Syllabus Content:

3.6.1 Overview of monitoring and control systems

- Difference between a monitoring system and a control system
- Sensors, actuators and their usage
- Additional hardware required to build these systems
- Software requirements of these systems
- Show understanding of the importance of feedback in a control system

3.6.2 Bit manipulation to monitor and control devices

- show understanding of how bit manipulation can be used to monitor/control a device
- carry out bit manipulation operations: test a bit and set a bit (using bit masking) using the instructions from Section 1.4.3 and those listed below
- show understanding of how to make use of appropriate bit manipulation in monitoring systems and control systems

Monitoring & Control Systems:

Monitoring and control (**M&C**) systems are designed to control large or complex facilities such as factories, power plants, network operations centers, airports, and spacecraft, with some degree of automation.

M&C systems may receive data from **sensors**, **user inputs**, and **pre-programmed procedures**. The software may send commands to **actuators**, computer systems, or other devices.

M&C systems may perform closed-loop control.

Sensors and Actuators & their usage

A sensor is an input device that captures physical data. It converts physical quantities into electrical voltages. It is also known as "input transducer".

Examples:

Temperature Sensor:

A device, used to measure amount of heat energy that allows to detect a physical change in temperature from a particular source and converts the data for a device or user, is known as a Temperature Sensor

Uses:

A/C control, refrigerators and similar devices used for environmental control. However, with the advent of the IoT world, they have found their role in manufacturing processes, agriculture and health industry. In the manufacturing process, many machines require specific environment temperature, as well as device temperature. With this kind of measurement, the manufacturing process can always remain optimal.

On the other hand, in agriculture, the temperature of soil is crucial for crop growth. This helps with the production of plants, maximizing the output.

Gas sensor

Gas sensors are similar to the chemical ones, but are specifically used to monitor changes of the air quality and detect the presence of various gases.

Uses:

- they are used in numerous industries such as manufacturing
- agriculture and health and used for air quality monitoring
- Detection of toxic or combustible gas, Hazardous gas monitoring in coal mines, Oil & Gas industries, chemical Laboratory research, Manufacturing – paints, plastics, rubber, pharmaceutical & petrochemical etc.

Following are some common Gas sensors:

- Carbon dioxide sensor
- Breathalyzer
- Carbon monoxide detector
- Catalytic bead sensor
- Hydrogen sensor
- Air pollution sensor
- Nitrogen oxide sensor
- Oxygen sensor
- Ozone monitor
- Electrochemical gas sensor
- Gas detector
- Hygrometer

Proximity sensor:

A device that detects the presence or absence of a nearby object, or properties of that object, and converts it into signal which can be easily read by user or a simple electronic instrument without getting in contact with them.

Uses:

Proximity sensors are largely used in the retail industry, as they can detect motion and the correlation between the customer and product they might be interested in. A user is immediately notified of discounts and special offers of nearby products.
Another big and quite an old use-case is vehicles. You are reversing your car and are alarmed about an obstacle while taking reverse, that's the work of proximity sensor.
They are also used for parking availability in places such as malls, stadiums or airports.

Pressure sensor

A pressure sensor is a device that senses pressure and converts it into an electric signal. Here, the amount depends upon the level of pressure applied.

Uses:

There are plenty of devices that rely on liquid or other forms of pressure. These sensors make it possible to create **IoT(I**nternet **o**f **T**hings**)** systems that monitor systems and devices that are pressure propelled. With any deviation from standard pressure range, the device notifies the system administrator about any problems that should be fixed.
Deployment of these sensors is not only very useful in manufacturing, but also in the maintenance of whole water systems and heating systems, as it is easy to detect any fluctuation or drops in pressure.
Further they are used in intruder detection systems, automatic doors in malls etc.

Smoke sensor

A smoke sensor is a device that senses smoke (airborne particulates & gases) and it's level.

