ICT-001 CHAPTER THREE

MONITORING AND CONTROL SYSTEMS

Sensor: A device that monitors and records data about the surrounding physical environment. The sensor inputs this data into a computer system to be processed. Sensors can automatically enter data into a computer system, resultantly it increases the accuracy of the data by removing the possibility of human error.

Analogue Data: The physical data that we stream in our daily life.

Analogue to digital device (ADC): A device used to convert analogue data into digital data.

Microprocessor: An integrated circuit used in monitoring and control technologies.

Digital to Analogue Converter (DAC): A device used to convert digital data into analogue data.

Actuator: This is a device usually a motor or a switch that converts energy into mechanical motion or action that is used to control a mechanism or a system. Think of actuator like a "muscle" in a system like how a robotic arm lifts an object or a motor opens a valve, etc. Examples of actuators include:

- Electric motors: used in robotics, industrial automation, etc
- Hydraulic cylinders: used in heavy machinery such as excavators, cranes.
- Piezoelectric electric actuators: used in precision motor control applications such as optics and microscopy.
- Air muscles: used in robotics and prosthetic devices.

MONITORING TECHNIQUES

Monitoring, or measurement as it is sometimes called, involves the use of a computer or **microprocessor-based** device to **monitor** or measure physical variables over a period of time. It is important to know which sensors would be appropriate in a given situation to measure physical variables such as light, temperature, atmospheric pressure, humidity, moisture, sound, blood pressure and pH, among others.

The process is actually **continuous** and never ends. Most sensors used in monitoring systems are analogue, which means the data sent to the computer is in analogue form. However, the computer can only process data in digital form, so the data has to be converted using an analogue to- digital converter (ADC). This is so the computer, which can only understand digital data, is able to process it. The **output** from the system is usually on a **screen or printed out**, but can be a warning sound if the monitoring that is taking place is critical**,** for example an overheating nuclear reactor.

Sensors	Description & Use
Light/ultraviolet sensors	It measures the amount or intensity of light. These sensors can be used in weather stations to measure the amount of sunshine. They are also used in automated street lights to measure the intensity of sunlight. When light falls on this type of sensor, it generates electrical energy. Ultraviolet sensors are used to measure the amount of UV radiation(specifically UVB radiation, which can be dangerous to humans, sometimes causing skin cancer).
Temperature sensors	They are used to measure the **surrounding temperature** in a weather station. They are also used to measure the temperature in a river or air quality. The components of different types of temperature sensor either change their electrical resistance or generate a voltage according to temperature. Whichever type is used, electrical signals are generated which are converted into values to represent temperature.
Pressure sensors	These sensors are used to measure atmospheric pressure in weather stations, compressed air pressure monitoring, vacuum cleaners, burglar alarms for home security systems, etc. A pressure sensor converts the force applied to its surface to generate electrical energy which is then converted into values to represent the applied pressure.
Humidity/Moisture sensors	Humidity sensors are used to measure the air humidity in a weather station. Moisture sensors are also used when monitoring soil quality. Humidity sensors are often a combination of a moisture sensor and a temperature sensor in one unit. This is because humidity can only be calculated by knowing how much water there is in the atmosphere together with the temperature.
Sound sensors	Sound sensors can be used in environmental monitoring systems to measure noise pollution. Also used in burglar alarm systems for home security, etc.

	These sensors convert sound waves into voltages or electrical signals which are converted by the computer into values to represent sound.
Infrared sensors	These sensors can be used in environmental monitoring, for example the Earth's surface temperature can be monitored by satellites. They are also used in burglar alarms for home security systems, as they can system if there is an intruder. All bodies possess thermal energy and therefore emit infrared radiation. This radiation is converted into electrical signals as a result.
Oxygen, carbon dioxide, pH, turbidity sensors	These are sensors used in environmental monitoring and water pollution monitoring. - Oxygen (O_2) sensors measure the level of oxygen in soil and water. - Carbon dioxide (CO_2) sensors measure the level of carbon dioxide in the air or in water and are basically an adaptation of an infrared sensor. - pH sensors measure the acidity of soil and acidity in rivers, lakes, etc. They are very similar to a simple battery and generate electricity depending on the number of hydrogen ions in the solution, which causes an electrode to generate a voltage. - Turbidity sensors measure the cloudiness of water in a river that is affected by pollution. A turbidity sensor is actually a light sensor usually placed at right angles to a light emitter. The greater the number of particles in the water, the greater the amount of light reflected off them on to the sensor.

