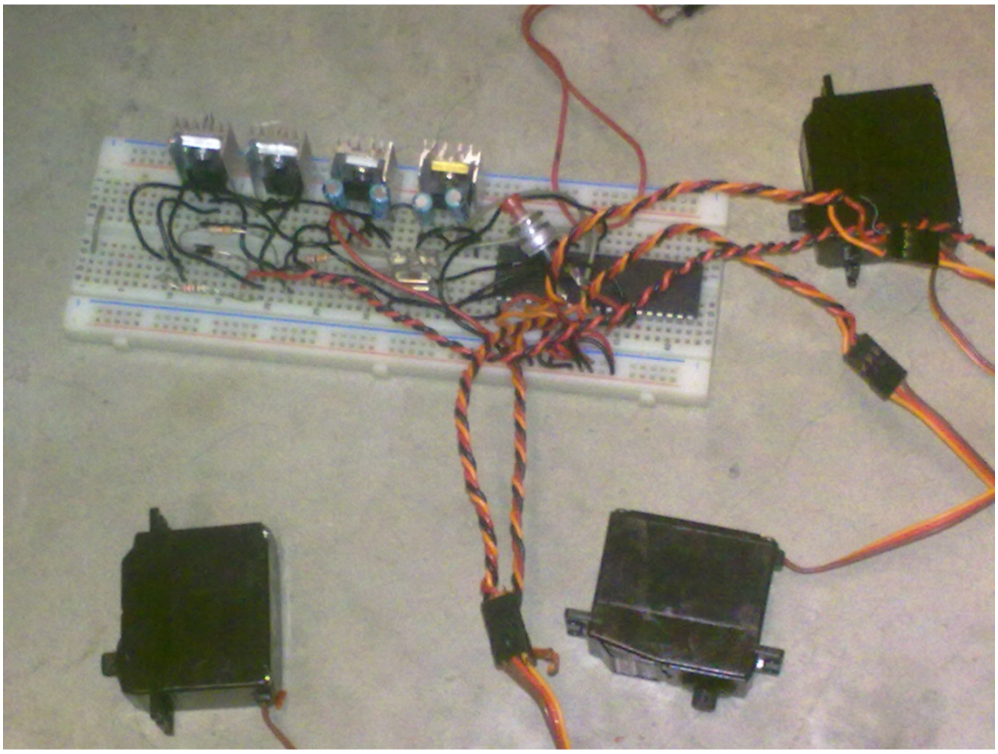


Figure 3.14: Circuit Simulation Using Protoboard

3.2 Mechanical Design

It is important to choose the right material for the frame (body). The material used for the body must be cheap, light weight, waterproof and heatproof. Easy to assemble material also important for robot built. Elastic and waterproof material such as rubber and thin film are used as the fin membrane. Figure 3.15 is the overview of the robot design.

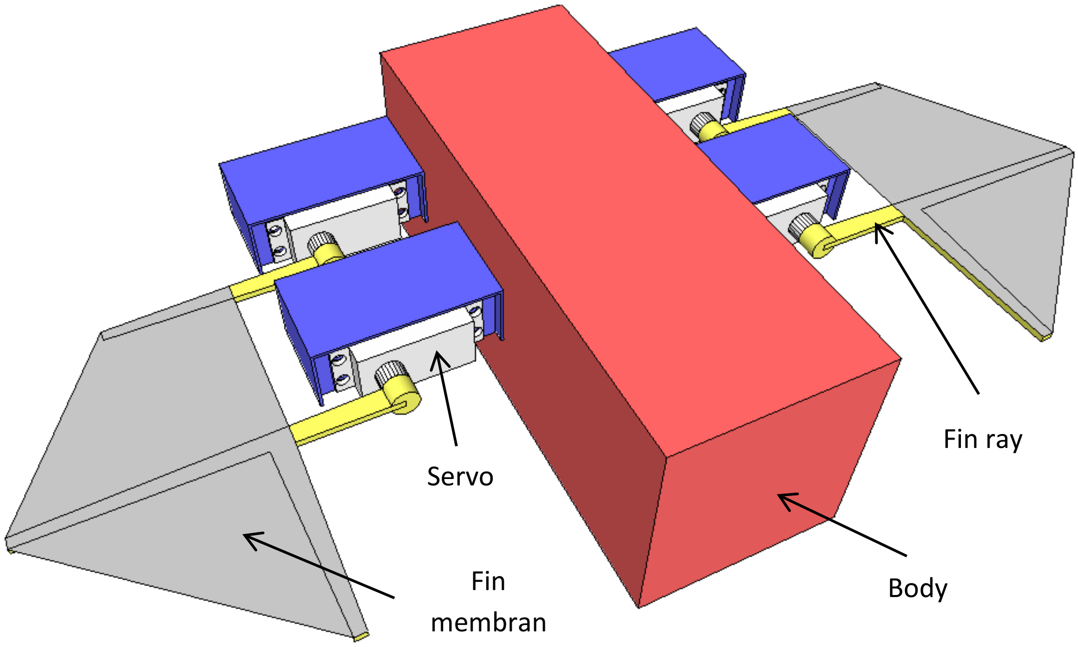


Figure 3.15: Overview of the Mechanical Design

The robot is design to be stable in the water. From the mechanical design, the details measurements have been made to assemble all the parts on the body. The back fin ray is place on the center of the body. The length of the body is approximately 200mm and the wing span is approximately 401.5mm. The measurement is based on the scaled diagram of a manta ray [13]. Figure 3.16 shows the scaled diagram of a manta ray

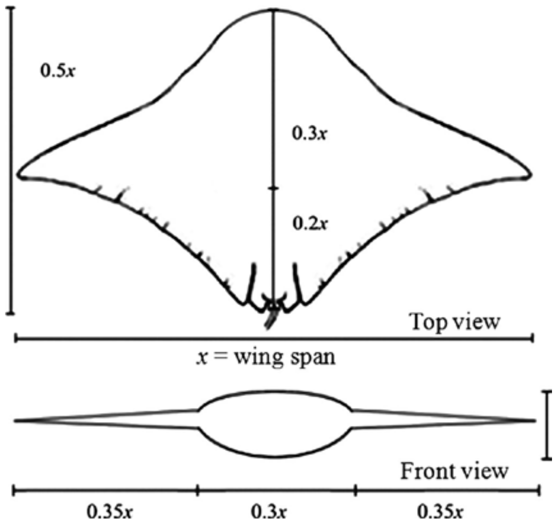


Figure 3.16: Scaled Diagram of a Manta Ray

3.2.1 The Body Frame

The materials chosen for the frame is important because the frame of the robot must be robust, symmetrical and the center of the gravity of the robot must be high. For this project, Perspex is chose because of it is easy to shape and assemble. The frame is design appropriately so that it can stably float and move on water. Aluminum angle bar is used as the joint between side parts. Acetoxy silicon sealant is used to join the aluminum and Perspex. These parts are carefully assembled and sealed to make sure water can’t enter the body frame. The overall dimension for this robot is approximately 200mm x 401.5mm x 81mm. Figure 3.17 shows the joining of perspex and aluminum angle bar. And figure 3.18 shows the body frame after the joining process done.

