PIC CONTROLLED ROBOT

By

NURHAYATI BINTI MOHD SHAH

FINAL PROJECT REPORT

Submitted to the Electrical & Electronics Engineering Programme
in Partial Fulfillment of the Requirements
for the Degree
Bachelor of Engineering (Hons)
(Electrical & Electronics Engineering)

Universiti Teknologi Petronas
Bandar Seri Iskandar
31750 Tronoh
Perak Darul Ridzuan

CERTIFICATION OF APPROVAL

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Approved:

13-06-07

Dr Taj Mohammad Baloch
Senior Lecturer
Electrical & Electronic Engineering
Universiti Teknologi PETRONAS
31750 Tronoh
Perak Darul Ridzuan, MALAYSIA

Dr. Taj Mohammad Baloch
Project Supervisor

UNIVERSITI TEKNOLOGI PETRONAS
TRONOH, PERAK

June 2007

CERTIFICATION OF ORIGINALITY

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

Nurhayati Binti Mohd Shah

ABSTRACT

A working prototype of a mobile robot is designed for the project. The robot has the capabilities to travel in a predetermined path with obstacle collision avoidance systems. The robot composed of five main components which are body structure, controller, mobility and movements, power distribution and sensors. The body of the robot is the platform where all the circuits and battery are positioned at. Controller is the main 'brain' or CPU controls the overall operation of the robot. Power supply on the other hand is used to distribute power and thus making to every circuit and parts of the robot to work. As a mobile robot, the mobility and movements are very important aspects in order to ensure the robot manages to travel in every path determined earlier. Sensors included in this project namely ultrasonic sensor as well as infrared sensor are used to make the robot 'feel' and 'see' the environment. All these components are fabricated partly and being integrated or combined to produce a one whole working prototype. Hardware and software simulation are two methods used in completing the project.

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LIST OF ABBREVIATIONS

FYP I – Final Year Project 1

PLC – Programmable Logic Control

PIC – Programmable Input Control

CPU - Central Processing Unit

CHAPTER 1
INTRODUCTION

1.1 BACKGROUND OF THE STUDY

Robot has become common in this new world of high technology. Most of robots are able to stand alone in doing some activities or making decisions such as avoiding obstacle and also to follow certain path without any human interventions.

Robot diverse from the type of the movement they make to the type of environment they were created for. There are bipedal robots, walking robots which move on two sets of 'foot' and there are also mobile robots which use tires to move from one place to another. There are even robots which can fly with the help of some wings or blades which commonly originates from model planes or helicopters. However, many robots use wheels for locomotion. No matter what size or the environment the robot is built for, the function of the robot is very crucial depending on the task that has been specified for it. NASA amazed the world when two of their autonomous robots have been safely landed on the surface of Mars back in 1998. These robots were sent to Mars due to the environment which hostile to the human at the moment. These robots were able to conduct some experiments to gather information for the scientists millions of miles away. The crucial thing is that both robots are autonomous and they are able to make decision on what path to choose and able to avoid any accident such as ending up in a crater.

1.2 PROBLEM STATEMENT

There is a need to design a robot that is capable of traveling from one point to another point in required path. The path is first being determined and programmed in the microcontroller circuit of the robot. Sensors are equipped on the robot so as to give information of the surrounding to the robot. The sensors act as the eyes and ears for the robot to identify if there is any obstacle around itself. Upon the meet with the obstacle, the robot should be able to trigger a buzzer and avoid the obstacle before continue with its tasks. Other significant of the robot is that it can be a 'transporter' as it is able to carry a light weight object along its pathway to the destination.

Throughout the period of study, all the parts of robots name it the body structure, controller, mobility and movement, sensors, power and tools are designed and finally integrated into one working robot. The robot is developed part by part to ensure all parts are working before the components are combined together. This project is significant as it develops the fundamentals of robotic systems that is needed by the university to further the study on this exciting area of electrical and electronics engineering. Related fields such as circuit drive design, micro processing, programming and mechanical designs are applied in this project in order to achieve the goal.

1.3 OBJECTIVES AND SCOPE OF STUDY

The objective of the project is to design and implement a working prototype of mobile robot with the capabilities to travel on the predetermined paths and trigger a buzzer upon meeting with the obstacle. The author has narrowed the objectives of the project which are as follow:

- To design a PIC controlled robot that travels along a predetermined path and able to avoid any obstacle collision.
- To design a simple body structure and moving mechanism for the robot.
- To design the robot in a way that it user-friendly with affordable cost which is in the range of RM 200 ~ RM 300.

1.3.1 The Relevancy of the Project

The universities and research institutions both local and international are doing research on robotics systems. It is really a relevant idea to develop an in house robot which is to be established as one of major work. Besides, the robot can be served as basis for future studies for the robotics systems. Having a design of robotics system can lead to detail understanding of the robot mechanism itself. The university can use the research material to compete in robotics competition around the world.

1.3.2 Feasibility of the Project within Scope and Time Frame

The project is considered feasible based on the time given and also the abundance of information on robotic systems which are available through the internet as well as reading materials.

The first half of the project period is used to concentrate most on research and literature review of the robotics systems and any related topics regarding the project title. Consequently, the design phase of the robot's components such as the structure, drive circuit, sensors, controller, and power distribution will take place after the research is conducted. The other second half project which is more or less of five months is used for the implementation of the design to produce a prototype.

CHAPTER 2
LITERATURE REVIEW AND/OR THEORY

Literature review is done through out the first half of project period by collecting or gathering information from various sources available such as from the internet websites, conference papers, journals as well as books.

2.1 OVERVIEW

Engineering and computer science are the core elements of mobile robotics. Autonomous mobile robotics is a fascinating research topic. Mobile robotics reverses the trend in science towards more specializations, demands lateral thinking and the combination of many disciplines of engineering.

The interest in investigating and developing mobile robots is very largely motivated by both a need and a desire to have robots that can work with and for people in their normal work or day-today different environments.

For any robot, its intelligence, behavior and the robot's environment cannot be evaluated independently from each other. A robot's function and operation are defined by the robot's own behavior within a specific environment, and its task taking into account a specific task (see Figure 1).

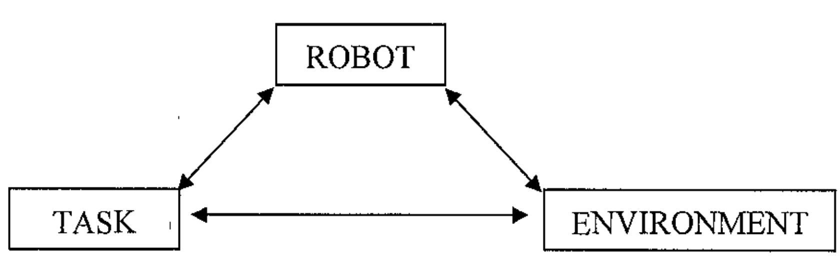


Figure 1 Interlink of robot, task, and environment

2.2 HISTORY

Robotic systems start as early as 1920 when Karel Capek, a Czechoslovakian playwright introduces the word 'Robot' in his play R.U.R. (Rossuum's Universal Robots). Robot comes from the word "robota" that means "tedious labour". However, there is an earlier idea about robot systems before that as a Greek mathematician; Archytas invented a mechanical bird propelled by steam back in 350 B.C. The invention was named "The Pigeon". [9]

Studies, inventions and knowledge about robotic systems have been spread to people through many ways. In 1940 for an example, Isaac Asimov produced short stories about robots titled "A Strange Playfellow" for Super Science Stories magazine. The story which later on renamed into "Robbie" is about a robot and the affection it had for a child that it is cannot protect. Later on, for over than 10 years Asimov produced more stories about robots.

The very first mobile robot that is able to know and react to its own actions was invented by Stanford Research Institute (known as SRI Technology). Amongst other achievements SRI was also the research institute that helped brings us modern day laundry detergent in the development of Tide.

As time grows, more and more inventions are created in the area of robotic systems. In 1993, an 8-legged walking robot named Dante was developed at Carnegie Mellon University was sent to go down at Mount Erebus, Antarctica. The mission was to collect data from harsh environment similar to what might be found on other planet.

People involving with robotics field are creating more histories. The latest history was done in 1994 where the second Mars Exploration Rover named "Opportunity" safely landed on the Meridium Planum; a plain near to equator.

2.3 BUILDING BLOCKS OF ROBOT AND AUTOMATION

Robots are comprised of several systems that are working together as a whole. These systems are very crucial as the failure in one of the systems can affect the overall performance of the robot. A robot system consists of the following:

1. Body Structure
2. Controller
3. Mobility and Movements
4. Power Distribution
5. Sensors

2.3.1 Body Structure

There are many shapes and sizes for the structure of robots such as round and box as well as oval shapes. The design normally depends on the application or the task and the environment of the robots. For an example, a robot that is needed to be landed in Martian land need to be able to withstand the corrosive environment with the high level of temperature difference and also light.

Industrial robots often use the shape of body less arm since industrial jobs normally require it to remain stationary relative to the tasks (see Figure 2). Space robot on the other hand, may have different types of body shapes as sphere which will give advantage to the robot in minimizing the damage at the space world (see Figure 3).

In a nutshell, the shapes and sizes of a robot do not matter as long as the drive motor must be sufficient enough to perform its tasks.

Figure 2 Industrial body less arm robot

Figure 3 A sphere structured robot

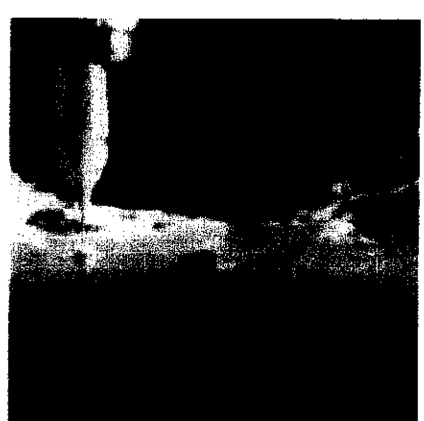


Figure 4 A sphere structured robot
(Figures taken from http://prime.jsc.nasa.gov)

2.3.2 *Controller*

Controller is known as the brain of a robot that is capable of performing any task that has been set in a program. In most of the robots available, the common controller used is PLC, which widely used in industrial field, as well as microcontrollers. Data and information will be set earlier in the microcontrollers and consequently will be processed and executed through the output.

There are several microcontrollers that can be used to control the robots. When the microprocessor is programmed or the memory is embedded, the microprocessor is then known as microcontroller. There are many types of microcontroller available in the market such as PIC from Microchip, Atmel, HC family and etc. The differences between these microprocessors are the architecture as well as the language they use.

Microchip PIC microcontroller model PIC 16F877 is the best candidate used as the main controller for this mobile robot project as it has 35 digital analog converter and PWM output that can be used for sensors and also driver circuit.

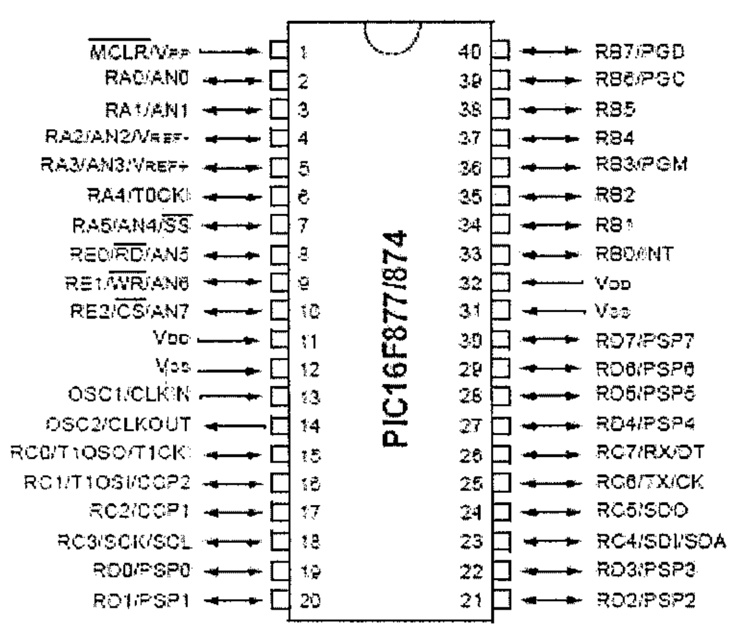


Figure 5 PIC 16F877 microcontroller from Microchip
(Taken from PIC 16F877 datasheet)

2.3.3 *Mobility and Movements*

The mobility and movements of robots depend on several factors. The estimated load that the robot needs to carry must be considered. This includes the weight of the robot that will be moved by the motors or other mechanism. The motor of the robot must have sufficient torque in order to move the load. Number of tires also determines the required torque for the robot. As to ease of giving mobility, 3 wheels are used in which 2 of them are coupled with DC motors and another castor wheel is used as support mechanism for the stability of the robot.

2.3.3.1 *Electric Motor*

The right and suitable motor must be chosen for any moving robot. For mobile robots, the motor is normally attached to the wheels. There are many types of motor available in the market today and some of them are highlighted as the following:

i. **DC Motor**: The most common linear motor that can rotate in one direction.
ii. **Stepper Motor**: A motor that can rotate the shaft for a few degrees and then stop before continue its rotation. It requires power to be pulsed to the motor.
iii. **Servo motor**: Normally used as joints for robots that can only move 180° in direction.

2.3.3.2 *Torque*

Torque is the angular force that a motor can deliver at a certain distance from the shaft. A 5 oz-in of torque means that at a distance of 1 inch away from the shaft of the motor, it can pull up a weight of 5 ounces using a pulley. The metric-unit of torque is in terms of Newton-meters (Nm). [1] The torque is given as τ, where:

$$\tau = F \times r$$

In motor, electrical power is converted into mechanical power. Power is the rate at which the energy is used up. Te following equation clarifies the relationship:

$$1\,\text{Watt} = 1\ (\text{Joule} / \text{sec})$$

2.3.4 Power Distribution

A mobile robot requires a power system that can meet several goals simultaneously. The power source must store energy sufficient to allow the robot to perform a useful amount of work. Power must be provided at constant voltage in order to ensure proper operation of the onboard electronic circuits.

2.3.4.1 Batteries

Batteries are the most common energy storage for mobile robots. A battery converts chemical energy into electrical on demand. An ideal battery would have a high density, maintain a constant voltage during discharge, have a low internal maintenance, and therefore be capable of rapid discharge. It should also withstand temperature extremes; exhibit an unlimited shelf life, rechargeable and low cost. Unfortunately, there is no single battery technology that exhibits all these criteria. Practically, it is necessary to make trade-offs among these qualities, depending on the task. For the project, Sealed Lead-Acid battery is used because the size and weight; very convenient to be carried on a mobile robot, easy to use, and has a long life span. Information given in Table 1 serves as a guide in choosing a proper trade-off for any task requirement.

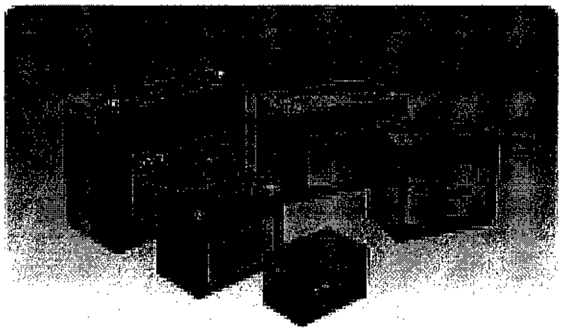


Figure 6 Samples of sealed lead-acid batteries
(Courtesy of BSB Power Company Limited)

Table 1 Comparison of characteristics for selected batteries and sizes

Battery Chemistry	**Recharge**	**Energy Density (W.hr / kg)**	**Cell Voltage (V)**	**Internal Resistance (Ω)**	**Comments**
Alkaline	No	130	1.5	0.1	Most common primary battery
Lead-Acid	Yes	40	2.0	0.006	Available in a wide variety of sizes
Lithium	No	300	3.0	0.3	Excellent in energy density but high cost
NiMH	Yes	57	1.3		Better energy density than NiCd but expensive
Zinc-Air	No	310	1.4		High energy density but not widely available and limited range of sizes
Carbon-Zinc	No	75	1.5		Inexpensive but obsolete

2.3.5 Sensors

Sensors are devices that can sense and measure physical properties of the environment such as temperature, luminance, weight, size and etc. Without sensors, a robot is just a machine that only capable of moving through a predetermined sequence of action. With sensors, robots can react and respond to changes in their environment in ways that can appear intelligent or life-like. There are varieties of common sensors used in robotics applications including touch switches, infrared sensors, ultrasonic sensors as well as shaft encoders. The sensors used for this project are as follow:

2.3.5.1 Shaft or Rotary Encoder

This sensor is used to control the wheel rotation by getting the data from the wheel and apply rotary encoder setup to the robot. The basic idea is to detect different state for two different conditions for example ON and OFF. By detecting this, the rate of change can be measured. These changes implies to several information such as speed, position and synchronization of the wheels. The rotary encoder is used to feed the data into the microcontroller.

