UNIT-5
ACTUATORS

Actuators

An actuator is a part of a device or machine that helps it to achieve physical movements by converting energy, often electrical, air, or hydraulic, into mechanical force

→ **Electro Magnetic Actuators**

These are normally force transducers, in this case producing a force from an electrical signal.

Moving coil actuators

The basic construction of all moving coil actuators is the same in that they consist of a coil situated in an air gap between the poles of a magnet.

1. Dynamic Transducer

This is the simplest form of moving coil actuator. A ring magnet and suitable pole pieces produce an intense magnetic field across a small circular air gap. A coil of fine wire, sometimes wound on a non-conducting former, is located centrally in the air gap by a highly compliant suspension. Connections to the coil are usually made along this suspension. Figure shows a typical arrangement.

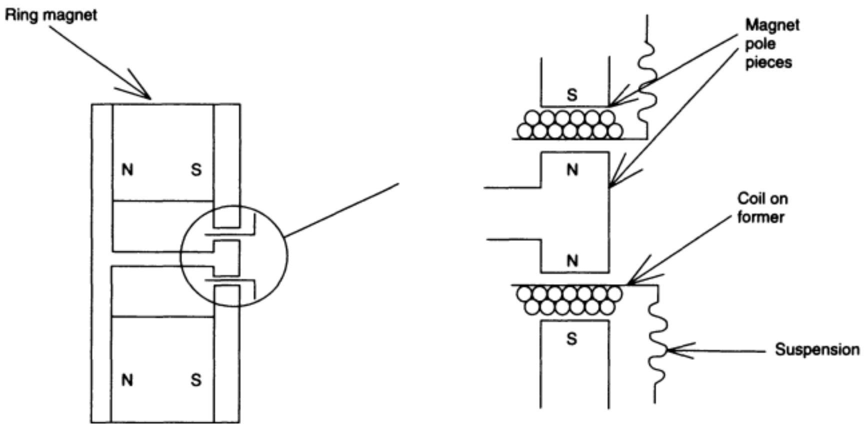


Figure. Cross-section through coil-magnet Assembly A typical application of this transducer is the dynamic loudspeaker in which the coil is bonded on to a rigid cone. Movement of the cone produces
sound waves over a limited frequency range and a number of differently sized cones are often used to cover the audio frequency range. Strictly speaking, coil-magnet assemblies should be current driven as the force F = (Bl)i.

2. d'Arsonval mechanism

Despite being invented over one hundred years ago, the ordinary d.c. ammeter is still in use today. Although it has widely been replaced by the digital meter, it still has some advantages. Being an analogue device, it is much easier to take approximate readings or to watch trends.

The coil is wound on a rectangular former and positioned between a central core and the poles of a magnet by jewelled bearings. Connections to the coil are made through two flat coil springs which also provide a rotational restoring force. Current flowing through the coil produces a turning torque which is resisted by the two springs. Displacement of the pointer is thus relatively linear over a limited angle. The fixed end of the top spring is usually attached to a screw on the front of the meter which allows the zero position to be set

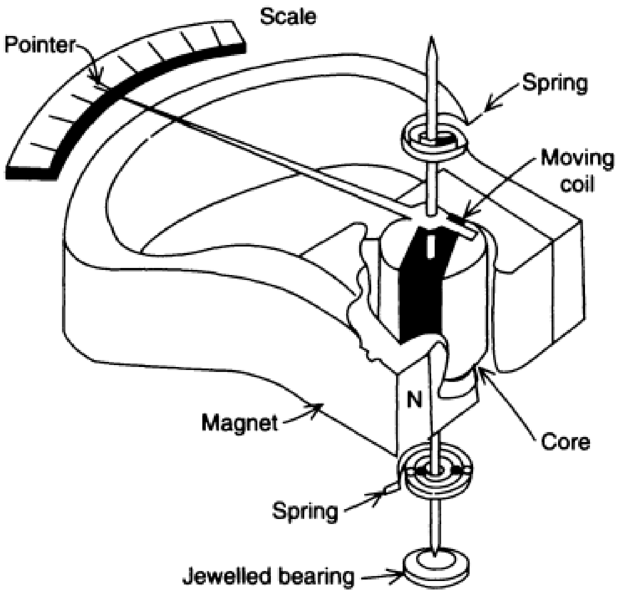


Figure D.C. ammeter.

3. D.C. Motor

In D.C Motor, the coil or armature is usually wound on a soft-iron core which is located between the poles of the permanent magnet. A split-ring commutator and brushes are used to reverse the direction of the current flow at the point at which the coil moves out of the magnetic field. Figure shows the basic principle of operation.

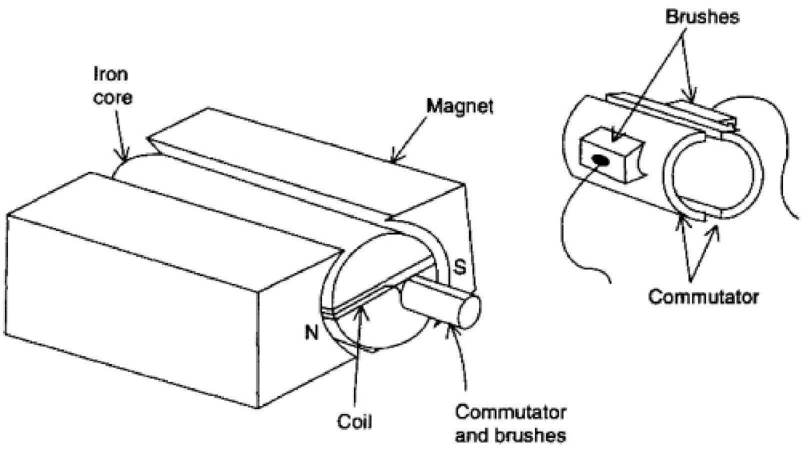


Figure. D.C Motor

In practice, multi-pole motors are used with many segments on the commutator so as to ensure a more constant torque over the full 360° rotation. These have more than one coil, and commutation is arranged to switch as one coil leaves the magnetic field and the next one enters. Ironless rotor motors have a coil with no iron core but instead a fixed steel tube inside the coil to complete the magnetic circuit. In this respect they are similar to the meter movement. They have much lower rotor mass and thus accelerate more quickly than conventional types and are often used in small servomechanisms. A typical ironless rotor d.c. motor is shown in figure.

