TWO WHEELED BALANCING ROBOT

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ABSTRAK

Robot Seimbang Dua Roda adalah berupaya untuk menyeimbangkan diri sendirinya dengan menggunakan dua roda sahaja. Untuk menyeimbangkan diri sendirinya, robot ini memerlukan maklum balas daripada sensor yang menunjukkan sudut condong robot. Robot akan bergerak ke hadapan atau ke belakang untuk kembali ke titik penentuan. Konsep asas bagi Robot Seimbang Dua Roda ialah pengimbangan dinamik. Jenis pengimbangan ini lebih mudah dijelaskan dalam perspektif manusia; untuk memastikan manusia berdiri, otak kita berterusan merasa sama ada badan sedang berdiri tegak. Apabila daya luaran menolak badan manusia manjadi tidak seimbang, otak akan mengarahkan otot-otot untuk meredakan daya tersebut. Tugas mikropengawal dalam projek ini adalah untuk memerhatikan sensor maklum balas, menghitung ralat di antara sudut hasrat dan sudut sebenar. Algoritma kawalan PID pula diaplikasikan supaya robot menjadi lebih stabil. Robot seimbang boleh digunakan sebagai kenderaan peribadi seperti skuter, ia dapat membantu orang cacat bergerak dari satu tempat ke tempat yang lain.

ABSTRACT

Two Wheeled Balancing Robot is capable to balance itself by using only two wheels. In order to balance itself, this robot requires feedback from a sensor that will indicate the tilt angle of the robot. The robot will then move forward or backward to recover the balance setting point. The basic concept of Two Wheeled Balancing Robot is a dynamic balancing. This type of balancing is easier to describe in human perspective for example; to keep humans standing, our brain constantly sense whether the body are standing upright. If an outside force pushes human body off-balance, the brains will instruct the muscles to counteract that force. The task of the microcontroller in this project is monitoring the feedback sensor, calculate the error between desired and actual tilt. Proportional derivative Integral or PID control algorithm will be applied to makes the robot even more stable. Balancing robot can apply for personal transport like scooter, which can help handicapper to move from one place to another.

CHAPTER I

INTRODUCTION

1.1 INTRODUCTION

The research on balancing robot has gained an interest among researchers over the last decade in a number of robotics laboratories around the world. This is due to the unstable dynamics of the robot. This type of robots are characterized by the ability to balance on its two wheels and spin on the spot. This additional manoeuvrability allows easy navigation on various terrains, turn sharp corners and traverse small steps or curbs. These capabilities have potential to solve a number of challenges in industry and society. For example, a motorized wheelchair utilizing this technology would give the operator greater manoeuvrability and thus access to places most able-bodied people take for granted. A small cart built utilizing this technology allows humans to travel short distances in small area or factories as opposed to using cars or buggies that is more polluting.

The basic concept of Two Wheeled Balancing Robot is a dynamic balancing. This type of balancing is easier to describe with human such as example. To keep humans standing, our brain constantly sense whether the body are standing upright. If an outside force pushes human body off-balance, the brains will instruct the muscles to counteract that force. This is how the robot is going to react. A feedback sensor like a tilt sensor is required to maintain the robot stability. This sensor will measure the tilt of the robot with respect to gravity. The measurement will be feedback to the platform, which the torque is proportional to the measurement and will result the robot balance.

1.2 OBJECTIVE

1. To design and develop a two-wheeled robot that capable to balance itself by using PID controller.
2. To study and understand basic concept of two-wheeled robot.
3. To identify the suitable type of microcontroller and drive system in the project.
4. To study the Proportional Integral Derivative (PID) control algorithms and its implementation using the microcontroller.

1.3 PROBLEM STATEMENT

Two Wheeled Balancing Robot is traveling by using a set of wheels, one on each side since there are only two points on the ground, these robots have a tendency to tip back and forth. To compensate for this, many people decide to add castors or ball-transfers to their robot to make them less prone to tipping and more stable. Advantage of Two Wheeled Balancing Robot is ease to assemble, economic and simple.

1.4 SCOPES OF WORK

The scopes of works in this project are:

1. Used PID to design the control system for this project.
2. Selected Microchip PIC16F877A as microcontroller for this project.
3. Chose Freescale MMA2260 accelerometer as sensor for this project.
4. Selected Parallax Continuous Servo Motor as motor for this project.
5. Used PicBasic Pro as programming language for this project.

1.5 REPORT STRUCTURE

This thesis is a documentary delivering the idea generated, concepts applied, activities done, and finally the final year project product itself. It consists of seven chapters. Following is a chapter-by-chapter description of information in this thesis.

Chapter 1 gives reader a basic introduction to how the idea of this project generated. The chapter contains introduction, objective of the project, problem statement, scopes of works and report structure.

Chapter 2 is a literature review on theoretical concepts applied in this project. The chapter concludes with brief explanation of how Two Wheeled Balancing Robot work, what are microcontroller, motor and sensor. Then, why choose the specific microcontroller, motor and sensor.

Chapter 3 introduces the construction of the project, which involves hardware development and software development. Basically, hardware development for the project concludes with circuit design, prototype or body design and PCB fabrication. Besides, software development for the project will be discuss on what is programming language, how to use MPLAB and PicBasic Pro compiler to develop program, and how to use IC Prog to download program into PIC microcontroller. Then, the programming flows are explained through flow chart.

Chapter 4 will be covered all the result from the designing process. It will also include a discussion about the project. The chapter concludes with discussion on the analyzable of the accelerometer sensor, PID and servo motor..

Chapter 5 will be the conclusion of the PSM project. The chapter concludes with some recommendations that can be implemented in future.

CHAPTER II

LITERATURE REVIEW

2.1 INTRODUCTION

This chapter is a literature review on theoretical concepts applied in this project. The chapter concludes with brief explanation of how Two Wheeled Balancing Robot work, what are microcontroller, motor and sensor. Then, why choose the specific microcontroller, motor and sensor.

2.2 BACKGROUND STUDY

Two Wheeled Balancing Robot is capable to balance itself with only two wheels. The basic idea for a Two Wheeled Balancing Robot is very simple: drive the wheels in the direction that the upper part of the robot is falling. If the wheels can be driven in such a way as to stay under the robot's center of gravity, the robot remains balanced.

2.3 MICROCONTROLLER

A microcontroller (or MCU) is a computer-on-a-chip used to control electronics devices. A typical microcontroller contains all the memory and interfaces needed for a simple application, whereas a general purpose microprocessor requires additional chips to provide these functions.