USES OF MONITORING TECHNOLOGIES

1. ***Weather stations***

Weather station could be used to monitor the weather in terms of temperature, rainfall, intensity of sunlight, atmospheric pressure, humidity, and UV radiation. For this purpose, it would need:

Temperature sensors to measure the ambient temperature. When referring to the weather, ambient temperature means the temperature of the surrounding air of the weather station.

Pressure sensors to measure atmospheric pressure, which is the pressure of the air above us.

Humidity sensors to measure absolute and relative humidity. Absolute humidity is the amount of moisture or water vapour in the air. Relative humidity is the ratio of the amount of moisture in the air to the maximum amount of moisture the air can hold.

Light sensors to measure the amount or intensity of sunlight. It measures the number of hours of sunlight. Measuring sunlight requires an array of light sensors which collectively measure the intensity of the light radiation.

HOW IT WORKS:

When the weather station is operating, the readings from the sensors are fed back to an ADC and then sent to the computer. The ADC converts the data from analogue to digital so that the computer can understand and process it.

On receiving the digital data, the computer stores the data in the form of a table, which could be done using a spreadsheet or database package, so that it can be processed. The processing might consist of calculating, for each day, the highest, lowest and mean temperature, the level of UV radiation, total rainfall, hours of sunshine, highest and lowest value of atmospheric pressure, and wind speed and direction. These values can also be calculated for the month and year to date.

Results can be output in the form of graphs, either to a monitor or printed out. This all happens automatically without the need for human intervention.

2. ***Monitoring water pollution***

This involves inserting two sets of sensors, one upstream from the suspected site of pollution and the other downstream, immediately after the site, whatever that may be, farm or factory. The sensors involved are temperature sensors, pH sensors, turbidity sensors, O2 and CO2 sensors.

Sensors feed data to an ADC and then the computer processing the digital data. The processing carried out is a comparison of the readings with normal values if it is the first method, or a comparison of the readings from the two sets of sensors if the second method is being used.

3. ***Environmental Monitoring***

- Detecting abnormally high temperatures using temperature sensors, so that people can be warned of the dangers.
- Monitoring the level of air pollution using O2 sensors and CO2 sensors; pH sensors can also help in this regard as they can provide acidity readings.
- Monitoring ultraviolet levels; excessive amounts can cause skin cancer, so these are often monitored by governments in high-risk countries to judge whether people should be advised to wear skin protection cream.

Advantages and disadvantages of monitoring technologies

Although computers are now used in all aspects of monitoring, there is still the need for humans to be involved. Here is a table showing the advantages and disadvantages of computer monitoring compared with people taking readings.

Advantages of computer monitoring	Disadvantages of computer monitoring
Humans are unable to take readings at very frequent intervals as they need to make a note of each reading. This takes time, during which they cannot take another reading. Computers are able to take readings at more frequent intervals and are capable of reading more than one variable simultaneously. Humans can only do one thing at a time, so take longer.	
It is very difficult for humans to keep taking readings for sustained periods, whereas computers can be left on to take readings at any time, day or night. The readings are always taken at regular intervals unlike with a human who might forget to take them.	Computers can be expensive to buy, whereas humans would be expected to do the monitoring as part of their job. Computers are also expensive to maintain.
It takes time for people to draw accurate graphs, whereas computers can produce them automatically after processing the data.	It is quite difficult to program computers to interpret the results, but humans can interpret results and are also needed to program the computers in the first place.
Results are produced automatically after the readings are received by the microprocessor or computer, unlike a human who would take a lot of time to write them down.	
Readings taken by computers tend to be more accurate than those by humans as computers are not subject to 'human error'.	Sensors can deteriorate after a period of time, whereas humans will tend to be more consistent.
Computer would not forget to take readings.	Measurement equipment is expensive.
Response time is much faster.	Computers do not respond to unusual circumstances.
Measurements are taken automatically.	If computer malfunctions then whole process will stop.
Readings will be more accurate.	
Computers do not take rest.	
Fewer staff required.	