The simplest method is to have black and white strips that are coupled to the wheels. Infrared transmitter and detector can be used to detect its state. The signal will be then converted to a stream of 1 and 0 pulses which then fed to the microcontroller in order to get information as the speed and the distance travel for the control of the robot.

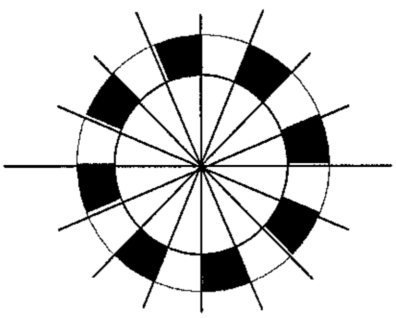


Figure 7 A simple black and white encoder

2.3.5.2 Ultrasonic Sensor

Ultrasonic sensor is commonly used in robotic systems. Ultrasonic is sound with a frequency greater than the upper limit of human hearing which is higher than 20 kHz. The frequency value normally this sensor used is 40 kHz. This sensor comprises of a transmitter and a receiver circuit. The transmitter circuit transmits a signal at a certain frequency (normally 40 kHz). This signal is then bounced back when it hits an object. The bounced signal retrieved by the receiver transducer. The receiver circuit will process the received signal by giving it to a set of amplifiers and finally convert to digital signal by means of comparator other method. One of the advantages of this sensor is that it is not sensitive to objects of different color and light reflective properties.

Ultrasonic sensor signal attenuates at a distance. Thus, in order to get a better range, high power is required to create the ultrasonic chirp and a problem will rise when the robot carries a limited power supply. Another drawback of the sensor is the accuracy fluctuates depending on the temperature and the air density of its surrounding. This is very common to some 'low grade' transducer. Higher grades transducers have intelligent ways to compensate the surrounding effects.

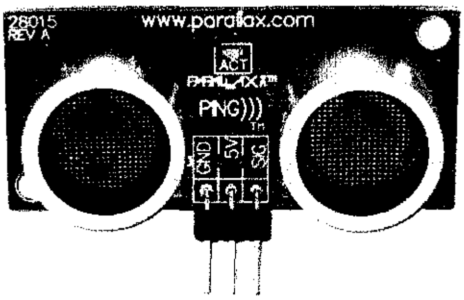


Figure 8 Sample of ultrasonic transmitter and receiver sensor
(Taken from www.parallax.com)

CHAPTER 3
METHODOLOGY OF PROJECT WORK

3.1 PROJECT PROCESS FLOW

The process flow of the project is done based on the simple flow which applied through out the project (Figure 9).

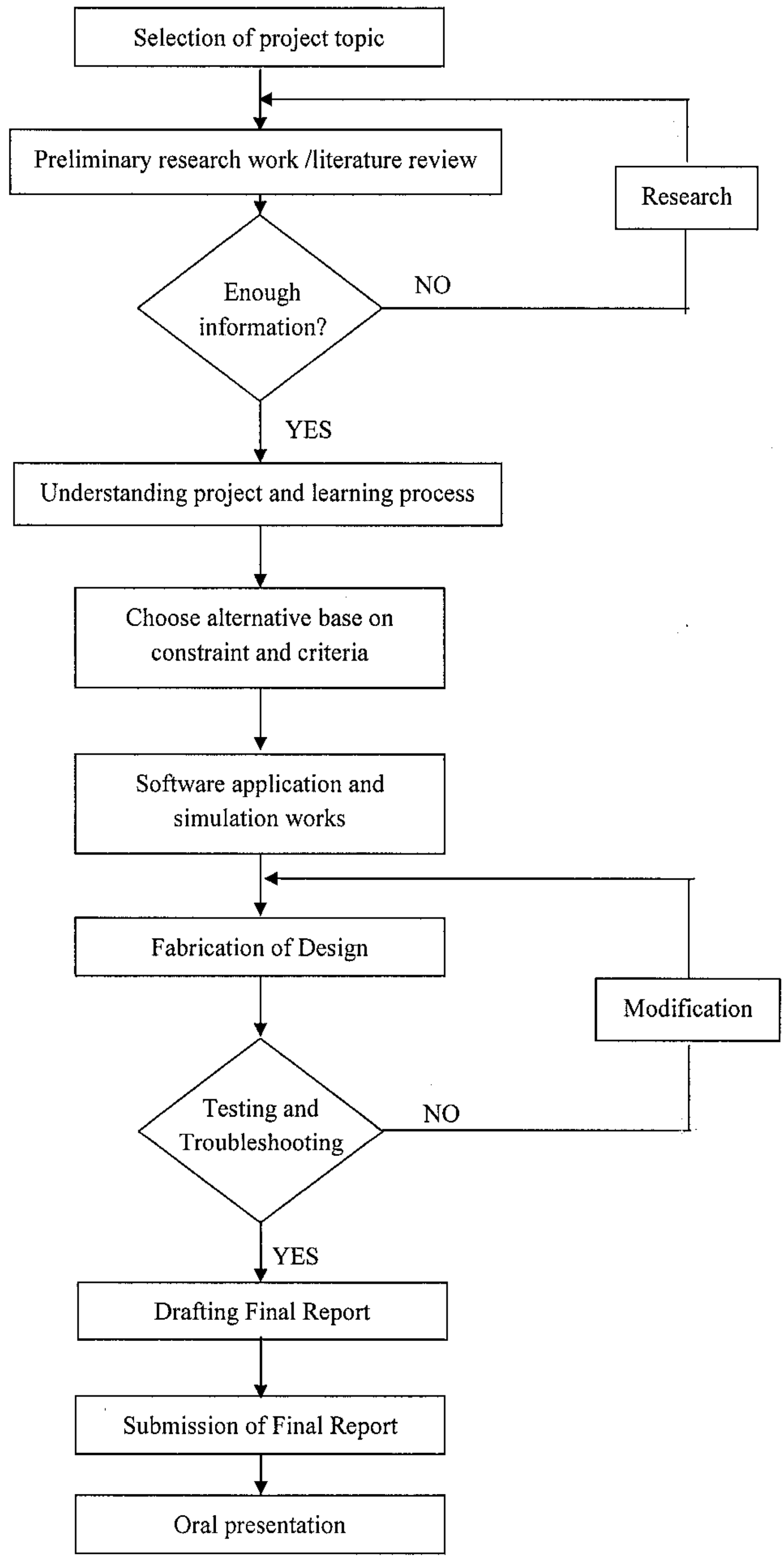
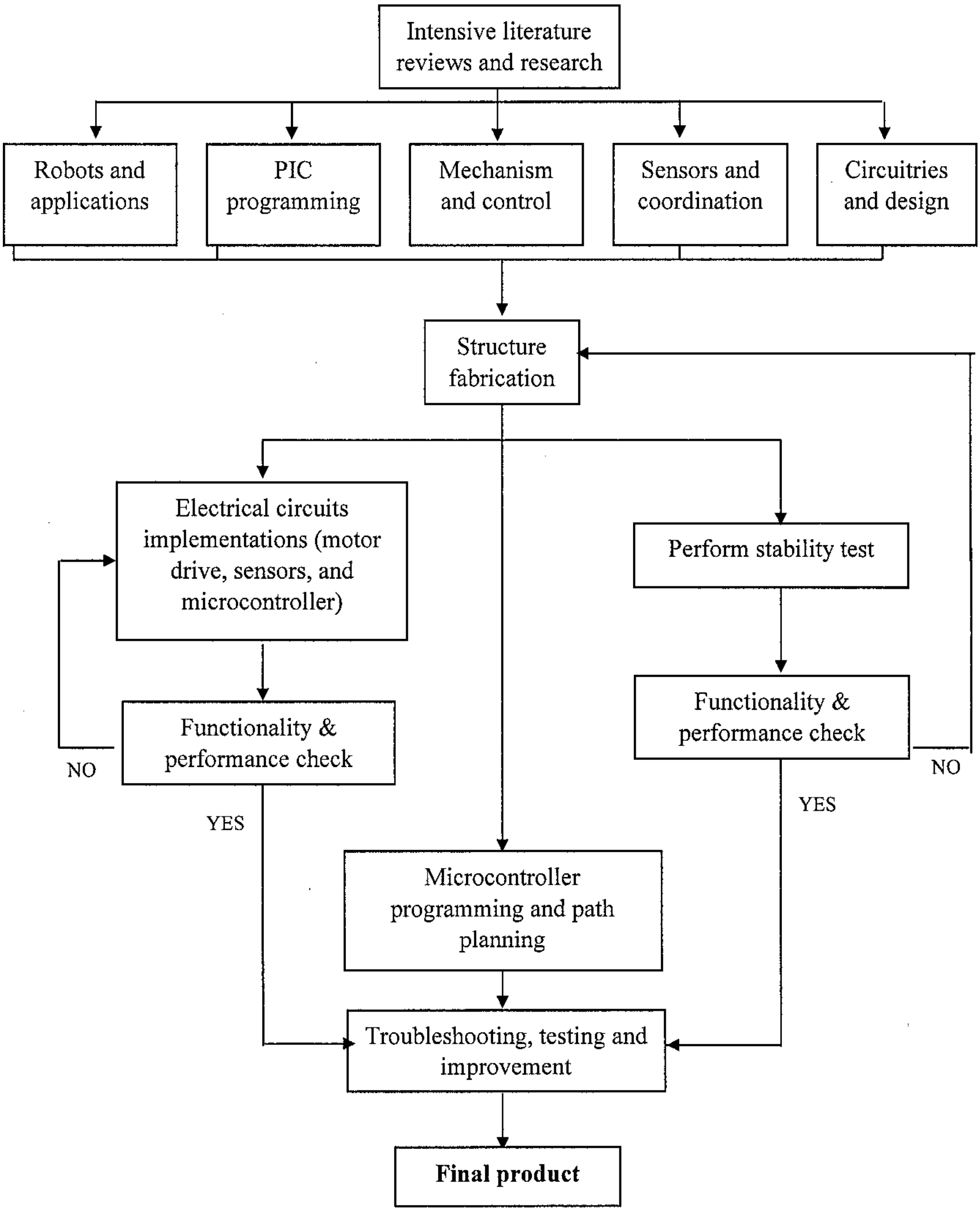


Figure 9 Process flow for the project

The first step taken was to select the project topic and thus conduct preliminary researches and literature review through the available source such as using the internet, text books, journals as well as conference papers. It is very crucial for the author to undergo learning process as robotics is not a familiar area to him/her. From the data gathered, the alternatives are layered out and the best alternatives are chosen based on constraint and criteria. The next step was to transfer or apply the information gathered by using related software or doing some stimulation pertaining to the project. The following step was the most crucial and hardest part of the project that is the fabrication of the design and to translate the simulation into the real project in order to have a robot prototype. During this step, a lot of modifications are made onto the robot from time to time in order to produce the best structured and stabled robot. The following step is the drafting of final report which has to be submitted before the final report is written and thus submitted to the committee. The final stage of the process flow of the project is the oral presentation which took place at the end of the semester.

3.2 PROJECT FLOW IDENTIFICATION



3.2.1 Literature Review

Intensive literature review is done at the initial stage of the project because robotic systems are very uncommon to the author. It is also being carried out from time to time during the completion of the project to ensure the best output is produced. A lot of resources are used for this crucial step including books, journals, and also the information available through the internet. Mainly, the literature study covers the following areas:

- Application of robots in the industry – technology used in robots application.
- PIC programming language – programming language used to program the microcontroller (PIC16F877) for the control system of the whole robot.
- Robot mechanism and control – identification of robot's locomotion, torque of the motor and the mechanism to be implemented on the design.
- Sensors and robot's coordination – Identifying the most suitable sensor to be used for obstacle avoidance system and distance measurement for path planning.
- Robot circuitries and design – Electrical circuits are very essential to ensure the functionality of the robot. The circuits involved in the project are motor drive circuit, power supply circuit, microcontroller circuit as well as sensor circuits including infrared and ultrasonic.

3.2.2 Mechanical and Electrical Design

Mechanical structures of the robot are designed to get a better and clear picture of how the robot would resemble. The robot is designed to be in square shaped and the design will be discussed in the following chapter. Electrical designs on the other hand are done using simulation software to test and check the ability and the effectiveness of the circuits gathered from the resources.

3.2.3 Structure Fabrication for Mobile Robot

The body of the robot is to be built by acrylic glass or better known as Perspex. Two geared DC motor will be mounted underneath the base of the robot. In producing a stable mobile robot, a castor wheel is then mounted at the centre of the robot base.

3.2.4 Microcontroller Programming and Path Planning

As microcontroller is the main operating system or the 'brain' of the robot, programming is very crucial for this project. Programming skill is highly required for is project as the movement and path planning directions depend on the microcontroller.

3.2.5 Troubleshooting and Testing

Troubleshooting and testing each part of the robot is very important. This is to ensure that a functioning robot will be produced at the end of the project duration.

3.3 PARTS AND TOOLS

Listed in the table below are the equipment and tools that are used in this project in producing a good and workable prototype.

Table 2 Parts and tools for the project

No	Parts	Material or Components	Tool
1.	Structure	1. Perspex 2. L-Bar Aluminum	1. Drill 3. Welding 4. Glue Gun
2.	Mobility and Movement	1. 12V DC motor 2. Tires and casters 3. Nuts and screws	1. Screw drivers 2. Pliers 3. Metal tie 4. PVC pipe
3.	Power distribution	1. Batteries 2. Connectors & Wires	1. Solders 2. Multimeter 3. Screw drivers
4.	Sensors	1. Electronics components (transistors, capacitors and etc.) 2. Ultrasonic and infrared transducers.	1. Simulation software Multisim or Pspice) 2. Breadboard 3. Solder 4. Multimeter 5. Oscilloscope
5.	Microprocessors	1. PIC Controller	1. Breadboard 2. Electronics components 3. Oscilloscope 4. PIC programming software 5. Connectors 6. Warp13

3.4 COST ESTIMATION

The following table summarizes the estimation cost of every tools and components used for the project;

Table 3 Estimation of cost for every components

No.	Item/Component	Cost (RM)
1	2x30cmx30cm; 4x30cmx20cm Perspex	80.00
2	1 x Sealed Lead-Acid battery	35.00
3	2 x Electrical DC motor	75.00
4	30 cm PVC Pipe	1.50
5	2 x Toy wheels	5.00
6	1 x Castor Wheel	2.50
7	6 x Circuit Board	10.00
8	Electronics Components (Resistors, Transistors, Capacitors and etc.)	40.00
9	1 x PIC 16F877	20.00
10	Miscellaneous Tools (Glue, Wire Connectors and etc.)	5.00
TOTAL		**274.00**

From the table above, the total building cost of the robot is clearly within the range of desired cost stated earlier which is between RM200 and RM300. This value of RM274 is expected to be affordable for user to buy as compared to any other mobile robot available in the market.

CHAPTER 4
RESULTS AND DISCUSSIONS

4.1 DESIGN OF BODY STRUCTURE

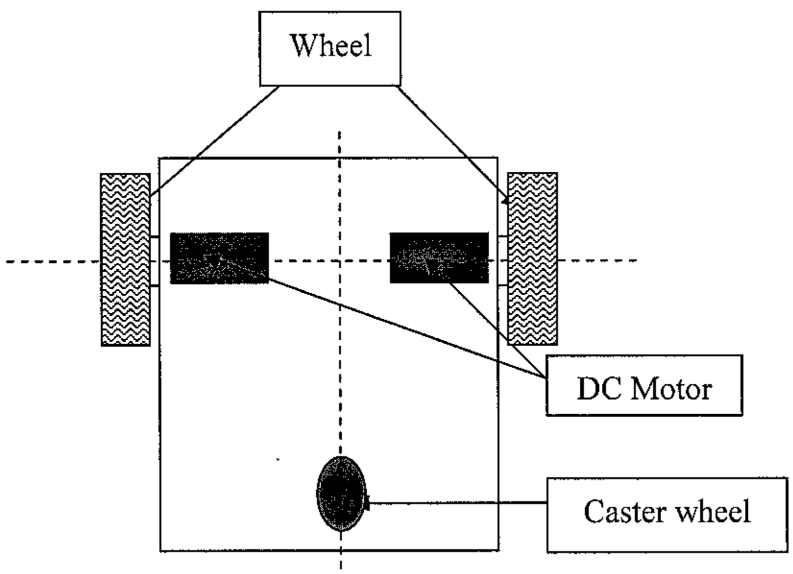


Figure 10 Location of motor and tyres on the robot body

The construction for the body structure of the robot is using Perspex. This material is used in order to give a lighter weight of robot than metal or aluminum robot. L-bar aluminum is used to build the chassis for the robot. Chassis is an important element in ensuring the stability of the robot's base. The shape of the robot is a square box as it is simple and spacious for all components and electrical circuitry to be placed in it. The body of the robot is also covered with Perspex in order to prevent all the circuits from damage caused by physical disturbances. The upper side of the chassis is an empty area where user can put any light object to be brought along the predetermined path.

Two wheels are used for the locomotion of the robot with a geared DC motor attached to each one. Both left and right wheel with motor the motor are then connected using a PVC pipe so that the position of the wheels is in radius to each other. This will result in easier and smooth movement of robot and enables the robot to make a round turn and save the turning radius. A castor wheel is used for the stability of the robot and to the ease of movements. The complete body dimension of the robot is concluded in Table 4 and the complete robot's prototype pictures are presented in Appendix A.

