Chapter 2

Motors

This chapter introduces several types of motors commonly used in robotic and related applications.

DC motors are inexpensive, small, and powerful motors that are used widely. Geartrain reductions are typically needed to reduce the speed and increase the torque output of the motor.

Stepper motors are not part of the 6.270 kit but commonly used in robotics, particular in mechanisms that perform linear positioning, such as floppy and hard disk drive head motors and X-Y tables.

Servo motors are used in radio control airplanes to control the position of wing flaps and similar devices. A servo motor includes a built-in geartrain and is capable of delivering high torques directly. The output shaft of a servo does not rotate freely as do the shafts of DC motors and stepper motors, but rather is made to seek a particular angular position under electronic control.

2.1 DC Motors

DC motors are widely used in robotics for their small size and high energy output. They are excellent for powering the drive wheels of a mobile robot as well as powering other mechanical assemblies.

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. Roboticists often use 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.

A low voltage (e.g., 12 volt or less) DC motor may draw from 100 milliamps to several amps at stall, depending on its design.

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 ounch 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).

Figure 2.1 lists some specifications of the Polaroid motor provided in the 6.270 kit (the speed and torque ratings were subjectively determined through comparisons with similar sized DC motors and could stand closer measurement).

Specification	**Rating**	**Comment**
Voltage	5 volts	normal low voltage
Current	up to 4 amps	high current capacity
Speed	4000-6000 RPM	slightly slow (?)
Torque	unknown	unusually high

Figure 2.1: Polaroid Motor Specifications

The motor is used to eject film in Polaroid instant cameras. For this application, the fact that it is low voltage (5 volts) is very important so that only a few cells are needed to run the motor. The motor is used with a several stage geartrain to reduce its speed and generate the torque need to eject the film. The fact that it is high torque is very desirable.

For an application in powering a mobile robot, the motor is very suitable. Again the low voltage is desirable, as is the high torque output. Probably the only undesirable characteristic is the high current draw; however, this is the only way to achieve the high torque at low voltages.

2.1.2 Measuring Motor Torque

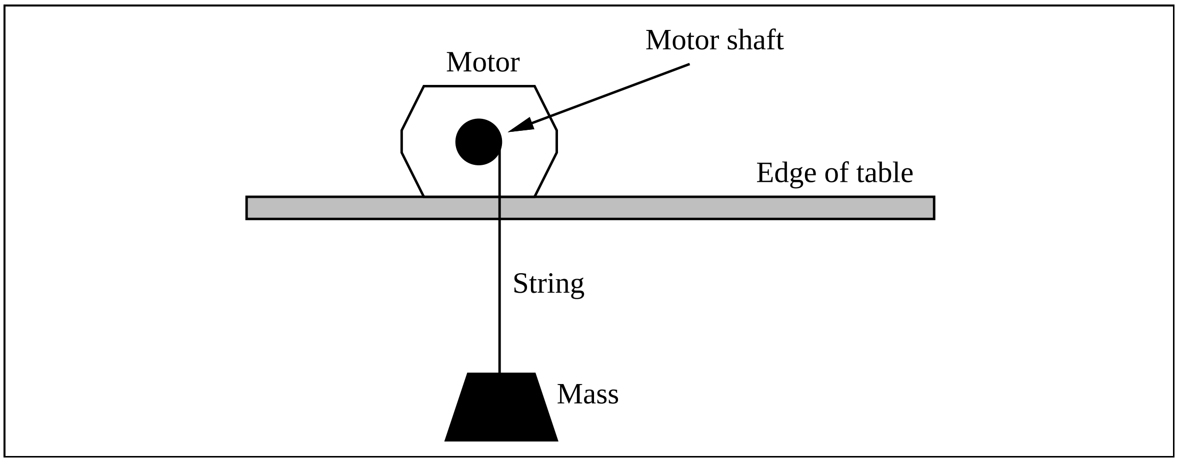

Figure 2.2: Experiment to Measure Motor Torque

A simple experiment can be performed to accurately determine the torque rating of a motor. All that is needed is a motor to be measured, a power supply for the motor, a piece of thread, a mass of known weight, a table, and a ruler.

The mass is attached to one end of the thread. The other end of the thread is attached to the motor shaft so that when the motor turns the thread will be wound around the motor shaft. The motor shaft must be long enough to wind the thread like a bobbin.

The motor is put near the edge of a table with the mass hanging over the edge, as illustrated in Figure 2.2. When the motor is powered on, it will begin winding up the thread and lifting the mass. At first this will be an easy task because the moment arm required to lift the mass is small—the radius of the motor shaft.

But soon, the thread will wind around the shaft, increasing the radius at which the force is applied to lift the mass. Eventually, the motor will stall. At this point, the radius of the thread bobbin should be measured. The torque rating of the motor is this radius per amount of mass that was caused the stall.

2.1.3 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 (see Figure 4.7). 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/geartrain assembly is faster than the peak efficiency point, the geartrain 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 geartrain.