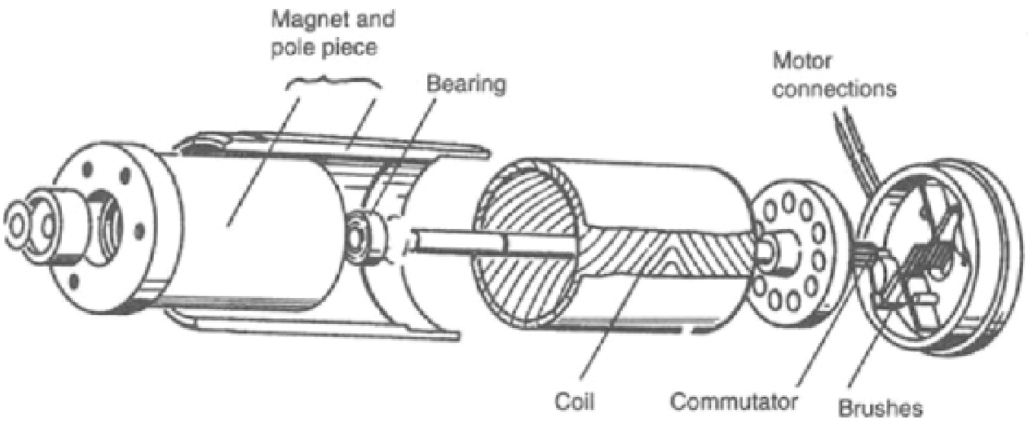


Figure. Ironless rotor d. c. motor.

The torque produced by a d.c. motor for a given current depends on the length of conductor in the magnetic field, the strength of the field and the diameter of the rotor. These factors are usually combined into a single constant km which also gives the speed-to-voltage relationship of the motor

$$\tau = k_{\mathrm{m}} I \qquad \omega = \frac{V}{k_{\mathrm{m}}}$$

4. Moving iron actuators

These can be split into two basic types: those that are coil/magnet assemblies with fixed coils and those that rely on the magnetic force generated when a soft-iron core is magnetised by a current flowing through a coil. Those in the first category differ little from moving coil types and produce a force or torque proportional to current. Those using magnetic attraction or repulsion, however, are usually highly non-linear.

5. Stepper Motor

The rotor of a stepper motor consists of a permanent magnet or series of permanent magnets. The stator windings are wound on soft-iron cores which surround the rotor as shown in figure

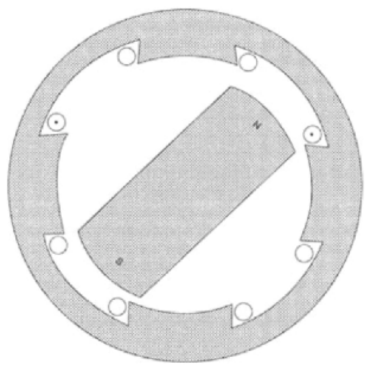


Figure. Basic Principles of Stepper Motor

If the two horizontal windings are energised as shown, the rotor will attempt to align itself horizontally. Energising the vertical windings would similarly cause the rotor to align itself vertically. Intermediate angles may be obtained by partially energising both windings. Real stepper motors have many windings and can achieve small step angles (typically< 2°) when driven with the appropriate signals. Figure shows a precision stepper motor with only two of the stator windings shown for clarity

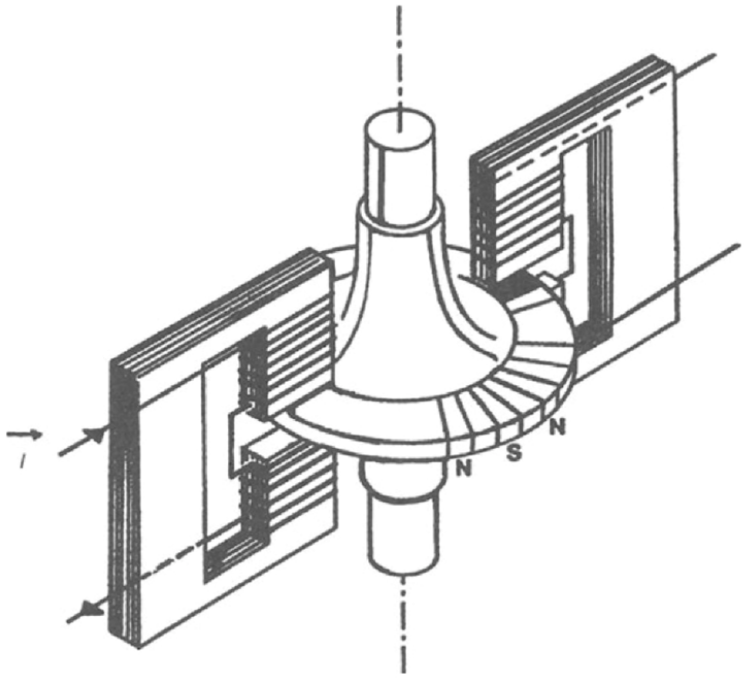
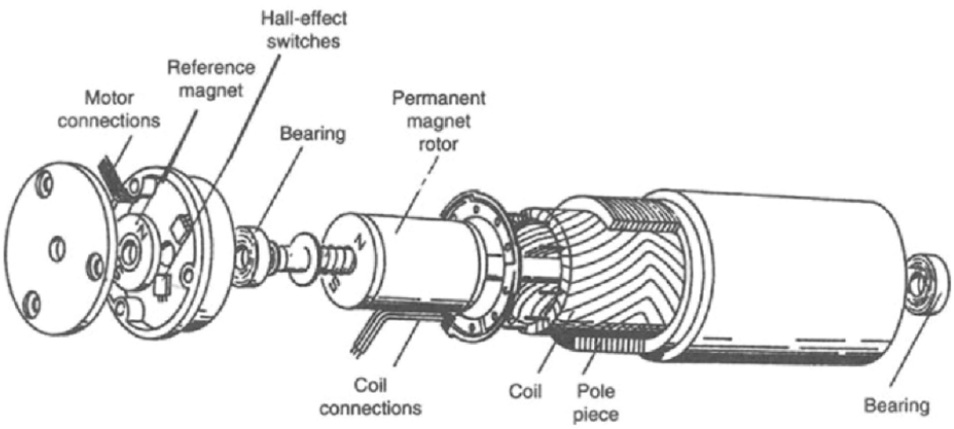


Figure. Typical precision stepper motor

Stepper motors are useful in positioning light loads from computer control

6. Brushless d.c. motor

The brushless d.c. motor is a special kind of stepper motor in which the stator is energised, depending on the position of the rotor. This is measured by Hall-effect devices which are placed around the permanent magnet rotor or a small reference permanent magnet. External circuitry is then used to switch the appropriate stator windings so as to achieve constant rotation. The advantages of brushless d.c. motors are that there are no brushes to wear and that electromagnetic interference may be reduced. A typical brushless d. c. motor is shown in figure



7. Solenoids

Strictly speaking, the word 'solenoid' refers to a long cylindrical coil of wire which may act as a magnet when carrying a current. The word has come to refer also to the mechanical actuator which uses a solenoid to produce a magnetic field and hence apply a force to a soft-iron core. Initially the core is only partially within the coil, as shown in Figure.

