7

Sensors, Participatory Sensing, RFIDs and Wireless Sensor Networks

Learning Objectives

LO 7.1 Elucidate sensor technology for sensing the real world using analog and digital sensors, and examples for sensing devices for IoT and M2M

LO 7.2 Define the concepts of participatory sensing, industrial IoT and automotive IoT

LO 7.3 Describe the uses of actuators in devices

LO 7.4 Describe the uses of data communication using serial bus protocols

LO 7.5 Explain the Radio Frequency Identification (RFID) technology

LO 7.6 Explain the Wireless Sensor Network (WSN) technology

Recall from Previous Chapters

From Chapters 1 and 5 we have learnt that sensors play an important role in gathering data for IoTs and M2M. One of the components of IoT devices is hardware which consists of a microcontroller, firmware and the sensor(s) and/or actuator(s). The automobile components embed the sensors and circuits consisting of microcontrollers and firmware in a car. The sensing devices network communicates the status of each component and sensed data to the applications at an automobile service centre. An application at the centre plans the service schedule and generates alerts for the urgent actions required and the need for specific actions.

Actuators are devices used for actions, such as switching ON a set of streetlights or delivering a chocolate in an automatic chocolate vending machine and then communicating information on the Internet for a service provider application.

RFIDs and their sensors play an active role in Internet of RFIDs. RFIDs are used for identifying objects using RF. Two examples of application of Internet of RFIDs are tracking parcels, goods and delivery, and supply chain management.

WSN can be defined as 'a wireless network consisting of spatially distributed autonomous devices using sensors to cooperatively monitor physical or environmental conditions, such as temperature, sound, vibration, pressure, motion or pollutants, at different locations.'

7.1 INTRODUCTION

IoT and M2M applications need a large magnitude of data which is generated from a large number of devices, ATMs, sensors at parking slots, health devices in ICUs, machines in industrial plants, embedded components in automobiles, RFIDs, or wireless sensor networks.

IoT and M2M data is generated using sensors, embedded devices and systems

Data is generated using sensors, embedded devices and systems at the physical layer in the IoT architecture. Thereafter, the data communicates through the data-link, data-adaptation, network, application-support and application layers to the applications of IoT.

Data is used for analytics, visualisation, intelligence and knowledge discovery or controls and monitoring. Control systems use the sensors for monitoring and the actuators for actions.

Prototyping and designing of IoT need embedded device platforms, which provide connectivity to the Internet and can communicate with applications using the Internet. The applications in IoT monitor and control devices, systems and machines using the actuators.

This chapter describes technological aspects of sensing, concepts of participatory sensing in M2M devices, industrial IoT and automotive IoT. It also introduces the role of actuators and describes details of use of RFIDs and WSNs.

Section 7.2 describes sensor technology and analog and digital sensors which are used in IoT and M2M. Section 7.3 describes participatory sensing concept, industrial IoT and automotive IoT. Section 7.4 describes use of actuators. Section 7.5 describes use of data communication protocols (UART, I2C, LIN, CAN, USB and MOST) by IoT and M2M devices. Sections 7.6 and 7.7 describe technological aspects of RFIDs and WSNs.

7.2 SENSOR TECHNOLOGY

LO 7.1 Elucidate sensor technology for sensing the real world using analog and digital sensors, and examples for sensing devices for IoT and M2M

Sensor technology is a technology used for designing sensors and associated electronic readers, circuits and devices. A sensor can sense a change in physical parameters, such as temperature, pressure, light, metal, smoke and proximity to an object. Sensors can also sense acceleration, orientation, location, vibrations or smell, organic vapours or gases. A microphone senses the voice and changes in the sound, and is used to record voice or music.

Sensor technology uses sensors and electronic circuits, readers and devices

A sensor converts physical energy like heat, sound, strain, pressure, vibrations and motion into electrical energy. An electronic circuit connects to the input at a sensor. The circuit receives the output of the sensor. The output is according to the variation in physical condition. A smart sensor includes the electronic circuit within itself, and includes computing and communication capabilities.

The circuit receives energy in form of variations through currents, voltages, phase-angles or frequencies. Analog sensors measure the variations in the parameters with respect to a reference or normal condition and provide the value of sensed parameter after appropriate calculations.

The change of states with respect to a reference or normal condition senses the states in the form of 0s and 1s in digital sensors.

7.2.1 Sensing the Real World

Electronic components can function as sensors. Sensor is an electronic device in a circuit that senses a physical environment or condition. The sensor sends signals to an electronic circuit, which interconnects to a serial port interface at a microcontroller or controller or computing device.

Sensors are electronic devices that sense the physical environment

A sensor senses a specific physical condition when it exhibits a measurable change in a characteristic circuit parameter on the change in the specific physical condition or environment.

Example of Resistive, Capacitive, Diode and Transistor-based Sensors

Example 7.1 gives the characteristic circuit parameters which change with the physical conditions.

Example 7.1

Problem

Assume R is resistance, C is capacitance, I_{rev} is reverse saturation current in a p-n diode and I_{sat} is saturation current in a bipolar junction transistor (BJT). How do the characteristic circuit parameters R, C, I_{rev} and I_{sat}, sense the physical environment? How are they used for measuring the surrounding condition?

Solution

- Resistance *R*, of a specially designed wire wound on a coil is used as temperature sensor. *R* functions as a component. *R* shows variation with temperature in metal wires such as platinum. A touch-screen senses the resistive variation in *R* with the touched position. A strain sensor resistance shows the variation in *R* with the strain. Change in *R* is proportional to change in length due to strain; for example, 12 cm per 10 kilo-Ohm. A flex-sensor senses the bending on applying a force by change in *R*. Sensor resistance *R* varies on flexing with the path or local deflection profile change which senses the flex.

  Resistance of a sensor of organic solvent vapours shows measurable drop in the vapours concentration in the vicinity. The conductivity (reciprocal of resistance) of sensor increases depending on the vapour or gas concentration in the air near the sensor. Gas sensor is a metal oxide coated sensor whose resistance varies with vapour adsorption; for example, Sensor (TGS2620) of Figaro Company.

  Resistance of a photo-conductor shows measurable drop in the presence of light. The conductivity (reciprocal of resistance) of the sensor increases depending on the radiation intensity. The sensor is basically a special semiconductor sensor, which shows conductivity variation exponentially with the received light intensity.
- *Capacitance, C,* is used as proximity sensor when the capacitance of sensing component shows variation with proximity to a specific object, such as a metal part or a finger. A level sensor capacitor shows variation with level of filler in a container.

  A touched position sensor (capacitor) shows variation when a finger touches or is in the proximity or vicinity to the touch position on a screen. The variation in *C* is as per the touched position. A position when corresponds to a menu item displayed to the user, then the selected application runs on touching.
- Reverse saturation current I_{rev} of a *p-n* junction diode is used as a temperature sensor when that shows measurable variations within the temperature range of the study.
- A specially made *p-n* diode with a window-entry for radiation at the junction can be used as a photo sensor. The sensor functions as an incident radiation-intensity sensor when the diode reverse-saturation current I_{rev} shows a measurable variation with radiation energy.
- A specially made BJT with a window-entry for radiation at the junction is used as a photo sensor (phototransistor). Saturation current I_{sat} between collector-emitter in the BJT shows measurable variation within incident infrared or light radiation intensity.

A characteristic parameter of a circuit changes with the physical conditions. Technology that facilitates such changes due to sensing is also used in mobile phone. A mobile phone can sense surrounding conditions. The touchscreen of a mobile phone can senses a finger touch and gestures. Smartphones have resistive and capacitive sensors, photodiode current-based sensors, and acceleration, gyroscope, temperature and pressure sensors. The sensors enable the functioning of applications and games.

> Mobile phones use a number of sensors, such as finger touch and gesture via a sensor on touchscreen

A microcontroller is an associate computing device with a sensor circuit which calculate the touched position and maps it to a user command when a resistive-based touchscree is used. Then the mobile phone takes further actions as per the command.

Analog Sensors

Analog sensors use a sensor and an associated electronic analog circuit. Analog sensors generate analog outputs as per the physical environmental parameters, such as temperature, strain, pressure, force, flex, vapours, magnetic field, or proximity. Resistance of the sensing component may show measurable changes with surrounding pressure or strain or magnetic field or humidity. Resistance of a pressure sensor increases on pressure which creates a strain on the sensor. A flex sensor, for example, of 2.2 inch or 4.5 inch length shows that its resistance across the sensor strip increases on flexing due to a changed path and deflection of the sensing resistor.

> Analog sensors generate analog outputs as per the physical environmental parameters such as temperature or strain

The measurement of analog output from a sensor circuit is performed as follows— the sensor output is given to the input of a signal conditioning-cum-amplifying circuit (SC). The SC output is the input to an Analog-to-Digital Converter (ADC). The ADC gives a digital output; for example, 8 or 12 bits. This output is read using a microcontroller. Microcontroller reading and computation gives the value of the sensed parameter value and shows the physical condition around the sensor.

Reading Temperature from Resistance Sensor

Example 7.2 shows how an analog sensor and a sensing resistor with associated electronics enables the sensing and measuring of temperature.

Example 7.2

Problem

Assume an electronic circuit with a sensing component resistance as a physical object. How are temperatures sensed?

Solution

A resistor in the form of a wire or a component can be a part of the electronic circuit. Ohm's law states that resistance remains constant only as long as physical conditions remain the same. The resistor functions as a sensor when its value changes measurably within the required temperature range for sensing.

The measurements can be first made using two standard or reference temperature points, such as 0°C and 100°C. An equation or table can be prepared for the sensing component resistance *R* values as a function of the temperature *T* in °C. When changes are linearly related to the change in the physical environment then the equation is used. When changes are nonlinearly or

> An equation or a table relates the sensor resistance with the sensed and measured parameter value at a given physical condition

exponentially related to the change in the physical environment, then use of the table is preferred.

When temperature, such as of oil or coolant plate in an M2M or IoT device in an automobile needs to be sensed then a simple electronic circuit uses the sensing component at the sensed object. The associate computing device calculates the temperature value at the measuring instance. Figure 7.1 shows a circuit consisting of a resistance bridge. The bridge has one sensing resistor at the sensing object and three fixed (standard) resistors. The figure shows a microcontroller using an electronic circuit with a port connected to sub-circuits, serial port interface, ADC, signal conditioning amplifier and resistance bridge.