2.3.1 Microcontroller Features

A microcontroller is a single integrated circuit with the following key features:

- central processing unit (CPU) - usually small and simple
- electrically erasable programmable read-only memory (EEPROM)
- random access memory (RAM)
- input/output (I/O) pins
- clock speed

2.3.1.1 Central Processing Unit (CPU)

The CPU is the internal core of the microcontroller. CPU is used to accept the input data, execute the programs, and output the results. Generally, the CPU will add data, move and compare data, execute loops, read and store data, read and modify internal status registers, and increment counters.

2.3.1.2 EEPROM and RAM

The EEPROM is where the programs and permanent data are stored. The RAM is where all of the temporary data that the microcontroller uses is stored. The amount of RAM of microcontroller will limits the number of variables that user can use in programs meanwhile the amount of EEPROM sets the limit on how large a program that user can use.

2.3.1.3 Input/Output (I/O) Pins

All microcontrollers have a certain number of I/O pins. Depending on the microcontroller, some I/O pins are input only or output only and some have the special-purpose I/O for such thins as analog-to-digital conversion. Most microcontrollers have bidirectional I/O pins.

2.3.1.4 Clock Speed

Clock speed is the speed of an external crystal oscillator (a clock) that is used to control how fast the microcontroller executes the internal instructions. Basically, all microcontrollers use an external oscillator with typical frequency range as 4MHz, 8MHz, 20MHz and 40MHz, and some microcontroller have the option of using a slower built-in clock. Clock speed is a general indicator on how fast a microcontroller is but that is unsuitable to determined which microcontroller is faster. Different microcontrollers have different structure and application internally with clock speed. Also different microcontrollers will handle the similar instructions differently where the amount of internal clock cycles required to execute an instruction can be different from microcontroller to microcontroller. And for a same type of microcontroller, the time required to execute a given instruction will be different for different programming language compilers like PICBASIC PRO Compiler. So that is difficult to judge which microcontroller is fastest.

2.3.2 Microcontroller Architectures

Basically, two types of Architectures are used in microcontrollers: Harvard Architecture and Von Neumann Architecture. In the Harvard Architecture, program memory and data memory are separated memories and they are accessed from separeted buses, and can be different bit widths. In the Von Neumann Architecture, only one bus between CPU and memory. So, program memory and data memory are share the same bus, and must have the same bit width.

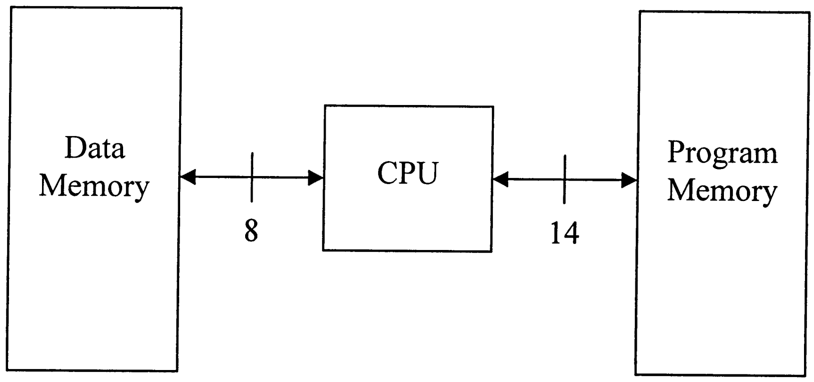


Figure 2-1: Harvard Architecture

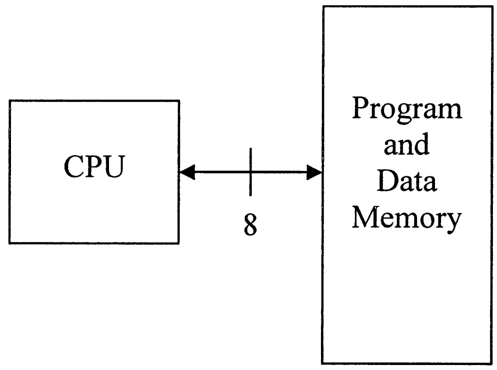


Figure 2-2: Von Neumann Architecture

2.3.3 RISC and CISC

RISC (Reduced Instruction Set Computer) and CISC (Complex Instruction Set Computer) refer to the instruction set of microcontroller. In a RISC microcontroller, instruction words are more than 8 bits wide (usually 12, 14 or 16 bits) and the instructions occupy one word in the program memory. Besides that, RISC microcontroller (e.g. PIC) usually have 35 instructions. CISC microcontroller have 8-bit wide instructions and they usually have over 200 instructions. Some instruction (e.g. branch) occupy more than one word in the program memory.

