Chapter Two:

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Theoretical component and subsystem

Actuators are one of the key components contained in a robotic system. A robot has many degrees of freedom, each of which is a servoed joint generating desired motion. We begin with basic actuator characteristics and drive amplifiers to understand behavior of servoed joints. Most of today's robotic systems are powered by electric servomotors. Therefore, we focus on electromechanical actuators, beside to the sensors and encoders used in addition to the robot source and motors control by power electronics, the possible languages used in programming.

2.1 DC servo motor

Figure 2.1.1 illustrates the construction of a DC servomotor, consisting of a stator,a rotor, and a commutation mechanism. The stator consists of permanent magnets, creating a magnetic field in the air gap between the rotor and the stator. The rotor has several windings arranged symmetrically around the motor shaft. An electric current applied to the motor is delivered to individual windings through the brush-commutation mechanism, as shown in the figure. As the rotor rotates the polarity of the current flowing to the individual windings is altered. This allows the rotor to rotate continually.

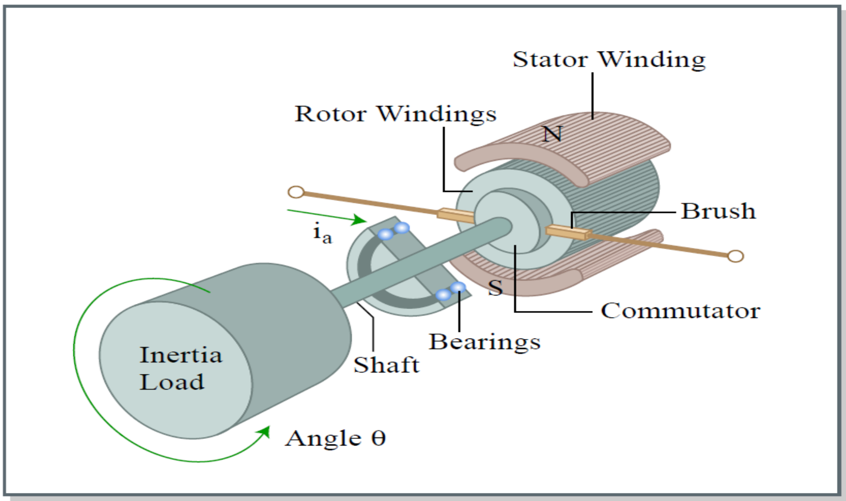


Figure 2.1.1 Construction of DC motor

Let τ_m be the torque created at the air gap, and i the current flowing to the rotor windings. The torque is in general proportional to the current, and is given by

$$\tau_m = K_t \, . \, i \tag{2.1}$$

Where the proportionality constant K_t , is called the ***torque constant,*** one of the key parameters describing the characteristics of a DC motor. The torque constant is determined by the strength of the magnetic field, the number of turns of the windings, the effective area of the air gap.

The radius of the rotor, and other parameters associated with materials properties. In an attempt to derive other characteristics of a DC motor, let us first consider an idealized energy transducer having no power loss in converting electric power into mechanical power. Let *E* be the voltage applied to the idealized transducer. The electric power is then given by $E \cdot i$, which must be equivalent to mechanical power:

$$P_{in} = E \cdot i = \tau_m \cdot \omega_m \quad (2.2)$$

Where ω_m is the angular velocity of the motor rotor. Substituting eq.(1) into eq.(2) and dividing both sides by *i* yield the second fundamental relationship of a DC motor:

$$E = K_{t} \cdot \omega_m \quad (2.3)$$

The above expression dictates that the voltage across the idealized power transducer is proportional to the angular velocity and that the proportionality constant is the same as the torque constant given by eq.(1).This voltage *E* is called the back emf (electro-motive force) generated at the air gap, and the proportionality constant is often called the back emf constant. Note that based on eq. (1), the unit of the torque constant is Nm/A in the metric system, whereas the one of the back emf constant is V/rad/s based on eq. (2). The actual DC motor is not a loss-less transducer, having resistance at the rotor windings and the commutation mechanism. Furthermore, windings may exhibit some inductance, which stores energy. Figure 2.2 shows the schematic of the electric circuit, including the windings resistance *R* and inductance *L*. From the figure.

$$u = R \cdot i + L \cdot (di/dt) + E \quad (2.4)$$

where *u* is the voltage applied to the armature of the motor.

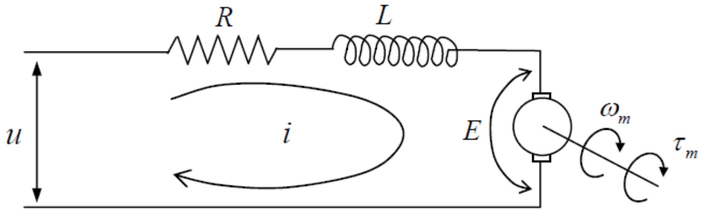


Figure 2.2: electric circuit of armature

Combining eq.(1),(3) and (4), we can obtain the actual relationship among the applied voltage u, the rotor angular velocity ω_m, , and the motor torque τ_m.

$$(K_t/R).u = \tau_m + T_e.(d\tau_m/dt) + (K_t^2/R).\omega_m \quad (2.5)$$

Where time constant $T_e = L/R$ called the motor reactance is often negligibly small. Neglecting this second term the above equation reduces to an algebraic relationship:

$$\tau_m = (K_t/R).u - (K_t^2/R).\omega_m \quad (2.6)$$

This is called the torque-speed characteristic.

That the motor torque increases in proportion to the applied voltage, but the net torque reduces as the angular velocity increases. Figure 2.3 illustrates the torque-speed characteristics The negative slope of the straight lines, $-K_t^2/R$, implies that the voltage-controlled DC motor has an inherent damping in its mechanical behavior. The power dissipated in the DC motor is given by

$$P_{dis} = R.i^2 = (R/K_t^2).\ \tau_m^{\ 2} \quad (2.7)$$

from eq.(1). Taking the square root of both sides yields

$$P_{dis}^{0.5} = \tau_m / K_m \ ,\ K_m = K_t/R^{0.5} \quad (2.8)$$

Where the parameter K_m is called the motor constant, the motor constant represents how effectively electric power is converted to torque. The larger the motor constant becomes, the larger the output torque is generated with less power dissipation A DC motor with more powerful magnets, thicker winding wires, and a larger rotor diameter has a larger motor constant A motor with a larger motor constant, however, has a larger damping, as the negative slope of the torque-speed characteristics becomes steeper, as illustrated in Figure 2.3.