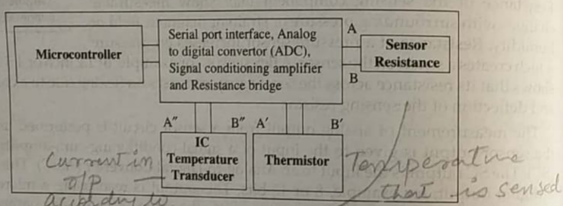

Figure 7.1 Microcontroller serial port connected to sub-circuits—serial port interface, ADC, signal conditioning amplifier, resistance bridge and sensor resistance outputs A ad B. Alternatively circuit connects to a thermistor output at A′ and B′ or IC based temperature-transducer output at A″ and B″

A transducer induces current or voltage. The output changes as per a change in the physical energy at input. An IC-based circuit for a temperature-transducer induces current in the output according to the heat energy, represented by the temperature.

Microcontroller is a computing device which reads the input at its ports, saves the reading in memory and then the reading is used for computations and communication.

Reading from Capacitive Sensor

Example 7.3 shows how a sensing capacitor enables sensing using a capacitance bridge.

Example 7.3

Problem

Assume an electronic circuit with a sensing component capacitor as a physical object. How are the changes of capacitance sensed when using an electronic circuit with a sensing capacitor as a physical object?

Solution

Consider two cases:

1. When a metal part is present in the vicinity of a parallel plate capacitor, the capacitance *C* changes and proximity distance is sensed.
2. When a finger reaches near a screen, and the screen has a metallic grid at its base, then *C* will change depending upon the touched position or *C* varies with time when the finger is approaching towards the vicinity to a menu item on the screen.

C of a sensor object is a part of a capacitive bridge. The associate computing device calculates the proximity distance in case 1 and touched position in case 2 as well as the successive variations. Microcontroller is a computing device which reads the input at its ports, saves the input at memory, and then uses the data for communication over the Internet.

Figure 7.2 shows a circuit using a capacitance bridge. The bridge consists of the sensing capacitor (object) and three fixed (standard) capacitors. The figure shows a microcontroller-based electronic circuit with port connected to four sub-circuits, serial port interface, ADC, signal conditioning amplifier, diode and capacitance bridge.

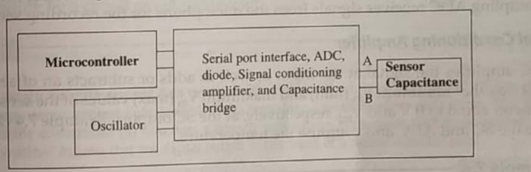

Figure 7.2 Microcontroller electronic circuit; port connected to sub-circuits; serial port interface, ADC, diode, signal conditioning amplifier and capacitance bridge, and sensor capacitance at A and B

Serial Port Interface

A serial port interface with the ADC has an advantage that the ADC 8 or 10 or 12 bit output is input to the interface, and the interface sends the input to the serial port at the microcontroller. Serial port interface has just two terminals in the output (Section 7.5).

Analog to Digital Converter

A microcontroller may consist of an in-circuit ADC or multiple inputs ADC. It processes the digital output from the in-circuit ADC. Alternatively, a port accepts the digital input consisting of 1s and 0s through an external ADC. An 8-bit port accepts the 8-bit input which corresponds to 0 to 255 decimal (255_d). The port

Analog sensor circuit connects to a signal conditioner amplifier, then to an analog to digital converter accepts the 12-bit input in two cycles, viz. once 8 bits and then 4 bits which correspond to 0 to 4096 decimal (4096_d). The analog output from a signal conditioning amplifier connects to the ADC input, V_{in}.

The decimal value of ADC digital output relates V_{in} and is in the form of the binary bits at the input. The decimal value of binary bits is proportional to the ratio of analog input V_{in} and reference voltage V_{ref}. Assume a microcontroller functions with V_{DD}, the microcontroller power supply + ve input and V_{SS} microcontroller power supply -ve input.

Assume $(V_{DD} - V_{SS}) = 5$ V. Half of the reference voltage $= (V_{ref}/2)$ is applied to ADC. Half reference voltage can be 1.65 V ($V_{ref} < 5$V. $(V_{ref}/2) << (V_{DD} - V_{SS})$.

Assume an ADC is of 8 bits. $[2^n - 1 = 255_d]$ Then ADC digital output $= V_{in} \times 255_d / V_{ref}$, because V_{ref} is the maximum input which can be applied to the ADC which gives maximum digital output, 11111111_b, which means 255_d.

Sampling ADC

Sampling means that an ADC accepts input signals at specified periodic intervals and converts them into digits. The interval is set as per the signal frequency and other needs. The applications of sampling ADC are many. For example, while recording voice or music, the sampling ADC receives signals from the microphone for the recording sensor.

Signal Conditioning Amplifier

An SC amplifies the signal at the input as well as adds or subtracts an offset voltage in such a way that minimum V_{in} (min) and maximum V_{in} (max) values of the sensed physical parameter equal to 0 V and V_{ref}, respectively, at the SC outputs. Example 7.4 clarifies how to use the SC and ADC and compute the temperature.

Example 7.4

Problem

How are the voltage inputs to ADC and signal conditioning amplifier designed when using a sensor for temperature? How is the sensed temperature computed? Assume that the sensor measures temperatures between −10°C and +40°C.

Solution

Output of the signal conditioning amplifier (SC) in the circuit shown in Figure 7.1 is set such that the voltages which apply to ADC inputs are always between 0 V and V_{ref} (reference voltage input) at the ADC. Since temperature range is between (T_{min}) and (T_{max}), when temperatures to be sensed are between −10 °C (T_{min}), and + 40°C (T_{max}), then the ADC input = SC output should be 0V when sensor is at −10 °C and input to ADC should be V_{ref} when sensor is at 40°C. (T_{min}) and (T_{max}) difference is 50°C.

Software in the microcontroller uses a predefined table or equation to compute the sensed temperature, T. The table saves T = 40°C when ADC output is 255_d (= 11111111 binary). The sensed temperature is [50°C × n/255 −10°C], when the ADC output in decimal equals n. The sensed temperature is −10°C when the ADC output equals 0_d.

The same approach of using SC, ADC and computations are followed not only for temperature but also for other sensors, such as, strain, pressure, force, flex, vapours, magnetic field or proximity distances sensors.

Digital Sensors

A specific electronic component or circuit gives digital output 1 or 0 (on-off state) or output of 1s and 0s as a binary number (corresponding to a set of on-off states). A digital sensor uses the sensor and has an associated electronic circuit which gives digital output. The output 1 or 0 (1s and 0s) is read through a port in a microcontroller. This circuit can be used for sensing a sudden change in specific physical state or condition or can be used for sensing a sudden change in specific set of physical states or conditions.

Digital sensor uses the sensor and an associated electronic digital circuit to read 1s and 0s

Sensing of an On-Off State

A number of conditions needs detection using the concept of digital output of on-off state. Example 7.5 gives four cases on how to sense an on-off state, which means binary 1 and 0 output for reading by a circuit or microcontroler.

Example 7.5

Problem

(a) How is the switch on state sensed? How does one-bit digital output, 1 or 0 generate? (b) How does a streetlight sensor sense ambient light condition? (c) How does a rotating wheel state sense that it has reached at a specific orientation? (d) How does a linearly moving part state sense that it has reached at a specific linear position? Assume that the digital output is the input of a microcontroller port.

Solution

(a) Figure 7.3 shows that the circuit (top left) consists of one end A of the resistance connected to ground potential (negative end of the supply). The other end B connects to the end C of the switch. A switch can have two states on or off and gives two outputs 1 or 0. The other end D connects to the supply voltage V+ (= 5V) terminal. Microcontroller port pins connect C and A.

Alternative (top right) circuit is that base end, B of BJT which connects to one end of the switch. The emitter end, E of BJT connects the ground potential. The collector end, C connects to +ve end of supply Vcc (= 5V) through a resistance. The switch one end connects to the microcontroller port pin. Microcontroller port pin other end connects to C.

Another alternative (bottom middle) circuit is that switch one end B connects to MOSFET (Metal-Oxide Field Effect Transistor) source end S. The drain end D of MOSFET connects to the supply voltage + terminal, VDD through a resistance. The gate G connects to end A of the switch. The inputs at the microcontroller port pins are from B and D.

The circuits give 1s and 0s at port pins when switch state is off and on.

The right side top circuit voltage at collector C < 0.8 V is taken as 0 and > 2.8 V is taken as 1 and VCC is at 5V.

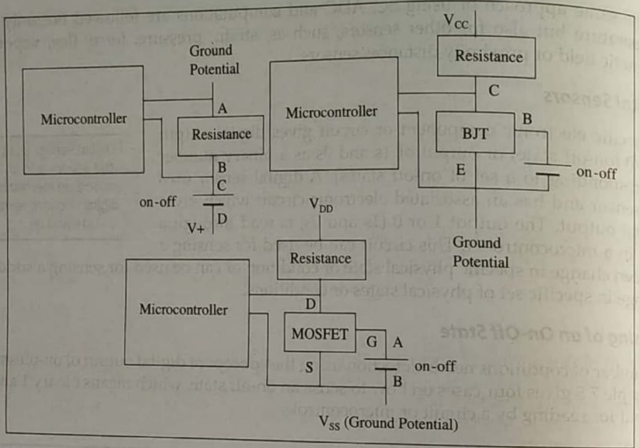

Figure 7.3 Three microcontroller electronic circuits for sensing On and Off states on generation of output 1 and 0 for the port pin

The middle bottom circuit voltage at drain D (with respect to supply terminal, VSS) less than (1/3) × (VDD – VSS) is considered as 0 and when greater than (2/3) × (VDD – VSS) that is taken as 1.]

(b) An environment ambient condition sensor at a streetlight senses the ambient light condition using a phototransistor, FPT. FPT detects the environment ambient light intensity above a threshold. Figure 7.4 shows a circuit. The circuit gives 1 in output when ambient light intensity is below threshold and gives 0 in output ambient light intensity is above threshold.