2.3.4 Pin Diagram of PIC16F877A

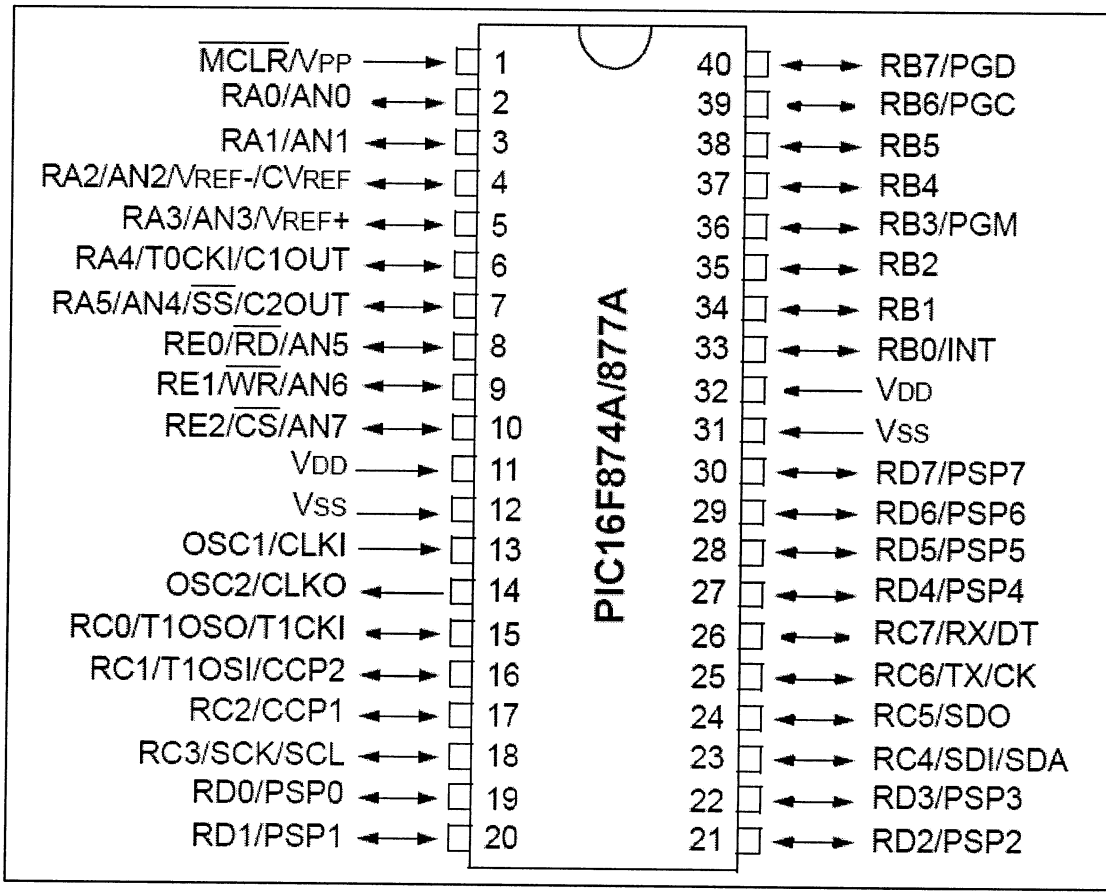
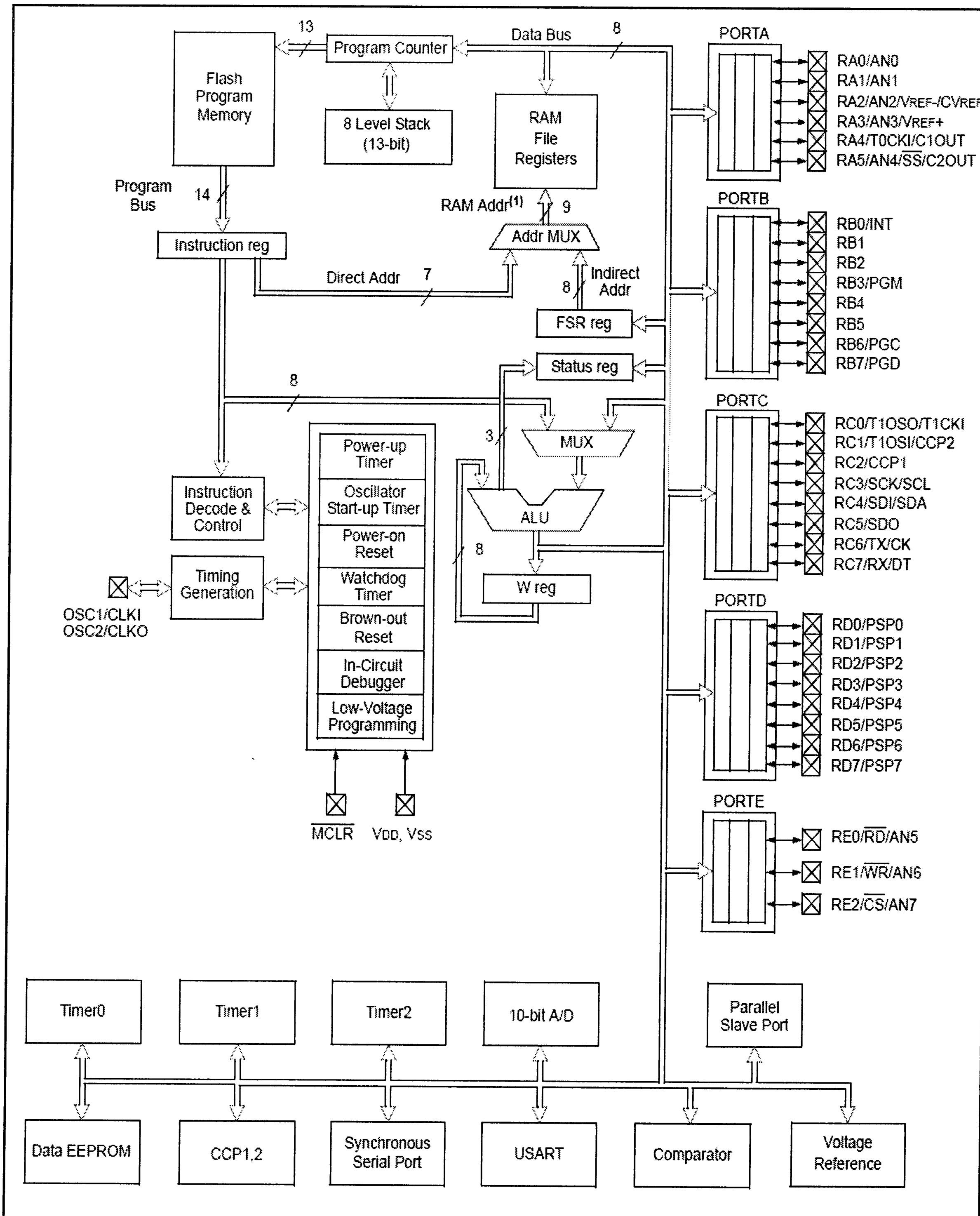


Figure 2-3: Pin Diagram of PIC16F877A

2.3.5 Block Diagram of PIC16F877A



Device	Program Flash	Data Memory	Data EEPROM
PIC16F874A	4K words	192 Bytes	128 Bytes
PIC16F877A	8K words	368 Bytes	256 Bytes