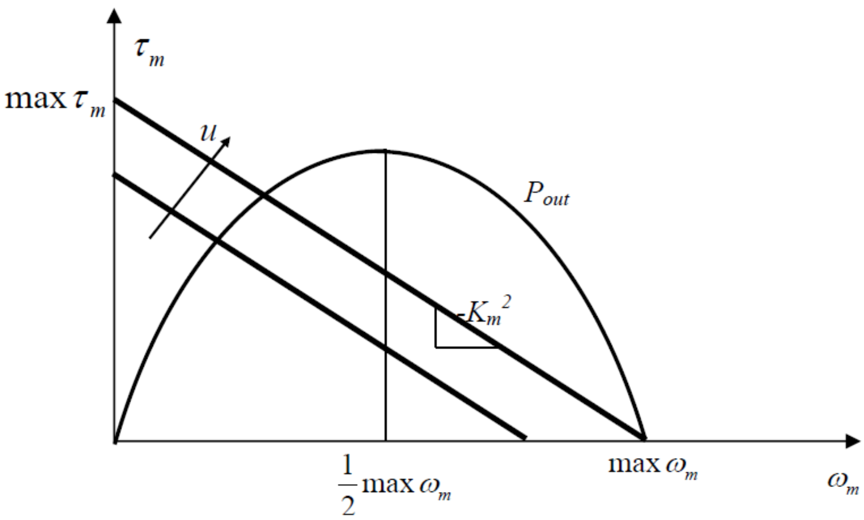


Figure 2.3: Torque-speed characteristics and output power

Taking into account the internal power dissipation, the net output power of the DC motor is given by:

$P_{out}= \tau_m.\omega_m = ((K_t/R).u-K_m^2.\omega_m).\ \omega_m$. (2.9)

This net output power is a parabolic function of the angular velocity, as illustrated in Figure 2.3. It should be noted that the net output power becomes maximum in the middle point of the velocity axis, i.e. 50 % of the maximum angular velocity for a given armature voltage *u*. This implies that the motor is operated most effectively at 50 % of the maximum speed. As the speed departs from this middle point, the net output power decreases, and it vanishes at the zero speed as well as at the maximum speed. Therefore, it is important to select the motor and gearing combination so that the maximum of power transfer be achieved.

2.1.1 Ratings and specifications

Several characteristics are important in selecting a DC motor. The first two are its input ratings that specify the electrical requirements of the motor.

Operating voltage: If batteries are the source of power for the motor, low operating voltages are desirable because fewer cells would be needed to obtain the specified voltage. However, the electronics to drive motors are typically more efficient at higher voltages.

Typical DC motors may operate on as few as 1.5 volts on up to 100 volts. Robotics often uses motors that operate on 6, 12, or 24 volts.

Operating current:

Ideally one would like a motor that produces a great deal of power while requiring a minimum of current. Typically however the current rating (in conjunction with the voltage rating) is a good indication of the power output capacity of a motor. Motors that draw more current will deliver more power. Also, a given motor draws more current as it delivers more output torque. Thus current ratings are often given when the motor is stalled. At this point it is drawing the maximal amount of current.

The next three ratings describe the motor's output characteristics:

Speed:

Usually this is specified as the speed in rotations per minute (RPM) of the motor when it is unloaded, or running freely, at its specified operating voltage. Typical DC motors run at speeds from several thousand to ten thousand RPM.

Torque:

The torque of a motor is the rotary force produced on its output shaft. When a motor is stalled it is producing the maximum amount of torque that it can produce. Hence the torque rating is usually taken when the motor has stalled and is called the stall torque. The motor torque is measured in ounce-inches (in the English system). A rating of one ounce-inch means that the motor is exerting a tangential force of one ounce at a radius of one inch from the center of its shaft. Torque ratings may vary from less than one ounce-inch to several dozen ounce- inches for large motors.

Power:

The power of a motor is the product of its speed and torque. The power output is greatest somewhere between the unloaded speed (maximum speed, no torque) and the stalled state (maximum torque, no speed).

2.1.2 Speed, Torque, and Gear Reduction

It was mentioned earlier that the power delivered by a motor is the product of its speed and the torque at which the speed is applied. If one measures this power over the full range of operating speeds"from unloaded full throttle to stall" one gets a bell-shaped curve of motor power output.

When unloaded, the motor is running at full speed, but at zero torque, thus producing zero power. Conversely, when stalled, the motor is producing its maximum torque output, but at zero speed "also producing zero power" Hence the maximum power output must lie somewhere in between.

A typical DC motor operates at speeds that are far too high to be useful, and torques that are far too low. Gear reduction is the standard method by which a motor is made useful.

Using gear reduction, the motor shaft is fitted with a gear of small radius that meshes with a gear of large radius. The motor's gear must revolve several times into order to cause the large gear to revolve once. It is evident that the speed of rotation is decreased, but, overall power is preserved (excepting losses due to friction) and therefore the torque must increase.

By ganging together several stages of this gear reduction, an immensely strong torque can be produced at the final stage.

The challenge when designing a high-performance gear reduction for a competitive robot is to determine the amount of reduction that will allow the motor to operate at highest efficiency. If the normal operating point of a motor/gear train assembly is faster than the peak efficiency point, the gear train will be able to accelerate quickly, but will not be operating at peak efficiency once it has reached the maximum velocity. Depending on the mass of the robot and the performance desired, different gear ratios might be appropriate. Experimentation is probably the best way to choose the best gear train.

2.2 Dynamics of Single-Axis Drive Systems

DC motors and other types of actuators are used to drive individual axes of a robotic system. Figure 2.4 shows a schematic diagram of a single-axis drive system consisting of a DC motor, a gear head, and arm links, An electric motor, such as a DC motor, produces a relatively small torque and rotates at a high speed, whereas a robotic joint axis in general rotates slowly, and needs a high torque to bear the load. In other words, the impedance of the actuator:

Z_m=Torque/angular velocity = τ_m/ω_m. (2.10)

is much smaller than that of the load.