(c) A rotating wheel gives two outputs 1 or 0, when it has a pair of LED or IR-LED (light emitting diode or infrared LED) and phototransistor (FPT) is on two sides of a slot in the wheel. Figure 7.5 shows the circuit. The circuit gives 1 in output when a slot of rotating wheel reaches near the FPT on completing a rotation and gives 0 in outputs till that is revolving towards the completion of the next revolution. The light to FPT does not block till the wheel completes the revolution.

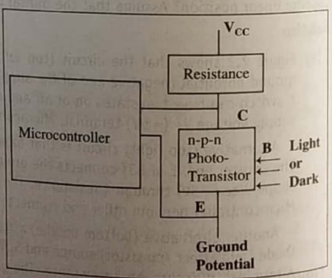

Figure 7.4 Microcontroller electronic circuit for a streetlight environment ambient condition sensor which senses two states and generates two outputs 1 or 0 for the port pin

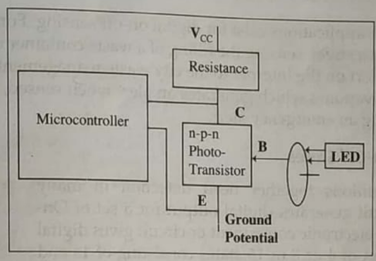

Figure 7.5 Microcontroller electronic circuit for a rotating wheel, rotation-completion sensing which senses two states (completion or incomplete) and generate two outputs 1 or 0 for the port pin

A Microcontroller port P_0 pin receives the input 1 or 0. Number of 1s within a specific time interval divided by the interval gives the rotational speed revolutions per minute (rpm). The values of the rpm and circumference of the tyre enable the computation of speed in km/hour in the automobile, as rotator motion converts to linear motion in the automobile.

(d) A moving part reaching at a specific location is sensed as follows: The part is attached with a light blocker. When the part reaches the empty space between a pair of LED (light emitting diode) and FPT, the blocker blocks the light falling on the FPT, and the circuit gives 1 in output. The circuit gives output = 0 when the part is not in the vicinity and is not blocking the light to FPT. Figure 7.6 shows the circuit.

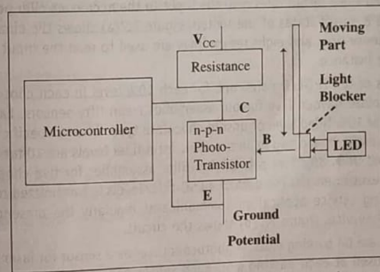

Figure 7.6 Microcontroller electronic circuit for sensing when a moving part reaches at a specific location and sensing two states (reached or yet to reach) and generate two outputs 1 or 0 for the port pin

A number of other applications exist for digital on-off sensing. For example, sensing of presence of traffic on a street, sensing the filling of a waste container up to a certain preset level that sends an alert on the Internet to the city waste management service, sensing the presence of organic vapours which generates an alert when sensed, sensing gas leakage or fire and generating an emergency alert.

Sensing a Set of On-Off States

> Digital sensor circuit connects to the microcontroller port

A number of conditions together need detection in many applications. A circuit generates digital output for a set of On-off states. A specific electronic component or circuit gives digital output, such as, a set of 4 or 8 or 16 states consisting of 1s and 0s for sensing a set of discrete changes in a specific set of physical states or conditions. The output connects to a port input of a microcontroller, which reads the input at a given instance. Example 7.6 clarifies this.

Example 7.6

Problem

(a) How does an array of 8 switches generate a set of 1s and 0s? (b) How is the "communication of a number of chocolates for each type of flavours that remain unsold at each instance of 10% sale of each type" in Internet of Automatic Chocolate Vending Machines done? (c) How does the data of unoccupied parking slots be identified among the number of parking slots and used in Internet of Parking Spaces?

Solution

(a) An array of 8 switches generates 8-bit input for a port. An output port pin in a microcontroller sends a sense signal = 1 and the 8 return lines give the input to the microcontroller port. The 8-bit port reads the input to sense 8 on-off states of the switch. Figure 7.7(a) shows the circuit. When a keyboard is used, then eight sense lines and eight return lines are used to read the input and sense which key is pressed at a given instance.

(b) Assume five arrays of ten FPT-LED pairs, one for each 10% level in each chocolate filler assembly for each type of chocolate flavour. Five flavour assemblies mean fifty sensors. Each sensor generates an on state signal 1 for 10% filled level of unsold chocolate type. When a specific flavour sells 80%, then eight sensors give eight 1s and two 0s in an array. Total filler levels are 10 for each chocolate flavour. Total sum of 1s and 0s is 80_d. Five sets of five-filler assemblies for five chocolate flavours are read cyclically at the preset intervals. The data of all 50-filler levels is transmitted to the Internet and then a chocolate vending service application communicates regularly the presence of unsold chocolate percentages to the service. Figure 7.7(b) shows the circuit.

(c) Assume that there are 64 parking slots. A photoconductor as a sensor for laser diode light beam block detection can be used at each parking slot. Each sensor generates an on state signal 1 whenever a slot gets vacant. An array of eight slots is selected by three encoded lines from microcontroller. A set of eight-slots status in an array is read cyclically. Each array is cyclically selected. Data of all 64 slots is transmitted to the Internet and then a parking service application communicates regularly the presence of vacant slots to the vehicles passing through the traffic lights nearby to the parking facility. Figure 7.7(c) shows the circuit.

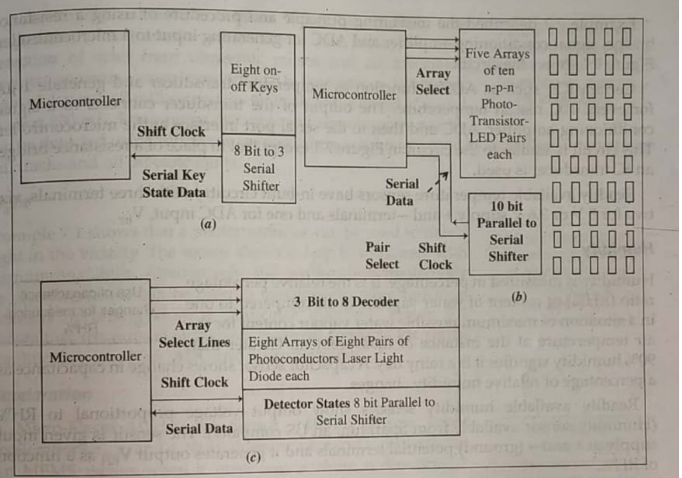

Figure 7.7 Microcontroller electronic circuits for sensing on-off states of (a) an array of 8 switches, (b) two-dimensional array of 50 sensors for 10 sales level when automatic chocolate vending machine sells 5 flavours, and (c) array of 64 sensors at parking slots with a sensor for each slot

7.2.2 Examples of Sensors

Temperature

A component called thermistor, shows larger changes in resistance within narrow environment temperature range (120°C to –90°C). An NTC thermistor shows negative temperature coefficient which means a drop in the resistance value with rise in temperature.

Thermistor finds applications in home automation or in sensing the clouds. The output of thermistor connects to the circuit of a signal conditioning amplifier, ADC and then to microcontroller serial port, similar to the circuit in Figure 7.1 except that in place of a resistance-bridge, a thermistor circuit is used.

A temperature sensor is called PTC, when it exhibits a Positive Temperature Coefficient. Resistance value of a PTC resistor rises with rise in temperature. A thin wire of platinum or other metallic alloys shows linear changes with its temperature. These can be used for sensing temperature and measuring the values over very wide ranges of temperatures, say (0–1600°C).

Example 7.2 described the measuring principle and procedure of using a resistance bridge, signal conditioning amplifier and ADC for generating input to a microcontroller. Figure 7.1 shows the circuit.

Certain ICs, such as AD590, function as temperature transducer and generate 1 μA for every 1°C rise in temperature. The output of the transducer connects to a signal conditioning amplifier, ADC and then to the serial port interface at the microcontroller. This circuit is similar to the circuit in Figure 7.1 except that in place of a resistance bridge, an IC transducer is used.

Readily available temperature sensors have in-built circuitry with three terminals, viz. two for 5 V or 3.6 V supply + and – terminals and one for ADC input, V_{in}.

Humidity

Humidity is measured in percentage. It is the relative percentage ratio (RH%) of content of water vapours in air compared to one in a situation of maximum possible water vapour content for the air temperature at the instance of measurement. Greater than 90% humidity signifies it is a rainy day. A capacitor sensor shows change in capacitance as a percentage of relative humidity changes.

Use of capacitance changes for measuring RH%

Readily available humidity sensors show output voltage proportional to RH% (Humidity sensor available from Sparkfun, an US company). The sensor is given input supply at + and – (ground) potential terminals and it generates output V_{RH} as a function of RH%.

Figure 7.2 shows a circuit for sensing using capacitive sensors, except that in place of capacitance bridge output, the sensor circuit is in-built in readily available sensors. V_{RH} is directly given to the ADC, and ADC output to the serial port interface at the microcontroller. The circuit can be used for measuring RH%. The computations give RH%.

Distance

Infrared (IR) sensor is useful for a 0.15 m to 0.8 m range of object. IR sensor works on the principle that when a narrow beam IR LED sends radiation at an inclined angle, the nearby phototransistor FPT receives the reflected radiation after travelling two times the object distance. The reflected radiation delay (= 2 × 3.3 ns per m) between transmitted and reflected signal is proportional to the distance. The distance can be measured for object from 0.1 m to 0.8 m. Above 0.8 m, the reflected intensity may be insufficient for detection and below 0.15 m, the time interval is less than 1 ns, which inhibits the detection.

Use of time intervals between IR pulses and reflected pulses for measuring the distance of an object

Readily available distance-based (IR) sensors shows output voltage proportional to distance (Sparkfun distance IR sensor). The sensor LED is given input supply at + and – (ground) potential terminals and IR-FPT along with internal circuitry generate output V_{dis} as a function of distance. V_{dis} is directly given as input to the ADC and ADC output to the microcontroller serial port. The computations give the distance.

Alternatively, ultrasonic sensors send the pulses. The frequencies of ultrasonic waves are of few kilocycles. The detection of echo from ultrasonic pulses and an associated circuitry generate a signal proportional to the distance. Ultrasonic wave delay is 2 × 3 millisecond/meter in air as the speed of sound in air is 330 m/s. Long-range distances and any obstacles nearby can be detected using ultrasonic sensors. These sensors are used in industrial automation, rail tracks and oil pipeline faults.

