MINE AUTOMATION AND DATA ANALYTICS

SWAYAM NPTEL COURSE ON

MINE AUTOMATION AND DATA ANALYTICS

By

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Module 03:
Proximity Sensors

Lecture 08 A:
Proximity Sensors

CONCEPTS COVERED

- Introduction on proximity sensor
- Sensor Working Principle
- Applications
- Challenges
- Advantages
- Type of Sensors
- Proximity sensor comparison

Introduction

Proximity sensors are a type of electronic device used to detect the presence or absence of an object within a specified range without any physical contact.

Proximity sensors are an essential component in various industrial, automotive, and consumer applications, providing a non-contact method for detecting the proximity, position, or movement of objects.

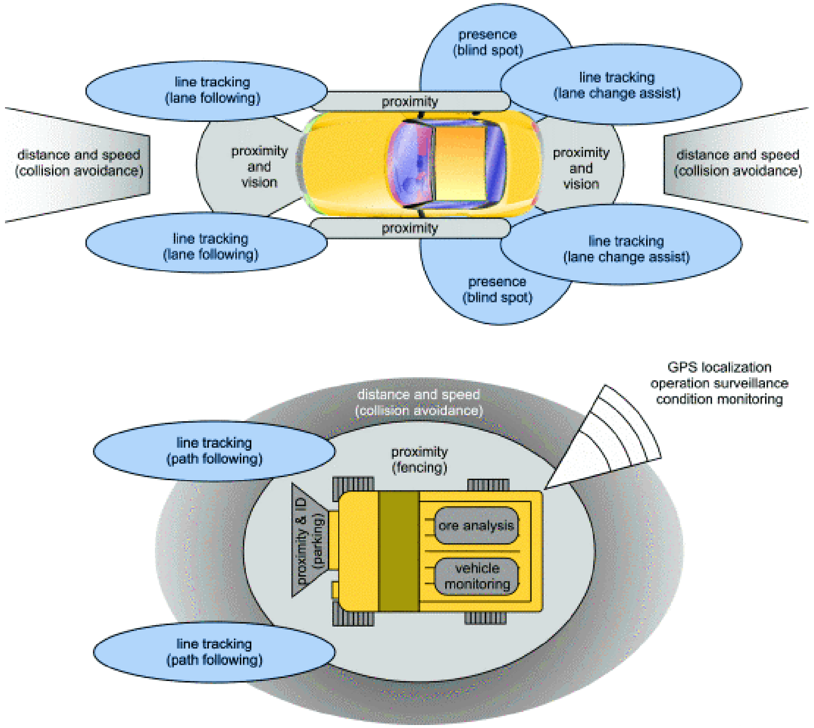


Figure 1. Schematic description of driving sensors used in passenger vehicles (top) and mining haul trucks (bottom).

Sensor Working Principle

Proximity sensors work on various principles, such as:

Ultrasonic sensor:

Ultrasonic sensors use high-frequency (30–500 kHz) sound waves and measure the time it takes for the sound waves to bounce back after hitting an object. They are versatile and can detect a wide range of materials.

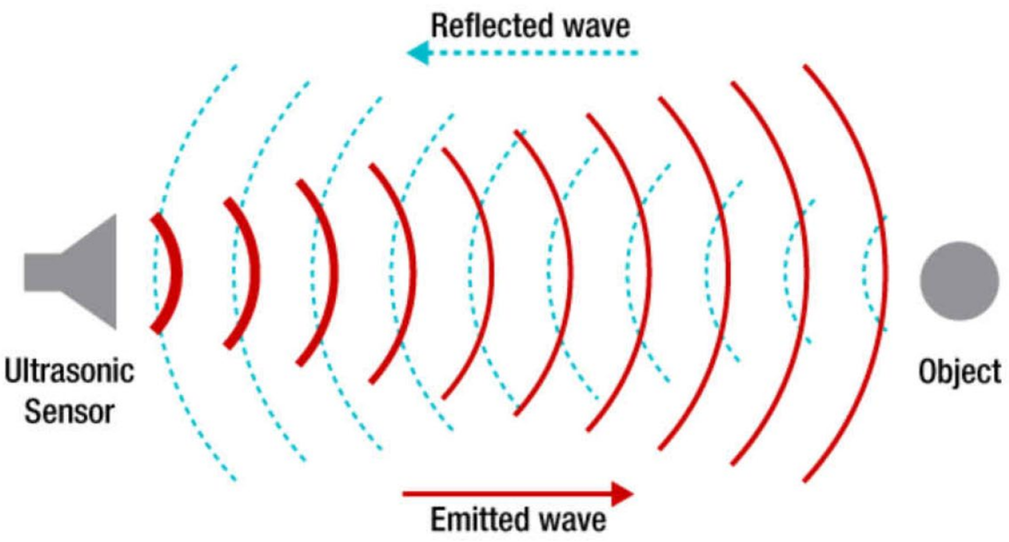


Figure 2. Ultrasonic Time-of-Flight Measurement

Infrared (IR) sensor:

IR sensors emit and receive infrared light to measure the distance of an object. IR sensors are commonly used in applications like object detection and object counting.

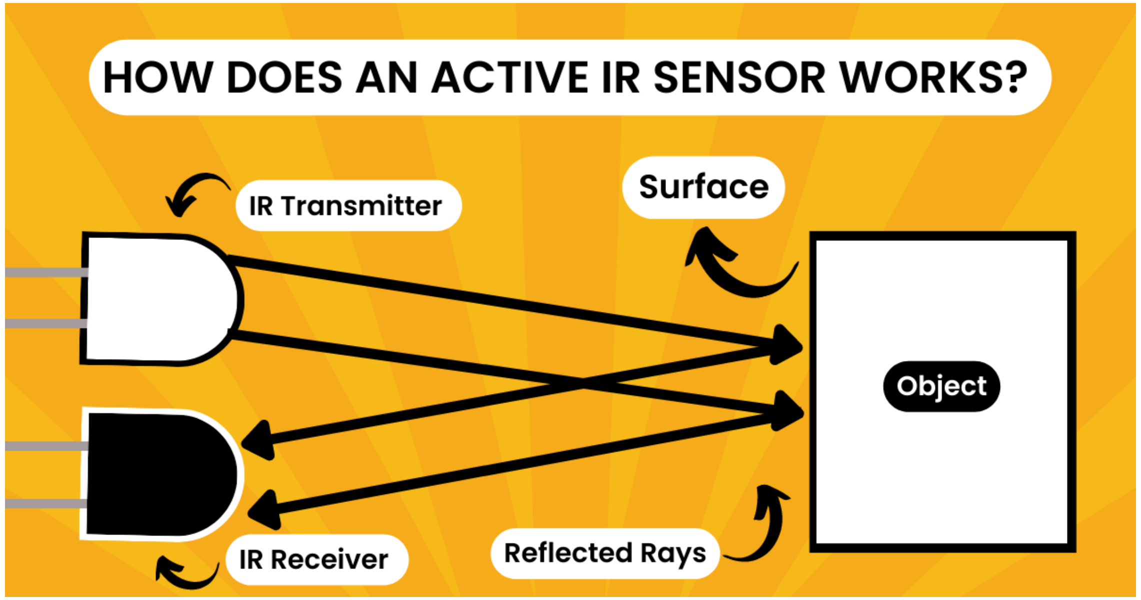


Figure 3. Active IR sensor working

Inductive sensor:

These sensors generate an electromagnetic field and detect changes in the field when a metallic object enters their detection range. They are commonly used for metal detection.