CALIBRATION OF SENSORS

When sensors measure physical variables, people believe that the results are always going to be accurate because a computer is involved. However, for this to be the case, sensors have to be calibrated. Calibration is making sure that when, for example, a temperature sensor is used to measure the temperature of boiling water, it actually causes the computer to output a value of 100 °C. It is done by comparing the value a sensor produces to a known measurement.

THE IMPORTANCE OF CALIBRATION

The accuracy of all sensors reduces after a period of time. This is often caused by constant use and exposure to the atmosphere or liquids that are being used. Slight erosion of the material the sensor is made out of is also bound to occur. It depends on the type of sensor and how it is being used as to how quickly this occurs but whatever the cause, regular calibration helps to maintain accuracy. The sensor is only one component in the monitoring system and devices like the ADC may also deteriorate over time, so calibration is important for that reason too. If a sensor is being used as part of a sensing system, as with a humidity sensor, then if that sensor loses accuracy, the whole system will need calibrating.

METHODS USED TO CALIBRATE DEVICES

1. One-point calibration

In order to carry out a one-point calibration, a reading is taken from the sensor in the range being measured and it is compared with either a pre-calibrated sensor or a known value. The sensor reading is subtracted from the known value which gives the 'offset'. In the algorithm, this offset is then added to every reading in the temperature range being measured. It is the simplest form of calibration.

2. Two-point calibration

To arrive at this conclusion, obviously we need to compare more than one reading. With a pH sensor, it is recommended to place sensors in solutions which are neutral (pH 7) and either one which is acidic (say, 4.0) or one that is alkaline (say, 10.0). The use of the two values will enable the relationship between the sensor and the standard to be established.

3. Multipoint calibration

Multi-point calibration is similar to other forms of calibration but is performed with at least three different readings. It is used to calibrate sensors that produce readings that do not naturally form a linear line i.e. the values from the sensor are a curve, whereas they should be a straight line. Multi-point calibration further increases the accuracy of the sensor reading and is more accurate than two point calibration.

Note following differences between one-point, two-point and multi-point calibrations:

One-point calibration	**Two-point calibration**	**Multi-point calibration**
Only one measurement point or reading is required with one point calibration	At least two readings are taken with two-point calibration	Multi-point calibration is performed using at least three different readings.
One point calibration is appropriate for sensors that are used to measure a value that is constant/never changes	Two-point calibration is used with sensors that measure a constantly changing variable	It is used to calibrate sensors that produce readings that do not naturally form a linear line
With one point calibration, only the offset is calculated. The sensor reading is subtracted from the known reading of a pre-calibrated or standardized sensor. This offset is then added to every subsequent reading.	With two point calibration, sensitivity needs to be included in the calculation, not just an offset. Two point calibration compensates for both offset errors and sensitivity/slope errors. Two point calibration is a more accurate method of calibration than one point calibration.	Multi-point calibration further increases the accuracy of the sensor reading and is more accurate than two point calibration.

CONTROL TECHNOLOGIES

A control system is one that uses microprocessors or computers to **control certain physical variables**. Computers can do this by maintaining certain physical conditions at the same level for a period of time or by controlling certain devices which cause the variables to change. Physical variables that can be controlled by computers and microprocessors include temperature, pressure, humidity, light, and moisture.