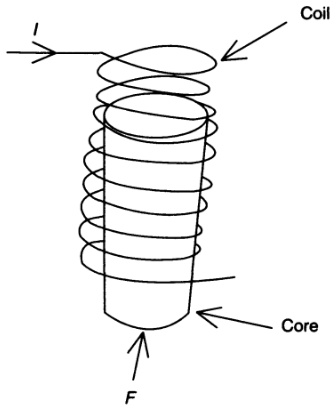


Figure. Typical Solenoid

Once a current flows in the coil, a force is exerted on the core so as to make it move in a direction that increases the inductance of the coil. The core thus tries to centralise itself vertically within the coil. The force f is given by

$$f = \frac{1}{2} I^2 \frac{dL}{dx}$$

where L is the inductance of the coil and x is the displacement of the core. This relationship is valid until the core becomes saturated when the available force will be less than predicted.

8. Moving iron meter

The moving iron meter, unlike the moving coil meter, is only used in particular circumstances. The reason is that, like the solenoid, it is highly non-linear. This does not mean that it is not capable of providing an accurate measure of current but that the range is limited. The non-linearity of the meter is compensated in the scale which is bunched at the ends and spread out in the middle. The basic principle of operation is shown in Figure.

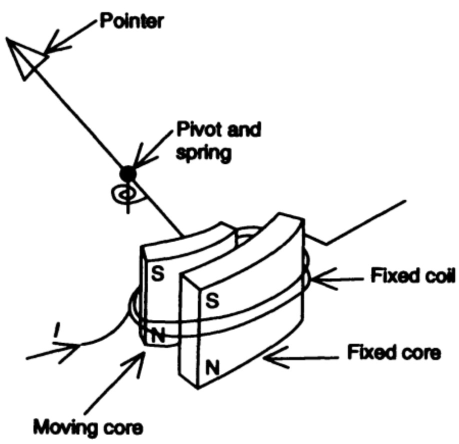


Figure. Moving iron meter

A current I flowing in the coil magnetises the two soft iron cores. As the field is the same for both, they will be magnetised with the same polarity and hence repel each other. This will be true irrespective of the direction of the current I and hence the meter will respond to a.c. currents as well as d.c. currents. This type of meter is thus very useful for monitoring a.c. power supplies, as the extended centre scale allows small changes from the normal value to be easily read.

9. Relays

The relay is an electrically activated switch which gives a high degree of electrical isolation between the control and switched circuits. The switch contacts are attached to a moving armature which is attracted to the core of a coil as shown in Figure.

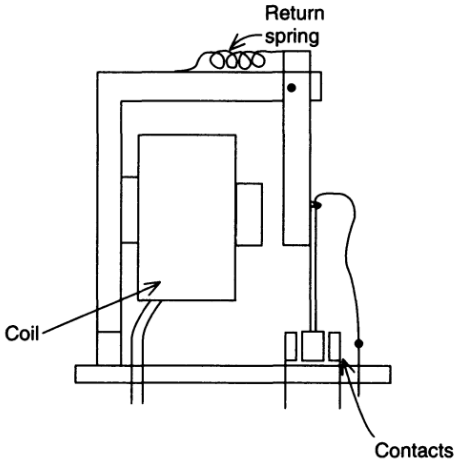


Figure. Typical relays

Similar devices without the contacts were used to give an acoustical output in early telegraph systems. Two distinct sounds were made by the relay opening and closing, and hence the difference between a long and short signal could be heard.

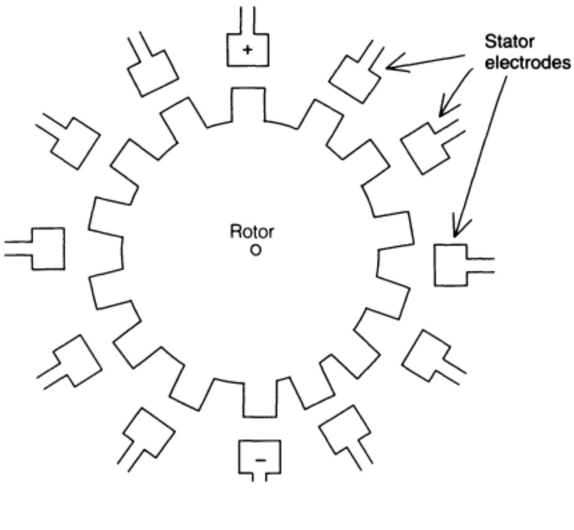
→ **Electrostatic Actuators**

Electrostatic actuators rely on the force between two conducting electrodes when a voltage is applied between them. If the plates of a parallel plate capacitor are charged to a voltage V, then there will be a force F attracting the two plates together; where F is given by

$$F = \frac{\varepsilon_0 A V^2}{2d^2}$$

where A is the area of the plates and d is the separation. This force is quite small unless the separation is small or the voltage large. For example, the attractive force between two plates each of area 1 cm2, separated by a distance of 1 mm and with a voltage of 10 V across them is only 4.4 x 10^{-8} newtons.

Electrostatic actuators are generally of limited use because of the high voltages required for reasonable plate separations but there are two significant exceptions. If the size of the actuator is very small indeed, for example it is integrated in silicon, then the forces become useful (if all the lengths in the previous example are reduced by the same factor, there is no change in force). Figure shows the basic principle of the electrostatic stepper motor.