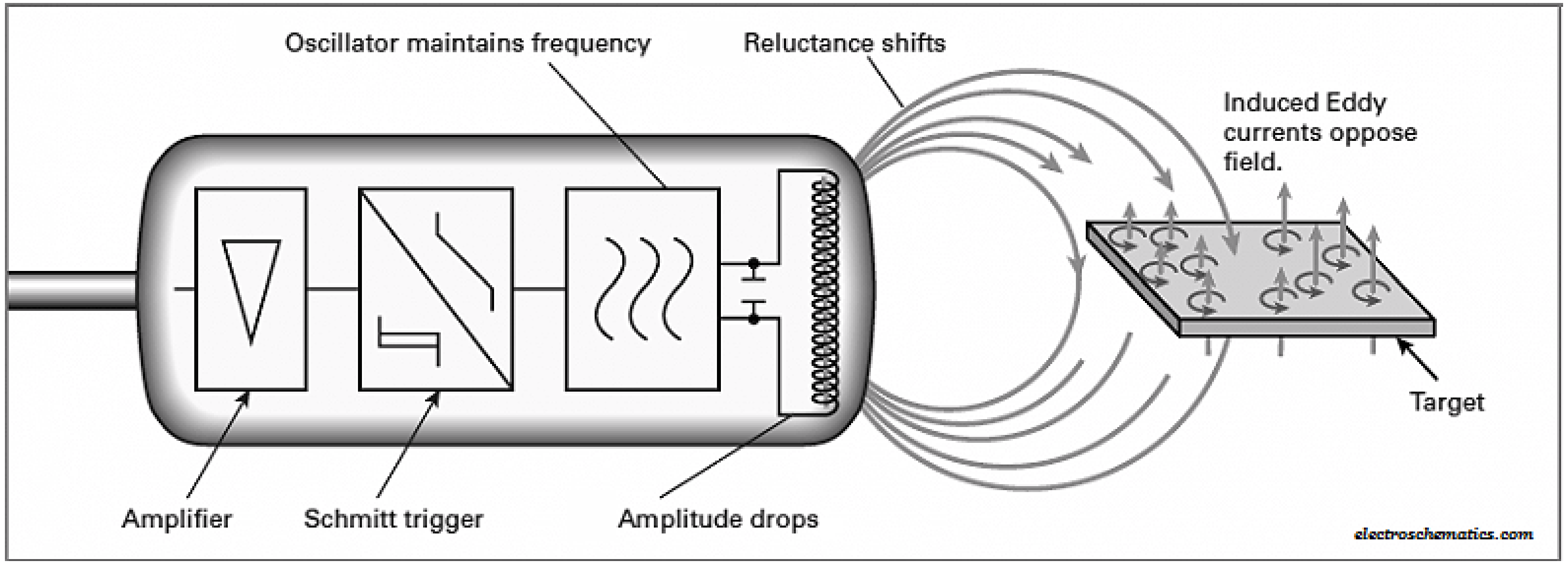
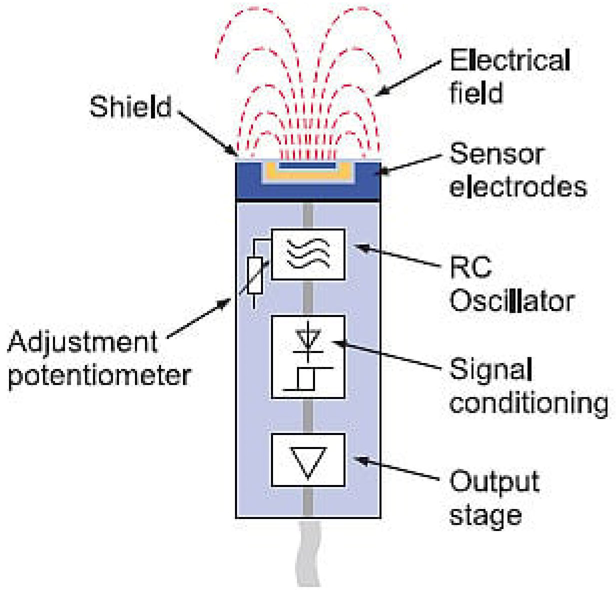


Figure 4. Inductive sensor working principle

Capacitive sensor:

Capacitive sensors detect changes in capacitance when an object enters their range. They are suitable for detecting both metal and non-metal objects.



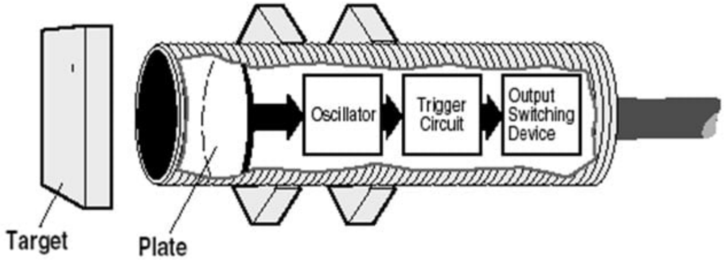


Figure 5. Working Principle of Capacitive Proximity Sensor

Applications

Proximity sensors have a wide range of applications, including:

Object Detection:

They can be used to detect the presence of objects on an assembly line, in elevators, or in automated machinery.

Obstacle Avoidance:

Proximity sensors are crucial for obstacle detection in autonomous vehicles and robots.