Table 4 Estimation of cost for every components

Width	30 cm
Length	29 cm
Height	10 cm
Net Weight	± 3kg
Body material	Perspex

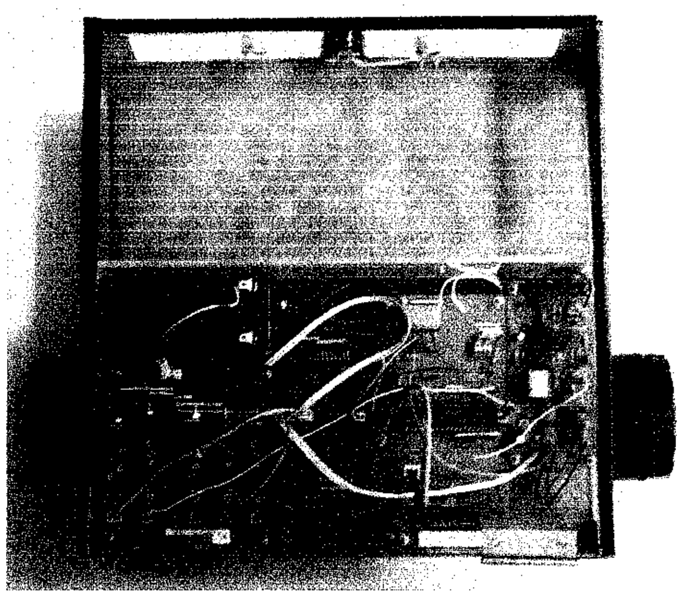


Figure 11 Upper view of the robot's prototype

4.2 POWER DISTRIBUTION

A 12V sealed lead acid battery is used as the source for the robot's functionality. As the voltage required for the DC motor is 12V. However, the circuits used in the project which are the motor drive circuit, shaft encoder circuit as well as microcontroller circuit only required voltage of 5V. Thus, for each circuit, a voltage regulator (LM7805) is used to step down the voltage from 12V to 5V while for ultrasonic sensor circuit LM7809 voltage regulator is used (to step down voltage to 9V).

The voltage regulator circuit consists of transistors that open and closes in the process to regulate the output voltage. If the voltage at the output is less, then the transistor will open more thus giving more voltage at the output. Voltage regulator supplies current around 1 A. Heat sink is attached to each voltage regulator to ensure it works at its operating point.

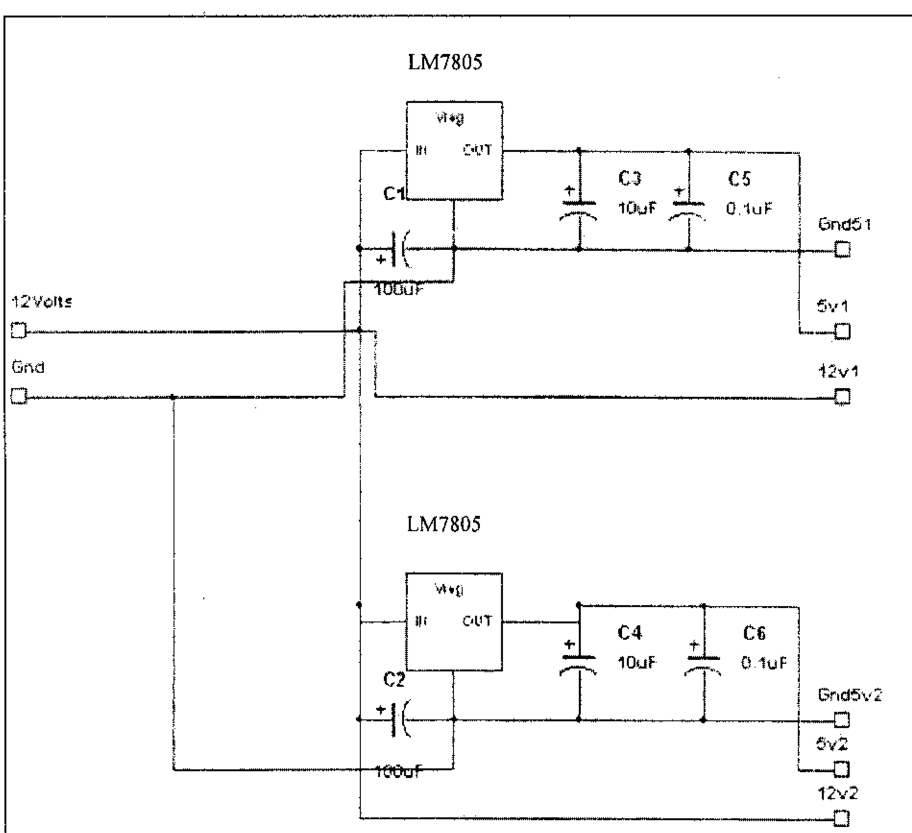


Figure 12 Voltage regulator circuit

Table 5 Specification of voltage regulator board

Input Voltage	12V
Output Voltage	4.89 V to 5 V
Current	1 A

4.3 DRIVE CIRCUIT

Drive train is very crucial for any robots. The navigation of the robot from one point to another is determined by the direction of DC motor whether it is forward, reverse, left turning, right turning or stop. The directions of the DC motors are controlled by the H Bridge circuit. Double full bridge drivers, LM 298 are used to construct an H bridge circuit for this project.

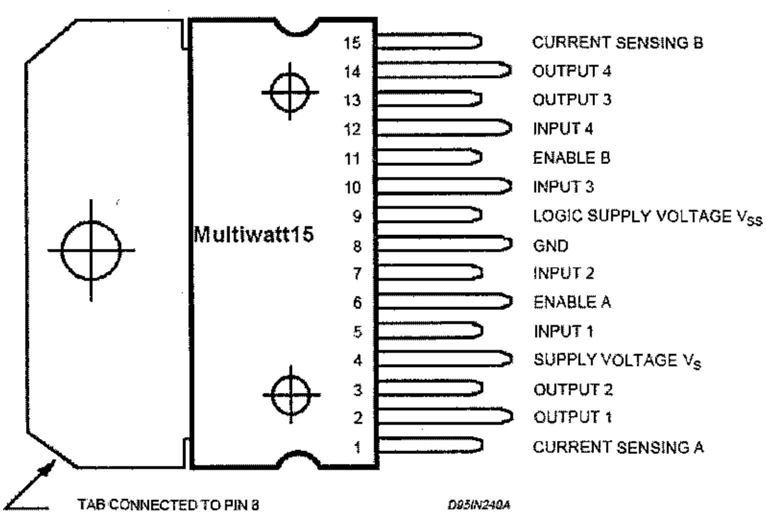


Figure 13 Dual full bridge driver LM298 pin configuration (Taken from LM 298 datasheet)

This chip is very high voltage, high current dual full bridge designed to accept standard TTL logic levels and drive inductive loads such as relays, solenoids, DC motor as well as stepper motor. Two enable inputs are used to enable or disable the device independently from the input signals. The emitters of the lower transistors of each bridge are connected together and the corresponding external terminal can be used for the connection of external sensing resistor. An additional apply input is provided so that the logic works at a lower voltage. [13]

Some of the advantages in using LM 298 are as the following:

1. Total DC current up to 4A
2. Low saturation voltage
3. Over temperature protection
4. Logical 0 input voltage up to 1.5 V (high noise immunity)

Initially, author decided to use only single full bridge LM298 to construct the motor drive circuit. However, the circuit conducted was very delicate and very unstable. Thus, by researching other information regarding the motor drive, the author decided to use double LM298.

H bridge circuit schematic for this project can be seen in Figure 14. The connection is conducted based on the datasheet from the manufacturer. It shows the connections of LM 298 with both left and right DC motors. The amount of current varies depending on the load of the motor. More current is needed to maintain the same speed as the robot weighs more. This has been a challenge as the maximum of the rating current is around 4A.

The internal design of LM298 chip does not allow higher current if the supplied voltage is less than certain level. The solution done was to connect the battery supplied in parallel and supply higher voltage and thus allowing higher current to the motor. Nevertheless, the LM298 chip heats up quickly which makes its life shorter. Fortunately, the H bridge circuit uses PWM signal to control output power to the motor. Using a low duty cycle (40% ~ 45%) the motor speed is at desirable range and that the generated heat is less.

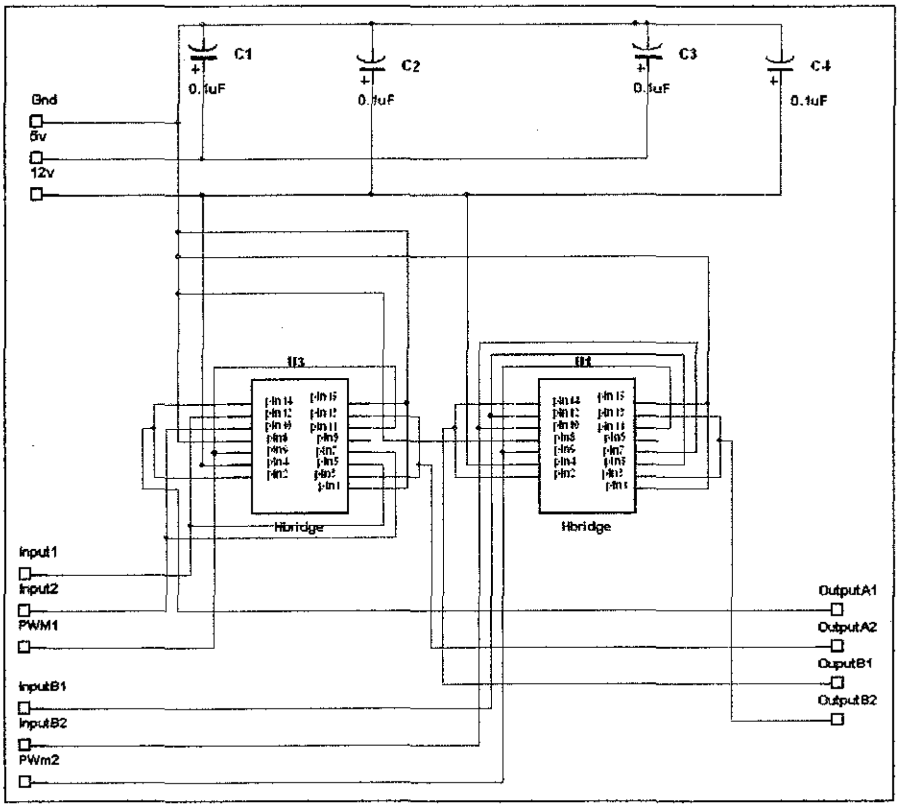


Figure 14 Double full bridge LM298 circuit connections

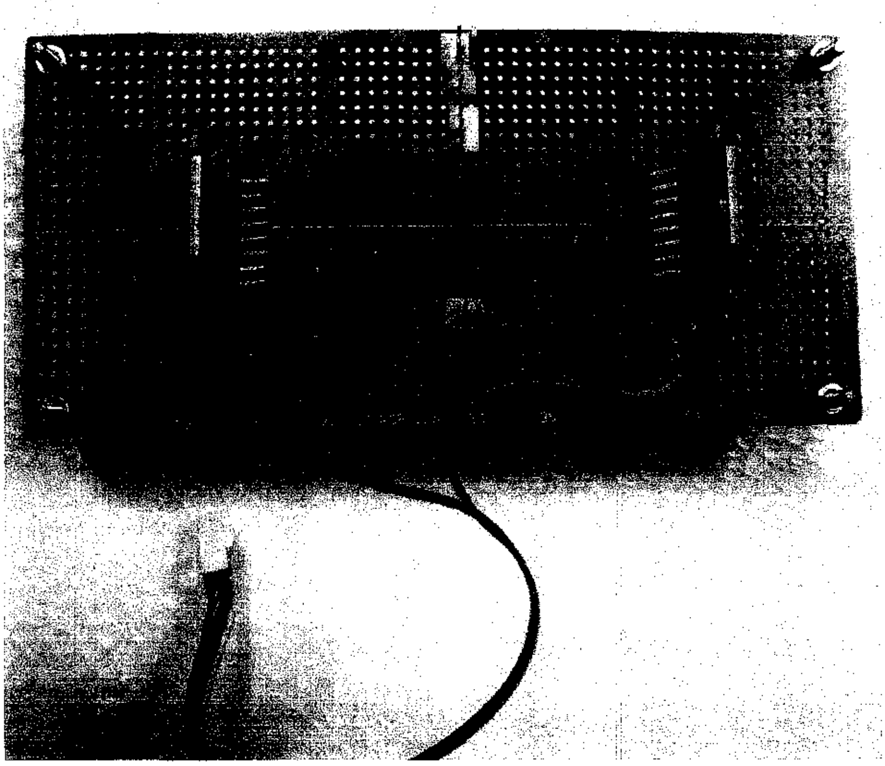


Figure 15 Actual H-Bridge circuit using LM 298

The operation of the DC motor is summarized as in the following table:

Table 6 Operation of DC motors based on LM 298 pins

<table>
<tr><th rowspan="2">Pin Number</th><th rowspan="2">Voltage (V)</th><th colspan="2">DC Motor</th></tr>
<tr><th>LEFT</th><th>RIGHT</th></tr>
<tr><td colspan="4">Robot moves in forward direction</td></tr>
<tr><td>5 (input 1)</td><td>5</td><td rowspan="2">FORWARD</td><td></td></tr>
<tr><td>7 (input 2)</td><td>0</td><td></td></tr>
<tr><td>10 (input 3)</td><td>5</td><td></td><td rowspan="2">FORWARD</td></tr>
<tr><td>12 (input 4)</td><td>0</td><td></td></tr>
<tr><td colspan="4">Robot moves in left direction</td></tr>
<tr><td>5 (input 1)</td><td>5</td><td rowspan="2">REVERSE</td><td></td></tr>
<tr><td>7 (input 2)</td><td>0</td><td></td></tr>
<tr><td>10 (input 3)</td><td>0</td><td></td><td rowspan="2">FORWARD</td></tr>
<tr><td>12 (input 4)</td><td>5</td><td></td></tr>
<tr><td colspan="4">Robot moves in right direction</td></tr>
<tr><td>5 (input 1)</td><td>0</td><td rowspan="2">FORWARD</td><td></td></tr>
<tr><td>7 (input 2)</td><td>5</td><td></td></tr>
<tr><td>10 (input 3)</td><td>5</td><td></td><td rowspan="2">REVERSE</td></tr>
<tr><td>12 (input 4)</td><td>0</td><td></td></tr>
<tr><td colspan="4">Robot stops</td></tr>
<tr><td>5 (input 1)</td><td>5</td><td rowspan="2">STOP</td><td></td></tr>
<tr><td>7 (input 2)</td><td>5</td><td></td></tr>
<tr><td>10 (input 3)</td><td>5</td><td></td><td rowspan="2">STOP</td></tr>
<tr><td>12 (input 4)</td><td>5</td><td></td></tr>
</table>

4.4 ROTARY ENCODER

A rotary encoder is fixed on each wheel. A circle plate of 60 black and white stripes is placed in the inner side of the wheel so that the infrared sensor used can detect the black and white color. The infrared transmitter and receiver circuit is capable of differentiating the black and white stripes.

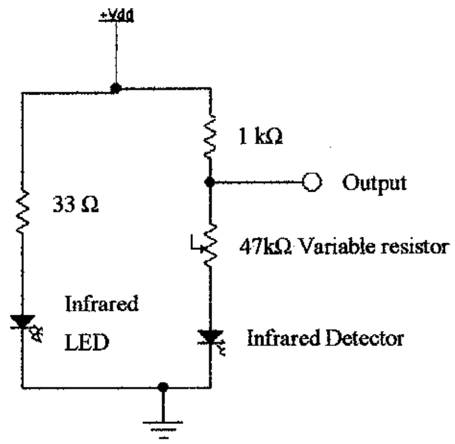


Figure 16 Infrared transmitter and detector circuit

The above circuit is used for rotary encoder. It consists of infrared transmitter and receiver. As the nature of infrared light which only white or reflective surface will be detected by the phototransistor and thus the rotation of the wheel is then converted into a stream of pulse by the circuit.