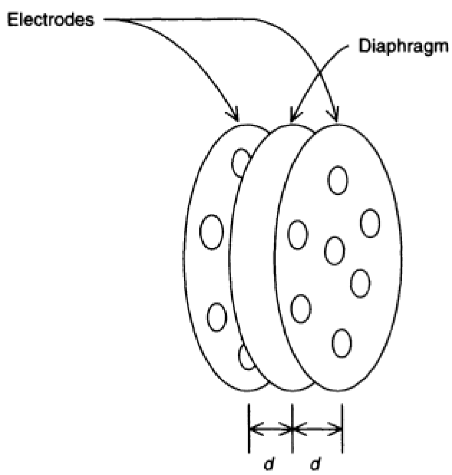


Figure. Electrostatic stepper motor **Figure. Diaphragm flanked by two electrodes**

The other significant advantage that the electrostatic force transducer has to offer, is that a force may be applied to a conducting surface without requiring any mechanical connection. This means, for example, that a diaphragm of very low mass may be moved without requiring any further mass to be added to it. A modified type of actuator is required, however, in order to keep the relationship between force and voltage linear, as it is normally a square law. Figure shows a diaphragm flanked by two electrodes.

→ **Electro-optic devices**

There are a great many electro-optic devices which may be used to provide a numeric or graphical display of the output of a measurement system. There are three types that are particularly common: the light emitting diode (LED), the liquid crystal display (LCD) and the cathode ray tube (CRT). It is beyond the scope of this book to describe the function of the LCD and CRT, as even these common types are complex in their operation.

1. The LED (Light Emitting Diode)

If a ***p-n*** diode is forward-biased then the normally empty electron states in the conduction band of the p-type material and the normally empty hole states in the valence band of the n-type material become populated by the injected carriers. These carriers recombine across the band-gap, releasing energy approximately equal to the band-gap energy. This energy may be radiated or dissipated as heat and the ratio of radiated to non-radiated energy depends on the materials used. If the energy is radiated then a photon is created with a frequency given by

$$E_g \approx h\nu$$

where E_g is the band-gap energy, vis the frequency and his Planck's constant

There are two types of band-gap in semiconductors: direct band-gaps where the electrons and holes have the same momentum, and indirect band-gaps where the momenta differ. Direct band-gap materials are the most useful as the electrons and holes may easily recombine, giving off a photon. A commonly used direct band-gap material is gallium arsenide (GaAs). In indirect band-gap materials, the electron must change momentum before it can recombine with a hole. To change this momentum, a third particle called a phonon must be emitted or absorbed.

Common indirect band-gap materials which give negligibly low levels of electroluminescence are silicon and germanium. The simplest structure for an LED is the planar structure shown in Figure.

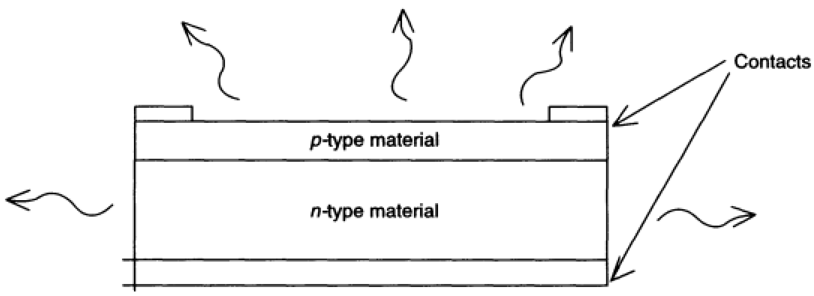


Figure. Structure of planar LED.

The relationship between current and light output is essentially linear and thus amplitude modulation of the light is readily achieved. LEDs are available in the wavelength range 0.5-1.5 μm approximately, with the most common being in the range 0.6-0.9 μm.

More common types have slower response times and may be modulated at between 500 kHz and about 10 MHz, depending on their application. This makes them well suited to use in a.c.-excited optical measurement systems

2. The Laser Diode

The laser diode is basically a special type of LED that contains an optical Fabry-Perot cavity. The term LASER is an acronym for Light Amplification by Stimulated Emission of Radiation and the basic laser is thus an amplifier rather than a source

Most lasers also contain a source and act as optical oscillators. In the case of the laser diode, the source functions in the same way as a conventional LED by spontaneous emission. Photons may also be created by stimulation however; that is, one photon interacting with an electron in a high-energy state causes it to fall to a lower state, creating another photon of identical wavelength and phase. Above a certain value of stimulation, the creation of photons exceeds the absorption in the cavity and lasing occurs. In the laser diode, the ends of the junction are cleaved or polished to form mirrors, and complex structures are used to create an optical waveguide which forms the sides of the cavity.

The relationship between light output and current in a typical laser diode is shown in Figure. Below the threshold current, the device functions in the same way as a standard LED by spontaneous emission but, above the threshold current, lasing occurs and the efficiency is much increased.

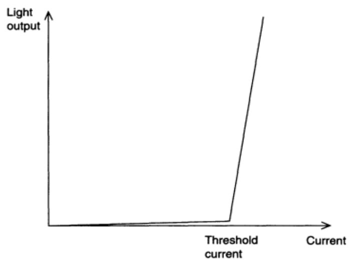


Figure. Light output versus current for typical laser diode

→ **Piezoelectric actuators**

A piezoelectric actuator is a transducer, used to change an electrical signal into an accurately controlled physical displacement or stroke by using piezoelectric effect based on electromechanical coupling rather than electromagnetic induction.

This effect may be exploited to produce an actuator whereby the application of a voltage across a disc of piezo-electric material (such as quartz) will cause it to change thickness. The relationship is **x=dv**

where x is the displacement, v the applied voltage and d the 'd coefficient' of the material.

Piezoelectric actuator is used in the generation of acoustic waves in air or water. Piezoelectric actuators are often used to produce high- frequency sound in air although they are more efficient when used in denser mediums such as water.

Robotic Applications

→ **Introduction**

Robotic applications are great examples of real-time embedded systems because they clearly use sensing and actuators to affect objects in the real world within the real-time physical constraints of environments that humans often operate in as well. Real-time applications also might have deadlines that are beyond human ability. A real-time system must simply operate within an environment to monitor and/or control a physical process at a rate required by the physics of the process.

Robots are often deployed in controlled environments, such as assembly lines, rather than in uncontrolled environments, where humans often operate better, at least presently.