Figure 2-4: Block Diagram of PIC16F877A

2.3.6 Why Choose PIC16F877A Microcontroller

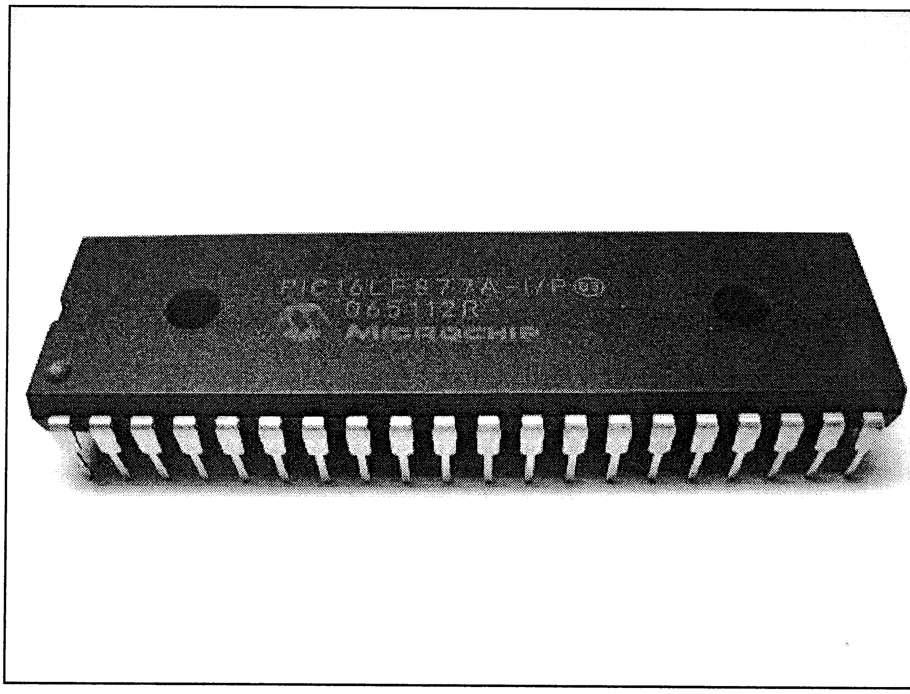


Figure 2-5: PIC16F877A Microcontroller

From various type of microcontroller in the market, the PIC16F877A microcontroller manufactured by Microchip is chosen to fulfill the requirements of balancing robot. The selection of PIC16F877A microcontroller is based on the available features of PIC16F877A as stated below:

- Low power consumption.
- Consists of 8 channel of 10-bit ADC (Analog-to-Digital Converter).
- Support up to 33 I/O pins from Port A, B, C, D, and E.
- Support up to 20 MHz clock input for operating speed, so that are 200ns instruction cycle. As a result, the program will execute faster if the frequency of clock input is higher.
- All single-cycle instructions except for program branches, which are two-cycle.
- Only require 35 single-word instructions to learn.
- Support for ICSP (In-Circuit Serial Programming).
- Support 100,000 erase/write cycle for Flash Program Memory and 1,000,000 erase/write cycle for EEPROM Data Memory.

- Support up to 8k x 14 words of Flash Program Memory, 368 x 8 bytes of Data Memory (RAM) and 256 x 8 bytes of EEPROM Data Memory.
- Power saving Sleep mode.
- Wide operating voltage range (2.0V to 5.5V).
- Supported by several programming software for example MPLAB IDE, ICProg, PicBasic Pro Compiler and etc. Also this chip able to program through these software by using several programming language like C#, BASIC, and assembly language.

2.4 SENSOR

2.4.1 Infrared Sensor

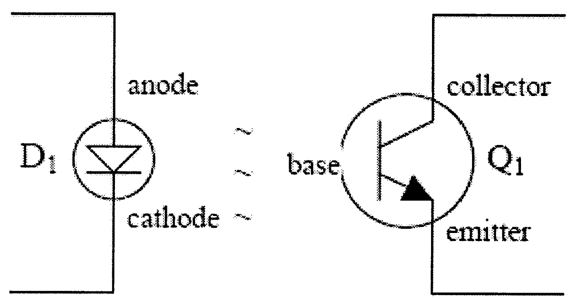


Figure 2-6: Basic Circuit for Infrared Sensor

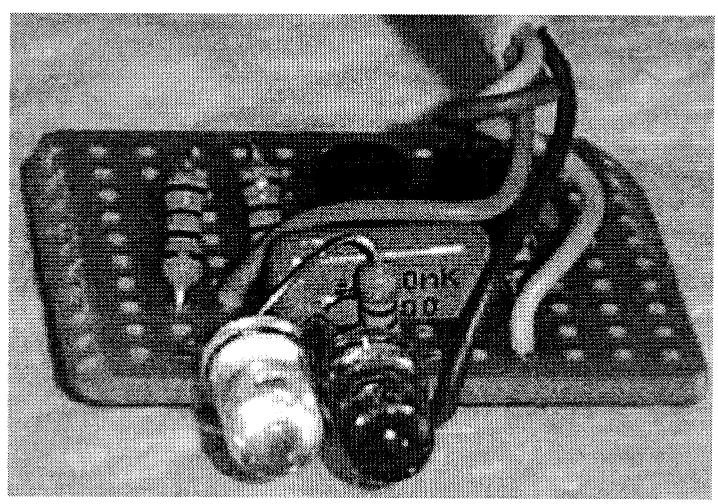


Figure 2-7: Infrared Transmitter and Receiver Pair

An infrared sensor consists of an infrared transmitter that sends out an invisible beam of light into the environment and an infrared receiver that absorbs the beam of light that is reflected back. The angle of the reflected beam indicates the proximity of the infrared receiver to the object that is reflecting light. There are basically two ways of using reflected light intensity in robot navigation. In proximity detection, the photosensitive receiver is simply looking for a set trigger value (for example, a high light intensity level), that when reached, will prompt the robot's response. The robot will wait until that trigger value is reached before doing anything.

Proximity detection is like an on/off switch. Distance detection, the more sophisticated of the two approaches, uses the changing angle of reflected light to actually measure the changing distance between the robot and obstacles. This allows for the taking of different actions depending on perceived distance.

2.4.2 Ultrasonic Sensor

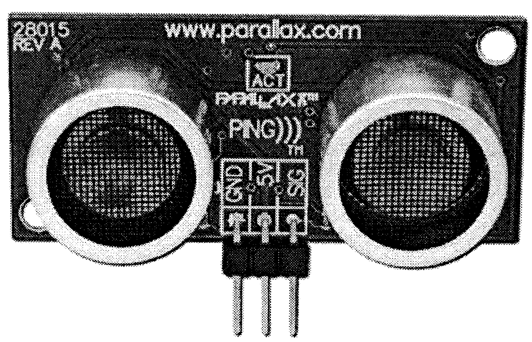


Figure 2-8: Ultrasonic Sensor

Ultrasonic sensor can be used for object detection since the speed of sound traveling through air is considerably slower than the speed of microcontroller. In ultrasonic sensor, an emitter transducer projects high-frequency sound wave outside the range of human hearing into environment, which then bounce off possible objects ahead, and return to a receiver transducer. The time it takes for the sound wave to return to the receiver is used to determine the robot's distance from the object.

2.4.3 Accelerometer Sensor

An accelerometer is an electromechanical device that will measure acceleration forces. These forces may be static, like the constant force of gravity pulling at feet, or they could be dynamic - caused by moving or vibrating the accelerometer.

An accelerometer measures acceleration (change in speed) of anything that it's mounted on. Single axis accelerometers measure acceleration in only one direction. Dual-axis accelerometers, which are the most common, measure acceleration in two directions, perpendicular to each other. Three-axis accelerometers measure acceleration in three directions.

Accelerometers are very handy for measuring the orientation of an object relative to the earth, because gravity causes all objects to accelerate towards the earth. A two-axis accelerometer can be used to measure how level an object is.