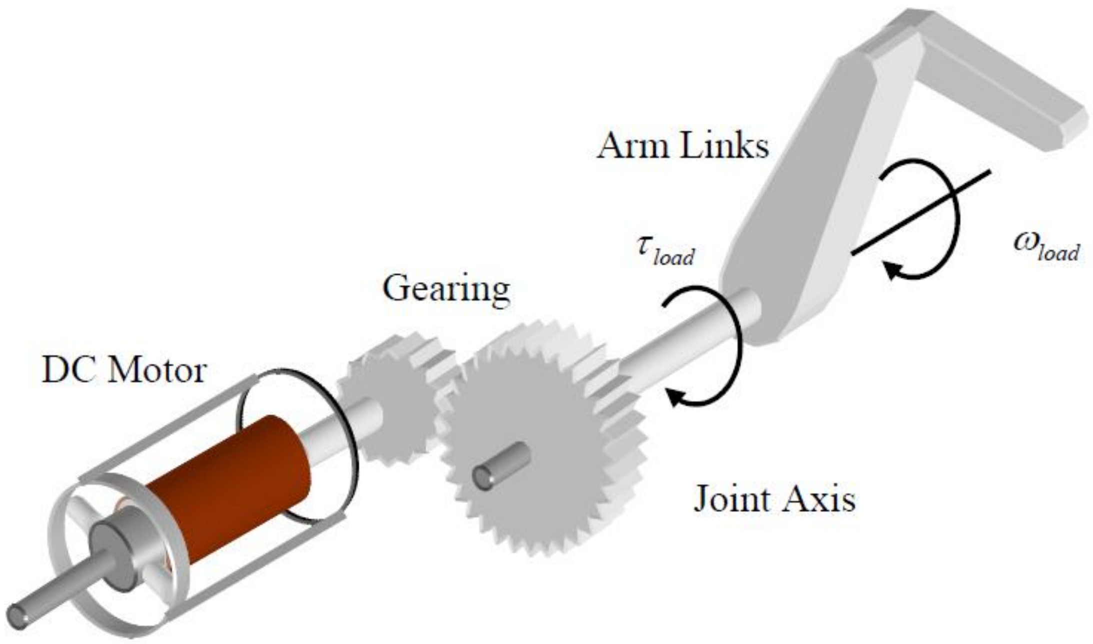


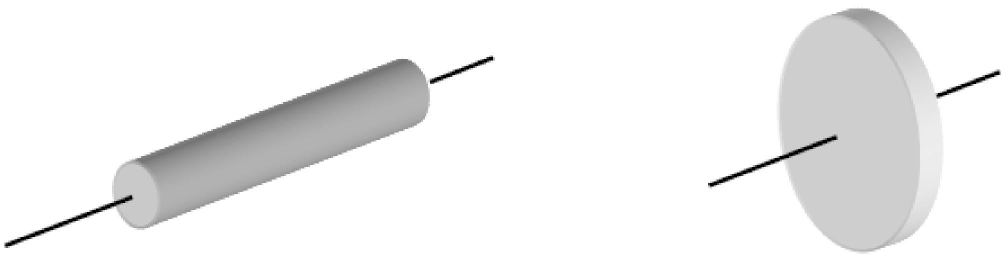
Figure 2.4: joint axis drive system

To fill the gap we need a gear reducer, as shown in Figure 2.4. Let (r > 1) be a gear reduction ratio (If *d*1 and *d*2 are diameters of the two gears, the gear reduction ratio is r = d_2/d_1). The torque and angular velocity are changed to:

$T_{load} = r.\tau_m$, $\omega_{load} = (1/r).\ \omega_m$ (2.11)

Note that the effective inertia of the motor rotor is r^2 times larger than the original value I_m when reflected to the joint axis. Likewise, the motor constant becomes r^2 times larger when reflected to the joint axis. The gear ratio of a robotic system is typically 20 ~ 100, which means that the effective inertia and damping becomes 400 ~ 10,000 times larger than those of the motor itself.

For fast dynamic response, the inertia of the motor must be small. This is crucial requirement as the gear ratio gets larger, like robotics applications. There are two ways of reducing the rotor inertia in motor design. One is to reduce the diameter and make the rotor longer, as shown in Figure 2.5-(a). The other is to make the motor rotor very thin, as a pancake, as shown in Figure(2.5)-b



(a) Long and slender (b) Pancake

Figure 2.5: two ways to reducing motor rotor inertia

Most robots use the long and slender motors as Figure (a), and some heavy-duty robots use the pancake type motor. Figure 2.2.3 shows a pancake motor by Mavilor Motors.

2.3 Power Electronic Devices

Performance of servomotors used for robotics applications highly depends on electric power amplifiers and control electronics, broadly termed power electronics. Power electronics has shown rapid progress in the last two decades, as semiconductors became faster, more powerful, and more efficient. In this section we will briefly summarize power electronics relevant to robotic system development.

2.3.1 Pulse width modulation (PWM)

In many robotics applications, actuators must be controlled precisely so that desired motions of arms and legs may be attained. This requires a power amplifier to drive a desired level of voltage (or current indirectly) to the motor armature, as discussed in the previous section. Use of a linear amplifier (like an operational amplifier), however, is power-inefficient and impractical, since it entails a large amount of power loss. Consider a simple circuit consisting of a single transistor for controlling the armature voltage, as shown in Figure 2.6. Let V be the supply voltage connected to one end of the motor armature. The other end of the armature is connected to the collector of the transistor. As the base voltage varies the emitter-collector voltage varies, and thereby the voltage drop across the motor armature, denoted u in the figure, varies accordingly. Let i be the collector current flowing through the transistor. Then the power loss that is dissipated at the transistor is given by:

$$P_{loss} = (V- u).i = 1/R.(V- u).u \quad (2.3.1)$$

Where R is the armature resistance. Figure 2.3.2 plots the internal power loss at the transistor against the armature voltage. The power loss becomes the largest in the middle, where half the supply voltage V/2 acts on the armature. This large heat loss is not only wasteful but also harmful, burning the transistor in the worst case scenario. Therefore, this type of linear power amplifier is seldom used except for driving very small motors.

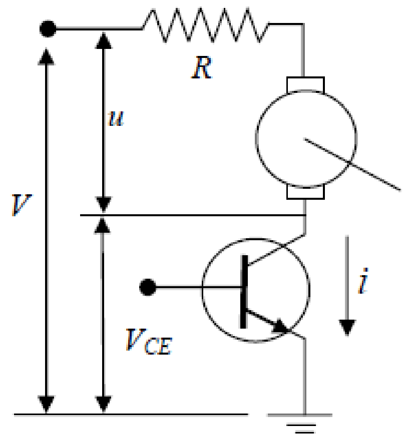


Figure 2.6: analogue power amplifier For driving the armature voltage

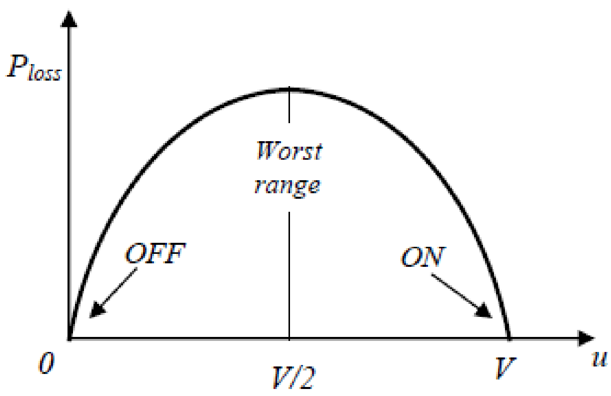


Figure 2.7: power loss at the transistor vs. the armature voltage.