→ **Robotic Arm**

- The robotic arm approximates the dexterity of the human arm with a minimum of five degrees of rotational freedom, including base rotation, shoulder, elbow, wrist, and a gripper.
- The gripper can be a simple claw or approximate the dexterity of a human hand with individual fingers. In general, the gripper is often called an end effector to describe the broad range of devices that might be used to manipulate objects or tools.
- Most industrial or research robotic arms have six or more degrees of freedom (additional wrist motion and complex end effectors) and can manipulate masses from one to hundreds of kilograms.
- Robotic arms are often combined with computer vision with cameras either fixed in the arm or with views of the arm from fixed locations
- A basic five-degree-of-freedom arm with end effector vision can be used to implement interesting tasks, including search, target recognition, grappling, and target relocation.
- Figure 17.3 shows the robotic trainer arm with a reference coordinate system

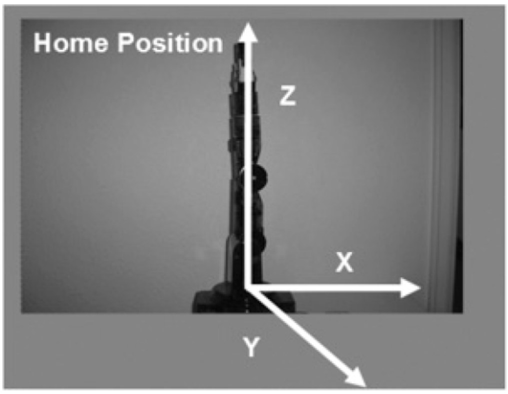


FIGURE 17.3 Robotic Arm Coordinates and Home Position

- Below Figure shows the OWI arm with elbow rotation so that the forearm is held parallel to the base surface. In this position, the base can be rotated to move the end effector over a circular trace around the arm base.

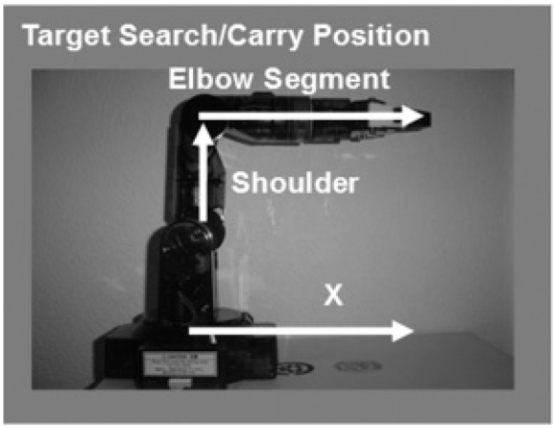


FIGURE 17.4 Robotic Elbow Rotation Only

→ **Sensing**

- Joint rotation sensing can be provided by joint position encoders and/or computer vision feedback. Position encoders include the following:
  - Electrical (multi-turn potentiometer)
  - Optical (LED and photodiode with light-path occlusion and counting)
  - Mechanical switch (with a momentary switch counter)
- Position encoders provide direct feedback during arm positioning. This feedback can be used to drive the feedback in a control loop when the arm is moved to a desired target position.
- Figure 17.15 shows the basic feedback control design for a position-encoded controlled process to move an arm from one target position to another

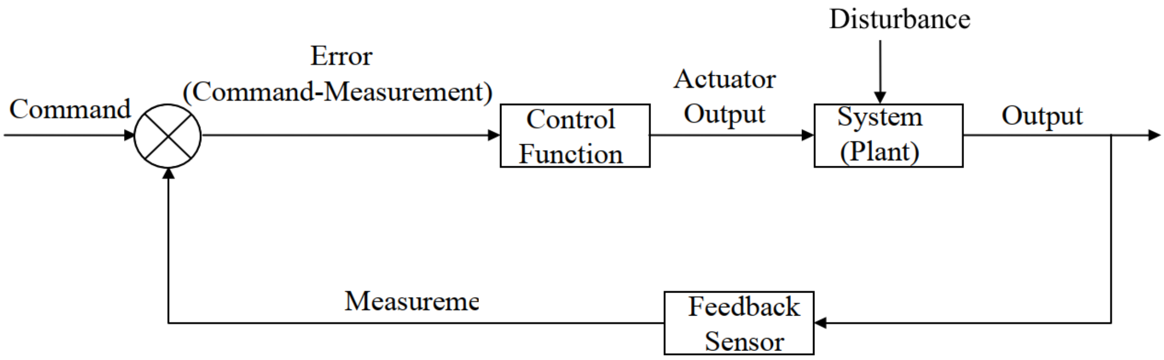


FIGURE 17.15 Basic Feedback Control Arm Positioning

- The main disturbance to constant rotation will come from stick/slip friction in the joint rotation and motor ramp-up and ramp down characteristics in the motor/arm plant. Figure 17.16 shows this specific feedback control design.

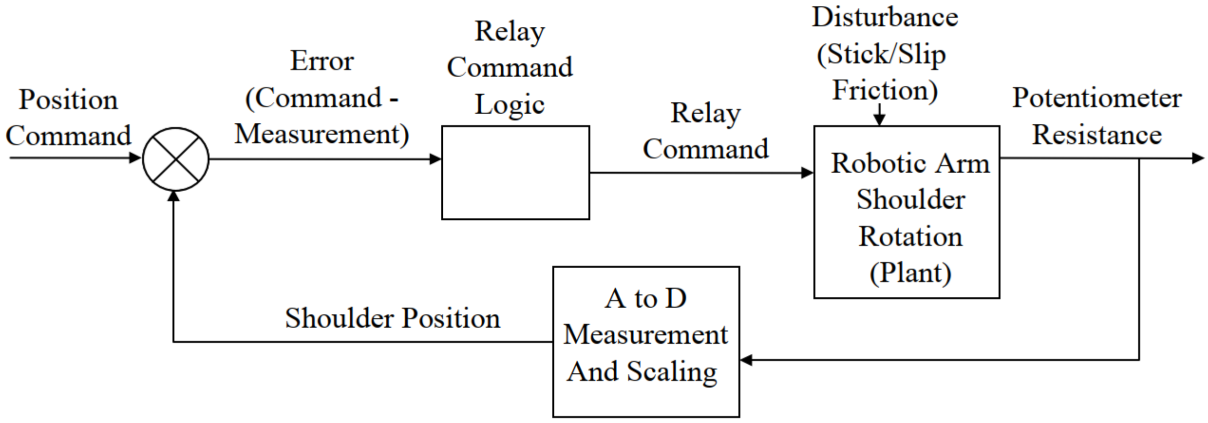


FIGURE 17.16 Relay Control with Position Encoder Feedback through an A/D Converter

- Closer inspection of the design in Figure 17.16 reveals that the control loop has an analog and a digital domain, as shown in Figure 17.17.