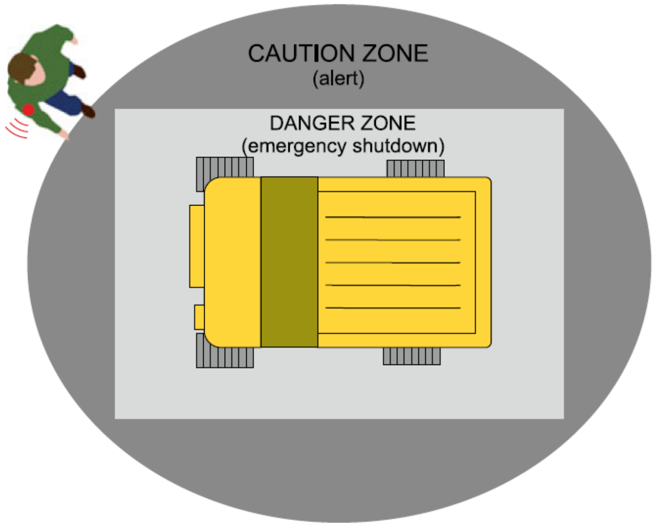


Figure 6. Description of fencing hazardous areas by proximity sensing.

Gesture Recognition:

Proximity sensors are utilized in consumer electronics for gesture-based control, such as in smartphones and gaming consoles.

Position Sensing:

They are employed in applications like level sensing in tanks and proximity-based switches in keyboards.

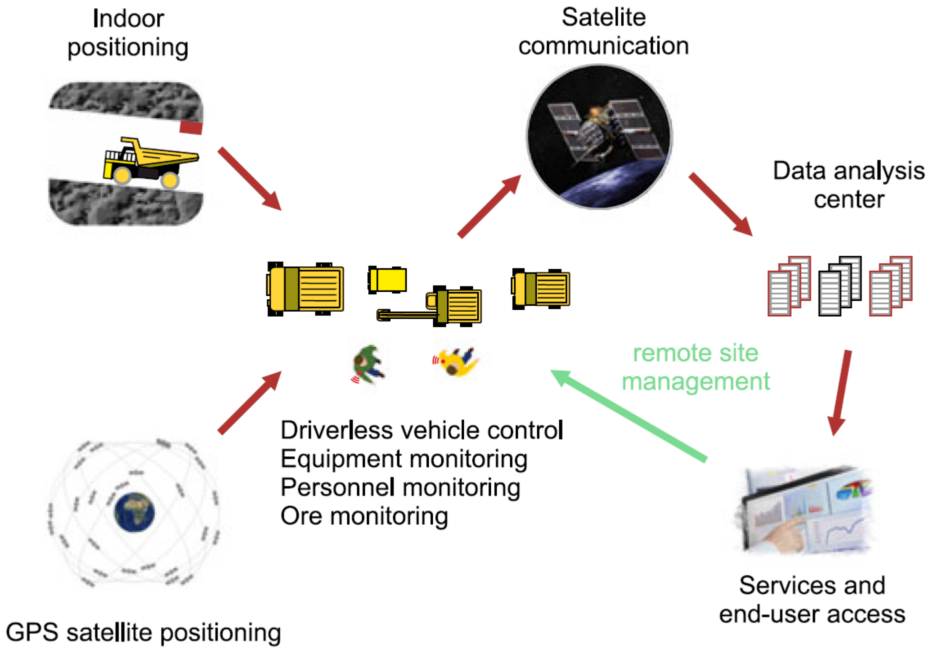


Figure 7. Data flow of positioning and monitoring in mining sites.

Advantages

Non-contact:

Proximity sensors do not physically touch the objects they detect, reducing wear and tear.

Speed and Accuracy:

They can provide fast and precise detection in various conditions.

Reliability:

These sensors are known for their long lifespan and minimal maintenance requirements.

Challenges

Limited Range:

The detection range of proximity sensors is typically limited, and it can vary based on the sensor type and technology used.

Material Sensitivity:

Some sensors may be affected by the material and surface properties of the objects they detect.

Environment Sensitivity:

Sensors may be affected due to humidity, presence of dust particles and temperature in the surrounding area.

Type of Sensors

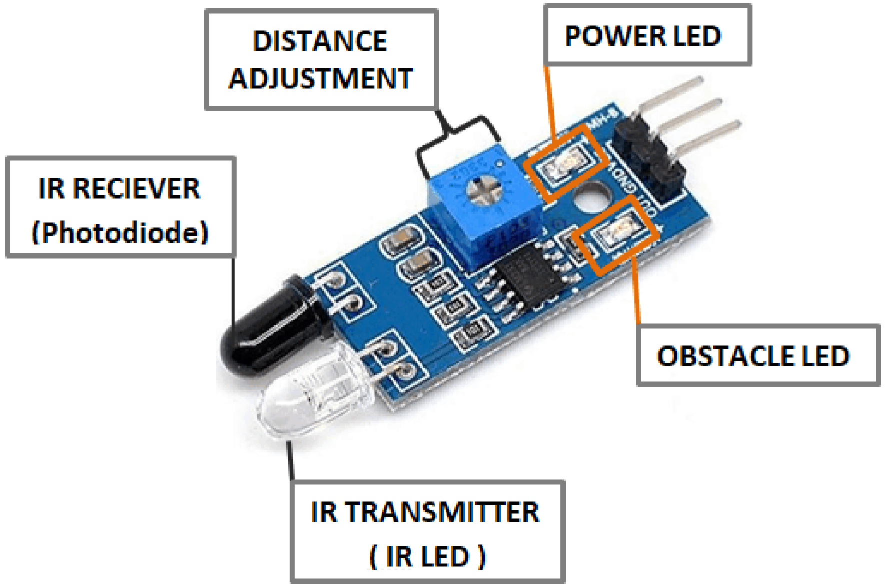
Various types of sensors used in Mining machinery, including:

- **Infrared (IR) Sensors (300 GHz to 400 THz)**
- **Ultrasonic Sensors (30–500 kHz)**
- **Lidar Sensors (Scanning LiDAR typically spin and measure distance in an angular range up to 360° circle based on spinning frequency between 1Hz and 100Hz)**
- **Cameras**
- **Wheel Encoders**
- **Gyroscopes**
- **Accelerometer**
- **Touch Sensors**

Types of sensors

Infrared (IR) Sensors

IR sensors applications in obstacle detection and avoidance.