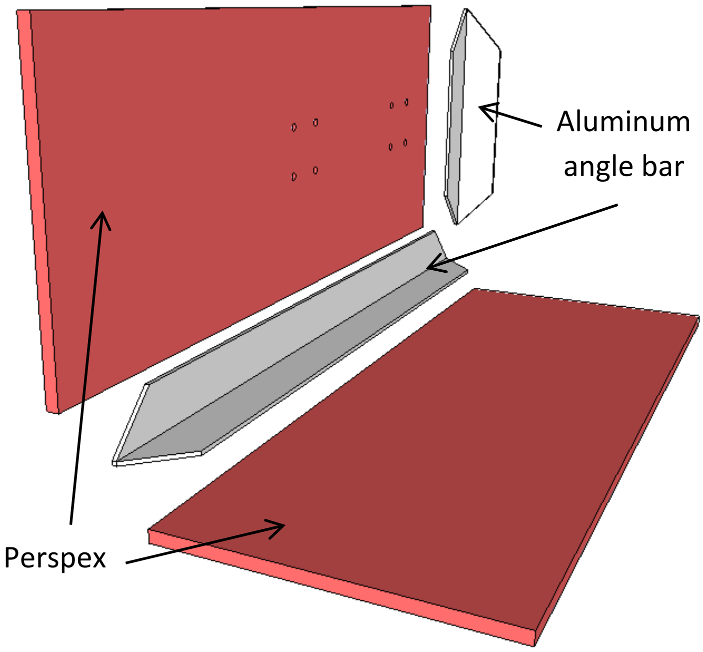


Figure 3.17 Perspex and Aluminum Angle Bar Joining

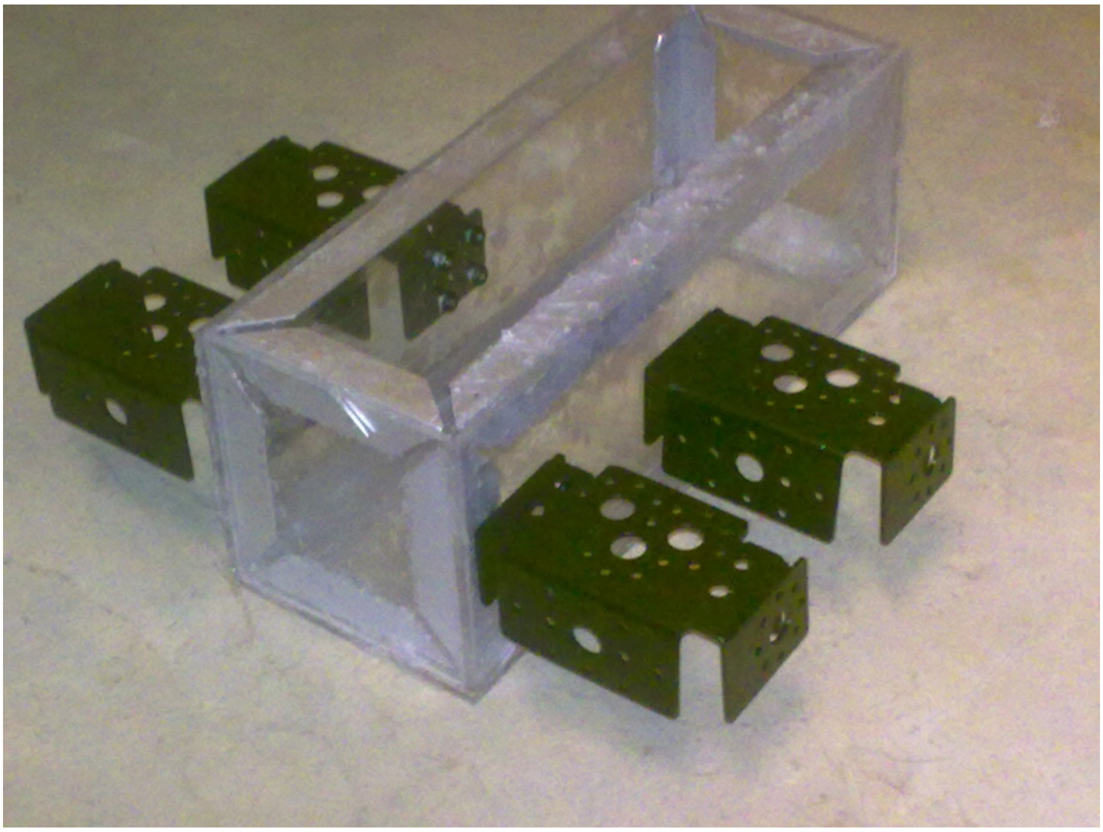


Figure 3.18: The Robot Body (Front View)

3.2.2 Fin

There are 4 fins used in this project. Each 2 fin have different size. The front fin length is approximately 80m while the back fin is 120mm. The thickness for both front and back fin is 2.4mm. The width of those fins is different at base end which is 8mm while at the distal end is 4mm. The fins are made by Polypropylene which is flexible. A fin membrane in silicon rubber sheet is taken as the cover of the fin rays. The fin length scale is based on the fin's joint structure showed in Figure 3.19. But for this project, different approach is used by only using 4 fin rays. The back fin ray is design like 'T' shape as shown in Figure 3.20 and Figure 3.21 so that the fin membrane will be in triangular shape.

