CHAPTER 2

Literature Review

2.1 Robotics overview

A robot is an automatically guided machine or virtual artificial agent, usually an electro-mechanical machine that is guided by a computer program or electronic circuitry, able to do tasks on its own [1].The word robot can refer to both physical robots and virtual software agents, but the latter are usually referred to as bots . There is no consensus on which machines qualify as robots, but there is a general agreement among experts and the public that robots tend to do some or all of the following: move around, operate a mechanical limb, sense and manipulate their environment, and exhibit intelligent behavior, especially behavior which mimics humans or other animals.

There is a conflict about whether the term can be applied to remotely operated devices, as the most common usage implies, or solely to devices which are controlled by their software without human intervention. In South Africa, robot is an informal and commonly used term for a set of traffic lights. Stories of artificial helpers and companions and attempts to make them have a long history but fully autonomous machines only appeared in the 20th century. The first digitally operated and programmable robot, the Unimate, was installed in 1961 to lift hot pieces of metal from a die casting machine and stack them. Today, commercial and industrial robots are in a widespread use performing jobs more cheaply or with greater accuracy and reliability than humans.

They are also employed for jobs which are too dirty, dangerous or dull to be suitable for humans. Robots are widely used in manufacturing, assembly and packing, transport, earth and space exploration, surgery, weaponry, laboratory research, and mass production of consumer and industrial goods. It is difficult to compare numbers of robots in different countries, since there are different definitions of what a "robot “is.

The International Organization for Standardization gives a definition of robot in ISO 8373 "an automatically controlled, reprogrammable, multipurpose, manipulator programmable in three or more axes, which may be either fixed in place or mobile for use in industrial automation applications "[2]. This definition is used by the International Federation of Robotics, the European Robotics Research Network (EURON), and many national standards committees.

The Robotics Institute of America (RIA) uses a broader definition: a robot is a "re-programmable multi-functional manipulator designed to move materials, parts, tools, or specialized devices through variable programmed motions for the performance of a variety of tasks.

The RIA subdivides robots into four classes: devices that manipulate objects with manual control, automated devices that manipulate objects with predetermined cycles, programmable and servo-controlled robots with continuous point-to-point trajectories, and robots of this last type which also acquire information from the environment and move intelligently in response. There is no one definition of robot which satisfies everyone, and many people have their own. For example, Joseph Eagleburger, a pioneer in industrial robotics, once remarked: "I can't define a robot, but I know one when I see one [1]. According to Encyclopedia Britannica, a robot is "any automatically operated machine that replaces human effort, though it may not resemble human beings in appearance or perform functions in a humanlike manner". Merriam-Webster describes a robot as a "machine that looks like a human being and performs various complex acts (as walking or talking) of a human being", or a "device that automatically performs complicated often repetitive tasks", or a "mechanism guided by automatic controls". Modern robots are usually used in tightly controlled environments such as on assembly lines because they have difficulty responding to unexpected interference. Because of this, most humans rarely encounter robots. However, domestic robots for cleaning and maintenance are increasingly common in and around homes in developed countries, particularly in Japan. Robots can also be found in the military.

2.2 History of robots

The history of robotics can be traced back to the Ancient Greeks. According to Greek mythology, the Greek God of fire and the forge - Hephaestus - was served by mechanical robots. Another historical record suggests that the origin of robotics is connected to ancient Egypt, where priests used steam-activated mechanisms to open the doors of their temple. It was around 350 BC, when veteran Greek mathematician - Archytas - constructed a mechanical bird named 'the Pigeon', a robot powered by steam, which could fly through the air. This was the first recorded model airplane and a milestone in the history of robotics.

The development of robot increased day by day until reached an advanced stage in the latter half of 20th century. Towards the end of 20th century, robotics saw a sea change in terms of the functionality of the robots. And time wise later, robots emerged as highly sophisticated machines, which could recognize environment, distinguish sounds very easy and observe the moving objects. Some of the wonderful inventions were 'RoboTuna', developed and built by David Barrett, in 1996. 'Gastrobot', a robot that digests organic mass to produce carbon dioxide, was developed by Chris Campbell and Stuart Wilkinson at the University of South Florida, in 1996. Three years later, in 1999, Sony released the AIBO robotic pet.

The advent of the millennium witnessed further development in the field of robotics. In 2000, Honda introduced humanoid robot – ASIMO [6]. Sony launched its third generation robotic pet in the market in 2003. It was named as 'AIBO ERS-7'. In The present time, Robots emerged as machines that could follow along with a human by holding hands. Today, with the advancement of science and technology, the researchers are coming up with innovative ideas to create robots that could simplify the sophisticated tasks, which are otherwise done with intense hard work, with work force. Robotics is a developing science.

2.3 Types of Robots

Nowadays, robots do a lot of different tasks in many fields and the number of jobs entrusted to robots is growing steadily. Given below are some types of robots that have been conceived, many of which are already in active use.

2.3.1 Industrial Robots

Robots today are being utilized in a wide variety of industrial applications. Any job that involves repetitiveness, accuracy, endurance, speed, and reliability can be done much better by robots, that is why many industrial jobs that used to be done by humans are increasingly being done by robots. For example, for the past 30 years or thereabouts robots have progressively taken over the fully automated production lines of the automobile industry, wherein a chassis of a vehicle is transported along a conveyor belt and is welded, affixed, painted, and assembled by a succession of robot stations. Some of the other industrial jobs robots are performing palletizing and packaging goods, dispensing jobs, laboratory applications, and robots that pick miniscule electronic components from trays or strips and accurately place them on printed circuit boards in the electronics industry.