Uses: Smoke sensors are extensively used by manufacturing industry, buildings and accommodation to detect fire and gas incidences. This serves to protect people working in dangerous environments, as the whole system is much more effective in comparison to the older ones.
Common Type of Smoke Sensors
Smoke sensors detect the presence of Smoke, Gases and Flame surrounding their field. It can be detected either optically or by the physical process or by the use of both the methods.
Optical smoke Sensor (Photoelectric): Optical smoke sensor used the light scatter principle trigger to occupants.
Ionization smoke Sensor: Ionization smoke sensor works on the principle of ionization, kind of chemistry to detect molecules causing a trigger alarm.

IR (Infra-Red) sensors

An infrared sensor is a sensor which is used to sense certain characteristics of its surroundings by either emitting or detecting infrared radiation. It is also capable of measuring the heat being emitted by the objects.

Uses:

- They are now used in a variety of IoT projects
- Healthcare as they make monitoring of blood flow and blood pressure.
- They are used smart devices such as smartwatches and smartphones as well.
- Other common use includes Home appliances & remote control, Breath analysis, Infrared vision (i.e. visualize heat leaks in electronics, monitor blood flow, art historians to see under layers of paint), wearable electronics, optical communication,
- non-contact based temperature measurements
- Automotive blind-angle detection.
- They are also a great tool for ensuring high-level security in your home. Also, their application includes environment checks, as they can detect a variety of chemicals and heat leaks.

Level sensors

A sensor which is used to determine the level or amount of fluids, liquids or other substances that flow in an open or closed system is called Level sensor.

Uses:

- They are primarily known for measuring fuel levels, but they are also used in businesses that work with liquid materials
- In Recycling industry, as well as the juice and alcohol industry rely on these sensors to measure the number of liquid assets in their possession.
- Fuel gauging & liquid levels in open or closed containers
- Sea level monitoring & Tsunami warning, water reservoir
- Medical equipment, compressors, hydraulic reservoirs, machine tool, Beverage and pharmaceutical processing, High or low-level detection etc.

Motion detection sensors

A motion detector is an electronic device which is used to detect the physical movement(motion) in a given area and it transforms motion into an electric signal ; motion of any object or motion of human beings

Uses:

- Motion detection plays an important role in the security industry.
- Businesses utilize these sensors in areas where no movement should be detected at all times, and it is easy to notice anybody's presence with these sensors installed.
- These are primarily used for intrusion detection systems
- Automatics door control, Smart Camera (i.e motion based capture/video recording)
- Toll plaza, Automatic parking systems, Automated sinks/toilet flusher,Hand dryers,energy management systems(i.e. Automated lighting, AC, Fan, Appliances control) etc.
- On the other hand, these sensors can also decipher different types of movements, making them useful in some industries where a customer can communicate with the system by waving a hand or by performing a similar action.
  For example, someone can wave to a sensor in the retail store to request assistance with making the right purchase decision.
- Even though their primary use is correlated with the security industry, as the technology advances, the number of possible applications of these sensors is only going to grow.

Accelerometer sensors

Accelerometer is a transducer that is used to measure the physical or measurable acceleration experienced by an object due to inertial forces and converts the mechanical motion into an electrical output. It is defined as rate of change of velocity with respect to time

Uses:

- These sensors are now present in millions of devices, such as smartphones.
- Their uses involve detection of vibrations, tilting and acceleration in general.
- This is great for monitoring your driving fleet, or using a smart pedometer

- In some instances, it is used as a form of anti-theft protection, as the sensor can send an alert through the system if an object that should remain stationary is moved.
- They are widely used in cellular & media devices, vibration measurement,
- Automotive control and detection, free fall detection, aircraft and aviation industries, movement detection
- Sports academy/athletes behavior monitoring
- Consumer electronics, industrial & construction sites etc.