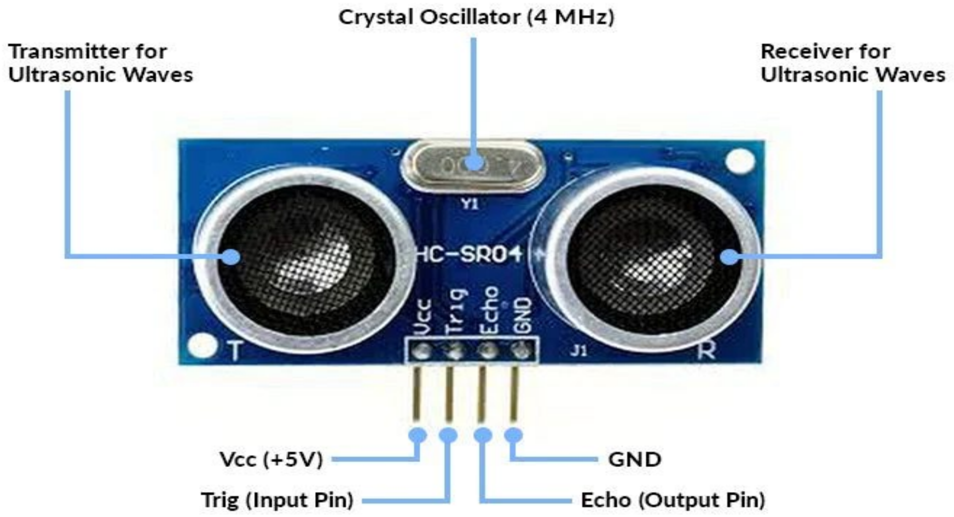


Main Chip	LM393
Operating Voltage (VDC)	3.6 ~ 5
Average Current Consumption (mA)	0.06
Detection Angle	35 Â°
Distance Measuring Range (CM)	2 ~ 30
Dimensions (mm) LxWxH	48 x 14 x 8
Weight (gm)	5
Shipping Weight	0.01 kg
Shipping Dimensions	5 × 4 × 1 cm

Figure 8. Infrared based proximity sensor and Specification

Ultrasonic Sensors

Ultrasonic sensors use in distance measurement and object detection.



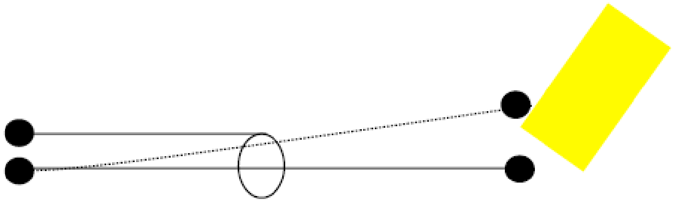
Specification
Supply voltage +5 V;
Consumption in silent mode 2mA;
Consumption at working of 15 mA;
Measurement range – 2 to 400 cm;
Effective measuring angle 15 Degree;
The dimensions are 45×20×15 mm.

Figure 9. Ultrasonic based proximity sensor and specification

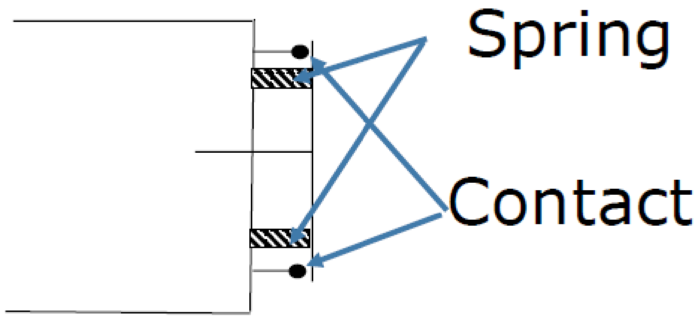
Example:

Tactile Sensors

Measure contact with objects



Touch sensor



Bumper sensor

Example:

Time of Flight Sensors

$$d = v \times t/2$$

Where
d: Distance
v: speed of the signal
t: time elapsed between broadcast of signal and reception of the echo

Example:

Polaroid ultrasonic sensor used for obstacle avoidance

- Emit an ultrasonic signal
- This sonar operates at its resonance frequency of 50 kHz.
- Wait until they receive the echo
- Time of flight sensor

Polaroyd
6500

Example:

The Polaroid 6500 Series (see Figure 10), which is commonly used on mobile robots for obstacle avoidance.

This sonar operates at its resonance frequency of 50 kHz.

The propagation pattern for the Polaroid 6500 sensor is shown in Figure 10.

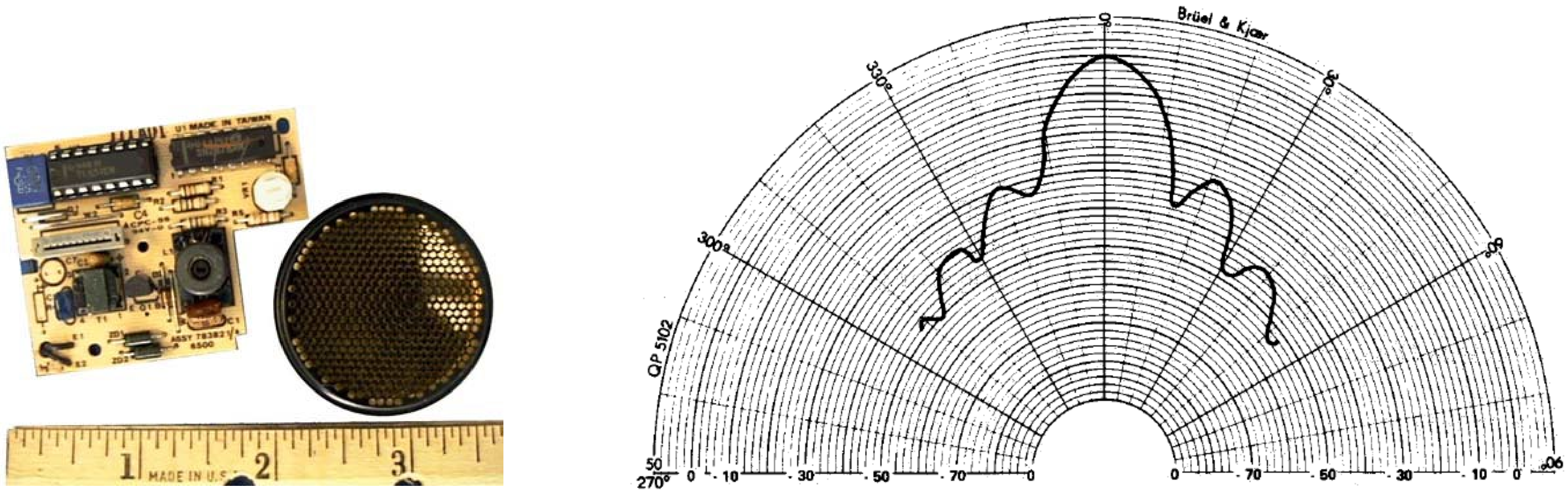
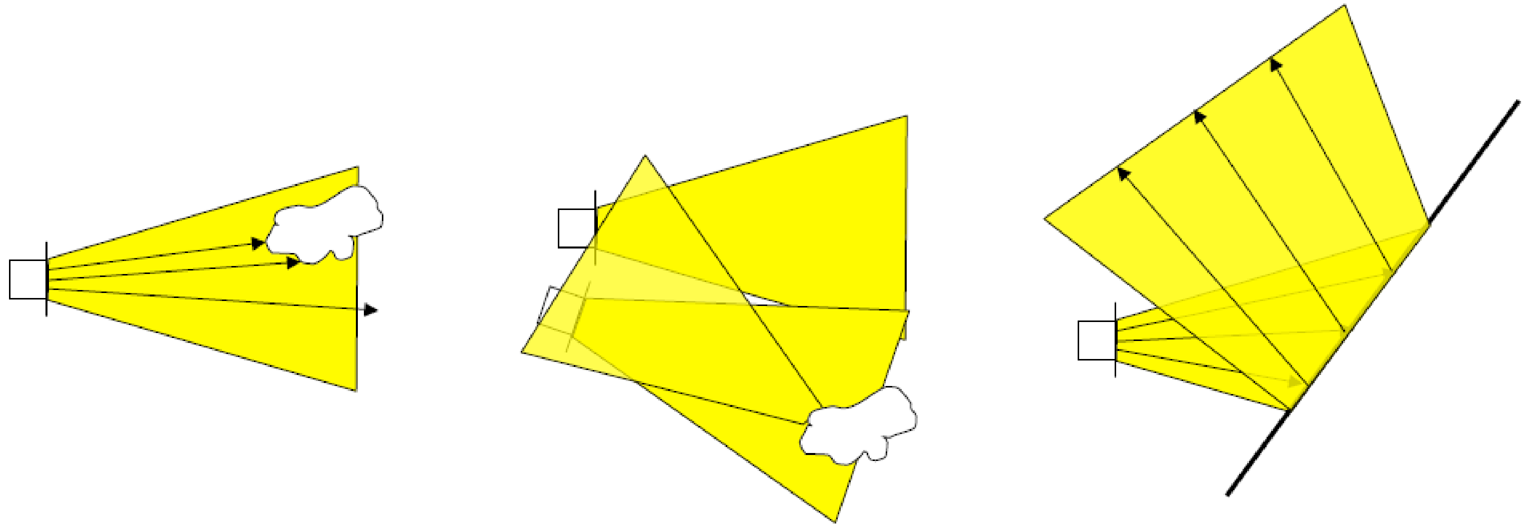