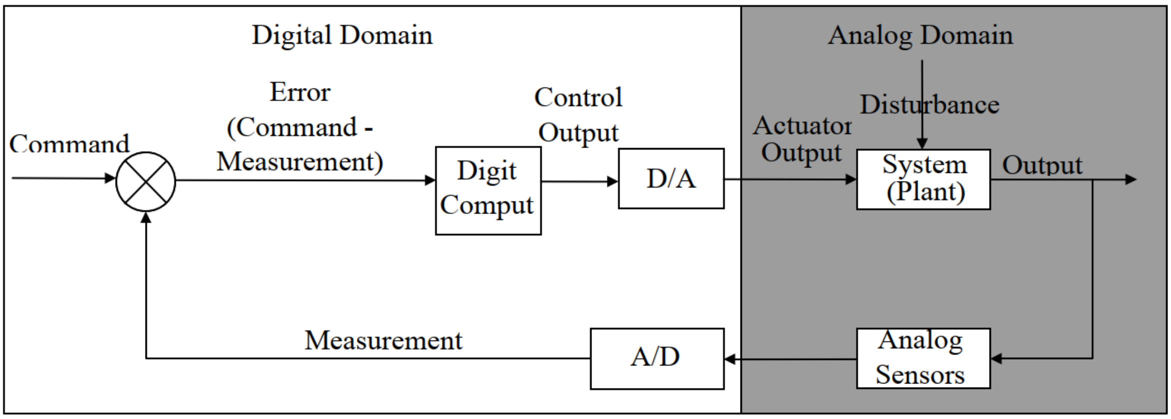


FIGURE 17.17 Arm Positioning with Feedback Digital and Analog Domains

→ **Actuation**

Actuation and end effector control is greatly simplified when the target object masses that the end effector must work with are negligible. Significant target mass requires more complex active joint motor torque control. Moving significant mass requires geared motor controllers with torque controlling DAC output. Another option for actuation is the use of stepper motors with active feedback control channels for each degree of freedom. For the OWI arm and negligible payload mass, the actuation can be designed using relays or simple H-bridge motor controllers. The motors must be reversible. The simplest circuit for reversing a motor can be implemented with switches to change the polarity across the motor leads, as shown in the below Figure.

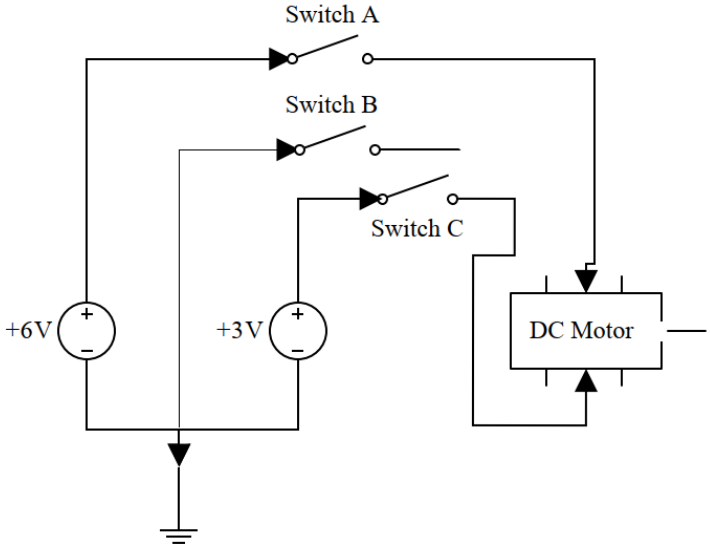


FIGURE 17.8 Three-Switch Reversible Motor

The possible switch states are enumerated in Table 17.1 along with the motor actuation provided.

TABLE 17.1 Three-Switch Reversible Motor Controls

SW-A	SW-B	SW-C	MOTOR
Off	X	Off	Off
Off	On	On	Forward
On	Off	On	Reverse

Figure 17.9 shows how two relays can be used to implement the three-switch reversible motor circuit by using relays that include normally open and normally closed poles.

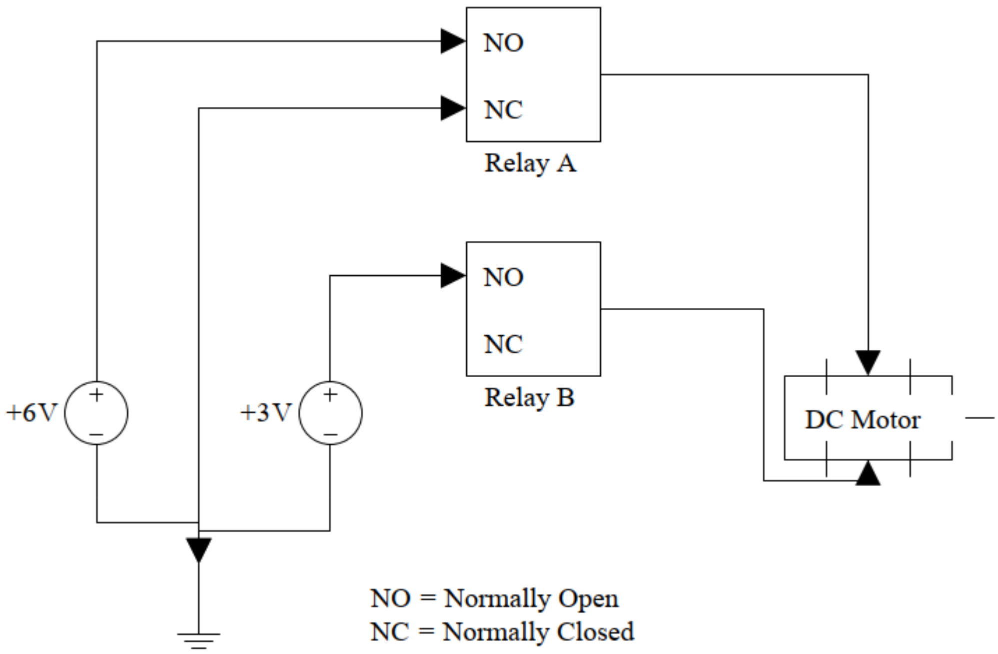


FIGURE 17.9 Two-Relay Reversible Motor

This simplifies the relay reversible motor actuation to 10 relays required for a five-degree-of-freedom arm. Table 17.2 summarizes the motor actuation as a function of the relay setting for this design.