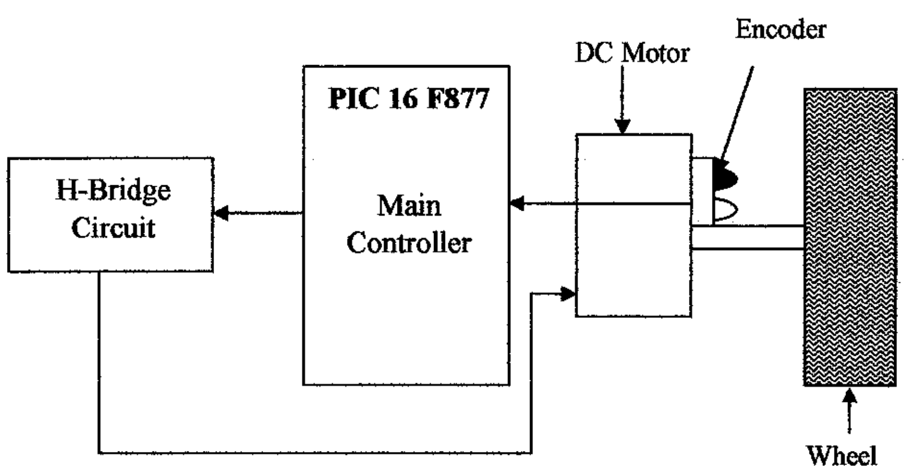


Figure 17 Block diagram for encoder loop

Based on Figure 17, the encoder reads the number of black and white stripes detected on the disk encoder. By comparing the distance of desired value programmed in the main controller, the signal will be sent to the H-Bridge circuit drive by the controller. H-Bridge controls the rotation of the motor and decides whether or not to continue navigating.

4.5 ULTRASONIC SENSOR

Based on early design, the author has constructed two types of ultrasonic sensors which the circuit schematic obtained from the internet. However, those circuits did not work well although trouble shooting has been done for few times. Due to time constraint, the author has decided to use electronic kit which was bought at electronic store.

The sensor is reliable in detecting object of half a meter away. Upon detecting any obstacle, the sensor circuit will be triggered and input will be sent to the microcontroller which will decide what step to be taken next.

The circuit required 12V power supply and this value is not suitable for the robot as the maximum power carried by the robot is 12V. After doing some experiments with the circuit, it is identified that 9V is sufficient enough to work the circuit.

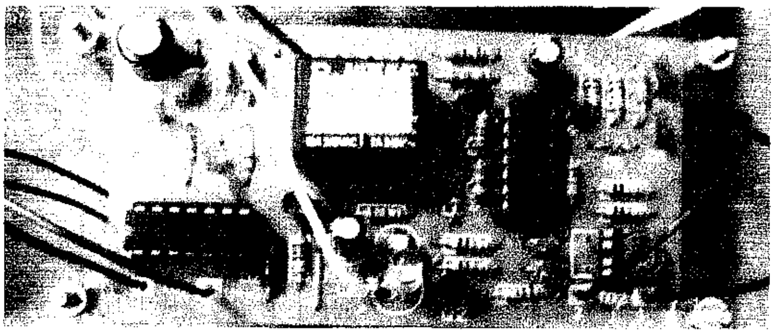


Figure 18 Actual circuit of ultrasonic sensor

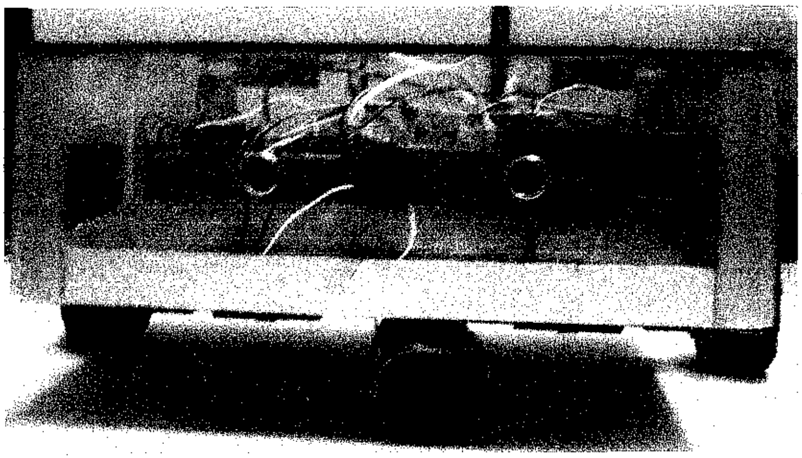


Figure 19 Implementation of ultrasonic transducer on the robot's body

4.6 MICROCONTROLLER BOARD

4.6.1 The PIC 16F877 Programming Board

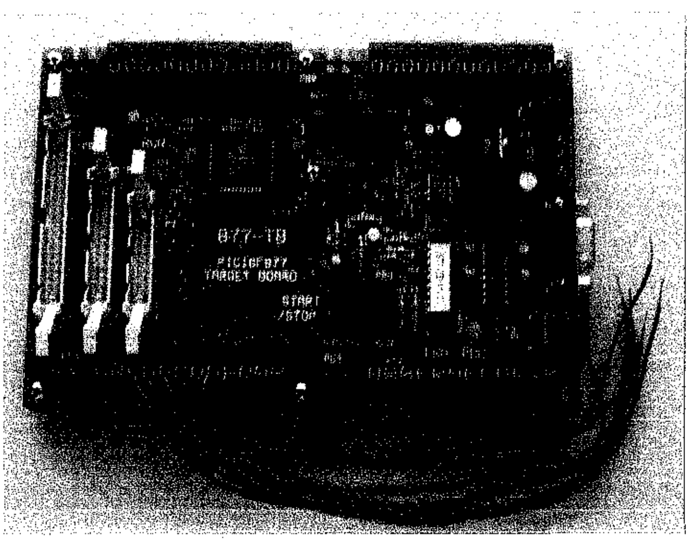


Figure 20 PIC 16F877 programmer target board

Programmer target board as in Figure 20 is used to program the programming codes for the microcontroller. This board which consists of a built-in microcontroller needs to be used while doing the programming for the robot using PIC-C Compiler. After completing all the codes in the compiler, the codes need to be burnt in the microcontroller using a microcontroller burner with the software of Bumble Bee.

4.6.2 The PIC 16F877 Microcontroller Circuit Board

Microcontroller is the most important part of the robot's control system in order to ensure it performs the desired tasks. PIC 16F877 is used in the project due to its function of Pulse Width Modulation (PWM) output pin which is used to control the motor drive circuit specifically in control the speed of the motor. This also helps to reduce power consumption due to rapid switching. The large numbers of digital to analog converter pins are suitable to be used with the ultrasonic transducers as the analog converter is used to define distance using "1" and "0". It is simpler and manageable to use C language compare to assembly language especially when the codes get into complex loop subroutine.

For hardware implementation, microcontroller requires 5V voltage regulated by voltage regulator LM7805. The microcontroller is capable of running at 20MHz clock but 4MHz is sufficient enough for codes processing. Normally open switches are used for process control. One of them is used as restart button which gives low signal to microcontroller clear pin which will restart the whole process. Another three normally open switches are used to control the operation of microcontroller as the robot has three different paths to undergo.

Six (6) output pins from microcontroller are fed into H-bridge circuit and another output is connected to a buzzer. From the six output pins mentioned earlier, four (4) of them give the combination bits for motor direction and the other two (2) provide the PWM signals to H-bridge. Input output pins of the microcontroller is summarized in Table 7.

Table 7 Microcontroller PIC 16F877 board specification

Pin Number	PIC Pin Number	Description	Type
1	MCLR	Reset Button	Switch
2	PIN_A0	Switch for Route 3	Input Switch
3	PIN_A1	Switch for Route 2	Input Switch
4	PIN_A2	Switch for Route 1	Input Switch
13	OSC1/CLKIN	4MHz Clock	Clock
15	PIN_C0	Encoder Right	Input
16	CCP2	PWM2	Output
17	CCP1	PWM1	Output
18	PIN_C3	Encoder Left	Input
22	PIN_D3	Direction Bit4	Output
21	PIN_D2	Direction Bit3	Output
20	PIN_D1	Direction Bit2	Output
19	PIN_D2	Direction Bit5	Output
33	PIN_B0	Ultrasonic Sensor	Input

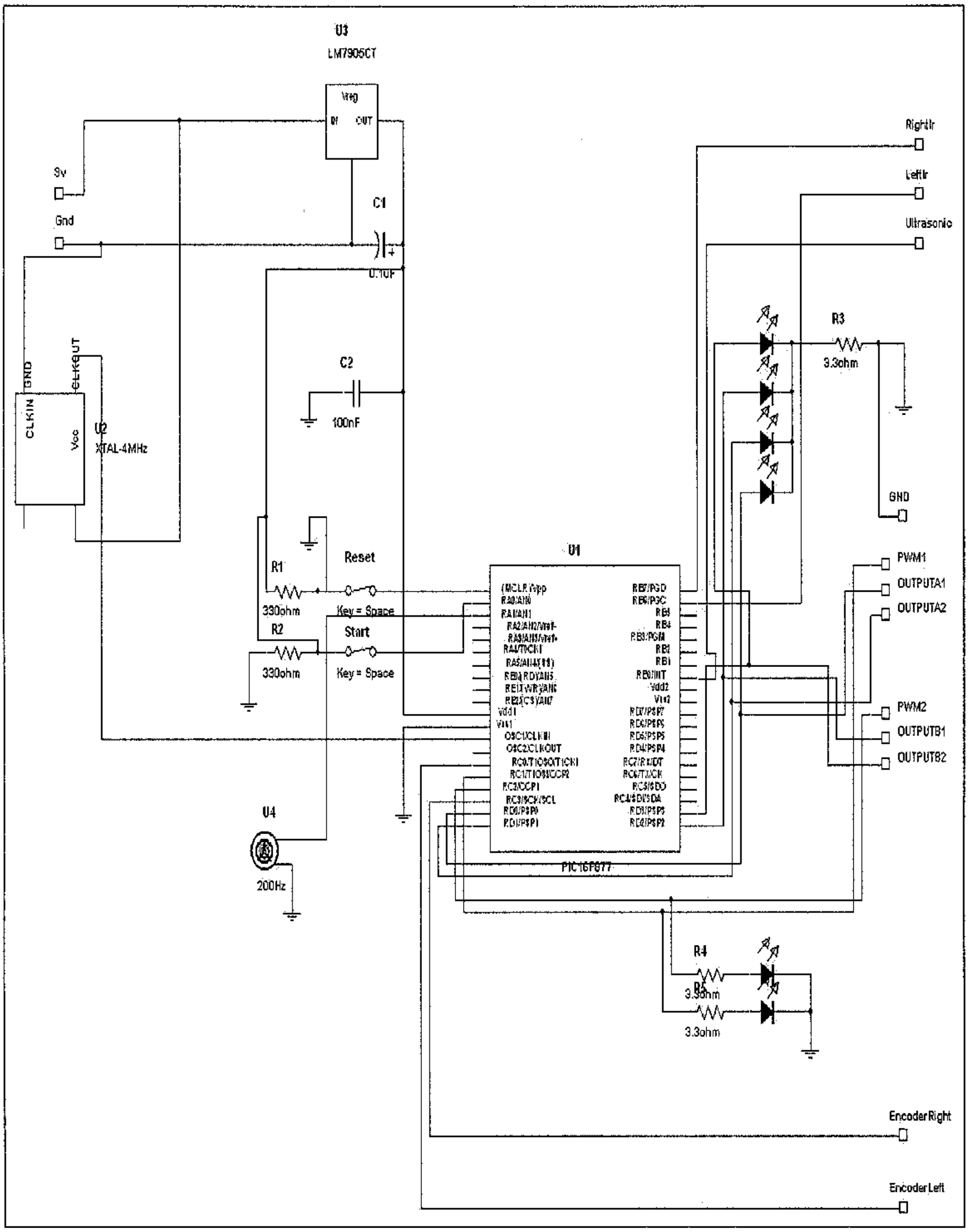


Figure 21 16F877 microcontroller circuit connections

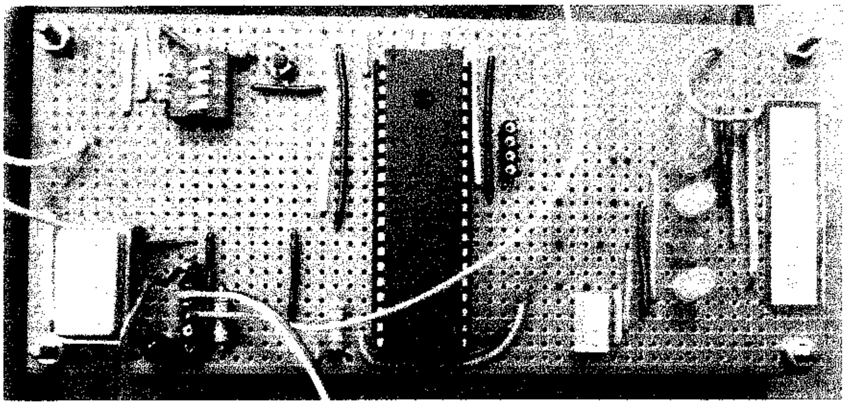


Figure 22 Actual circuit of PIC 16F877 microcontroller

4.7 MOTORS

Two 12V 60 rpm DC motors (Figure 23) are coupled each one of them to the wheel of the robot. Previously, during the design step (FYP I) the author has decided to use a stepper motor for the turning purposes of the robot. However, as modification and for the ease of work, instead of using stepper motor, a motor controller will be attached to both DC motors.

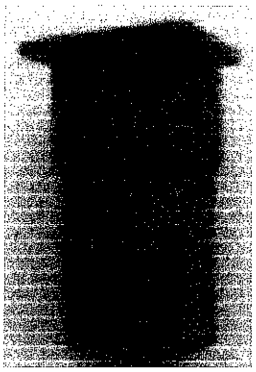


Figure 23 12V 60 rpm DC motor

4.8 PATH PLANNING AND MOVEMENTS

4.8.1 Path Planning

Path planning is very important as it allows the robot to mobile in a predetermine way and not to go beyond the specific area which is set earlier by the user. Initially, during the design process, the author has decided to use 5 points for the robot to travel but with only one type of traveling route. However, after had some discussion with the supervisor as well as his/her colleagues, the author has decided to reduce the points of traveling but increase the variety of the robot's route. As for modification, the author decided to present three different types of routes for the robot to travel with three static points; A, B and C as shown in the following figure.