Figure 10. The Polaroid 6500 Series ultrasonic Sensor and Typical propagation pattern for the Polaroid 6500 Series ultrasonic sensor.

Example:

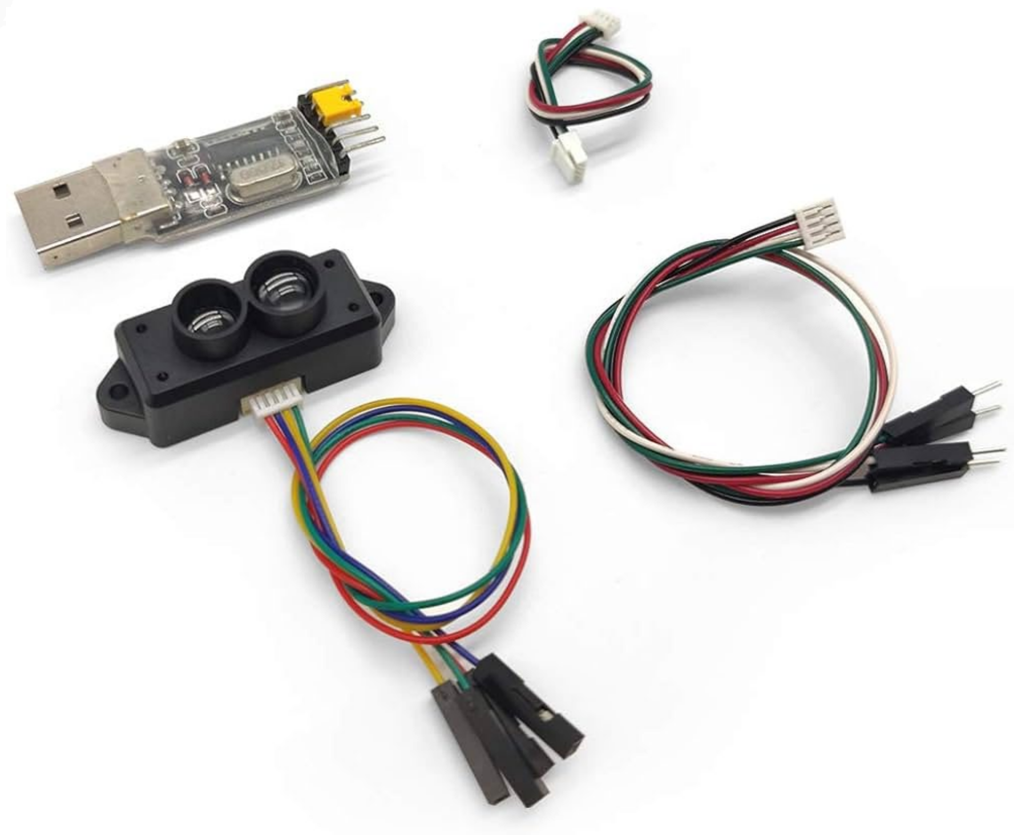
Sources of Error

- Opening angle
- Crosstalk
- Specular reflection



Lidar Sensors

Highlight their role in creating detailed 2D or 3D maps of the environment.

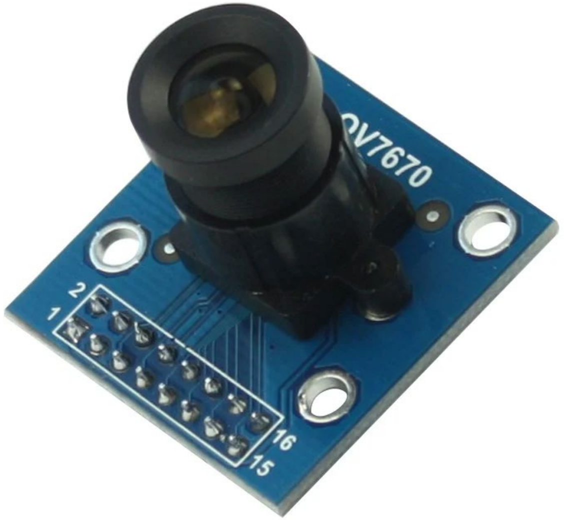


Specification
Operating Range 0.3 - 12m;
Average Power Consumption 0.12W;
Resolution 1cm;
Operating Voltage 4.5 - 6V DC;
Acceptance Angle 2.3°;
Frequency Range 100Hz;
Wavelength 850nm;
Dimensions 3 x 2 x 1cm;
Weight 15gm;

Figure 11. Lidar based proximity sensor

Cameras

Mention applications like object recognition, navigation, and image processing.