2.4.3.1 What Are Accelerometers Useful For?

By measuring the amount of static acceleration due to gravity, so can find out the angle the device is tilted at with respect to the earth. By sensing the amount of dynamic acceleration, so can analyze the way the device is moving.

At first, measuring tilt and acceleration doesn't seem all that exciting. However, engineers have come up with many ways to make really useful products using them.

An accelerometer can help the project understand its surroundings better. Is it driving uphill? Is it going to fall over when it takes another step? A good programmer can write code to answer all of these questions using the data provided by an accelerometer. An accelerometer can help analyze problems in a car engine using vibration testing.

In the computing world, IBM and Apple have recently started using accelerometers in their laptops to protect hard drives from damage. If accidentally the laptop drops, the accelerometer detects the sudden freefall, and switches the hard drive off so the heads don't crash on the platters. In a similar fashion, high g accelerometers are the industry standard way of detecting car crashes and deploying airbags at just the right time.

2.4.3.2 What is a “g”?

A unit of acceleration equal to the average force of gravity occurring at the earth’s surface. A g is approximately equal to 32.17 ft/s^2 or 9.807 m/s^2. Low-g accelerometers are typically ranged from ±1g to ±20g. Meanwhile high-g accelerometers are typically ranged from ±20g to ±250g.

2.4.3.3 Common Type of Accelerometers

Table 2-1: Common Type of Accelerometers

Sensor Category	**Key Technologies**
Capacitive	Metal beam or micromachined feature produces capacitance; change in capacitance related to acceleration.
Piezoelectric	Piezoelectric crystal mounted to mass –voltage output converted to acceleration.
Piezoresistive	Beam or micromachined feature whose resistance changes with acceleration.
Hall Effect	Motion converted to electrical signal by sensing of changing magnetic fields.
Magnetoresistive	Material resistivity changes in presence of magnetic field.
Heat Transfer	Location of heated mass tracked during acceleration by sensing temperature.

2.4.3.4 Principle of Operation

The Freescale accelerometer is a surface-micromachined integrated-circuit accelerometer.

The device consists of a surface micromachined capacitive sensing cell (g-cell) and a CMOS signal conditioning ASIC contained in a single integrated circuit package. The sensing element is sealed hermetically at the wafer level using a bulk micromachined "cap" wafer.

The g-cell is a mechanical structure formed from semiconductor materials (polysilicon) using semiconductor processes (masking and etching). It can be modeled as a set of beams attached to a movable central mass that moves between fixed beams. The movable beams can be deflected from their rest position by subjecting the system to acceleration (Figure 2-9).

When the beams attached to the center mass move, the distance from them to the fixed beams on one side will increase by the same amount that the distance to the fixed beams on the other side decreases. The change in distance is a measure of acceleration.

The g-cell beams form two back-to-back capacitors (Figure 2-10). As the center plate moves with acceleration, the distance between the beams change and each capacitor's value will change, ($C = NA\varepsilon/D$). Where A is the area of the facing side of the beam, ε is the dielectric constant, and D is the distance between the beams, and N is the number of beams.

The CMOS ASIC uses switched capacitor techniques to measure the g-cell capacitors and extract the acceleration data from the difference between the two capacitors. The ASIC also signal conditions and filters (switched capacitor) the signal, providing a high level output voltage that is ratiometric and proportional to acceleration.