Humidity sensors

Humidity is defined as the amount of water vapour in an atmosphere of air or other gases. The most commonly used terms are “Relative Humidity (RH)

Uses:

- Industrial & residential domain for heating, ventilating, and air conditioning systems control.
- They can also be found in Automotive, museums, industrial spaces
- Greenhouses and meteorology stations.
- Paint and coatings industries, hospitals
- Pharma industries to protect medicines

Optical sensors

A sensor which measures the physical quantity of light rays and converts it into electrical signal which can be easily readable by user or an electronic instrument/device is called optical sensor.

Uses:

- Optical sensors are loved by IoT experts, as they are practical for measuring different things simultaneously. The technology behind this sensor allows it to monitor electromagnetic energy, which includes, electricity, light and so on.
- They are used in healthcare, environment monitoring, energy, aerospace and many more industries
- Their main use can be found in Ambient light detection, digital optical switches, optical fibres communications

Photo-detector: It uses light sensitive semiconductor materials like photocells, photodiodes or phototransistors to work as photo-detector

Fiber Optics: Fibers optics carry no current, So its immune to electrical & electromagnetics interference and even in damaged condition no sparking or shock hazard happens.

Pyrometer: It estimates the temperature of an object by sensing the color of the light and Objects radiate light according to their temperature and produce same colors at same temperature.

Proximity & Infrared: Proximity use light to sense objects nearby and Infrared are used where visible light would be inconvenient.

Actuator:

An **actuator** is a component of a machine that is responsible for moving and controlling a mechanism or system, for example by opening a valve. In simple terms, it is a "mover".

An actuator requires a control signal and a source of energy.

- The control signal is relatively low energy and may be electric voltage or current
- pneumatic or hydraulic pressure
- or even human power.

Its main energy source may be an electric current, hydraulic fluid pressure, or pneumatic pressure.

When it receives a control signal, an actuator responds by converting the signal's energy into mechanical motion.

An actuator is the mechanism by which a control system acts upon an environment. The control system can be simple (a fixed mechanical or electronic system), software-based (e.g. a printer driver, robot control system), a human, or any other input.

Monitoring system

Monitoring can be used to describe a very wide range of activities but all are characterised by the measurement of some physical property.

Typical examples of the physical property could be

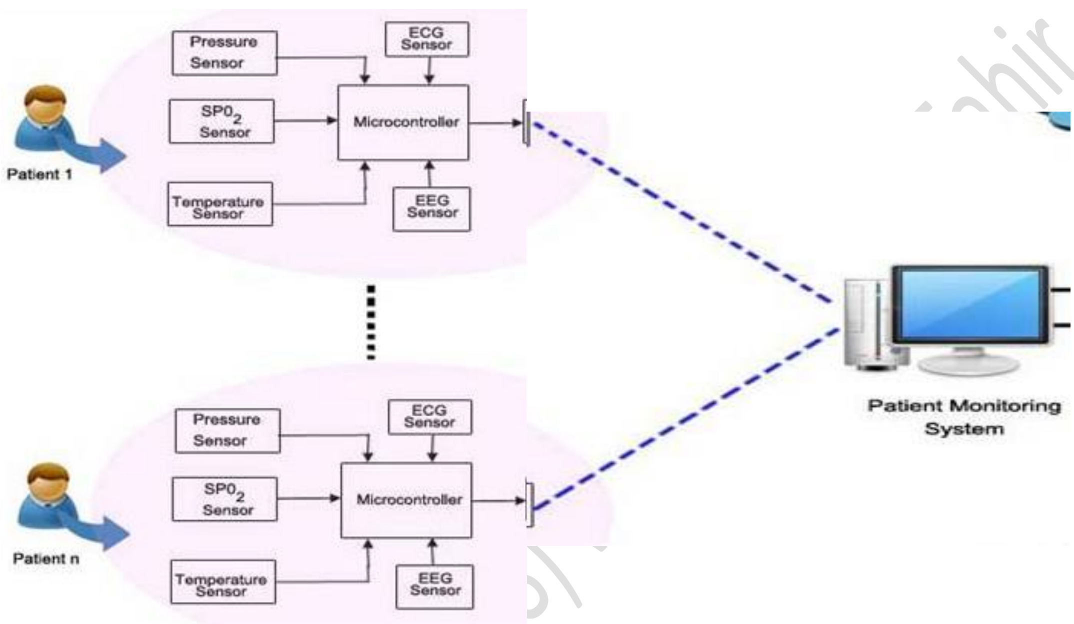
- temperature
- pressure
- light intensity
- flow rate
- Movement etc.