Specifications (MODEL: OV7670 640X480 VGA CMOS CAMERA)
Pixel Coverage: 3.6um x 3.6um;
Duck Current: 12 mV/s at 6'C
Support VGA, CIF and from CIF to 40 x 30 format;
Vario Pixel method for sub-sampling; Auto Image Control: AEC, AGC, AWB, ABF, ABLC;
Image Quality Control: Color saturation, hue, gamma, sharpness, and anti-blooming;
ISP includes noise reduction and defect correction; Support image scaling; Lens shading correction;
Flicker 50/60Hz auto-detection;
Color saturation level auto adjust;
Edge enhancement level auto adjust;
High sensitivity for low light applications
Low voltage suitable for embedded applications
Standard sccb interface, compatible with i2c interface

Figure 12. OV7670 640×480 VGA CMOS Camera Image Sensor Module and specification

Wheel Encoders

Their importance in odometry and tracking the robot's position.

Figure 13. Wheel based proximity sensor

Example:

Sensors of Wheeled Robots

Perception of the environment

Active:
- Ultrasound
- Laser range finder
- Infrared

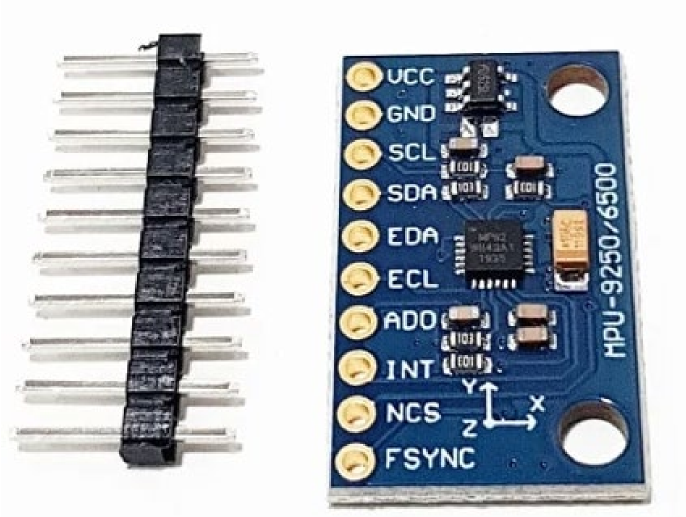
Time of flight

Passive:
- Cameras
- Tactiles

Intensity-based

Gyroscope and Accelerometer

Analyze the movement of machine. They can be used in stabilizing and controlling the robot.



Power Supply	4.4 to 6.5 V or 3.3V (if you solder the jumper near the on-board voltage regulator)
Gyro range	± 250 500 1000 2000 ° / s
Acceleration range	± 2 ± 4 ± 8 ± 16g
Degree of Freedom (DOF)	6
Interface	I2C
Shipping Weight	0.01 kg
Shipping Dimensions	4 × 2 × 1 cm

Figure 14. MPU6500 Gyroscope/Accelerometer/Digital Motion Processor (DMP) 6-axis Motion Sensor with I2C/SPI Interface and specification

Touch Sensor

It has applications such as detecting physical interactions, heavy machinery control (Rugged touch screen), telemetry system (machine health and performance), ergonomic workstation (comfortable machinery control), digital communication and collisions.

Operating Voltage (VDC)	2 ~ 5.5
Output high VOH	0.8VCC V
Output low VOL	0.3VCC V
Response time (touch mode)	60 mS
Response time (low power mode)	220 mS
Length (mm):	24
Width (mm)	24
Height (mm)	2
Weight (gm)	0.6
Shipping Weight	0.085 kg
Shipping Dimensions	3 × 3 × 1 cm

Figure 15. Digital Sensor TTP223B Module Capacitive Touch Switch and specification

Sensor Fusion

Combining data from multiple sensors can enhance a robot's perception.

Accelerometer

Gyroscope

Magnetometer

IMU (Inertial Measuring Unit)

Motion and orientation monitoring

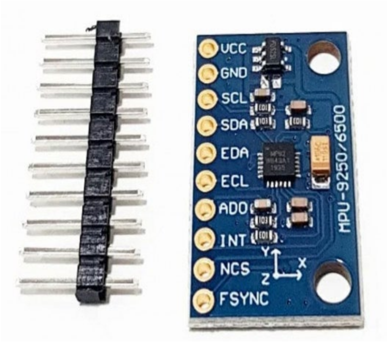


Figure 16. Fusion based sensor

Sensor Fusion application in Opencast mine

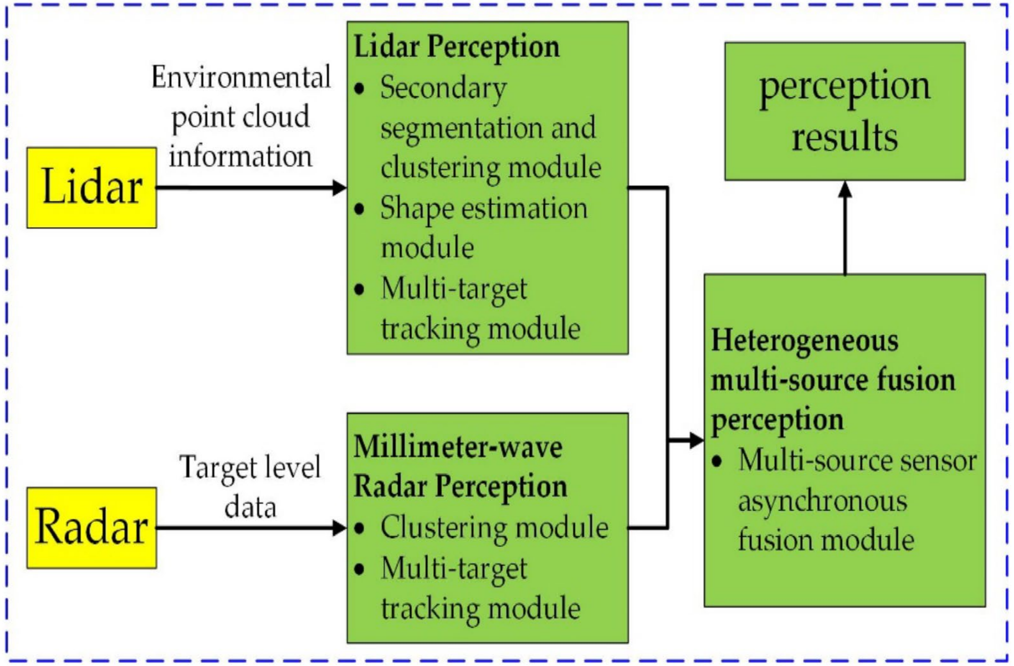
- There exist many difficulties in environmental perception in transportation at open-pit mines, such as unpaved roads, dusty environments, and high requirements for the detection and tracking stability of small irregular obstacles.