Use of time intervals between ultrasonic pulses and their echoes for measuring distance from an object

Light

Example 7.1 shows that a photoconductor can be used to detect light in the vicinity. The sensor shows a drop in resistance with surrounding light. Alternatively, the p-n junction photodiode or phototransistor can be used to measure incoming radiation intensity incoming from a particular direction. Figure 7.1 shows that the output of the sensor circuit connects the signal conditioning amplifier, ADC and microcontroller.

Use of photoconductor, p-n junction photodiode or phototransistor for measuring the intensity of light

Acceleration

A Micro-Electro-Mechanical Sensor (MEMS) detects linear accelerations a_x, a_y and a_z along three axes x, y and z, respectively. An MEMS moves when a mass moves along a direction. A mechanical movement has three components. The variations cause the variation in three capacitance values, C_x, C_y and C_z. The value of each C depends on the space between two plane surfaces, which varies on acceleration along an axis. These capacitances are part of an electronic circuit and the resulting voltage variations give the a_x, a_y and a_z.

Use of MEMS for measuring the acceleration components in three axes by capacitive variations in three axes

An accelerometer sensor is used in new generation mobile phones. The display screen image and menu items rotate and align horizontally or vertically on detecting the three components using the sensor when it rotates along with the phone. The accelerometer also detects up/down, right/left and front/back accelerations given to the device by the user.

Sparkfun ADX335 is a readily available accelerometer sensor. The accelerometer is given input supply at + and – (ground) potential terminals and it generates three outputs, V_x, V_y and V_z as a function of time. The computations give a_x, a_y and a_z. Figure 7.8 shows the accelerometer circuit.

Vibrations and Shocks

Alternatively, MEMS may use piezoelectric effect in place of capacitive change effects. The effect observed in certain specific materials is accumulation of electric changes on surfaces due

MEMS measures the vibrations and shocks by changes due to piezoelectric effect

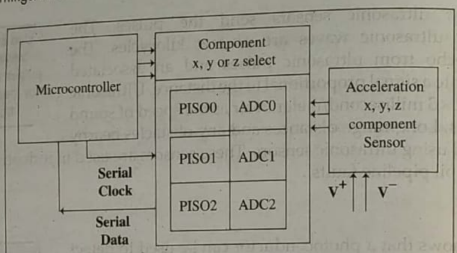

Figure 7.8 Microcontroller electronic circuit for measuring three acceleration components from the accelerometer sensor

to mechanical compression of the piezoelectric material. The rate of change of number of charges with time implies a flow of current. Vibrations create repeated compression and decompression. An associated electronic circuit generates output according to the intensity of vibrations. The circuit also senses the mechanical shocks. A user initiates the vibrations or shocks, or the device shakes when it falls, then the in-built sensor in the mobile senses these changes and the system takes action as programmed.

Angular Acceleration and Change in Direction (Angle)

Gyroscope is a sensor which measures the change in angular velocity (angular acceleration) and the change in direction (angle). An application takes measurements using a gyroscope or accelerometer and the system initiates actions as programmed. For example, mobile gaming application uses in-motion gestures of a player when deploying a gyroscope.

Orientation and Direction Compass

A gyroscope can be used as an electronic compass or a digital compass as it shows the change in direction (angle).

Alternatively a digital compass can also be used. A compass shows the directions—North, South, East and West. It also shows the direction in which an object is inclined. The compass is a very simple device used for navigation. It has a magnetic strip which aligns towards the Earth's magnetic north under the influence of the Earth's magnetic field. The compass shows by how many degrees ϕ the device's *north* is inclined from the actual Earth's magnetic north in a clockwise direction. Mobile device's *north* means the screen's upper direction, *south* the lower, *west* the left and *east* the right.

A digital compass is an electronic device used to detect the orientation or direction with respect to the *north* in degrees. The compass gives a digital output in terms of a sequence of 1s and 0s. A readily available digital compass sensor sends 1s and 0s to the

microcontroller serial port. The sensor is given input supply at + (V_{CC}) and – (ground) potential terminals and it connects serial-port terminals, SCL (Serial Clock) and SDA (Serial Data) (Section 7.5). The sequence of serial bits corresponds to a byte (8-bit binary number). For that number computation give angle ϕ with respect to the north direction.

Magnetic Sensors/Magnetometer

Example 7.7 explains sensing principle and procedure.

Example 7.7

Problem

How does a magnetometer show the direction and changes in the magnetic field?

Solution

A magnetometer present in a device enables three-dimensional interactions between a tiny magnet M1 in the device and a nearby iron magnetised piece M2 without touch. It uses the magnetic field created in the environment of the device. The magnetometer is also used as an orientation, proximity and distance sensor for iron or steel objects in industrial automation.

One application also identifies presence of iron or steel objects and switches off the phone upon detection. Another application monitors the changes in magnetic fields of M1 and identifies the gestures of the user.

Electric Current

Alternating Current (AC) is detected by a miniature transformer and its associated circuitry. A Direct Current (DC) flows in one direction at all instances. It detects using a sensor circuit, which detects the magnetic field by flowing current. Readily available electric current i and voltage v or power (product of i and v) are used. They can connect to the microcontroller using its associated circuitry. The computation can be done in the microcontroller. A wireless transmitter can transmit the data through Wi-Fi to the utility company.

Sound

A microphone is used to sense sound. A readily available electronic board with a microphone connects to the microcontroller, which can control an actuator for actions based on the sensed sound, or recognise the voice and then take required action, such as dialing a number using the actuator circuit or switching on the car.

Sensing the Things

Reading Barcodes

Bar coding uses 1D or 2D code

A barcode is a representation of data. The data relates to the object where the printed code strip is attached. The code is read by an optical scanner. Earlier a barcode would systematically represent data by varying the widths and spacing of parallel lines. The code was a linear or one-dimensional code (1D). Later, barcodes evolved into rectangles, dots, hexagons and other geometric patterns in two dimensions (2D). The 2D system use symbols which are also referred to as barcodes.

A barcode reader is a scanner for a printed code called the barcode. An electronic device reads the output for a port of microcontroller or computing device or computer. The scanner has a light source. When it is switched on, the light impulses pass through a lens and focuses on the black and white spaces of the barcode. The light source can be laser based or LED based.

Reflected light sensor or CCD (Charge Coupled Device) detector at the scanner along with an associated decoder circuit converts the optical impulses into electronic pulses and analyses the barcode's image data. The resolution commonly used is of dimension 0.33 mm of the printed code. The sensor sends the contents of the barcode as 1s and 0s at the input port of the computing device.

QR Code

QR code is an abbreviation for Quick Response Code. It was first used in automotive industry. Its applications are product identification, tracking, marketing and document management.

The QR code uses standardised encoding modes, such as numeric, alphanumeric, byte/binary or other. The code stores the data efficiently and is extendable. It is now popular in industries other than the automotive industry. It is read faster and the data stored is more than that using a standard Universal Product Code (UPC).

The QR code consists of black square dots arranged in a square grid format on a white background. The required data is at patterns in both horizontal and vertical components of the image. A scanner or camera reads the code and the data is processed using an error-correction method called Reed Solomon method. The processing takes place till the process results in appropriate interpretation of the data.

Motion Sensors for Moving Objects

Motion or speed is measured in m/s. The sensor measures delay between successive reflected IR light pulses. An LED source is an IR light source and a phototransistor is an IR sensor. Alternatively, ultrasonic wave echoes can be used to sense the motion of light. The sensor measures the delay between successive echoes.

Readily available motion sensors, such as Sparkfun sensor show output voltage proportional to motion. The sensor is given input supply at + and – (ground) potential terminals and it generates output V_m as a function of m/s.

The computations give variation in the speed of nearby objects and also show vibrations. Security systems use the motion sensors to communicate data on the Internet and raise security alarms.

Pressure Sensors

Pressure P is measured as force per m^2. Pressure can be sensed in a number of ways. The sensor is called pressure transducer, pressure transmitter, pressure sender or pressure indicator. Piezometer pressure transducer uses a piezoelectric object between two surfaces. The compression creates electric charges on the opposite surfaces of the object. The flow of charges generates current and voltages, which provide the measure of pressure.

> Pressure sensors use the resistance changes due to strain. Alternatively, they use piezoelectric effect

A resistive sensor also measures variation of resistance with force. The force creates stress and thus the strain.

Readily available pressure sensors, such as Sparkfun sensor show output voltage proportional to pressure. The sensor is given input supply at + and – (ground) potential terminals and it generates output V_P as a function of P.

Application of pressure sensor can be explained as, a tyre pressure monitoring system uses the pressure sensors on each tyre. The sensors communicate the tyre pressure in each tyre, and a corresponding monitoring circuit sends alerts on the dashboard of the vehicle.

Figure 7.1 shows the circuit for sensing using resistance sensors, except that in place of resistance bridge output, the sensor circuit is in-built using readily available sensors. V_P is directly given to the ADC, and ADC output to the serial port interface at the microcontroller. The circuit can be used for measuring P. The computations give the pressure, P.

Environmental Monitoring Sensor

Environment parameters are temperature, humidity, barometric pressure and light. A collective use of these parameter sensors enable monitoring of the environment. The data of these sensors adapts to the requirement and sends communication on the Internet to the cloud or web for the environment monitoring applications. For example, light environment on the streets monitors the lights (Examples 1.2 and 5.5).

Location Data

Determining location of an object means finding its distance from several fixed locations which are in multiple directions and also measuring the intensity of light or IR or ultrasonic waves enables computations for a location, in case the source location intensities and attenuation per metre is known.

GPS

Location determination can be done using a Global Positioning System (GPS), also known as Geographical Positioning System. A user can receive the location from a service provider. The service provider finds the GPS location through signals from satellites. The service provider finds the user location with respect to the service provider through its base stations.

Camera

Camera is an image sensor. The camera uses CCD, which consists of a large number of pixels, exposed to the light from the image. It accumulates charges on each of the pixel present at a large number of horizontal and vertical coordinates. The charge accumulation is as per the intensity of light at the corresponding pixel coordinate in the image. Coloured camera has set of R, G and B (Red, Green and Blue) light intensity components at each pixel coordinate.