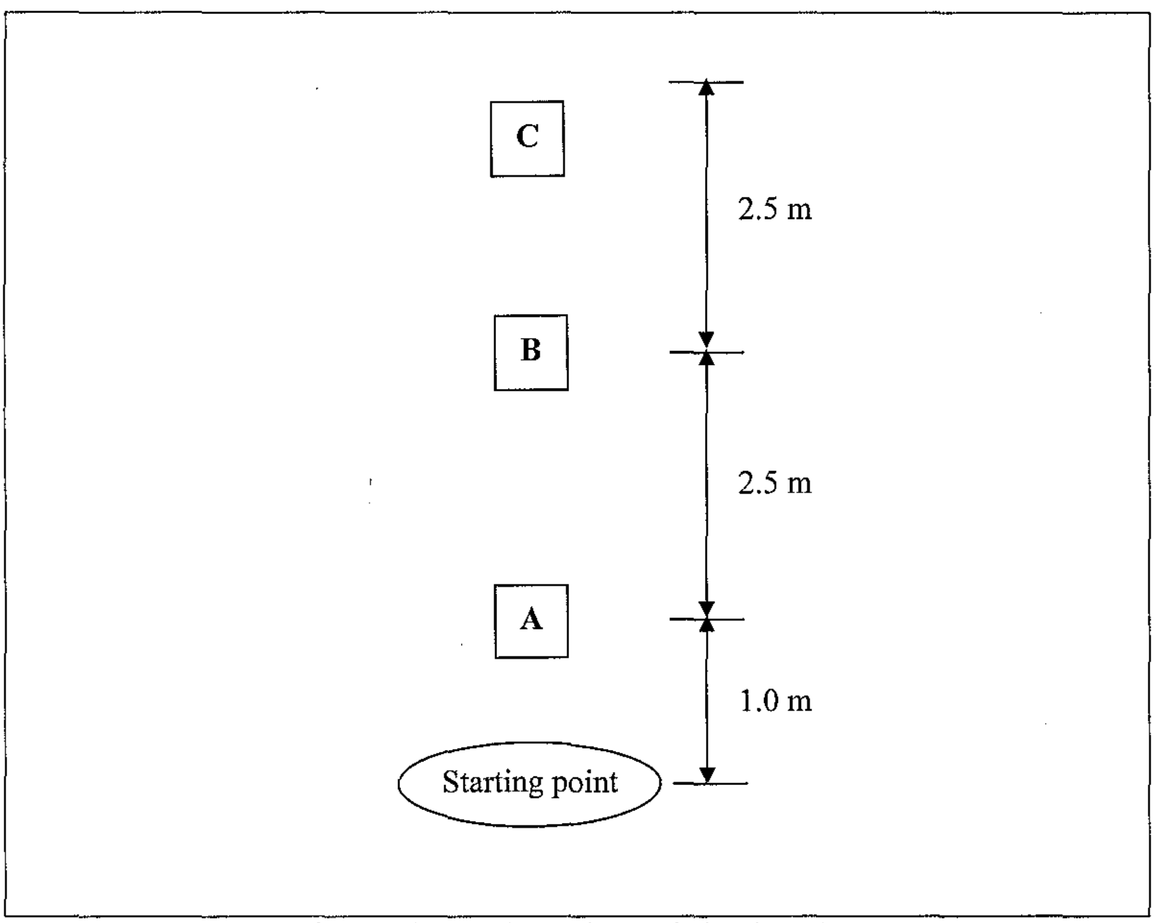


Figure 24 Predetermine path for the robot

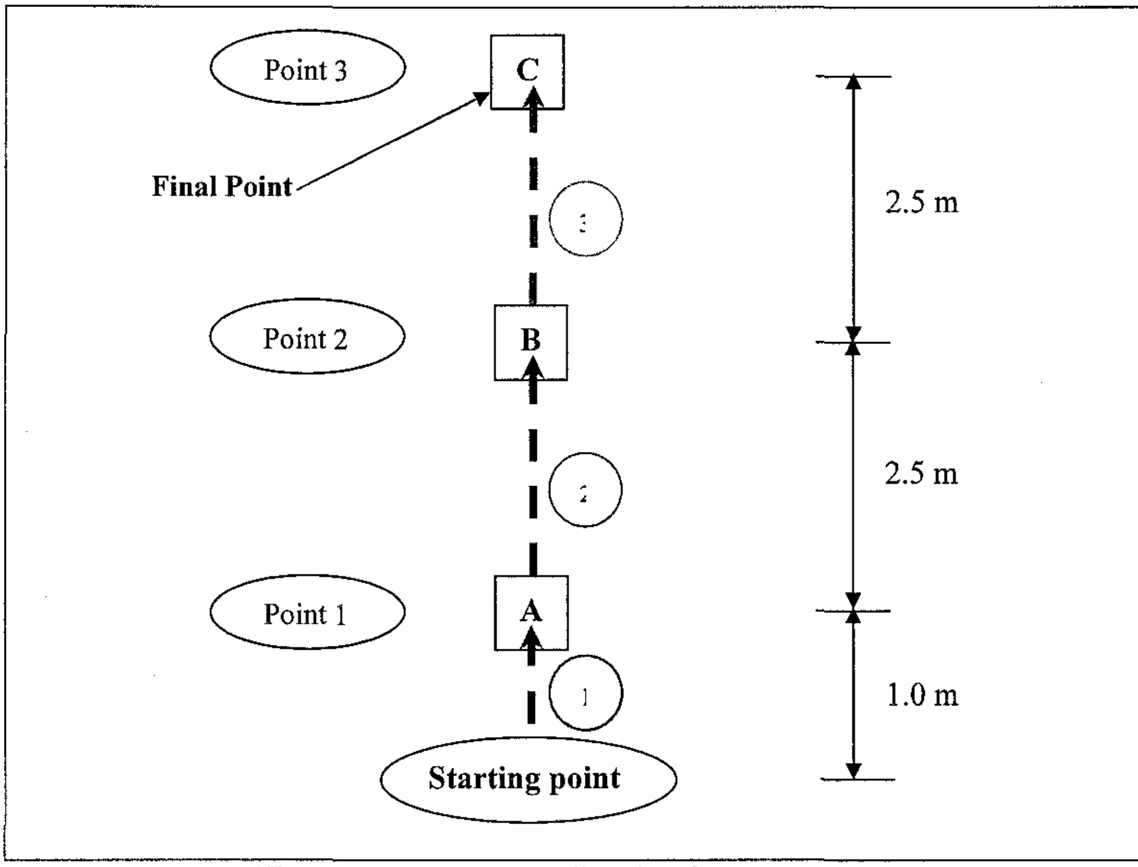


Figure 25 Movement direction for Route 1 type

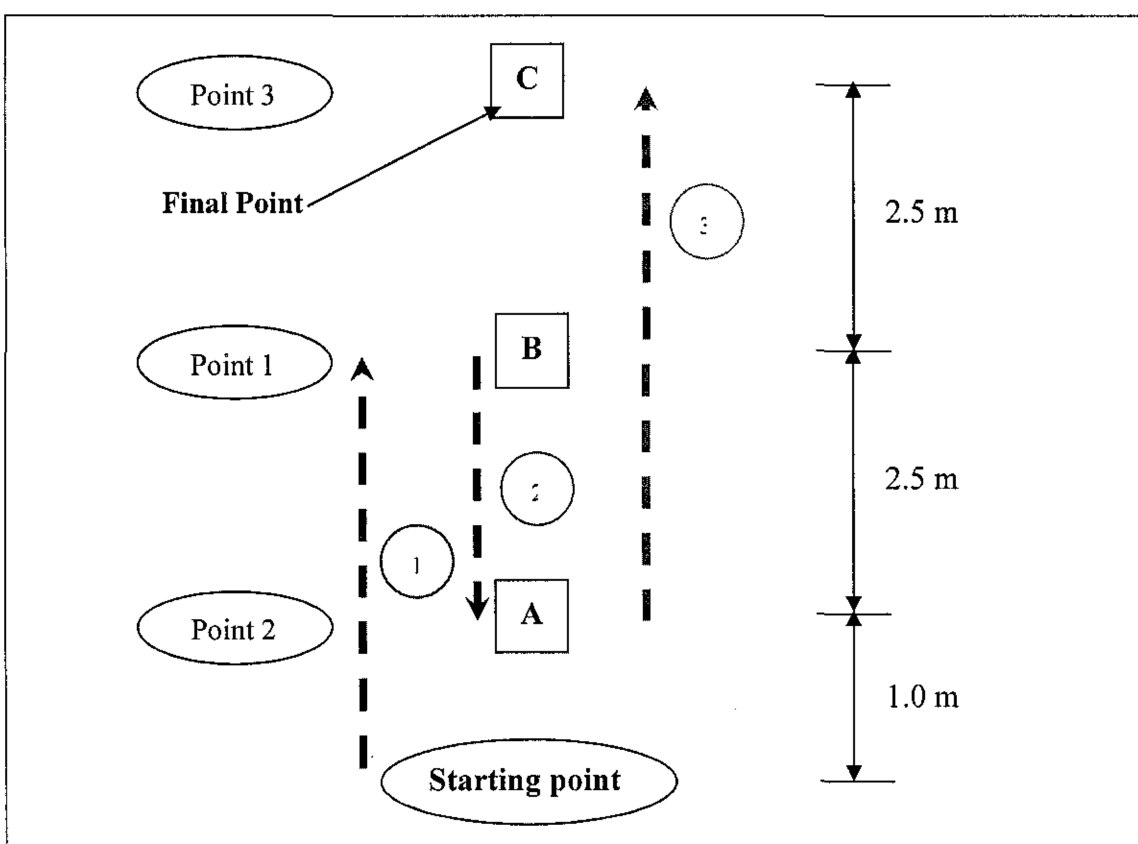


Figure 26 Movement direction for Route 2 type

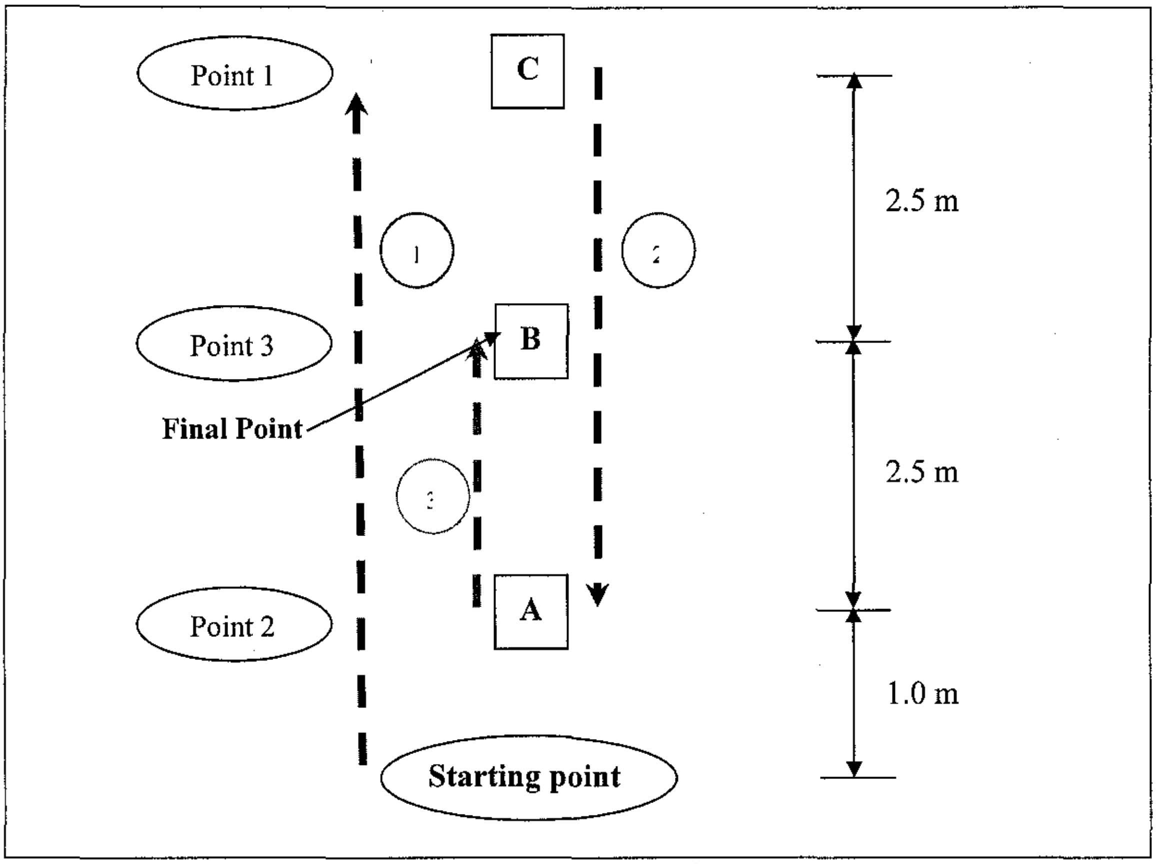


Figure 27 Movement direction for Route 3 type

All three figures above show the different types of route to be traveled by the robot. This gives more options and varieties for the user to choose. However, user can only choose one route at one time. Red, blue and green dashed arrows show the stop points 1, 2 and 3 respectively. For each stop point, the robot will stop for 2 seconds before continue to the next point. Brief descriptions about the routes are described as follow:

(i) Route 1: Robot travels in a forward straight line directly from its starting point go through Point A and B and thus end at Point C.

Total displacement: **1m+2.5m+2.5m =6m**

(ii) Route 2: Robot travels in straight line from starting point and ends at Point C. The difference between this route and Route 1 is that as the robot reach the second point (B), the robot will move backward (reverse) before continue to its final destination at point C.

Total displacement: **1m+2.5m+2.5m+2.5m = 8.5m**

(iii) Route 3: Robot travels from starting point and ends at point B. First, the robot will travel from starting point to point C. At point C, it will turn 180° and move forward to point A before it turns 180° again and ends the transmission at point B.

Total displacement: **1m+2.5m+2.5m+2.5m+2.5m+2.5m = 13.5m**

4.8.2 Position Tracking

Position tracking acknowledge the robot with its position and whether it has reach the destination. This step is done using the shaft encoder by calculating the rotation of the wheels which consequently gives results on the pulses of the encoder. The encoder consists of 60 black and white strips which mean 60 pulses need to be detected for 1 full revolution.

$$\text{Pulse} = (2\pi r) / 60 \qquad \text{where r: radius of the wheel}$$

In real time, the coordinate that is being programmed into the robot in centimeters can be converted into number of pulse. The robot will move as long as the count of pulse has not reach the desired number if pulse.

4.8.3 Obstacle Avoidance

This part is essential to ensure the robot can avoid any obstacle that comes along its pathway. Upon sensing the obstacle, the robot should be able to stop and trigger the buzzer. Once the object is moved or taken away from the path, the robot should continue its task by traveling to the destination. If happen that the object or obstacle does not move or keep remaining on the pathway of the robot, it will change the direction to move around the obstacle and get back to the predetermined path to continue the travel.

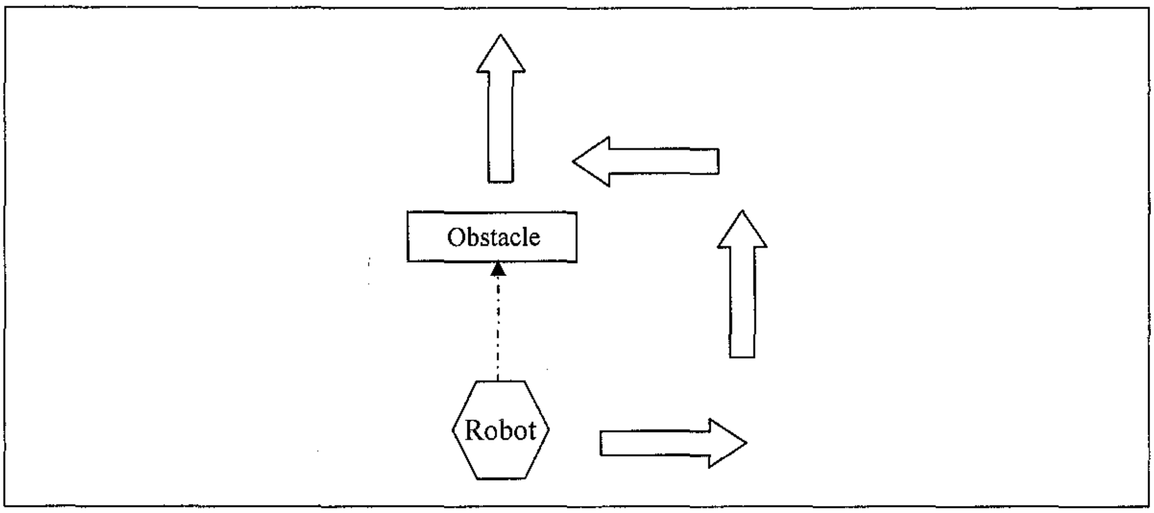
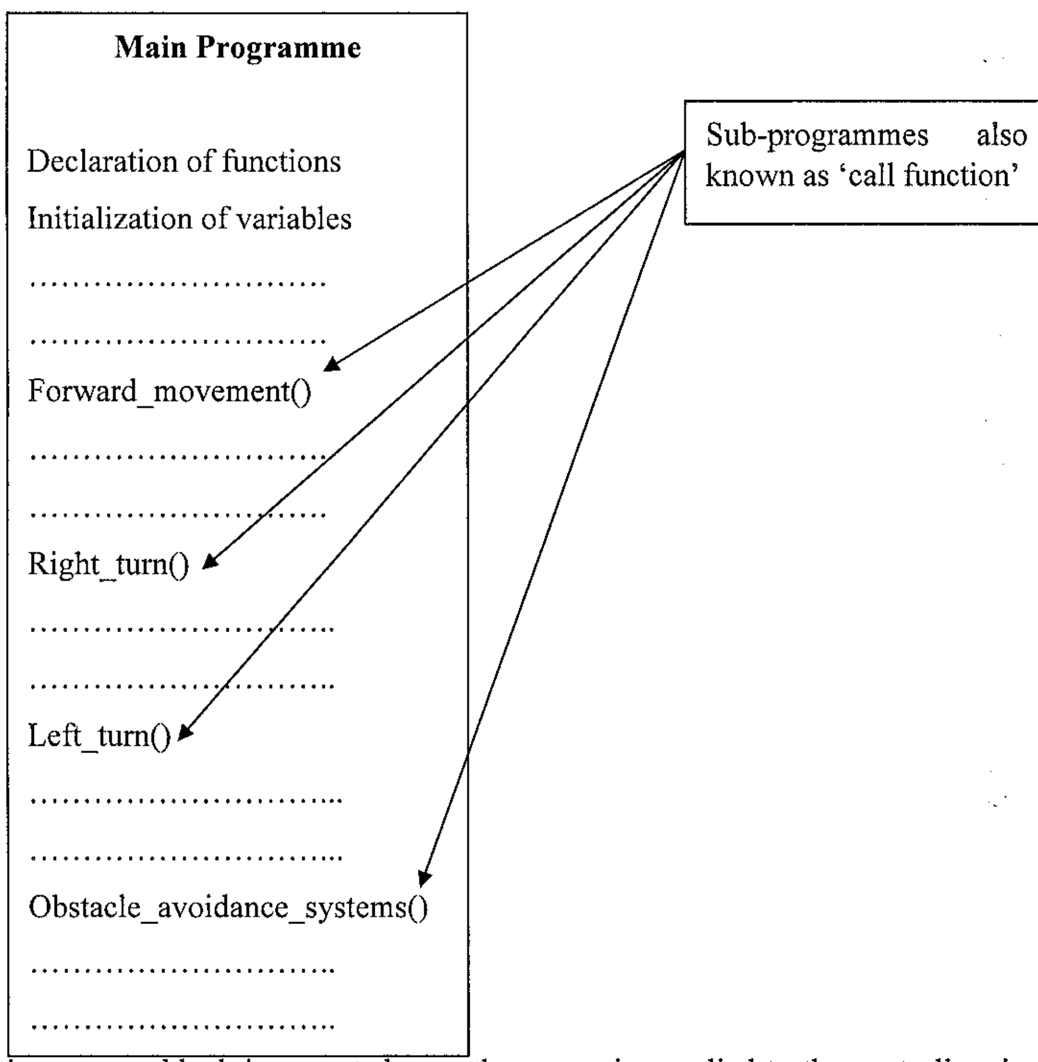


Figure 28 Simple obstacle avoidance (same algorithm on left or right movement)

4.9 PIC PROGRAMMING

The compiler used for this microcontroller for this project is CCS compiler. The software is obtained from Microprocessor Lab technician. Prior to the program written on the PIC controller, the locomotion of the robot under the predetermined path will be executed by the movement of DC motor which in return will direct the wheels of the robot.