2.3.2 Mobile Robots

Also known as Automated Guided Vehicles, or AGVs, these are used for transporting material over large sized places like hospitals, container ports, and warehouses, using wires or markers placed in the floor, or lasers, or vision, to sense the environment they operate in. An advanced form of the AGV is the SGV, or the Self Guided Vehicle, like PatrolBot Gofer, Tug, and Speci-Minder, which can be taught to autonomously navigate within a space, or do it by being given a map of the area. These robots have the ability of performing tasks that are non-sequential and non-repetitive in environments that are complex, hence are defined as intelligent robots. Telerobots are used in places that are hazardous to humans, or are inaccessible or far away. A human operator located at a distance from a telerobot controls its action, which was accomplished with the arm of the space shuttle. Some other examples of telerobots are laparoscopic surgery being done with the help of a telerobot, or doctors using remotely located robots to communicate with their patients, which enables them to treat patients anywhere in the world. This has the potential of dealing with patients in remote places of the world, without adequate medical facilities, being able to consult doctors across the world, or even in the next town, and the doctors in turn having the ability to monitor them. Telerobots are also useful in nuclear power plants where they, instead of humans, can handle hazardous material or undertake operations potentially harmful for humans.

2.4 Structure

The structure of a robot is usually or mostly mechanical and can be called a kinematic chain (its functionality being similar to the skeleton of the human body). The chain is formed of links (its bones), actuators (its muscles), and joints which can allow one or more degrees of freedom. Most contemporary robots use open serial chains in which each link connects the one before to the one after it. These robots are called serial robots and often resemble the human arm. Some robots, such as the Stewart platform, use a closed parallel kinematical chain. Other structures, such as these mimic the mechanical structure of humans, various animals, and insects, are comparatively rare. However, the development and use of such structures in robots is an active area of research (e.g. biomechanics). Robots used as manipulators have an end effecter mounted on the last link. This end effecter can be anything from a welding device to a mechanical hand used to manipulate the environment.

2.5 Power Source of the robot

At present; mostly (lead-acid) batteries are used, but potential power sources could be:

- Pneumatic (compressed gases).
- Hydraulics (compressed liquids).
- Flywheel energy storage.
- Organic garbage (through anaerobic digestion).

- faeces (human, animal); may be interesting in a military context as faeces of small combat groups may be reused for the energy requirements of the robot assistant (see DEKA's project Slingshot stirling engine on how the system would operate).
- Still untested energy sources (e.g. Joe Cell, ...).
- Radioactive source (such as with the proposed Ford car of the 50) ; to those proposed in movies such as Red Planet

2.6 Control of the robot

The mechanical structure of a robot must be controlled to perform tasks. The control of a robot involves three distinct phases - perception, processing, and action (robotic paradigms). Sensors give information about the environment or the robot itself (e.g. the position of its joints or its end effecter).

This information is then processed to calculate the appropriate signals to the actuators (motors) which move the mechanical.

The processing phase can range in complexity. At a reactive level, it may translate raw sensor information directly into actuator commands. Sensor fusion may first be used to estimate parameters of interest (e.g. the position of the robot's gripper) from noisy sensor data. An immediate task (such as moving the gripper in a certain direction) is inferred from these estimates. Techniques from control theory convert the task into commands that drive the actuators. At longer time scales or with more sophisticated tasks, the robot may need to build and reason with a "cognitive" model. Cognitive models try to represent the robot, the world, and how they interact. Pattern recognition and computer vision can be used to track objects. Mapping techniques can be used to build maps of the world. Finally, motion planning and other artificial intelligence techniques may be used to figure out how to act. For example, a planner may figure out how to achieve a task without hitting obstacles, falling over, etc.

2.7 Autonomy Levels

Autonomous robots are robots that can perform desired tasks in unstructured environments without continuous human guidance .Robots have varying levels of autonomy.

Direct interaction is used for haptic or tele-operated devices, and the human has nearly complete control over the robot's motion.

Operator-assist modes have the operator commanding medium-to-high-level tasks, with the robot automatically figuring out how to achieve them.

An autonomous robot may go for extended periods of time without human interaction. Higher levels of autonomy do not necessarily require more complex cognitive capabilities. For example, robots in assembly plants are completely autonomous, but operate in a fixed pattern.

Another classification takes in account the interaction between human control and the machine motions :

1. Teleoperation. A human controls each movement; each machine actuator change is specified by the operator.
2. Supervisory. A human specifies general moves or position changes and the machine decides specific movements of its actuators.
3. Task-level autonomy. The operator specifies only the task and the robot manages itself to complete it.
4. Fully autonomy. The machine will create and complete all its tasks without human interaction.

2.8 Robot Research

Much of the research in robotics focuses not on specific industrial tasks, but on investigations into new types of robots, alternative ways to think about or design robots, and new ways to manufacture them but other investigations, such as MIT's cyber flora project, are almost wholly academic.

A first particular new innovation in robot design is the open sourcing of robot-projects. To describe the level of advancement of a robot, the term "Generation

Robots" can be used. This term is coined by Professor Hans Moravec, Principal Research Scientist at the Carnegie Mellon University Robotics Institute in describing the near future evolution of robot technology. First generation robots, Moravec predicted in 1997, should have an intellectual capacity comparable to perhaps a lizard and should become available by 2010. Because the first generation robot would be incapable of learning, however, Moravec predicts that the second generation robot would be an improvement over the first and become available by 2020, with intelligence maybe comparable to that of a mouse. The third generation robot should have intelligence comparable to that of a monkey. Though fourth generation robots, robots with human intelligence, professor Moravec predicts, would become possible, he does not predict this happening before around 2040 or 2050 [7]. The second is Evolutionary Robots. This is a methodology that uses evolutionary computation to help design robots, especially the body form, or motion and behavior controllers. In a similar way to natural evolution, a large population of robots is allowed to compete in some way, or their ability to perform a task is measured using a fitness function. Those that perform worst are removed from the population, and replaced by a new set, which have new behaviors based on those of the winners. Over time the population improves, and eventually a satisfactory robot may appear. This happens without any direct programming of the robots by the researchers. Researchers use this method both to create better robots, and to explore the nature of evolution. Because the process often requires many generations of robots to be simulated, this technique may be run entirely or mostly in simulation, then tested on real robots once the evolved algorithms are good enough. Currently, there are about 1 million industrial robots toiling around the world, and Japan is the top country having high density of utilizing robots in its manufacturing industry.

2.9 Employment in Robotics

As the number of robots increases, robotics-related jobs grow. Some jobs require existing job skills, such as building cables, assembling parts, and testing.