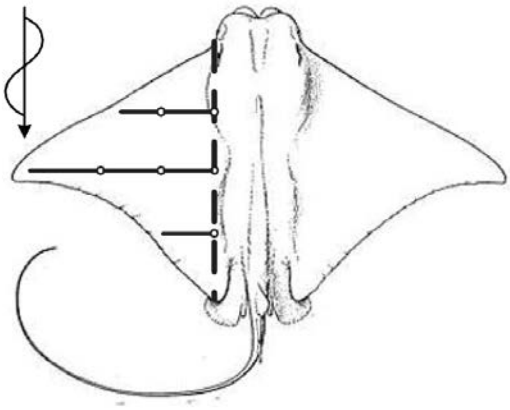


Figure 3.19: Fin's Joint Structure

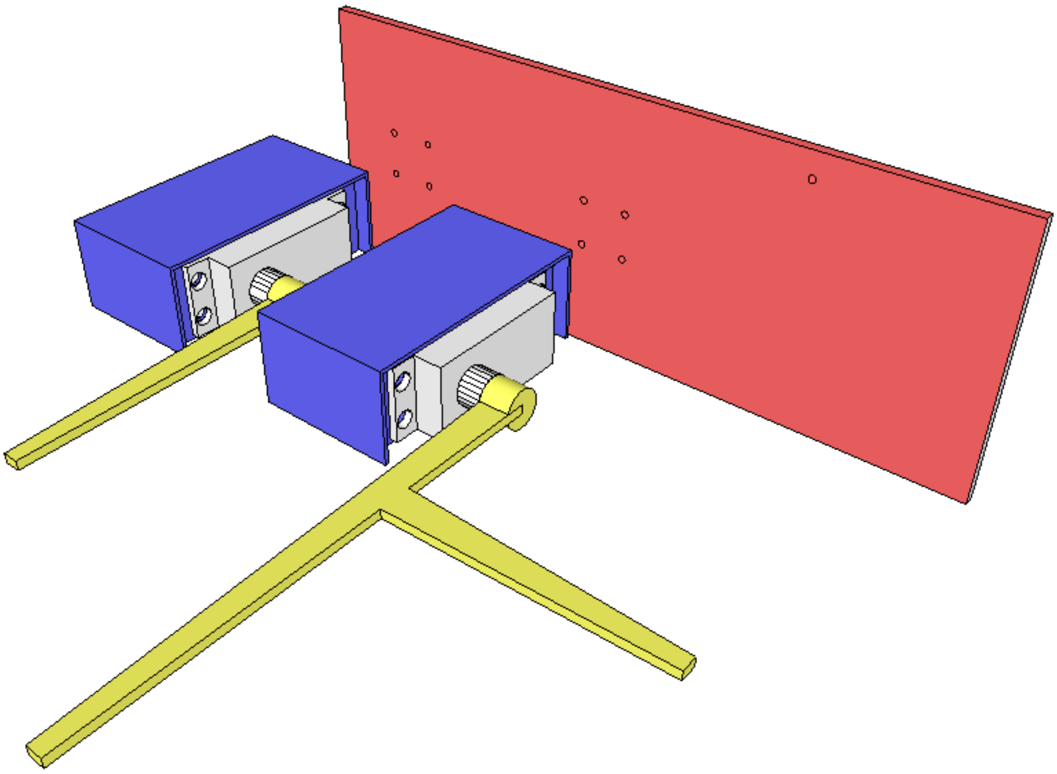


Figure 3.20: Overview of Fin’s Joint Structure

Figure 3.21: Actual Fin’s Joint Structure

3.2.2 Waterproofing

Waterproofing is very important thing for underwater robot. Failing this may cause damage to electrical circuit. The servos and the body need to be seal perfectly to prevent major damage.

3.2.2.1 Servo Motor

The servo motor need to be waterproof perfectly as this part cost the most. In order to make the servo waterproof, the internal circuit of the servo needs to be seal. The servo needs to be disassembled first. Grease is used as the sealant. Grease is applied on the gears, the control circuit and the motor. After reassemble the servo, the outer body of servo also being seal with silicon sealant on the part that allow the water through. Figure 3.22 shows the step of waterproofing the servo.

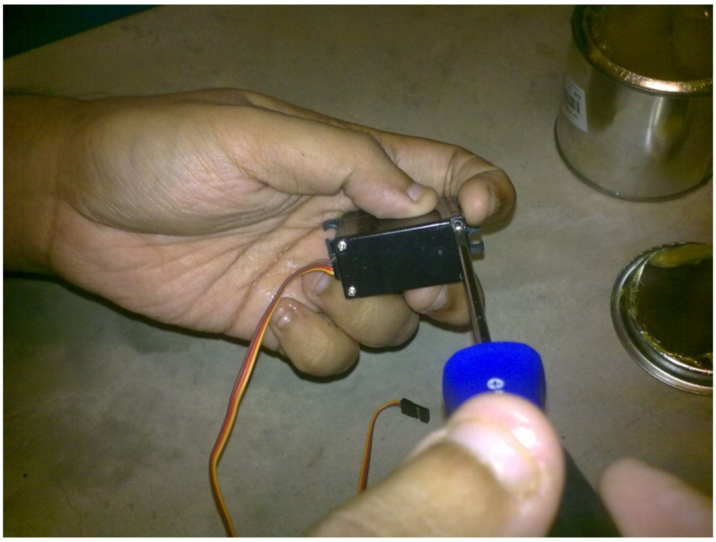


Figure 3.22 (a): Loosen the Screw to Open the Servo Case

Figure 3.22 (b): Gears Under Top Case of Servo

Figure 3.22 (c): Grease Is Applied On Top Case

Figure 3.22 (d): Grease Is Applied On bottom Case

Figure 3.22 (e): Top and Bottom Case Is Reassembled.