2.4.3.5 Transducer Physical Model

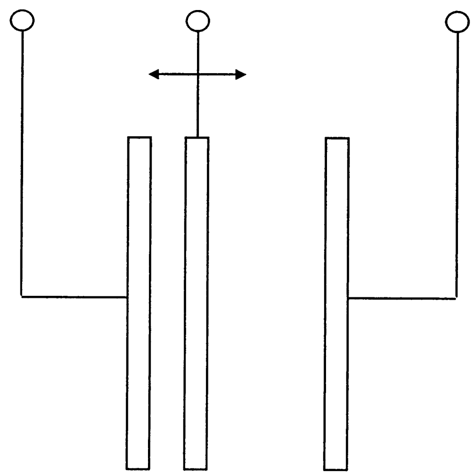


Figure 2-9: Transducer Physical Model

2.4.3.6 Equivalent Circuit Model

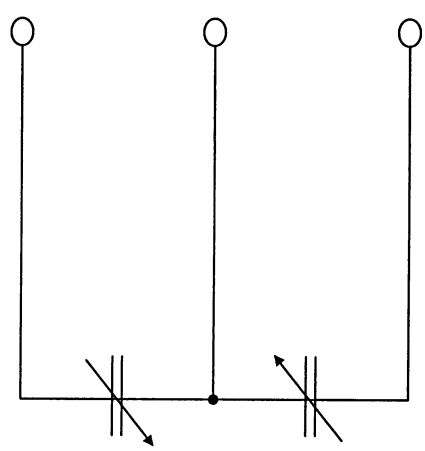


Figure 2-10: Equivalent Circuit Model

2.4.3.7 Block Diagram of MMA2260 Accelerometer

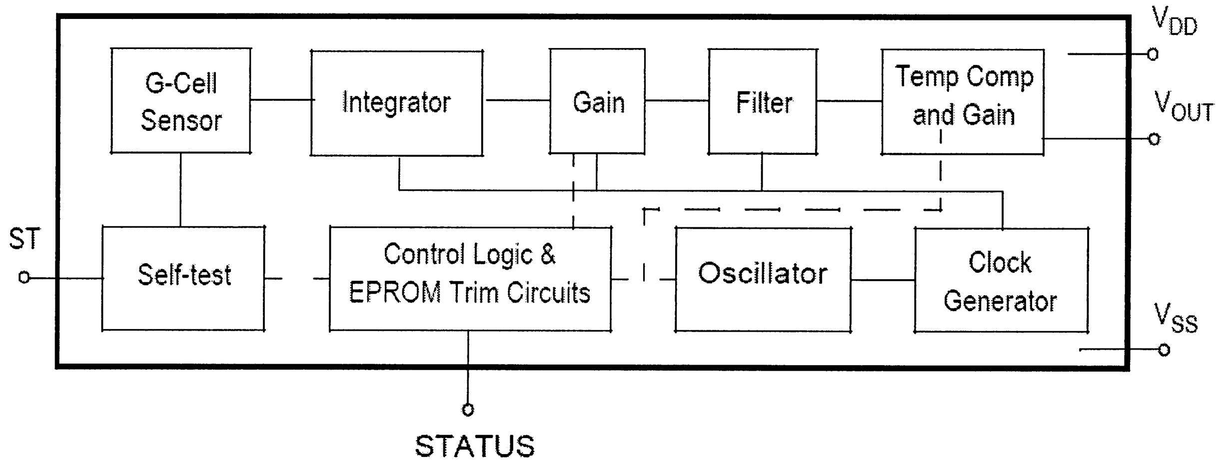


Figure 2-11: Block Diagram of MMA2260 Accelerometer

2.4.3.8 Pin Diagram of MMA2260 Accelerometer

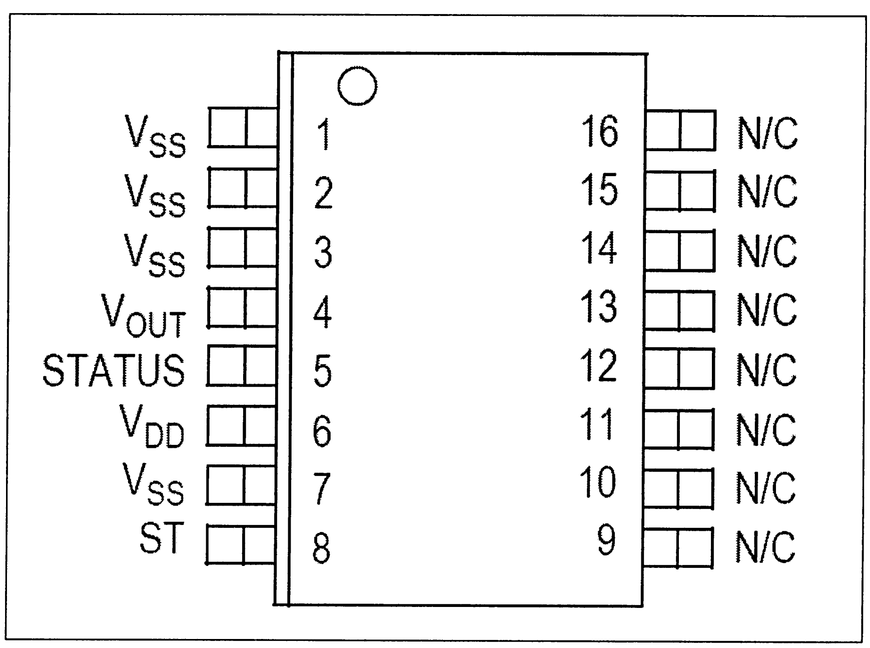


Figure 2-12: Pin Diagram of MMA2260 Accelerometer

2.4.3.9 Dynamic & Static Acceleration

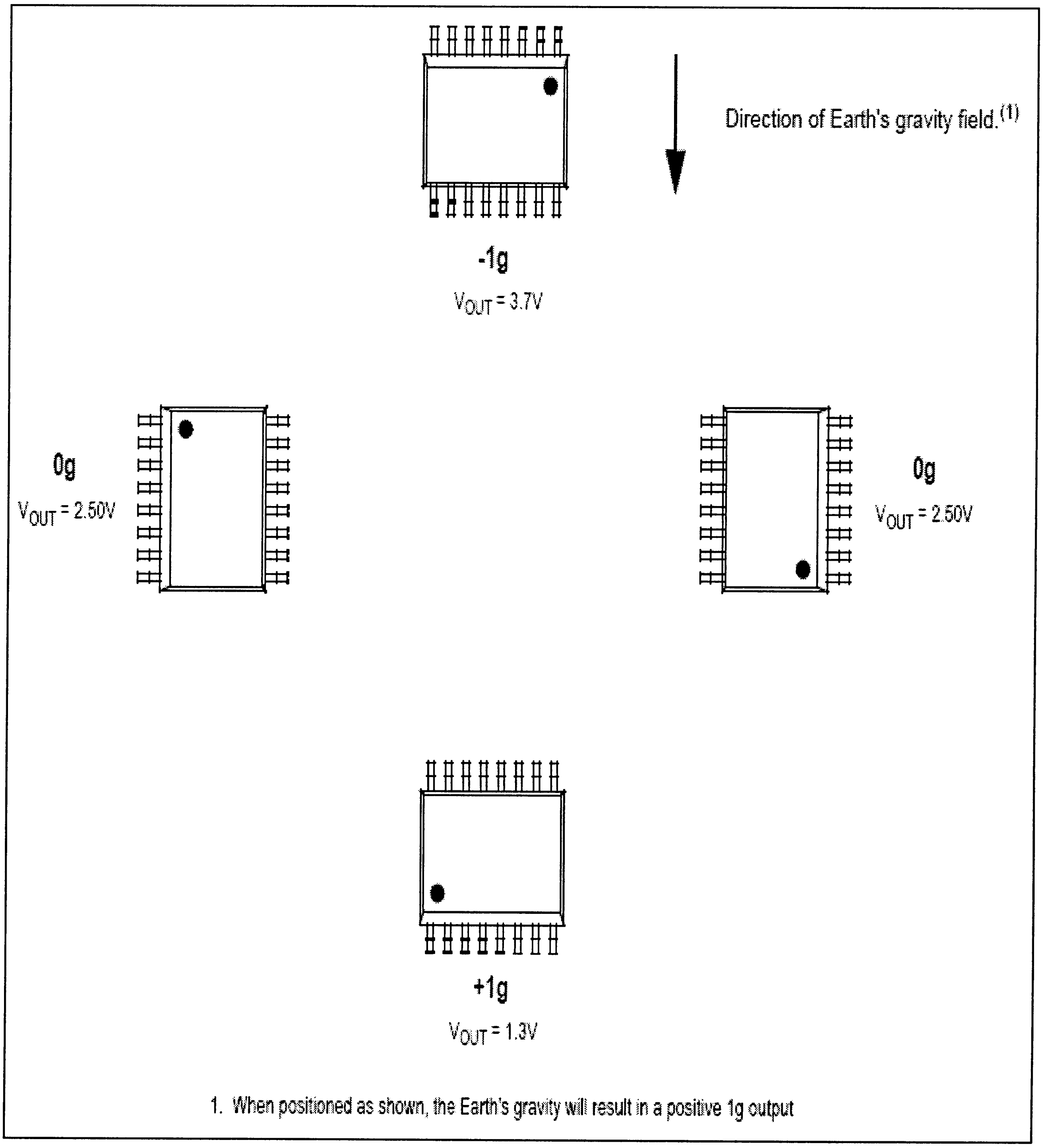


Figure 2-13: Static Acceleration

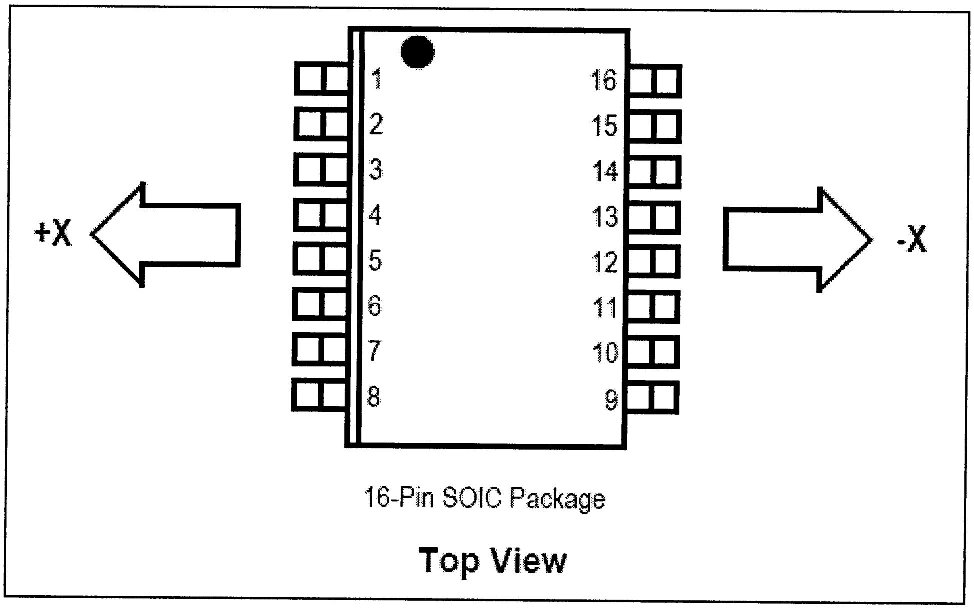


Figure 2-14: Dynamic Acceleration

2.4.3.10 Calculating Degree of Tilt

$$V_{OUT} = V_{OFFSET} + \left(\frac{\Delta V}{\Delta g} \text{ x } 1.0\text{g} \text{ x } \sin\theta\right)$$

$$\theta = \arcsin\left[(V_{OUT} - V_{OFFSET}) / \frac{\Delta V}{\Delta g}\right]$$

Where:

V_{OFFSET} = Accelerometer 0g offset

V_{OUT} = Accelerometer output in volts

$\frac{\Delta V}{\Delta g}$ = Sensitivity

1g = Earth's Gravity
= 9.807 m/s^2

θ = Angle of Tilt

2.4.3.11 Why Choose MMA2260 Accelerometer

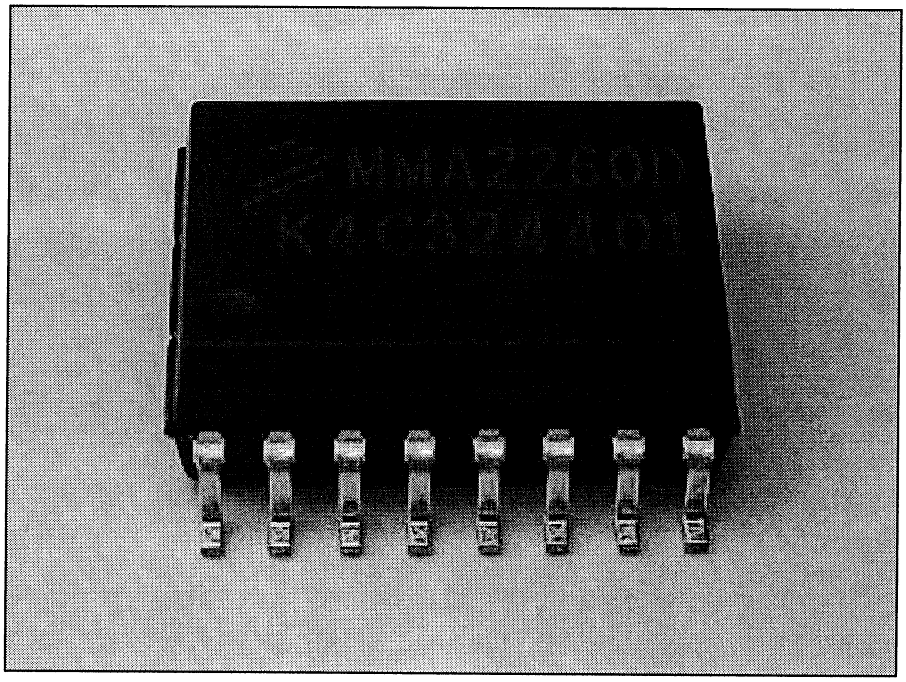


Figure 2-15: MMA2260 Accelerometer