TABLE 17.2 Two-Relay Reversible Motor Controls

RLY-A	RLY-B	MOTOR
Off	Off	Off
Off	On	Forward
On	Off	Off
On	On	Reverse

This is scaled to actuate a five-degree-of-freedom arm using 10 relays, as shown in Figure 17.10.

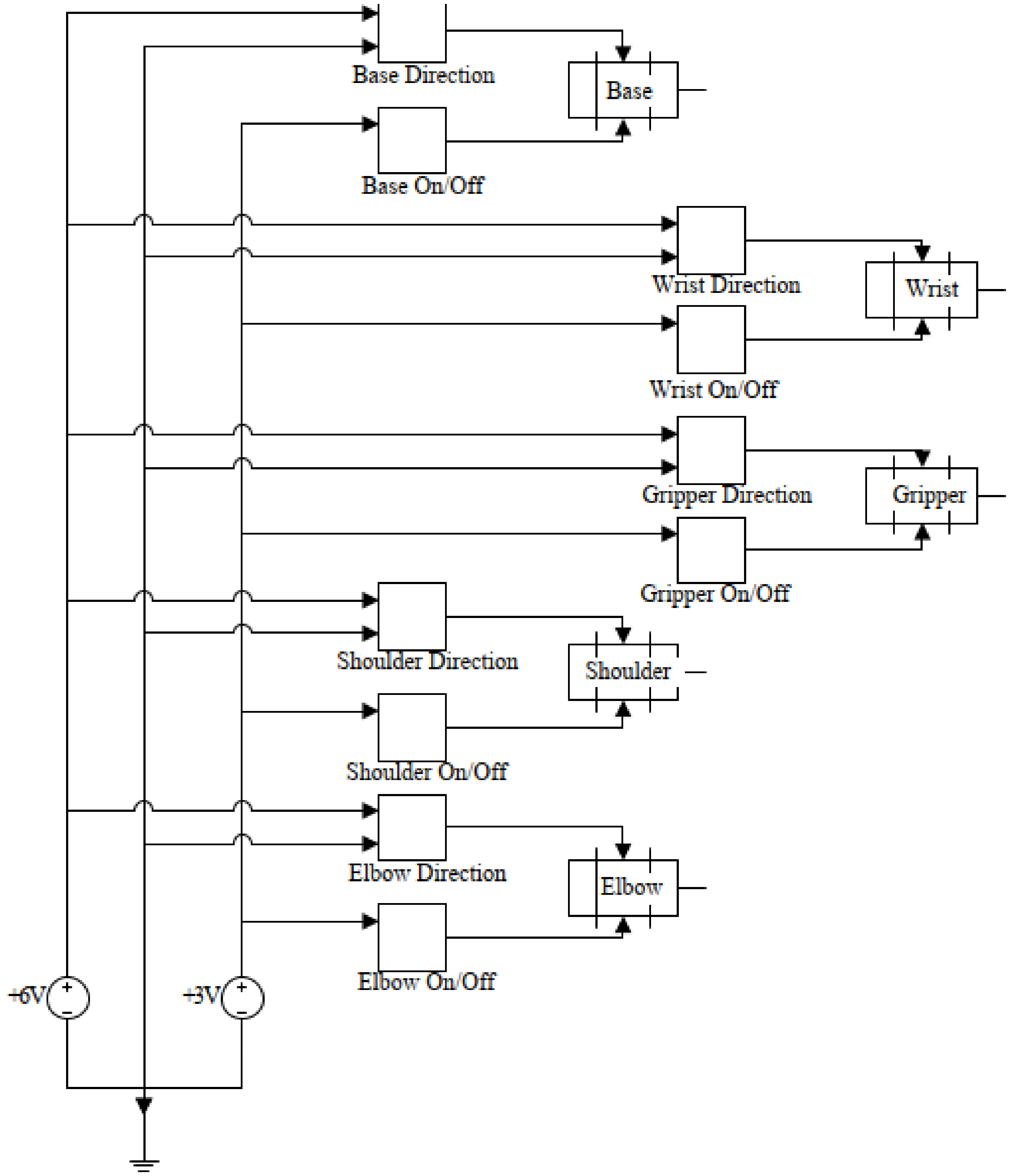


FIGURE 17.10 Five-Degree-of-Freedom Robotic Arm Relay Circuit

The concept of reversible motor poles can be generalized using relays in an H-bridge, providing more motor control states than the two-relay design. The H-bridge relay circuit is shown in Figure 17.13.

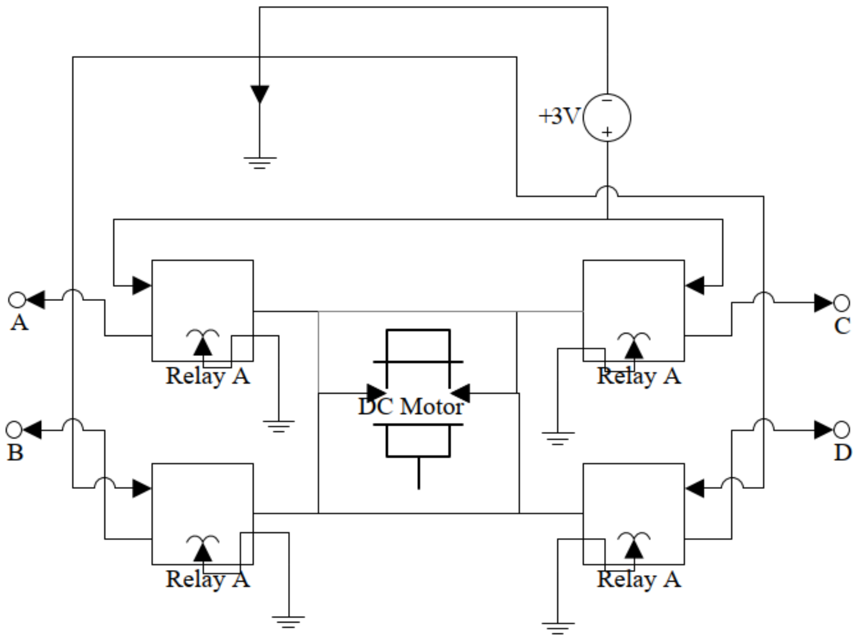


FIGURE 17.13 Relay H-Bridge Motor Control

Inspection of the relay H-bridge states shows that the H-bridge also provides additional control features, as listed in Table 17.3.