Let's have a discussion of Patient-Monitoring System in Hospital as an example.

Patient-Monitoring:

- What is patient monitoring, and why is it done?

- What are the primary applications of computerized patient-monitoring systems in the intensive-care unit?
- What are the advantages of using microprocessors in bedside monitors?
- What are the important issues for collecting high-quality data either automatically or manually in the intensive-care unit?



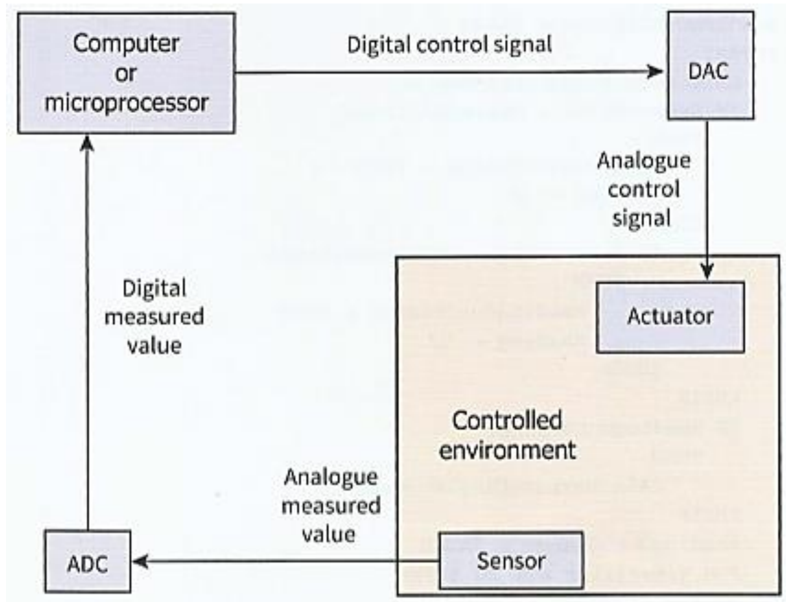
Monitoring system will only monitor the patient and does the following:

- Sensors get the readings of the patient's body
  - Temperature
  - Oxygen
  - Heart rate etc.
- All readings taken from sensors are analogue values which have to be converted to digital data for computer to process it.
- Analogue values are converted to Digital data by ADC(Analogue to Digital Converter)
- It has pre-stored values already stored in it, from which it will compare the values.
- If values are within the range, it will keep on taking reading after set intervals in a loop
- If the values are outside the range, it will display a Warning Sign monitor a beep etc.
- Monitoring system just monitors, and doesn't do any action based on readings if they are outside the range.

Control system

Control System includes:

- Sensors
- an Analogue-to-digital converter (ADC)
- Microprocessor/ Computer
- Digital-to analogue converter (DAC)
- An actuator: is an electric motor that drives a controlling device which is not shown.

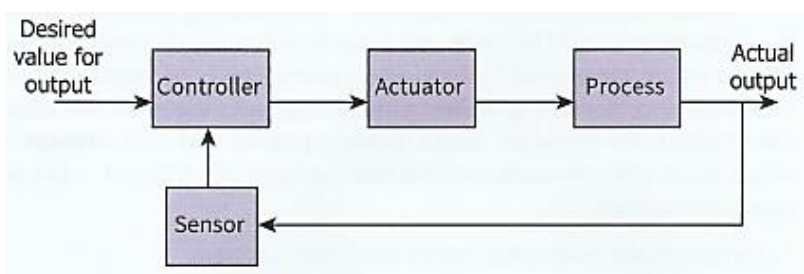


The system shown in Figure involves a continuous process where measurement is made and then, if needed, a control action is initiated. Following this control action, a measurement is taken again. There is therefore an element of feedback in the system.