Script Pro manufactures a robot designed to help pharmacies fill prescriptions that consist of oral solids or medications in pill form. The pharmacist or pharmacy technician enters the prescription information into its information system. The system, upon determining whether or not the drug is in the robot, will send the information to the robot for filling. The robot has 3 different size vials to fill determined by the size of the pill. The robot technician, user, or pharmacist determines the needed size of the vial based on the tablet when the robot is stocked. Once the vial is filled it is brought up to a conveyor belt that delivers it to a holder that spins the vial and attaches the patient label. Afterwards it is set on another conveyor that delivers the patient’s medication vial to a slot labeled with the patient's name on an LED read out. The pharmacist or technician then checks the contents of the vial to ensure it’s the correct drug for the correct patient and then seals the vials and sends it out front to be picked up. The robot is a very time efficient device that the pharmacy depends on to fill prescriptions. McKesson’s Robot RX is another healthcare robotics product that helps pharmacies dispense thousands of medications daily with little or no errors. The robot can be ten feet wide and thirty feet long and can hold hundreds of different kinds of medications and thousands of doses. The pharmacy saves many resources like staff members that are otherwise unavailable in a resource scarce industry.

2.10 Electric motors

Firstly, know the definition of an electric motor. An electric motor is a device that converts electrical energy to mechanical energy [2]. For the reverse task, the device converts mechanical energy to electrical energy. This is not related to electric motor but this function always known as generator or dynamo. Frequently, an electric motor will apply the electromagnetism concept. The fundamental principle upon which electromagnetic motors are based is that there is a mechanical force on any current carrying wire contained within a magnetic field. The force is described by the Lorentz force law and is perpendicular to both the wire and the magnetic field [2]. The motor will have two types. First is rotary motor and second one is linear motor.

However, must of magnetic motor, it will rotate. In a rotary motor, the rotary part is called as rotor and the stationary part is called as stator. When the rotor rotate, the torque will be developed based on the rotor’s axis. The motor contains electromagnets that are wound on a frame. This frame is often called as armature. Correctly, the armature is that part of the motor across which the input voltage is supplied. Depending upon the design of the machine, either the rotor or the stator can serve as the armature

2.10.1 AC motor

A typical AC motor consists of two parts. First is an outside stationary stator having coils supplied with AC current to produce a rotating magnetic field, and second is an inside rotor attached to the output shaft that is given a torque by the rotating field [2]. There are two fundamental types of AC motor, depending on the type of rotor used. First is the synchronous motor, which rotates exactly at the supply frequency or a sub multiple of the supply frequency. Second is the induction motor, which turns slightly slower, and typically (though not necessarily always) takes the form of the squirrel cage motor. Three-phase AC induction motor is commonly used especially for high powered motor. The phase's differences between the three phase of electrical supply create a rotating electromagnetic field in the motor. In the rotor, the current will be induced by the rotating magnetic field caused by electromagnetic induction, which in turn sets up a counterbalancing magnetic field that causes the rotor to turn in the direction the field is rotating.

The rotor must always rotate slower than the rotating magnetic field produced by the polyphase electrical supply; otherwise, no counterbalancing field will be produced in the rotor.

2.10.2 Stepper motor

Stepper motors are special motors that are used when motion and position have to be precisely controlled [3]. The stepper motor is closely related in design to three-phase AC synchronous motors where an internal rotor containing permanent magnets or a large iron core [2] with salient poles is controlled by a set of external magnets that are switched electronically. A stepper motor may also be thought of as a cross between a DC electric motor and a solenoid. As each coil is energized in turn, the rotor aligns itself with the magnetic field produced by the energized field

winding. Unlike a synchronous motor, in its application, the motor may not rotate continuously; instead, it "steps" from one position to the next as field windings are

energized and de-energized in sequence. Depending on the sequence, the rotor may turn forwards or backwards. Simple stepper motor drivers entirely energize or entirely de-energize the field windings, leading the rotor to "cog" to a limited number of positions; more sophisticated drivers can proportionally control the power to the field windings, allowing the rotors to position "between" the "cog" points and thereby rotate extremely smoothly. Computer controlled stepper motors are one of
the most versatile forms of positioning systems, particularly when part of a digital servo controlled system. Stepper motors can be rotated to a specific angle with ease, and hence stepper motors are used in computer disk drives, where the high precision they offer is necessary for the correct functioning of, for example, a hard disk drive or CD drive. Only very old hard drives (from the pre-gigabyte era) use stepper motors; newer drives use systems based on voice coils. Stepper motors were upscaled to be used in electric vehicles under the term SRM (switched reluctance machine). The stepper motor is turned one step at a time or can turn at a specific rate
[4] (specified by the speed in which the steps are executed). In term of hardware interface, the stepper motor requires a bit more complex to wire and more current. But this motor has more advantages in software control. A stepper motor can be controlled by stepper-motor controlled chips, such as the UC1517.

2.10.3 Servo motor

Servomotors are available as AC or DC motors. Early servomotors were generally DC motors because the only type of control for large currents was through SCRs for many years. As transistors became capable of controlling larger currents and switching the large currents at higher frequencies, the AC servomotor became used more often. Early servomotors were specifically designed for servo amplifiers.

Today a class of motors is designed for applications that may use a servo amplifier or a variable-frequency controller, which means that a motor may be used in a servo system in one application, and used in a variable-frequency drive in another application. Some companies also call any closed-loop system that does not use a stepper motor a servo system, so it is possible for a simple AC induction motor that is connected to a velocity controller to be called a servomotor.