TABLE 17.3 Relay H-Bridge Motor Control States

A	B	C	D	MOTOR
0	0	0	0	Off
0	0	1	1	Brake
0	1	0	1	FuseTest
0	1	1	0	Reverse
1	0	0	1	Forward
1	0	1	0	FuseTest
1	1	0	0	Brake

→ **Automation and Autonomy**

The below Figure shows command and control loops for a robotic system that ranges from fully autonomous to telerobotic. Telerobotic operation is commonly known as "joystick" operation, where all robotic motion mimics operator inputs.

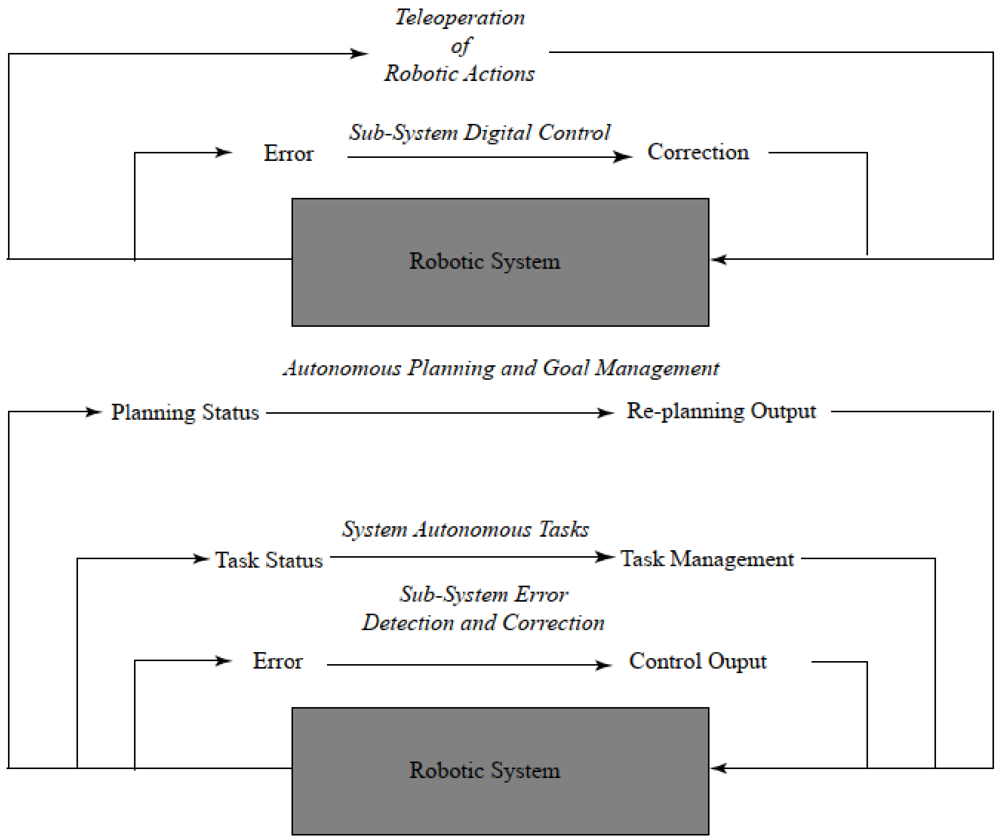


Figure 17.22 Teleoperated and Fully Autonomous Robotic Task Control Loops

An intermediate level of control between fully autonomous and telerobotic is called shared control. In shared control, some aspects of robotic tasking are autonomous, some are telerobotic, and others are automated but require operator concurrence to approve the action or initiate the action. The concept of shared control is shown in Figure 17.23.

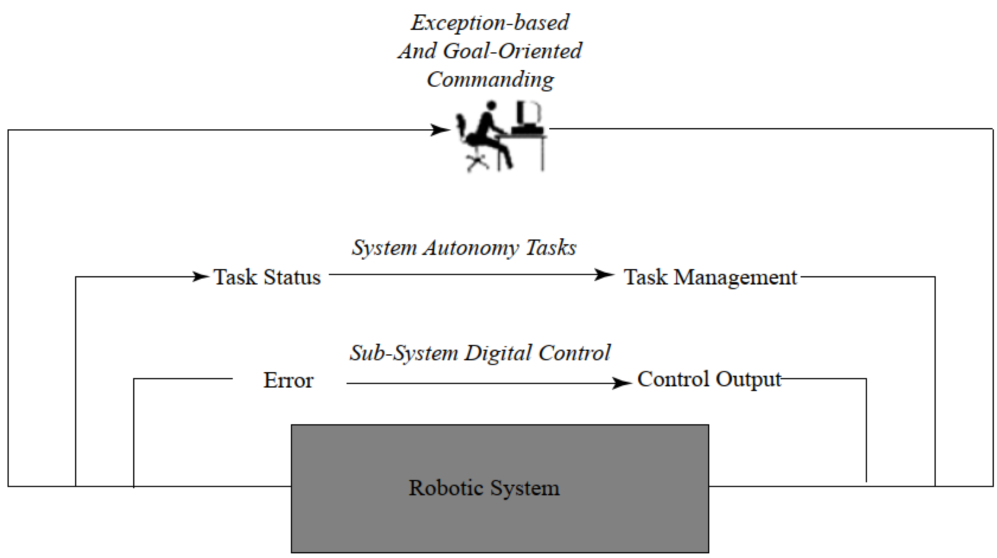


Figure 17.23 Shared Control of a Robotic System

Telerobotic systems may still have closed-loop digital control, but all tasking and decision making come from the operator; in the extreme case, literally every movement of the robot is an extension of the user's movements, and no actuation is initiated autonomously. After the robotic action is commanded by the user, controlled motion may be maintained by closed-loop digital control. This is similar to concepts in virtual reality, where a user's input is directly replicated in the virtual model, and the concept of remotely piloting aircraft.