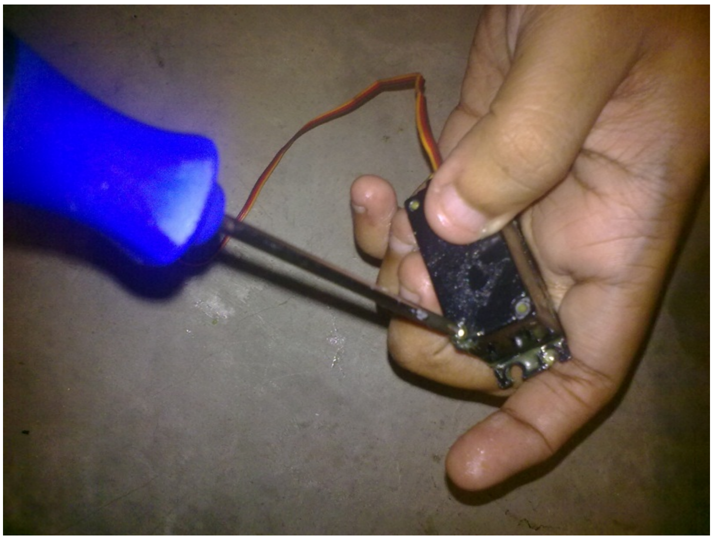


Figure 3.22 (f): Tighten The Screw And Apply Electrical Tape On Places Where Water Can Enter The Servo

3.2.2.2 Circuit

The circuit consists of the main circuit and battery. These 2 parts is placed in the body. The body is seal with silicon sealant at the joint. Also the servo cable hole also is sealed with silicon sealant.

3.3 Software

CCS C Compiler software is used to compile the source code and build a HEX file. The HEX file will be used to simulate the program using Proteus 7 Professional and then will be downloaded to the microcontroller using USB ICSP PIC Programmer V2010 and ICSP Programmer Socket through Microchip PICkit2 Programmer software.

3.3.1 Flow Chart

The first step must be done in the software design is sketching a flow chart describing the robot algorithm. The flow chart is helpful when writing the source code.

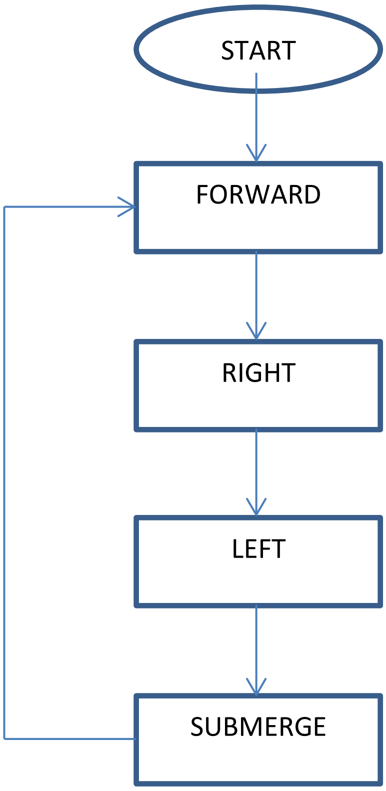
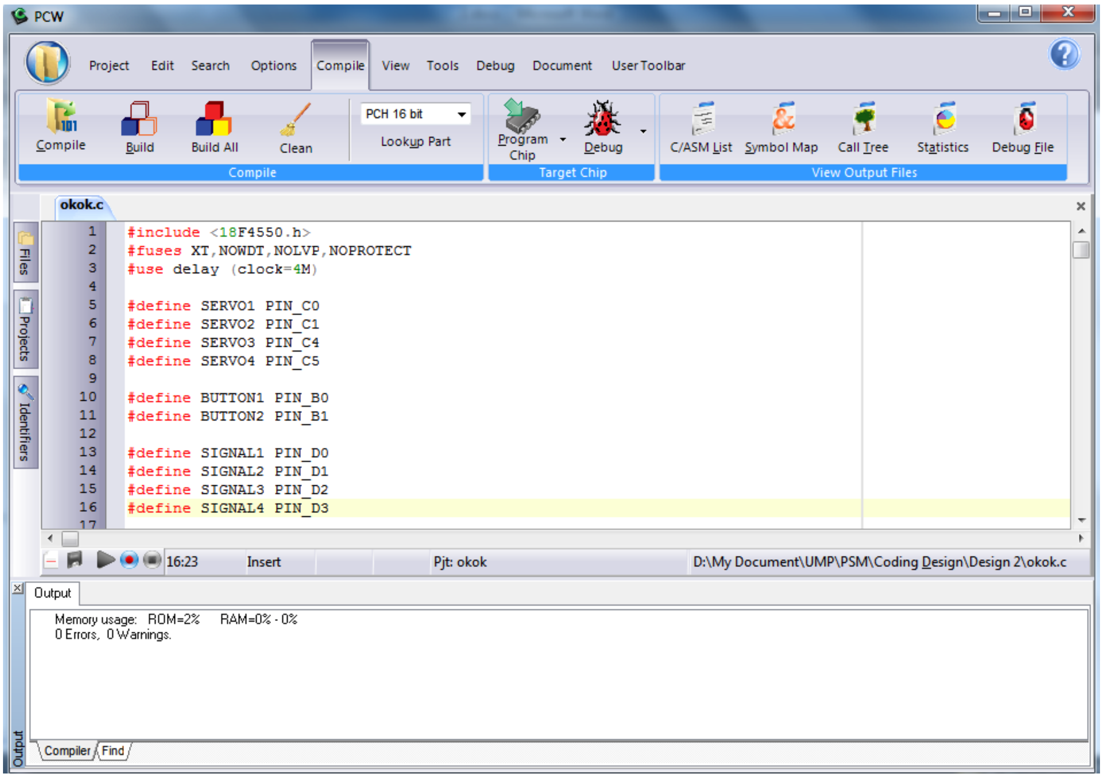


Figure 3.23: Flow Chart

3.3.1 CCS C Compiler

First step in building the system is by construct a source code using CCS C Compiler software. The source code is constructed in C language. Then, the source codes are compiled and converted to HEX file. Figure 3.24 shows the C Compiler Window and compiling process as shown in Figure 3.25.