From various type of accelerometer in the market, the MMA2260 accelerometer manufactured by Freescale is chosen to fulfill the requirements of balancing robot. The selection of MMA2260 accelerometer is based on the available features of MMA2260 as stated below:

- Low power consumption.
- High Sensitivity (1200mV/g)
- Low-g (1.5g)
- Linear Output
- Integral Signal Conditioning
- Calibrated Self-test
- EPROM Parity Check Status
- 2nd Order Bessel Filter
- Robust Design, High Shock Survivability
- Transducer Hermetically Sealed at Wafer Level for Superior Reliability

2.5 MOTOR

Motor is used in the drive system to converts the electrical energy into mechanical energy. In constructing a robot, motor plays an important role as to give movement to the robot. In general, motor operates with the effect of conductor with current and the permanent magnetic field. The conductor with current will produces magnetic field which will react with the magnetic field produces by the permanent magnet to make the motor rotate.

There are three basic types of motor, DC motor, servo motor and stepper motor which are commonly being used in building a robot.

2.5.1 DC Motor

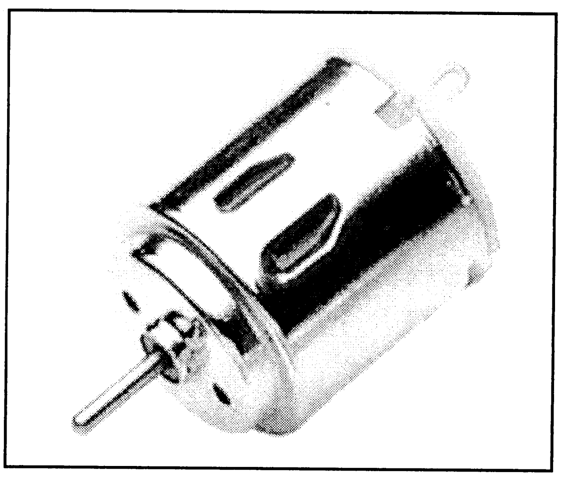


Figure 2-16: DC Motor

DC motor is an electric motor converts electrical energy into mechanical motion. The reverse task that of converting mechanical motion into electrical energy is accomplished by a generator or dynamo.