Control systems use **real-time processing**, they make use of actuators to control devices, although

some devices are actuators in their own right, such as a motor. Unlike in monitoring systems, in control systems the output affects the input. **For example**, think about a room's temperature as being controlled by a microprocessor connected to a temperature sensor and a heater. The temperature is *input* by the sensor to the microprocessor.

If the temperature is below a certain value, the microprocessor sends a signal to the heater to switch

on, which is the *output*. The heater being on causes the temperature to rise which means the input value has now changed, so the output has obviously affected the input. Control systems involve continuous processes.

All of the sensors described above on monitoring technologies can also be used in control systems, but there are some sensors that are more likely to be found in control systems than monitoring systems. They include the following sensors:

Sensors	Description & Use
Electromagnetic field sensor	This sensor measures the change in the Earth’s natural magnetic field caused by the presence of a ferromagnetic object. Magnetic field sensors and induction loops are used at the entrances to car parks to control barriers but magnetic field sensors can be used to detect the number of spaces available. They are also used in some automated car parking systems to help drivers park their car, in a similar way to ultrasonic sensors.
Ultrasonic sensors	It measures the amount of time taken for the sound to be sent and received which, combined with knowledge of the speed of these sound waves, can be used by the microprocessor to calculate the distance. It is used in automated car parking systems which let the driver know when they are close to another vehicle or other object so they can park their car without hitting that obstacle.
Proximity sensor	A proximity sensor can be a mixture of sensors but usually comprises a device that sends out a signal and a sensor which receives the reflected signal back. This can be an infrared beam, ultrasound or a magnetic field. One use is in smartphones to switch off the screen display when the phone is held near to the ear.
Touch sensors	One type of touch sensor is used for measuring fluid levels. A capacitive touch sensor measures the capacitance between two conductors separated by an insulating plate. One of the conductors will be the fluid whose level is being measured. When the fluid is touching the sensor, it detects that it is at that level. This type of sensor is often used in detection devices used to measure fluid levels such as the cooling water level in nuclear power plants to ensure that there is sufficient water to cool the reactors.

A real-life example of a control technology in operation would be an **automated street light.** This may work as follows:

1- Light sensor will measure the intensity of the sunlight.

2- The data from light sensor will pass through ADC and sent towards microprocessor.

3- The microprocessor will check the intensity of light by comparing it to a known value in his memory, if the intensity is low, it will send a signal towards the actuator (electric switch) to turn on the light. If the intensity is not low then it will not send the signal towards the actuator.

4- The signal of the microprocessor will be sent towards the actuator through DAC.

5- When electric switch receives the signal, it turns the light on.

GREENHOUSE/GLASSHOUSE ENVIRONMENT CONTROL:

Five different sensors could be used to control the glasshouse environment namely; humidity, temperature, pH, moisture and light.

1- Sensors monitor the values and send to the computing device.

2- The signals are sent through ADC.

3- The computer's microprocessor compares the value of the sensors with its stored values.

4- If values are same to stored/preset values then no action is taken.

5- If values vary then signal is sent to the actuators through DAC.

```
WHILE system switched on
   INPUT temperature
      IF temperature > pre-set
         THEN
            send signal to window motor to open window or leave it open
            send signal to actuator to switch off heater or leave it off
         ELSE
            send signal to window motor to close window or leave it closed
            send signal to actuator to switch on heater or leave it on
      ENDIF
ENDWHILE
```

MAINTAINING THE REQUIRED SOIL MOISTURE

1. At the start of the process, the user inputs the required moisture level (pre- set value) using a keypad, number pad or touchscreen.
2. The microprocessor (computer) receives data about the amount of moisture in the soil in the greenhouse from the moisture sensor. It needs an ADC to change the analogue moisture data to a digital value the computer can understand.
3. The computer compares the sensor data to the pre-set value input earlier by the user. If the level of moisture is below the pre-set value, it sends a signal to an actuator which activates the sprinkler valve to open or leave it open if it already is open. If the moisture level is above or equal to the pre-set value, the computer sends a signal to the actuator to close the sprinkler valve or leave it closed if it already is closed.