The camera generates a file from the R, G and B intensities at each image pixel. The file gets saved in the memory after compression in jpg or gif or any other standard format. A computer communicates the saved file to the Internet for applications such as industrial IoT, home security systems, ATM security systems, automotive IoT or participatory sensing IoT.

LIDAR

LIDAR (Light + Radar) [Laser Imaging, Detection and Ranging] sensors and laser 3D imaging technology enables remote sensing and imaging. It finds distances by throwing light using laser on target. The sensor senses the reflected light which enables computations of distance.

Laser 3D Imaging

3D imaging is feasible using laser 3D imaging technology. The technology uses both scanning and non-scanning systems. 3D gated viewing laser radar is a non-scanning system using pulse laser and fast gated camera.

Reconfirm Your Understanding

- Sensors can sense temperature, humidity, acceleration, angular acceleration, object distance, orientation angle with respect to a fixed direction, magnetic object proximity, touch and gestures of users, motion, sound, vibrations, shocks, electric current and environment conditions.
- Many IoT applications need data generated from sensing devices. A sensor converts physical energy like heat, sound, strain, flex, pressure, vibrations and motion into electrical energy. An electronic circuit is associated with sensor. The circuit receives the output from the sensor. The output is according to the variation in physical parameters or state.
- Sensors are of two types—analog and digital.
- A circuit parameter can be used as a sensor when it shows measurable variation with heat, sound, strain, pressure, vibrations and motion.
- A complex sensor includes the output processing circuit and computing and communication capabilities. Digital sensing needs a circuit to generate 1 or 0 or binary output of 1s and 0s for storing, computing and communication device. A sensor can use a phototransistor-LED pair and digital circuit to generate 1s and 0s.
- A set of digital sensors sense the number of chocolates of each type of flavour remaining unsold and communicate in IoT application of automatic chocolate vending machines (Example 5.5).

- Digital sensors sense unoccupied parking slots and digital output identifies the unoccupied slots among the number of parking slots. These are used in Internet of Parking Spaces. Sensor uses photoconductor-light beam pair and digital circuit.
- MEMS is a microelectromechanical sensor that detects linear accelerations a_x, a_y and a_z along three axes x, y and z, respectively.
- Things get sensed and identified by barcode readers or QR codes, and associate circuit communicates the object identity and object document information to the Internet.
- The identity, location, document information, pressure, motion, environment parameters and other characteristics data communicate to the Internet for IoT applications.

Self-Assessment Exercise

1. What are the characteristic parameters which change with physical environment and therefore are used for sensing applications? ★
2. What are the circuits for measuring variation in resistance with respect to temperature? Compare these and describe their application. ★★
3. Draw a circuit for measuring variation in capacitance with respect to an organic solvent vapour concentration using a microcontroller? ★
4. When do you use an analog sensor and a digital sensor? ★
5. What is a smart sensor? What are the capabilities of a smart sensor? ★★★
6. Why and when is ADC required? What does a signal-conditioning amplifier require before the ADC? ★★
7. How do you measure temperature in range –20°C and +100°C with a resolution of 1°C? ★★★
8. Tabulate the sensors for temperature, level of filling in a container, pressure, tyre-pressure, humidity, ambient light intensity, traffic in proximity, acceleration, distance of in-front object, location with respect to fixed locations, object proximity, metallic object proximity, iron object proximity, orientations with respect to north, sound, vibrations and empty parking spaces and their characteristic parameters which enable sensing the changes and their values? ★★
9. How can a sensor for sensing four states of filling a waste container, viz., below 80%, up to 80%, up to 90% and full 100%, be designed for a city waste management service? ★★★
10. What is an MEMS? What are the physical entities which are sensed using an MEMS? ★★
11. What is piezoelectric effect? What are the physical entities which are sensed using piezoelectric effect? ★★

Note:
★ Level 1 & Level 2 category
★★ Level 3 & Level 4 category
★★★ Level 5 & Level 6 category

12. How is sound sensed and voice recognised? ★
13. How do you sense the things and identify product information using a barcode reader? What are the applications of IoTs when using barcode sensors? ★★
14. What is QR code? How do you use QR code in the applications of IoTs? ★★
15. How is the motion of a moving object sensed? ★

7.3 PARTICIPATORY SENSING, INDUSTRIAL IoT AND AUTOMOTIVE IoT

LO 7.2 Define the concepts of participatory sensing, Industrial IoT and Automotive IoT

Information collected from sensors of multiple heterogeneous sources can lead to knowledge discovery after analytics and data visualisation. A web source defines Participatory Sensing (PS) as "sensing by the individuals and groups of people contributing sensory information to form a body of knowledge". Deborah Estrin, University of California, Los Angeles now at Cornell University, defines participatory sensing as, "Participatory sensing is the process whereby individuals and communities use evermore-capable mobile phones and cloud services to collect and analyse systematic data for use in discovery."

A participant of a PS process can be sensors used in mobile phones. Mobile phones have camera, temperature and humidity sensors, an accelerometer, a gyroscope, a compass, infrared sensors, NFC sensors, bar or QR code readers, microphone and GPS. Mobiles communicate on the Internet the sensed information with time, date and location stamps.

Applications of PS include retrieving information about weather, environment information, pollution, waste management, road faults, health of individuals and group of people, traffic congestion, urban mobility, or disaster management, such as flood, fire, etc. Participatory sensing has many challenges such as—security, privacy, reputation and ineffective incentives to participating entities.

Figure 7.9 (a) shows the sources of data in the PS process for IoT applications. Figure 7.9 (b) shows the phases of a PS process. Phase 1 is coordination, in which the participants of a PS process organise after identifying the sources. Next two phases, i.e. phases 2 and 3 involve data capture, communication and storage on servers or cloud. Next two phases, i.e. phases 4 and 5 involve PS data processing and analytics, visualisation and knowledge discovery. Last phase, i.e. phase 6 is for initiating appropriate actions.

7.3.1 Industrial IoT

Industrial Internet of Things (IIoT) involves the use of IoT technology in manufacturing. IIoT involves the integration of complex physical machinery M2M communication with the networked sensors and use of software, analytics, machine learning and knowledge discovery. Example of the functions of IIoT are refining the operations for manufacturing or maintenance, or refining the business model of an industry.

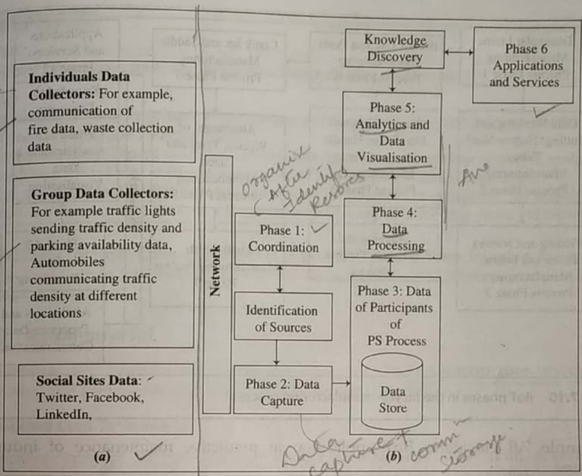

Figure 7.9 (a) Sources of data in the PS processes and (b) Phases of a participatory sensing process for IoT applications and services

IIoT applications are in the manufacturing, railways, mining, agriculture, oil and gas, utilities, transportation, logistics and healthcare services.

Example 7.8 explains use of IoT technologies in manufacturing and industrial processes.

Example 7.8

Problem

How is IIoT technology used in optimising the bicycle manufacturing process?

Solution

The sensors at each manufacturing stage in a bicycle industry communicate information on completion at each stage for each bicycle. An IIoT application analyses that data on completion of each activity at each stage, including data of breakdowns, work stoppages and failures at the stages. The application enables the company to take steps and synchronises various actions to remove any bottlenecks due to the components supply or the manufacturing stage machinery or human failures. Bicycle manufacturing is thus optimised. Figure 7.10 shows IIoT phases in the bicycle manufacturing process.

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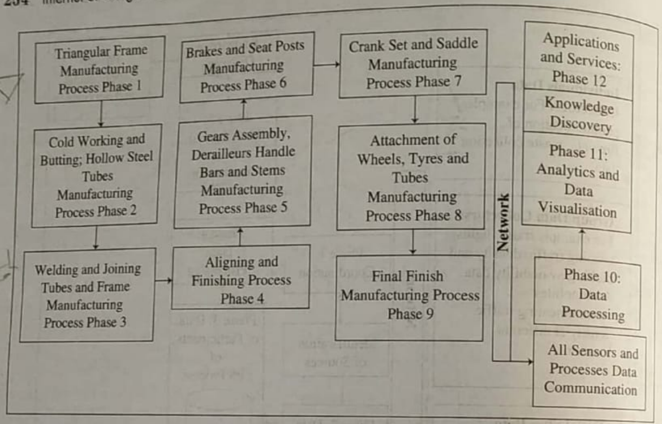

Figure 7.10 IIoT phases in the bicycle manufacturing process

Example 7.9 elucidates IIoT application in predictive maintenance of industrial processes.

Example 7.9

Problem

How is IIoT technology useful in predictive maintenance of industrial processes?

Solution

Consider an application for predictive railroad service centre. Ultrasonic sensors, infrared temperature sensors and microphone sensors along railway tracks sense and communicate the captured data for each train passing through each segment track. The application predicts the failures. This enables undertaking of preventive maintenances.

Similarly, IIoT finds applications in predictive maintenance of aircraft parts, gas pipelines and machines used in production.

Service-Oriented Cross-Layer Infrastructure for Smart Embedded Devices (SOCRADES) project developed an integration architecture which integrates shop floor industrial machines with enterprise systems. Three-level architecture has three levels—device management, service management and application interface for the systems.

Example 7.10 describes software for IIoT and M2M applications.

Example 7.10

Problem

How is IIoT technology useful in predictive maintenance of industrial processes?

Solution

- GE Industrial Analytics Software Predix provides an IIoT platform. The platform provisions for sensor-based computing and predictive analytics.
- An advanced cloud-based service and software from Axeda Company manages connected products and machines. The software enables implementation of innovative M2M and IoT applications.
- OSI soft is software for real-time data management for sensor-driven computing. The sensors data is from the manufacturing processes and utilities companies such as electricity, phone and mining.