Some changes that must be made to any motor that is designed as a servomotor includes the ability to operate at a range of speeds without overheating, the ability to operate at zero speed and retain sufficient torque to hold a load in position, and the ability to operate at very low speeds for long periods of time without overheating. Older-type motors have cooling fans that are connected directly to the motor shaft. When the motor runs at slow speed, the fan does not move enough air to cool the motor. Newer motors have a separate fan mounted so it will provide

optimum cooling air. This fan is powered by a constant voltage source so that it will turn at maximum RPM at all times regardless of the speed of the servomotor. One of the most usable types of motors in servo systems is the permanent magnet (PM) type motor. The voltage for the field winding of the permanent magnet type motor can be AC voltage or DC voltage. The permanent magnet-type motor is similar to other PM type motors presented previously. Figure 2.1 shows a cutaway picture of a PM motor and Fig. 2.2 shows a cutaway diagram of a PM motor. From the picture and diagram you can see the housing, rotor and stator all look very similar to the previous type PM motors. The major difference with this type of motor is that it may have gear reduction to be able to move larger loads quickly from a stand still position. This

type of PM motor also has an encoder or resolver built into the motor housing. This ensures that the device will accurately indicate the position or velocity of the motor shaft .Show figure 2.1 and figure 2.2

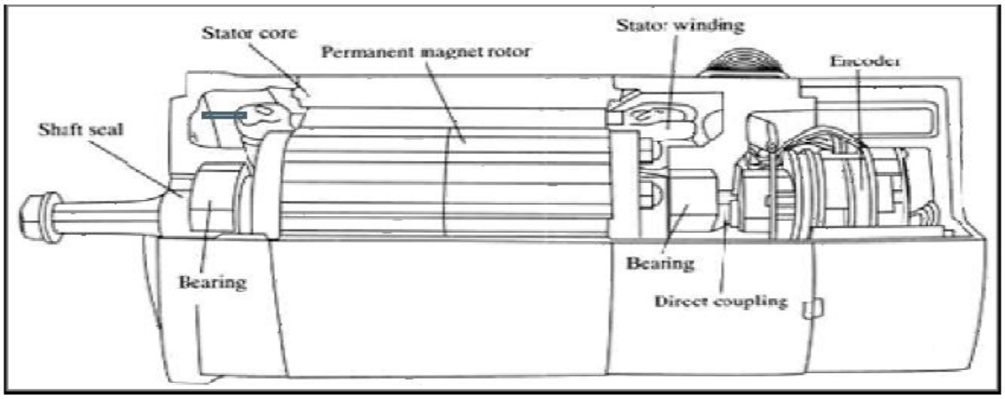

Figure 2.1: Typical PM servomotors

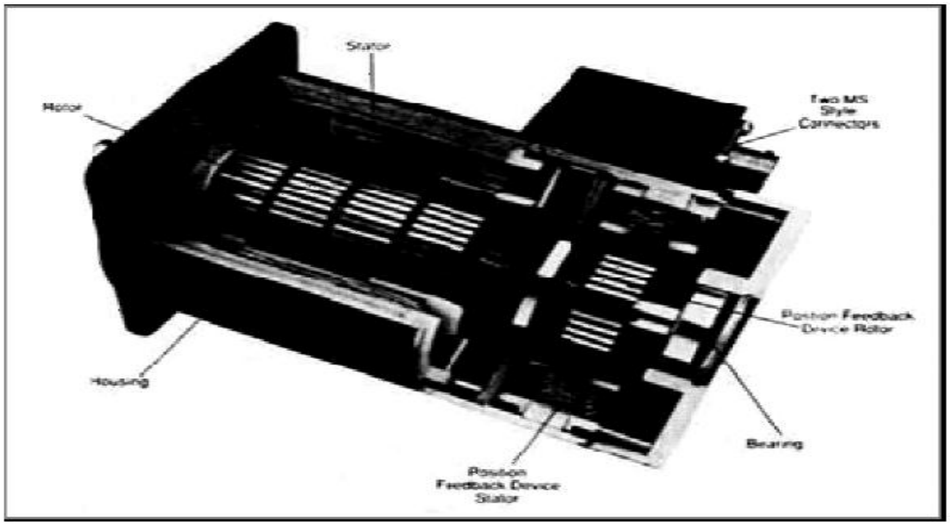

Figure 2.2: permanent magnet

2.10.4 DC motor

When the coil is powered, a magnetic field is generated around the armature. First, the left side of the armature is pushed away from the left magnet and drawn toward the right, causing rotation. Second, the armature continues to rotate. Third, when the armature becomes horizontally aligned, the commutator reverses the direction of current through the coil, reversing the magnetic field. The process then repeats. If the shaft of a DC motor is turned by an external force, the motor will act like a generator and produce an Electromotive force (EMF) [2]. During normal operation, the spinning of the motor produces a voltage, known as the counter-EMF (CEMF) or back EMF, because it opposes the applied voltage on the motor. This is the same EMF that is produced when the motor is used as a generator (for example when an electrical load (resistance) is placed across the terminals of the motor and the motor shaft is driven with an external torque). The CEMF is proportional to motor speed, when an electric motor is first started or is completely stalled, there is zero CEMF [2]. Therefore the current through the armature is much higher. As the motor spins, the CEMF increases until it is equal to the applied voltage, minus the parasitic voltage drop. Generally, the rotational speed of a DC motor is proportional to the voltage applied to it, and the torque is proportional to the current. Speed control can be achieved by variable battery tapping, variable supply voltage, resistors or electronic controls. The direction of a wound field DC motor can be changed by reversing either the field or armature connections but not both.Show figure 2.3

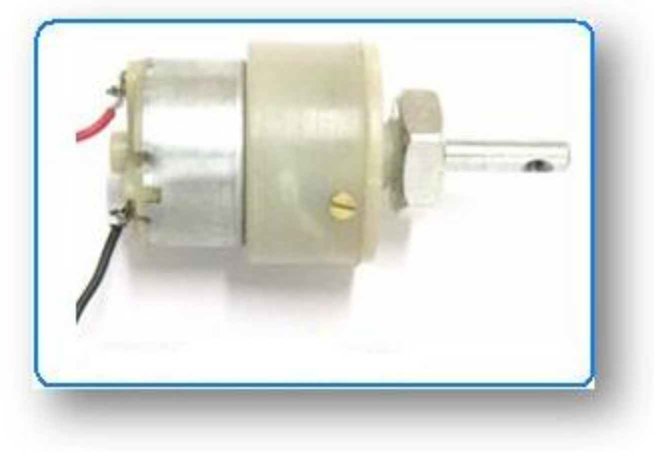

Figure 2.3 DC Motors

2.10.5 DC Motors mathematics model

We consider a DC shunt motors as is shown in Figure.2.4. DC shunt motors have the field coil in parallel (shunt) with the armature. The current in the field coil and the armature are independent of one another. As a result, these motors have excellent speed and position control. Hence DC shunt motors are typically used applications that require five or more horse power. The equations describing the dynamic behavior of the DC motor are given below