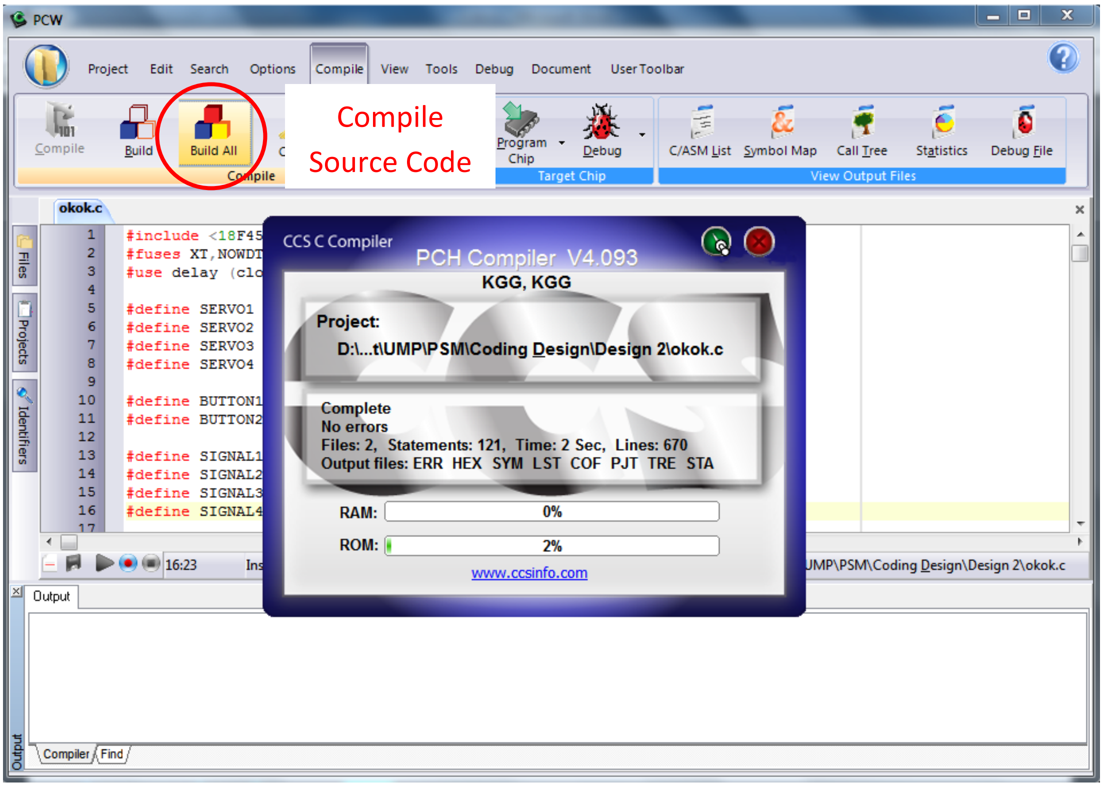


```
#include <18F4550.h>
#fuses XT,NOWDT,NOLVP,NOPROTECT
#use delay (clock=4M)

#define SERVO1 PIN_C0
#define SERVO2 PIN_C1
#define SERVO3 PIN_C4
#define SERVO4 PIN_C5

#define BUTTON1 PIN_B0
#define BUTTON2 PIN_B1

#define SIGNAL1 PIN_D0
#define SIGNAL2 PIN_D1
#define SIGNAL3 PIN_D2
#define SIGNAL4 PIN_D3
```

16:23 Insert Pjt: okok D:\My Document\UMP\PSM\Coding Design\Design 2\okok.c

```
Memory usage:   ROM=2%     RAM=0% - 0%
0 Errors,  0 Warnings.
```

Figure 3.24: C Compiler Window



PCH Compiler V4.093
KGG, KGG

Project:
D:\...t\UMP\PSM\Coding Design\Design 2\okok.c

Complete
No errors
Files: 2, Statements: 121, Time: 2 Sec, Lines: 670
Output files: ERR HEX SYM LST COF PJT TRE STA

RAM: 0%
ROM: 2%

www.ccsinfo.com

Figure 3.25: Compile Source Code (HEX File)

3.3.2 Proteus 7 Professional

Next, Proteus 7 Professional is used as the simulation tool to analyze the source code performance to operate the servo and dc motors. The HEX file created from CCS C Compiler is uploaded into PIC18F4550 in the Proteus 7 Professional software as shown in Figure 3.27. Figure 3.26 show Proteus 7 Professional window.

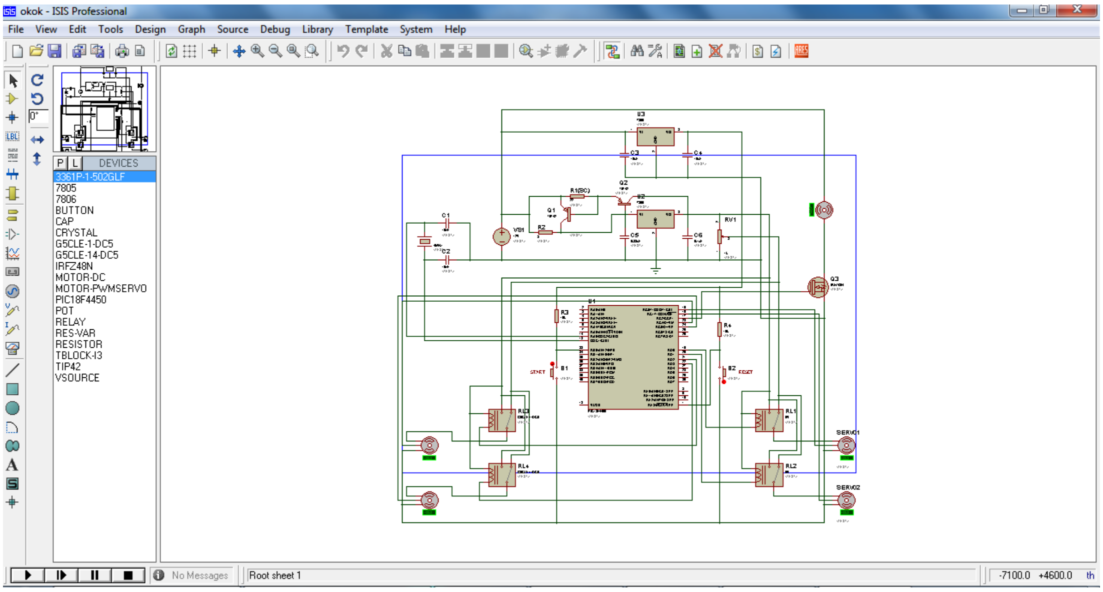
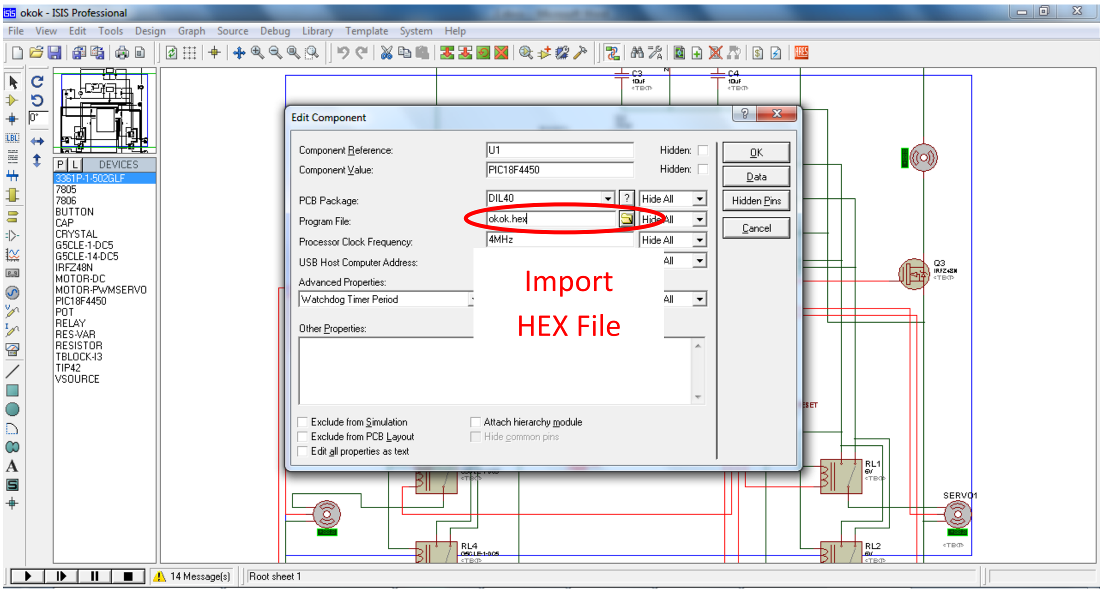