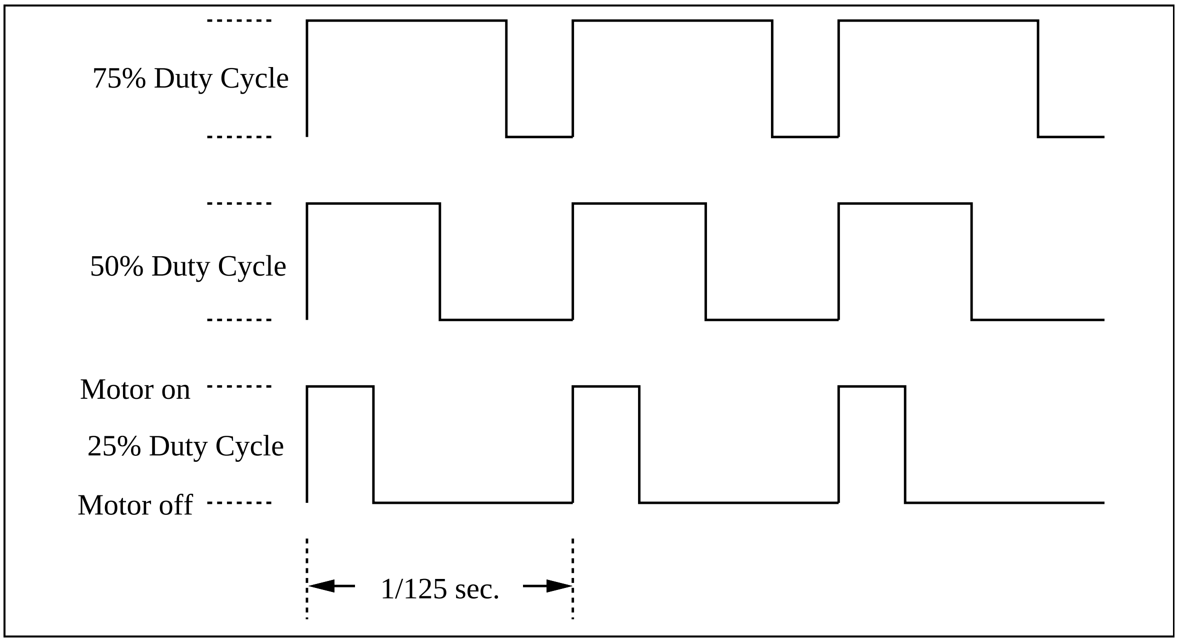

Figure 2.3: Example of Several Pulse Width Modulation Waveforms

2.1.4 Pulse Width Modulation

Pulse width modulation is a technique for reducing the amount of power delivered to a DC motor. This is typically used in mechanical systems that will not need to be operated at full power all of the time. For a 6.270 robot, this would often be a system other than the main drivetrain.

Instead of reducing the voltage operating the motor (which would reduce its power), the motor's power supply is rapidly switched on and off. The percentage of time that the power is on determines the percentage of full operating power that is accomplished.

Figure 2.3 illustrates this concept, showing pulse width modulation signals to operate a motor at 75%, 50%, and 25% of the full power potential.

A wide range of frequencies can be used for the pulse width modulation signal. 6.270 system software used to control the motors operates at 1000 Hertz.

A PWM waveform consisting of eight bits, each of which may be on or off, is repetitiously used to control the motor. Every $\frac{1}{1000}$ of a second, a control bit determines whether the motor is enabled or disabled. Every $\frac{1}{125}$ of second the waveform is repeated.

Because one to eight bits may be set in the PMW waveform, the motors may be adjusted to eight power levels between off and full on.

2.2 Stepper Motors

Stepper motors have several electromagnetic coils that must be powered sequentially to make the motor turn. By reversing the order that the coils are powered, a stepper motor can be made to reverse direction. The rate at which the coils are respectively energized determines the velocity of the motor up to a physical limit.

Typical stepper motors have two or four coils. The shaft of a stepper motor moves between discrete rotary positions that correspond to the particular coil that was last energized. Because of this precise position controllability, stepper motors are excellent for applications that require high positioning accuracy.

Stepper motors are used in X-Y scanners, plotters, and machine tools, floppy and hard disk drive head positioning, computer printer head positioning, and numerous other applications.

Unfortunately, the 1992 6.270 kit does not include a servo motor.

2.3 Servo Motors

Servo motors incorporate several components into one device package:

- a small DC motor;
- a gear reduction drive for torque increase;
- an electronic shaft position sensing and control circuit.

The output shaft of a servo motor does not rotate freely, but rather is commanded to move to a particular angular position. The electronic sensing and control circuitry—the servo feedback control loop—drives the motor to move the shaft to the commanded position. If the position is outside the range of movement of the shaft, or if the resisting torque on the shaft is too great, the motor will continue trying to attain the commanded position.

Servo motors are used in model radio control airplanes and helicopters to control the position of wing flaps and other flight control mechanisms. They also have been used to drive the legs of Genghis, the MIT A.I. Laboratory's walking robot.

The gear reduction unit incorporated into most servo motors is quite powerful. The servo motor provided in the 6.270 kit delivers approximately 50 ounce-inches of torque.

2.3.1 Control

A servo motor has three wires: power, ground, and control. The power and ground wires are simply connected to a power supply. Most servo motors operate from five volts.

The control signal consists of a series of pulses that indicate the desired position of the shaft. Each pulse represents one position command. The length of a pulse in time corresponds to the angular position.

Typical pulse times range from 0.7 to 2.0 milliseconds for the full range of travel of a servo shaft. Most servo shafts have a 180 degree range of rotation. The control pulse must repeat every 20 milliseconds.

2.3.2 Application

For 6.270 purposes, servo motors would be excellent for operating a rotating sensor platform. A 1:2 gear-up from the servo motor to the platform could be used to yield a full 360 degrees of rotation. Because the servo includes position sensing circuitry, an external sensor to measure the position of the sensor platform would not be needed.

Servo motors would also be excellent for meshing with a gear rack, accomplishing highly controllable rectilinear motion.