A closed-loop feedback control system is a special type of monitoring and control system where the feedback directly controls the operation. Figure below shows a schematic diagram of such a system.

A microprocessor functions as the controller. This compares the value for the actual output, as read by the sensor, with the desired output. It then transmits a value to the actuator which depends on the difference calculated

Real- Time Programming:



Monitoring and control systems require real-time programming. Whether a program is just monitoring or is monitoring and controlling, it must incorporate a structure for repetitive sensor reading. This must continue for the whole duration of the period that the system is switched on. A simple loop structure will achieve this but reading sensor values every clock cycle of a processor is unnecessarily frequent.

The program must control the timing of the repetitions. This might be done by creating a timed sequence for reading values or possibly by including a time delay inside a loop

Example of Control system:

Let us consider an example of Air-Conditioning/heating system as an example of control system.

- A desired value (temperature) is set on Air-conditioning/ heating unit
- Sensors get data from environment
- Analogue data from sensors is converted to digital by **ADC**
- Computer /Microprocessor examines the received data and compares it with pre-stored values
- If data is outside the range, it will send a signal to activate compressor/heater
- Digital data sent from microprocessor is converted to analogue by **DAC**
- An actuator: is an electric motor that drives a controlling device which runs the compressor / heater
- System is set in a loop and reading is taken again after a set timings from the sensor and sent to microprocessor.

An example monitoring program: Consider the following fragment of pseudocode

```
EndReadingSensor ← FALSE
ReadingOutOfRange ← FALSE
REPEAT
   CALL SensorRead(SensorValue)
   IF SensorValue > MaximumAllowed
      THEN
         ReadingOutOfRange ← TRUE
         Reading ← 'H'
      ELSE
         IF SensorValue < MinimumAllowed
            THEN
               ReadingOutOfRange ← TRUE
               Reading ← 'L'
         ENDIF
   ENDIF
   IF ReadingOutOfRange
      THEN
         CALL WarningDisplay(Reading)
   ENDIF
   ReadingOutOfRange ← FALSE
   FOR TimeFiller ← 1 TO 999999
   ENDFOR
UNTIL EndReadingSensor
```

Note the following features of the program:

- There is an infinite loop.

- The loop finishes with another loop that does nothing other than create a delay before the outer loop repeats.
- When the sensor reading indicates a problem, the loop calls a procedure to handle whatever notification method is to be used.
- Following this call, the loop continues so the Boolean variable has to be reset to prevent the warning procedure being repetitively called.

An example monitoring and control program Consider a system which is controlling an enclosed environment. The environment has a sensor to monitor a property and an actuator to control that property. The following fragment of code might be used:

```
EndReadingSensor ← FALSE
READ DesiredOutputLevel
REPEAT
   CALL SensorRead(SensorValue)
   SensorDifference ← DesiredOutputLevel - SensorValue
   IF ABS(SensorDifference) < DesiredOutputLevel/100
      THEN
         SensorDifference ← 0
   ENDIF
   IF SensorDifference > 0
      THEN
         ActuatorAdjustmentFactor ← SensorDifference/DesiredOutputLevel
         AdjustmentDirection ← 'up'
         CALL ActivateActuator(AdjustmentDirection, ActuatorAdjustmentFactor)
   ENDIF
   IF SensorDifference < 0
      THEN
         ActuatorAdjustmentFactor ← ABS(SensorDifference)/DesiredOutputLevel
         AdjustmentDirection ← 'down'
         CALL ActivateActuator(AdjustmentDirection, ActuatorAdjustmentFactor)
   ENDIF
   FOR TimeFiller ← 1 TO 999999
   ENDFOR
UNTIL EndReadingSensor
```