Figure 3.26: Proteus 7 Professional



Component Reference: U1 Hidden: ☐

Component Value: PIC18F4450 Hidden: ☐

PCB Package: DIL40 Hide All

Program File: okok.hex Hide All

Processor Clock Frequency: 4MHz Hide All

USB Host Computer Address:

Advanced Properties:

Watchdog Timer Period

Other Properties:

☐ Exclude from Simulation

☐ Exclude from PCB Layout

☐ Edit all properties as text

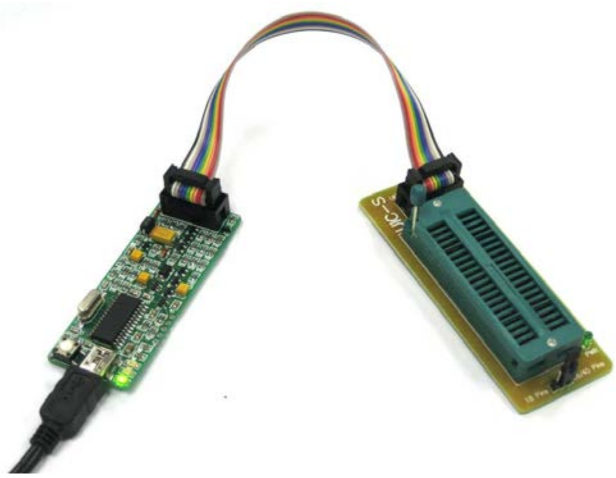
☐ Attach hierarchy module

☐ Hide common pins

Figure 3.27: Import HEX File into PIC18F4550 in Proteus 7 Professional

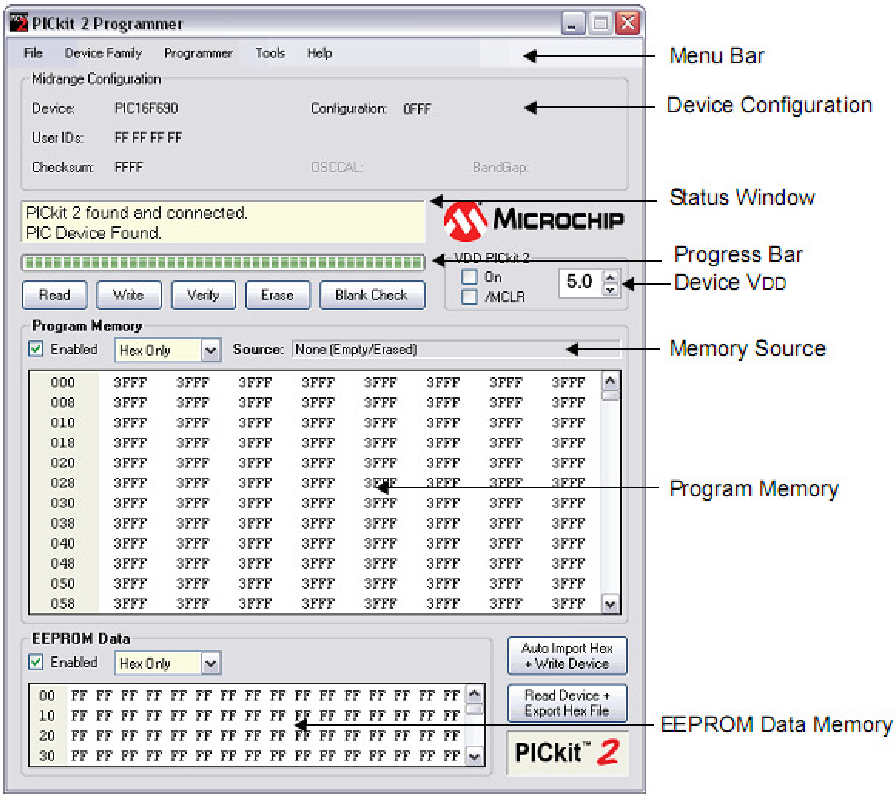
3.3.3 Microchip PICkit2 Programmer

The HEX file created is downloaded into PIC microcontroller using USB ICSP PIC Programmer V2010 and ICSP Programmer Socket through Microchip PICkit2 Programmer software as shown in Figure 3.29. Then, the HEX file is burnt into the PIC, the microcontroller now is ready to be used. Figure 3.28 shows the connection between USB ICSP PIC Programmer V2010 and ICSP Programmer Socket.