Main program block is executed once the power is supplied to the controller circuit. The program begins with declaration of all the functions available in the program and thus initialization of variables. The compiler then executes line by line accordingly and as the compiler reaches the sub-programs, it will call the function from its block run its function. After finish executing the sub-programs, compiler will return to the main program and continue doing the same thing until the program ends.

CHAPTER 5
CONCLUSION AND RECOMMENDATIONS

5.1 CONCLUSIONS

The implementation of mobile robot incorporates several parts; controller for positioning and navigating, sensor part, mechanical part which includes body structure and mobility and movement part. Basic knowledge on programming, hardware implementation experience and ability to capture new knowledge are very important in completing the project.

This affordable mobile robot is very convenient to the user as it is user-friendly and easy to operate. For future recommendation, there are a lot of aspects on this project that can be improved in the future

5.2 RECOMMENDATION

5.2.1 Structure Design

Until the fabrication is completed, the robot is not properly designed with mathematical and mechanical analysis in terms of static and dynamic. These two elements are very important in producing a solid and stable mobile robot. A help from mechanical department is very much needed in order to build a better light weight and stronger chassis compared to the present project.

5.2.2 Accuracy

In order to obtain more accurate mobile robot in terms of its locomotion systems, few aspects need to be improved. One of the ways is to use the components with a good quality which are designed only for robotics. This is important as these specific components are better than just normal components. For an example, a drive circuit which is built using normal components and modifying them to suit the robotics project is not a good idea in producing accurate robot. The circuit has to be bought or first design from robotics shops available in the market. Sensors and encoders should also reliable to get a higher accuracy. This will help in reducing errors.

5.2.3 Actuators

Grippers, hands are actuators that might be better included in the robot for further enhancement of the robot. This component will give the robot more commercial values as users do not have to put the object onto the robot themselves.

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[10] http://robotics.megagiant.com/history.html

[11] http://science.nasa.gov/headlines/y2004/22jan_meridianiplanum.htm

[12] PIC 16F877 Datasheet and application

[13] L298N Datasheet and application

APPENDICES

APPENDIX A

C CODES FOR TESTING STRAIGHT MOVEMENT

```
#include <16F877.h>
#include <stdio.h>
#include <stdlib.h>
#USE DELAY(CLOCK=4000000)
#FUSES XT,NOWDT,NOPROTECT,NOPUT,NOBROWNOUT,NOLVP

//PORT# = PIN# FUNCTION
//A = PIN0 [2] Start Button Route 3
// = PIN1 [3] Start Button Route 2
// = PIN2 [4] Start Button Route 1
// = PIN3 [5] Buzzer

//B = PIN0 [33] Input Ultrasonic Sensor

//C = PIN0 [15] Input Encoder Right
// = PIN1 [16] CCP2 PWM Motor Left
// = PIN2 [17] CCP1 PWM Motor Right
// = PIN3 [18] Input Encoder Left

//D = PIN0 [19] Right Motor LSB
// = PIN1 [20] Right Motor MSB
// = PIN2 [21] Left Motor LSB
// = PIN3 [22] Left Motor MSB

//Drive Data : No Movement=00; Forward=10; Reverse=01

/* Declaration of Functions*/
/*
void moveforward(int distance);
void leftturn(void);
void rightturn(void);
void stop(void);
void initialize(void);
void buzzer_on(int maxcount);
*/

int dutycycle_left;
int dutycycle_right;
/**********************************Main Code Starts****************************/
void main()
{

/* Declaring Ports for input and output*/

set_tris_a(0xff);
set_tris_b(0x00);
set_tris_c(0x00);
set_tris_d(0xff);

setup_timer_2(T2_DIV_BY_1,99,1);   //to enable Timer2,PR2=99, prescaler=1
setup_ccp1(CCP_OFF);               //to unable PWM mode
setup_ccp2(CCP_OFF);               //to unable PWM mode

output_bit(PIN_A0,0);              //initializing push button route 3 OFF
output_bit(PIN_A1,0);              //initializing push button route 2 OFF
output_bit(PIN_A2,0);              //initializing push button route 1 OFF
```

```
output_bit(PIN_A3,0);          //initializing buzzer(OFF mode)

/*==============ROUTE 1 PROGAMME STARTS=========================*/

if (input(PIN_A2)==1)

//int dutycycle_left;
//int dutycycle_right;
{

delay_ms(2000);

    while (true)

      {
        setup_ccp1(CCP_PWM);       // Configure CCP1 as a PWM
        setup_ccp2(CCP_PWM);       // Configure CCP1 as a PWM

        CCP_1=dutycycle_right;      //PIN_C2=CCP1=right motor
        CCP_2=dutycycle_left;      //PIN_C1=CCP2=left motor
        dutycycle_left=100;
        dutycycle_right=100;
        output_bit(PIN_C1,1);
        output_bit(PIN_C2,1);

        output_high(PIN_D0);
        output_low(PIN_D1);
        output_high(PIN_D2);
        output_low(PIN_D3);

        delay_ms(1000);

      }
      {

    break;
      }
}

/*=================ROUTE 1 PROGAMME ENDS========================*/

else

  {

   output_high(PIN_D0);
   output_high(PIN_D1);
   output_high(PIN_D2);
   output_high(PIN_D3);

  }
{
while (1);

}
}
```

APPENDIX B

MOBILE ROBOT PARTS

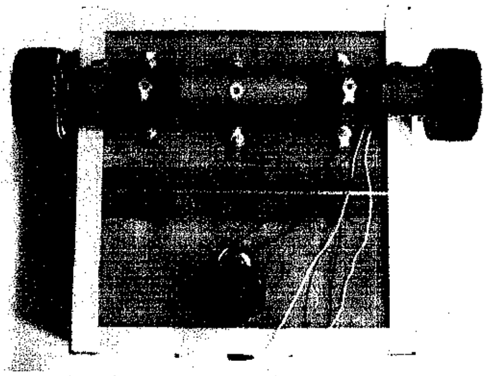


Figure A-1: Positions of wheels, motor and castor tyre mounted on robot's base

Figure A-2: Infrared / Encoder / Black and white stripes

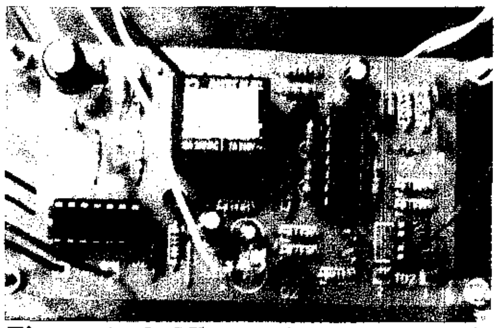


Figure A -3: Ultrasonic sensor circuit

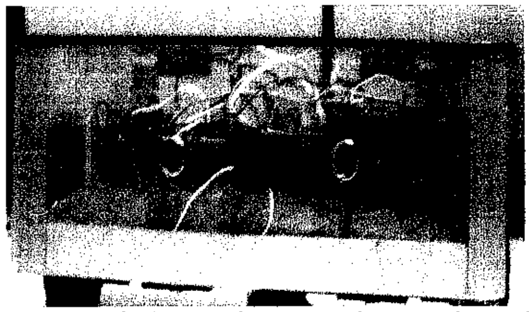


Figure A -4: Positions of ultrasonic transmitter and receiver transducers

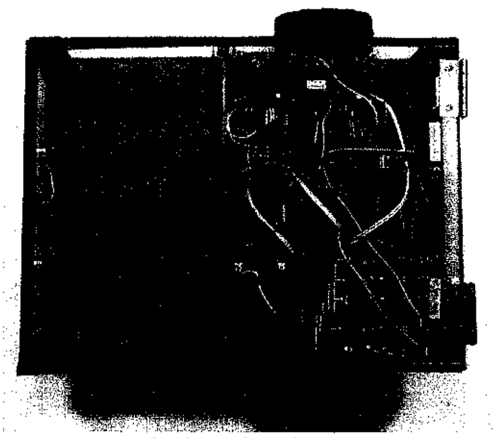


Figure A -5 Whole robot layout (upper view)

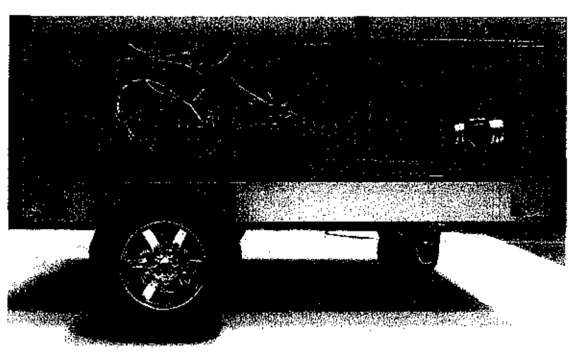


Figure A -6 Whole robot layout (side view)

APPENDIX C

PIC 16F877 DATASHEET

PIC16F87X

28/40-pin 8-Bit CMOS FLASH Microcontrollers

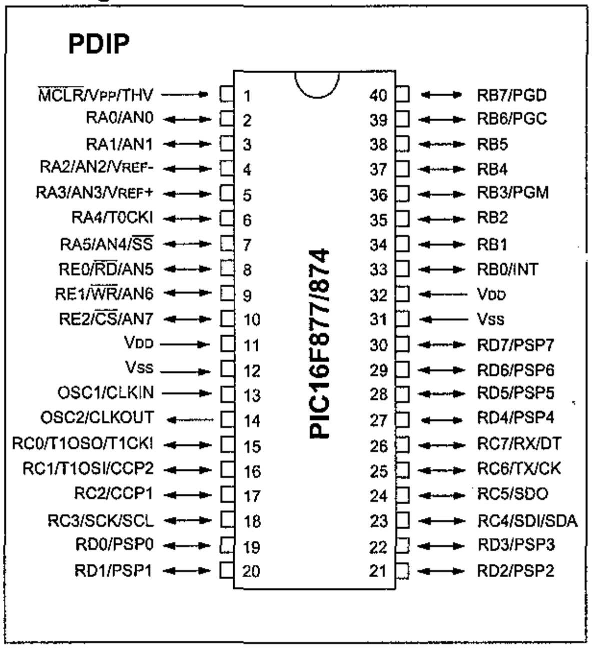
Devices Included in this Data Sheet:

- PIC16F873
- PIC16F874
- PIC16F876
- PIC16F877

Microcontroller Core Features:

- High-performance RISC CPU
- Only 35 single word instructions to learn
- All single cycle instructions except for program branches which are two cycle
- Operating speed: DC - 20 MHz clock input
  DC - 200 ns instruction cycle
- Up to 8K x 14 words of FLASH Program Memory,
  Up to 368 x 8 bytes of Data Memory (RAM)
  Up to 256 x 8 bytes of EEPROM data memory
- Pinout compatible to the PIC16C73B/74B/76/77
- Interrupt capability (up to 14 sources)
- Eight level deep hardware stack
- Direct, indirect and relative addressing modes
- Power-on Reset (POR)
- Power-up Timer (PWRT) and Oscillator Start-up Timer (OST)
- Watchdog Timer (WDT) with its own on-chip RC oscillator for reliable operation
- Programmable code-protection
- Power saving SLEEP mode
- Selectable oscillator options
- Low-power, high-speed CMOS FLASH/EEPROM technology
- Fully static design
- In-Circuit Serial Programming™ (ICSP) via two pins
- Single 5V In-Circuit Serial Programming capability
- In-Circuit Debugging via two pins
- Processor read/write access to program memory
- Wide operating voltage range: 2.0V to 5.5V
- High Sink/Source Current: 25 mA
- Commercial and Industrial temperature ranges
- Low-power consumption:
  - < 2 mA typical @ 5V, 4 MHz
  - 20 μA typical @ 3V, 32 kHz
  - < 1 μA typical standby current

Pin Diagram

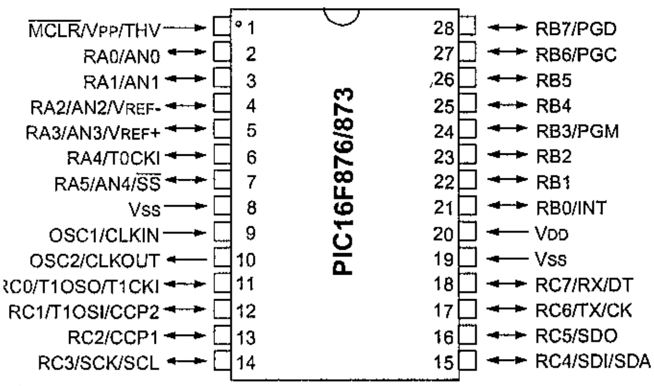


Peripheral Features:

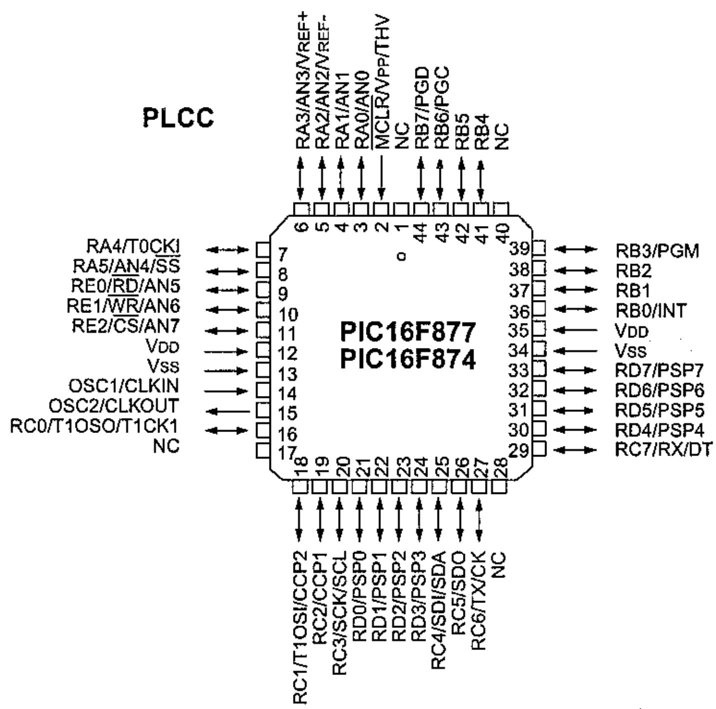
- Timer0: 8-bit timer/counter with 8-bit prescaler
- Timer1: 16-bit timer/counter with prescaler, can be incremented during sleep via external crystal/clock
- Timer2: 8-bit timer/counter with 8-bit period register, prescaler and postscaler
- Two Capture, Compare, PWM modules
  - Capture is 16-bit, max. resolution is 12.5 ns
  - Compare is 16-bit, max. resolution is 200 ns
  - PWM max. resolution is 10-bit
- 10-bit multi-channel Analog-to-Digital converter
- Synchronous Serial Port (SSP) with SPI™ (Master Mode) and I^{2}C™ (Master/Slave)
- Universal Synchronous Asynchronous Receiver Transmitter (USART/SCI) with 9-bit address detection
- Parallel Slave Port (PSP) 8-bits wide, with external $\overline{RD}$, $\overline{WR}$ and $\overline{CS}$ controls (40/44-pin only)
- Brown-out detection circuitry for Brown-out Reset (BOR)

Pin Diagrams

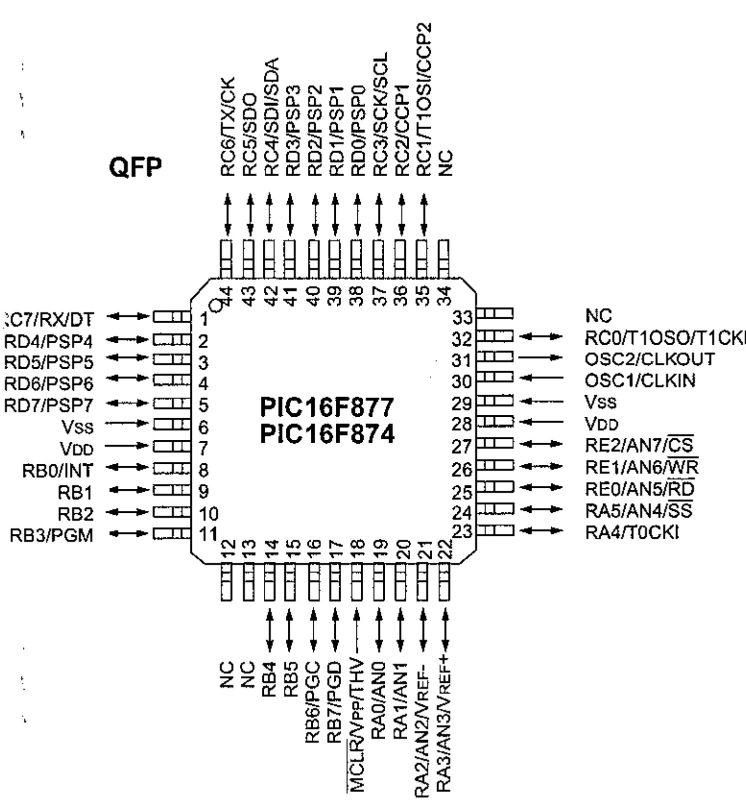
DIP, SOIC



PLCC



QFP



Key Features PICmicro™ Mid-Range Reference Manual (DS33023)	**PIC16F873**	**PIC16F874**	**PIC16F876**	**PIC16F877**
Operating Frequency	DC - 20 MHz	DC - 20 MHz	DC - 20 MHz	DC - 20 MHz
Resets (and Delays)	POR, BOR (PWRT, OST)	POR, BOR (PWRT, OST)	POR, BOR (PWRT, OST)	POR, BOR (PWRT, OST)
FLASH Program Memory (14-bit words)	4K	4K	8K	8K
Data Memory (bytes)	192	192	368	368
EEPROM Data Memory	128	128	256	256
Interrupts	13	14	13	14
I/O Ports	Ports A,B,C	Ports A,B,C,D,E	Ports A,B,C	Ports A,B,C,D,E
Timers	3	3	3	3
Capture/Compare/PWM modules	2	2	2	2
Serial Communications	MSSP, USART	MSSP, USART	MSSP, USART	MSSP, USART
Parallel Communications	—	PSP	—	PSP
10-bit Analog-to-Digital Module	5 input channels	8 input channels	5 input channels	8 input channels
Instruction Set	35 Instructions	35 Instructions	35 Instructions	35 Instructions