Industrial Internet Consortium (2014) is body which has been founded for creation of standards, open interoperability and the development of architectures for Industrial Internet of Things (IIoT).

7.3.2 Automotive IoT

Automotive IoT enables the connected cars, vehicles-to-infrastructure technology, predictive and preventive maintenances and autonomous cars.

Connected Cars Technology

Automotive vehicles can drive through roads with little or no effort at all. A connected car with the combination of GPS tracking and an Internet connection enables applications such as:

1. Display for driver that enables driving through the shortest route, avoiding the congested route, etc.
2. Customisation of functioning of the vehicle to meet the driver's needs and preferences
3. Get notifications about traffic
4. Protecting cars against theft
5. Weather and enroute destinations
6. Keeping a tab on driver's health and behaviour.

Vehicle-to-Infrastructure Technology

Automotive IoT enables Vehicle-to-Infrastructure (V2I) technology. A vehicle communicates with other vehicles, the surrounding infrastructure and a Wi-Fi LAN. Examples of V2I applications are:

- Alerts and warnings for forward collision
- Information about blind spots
- Notification about a vacant parking space
- Information about traffic congestion on route to destination
- Stream live music and news.

Predictive and Preventive Maintenances

Example 7.11 shows automotive IoT application for predictive and preventive maintenances of automobiles by service centre application.

Example 7.11

Problem

How is an automotive IoT technology useful in predictive maintenance of an automobile by a service centre application?

Solution

Consider Internet of connected automotive components (Example 5.2). A number of sensors for statuses and conditions of components are used. Examples are engine movements unit, axle, steering unit, brake linings, wipers, air conditioners, battery, tyre movements, coolant and shockers. The statuses and conditions data are needed for predictive maintenance. A component embeds computing hardware and for ultrasonic sensors, IR sensors, sound sensors, seat alignment sensors, height sensors, driver acceleration sensors at start, during running and driver braking characteristics and road friction, and microphone sensors. The sensors capture the data for noise, vibration and harsh driving and actions of the vehicle.

The sense data communicates in real-time or stores and transmit when the automobile reaches a Wi-Fi node. The service centre application schedules maintenance alerts and predicts the failures and alerts for the actions. Figure 7.11 shows Internet of connected car components for predictive and preventive maintenances of automobile by a service centre.

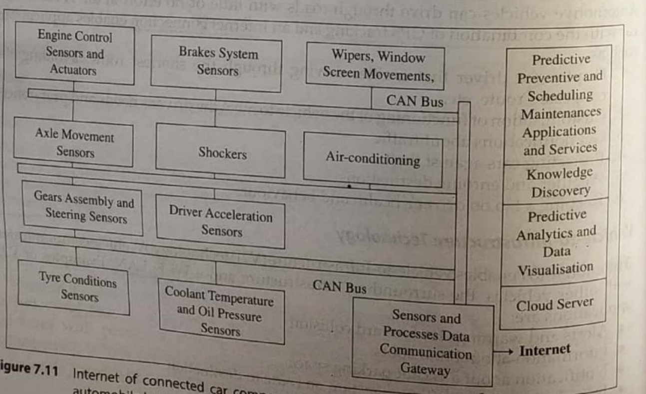

Figure 7.11 Internet of connected car components for predictive and preventive maintenances of automobile by service centre

Autonomous Cars

Driverless cars (also known as autonomous cars or robotic cars) have become a reality. These deploy LIDAR and laser 3D imaging technology.

Reconfirm Your Understanding

- Participatory sensing (PS) is sensing by individuals and groups of people contributing sensory information to form a body of knowledge.
- Applications of PS are many, such as retrieving information about the weather and environment, pollution, waste management, road faults, individual and group of personals health, traffic congestion, urban mobility and disaster management, such as flood, fire.
- Industrial Internet of Things (IIoT) is the use of IoT technologies in manufacturing and predictive maintenance. IIoT involves the integration of complex physical machinery M2M communication with the networked sensors, and use of software, analytics, machine learning and knowledge discovery.
- Automotive IoT enables connected cars, vehicle to infrastructure technology, predictive and preventive maintenances and autonomous cars.

Self-Assessment Exercise

1. List the merits of participatory sensing. ★
2. How does PS enable traffic congestion reports? Show an architectural diagram of the process. ★★★
3. List the applications of industrial IoT. ★
4. How is industrial IoT used for predictive maintenance of machines in the industry? ★★★
5. List the sensors needed in a car for automotive IoT. ★
6. Draw an architectural diagram of the processes in automotive IoT for predictive and preventive maintenance. ★★

7.4 ACTUATOR

LO 7.3 Describe the uses of actuators in devices

An actuator is a device that takes actions as per the input command, pulse or state (1 or 0), or set of 1s and 0s, or a control signal. An attached motor, speaker, LED or an output device converts electrical energy into physical action. Examples of applications of actuators are:

- Light sources
- LEDs

- Piezoelectric vibrators and sounders
- Speakers
- Solenoids
- Servomotor
- Relay switch
- Switching on a set of streetlights
- Application of brakes in a moving vehicle
- Ringing of alarm bell
- Switching off or on a heater or air-conditioner or boiler current in a steam boiler in a thermal plant.

Light Source

Traffic lights are examples of function of light sources as actuators controlled by the inputs.

LED

LED is an actuator which emits light or infrared radiation. Uses of different colour LEDs, RGB (Red-Green-Blue) LEDs, intensity variation of LED and colours, graphic and text display using big screens are actions which are controlled using the inputs. RGB LED has three inputs to control, i.e. R, G and B components and thus the composite colour. Pulse width modulated pulses control the LED light emission intensity. A microcontroller is used for generating PWM outputs.

Piezoelectric Vibrator

Piezoelectric crystals when applied in varying electric voltages at the input generate vibrations.

Piezoelectric Speaker

A piezoelectric speaker enables synthesised music tunes and sounds. The appropriately programmed pulses generate the music, sounds, buzzers and alarms when they are the input to the speaker. A microcontroller is used for generating PWM outputs for actions using speakers.

Solenoid

A solenoid is an actuator consisting of a number of cylindrically wound coils. The flow of current creates a magnetic field in proportion to the number of turns in the solenoid and the current in it. If a shaft made of iron is placed along the axis, then its motion can be controlled by the input current, pulses and variations of current with time. It can create a sharp forward push, backward push and repeated to and fro motion. It can also create rotator motion from linear motion by using a Cam.

A cam with linear shaft assembly is used in an engine to convert rotatory motion into linear motion and vice versa. A cam is an especially cut mechanical rotating object such

that the radius linearly increases (from the centre) between 0° and 180° rotation and decreases between 180° and 360°. When a cam assembly rotates, then a linear shaft moves in forward and backward motions in each rotation.

Motor

A motor can be DC (direct current controlled) or AC (alternating current controlled). IO modules are readily available to receive the control digital inputs of 1s and 0s and deliver high currents. The dc or ac rotates the motor. A cam also converts rotator motion into linear motion when it rotates using a motor.

Servomotor

Servomotor is a geared DC motor for applications such as robotics. It rotates the shaft of a motor. The shaft of the motor can be controlled and positioned or rotated through 180° (+90°) degrees. The shaft's angular position is controlled through 180°, between –90° and +90° degrees.

Example 7.12

Problem

How does angular position in a servomotor shaft control using input pulse widths?

Solution

A servomotor has just three terminals, viz. two for voltage supply + and – terminals and one for a pulse width modulated (PWM) input. A servomotor is conveniently controlled by PWM. The motor has three terminals. Two are for the supply voltage and ground. A position control PWM signal to the motor is given at the third terminal.

Figure 7.12 shows an interface circuit for controlling servomotor angular position. The pulse repeats 50 times (means at 20 ms intervals) to the motor input. The input is through a PWM control output at a port pin of microcontroller. It controls the movement as well as the angle of a servomotor between –90° and +90°.

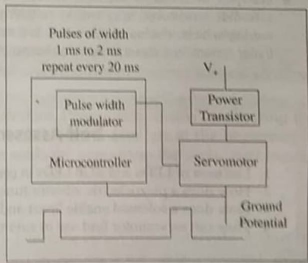

Figure 7.12 Microcontroller circuit for controlling servomotor angular position

The microcontroller has an internal circuit to generate pulses of different widths as per value, *p* loaded in the PWM register.

When the port output PWM pulse is of width 1.5 ms, then it places the shaft at a mid-angular position. Let us assume that when the pulse width is 1 ms, the angle is –90°. When the width is 2 ms, then the angular position is +90°. Varying the width, *pw* ms between 1 has distinct programs for each serial interface protocol. A program enables a user to directly use a protocol. For example, a library program is used for reading an RFID tag. Another can be used for sending data to a USB port. A USB port is used for onward transmission to the Internet.

Using UART Communication for a RFID Tag

A header character is sent before the tag. A tag ID has ten digit characters. An end character consists of 1 byte. It succeeds the 10 digits of the tag. The total number of digits communicated is equal to 12.

Reciprocal of baud interval is called baud rate. The 125 kHz corresponds to 125 kbaud/s (kilo bauds per second) which means 12.5 k characters per second. 'Baud' is a German word that means *drop*, such as raindrop. Bits in UART protocol communicate like bauds.

A library program for RFID using UART serial interface protocol enables its direct use for an RFID tag.

Using the I2C protocol for a Serial Bus

Integrated circuits, sensors or actuators can be interconnected with the serial synchronous interface, I2C. A library program for I2C serial interface protocol enables direct use of a sensor IC. I2C bus means different integrated circuits using I2C interface communication over the same set of wires.

I2C is inter-integrated circuit bus. Sensors using I2C bus protocol consists of two active signal terminals, i.e. Serial Data (SDA) and Serial Clock (SCL) lines and one ground line terminal. Uses of I2C, pronounced as I square C (I2C) are for serial bus communication of the number of device circuits. For example, one for flash memory, touch screen, one for measuring temperature and one for measuring pressure in a number of processes in a plant. These ICs mutually network through a common synchronous serial bus. Figure 7.13 shows bus SCL and SDA lines for serial synchronous data communication using I2C protocol.