(a) (b)

Figure 3.28 (a): USB ICSP PIC Programmer V2010 and (b) ICSP Programmer Socket



Device: PIC16F690
Configuration: 0FFF
User IDs: FF FF FF FF
Checksum: FFFF
OSCCAL:
BandGap:

PICkit 2 found and connected.
PIC Device Found.

5.0

Source: None (Empty/Erased)

```
000   3FFF  3FFF  3FFF  3FFF  3FFF  3FFF  3FFF  3FFF
008   3FFF  3FFF  3FFF  3FFF  3FFF  3FFF  3FFF  3FFF
010   3FFF  3FFF  3FFF  3FFF  3FFF  3FFF  3FFF  3FFF
018   3FFF  3FFF  3FFF  3FFF  3FFF  3FFF  3FFF  3FFF
020   3FFF  3FFF  3FFF  3FFF  3FFF  3FFF  3FFF  3FFF
028   3FFF  3FFF  3FFF  3FFF  3FFF  3FFF  3FFF  3FFF
030   3FFF  3FFF  3FFF  3FFF  3FFF  3FFF  3FFF  3FFF
038   3FFF  3FFF  3FFF  3FFF  3FFF  3FFF  3FFF  3FFF
040   3FFF  3FFF  3FFF  3FFF  3FFF  3FFF  3FFF  3FFF
048   3FFF  3FFF  3FFF  3FFF  3FFF  3FFF  3FFF  3FFF
050   3FFF  3FFF  3FFF  3FFF  3FFF  3FFF  3FFF  3FFF
058   3FFF  3FFF  3FFF  3FFF  3FFF  3FFF  3FFF  3FFF
```

```
00  FF FF FF FF FF FF FF FF FF FF FF FF FF FF FF FF
10  FF FF FF FF FF FF FF FF FF FF FF FF FF FF FF FF
20  FF FF FF FF FF FF FF FF FF FF FF FF FF FF FF FF
30  FF FF FF FF FF FF FF FF FF FF FF FF FF FF FF FF
```

Figure 3.29: Microchip PICkit2 Programmer Software

CHAPTER 4

RESULT

This chapter discusses on the result, findings and the assessment from the analysis conducted in this project. After the development of the Stingray Robot, the robot will be analyzed to make sure the robot will function as desired and to ensure the objectives are fulfill. Throughout the analysis, its strengths and weaknesses were identified.

4.1 Robot Abilities

The strengths and weaknesses of robot are analyzed once the robot characteristics have been identified. Robot is tested in the water. From experiments conducted, the fin flaps as desired resulting the robot forward, right, left and down movement underwater.

4.2 The Movement Underwater

The first step in the analysis process is to identify the functionality of the robot. Analysis is performed based on the objectives of the project which is the ability to move as programmed. The programming of servo motor rotational need to be very detailed as the fins are the main part of the robot movement and also to prevent damage of the servos.

As the result of robot development, the robot is able to move forward, right and left. Forward movement needs all fins to flap. The right and left movement of the robot depend on the flapping fin. The robot will turn to the right when only the left side fins flap and making left turn when only the right fins flap. Due to certain problem in waterproofing, the water slowly enter the body frame resulting failure in operating the robot.

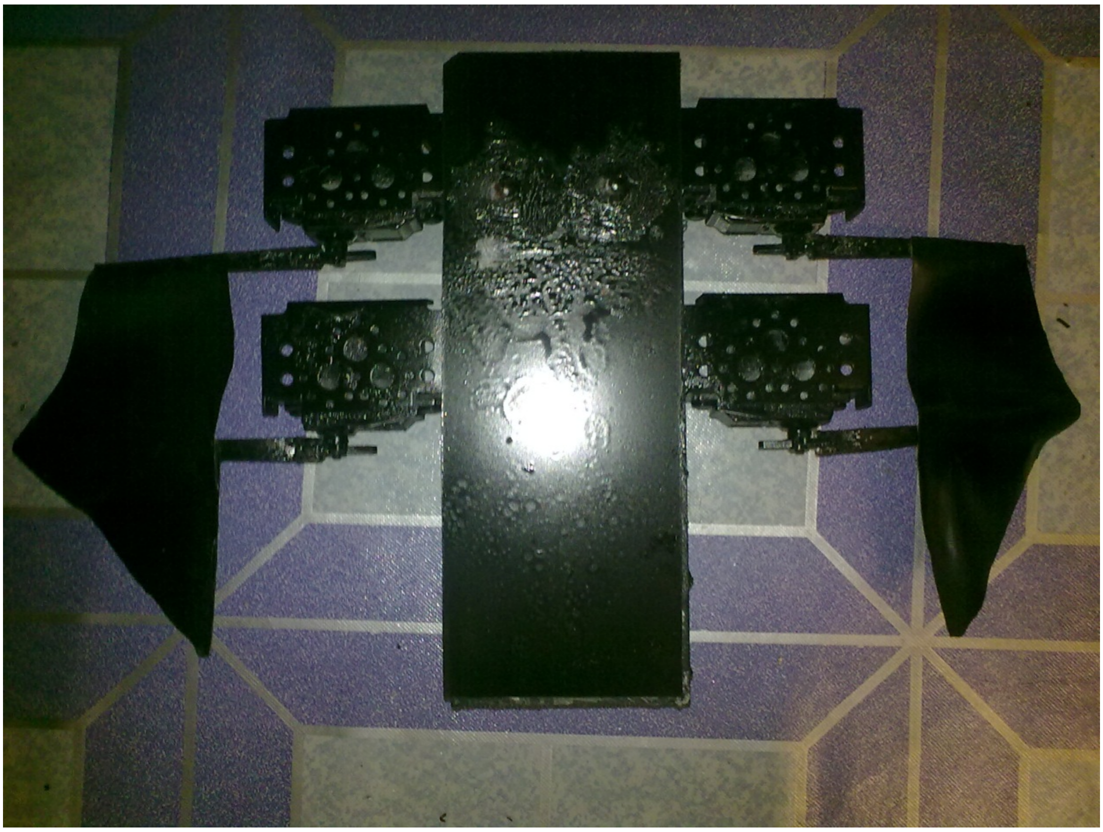


Figure 4.1: The StingrayRobot

CHAPTER 5

CONCLUSION & RECOMMENDATION

These studies and investigations on stingray robot built will help to build a functional robot. The flaps of fins needs to be precise, in order make the robot functional. The material and devices use for the robot also must be carefully choose for best performance of robot. Waterproofing is the most important thing in developing underwater robot. With deep studies and investigations, this robot can be further develop.