An alternative is to control the voltage via ON-OFF switching. Pulse Width Modulation, or PWM for short, is the most commonly used method for varying the average voltage to the motor. In Figure 2.7 it is clear that the heat loss is zero when the armature voltage is either 0 or V. This means that the transistor is completely shutting down the current (OFF) or completely admitting the current (ON). For all armature voltages other than these complete ON-OFF states, some fraction of power is dissipated in the transistor. Pulse Width Modulation (PWM) is a technique to control an effective armature voltage by using the ON-OFF switching alone. It varies the ratio of time length of the complete ON state to the complete OFF state. Figure 2.8 illustrates PWM signals. A single cycle of ON and OFF states is called the PWM period, whereas the percentage of the ON state in a single period is called duty rate. The first PWM signal is of 60% duty, and the second one is 25 %. If the supply voltage is *V=10 volts*, the average voltage is 6 volts and 2.5 volts, respectively.

The PWM period is set to be much shorter than the time constant associated with the mechanical motion. The PWM frequency, that is the reciprocal to the PWM period, is usually 2 ~ 20 kHz, whereas the bandwidth of a motion control system is at most 100 Hz. Therefore, the discrete switching does not influence the mechanical motion in most cases.

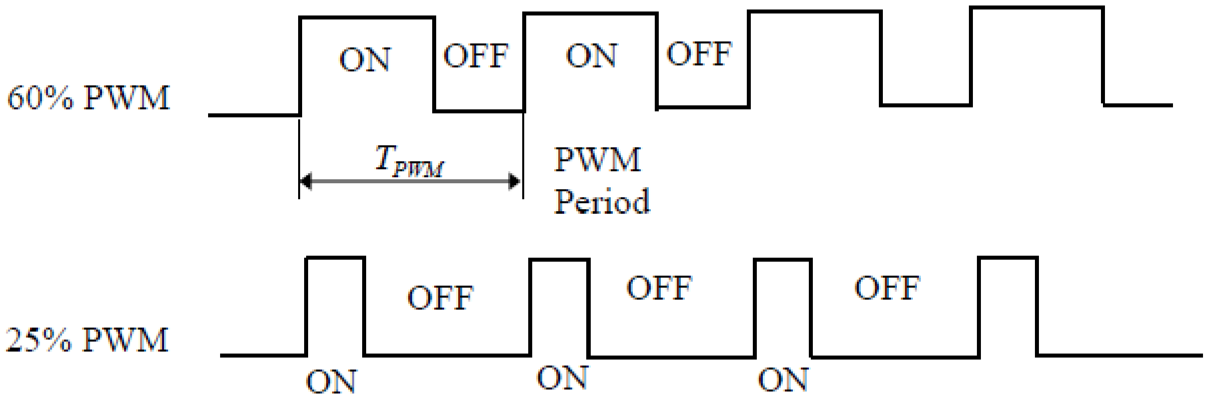


Figure 2.8: pulse width modulation

As modeled in eq.(2.4), the actual rotor windings have some inductance *L*. If the electric time constant *Te* is much larger than the PWM period, the actual current flowing to the motor armature is a smooth curve, as illustrated in Figure 2.9-(a). In other words, the inductance works as a low-pass filter, filtering out the sharp ON-OFF profile of the input voltage. In contrast, if the electric time constant is too small, compared to the PWM period, the current profile becomes zigzag, following the rectangular voltage profile, as shown in Figure 2.9-(b). As a result, unwanted high frequency vibrations are generated at the motor rotor. This happens for some types of pancake motors with low inductance and low rotor inertia.

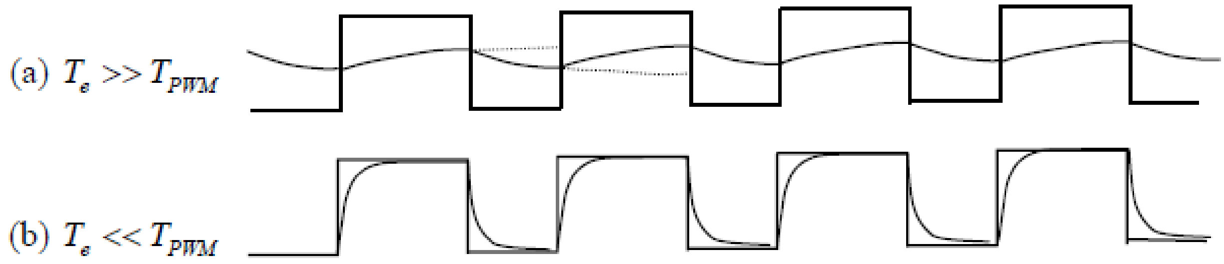
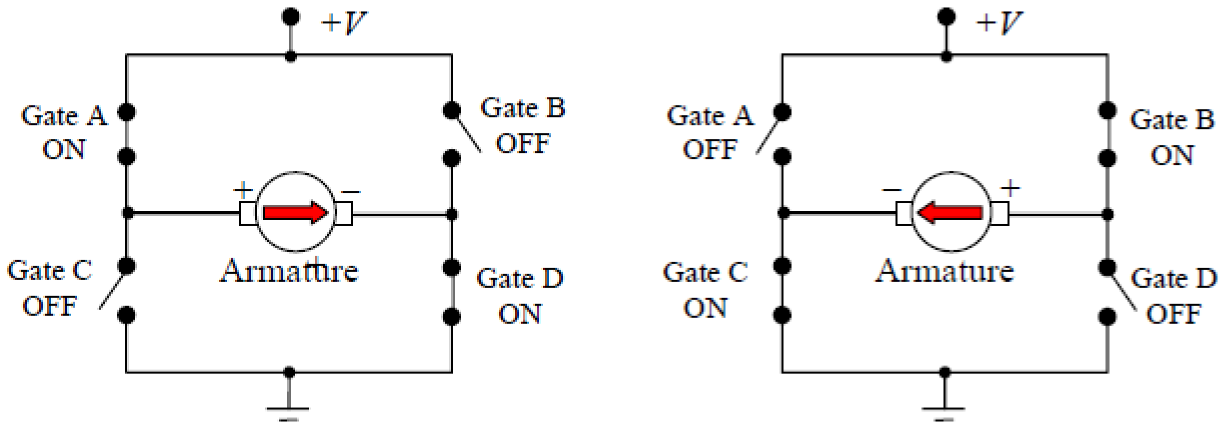