ıle of Contents

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orrections to this Data Sheet

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1.0 DEVICE OVERVIEW

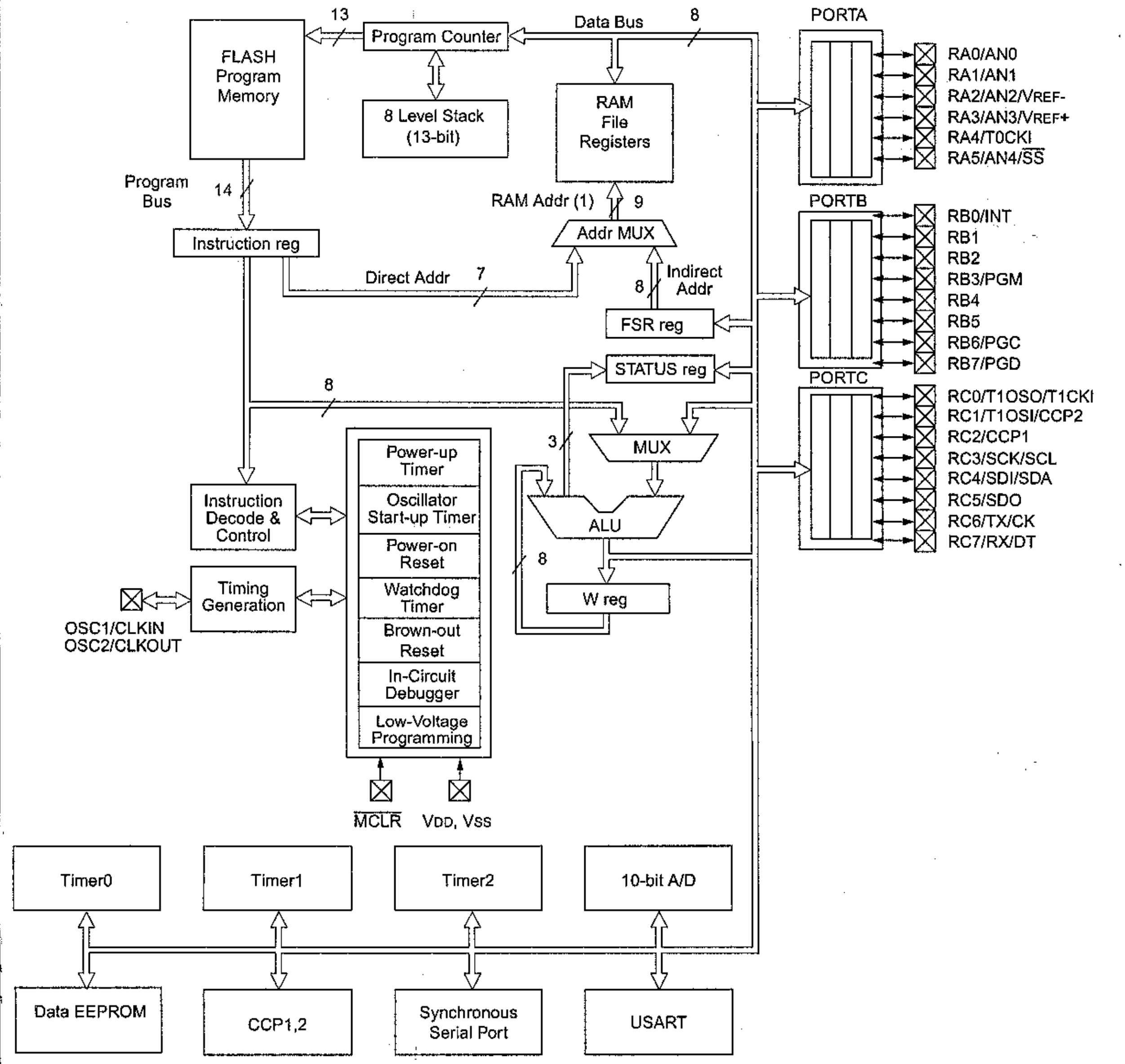
This document contains device-specific information. Additional information may be found in the PICmicro™ Mid-Range Reference Manual, (DS33023), which may be obtained from your local Microchip Sales Representative or downloaded from the Microchip website. The Reference Manual should be considered a complementary document to this data sheet, and is highly recommended reading for a better understanding of the device architecture and operation of the peripheral modules.

There are four devices (PIC16F873, PIC16F874, PIC16F876 and PIC16F877) covered by this data sheet. The PIC16F876/873 devices come in 28-pin packages and the PIC16F877/874 devices come in 40-pin packages. The 28-pin devices do not have a Parallel Slave Port implemented.

The following two figures are device block diagrams sorted by pin number; 28-pin for Figure 1-1 and 40-pin for Figure 1-2. The 28-pin and 40-pin pinouts are listed in Table 1-1 and Table 1-2, respectively.

FIGURE 1-1: PIC16F873 AND PIC16F876 BLOCK DIAGRAM

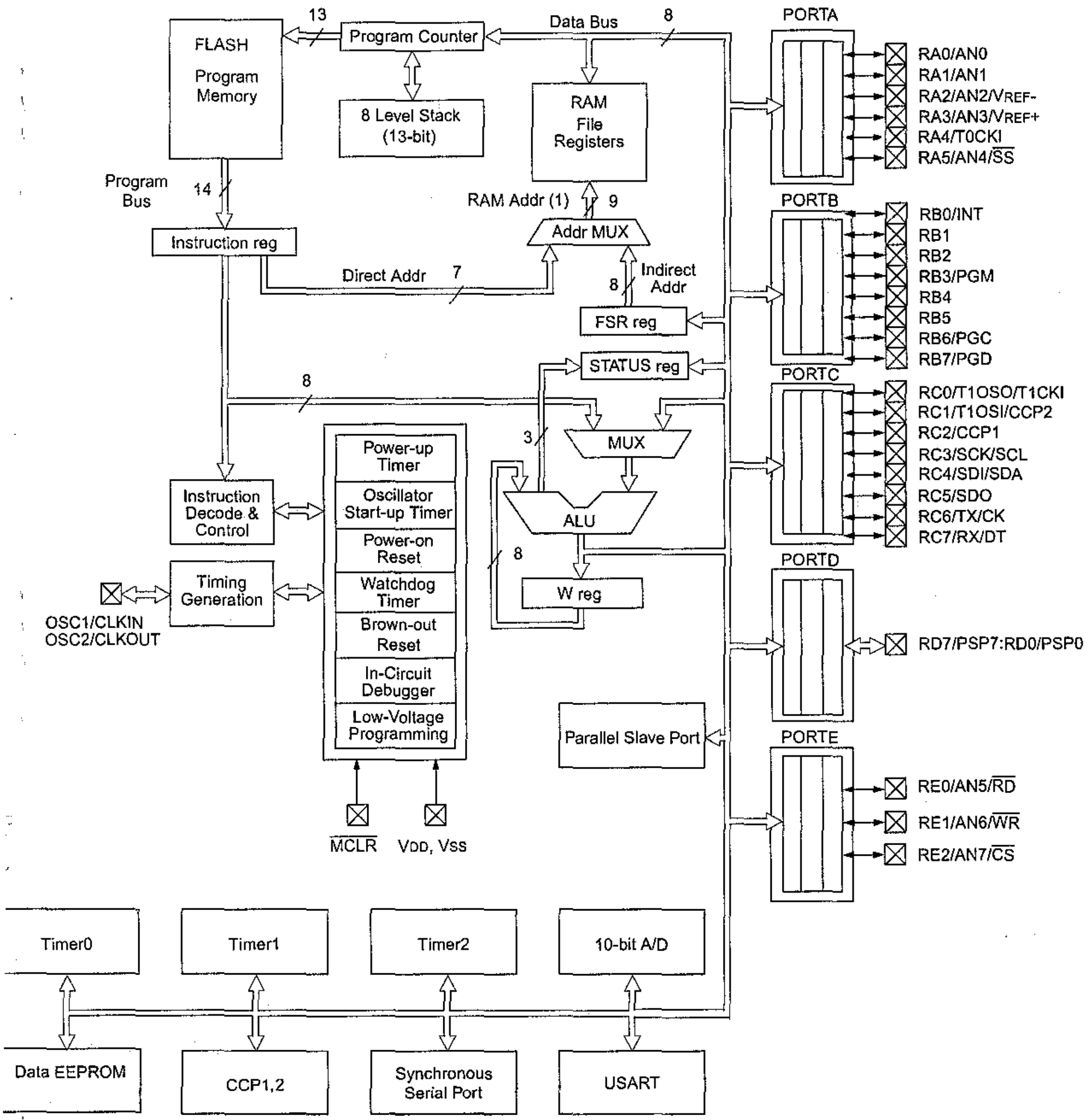
Device	Program FLASH	Data Memory	Data EEPROM
PIC16F873	4K	192 Bytes	128 Bytes
PIC16F876	8K	368 Bytes	256 Bytes



Note 1: Higher order bits are from the STATUS register.

URE 1-2: PIC16F874 AND PIC16F877 BLOCK DIAGRAM

Device	Program FLASH	Data Memory	Data EEPROM
PIC16F874	4K	192 Bytes	128 Bytes
PIC16F877	8K	368 Bytes	256 Bytes



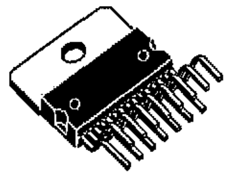
Note 1: Higher order bits are from the STATUS register.

APPENDIX D

LM298 DATASHEET

DUAL FULL-BRIDGE DRIVER

- OPERATING SUPPLY VOLTAGE UP TO 46 V
- TOTAL DC CURRENT UP TO 4 A
- LOW SATURATION VOLTAGE
- OVERTEMPERATURE PROTECTION
- LOGICAL "0" INPUT VOLTAGE UP TO 1.5 V (HIGH NOISE IMMUNITY)



Multiwatt15

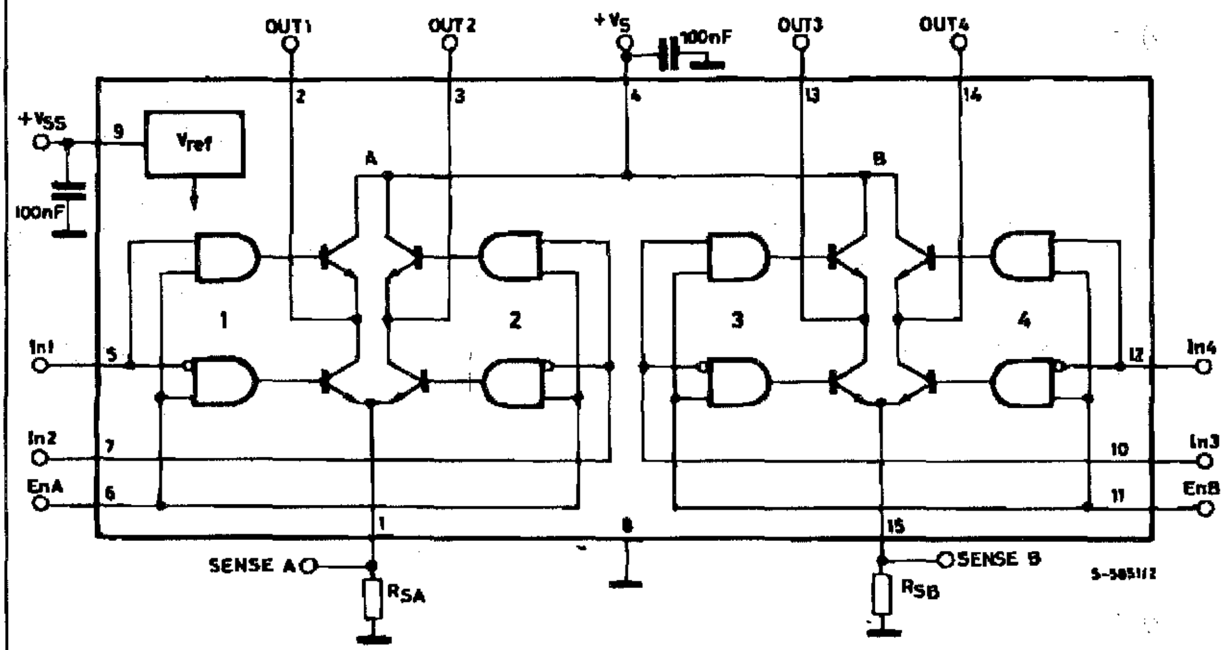
PowerSO20

ORDERING NUMBERS : L298N (Multiwatt Vert.)
L298HN (Multiwatt Horiz.)
L298P (PowerSO20)

DESCRIPTION

The L298 is an integrated monolithic circuit in a 15-lead Multiwatt and PowerSO20 packages. It is a high voltage, high current dual full-bridge driver designed to accept standard TTL logic levels and drive inductive loads such as relays, solenoids, DC and stepping motors. Two enable inputs are provided to enable or disable the device independently of the input signals. The emitters of the lower transistors of each bridge are connected together and the corresponding external terminal can be used for the connection of an external sensing resistor. An additional supply input is provided so that the logic works at a lower voltage.