By further study and research, this robot can be improve and upgrade. The improvement can be made on the body by replacing Perspex with lighter, more solid and easy to assemble material. The body can be lightened by using lighter and smaller battery. A highly waterproof body is highly recommended (with no sealant needed). The usage of the servo also can be reduced by further study and research. Also the usage of servo with greater ability in term of torque, speed and payload will improve the maneuverability of the robot. The robot will be more flexible with the addition of underwater cameras and spotlight.

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[8] **Jun Gao, Shusheng Bi, Yicun Xu and Cong Liu**, *Development and Design of a Robotic Manta Ray Featuring Flexible Pectoral Fins,* Proceedings of the 2007 IEEE International Conference on Robotics and Biomimetics, Robotics Institute Beijing University of Aeronautics and Astronautics, Beijing.

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[12] **Wan Zakaria Bin Wan Hassan**, *The Stingraybot,* May 2008, Universiti Teknologi Malaysia

[13] **Chunlin Zhou and K. H. Low,** *Design and Locomotion Control of a Biomimetic Underwater Vehicle With Fin Propulsion,* Ieee/Asme Transactions On Mechatronics, Vol. 17, No. 1, February 2012

APPENDIX A

```
#include <18F4550.h>

#fuses XT,NOWDT,NOLVP,NOPROTECT

#use delay (clock=4M)


#define SERVO1 PIN_C0

#define SERVO2 PIN_C1

#define SERVO3 PIN_C4

#define SERVO4 PIN_C5


#define BUTTON1 PIN_B0

#define BUTTON2 PIN_B1


#define SIGNAL1 PIN_D0

#define SIGNAL2 PIN_D1

#define SIGNAL3 PIN_D2

#define SIGNAL4 PIN_D3


void forward(void);

void right(void);

void left(void);

void sink(void);
```

```
void servo_all_45(void);

void servo_all_135(void);

void servo_right_45(void);

void servo_right_135(void);

void servo_left_45(void);

void servo_left_135(void);


void main()
{
set_tris_b(0xFF);

set_tris_c(0x00);

set_tris_d(0x00);


output_b(0xFF);

output_c(0x00);

output_d(0x00);


setup_timer_2(T2_DIV_BY_4,254,1);

setup_ccp1(ccp_pwm);


while(TRUE)

 {


if (!input(BUTTON1))

  {
```

```
         forward();

         right();

         left();

         sink();


   }

  }

 }

 void forward(void)

 {

       unsigned int i;

       for (i = 0; i <6; i++)

       {

         output_d (0x00);

         servo_all_45();

         output_d (0x0F);

         servo_all_135();

       }

 }

 void right(void)

 {

       unsigned int i;
```

```
    for (i = 0; i <6; i++)
    {
      output_d (0x00);
      servo_right_45();
      output_d (0x03);
      servo_right_135();
    }
}

void left(void)
{
    unsigned int i;
    for (i = 0; i <6; i++)
    {
      output_d (0x00);
      servo_left_45();
      output_d (0x0C);
      servo_left_135();
    }
}

void sink(void)
{
    output_high (MOTOR1);
```

```
    output_low (MOTOR1);
    set_pwm1_duty(50);
}

void servo_all_45(void)
{
    unsigned int i;
    for (i = 0; i <21; i++)  // -45 deg
    {
      if((i>=0)&&(i<6))
      {
        output_c (0x11);
        delay_us(1000);
        output_c (0x00);
        delay_us(19000);
      }
      else if(i>=6)
      {
        output_c (0x33);
        delay_us(1000);
        output_c (0x00);
        delay_us(19000);
      }
```

```
    }
}

void servo_all_135(void)
{
    unsigned int i;
    for (i = 0; i <21; i++)  // -45 deg
    {
      if((i>=0)&&(i<6))
      {
        output_c (0x11);
        delay_us(2000);
        output_c (0x00);
        delay_us(18000);
      }
      else if(i>=6)
      {
        output_c(0x33);
        delay_us(2000);
        output_c(0x00);
        delay_us(18000);
      }
    }
```

```
}

void servo_right_45(void)
{
    unsigned int i;
    for (i = 0; i <21; i++)  // -45 deg
    {
      if((i>=0)&&(i<6))
      {
        output_c (0x01);
        delay_us(1000);
        output_c (0x00);
        delay_us(19000);
      }
      else if(i>=6)
      {
        output_c (0x03);
        delay_us(1000);
        output_c (0x00);
        delay_us(19000);
      }
    }
}
```

```
void servo_right_135(void)

{

      unsigned int i;

      for (i = 0; i <21; i++)  // -45 deg

      {

         if((i>=0)&&(i<6))

         {

            output_c (0x01);

            delay_us(2000);

            output_c (0x00);

            delay_us(18000);

         }

         else if(i>=6)

         {

            output_c (0x03);

            delay_us(2000);

            output_c (0x00);

            delay_us(18000);

         }

      }

}


void servo_left_45(void)
```

```
{
    unsigned int i;
    for (i = 0; i <21; i++)  // -45 deg
    {
      if((i>=0)&&(i<6))
      {
        output_c (0x10);
        delay_us(1000);
        output_c (0x00);
        delay_us(19000);
      }
      else if(i>=6)
      {
        output_c (0x30);
        delay_us(1000);
        output_c (0x00);
        delay_us(19000);
      }
    }
}

void servo_left_135(void)
{
```

```
      unsigned int i;

      for (i = 0; i <21; i++)  // -45 deg

      {



        if((i>=0)&&(i<6))

        {

          output_c (0x10);

          delay_us(2000);

          output_c (0x00);

          delay_us(18000);

        }

        else if(i>=6)

        {

          output_c(0x30);

          delay_us(2000);

          output_c(0x00);

          delay_us(18000);

        }

      }

}
```