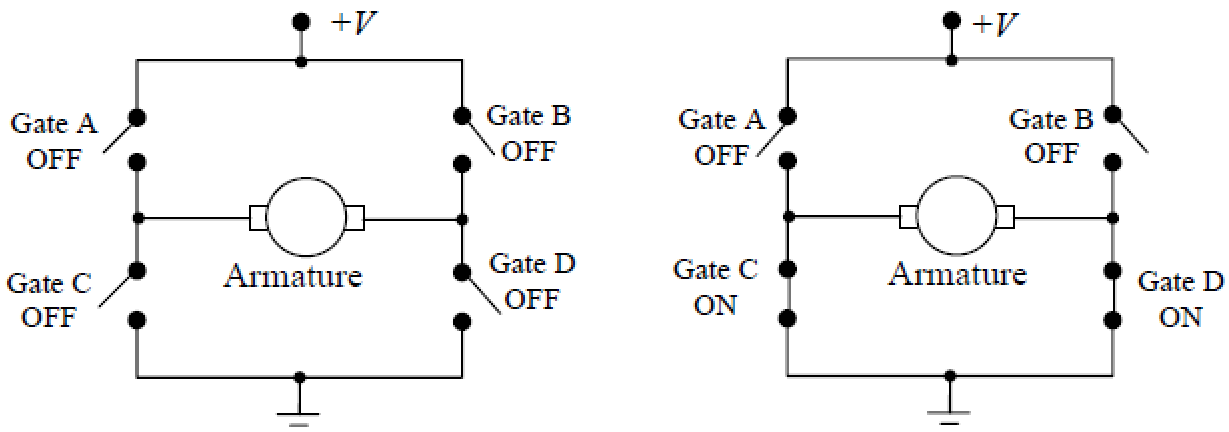
Figure 2.9: current to the motor is smoothed due to inductance

2.3.2 The H-bridge and bipolar PWM amplifiers

In most robotics applications, bi-directional control of motor speed is necessary. This requires a PWM amplifier to be bipolar, allowing for both forward and backward rotations. The architecture described in the previous section needs to be extended to meet this bipolar requirement. The H-Bridge architecture is commonly used for bipolar PWM amplifiers. As shown in Figure 2.10, the H-Bridge architecture resembles the letter H in the arrangement of switching transistors around the motor armature. Switching transistors A and B are pulled up to the supply voltage V, whereas transistors C and D are connected to ground. Combinations of these four switching transistors provide a variety of operations. In figure (i), gates A and D are ON, and B and C are OFF. This gate combination delivers a current to the armature in the forward direction. When the gate states are reversed, as shown in figure (ii), the direction of current is reversed. Furthermore, the motor coasts off when all the gates are turned OFF, since the armature is totally isolated or disconnected as shown in figure (iii). On the other hand, the armature windings are shortened, when both gates C and D are turned ON and A and B are turned OFF. See figure (iv). This shortened circuit provides a "braking" effect, when the motor rotor is rotating.



(i)Forward motion (ii) Reverse motion



(iii) The motor armature costs off shortened (iv) The motor winding are

Figure 2.10: H-bridge and four quadrant control

It should be noted that there is a fundamental danger in the H-bridge circuit. A direct short circuit can occur if the top and bottom switches connected to the same armature terminal are turned on at the same time. A catastrophic failure results when one of the switching transistors on the same vertical line in Figure 2.10 fails to turn off before the other turns on. Most of H-bridge power stages commercially available have several protection mechanisms to prevent the direct short circuit.

2.4 Optical Shaft Encoders

The servomechanism is based on analogue feedback technology, using a potentiometer and a tachometer generator. These analogue feedbacks, although simple, are no longer used in industrial robots and other industrial applications, due to limited reliability and performance. A potentiometer, for example, is poor in reliability, resolution, accuracy, and signal to noise ratio. The output tap of the variable resistance slides on a track of resistive material, making a mechanical contact all the time. This slide contact causes not only electric noise but also wear of the contacting surfaces. The resolution of the sensor are also limited by the mechanical contact. Furthermore, linearity depends on the uniformity of the resistive material coated on the substrate, and that is a limiting factor of a potentiometer’s accuracy. Today’s industrial standard is optical shaft encoders, having no sliding contact. This will be discussed next.

2.4.1 Basic principle

An optical encoder consists of a rotating disk with grids, light sources, photodetectors, and electronic circuits. As shown in Figure 2.11, a pattern of alternating opaque and translucent grids is printed on the rotating disk. A pair of light source and photodetector is placed on both sides of the rotating disk. As an opaque grid comes in, the light beam is blocked, while it is transmitted through the disk, when the translucent part comes in. The light beam is then detected by the photodetector. The disk is coupled to a motor shaft or a robot joint to measure. As it rotates, an alternating ON-OFF signal is obtained with the photodetector. The number of grids passing through the optical elements represents the distance traveled.

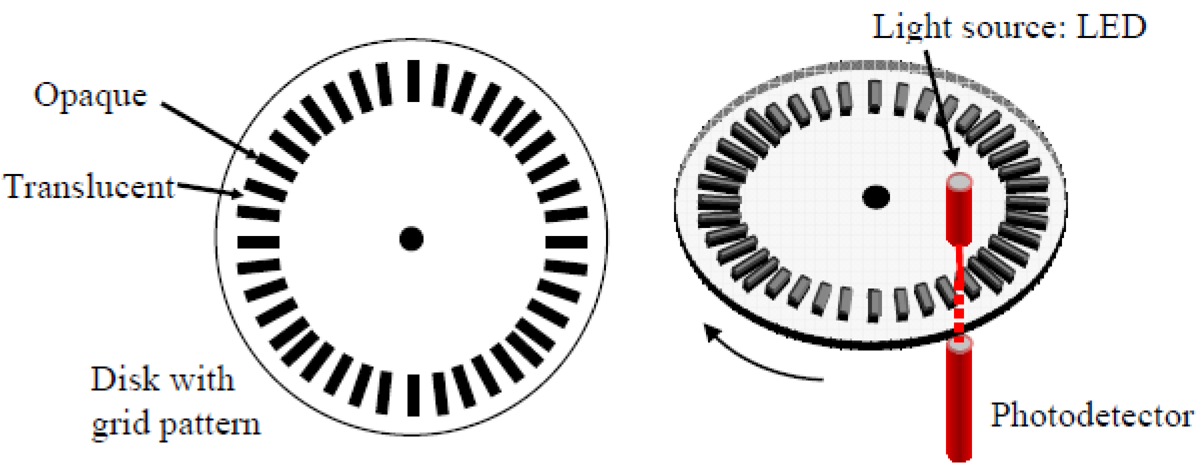


Figure 2.11: Basic construction of optical shaft encoder

This optical shaft encoder has no mechanical component making a slide contact, and has no component wear. An optical circuit is not disturbed by electric noise, and the photodetector output is a digital signal, which is more stable than an analogue signal. These make an optical shaft encoder reliable and robust; it is a suitable choice as a feedback sensor for servomotors.