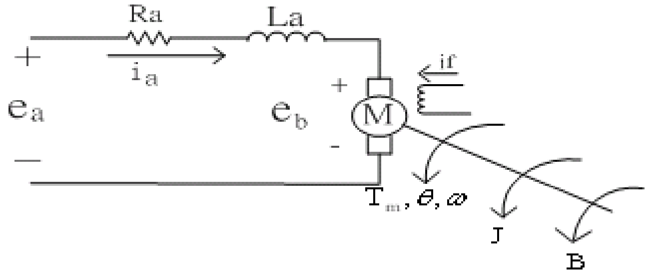

Figure 2. 4 DC motor using the armature voltage control method

Where, Ra : the armature resistance.

La : the armature inductance .

I_a : the armature current.

I_f : the field current.

E_a : the input voltage.

E_b : the back electromotive force

T_m : the motor torque.

ω : an angular velocity of rotor.

J : rotating inertial measurement of motor bearing.

B : a damping coefficient. Because the back EMF e_b is proportional to speed ω directly, then:-

$$e_b = K_b \frac{d\theta(t)}{dt} = K_b\omega(t) \tag{2.1}$$

Making use of the voltage law can get

$$e_a(t) = R_a\, i_a(t) + L_a \frac{di_a(t)}{dt} + e_b(t) \tag{2.2}$$

From Newton law, the motor torque can obtain

$$T_m(t) = J\frac{d^2\theta(t)}{d\,t^2} + B\frac{d\theta}{dt} = K_T i_a \tag{2.3}$$

Take (1), (2), and (3) into Laplace transform respectively, the equations can be formulated as follows:

$$E_b(s) = K_b\Omega(s) \tag{2.4}$$

$$E_a(s) = (R_a + L_a s)I_a(s) + E_b(s) \tag{2.5}$$

$$T_m(s) = B\Omega(s) + Js\Omega(s) = K_T I_a(s) \tag{2.6}$$

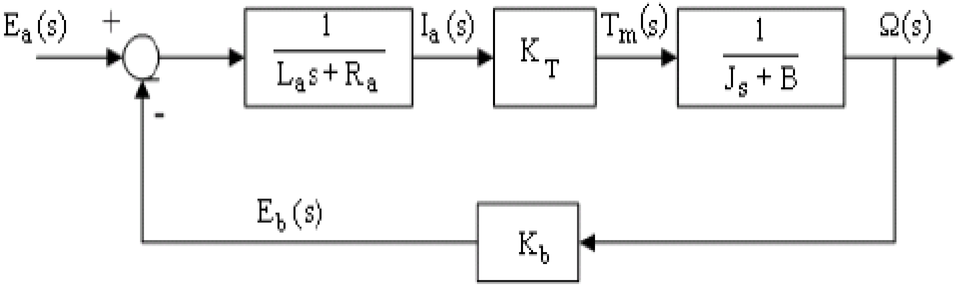

Figure 2.5 Function block diagram of DC motor

The transfer function of DC motor speed with respect to the input voltage can be written as follows:

$$G(s) = \frac{\Omega(s)}{E_a(s)} = \frac{K_T}{(L_a s + R_a)(Js + B) + K_b K_T} \tag{2.7}$$

From Equation (7) the armature inductance is very small in practices, hence, the transfer function of DC motor speed to the input voltage can be simplified as follows:

$$\frac{\Omega(s)}{E_a(s)} = \frac{K_m}{\tau s + 1} \tag{2.8}$$

$$where \quad K_m = \frac{K_T}{R_a B + K_b K_T} \qquad is\ a\ motor\ gain$$

$$\tau = \frac{R_a J}{R_a B + K_b K_T} \qquad is\ the\ motor\ time\ constant$$

From Equation (8), the transfer function can be drawn the DC motor system block diagram which is shown in figure 2.6

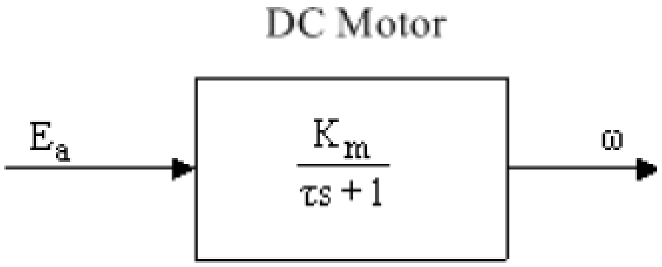

Figure 2. 6 Simplified block diagram of DC motor

2.11.1 History of PID Control

PID controllers date to 1890s governor design.PID controllers were subsequently developed in automatic ship steering. One of the earliest examples of a PID-type controller was developed by Elmer Sperry in 1911,[4] while the first published theoretical analysis of a PID controller was by Russian American engineer Nicolas Minorsky, in (Minorsky 1922). Minorsky was designing automatic steering systems for the US Navy, and based his analysis on observations of a helmsman, observing that the helmsman controlled the ship not only based on the current error, but also on past error and current rate of change;[5] this was then made mathematical by Minorsky. His goal was stability, not general control, which significantly simplified the problem. While proportional control provides stability against small disturbances, it was insufficient for dealing with a steady disturbance, notably a stiff gale (due to droop), which required adding the integral term. Finally, the derivative term was added to improve control.

Trials were carried out on the USS New Mexico, with the controller controlling the angular velocity (not angle) of the rudder. PI control yielded sustained yaw (angular error) of ±2°, while adding D yielded yaw of ±1/6°, better than most helmsmen could achieve.[4]

The Navy ultimately did not adopt the system, due to resistance by personnel. Similar work was carried out and published by several others in the 1930s.