This whole process is continuous as long as the system is switched on. Some greenhouses have sensors which measure the humidity of the air as well, because some plants require high humidity as well as warmth. These have separate watering systems, one to spray water into the air and another to put more moisture into the soil. The principle for these systems is much the same as for the light one described later.

```
WHILE system switched on
    INPUT moisture
    IF moisture < pre-set
        THEN
            send signal to actuator to open sprinkler valve or remain
            open
        ELSE
            send signal to actuator to close sprinkler valve or remain
            closed
    ENDIF
ENDWHILE
```

BURGLAR ALARMS

Microprocessor-controlled burglar alarm systems are used in many houses to protect against intruders.

1. The **sensors** needed in such a system are:

» infrared sensors to detect movement of human bodies, which emit heat.

» sound sensors to detect the level of sound an intruder might make.

» pressure sensors that are placed under a carpet or rug to detect an increase in weight caused by a burglar treading on it.

2. The microprocessor is programmed to have certain acceptable levels and it only acts if the sensor readings are greater than these.
3. An ADC is required so that data from the sensors can be understood by the microprocessor.
4. In the event of detecting an intruder, the burglar alarm sounds an alarm and causes lights to flash and probably also sends a signal to the police to alert them to the presence of a possible intruder. Of course, at the start of the process the user would need to switch the system on!

CONTROL OF TRAFFIC/PEDESTRIAN FLOW

An **automated traffic control system** uses sensors, communication networks, and intelligent algorithms to manage the movement of **vehicles and pedestrians** efficiently and safely.

These systems sometimes need to allow for pedestrians crossing at the junction. If this is the case, the **pedestrian presses** a button at the side of the road. The computer registers this input and after a predefined delay sends a signal to the actuator to change the traffic lights from green to red, in addition to lighting up the sign telling the pedestrians they can cross (usually a green man). There can be a reasonable delay if the lights have only recently changed, but most modern systems, using induction loops, can tell if traffic is light and thereby reduce the time delay.

Here’s a clear breakdown of how it works:

1.) **Detection and Data Collection:**
The system continuously collects real-time data from multiple sources:

- Vehicle detectors – Inductive loops, radar, infrared, or video cameras embedded in or above the roads identify, count and classify vehicles.
- Pedestrian sensors – Infrared motion detectors, push buttons, or computer vision systems detect people waiting to cross.

2.) **Processing and Decision Making:**
The data collected from the sensors flows into a **central control unit** (in a computer) that uses:

- **Algorithms and AI models** to predict congestion and determine optimal signal timings.

- **Traffic flow models** to balance the needs of vehicles and pedestrians.
- **Priority rules** to give special treatment to emergency vehicles, buses, or pedestrians during certain times.

For example:

- If a long queue of vehicles is detected in one direction, the system extends the **green phase**.
- If pedestrians are waiting but traffic is light, it allows an early **walk signal**.

3. **Signal Control and Coordination:**

Once decisions are made, the system adjusts the:

- **Traffic lights** (red, yellow, green) to regulate vehicle movement.
- **Pedestrian signals** ("walk" and "don't walk") to control crossing times.

4.) **Communication and Feedback:**

- Systems communicate via fiber-optic or wireless networks to share information citywide.
- Central operators can **monitor traffic cameras** and override automatic control if needed (e.g., for emergencies).

5.) Pedestrian Safety and Efficiency

- Sensors ensure pedestrians have enough time to cross safely.
- Audible signals and countdown timers enhance accessibility.
- AI-based systems can detect if a pedestrian is still in the crosswalk and delay the green for cars accordingly.

In summary:

- **Sensors** detect vehicles, pedestrians, and environmental conditions.
- **Control units** analyze this data to decide signal timings based on traffic flow and demand.
- **Traffic and pedestrian lights** are automatically adjusted for smooth and safe movement.
- It uses real-time data and automation to optimize traffic flow and pedestrian safety.