2.5.1.1 How Does a DC Motor Work?

DC motor contains a stator which is an arrangement of two permanent magnets that provide a magnetic field in which the armature rotates. The armature, positioned in the center of the motor, has an odd number of poles that have windings connected to a contact pad on the center shaft known as commutator. Brushes provide the power to the windings of the armature so that they are alternately attracted to and repelled from the permanent magnets of the stator. As the Lorenz Force propels the coils, torque is transmitted through the shaft and causes the armature to turn in a circular motion.

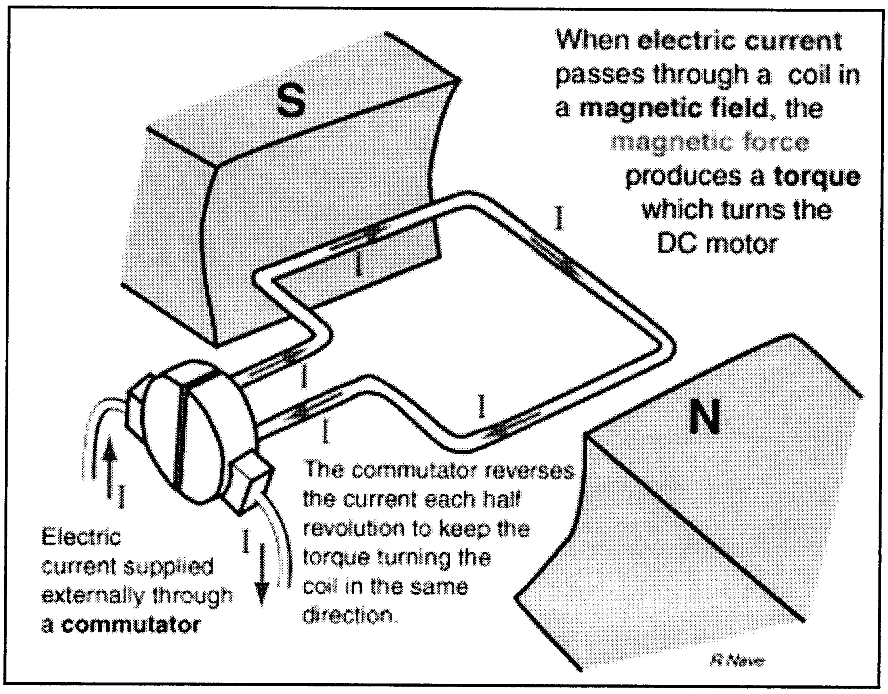


Figure 2-17: Current in DC Motor

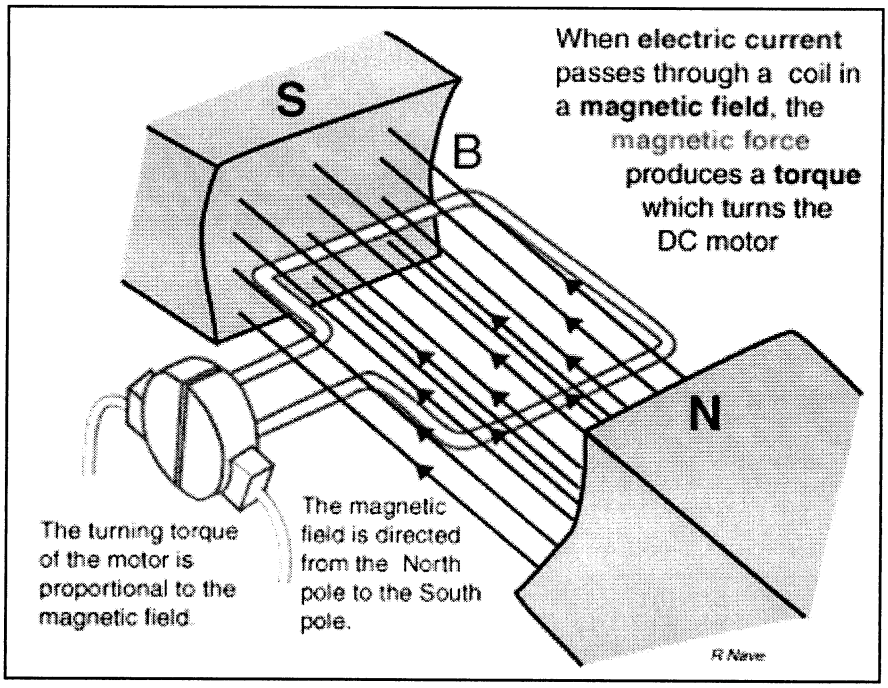


Figure 2-18: Magnetic Field in DC Motor

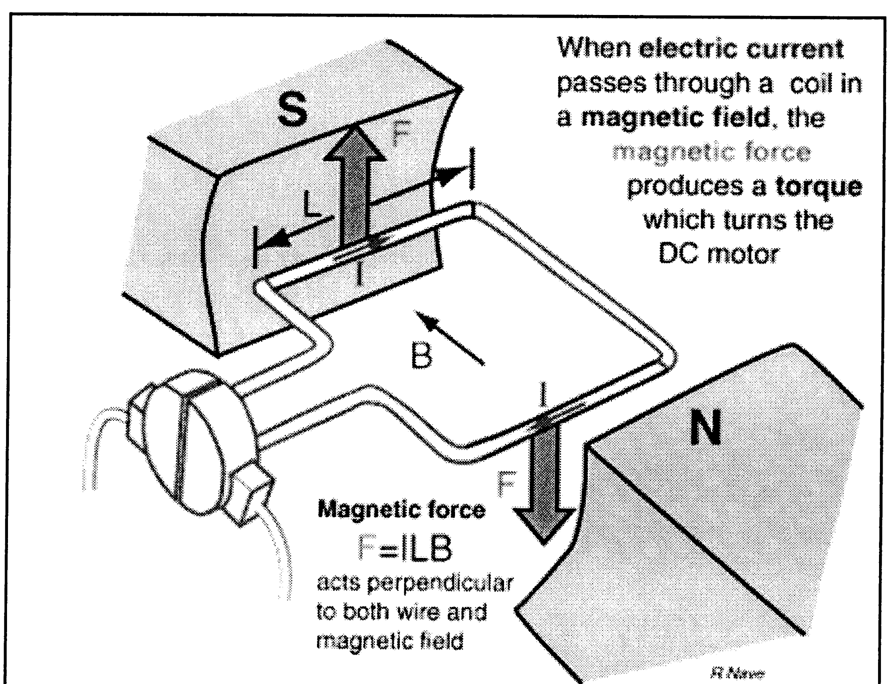


Figure 2-19: Force in DC Motor