In the early history of automatic process control the PID controller was implemented as a mechanical device. These mechanical controllers used a lever, spring and a mass and were often energized by compressed air. These pneumatic controllers were once the industry standard.

Electronic analog controllers can be made from a solid-state or tube amplifier, a capacitor and a resistor. Electronic analog PID control loops were often found within more complex electronic systems, for example, the head positioning of a disk drive, the power conditioning of a power supply, or even the movement-detection circuit of a modern seismometer. Nowadays, electronic controllers have largely been replaced by digital controllers implemented with microcontrollers or FPGAs.

Most modern PID controllers in industry are implemented in programmable logic controllers (PLCs) or as a panel-mounted digital controller. Software implementations have the advantages that they are relatively cheap and are flexible with respect to the implementation of the PID algorithm. PID temperature controllers are applied in industrial ovens, plastics injection machinery, hot stamping machines and packing industry.

Variable voltages may be applied by the time proportioning form of pulse-width modulation (PWM)—a cycle time is fixed, and variation is achieved by varying the proportion of the time during this cycle that the controller outputs +1 (or −1) instead of 0. On a digital system the possible proportions are discrete—e.g., increments of 0.1 second within a 2 second cycle time yields 20 possible steps: percentage increments of 5%; so there is a discretization error, but for high enough time resolution this yields satisfactory performance.

2.11.2 PID structure

The PID controller includes a proportional term, integral term and derivative term, where the proportional term is to adjust the output of controller according to all of the magnitude of error, the integral term is used to remove the steady state error of control system and improve the steady state response, the derivative term is used to predict a trend of error and improve the transient response of the system. These functions have been enough to the most control processes. Because the structure of PID controller is simple, it is the most extensive control method to be used in industry so far. The PID controller is mainly to adjust an appropriate proportional gain (K_p) , integral gain (K_i) , and differential gain (K_d) to achieve the optimal control performance. The PID controller block diagram of this part is shown in figure 2. 7.

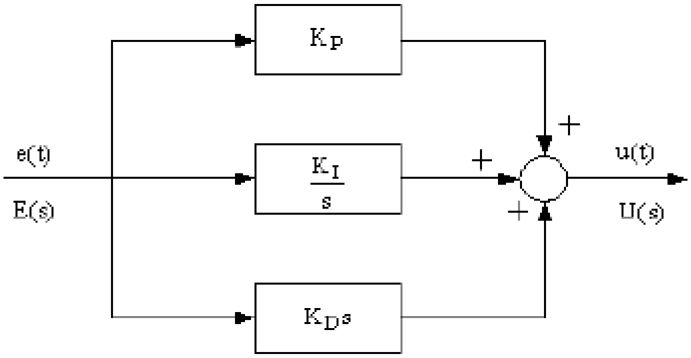

Figure 2. 7 PID controller system block diagram

The relationship between the input e(t) and output u(t) can be formulated in the following,

$$u(t) = K_p . e(t) + K_I . \int_0^t e(t)dt + K_D \frac{de(t)}{dt} \tag{2.9}$$

The transfer function is expressed as follows:

$$C(s) = \frac{U(s)}{E(s)} = K_p + \frac{K_I}{s} + K_D s \tag{2.10}$$

The controlled plant in this project is a DC motor. The combination of the PID controller and DC motor is shown in figure 2.8.

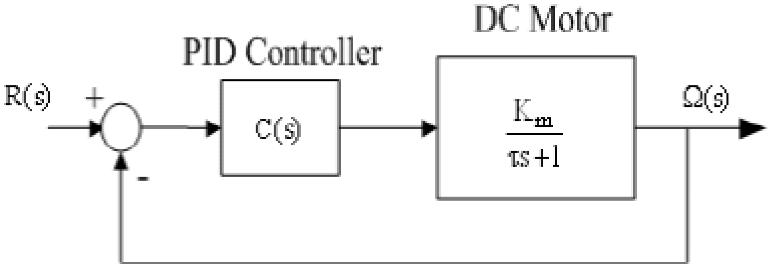

Figure 2. 8 PID DC motor speed control system block diagram

The closed loop transfer function of the block diagram figure 2.8

$$G(s) = \frac{\Omega(s)}{R(s)} = \frac{(K_p + \frac{K_I}{s} K_D s)\frac{K_m}{1+\tau s}}{1 + (K_p + \frac{K_I}{s} + K_D s)\frac{K_m}{1+\tau s}} \qquad (2.11)$$

$$= \frac{(K_D s^2 + K_p s + K_I)K_m}{(K_D K_m + \tau)s^2 + \left(1 + K_p K_m\right)s + K_I K_m} \qquad (2.12)$$

2.11.3 PID Controller Types

In literature various PID controller laws and types have been described. In industry two types prevail: the parallel form and the series form

2.11.3.i Parallel Form

A PID controller in parallel form (also known as standard form, ISA form or non-interacting form), has the control equation:

$$U=K\left[1 + \frac{1}{S.T_I} + S.T_d\right].E \qquad (2.13)$$

The controller actions (P, I and D) act independently as can be seen in the corresponding block diagram representation .Show figure 2.9

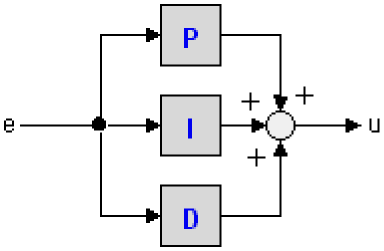

Figure 2.9 PID controllers in parallel

2.11.3.ii Series Form

A PID controller in series form (also known as interacting form), has the control equation:

$$U=\left[1+\frac{1}{ST_I}+ST_d\right](1+S.T_d).E \tag{2.14}$$

The controller actions (P, I and D) act dependently as can be seen in the corresponding block diagram representation. Show Figure 2.10

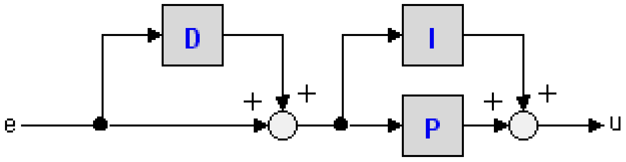

Figure 2.10 PID controllers in series

2.11.4 Tuning

All general methods for control design can be applied to PID control. A number of special methods that are tailor-made for PID control have also been developed, these methods are often called tuning methods. Irrespective of the method used it is essential to always consider the key elements of control, load disturbances, sensor noise, process uncertainty and reference signals. The most well-known tuning methods are those developed by Ziegler and Nichols. They have had a major influence on the practice of PID control for more than half a century. The methods are based on characterization of process dynamics by a few parameters and simple equations for the controller parameters. It is surprising that the methods are so widely referenced because they give moderately good tuning only in restricted situations. Plausible explanations may be the simplicity of the methods and the fact that they can be used for simple student exercises in basic control courses.

