energy requirements, and lesser is its demand for the bulk of the IoT applications. Consider a simple human activity detector. If the detection unit is too large to be carried or too bulky to cause hindrance to regular normal movements, the demand for this solution would be low. It is because of this that the onset of wearables took off so strongly. The wearable sensors are highly energy-efficient, small in size, and almost part of the wearer's regular wardrobe.

Check yourself

Principle of virtualization, MEMS

5.7 Actuators

An actuator can be considered as a machine or system's component that can affect the movement or control the said mechanism or the system. Control systems affect changes to the environment or property they are controlling through actuators. The system activates the actuator through a control signal, which may be digital or analog. It elicits a response from the actuator, which is in the form of some form of mechanical motion. The control system of an actuator can be a mechanical or electronic system, a software-based system (e.g., an autonomous car control system), a human, or any other input. Figure 5.5 shows the outline of a simple actuation system. A remote user sends commands to a processor. The processor instructs a motor controlled robotic arm to perform the commanded tasks accordingly. The processor is primarily responsible for converting the human commands into sequential machine-language command sequences, which enables the robot to move. The robotic arm finally moves the designated boxes, which was its assigned task.

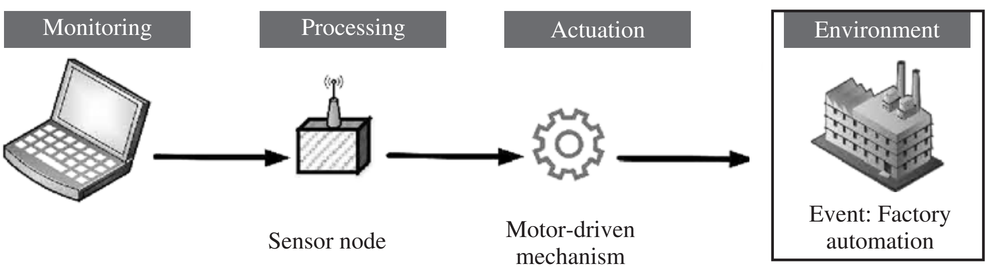

Figure 5.5 The outline of a simple actuation mechanism

5.8 Actuator Types

Broadly, actuators can be divided into seven classes: 1) Hydraulic, 2) pneumatic, 3) electrical, 4) thermal/magnetic, 5) mechanical, 6) soft, and 7) shape memory polymers. Figure 5.6 shows some of the commonly used actuators in IoT applications.

5.8.1 Hydraulic actuators

A hydraulic actuator works on the principle of compression and decompression of fluids. These actuators facilitate mechanical tasks such as lifting loads through the use of hydraulic power derived from fluids in cylinders or fluid motors. The mechanical motion applied to a hydraulic actuator is converted to either linear, rotary, or oscillatory motion. The almost incompressible property of liquids is used in hydraulic actuators for exerting significant force. These hydraulic actuators are also considered as stiff systems. The actuator's limited acceleration restricts its usage.

5.8.2 Pneumatic actuators

A pneumatic actuator works on the principle of compression and decompression of gases. These actuators use a vacuum or compressed air at high pressure and convert it into either linear or rotary motion. Pneumatic rack and pinion actuators are commonly used for valve controls of water pipes. Pneumatic actuators are considered as compliant systems. The actuators using pneumatic energy for their operation are typically characterized by the quick response to starting and stopping signals. Small pressure changes can be used for generating large forces through these actuators. Pneumatic brakes are an example of this type of actuator which is so responsive that they can convert small pressure changes applied by drives to generate the massive force required to stop or slow down a moving vehicle. Pneumatic actuators are responsible for converting pressure into force. The power source in the pneumatic actuator does not need to be stored in reserve for its operation.

5.8.3 Electric actuators

Typically, electric motors are used to power an electric actuator by generating mechanical torque. This generated torque is translated into the motion of a motor's shaft or for switching (as in relays). For example, actuating equipments such as solenoid valves control the flow of water in pipes in response to electrical signals. This class of actuators is considered one of the cheapest, cleanest and speedy actuator types available. Figures 5.6(a), 5.6(b), 5.6(c), 5.6(d), 5.6(e), 5.6(f), 5.6(i), and 5.6(j) show some of the commonly used electrical actuators.

(a) Brushless DC motor

(b) Brushless DC motor

(c) Stepper motor

(d) Geared stepper motor

(e) DC motor

(f) Relay array

(g) Hydroelectric generator

(h) Hydroelectric generator

(i) Solenoid-based flow valve

(j) Solenoid-based flow valve

(k) DPDT switch

(l) Push button switch

Figure 5.6 Some common commercially available actuators used for IoT-based control applications

5.8.4 Thermal or magnetic actuators

The use of thermal or magnetic energy is used for powering this class of actuators. These actuators have a very high power density and are typically compact, lightweight, and economical. One classic example of thermal actuators is shape memory materials (SMMs) such as shape memory alloys (SMAs). These actuators do not require electricity for actuation. They are not affected by vibration and can work with liquid or gases. Magnetic shape memory alloys (MSMAs) are a type of magnetic actuators.