2.4.2 Position measurement

One problem with the above optical encoder design is that the direction of rotation cannot be distinguished from the single photodetector output. The photodetector output is the same for both clockwise and counter-clockwise rotations. There is no indication as to which way the disk is rotating. Counting the pulse number merely gives the total distance the shaft has rotated back and forth. To measure the angular “position”, the direction of rotation must be distinguished.

One way of obtaining the directional information is to add another pair of light source/photodetector and a second track of opaque/translucent grids with 90 degrees of phase difference from the first track. Figure 2.12 illustrates a double track pattern and resultant output signals for clockwise and counter-clockwise rotations. Note that track A leads track B by 90 degrees for clockwise rotation and that track B leads track A for counter-clockwise rotation. By detecting the phase angle the direction of rotation can be distinguished, and this can be done easily with an up-down counter.

By simply feeding both A phase and B phase encoder signals to an up-down counter, the direction of rotation is first detected, and the number of rising edges and falling edges of both signals is counted in such a way that the counter adds the incoming edge number for clockwise rotation and subtract the edge numbers for counter-clockwise rotation. The up-down counter indicates the cumulative number of edges, that is, the angular “position” of the motor. The output of the up-down counter is binary *n*-bit signals ready to be sent to a digital controller withoutA/D (digital-to-analogue-conversion).

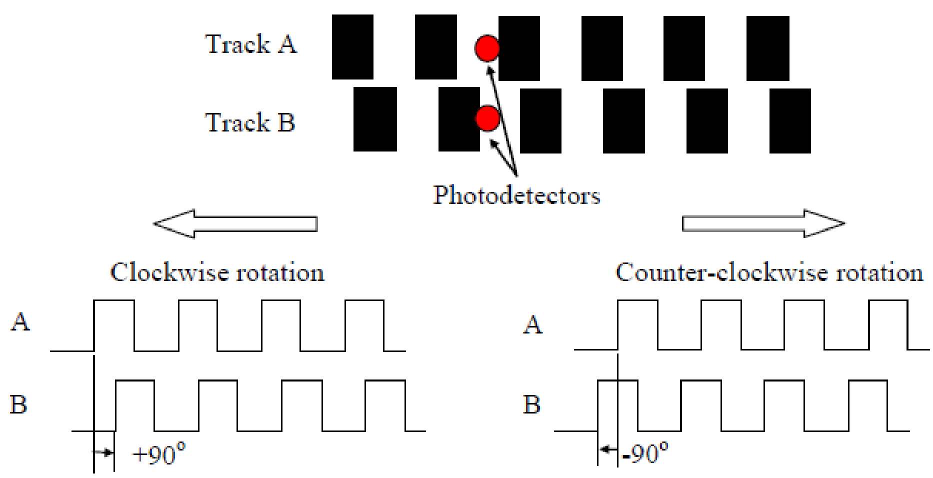


Figure 2.12: double track encode for detection of direction of rotation

It should be noted that this type of encoder requires initialization of the counter prior to actual measurement. Usually a robot is brought to a home position and the up-down counters are set to the initial state corresponding to the home position. This type of encoder is referred to as an ***incremental encoder***, since A-phase and B-phase signals provide relative displacements from an initial point. Whenever the power supply is shut down, the initialization must be performed for incremental encoders.

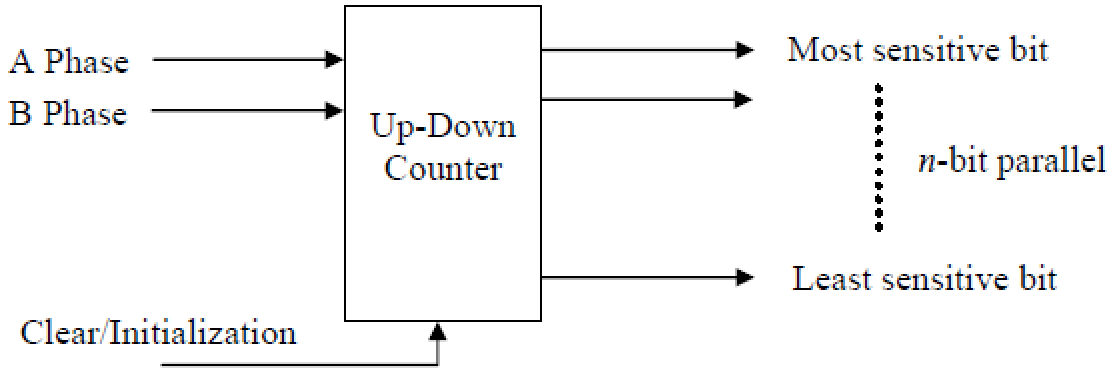


Figure 2.13: Up-down counters for an incremental encoder

2.5 Fluid Used In Actuators

2.5.1 Hydraulic Actuators

Hydraulic actuators are frequently used as joint or leg actuators in robotics applications requiring high payload lifting capability. Hydraulic actuators output mechanical motion through the control of incompressible fluid flow or pressure. Because incompressible fluid is used, these actuators are well suited for force, position, and velocity control. In addition, these actuators can be used to suspend a payload without significant power consumption. Another useful option when using hydraulics is that mechanical damping can be incorporated into the system design.

The primary components in a hydraulic actuation system include:

1. A pump: converts input electrical power to hydraulic pressure.
2. Valves: to control fluid direction, flow and pressure.
3. An actuators: converts fluid power into output mechanical energy.
4. Hoses or piping: used to transport fluids in the system.
5. Incompressible fluid: transfers power within the system.
6. Filters, accumulator, and reservoirs.

7. Sensors and controls.

Positive displacement pumps are used hydraulic actuator systems and include gear, rotary vane, and piston pumps. The valves that are used include directional valves (also called distributors), on-off or check valves, pressure regulator valves, flow regulator valves, and proportional or servo valves.

Both linear and rotary hydraulic actuators have been developed to convert fluid power into output motion. A linear actuator is based on a rod connected to a piston which slides inside of a cylinder. The rod is connected to the mechanical load in motion. The cylinder may be single or double action. A single action cylinder can apply force in only one direction and makes use of a spring or external load to return the piston to its nominal position. A double action cylinder can be controlled to apply force in two directions. In this case, the hydraulic fluid is applied to both faces of the piston.