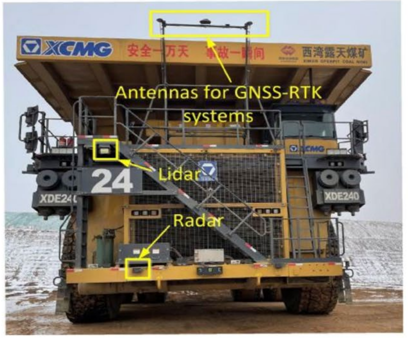
- In order to solve the above problems, a new multi-target detection and tracking method is proposed based on the fusion of sensors (Lidar and millimeter-wave radar).

- It advances a secondary segmentation algorithm suitable for open-pit mine production scenarios to improve the detection distance and accuracy of small irregular obstacles on unpaved roads.

- An adaptive heterogeneous multi-source fusion strategy of filtering dust, which can significantly improve the detection and tracking ability of the perception system for various targets in the dust environment by adaptively adjusting the confidence of the output target.

Sensor Fusion application in Opencast mine





(a) main sensors of a mining truck

(b) main road

(c) rough road

(d) dust scene

Figure 16. The framework of the multi-target detection and tracking method diagram (a) The photo of the mine truck with Lidar and millimeter-wave radar; (b) The main road littered with stones; (c) The rough road in the loading area; (d) The dust scene in the unloading area.

Proximity sensor comparison

Sensor Type	Operating Principle	Sensing Range	Output Type	Target Material	Power Supply	Application Example
Inductive	Eddy Currents	0.8mm - 80mm	NPN/PNP, Analog	Metal (usually ferrous)	10-30V DC	Metal detection, automation
Capacitive	Change in Capacity	1mm - 30mm	NPN/PNP, Analog	Non-metallic materials	10-30V DC	Liquid level sensing, touch
Ultrasonic	Sound Waves	2cm - 10m	Digital, Analog	Almost any material	5-24V DC	Object detection, distance
Photoelectric	Light Beam	1mm - 100m	NPN/PNP, Analog	Various materials	10-30V DC	Object detection, counting
Magnetic	Magnetic Field	1mm - 15mm	NPN/PNP, Analog	Ferrous materials	5-24V DC	Position sensing, security
Hall Effect	Hall Effect	0.1mm - 10mm	Analog	Ferrous and magnetic	5-24V DC	Position sensing, rotation
Infrared (IR)	Infrared Light	2cm - 150cm	Digital, Analog	Various materials	5-24V DC	Proximity detection, gesture

REFERENCES

- https://www.ti.com/lit/an/slaa907d/slaa907d.pdf?ts=1702226618839
- https://ccrma.stanford.edu/~gary/controllers/ir.html
- https://vayuyaan.com/blog/ir-sensor-module-infrared-sensor-complete-guide/
- https://robu.in/inductive-proximity-sensor-working-principle/
- https://robu.in/capacitive-proximity-sensor-working-principle/
- Kim, Y.; Baek, J.; Choi, Y. Smart Helmet-Based Personnel Proximity Warning System for Improving Underground Mine Safety. Appl. Sci. 2021, 11, 4342. https://doi.org/10.3390/app11104342
- https://www.electronicscomp.com/mpu9250-9-axis-gyro-accelerometer-module?gad_source=1
- M. E. Kiziroglou, D. E. Boyle, E. M. Yeatman and J. J. Cilliers, "Opportunities for Sensing Systems in Mining," in IEEE Transactions on Industrial Informatics, vol. 13, no. 1, pp. 278-286, Feb. 2017, doi: 10.1109/TII.2016.2636131.

REFERENCES

- Liu, H.; Pan, W.; Hu, Y.; Li, C.; Yuan, X.; Long, T. A Detection and Tracking Method Based on Heterogeneous Multi-Sensor Fusion for Unmanned Mining Trucks. Sensors 2022, 22, 5989. https://doi.org/10.3390/s22165989

CONCLUSION

- **Proximity sensors are devices that detect the presence or absence of objects within a certain range without direct contact.**

- **Utilizing technologies like infrared, ultrasonic, capacitive, inductive, or magnetic sensing, these sensors are crucial in various industries such as manufacturing, automotive, and consumer electronics.**

- **They offer non-contact operation, reliability, and quick response times, enhancing efficiency and safety in applications ranging from automation in factories to proximity detection in smartphones.**


THANK YOU

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Module 04:
Proximity Sensors and Control System

Lecture 08 B:
Proximity Sensors and Control System

CONCEPTS COVERED

- Proximity Sensors and Control System
- Personnel Proximity Warning System
- Design of the Proximity Warning System (PWS) Based on Bluetooth Beacons and Smart Helmets
- Experiment of the Proximity Warning System Based on Bluetooth Beacon and Smart Helmet
- Results of smart helmet

Proximity Sensors and Control System

More and more design engineers are selecting proximity sensors for their versatility, reliability, durability, and cost-efficiency over mechanical switches for access control.

Especially when large machinery and heavy vehicles are operating in the mines safety aspect has to be taken care of everything else.

Sophisticated proximity alert systems and proximity detection devices are an essential investment to avoid collisions in the mines.

Figure 1. Proximity sensor system for human safety

Personnel Proximity Warning System (PWS)

- A wearable personnel proximity warning system can prevent collisions between equipment and pedestrians in mines.

- Sensors warn miners by indicating signals and alarm sounds.

- PWS uses a fusion of sensors (Bluetooth beacon & inductive sensors) for detecting proximity and awareness in the mine environment.

- Example: The smart helmet-based PWS can provide visual proximity warning alerts to both the equipment operator and the pedestrian, and it can be expanded to provide worker health monitoring and hazard awareness functions by adding sensors to the Arduino board.

Design of the Proximity Warning System (PWS) Based on Bluetooth Beacons and Smart Helmets

- A smart helmet-based wearable personnel proximity warning system can be used to prevent collisions between equipment and pedestrians in mines.

- The design of PWS based on Bluetooth beacons and smart helmets is summarized in Figure 2.

- The smart helmet worn by the worker receives a Bluetooth low energy (BLE) signal transmitted from the Bluetooth beacon and provides a visual alert when it comes close to the beacon.