5.8.5 Mechanical actuators

In mechanical actuation, the rotary motion of the actuator is converted into linear motion to execute some movement. The use of gears, rails, pulleys, chains, and other devices are necessary for these actuators to operate. These actuators can be easily used in conjunction with pneumatic, hydraulic, or electrical actuators. They can also work in a standalone mode. The best example of a mechanical actuator is a rack and pinion mechanism. Figures 5.6(g), 5.6(h), 5.6(k), and 5.6(l) show some of the commonly available mechanical actuators. The hydroelectric generator shown in

Figures 5.6(g) and 5.6(h) convert the water-flow induced rotary motion of a turbine into electrical energy. Similarly, the mechanical switches shown in Figures 5.6 (k) and 5.6(l) uses the mechanical motion of the switch to switch on or off an electrical circuit.

5.8.6 Soft actuators

Soft actuators (e.g., polymer-based) consists of elastomeric polymers that are used as embedded fixtures in flexible materials such as cloth, paper, fiber, particles, and others [7]. The conversion of molecular level microscopic changes into tangible macroscopic deformations is the primary working principle of this class of actuators. These actuators have a high stake in modern-day robotics. They are designed to handle fragile objects such as agricultural fruit harvesting, or performing precise operations like manipulating the internal organs during robot-assisted surgeries.

5.8.7 Shape memory polymers

Shape memory polymers (SMP) are considered as smart materials that respond to some external stimulus by changing their shape, and then revert to their original shape once the affecting stimulus is removed [6]. Features such as high strain recovery, biocompatibility, low density, and biodegradability characterize these materials. SMP-based actuators function similar to our muscles. Modern-day SMPs have been designed to respond to a wide range of stimuli such as pH changes, heat differentials, light intensity, and frequency changes, magnetic changes, and others.

Photopolymer/light-activated polymers (LAP) are a particular type of SMP, which require light as a stimulus to operate. LAP-based actuators are characterized by their rapid response times. Using only the variation of light frequency or its intensity, LAPs can be controlled remotely without any physical contact. The development of LAPs whose shape can be changed by the application of a specific frequency of light have been reported. The polymer retains its shape after removal of the activating light. In order to change the polymer back to its original shape, a light stimulus of a different frequency has to be applied to the polymer.

5.9 Actuator Characteristics

The choice or selection of actuators is crucial in an IoT deployment, where a control mechanism is required after sensing and processing of the information obtained from the sensed environment. Actuators perform the physically heavier tasks in an IoT deployment; tasks which require moving or changing the orientation of physical objects, changing the state of objects, and other such activities. The correct choice of actuators is necessary for the long-term sustenance and continuity of operations, as well as for increasing the lifetime of the actuators themselves. A set of four characteristics can define all actuators:

- **Weight**: The physical weight of actuators limits its application scope. For example, the use of heavier actuators is generally preferred for industrial applications and applications requiring no mobility of the IoT deployment. In contrast, lightweight actuators typically find common usage in portable systems in vehicles, drones, and home IoT applications. It is to be noted that this is not always true. Heavier actuators also have selective usage in mobile systems, for example, landing gears and engine motors in aircraft.
- **Power Rating**: This helps in deciding the nature of the application with which an actuator can be associated. The power rating defines the minimum and maximum operating power an actuator can safely withstand without damage to itself. Generally, it is indicated as the power-to-weight ratio for actuators. For example, smaller servo motors used in hobby projects typically have a maximum rating of 5 VDC, 500 mA, which is suitable for an operations-driven battery-based power source. Exceeding this limit might be detrimental to the performance of the actuator and may cause burnout of the motor. In contrast to this, servo motors in larger applications have a rating of 460 VAC, 2.5 A, which requires standalone power supply systems for operations. It is to be noted that actuators with still higher ratings are available and vary according to application requirements.
- **Torque to Weight Ratio**: The ratio of torque to the weight of the moving part of an instrument/device is referred to as its torque/weight ratio. This indicates the sensitivity of the actuator. Higher is the weight of the moving part; lower will be its torque to weight ratio for a given power.
- **Stiffness and Compliance**: The resistance of a material against deformation is known as its stiffness, whereas compliance of a material is the opposite of stiffness. Stiffness can be directly related to the modulus of elasticity of that material. Stiff systems are considered more accurate than compliant systems as they have a faster response to the change in load applied to it. For example, hydraulic systems are considered as stiff and non-compliant, whereas pneumatic systems are considered as compliant.

Check yourself

Operation of PLC and SCADA, Working principle of electric motors, applications of pneumatic and hydraulic actuators, Differences between pneumatic, hydraulic, electrical, and mechanical actuators

Summary

This chapter covered the basics of sensing and actuation in order to help the readers grasp the intricacies of designing an IoT solution keeping in mind the need to select