2.11.5 Overview of methods

There are several methods for tuning a PID loop. The most effective methods generally involve the development of some form of process model, then choosing P, I, and D based on the dynamic model parameters. Manual tuning methods can be relatively inefficient, particularly if the loops have response times on the order of minutes or longer.

The choice of method will depend largely on whether or not the loop can be taken "offline" for tuning, and on the response time of the system. If the system can be taken offline, the best tuning method often involves subjecting the system to a step change in input, measuring the output as a function of time, and using this response to determine the control parameters

i. Manual Tuning

If the system must remain online, one tuning method is to first set $K_i$and $K_d$values to zero. Increase the $K_p$until the output of the loop oscillates, then the $K_p$should be set to approximately half of that value for a "quarter amplitude decay" type response. Then increase $K_i$until any offset is corrected in sufficient time for the process. However, too much $K_i$will cause instability. Finally, increaseK_d, if required, until the loop is acceptably quick to reach its reference after a load disturbance. However, too much $K_d$will cause excessive response and overshoot. A fast PID loop tuning usually over shoots slightly to reach the set point more quickly; however, some systems cannot accept overshoot, in which case an over-damped closed-loop system is required, which will require a $K_p$setting significantly less than half that of the K_p setting that was causing oscillation.

Table 2.1 Effects of *increasing* a parameter independently

Parameter	**Rise time**	**Overshoot**	**Settling time**	**Steady-state error**	**Stability**[9]
K_p	Decrease	Increase	Small change	Decrease	Degrade
K_i	Decrease	Increase	Increase	Eliminate	Degrade
K_d	Minor change	Decrease	Decrease	No effect in theory	Improve if K_d small

ii. Ziegler–Nichols method

For more details on this topic, see Ziegler–Nichols method. Another heuristic tuning method is formally known as the Ziegler–Nichols method, introduced by John G. Ziegler and Nathaniel B. Nichols in the 1940s. As in the method above, the K_i and k_d gain are first set to zero. The proportional gain is increased until it reaches the ultimate gain, K_u , at which the output of the loop starts to oscillate. K_u and the oscillation period P_u are used to set the gains as shown:

Table2.2 Ziegler–Nichols method

Control Type	K_p	K_i	K_d
P	$0.50K_u$	-	-
PI	$0.45K_u$	$1.2K_p/P_u$	-
PID	$0.60K_u$	$2K_p/P_u$	$K_pP_u/8$

These gains apply to the ideal, parallel form of the PID controller. When applied to the standard PID form, the integral and derivative time parameters $T_i$and $T_d$are only dependent on the oscillation period P_u.

iii. PID tuning software

Most modern industrial facilities no longer tune loops using the manual calculation methods shown above. Instead, PID tuning and loop optimization software are used to ensure consistent results. These software packages will gather the data, develop process models, and suggest optimal tuning. Some software packages can even develop tuning by gathering data from reference changes.

Mathematical PID loop tuning induces an impulse in the system, and then uses the controlled system's frequency response to design the PID loop values. In loops with response times of several minutes, mathematical loop tuning is recommended, because trial and error can take days just to find a stable set of loop values. Optimal values are harder to find. Some digital loop controllers offer a self-tuning feature in which very small setpoint changes are sent to the process, allowing the controller itself to calculate optimal tuning values. Other formulas are available to tune the loop according to different performance criteria. Many patented formulas are now embedded within PID tuning software and hardware modules.[12] Advances in automated PID Loop Tuning software also deliver algorithms for tuning PID Loops in a dynamic or Non-Steady State (NSS) scenario. The software will model the dynamics of a process, through a disturbance, and calculate PID control parameters in response.

2.12.1 Introduction Microcontrollers

Circumstances that we find ourselves in today in the field of microcontrollers had their beginnings in the development of technology of integrated circuits. This development has made it possible to store hundreds or thousands of transistors into one chip. That was a prerequisite for production of microprocessors, and the first computers were made by adding external peripherals such as memory, input-output lines, timers and other. Further increasing of the volume of the package resulted in creation of integrated circuits. These integrated circuits contained both processor and peripherals. That is how the first chip containing a microcomputer, or what would later be known as a microcontroller came about.

In 1969, a team of Japanese engineers from the BUSICOM Company arrived to United States with a request that a few integrated circuits for calculators be made using their projects. The proposition was set to INTEL, and Mercian Hoff was responsible for the project. Since he was the one who has had experience in working with a computer (PC) PDP8, it occurred to him to suggest a fundamentally different solution instead of the suggested construction. This solution presumed that the function of the integrated circuit is determined by a program stored in it. That meant that configuration would be more simple, but that it would require far more memory than the project that was proposed by Japanese engineers would require. After a while, though Japanese engineers tried finding an easier solution, Mercian's idea won, and the first microprocessor was born. In transforming an idea into a readymade product, Frederico Faggin was a major help to INTEL. He transferred to INTEL, and in only 9 months had succeeded in making a product from its first conception. INTEL obtained the rights to sell this integral block in 1971. First, they bought the license from the BUSICOM company who had no idea what treasure they had. During that year, there appeared on the market a microprocessor called 4004. That was the first 4-bit microprocessor with the speed of 6 000 operations per second. Not long after that, American company CTC requested from INTEL and Texas Instruments to make an 8-bit microprocessor for use in terminals. Even though CTC gave up this idea in the end, Intel and Texas Instruments kept working on the microprocessor and in April of 1972, first 8-bit microprocessor appeard on the market under a name 8008. It was able to address 16Kb of memory, and it had 45 instructions and the speed of 300 000 operations per second. That microprocessor was the predecessor of all today's microprocessors. Intel kept their developments up in April of 1974, and they put on the market the 8-bit processor under a name 8080 which was able to address 64Kb of memory, and which had 75 instructions, and the price began at $360.In another American company Motorola, they realized quickly what was happening, so they put out on the market an 8-bit microprocessor 6800. Chief constructor was Chuck Peddle, and along with the processor itself, Motorola was the first company to make other peripherals such as 6820 and 6850. At that time many companies recognized greater importance of microprocessors and began their own developments [1].