Note the following features of the program:

- A procedure is called to activate the actuator only if the sensor reading shows a significant change.
- The code will only work properly if it can be guaranteed that the activation of the actuator has caused a change in the property before the sensor rea ding in the next iteration of the loop

Bit manipulation:

The two fragments of code in have a direct call to a procedure to take some action.
A slightly different approach would be to set values for Boolean variables subject to what the sensors detect. For instance if a controlled environment had two properties to be monitored and

controlled, four Boolean variables could be used. Values could be set by assignment statements such as

```
IF SensorDifference1 > 0 THEN Sensor1HighFlag ← TRUE
IF SensorDifference1 < 0 THEN Sensor1LowFlag ← TRUE
IF SensorDifference2 > 0 THEN Sensor2HighFlag ← TRUE
IF SensorDifference2 < 0 THEN Sensor2LowFlag ← TRUE
```

Masking means to keep/change/remove a desired part of information.

A bitmask is a way of accessing a particular bit. The bitmask is a number which has 0 in all bits that we don't care about, and a 1 for the bit(s) that we want to examine. By ANDing the bitmask with the original number, we can "extract" the bit(s) – if that bit was 0, then the new number will be completely zero; if the bit was 1, then the new number will be non-zero.
Consider these Masks:

	AND	OR	XOR
0	Clears the value	Retains the value	Retains the value
1	Retains the value	Sets the value	Inverts the value
Uses	Setting chosen bits to 0	Setting chosen bits to 1	Inverting chosen bits, finding differences between

Another part of the monitoring and control program would be checking whether any of the four flags were set. The machine code for running such a program could use individual bits to represent each flag. The way that flags could be set and read are illustrated by the following assembly language code fragments in which the three least significant bits (positions 0, 1 and 2) of the byte are used as flags:

LDD 0034	Loads a byte into the accumulator from an address
AND #B00000000	Uses a bitwise AND operation of the contents of the accumulator with the operand to convert each bit to 0
STO 0034	Stores the altered byte in the original address
:	
LDD 0034	
XOR #B00000001	Uses a bitwise XOR operation of the contents of the accumulator with the operand to toggle the value of the bit stored in position 0. This changes the value of the flag it represents.
STO 0034	
:	
LDD 0034	
AND #B00000010	Uses a bitwise AND operation of the contents of the accumulator with the operand to leave the value in position 1 unchanged but to convert every other bit to 0. A subsequent instruction can now compare the value of the byte with denary 2 to see if the flag represented by this bit position is set.
STO 0034	
:	
LDD 0034	
OR #B00000100	Uses a bitwise OR operation of the contents of the accumulator with the operand to set the flag represented by the bit in position 2. All other bit positions remain unchanged.
STO 0034	

Masking:

A mask defines which bits you want to keep, and which bits you want to clear.

Masking is the act of applying a mask to a value. This is accomplished by doing:

- Bitwise ANDing in order to extract a subset of the bits in the value
- Bitwise ORing in order to set a subset of the bits in the value
- Bitwise XORing in order to toggle a subset of the bits in the value

Below is an example of extracting a subset of the bits in the value:

Below is an example of extracting a subset of the bits in the value:

```
Mask:   00001111b
Value:  01010101b
```

Applying the mask to the value means that we want to clear the first (higher) 4 bits, and keep the last (lower) 4 bits. Thus we have extracted the lower 4 bits. The result is:

```
Mask:   00001111b
Value:  01010101b
Result: 00000101b
```

Masking is implemented using AND in above example.

References:

- Computer Science Course book by Sylvia Langfield & Dave Duddell
- https://www.finoit.com/blog/top-15-sensor-types-used-iot/
- https://stackoverflow.com/questions/10493411/what-is-bit-masking