Hydraulic actuators have been used in many factory automation problems and have also been used in mobile robotics. Figure 2.14 is a picture of the TITAN 3 servo-hydraulic manipulator system from Schilling Robotics. This is a remote manipulator that was originally developed for mobile underwater applications but is also being used in the nuclear industry.

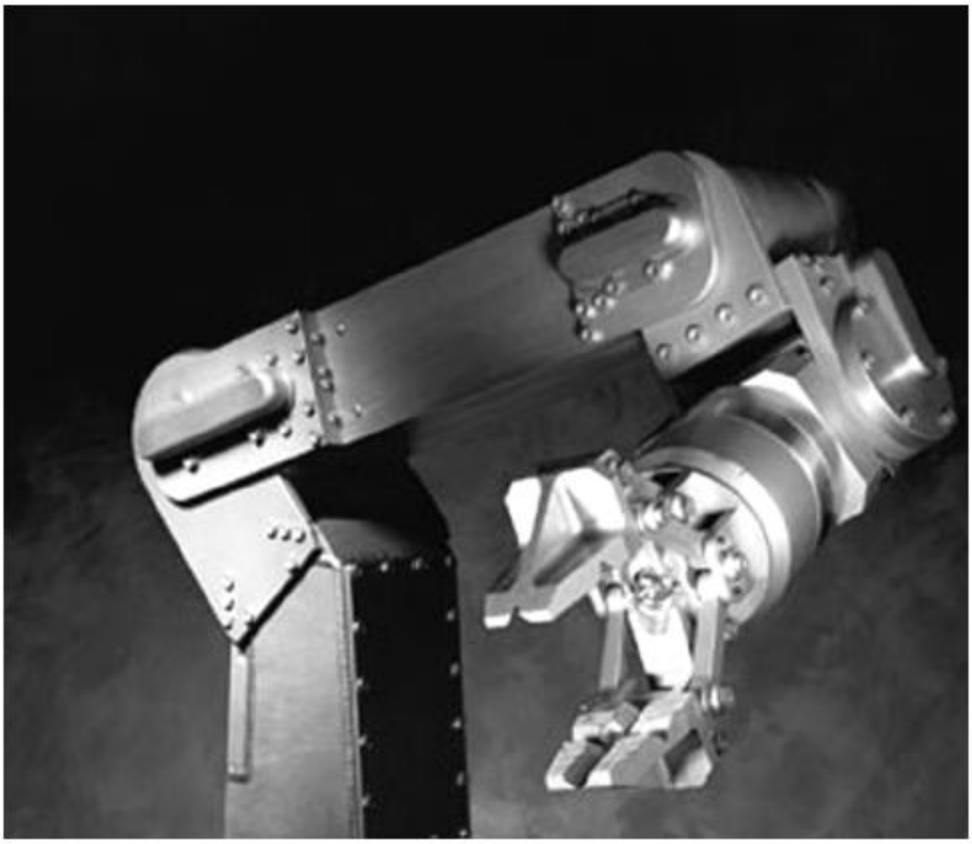


Figure 2.14: Titan 3 servo-hydraulic manipulator

2.5.2 Pneumatic Actuators

Pneumatic actuators are similar to hydraulic actuators in that they are also fluid powered. The difference is that a compressible fluid, pressurized air, is used to generate output mechanical motion. Pneumatic actuators have less load carrying capability than hydraulic actuators because they have lower working pressure. However, pneumatic actuators have advantages in lower system weight and relative size. They are also less complex in part because exhausted pressurized air in the actuator can be released to the environment through an outlet valve rather than sent through a return line.

Because compressed air is used, the governing dynamic equations of pneumatic actuators are nonlinear. In addition, compressed air adds passive compliance to the actuator. These two factors make these actuators more difficult to use for force, position, and velocity control. However, pneumatic actuators are frequently used in industry for discrete devices such as grippers on robotic end effectors.

The primary components in a pneumatic actuation system include:

1. A compressor: converts input electrical power to air pressure
2. Compressed air treatment unit: includes filters and pressure regulation and lubricators.
3. Valves: to control pneumatic power.
4. An actuator: converts pneumatic power into output mechanical power.
5. Hoses or piping: used to transport the air in the system.
6. Sensors and controls.

There are many types of pump technologies used in pneumatic compressors. They include positive displacement pumps such as piston, diaphragm, and rotary vane types as well as non-positive displacement pumps such as centrifugal, axial, and regenerative blowers. The compressor may include a storage tank or it may output pressurized air directly to a regulator valve. The types of valves used are similar to those used in hydraulic actuation systems as described in the previous section. Both rotary and linear actuators are available and are also similar in design to those used in hydraulic actuation systems.

2.6 Common Uses for Digital Sensors

Digital sensors can be used in a wide variety of applications within robotics. These include proximity sensors, limit sensors, and safety sensors such as light curtains.

2.6.1 Proximity Sensors

Proximity sensors are similar to analog displacement sensors, but they offer a static digital output as opposed to an analog output. Proximity sensors are used to determine the presence or absence of an object. They may be used as limit sensors, counting devices, or discrete positioning sensors. They are typically noncontact digital sensors and are based on inductive, capacitive, photoelectric, or Hall effect technology. These technologies are discussed in the previous section on analog sensors. Their design is frequently similar to that of analog position sensors but with threshold detecting electronics included so that their output is digital.

2.6.2 Limit Switches and Sensors

Limit switches or limit sensors are digital inputs to a robot controller that signal the end of travel for motors, actuators, or other mechanisms. The incorporation of limit of limit sensors help. Prevent mechanical failure caused by part of a mechanism hitting a hard stop in the system. The limit sensor itself can be a physical switch with mechanical contacts or a digital proximity sensor as described above. Limit sensors may be mounted to individual joints in the robot or to axes of motion in a robotic workcell. When the limit sensor is encountered for a particular joint or axis, the robot controller will bring the motion to a safe stop.

Both a forward and a reverse limit sensor can be connected to each joint or axis in a robotic system. Forward is defined as the direction of increasing position as measured by the encoder or analog feedback signal. Limit sensors can be used with both rotational and linear axes. A home switch or sensor can also be built into each axis and used to indicate a center position reference for the axis.

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2.6.3 Light Curtains

Light curtains can automatically detect when an operator moves within the danger area for a robot or robotic operation. This danger area will usually include the entire workspace of the robot. Light curtains are typically based on photoelectric sensors which emit multiple beams of infrared light. When any of the beams of light is broken, the control circuit for the light curtain is activated, and the robotic system is immediately shut down in a safe manner.

2.7 Vision

Many robots use industrial cameras for part detection, inspection and, sometimes, guidance. The camera output may be analog or digital and may be acquired by a computer through several means. Often, a frame grabber or image acquisition plug-in board is used and installed in a computer. More recently, computer bus technologies such as IEEE 1394, Camera Link®, Gigabit Ethernet, and USB have been used to transfer data between the camera and the computer.