2.12.2 Atmag8 microcontroller

The Atmel AVR core combines a rich instruction set with 32 general purpose working registers. All the 32 registers are directly connected to the Arithmetic Logic Unit (ALU), allowing two independent registers to be accessed in one single instruction executed in one clock cycle. The resulting architecture is more code efficient while achieving throughputs up to ten times faster than conventional CISC microcontrollers. The ATmega8 provides the following features: 8 Kbytes of In-System Programmable Flash with Read-While-Write capabilities, 512 bytes of EEPROM, 1 Kbyte of SRAM, 23 general purpose I/O lines, 32 general purpose working registers, three flexible Timer/Counters with compare modes, internal and external interrupts, a serial programmable USART, a byte oriented Two wire Serial Interface, a 6-channel ADC (eight channels in TQFP and QFN/MLF packages) with 10-bit accuracy, a programmable Watchdog Timer with Internal Oscillator, an SPI serial port, and five software selectable power saving modes. The Idle mode stops the CPU while allowing the SRAM, Timer/Counters, SPI port, and interrupt system to continue functioning. The Power down mode saves the register contents but freezes the Oscillator, disabling all other chip functions until the next Interrupt or Hardware Reset. In Power-save mode, the asynchronous timer continues to run, allowing the user to maintain a timer base while the rest of the device is sleeping. The ADC Noise Reduction mode stops the CPU and all I/O modules except asynchronous timer and ADC, to minimize switching noise during ADC conversions. In Standby mode, the crystal/resonator Oscillator is running while the rest of the device is sleeping. This allows very fast start-up combined with low-power consumption. The device is manufactured using Atmel’s high density non-volatile memory technology. The Flash Program memory can be reprogrammed In-System through an SPI serial interface, by a conventional non-volatile memory programmer, or by an On-chip boot program running on the AVR core. The boot program can use any interface to download the application program in the Application Flash memory. Software in the Boot Flash Section will continue to run while the Application Flash Section is updated, providing true Read-While-Write operation. By combining an 8-bit RISC CPU with In-System Self-Programmable Flash on a monolithic chip, the Atmel ATmega8 is a powerful microcontroller that provides a highly-flexible and cost-effective solution to many embedded control applications. The ATmega8 is supported with a full suite of program and system development tools, including C compilers, macro assemblers, program simulators, and evaluation kits.

2.13 Sensors

Without sensor ,a robot is just a machine , capable only of moving through a predetermined sequence of action ,with sensors ,robots can react and respond to changes in their environment in ways that appear intelligent or life-like . in general ,the sensors are divided into two major types which are proximity sensor and distance measuring sensor.

proximity sensors only detect whether or not an object is within a predetermined range from the robot , while the distance measuring sensor determine the actual distance between an object and the robot . the robot processes the information received from sensors and reacts in a determined manner according to the design of the control system .for line following function , the sensors are needed to sense the white line of the track and in order to keep track to center .however, there are several types of sensors to be considered that is suitable in applying to line following

2.13.1 Infrared sensor

IR reflective sensors have one emitter (IR LED) and one receiver Phototransistor or photo diode, show in the figure 2.11 If we have white surface it reflects the light and it will sensed by the receiver, similarly if we have black surface it absorbs the light and receiver cannot sense light [2] more details sees the appendix A-(b).

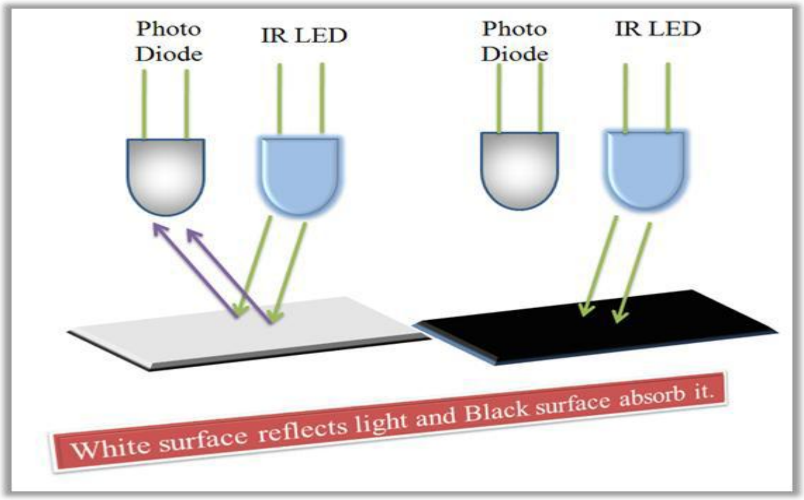

Figure 2.11 Sensor in an opto-coupler

2.13.2 Arrangement of Sensors

An array of sensors arranged in a straight row pattern is bolted under the front of the robot. It is used to locate the position of line below the robot. We can use any number of sensors. If we have lesser number then our robot movement is not smooth and it may face problems at sharp turns. If we used higher number of sensors robot movement will become smooth and reliable for sharp turns, only drawbacks it requires complex programming for micro-controller and requires more hardware.

The distance between each sensors depend on:

1. No of sensors used
2. Width of straight line (distance between sensors should be less than width of line).
3. Distance between sensors may not be constant (it depends on the logic) [2]