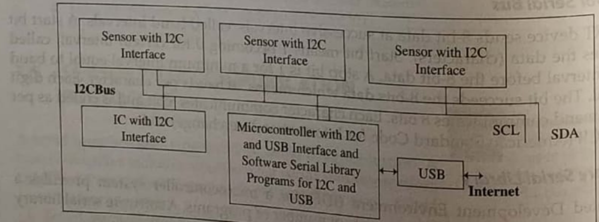

Figure 7.13 Bus SCL and SDA lines for serial synchronous data communication using I2C protocol

Three I2C bus standards are industrial 100 kbps I2C, 100 kbps SM I2C and 400 kbps I2C. I2C is serial computer bus which communicates single ended (one-end communicating at an instance), multi-master (number of master devices can connect the bus) and multi-slave (number of slave devices can connect the bus). A communicating device sends signals using SCL and SDA and can function as a master. Another device receiving signals SCL and SDA is the slave. The receiving device acknowledges use input SCL of master for sending SDA output.

Using the LIN Serial Bus

Local Interconnect Network (LIN) is a serial bus network protocol for communication between automobile circuits, sensors and actuator circuits, components and systems, such as window movements, seat movements and wipers. The protocol is simpler to use compared to CAN in automobiles.

LIN communication is single master with maximum 15 slaves with no bus arbitration. No bus arbitration means the bus does not select the destination, when number of devices request for the bus.[3]

LIN features are (i) use of single wire using which communication up to 19.2 kbit/s for 40 m bus length can be done, (ii) variable length of data frame (2, 4 and 8 byte) and (iii) configuration flexibility.

Using the CAN Protocol for Serial Bus

Embedded controllers with sensors and actuators are networked and are controlled through the CAN bus. Figure 7.14 shows serial bidirectional line network of number of CAN controllers and devices.

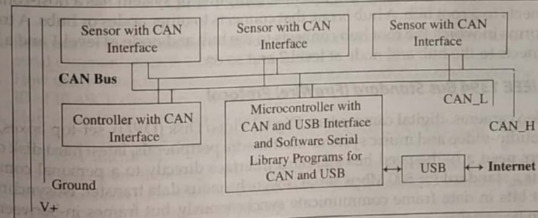

Figure 7.14 CAN bus serial bidirectional line network of number of CAN controllers and devices on a CAN bus

3 https://en.wikipedia.org/wiki/Local_Interconnect_Network

A library program for CAN serial interface protocol enables direct use for embedded circuits with a sensor. CAN bus means different controller circuits using CAN communicate with the same set of wires.

A number of devices are located and are distributed in a Vehicular Control Network (VCN). An automobile uses a number of distributed controllers. The controllers provide the controls for brakes, engine, electric power, lamps, temperature, air conditioning, car-gate, front display panel, meter display panels and cruising. Medical electronics and industrial-plant serial communication also use the CAN bus.

CAN bus has a serial bidirectional line. A CAN device receives or sends a bit at an instance by operating at the maximum rate of 1 Mbps. It employs a twisted pair connection to each node. The pair runs up to a maximum length of 40 m. A CAN version also functions up to 2 Mbps. CAN bus is a standard bus in a distributed network.

Using USB Bus

Universal Serial Bus (USB) is a bus between a host system and a number of interconnected peripheral devices. Maximum 127 devices can connect to a host. It provides a fast (up to 12 Mbps) and as well as a low-speed (up to 1.5 Mbps) serial transmission and reception between the host and serial devices. Both the host and devices can function in a system. Three standard protocols for USB are USB 1.1 (a low speed 1.5 Mbps 3 meter channel along with a high speed 12 Mbps 25 meter channel), USB 2.0 (high speed 480 Mbps 25 meter channel), and wireless USB (high speed 480 Mbps 3 m).

A library program for USB serial interface protocol enables direct use for USB bus connected host system and serial devices.

USB bus uses tree topology. A host connects to the devices or nodes using a USB port driving software and a host controller. The host computer or system has a host-controller, which connects to a root hub. A hub is one that connects to other nodes or hubs. A tree-like topology forms in which the root hub connects to the hub and node at level 1 and a hub at level 1 connects to the hub and node at level 2 and so on.

Using the IEEE 1394 Bus Standard (FireWire) Protocol

Digital video cameras, digital camcorders, Digital Video Disk (DVD), set-top boxes, high-definition audio-video and music systems multimedia peripherals, latest hard disk drives, and printers need a high-speed bus standard interface directly to a personal computer. IEEE 1394 is a standard for 800 Mbps serial isosynchronous data transfer. Isosynchronous means that bits in data frame communicate synchronously, but frames in-between time interval can be variable.

Using the MOST Protocol

The communication functionality is provided by a driver software called MOST network services. The services are service programs. The software for processing the MOST protocol communication between a MOST Network Interface Controller (NIC) and devices.

The services enable a user to directly use these service programs, such as communicating media files using MOST NIC.

MOST protocol enables high-speed serial bus for synchronous data communication. It forms a multimedia network optimised for automotive and other industries. The MOST bus uses a ring topology.

Reconfirm Your Understanding

- Each serial interface uses a serial communication protocol. A microcontroller includes serial communication interfaces using UART and serial protocols, such as I2C, CAN.
- Sensor circuits send serial data on a serial bus using UART, SPI or I2C or CAN protocols.
- Automotive sensors communicate serial data using LIN, CAN and MOST serial protocols.
- A UART device sends 10-bits for each 8-bit data (character or digit or command) at successive intervals.
- RFID UART interface communicates 12 characters, i.e. one start, 10 for ID and one end character.
- A software serial library is provided in the Integrated Development Environment (IDE) for a microcontroller system. The library consists of a number of programs. A distinct program exists for use during communication using a serial interface protocol.
- Bus enables a number of interfaces connected through a common set of lines.
- A USB is used for serial synchronous communication to computer, tablet, mobile and other devices.
- MOST protocol communication enables multimedia file transfers in automobiles.

Self-Assessment Exercise

1. How many characters of 8-bit each can transfer in 1 s when baud rate in UART serial communication is 1.2 kbaud per second? ★
2. How many characters communicate when an RFID UART communicates the ID of 10 ASCII characters to a reader? ★
3. How is a software serial library used? ★★
4. List the features of the following serial protocols: UART, I2C, USB, CAN, LIN, IEEE 1394 and MOST. ★★★
5. Draw a diagram for using a microcontroller I2C bus interface and I2C bus for environment parameters temperature, barometric pressure, humidity and organic solvent vapour leakage sensors. ★★
6. List the LIN applications in an automobile network of electronic control units. ★
7. How and when is a USB bus used? ★
8. When are the following serial protocols: UART, I2C, USB, CAN, LIN, IEEE 1394 and MOST used? ★★★

7.6 RADIO FREQUENCY IDENTIFICATION TECHNOLOGY

LO 7.5 Explain the Radio Frequency Identification (RFID) technology

Section 1.5.2 introduced RFID, its functions, role and IoT applications. RFID is an identification system using tagging and labelling of objects. The following subsections give a detailed description of RFID technology.

7.6.1 RFID IoT Systems

Section 2.3.1 described the RFID wireless communication. A tag enables identification of an object at different locations and times. A product, parcel, postal article, person, bird, animal, vehicle or object can have a tag or label in order to make the identification feasible.

The reader circuit of an ID can use UART or NFC protocol to identify the tag, when the RFID tag is at a distance less than 20 cm. An active NFC device/mobile generates an RF field which induces the currents in RFID and generates enough power for RFID. Using that power, the RFID transmits the identification of tag contents.

Passive device drives power from the electrical current induced in its antenna by the incoming RF signals from a reader or hotspot, and then transmits the tag information back. The active device has an in-built power source (battery) and transmits the information on its own.

A hotspot consists of a wireless transceiver or Wi-Fi transceiver for Internet connectivity. It receives signals from a number of RFID tags in an organisation and transmits the data to the web server over the Internet. The hotspot connects to the Internet for IoT services, applications and business processes. A mobile or wireless nearby the device can also function as a hotspot.

RFIDs form an IoT network. They connect to the Internet and then to an IoT server. An IoT server consists of RFID identity manager, device manager, data router, analyser, storage and database server and services.

Principle of RFID

A tag is an electronic circuit which transmits its ID using RF signals. The ID transmits to a reader, then that transmits along with the additional information to a remote server or cloud connected through the Internet. The additional information is as per the application. For example, for a tracking application, it is location and time-stamped data along with the ID. Example 7.13 gives the methods for communication of an ID from a tag and its reading by a reader.

RFID device functions as a tag or label which may be placed over an object

Example 7.13

Problem

How does an RFID tag communicate and is read by a reader?

Solution

- Method 1: Communication is according to UART protocol of 10-bit per character. Reading RFID tag for processing is as follows—the tag circuit communicates first a header, which corresponds to ASCII code for a carriage return. The code is 13_d. Then ten digits (bytes) communicate which correspond to unique tag ID. The end byte is for communicating the finishing of data. The byte corresponds to new line ASCII code. The code is 10_d. Twelve bytes communicate serially.
- Method 2: Communication is according to NFC or another protocol, for which the ID reader is adapted.

An RFID tag has an advantage over a barcode or QR code in terms of simpler processing of the RFID data. It can also be made invisible to a person. This is because it uses short-range RF transceivers instead of light or laser. The tag transmits back a short string of data to reader. The RFID reader picks the RF and communicates to the Internet or remote web server or cloud server. An active system can transmit to the reader at longer range compared to a passive system. An active system can receive commands, process and then send information compared to no actions except sending the ID in the passive system.

RFID IoT Network Architecture

Example 2.2 explained a four layered ITU-T reference model for the Internet of RFIDs, individual capabilities of the layers and data interchange. Fourth layer capabilities are for IoT/M2M services and applications. RFID technology has many applications.

RFID IoT Applications

Examples are tracking and inventory control of goods, supply chain systems, business processes such as for payment, leasing, insurance, and quality management, access to buildings and road tolls or secured store centre entries, and devices such as RFID based temperature or any other parameter sensor. New applications of RFID network have been found in designing a factory, protecting a brand and anti-counterfeiting measures.

Components of an RFID System

Figure 7.15 shows the components needed in a system for IoT applications and services.

The components of an RFID system are:

RFID is a tiny chip which functions as a tag or label onto an object. The chip is one of three types—passive, active and battery-powered passive (battery switches when reader is nearby).