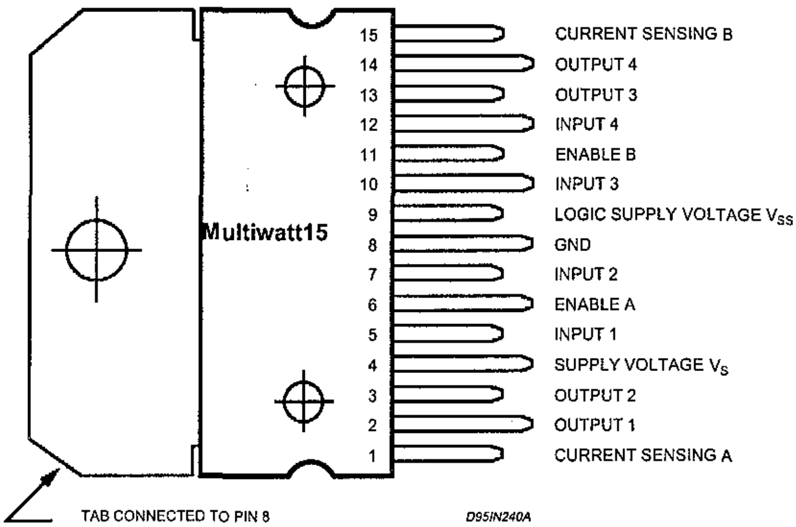
BLOCK DIAGRAM

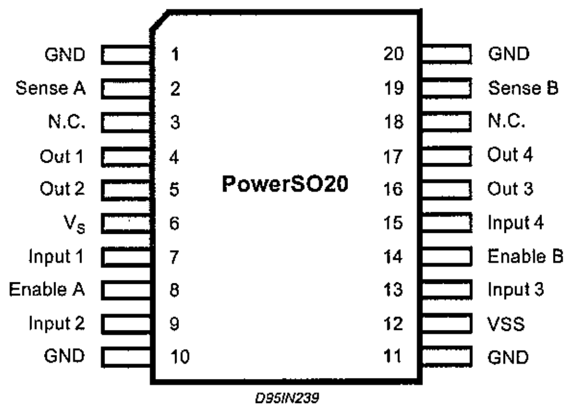


ABSOLUTE MAXIMUM RATINGS

Symbol	Parameter	Value	Unit
V_S	Power Supply	50	V
V_{SS}	Logic Supply Voltage	7	V
V_I, V_{en}	Input and Enable Voltage	–0.3 to 7	V
I_O	Peak Output Current (each Channel) – Non Repetitive (t = 100μs) –Repetitive (80% on –20% off; t_{on} = 10ms) –DC Operation	 3 2.5 2	 A A A
V_{sens}	Sensing Voltage	–1 to 2.3	V
P_{tot}	Total Power Dissipation (T_{case} = 75°C)	25	W
T_{op}	Junction Operating Temperature	–25 to 130	°C
T_{stg}, T_j	Storage and Junction Temperature	–40 to 150	°C

PIN CONNECTIONS (top view)





THERMAL DATA

Symbol	Parameter		PowerSO20	Multiwatt15	Unit
$R_{th\ j\text{-}case}$	Thermal Resistance Junction-case	Max.	–	3	°C/W
$R_{th\ j\text{-}amb}$	Thermal Resistance Junction-ambient	Max.	13 (*)	35	°C/W

(*) Mounted on aluminum substrate

PIN FUNCTIONS (refer to the block diagram)

MW.15	PowerSO	Name	Function
1;15	2;19	Sense A; Sense B	Between this pin and ground is connected the sense resistor to control the current of the load.
2;3	4;5	Out 1; Out 2	Outputs of the Bridge A; the current that flows through the load connected between these two pins is monitored at pin 1.
4	6	V_S	Supply Voltage for the Power Output Stages. A non-inductive 100nF capacitor must be connected between this pin and ground.
5;7	7;9	Input 1; Input 2	TTL Compatible Inputs of the Bridge A.
6;11	8;14	Enable A; Enable B	TTL Compatible Enable Input: the L state disables the bridge A (enable A) and/or the bridge B (enable B).
8	1,10,11,20	GND	Ground.
9	12	VSS	Supply Voltage for the Logic Blocks. A100nF capacitor must be connected between this pin and ground.
10; 12	13;15	Input 3; Input 4	TTL Compatible Inputs of the Bridge B.
13; 14	16;17	Out 3; Out 4	Outputs of the Bridge B. The current that flows through the load connected between these two pins is monitored at pin 15.
–	3;18	N.C.	Not Connected

ELECTRICAL CHARACTERISTICS (V_S = 42V; V_{SS} = 5V, T_j = 25°C; unless otherwise specified)

Symbol	Parameter	Test Conditions	Min.	Typ.	Max.	Unit
V_S	Supply Voltage (pin 4)	Operative Condition	V_{IH} +2.5		46	V
V_{SS}	Logic Supply Voltage (pin 9)		4.5	5	7	V
I_S	Quiescent Supply Current (pin 4)	V_{en} = H; I_L = 0 V_i = L V_i = H		13 50	22 70	mA mA
		V_{en} = L V_i = X			4	mA
I_{SS}	Quiescent Current from V_{SS} (pin 9)	V_{en} = H; I_L = 0 V_i = L V_i = H		24 7	36 12	mA mA
		V_{en} = L V_i = X			6	mA
V_{iL}	Input Low Voltage (pins 5, 7, 10, 12)		–0.3		1.5	V
V_{iH}	Input High Voltage (pins 5, 7, 10, 12)		2.3		VSS	V
I_{iL}	Low Voltage Input Current (pins 5, 7, 10, 12)	V_i = L			–10	μA
I_{iH}	High Voltage Input Current (pins 5, 7, 10, 12)	Vi = H ≤ V_{SS} –0.6V		30	100	μA
V_{en} = L	Enable Low Voltage (pins 6, 11)		–0.3		1.5	V
V_{en} = H	Enable High Voltage (pins 6, 11)		2.3		V_{SS}	V
I_{en} = L	Low Voltage Enable Current (pins 6, 11)	V_{en} = L			–10	μA
I_{en} = H	High Voltage Enable Current (pins 6, 11)	V_{en} = H ≤ V_{SS} –0.6V		30	100	μA
$V_{CEsat(H)}$	Source Saturation Voltage	I_L = 1A I_L = 2A	0.95	1.35 2	1.7 2.7	V V
$V_{CEsat(L)}$	Sink Saturation Voltage	I_L = 1A (5) I_L = 2A (5)	0.85	1.2 1.7	1.6 2.3	V V
V_{CEsat}	Total Drop	I_L = 1A (5) I_L = 2A (5)	1.80		3.2 4.9	V V
V_{sens}	Sensing Voltage (pins 1, 15)		–1 (1)		2	V

ELECTRICAL CHARACTERISTICS (continued)

Symbol	Parameter	Test Conditions	Min.	Typ.	Max.	Unit
T_1 (V_i)	Source Current Turn-off Delay	0.5 V_i to 0.9 I_L (2); (4)		1.5		μs
T_2 (V_i)	Source Current Fall Time	0.9 I_L to 0.1 I_L (2); (4)		0.2		μs
T_3 (V_i)	Source Current Turn-on Delay	0.5 V_i to 0.1 I_L (2); (4)		2		μs
T_4 (V_i)	Source Current Rise Time	0.1 I_L to 0.9 I_L (2); (4)		0.7		μs
T_5 (V_i)	Sink Current Turn-off Delay	0.5 V_i to 0.9 I_L (3); (4)		0.7		μs
T_6 (V_i)	Sink Current Fall Time	0.9 I_L to 0.1 I_L (3); (4)		0.25		μs
T_7 (V_i)	Sink Current Turn-on Delay	0.5 V_i to 0.9 I_L (3); (4)		1.6		μs
T_8 (V_i)	Sink Current Rise Time	0.1 I_L to 0.9 I_L (3); (4)		0.2		μs
fc (V_i)	Commutation Frequency	I_L = 2A		25	40	KHz
T_1 (V_{en})	Source Current Turn-off Delay	0.5 V_{en} to 0.9 I_L (2); (4)		3		μs
T_2 (V_{en})	Source Current Fall Time	0.9 I_L to 0.1 I_L (2); (4)		1		μs
T_3 (V_{en})	Source Current Turn-on Delay	0.5 V_{en} to 0.1 I_L (2); (4)		0.3		μs
T_4 (V_{en})	Source Current Rise Time	0.1 I_L to 0.9 I_L (2); (4)		0.4		μs
T_5 (V_{en})	Sink Current Turn-off Delay	0.5 V_{en} to 0.9 I_L (3); (4)		2.2		μs
T_6 (V_{en})	Sink Current Fall Time	0.9 I_L to 0.1 I_L (3); (4)		0.35		μs
T_7 (V_{en})	Sink Current Turn-on Delay	0.5 V_{en} to 0.9 I_L (3); (4)		0.25		μs
T_8 (V_{en})	Sink Current Rise Time	0.1 I_L to 0.9 I_L (3); (4)		0.1		μs

1) 1)Sensing voltage can be –1 V for t ≤ 50 μsec; in steady state V_{sens} min ≥ –0.5 V.
2) See fig. 2.
3) See fig. 4.
4) The load must be a pure resistor.

Figure 1 : Typical Saturation Voltage vs. Output Current.

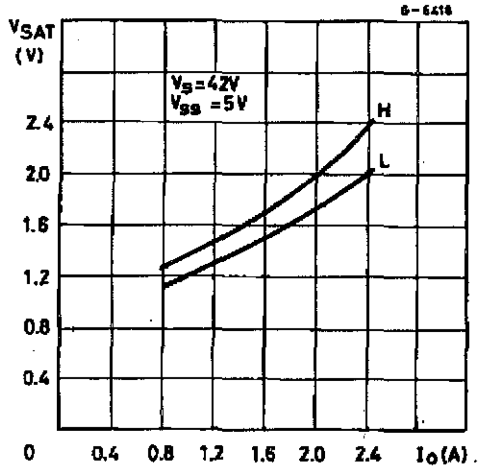
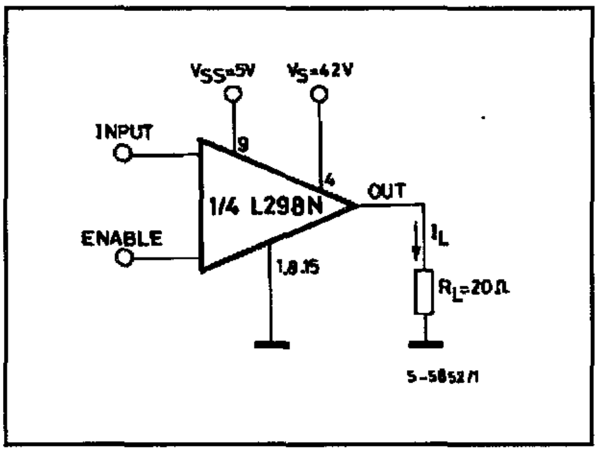


Figure 2 : Switching Times Test Circuits.



Note : For INPUT Switching, set EN = H
For ENABLE Switching, set IN = H

Figure 3 : Source Current Delay Times vs. Input or Enable Switching.

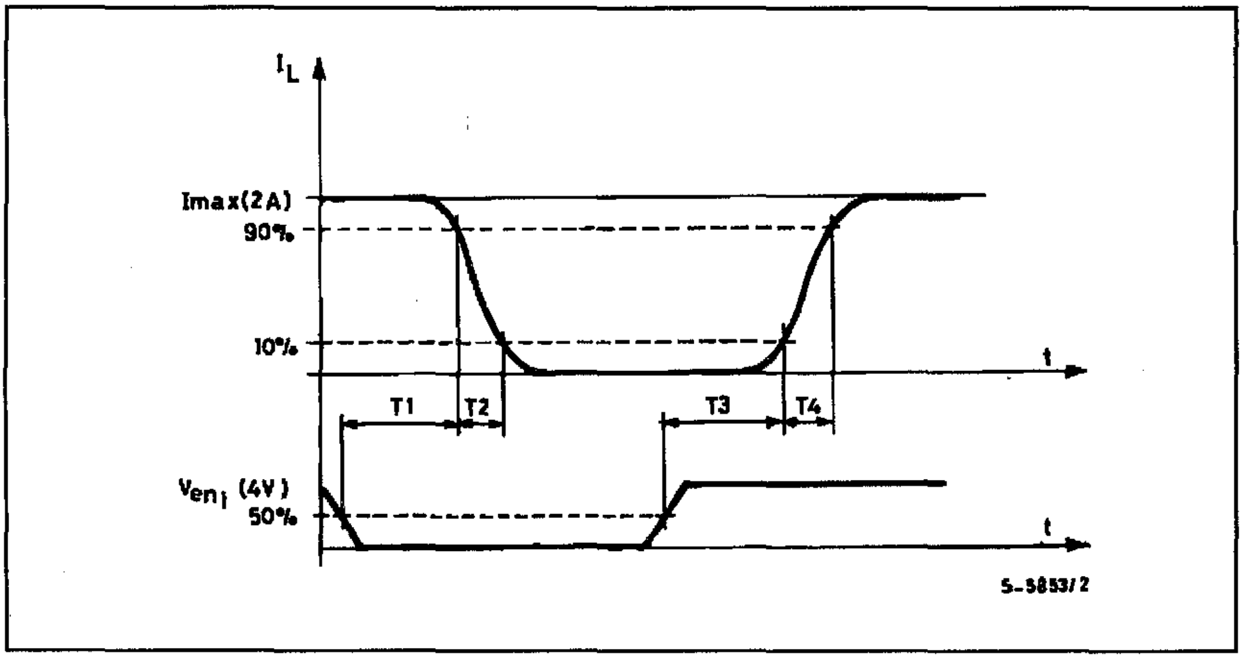
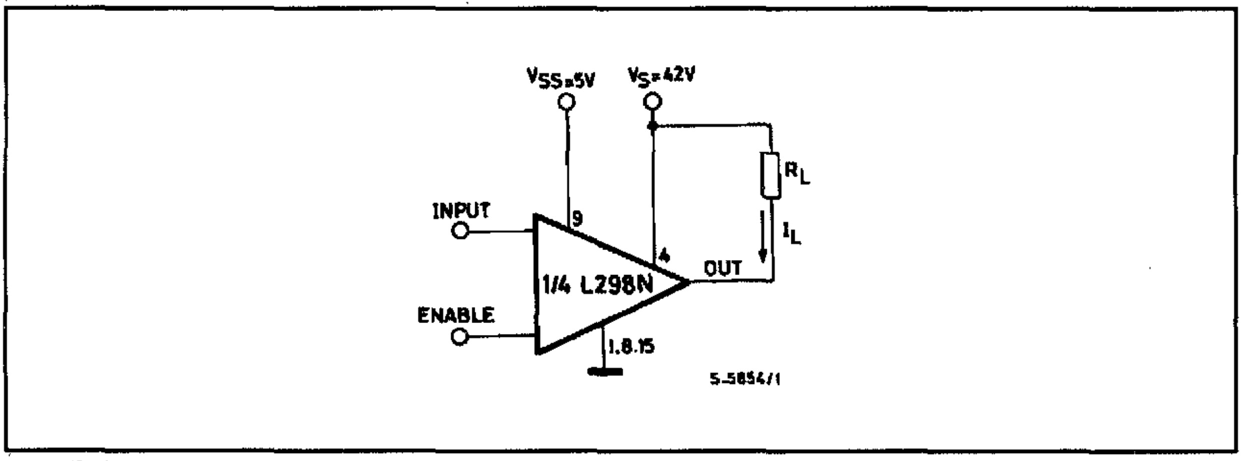


Figure 4 : Switching Times Test Circuits.



Note : For INPUT Switching, set EN = H
For ENABLE Switching, set IN = L

Figure 5 : Sink Current Delay Times vs. Input 0 V Enable Switching.

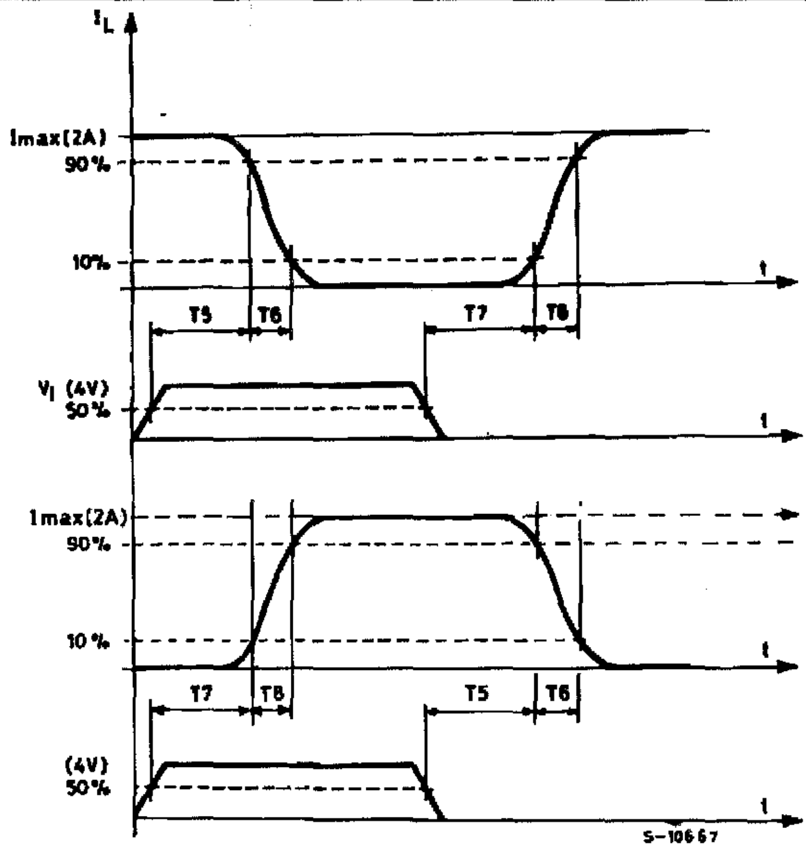
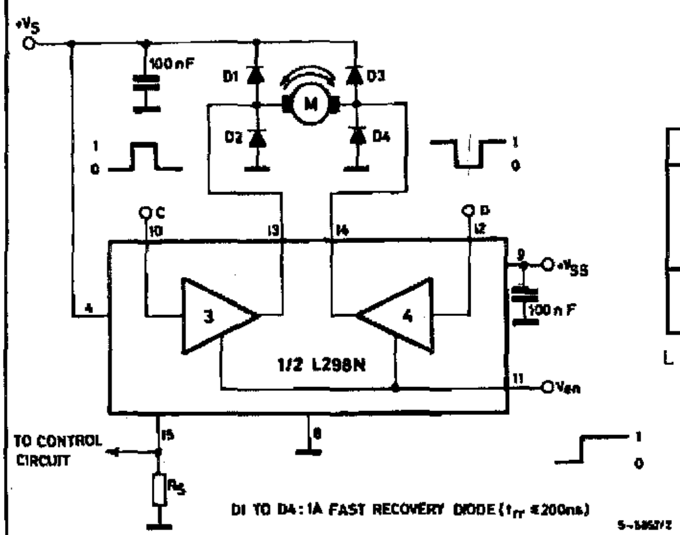


Figure 6 : Bidirectional DC Motor Control.



Inputs		Function
V_{en} = H	C = H ; D = L	Forward
	C = L ; D = H	Reverse
	C = D	Fast Motor Stop
V_{en} = L	C = X ; D = X	Free Running Motor Stop

L = Low H = High X = Don't care