2.8 Batteries

Robots may be powered by a variety of methods. Some large robots use internal combustion engines to generate electricity or power hydraulic or pneumatic actuators. For a small robot, however, battery power offers a number of advantages over any other method. Batteries are cheap, relatively safe, small, and easy to use. Also, motors convert electrical power into mechanical power with relative efficiency. There are many different types of batteries, each with its own tradeoffs. This section introduces a variety of batteries, explains standard ways of rating batteries, and discusses the design of the battery charger.

2.8.1 Cell Characteristics

Two terms that are often used interchangeably, but actually have a different meaning, are the words *battery* and *cell*. Technically, a cell is a unit that houses a single chemical reaction to produce electricity. A battery is a bank of cells.

2.8.1.1 Voltage

Cells use chemical reactions to produce electricity. Depending on what materials are used to create the reaction, a different voltage will be produced. This voltage called *a nominal cell voltage* and is different for different battery technologies.

For example, a standard flash light cell uses a carbon-zinc reaction and has a cell voltage of 1.5 volt. Car batteries have six lead-acid cells each with a cell voltage of 2 volts (yielding the 12 volt battery).

2.8.1.2 Capacity

In general, the larger the cell is, the more electricity it can supply. This *cell capacity* is measured in *ampere- hours*, Which are the number of hours that the cell can supply a certain amount of current before it's voltage drops below a predetermined threshold value.

For example, 9 volt alkaline batteries (which consist internally ofsix 1.5 volt alkaline cells) are generally rated at about 1 ampere hour. This means that the battery can continuously supply one ampere of current for one hour before \dying." In the capacity measurement, the 9 volt alkaline battery \dies" when the battery voltage drops below 5.4 volts.

2.8.1.3 Power density

There are large differences in capacity per unit weight-the cell's power density- across battery types. This is of the cell most important rating.

Inexpensive carbon-zinc cells have the lowest power density of all cell types. Alka-line cells have about ten times the power density of carbon-zinc cells. Nickel-cadmium cells have less power density than alkalines, but they are rechargeable.

2.8.1.4 Internal resistance

A cell can be modelled as a perfect voltage source in series with a resistor. When current is drawn out of the cell, its output voltage drops as voltage is lost across the resistor.

This cell characteristic, called the *internal resistance*, is important because it determines the maximum rate at which power can be drawn out the cell.

2.8.1.5 Rechargeability

Another important characteristic of a cell is whether or not it is rechargeable, and if so, how many times. Because cells are quite toxic to the environment, use of rechargeable cells is an important issue.

Unfortunately, the cells with highest power densities-alkaline and lithium- aren't rechargeable. But advances in rechargeable technologies are catching up.

Table 2.1: cell characteristic

Cell Type	Voltage	Power Density	Internal Resistance	Rechargeable	Cost
Carbon-Zinc	1.5 volts	low	high	no	low
Alkaline	1.5 volts	high	high	no	moderate
Lithium	1.5 volts	very high	low	no	high
Nickel-Cadmium	1.2 volts	moderate	low	yes	moderate
Lead-Acid	2.0 volts	moderate	low	yes	moderate
Nickel-Hydride	1.2 volts	high	low	yes	very high

2.8.2 Battery packs

There are two ways that cells may be combined to make batteries: series connections and parallel connections.

When cells are connected in series, their voltages add but their amp-hour capacity does not. Series batteries should be composed of cells of equal capacities. When cells are connected in parallel, their voltages remain the same, but their capacities add.

2.9 Robot programming languages

In this section we began to consider the interface between the human user and the robot. It’s by means of this interface that a user takes advantage of all the underlying mechanics and control algorithms.

2.9.1 The three levels of robot programming

There have been many styles of user interface developed for programming robots. Before the rapid proliferation of microprocessor in industry, robot controllers resembled the simple sequencers often used to control fixed automation. Modern approaches focus on computer programming, and issues in programming robots include all issues faced in general computer programming, and more.

1. **Teach by showing**

Early robots were all programmed by a method that we will call *teach by showing*, which involved moving the robot to a desired goal point and recording it’s position in a memory which the sequencer would read during playback.

2. Explicit robot programming languages

Robot programming languages have taken on many forms as well. We will split them into three categories as follows:

1- Specialized manipulation languages.
2- Robot library for an existing computer language.
3- Robot library for a new general-purpose language.

3. Task level programming languages

The third level of robot programming methodology is embodied in *Task level programming languages*. These are languages which allow the user to command desired sub goals of the task directly, rather than to specify the details of every action the robot is to take.

2.9.2 A sample application

Figure 2.16 shows an automated work cell which consists of a conveyor under computer control which deliver a workpiece. A camera connected to a vision system is used to allocate the workpiece on the conveyor. There is an industrial robot (i.e. a puma 560 is pictured) equipped with a force sensing wrist.

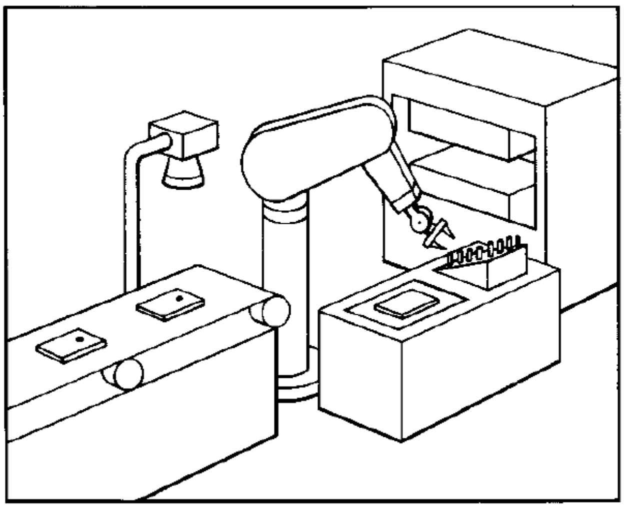

Figure 2.15: an automated work cell containing an industrial robot

2.10 Literature Reviews

It has been designed in Palestine polytechnic university (PPU), a robot for painting, the designers use it to replace the role of man in painting process, and with helping to get rid of most hazards in painting process, they use the Cartesian robot that facilitates the painting process and give a fixed distance from the painted plate, the data about the plat are inserted by the personal, and if there is error occurred while inputting data inside the computer about the measurement of the plate the source of painting will be turned off using photo sensor.

In their system they used pneumatic elements which represent in reciprocating compressor, spray gun, rubber pipes, and the quantity of painting can be controlled by nozzle at the top of the spray gun.