CAR-PARK BARRIERS

One of the most common ways to detect vehicles in a microprocessor-controlled car-park barrier system is by using an **induction** (sometimes called inductive) **loop** buried just **below the surface of the road** in front of the barrier. As a vehicle passes over the loop, it causes a change in inductance which is detected by the loop. The metal in the vehicle causes a change in the magnetic field. This in turn causes a current to flow. The **loop sends back data which is converted to digital** and if the computer detects any change compared to a pre-set value, it sends a signal to the actuator. In this case, the **actuator is the motor** which, when activated, causes the barrier to rise. There is usually a second sensor, often a light sensor, which is used to detect when the vehicle has passed beyond the barrier. A light beam passes across the space occupied by the vehicle. If the vehicle prevents the light beam from reaching the sensor, then the microprocessor will keep the barrier raised. When the vehicle is clear of the barrier, the microprocessor detects that the light beam has resumed and so can send a signal to **the motor to retract** and allow the barrier to lower. This makes sure the barrier stays up until the vehicle has passed through the beam.

DIFFERENCES BETWEEN MONITORING SYSTEM & CONTROL SYSTEM

Monitoring System	Control System
A monitoring system takes in data readings and simply records them for human analysis or output the results of the monitoring in the form of graphs or charts.	A control system takes in data readings that are analyzed automatically and an action is triggered to control an element of the system as a result of the monitoring that is taking place.
Monitoring systems can be used in scientific experiments. The readings are then output and can be analyzed.	IT is used to control a system for specific conditions.
May require a human interaction to analyse the readings.	No human interaction is required to analyse the readings.
The output has no effect on the input	The output affects the input

SMART HOMES

A smart home is a home in which devices and **appliances are connected** so that they can **communicate** with each other and can be controlled using commands by anyone living in that home. A smart home makes use of the **home computer network** and router and is an example of a WSAN (**wireless sensor and actuator network**).

The **commands** can be given by **voice**, **remote control**, tablet or smartphone. The most common devices controlled in this way are televisions, music centers, lights, burglar alarms, central heating and air-conditioning units. Smart homes have developed due to the increase in the use of smartphones and tablet computers. The ability to control such devices remotely – it is possible to **switch on the heating** while the user is in an **office mile away**, for example – is **called the Internet of Things (IoT).** IoT is a term used to describe the remote control of appliances and devices that are interconnected through digital networks and includes refrigerators, cookers and others. A smart home or IoT allows the home owner to do all these things and more, remotely. For example, when still in their office at work, the homeowner can switch the oven on so that dinner will be ready as soon as they walk in the door; the central heating or air-conditioning unit can be switched on and the temperature set so that the house will be nice and comfortable for when they return home. However, there is at least one drawback to having asmart home and that is being vulnerable to hackers, who could access a home network and turn off the burglar alarm, making it easy for someone to break in, or they could just cause a nuisance by turning lights off, changing channels on the television, and so on.

Advantages of Control Systems	**Dis-advantages of Control System**
Smart homes can reduce the amount of energy needed to heat and provide light within a home.	IT technicians are needed to maintain the computers, and programmers are required to program the systems
The use of computer-controlled traffic lights has led to there being fewer traffic jams than when they are mechanically or time controlled.	But they can lead to people becoming lazy since they can become over-reliant on microprocessor-controlled devices in the home
Most control systems, generally, can help people with disabilities who may find it difficult to get around and use devices in the home.	Smart devices used in a smart home are much more expensive than non-smart devices.
Computer-controlled systems process data more quickly than a human could which, in turn, leads to almost immediate reactions to changes in the inputs to the system.	A computer-controlled system will not be able to function if there is a problem with the computer or there is a power outage without backup power supplies.
The readings taken by computers are more reliable and more accurate than human readings as humans can make mistakes.	