A *transceiver* is in-built at the chip. It communicates in a range 10 cm to 200 m according to the chip. The chip does UART communication to the reader either using RF link or does NFC

Components of an RFID system are the tag, transceiver, reader, data processing subsystem, middleware, and applications and services

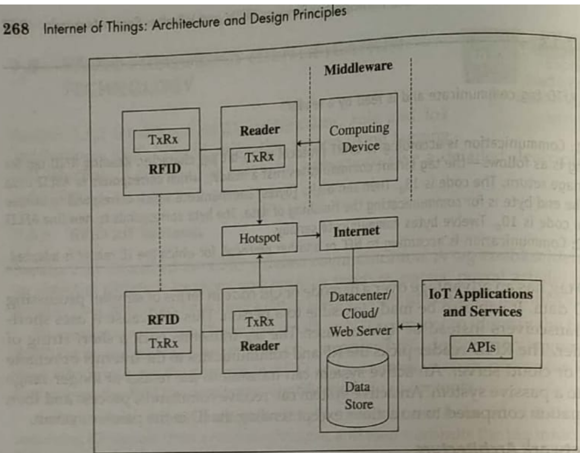

Figure 7.15 Components needed in a system for RFID IoT applications and services

communication to the reader within 20 cm range; standard frequency range used can be between 120 kHz to 150 kHz, 13.56 MHz, 433 MHz, higher when using UHF and microwave frequencies. Transceiver using RF frequencies recommended by Regulator has the data transfer rate of 115 kbps using carrier RF signals from 915 MHz to 868 MHz, 315 MHz or 27 MHz.

A nearby RFID reader for receiving ID uses the transceiver within it. It receives the header which consists of 1 start byte, then 10 byte ID and then one end byte when using the UART protocol. Hotspot, mobile or computer with wireless transceiver or Wi-Fi transceiver transmits and receives signals from the RFID tag.

Data processing subsystem: A reader associates a data processing subsystem which consists of a computing device and a middleware and provides connectivity to the Internet, directly or through a gateway which includes a data adaptation sublayer. The subsystem is a backend system. A reader circuit may send data directly or through a computer, mobile or tablet to the Internet. The computations for transmission (of the contents information of tagged device) are usually little. Example of a reader is SparkFun SEN-08419 for prototype developments.

Middleware: Middleware are software components used at the reader, read manager, data store for the transaction data store and APIs of the applications.

Applications and services and other associated applications software use the data store at the cloud or web server.

Issues

The issues are:

- ***Design issue:*** Designing a unique ID system needs a standard global framework.
- ***Security issue:*** A tag is read only. It can thus interact with any reader and thus allows automated external monitoring. A tag can thus be tracked without authority. A privacy issue arises when a tag and reader need not to be authenticated before their use. Full implementation of privacy and security needs data processing at the tag and reader with access encryption and authentication algorithms. Another issue is that the RFID system can be vulnerable to external virus attacks.
- ***Cost issue:*** RFID tag and reader become costly with data processing and security enhancing technology.
- ***Protection issue:*** The tag needs protection from the adverse weather condition which may damage the tag.
- ***Recycling issue:*** Recycling of the tags can be an environmental concern.
- ***Active life issue:*** Active RFID, which consists of battery, has limited life of up to 2 to 4 years.

7.6.2 EPCglobal Architecture Framework

MIT Auto-ID Labs is a group which consists of research laboratories of seven universities. The group has designed an architectural framework for IoTs. The group works in the field of networked RFIDs and emerging sensing technologies. The group works together with EPCglobal research group.

> EPCglobal is a standard architecture framework, which uniquely identifies physical objects, loads, locations, assets and other entities

The group has suggested the Electronic Product Code (EPC) standards, roles and architecture. The goal of the EPCglobal architecture framework is assignment of a unique identity. The framework facilitates business processes, applications and services uniquely identifying physical objects, loads, locations, assets and other entities.

EPCIS and ONS, Design Issues

EPC Information Services (EPCIS) is a design of EPC global standards which enables EPC-related data sharing within and across enterprises.

The EPC global architecture defines the following:

- EPCIS Capturing Application (ECA) for capturing EPC-related data required for business processes
- EPCIS Accessing Application (EAA) for enterprise business processes supported by data captured using ECA
- EPCIS-enabled Repository for storing records of events and for retrieving information using queries from EAA

- Partner applications such as postal tracking system connected with payment systems.

Object Name Service (ONS) version 2.0.1 is a standard recommended in 2013. The ONS performs the lookup functions which are based upon the DNS. A DNS name enables connectivity to the web server using the Internet. ONS implements that function using a distributed set of servers. DNS is Domain Name System governed by IETF. Lookup function refers to looking at the DNS name for enabling the web server connectivity.

ONS enables web connectivity to web server by lookup functions based on the DNS

ONS characteristics are robustness, less needs of power and memory at the tag circuit and less wireless bandwidth need for the data communication. Functions of data communication use a backend network, such as a hot-spot or Wi-Fi device. Transfer of the data communication task to the backend network saves the wireless bandwidth.

Design issues include governance model and architecture of the ONS. The concerns involved are:

- Political for control over information
- Capability issue of loss of domestic and strategic capability
- Security issue of collecting business intelligence
- Commercial issues
- Innovation control issues

This joint control by countries of ONS model can handle and mitigate the risks which associate the single-country control.

Technological Challenges

RFID technology challenges are as follows:

- Interference: When an organisation uses a number of wireless systems, since RFID hotspot also requires wireless installation, the frequencies may interfere among the systems. The systems require effective mitigation from interference.
- Effective implementation at data processing subsystem consisting of reader and tag protocols, middleware architecture and EPC standards
- Need of low cost tags and RFID technology
- Design robustness
- Data security

Security Challenges

The issues associated with RFID security are:

- Discovery of foreign attacks (intrusions) and maintain overall data integrity
- Unauthorised disabling of a tag by a reader which is external, thus making the tag useless
- Unauthorised tag manipulation by a reader which is external, thus making the tag useless
- Cloning of the tag by an unauthorised entity

- Eavesdropping, which means setting up an additional reader pretending to be a reader belonging to the system
- Man-in-the-Middle attack: When an external object pretends to be either a tag or reader between system tags and readers

Solutions can be encryption, tag deactivation on detection of intrusion, mutual authentication between the tag and reader, detection of the tag owner, use of read data analyser and data cleaning. Example 7.14 gives the methods for solving security issues.

Example 7.14

Problem

How does an RFID tag securely communicate and read by a reader? How is an RFID tag secured?

Solution

Method 1: An RFID tag may have a processor and memory. Then it computes one-way hash function called meta ID on tag. When the RFID reader uses the meta-ID, then only the tag communication unlocks and the tag becomes readable. After the reader finishes reading, the tag gets locked. This disables reading by unknown entities to the system.

Method 2: The tag can self-destruct if under attack.

IP for an RFID in Internet of RFIDs

Data from the RFID reader after filtering, aggregation and routing get stored at an IP address. This data is in XML format. Data accesses using HTTP and SOAP protocols.

Internet protocol (IP), IPv6 is 128-bit IP address, which is required for routing data on the Internet. It needs to be mapped with the 96-bit EPC. The EPC is header, manufacturer, product and serial number bits.

A method for secure IPv6 communication is the use of Cryptographically Generated Addresses (CGAs). A host suffix/interface identifier generates a cryptographic one-way hash function. The function input is a public key as binary input. CGA is meant to be globally unique in a statistical sense. CGAs may, however, not be workable routing addresses at the IP layer for RFID IoT system.

Another method is Overlay Routable Cryptographic Hash Identifiers (ORCHID). It is a newly suggested class of identifiers. The identifier is based on CGAs. The ORCHID format is compatible to IPv6-like address format.

The ORCHID identifier is used just by the APIs and applications. It differs for IPv6 address. It does not identify the network locations, while IPv6 has locator which is 64-bit network prefix.

7.6.3 Web of Things of RFIDs

Web of Things (WoT) means making objects a part of the World Wide Web. WoT software, architecture styles such as JSON, REST, JSON, and programming patterns such as web sockets, makes this feasible. WoT data store of objects is similar to web pages store. The web (application layer) receives and sends data using the Internet (IP network layer). WoT enables IoT applications for the RFIDs also as RFID enables identification of each object distinctly on the web.

Reconfirm Your Understanding

- A tag is an electronic circuit which transmits its ID using RF signals. The ID transmits to a reader which associates a computing device and connects to the Internet.
- RFID forms the IoT network using the computing system which connects to the Internet and then to IoT server.
- RFID system components for IoT applications and services are RFID tag with transceiver; reader with associated computing device and transceiver; hotspot or mobile of computer for Internet connectivity; middleware, and applications and services.
- Middleware consists of RFID identity manager, device manager, data router, analyser, storage and database server and services.
- Examples of IoT applications of RFIDs are for tracking and inventory control, identification in supply chain systems, business processes, RFID based temperatures or any other parameter sensor, in factory design, brand protection, and anti-counterfeiting and business processes.
- Design, security, cost, protection, recycling and active life are issues in IoT RFID applications and services.
- EPCglobal architecture framework assigns a unique identity for business processes. Applications and services uniquely identify physical objects, loads, locations, assets and other entities using the framework.
- EPC Information Services (EPCIS) is a design of EPCglobal standards which enables EPC-related data sharing within and across enterprises.
- ONS performs the lookup functions based upon the DNS. DNS name enables web server Internet connectivity using HTTP, REST, webSockets and Internet protocols.
- Technological challenges are wireless interference, implementing data processing subsystems, reducing system components' costs, robust system design and security of the system components.
- Data security solutions can be encryption, tag deactivation on intrusion detection, mutual authentication between the tag and reader, detections of the tag owner, reader analyser and data cleaning.
- RFID IoT system 128-bit IPv6 address can be generated using CGA.
- ORCHID is a newly suggested class of identifiers with a format compatible to IPv6-like address format.
- Web of Things means making objects data and object applications and services a part of the World Wide Web.

Self-Assessment Exercise

1. How is an RFID identified for IoT applications? ★★
2. Why does the RFID tag not create a network on its own? Why does it need a nearby reader for creating a network of RFIDs? ★★★
3. Show the RFID IoT system components for the parcel tracking applications and services using a diagram. ★