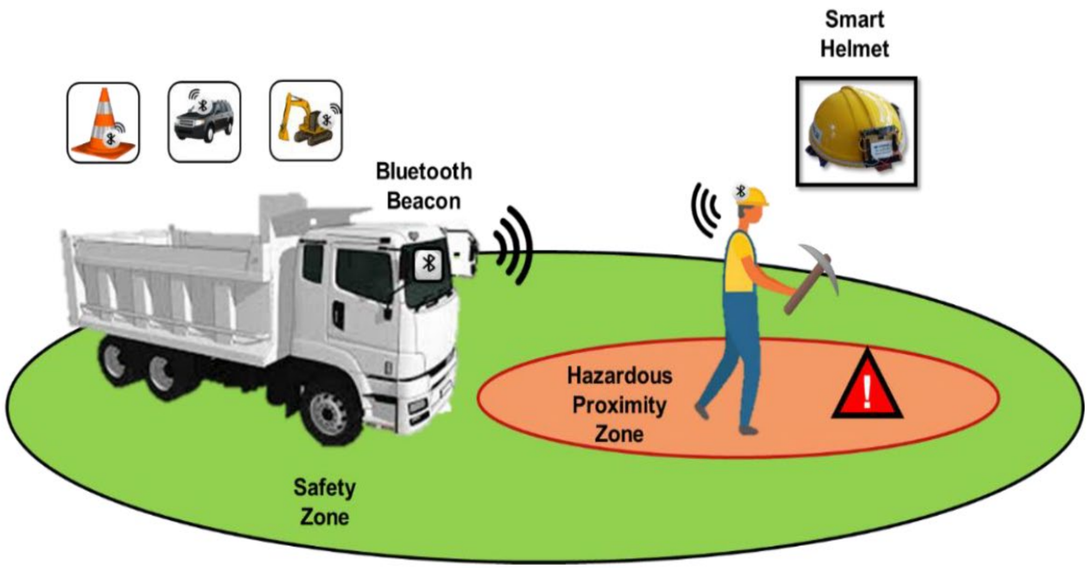


Figure 2. Overview of personal proximity warning system (PWS) using smart helmet.

- **The Bluetooth beacon can be attached to heavy equipment, a management vehicle, or a dangerous area at the mine site, and the attached beacon continuously transmits the Bluetooth low energy (BLE) signal.**

- **The smart helmet can warn wearers of access to heavy equipment or vehicles and access dangerous areas and warn drivers that there are workers nearby.**

- **Visual proximity alerts are received through a smart helmet while working on the spot; therefore, both workers and drivers can quickly detect and respond to dangerous situations.**

- **The smart helmet worn by pedestrians receives signals transmitted by Bluetooth beacons attached to heavy equipment, light vehicles, or dangerous zones, and provides visual LED warnings to the pedestrians and operators simultaneously.**

1. Design of BLE Transmission Units Using Bluetooth Beacon

- **Bluetooth beacons periodically transmit information, including the general-purpose unique identifier of the beacon and media access control (MAC) address through the BLE signal.**

- **The intensity of the BLE signal transmitted by the Bluetooth beacon is expressed as Tx power, and the unit is dBm. dBm is a unit of level used to indicate that a power level is expressed in decibels (dB) with reference to one milliwatt.**

- **The received intensity of the BLE signal can be quantified using the RSSI (Received Signal Strength Indicator) value. RSSI is represented in a negative form by a value between −99 dBm and −35 dBm. Bluetooth RSSI is a measure that represents the relative quality level of a Bluetooth signal received on a device.**

- **The propagation distance of the BLE signal may vary depending on the signal transmission intensity and direction of the signal propagation of the Bluetooth beacon.**

- An increase in the BLE signal transmission intensity increases the signal propagation distance.

- The signal propagation direction is bidirectional, and the signal can be spread uniformly in all directions, but this limits the propagation distance.

- The BLE signal is first propagated relative to the Bluetooth beacon when the signal is transmitted as the directional signal.

- The change in RSSI according to the BLE signal transmission intensity and the direction of the radio wave of the Bluetooth beacon was previously analyzed

In this case study, RECO beacons (Perples, Seoul, Korea) were used as BLE transmission devices.

RECO beacons are certified by institutions in Korea, the United States, Europe, and Japan and meet global beacon standards (Table).

Table 1. Specifications of the RECO beacon

Item	Value
Dimensions (Diameter × Height)	45 mm × 20 mm
Weight	11.6 g (0.4 oz)
Processor	32-bit ARM® Cortex®-M0
Battery	CR2450 Lithium Coin Battery (3 V, 620 mAh)
Casing	Acrylonitrile Butadiene Styrene (ABS) Plastic
Chipset	Nordic nrf51822
Thermal Resistance	93 °C (200 °F)
Operating Temperature	−10–60 °C (14–140 °F)
Wireless Technology	Bluetooth 4.0 (i.e., BLE or Bluetooth® Smart)
Signal range	1 m~70 m (3.2 ft~230 ft)
Signal transmission period	Min (10 ms), Max (2 s)
Transmission power	Min (−16 dBm), Max (4 dBm)
	Korea Certification (KC)

Figure 3 shows examples of heavy equipment and vehicles at the mine site with RECO beacons.

A Bluetooth beacon was installed on the back of the room mirror on the front of the truck, and a Bluetooth beacon was provided on the front of the heavy equipment.

The Bluetooth beacons set the directional signal such that the signal could be propagated further. The signal transmission strength and period of the beacons were set to - 4 dBm and 1 s, respectively.

Bluetooth beacons periodically transmit information, including the general-purpose unique identifier of the beacon and media access control (MAC) address through the BLE signal.

Figure 3. Bluetooth beacons attached to trucks (a,b) and excavators (c, d).

2. Design of BLE Receiver Units Using an Arduino Board

Arduino is an open source electronic platform based on easy-to-use hardware and software (Table 2).

The Arduino board reads the input data, including sensor illumination and button pressing and converts it into output data.

Because the Arduino board and software are open sources, users can independently build boards to adjust the system to meet specific needs.

Table 2. Specifications of the Arduino Uno board

Item	Value
Model	Arduino Uno R3
Microcontroller	ATmega328P
Length	68.6 mm
Width	53.4 mm
Weight	25 g
Operating Voltage	5 V
Input Voltage	7–12 V (recommended), 6–20 V (limit)
Digital I/O Pins	14 (of which 6 provide PWM output)
PWM Digital I/O Pins	6
Analog Input Pins	6
DC Current per I/O Pin	20 mA
DC Current for 3.3V Pin	50 mA
Flash Memory	32 KB (ATmega328P) of which 0.5 KB used by bootloader
SRAM	2 KB (ATmega328P)
EEPROM	1 KB (ATmega328P)
Clock Speed	16 MHz
LED_BUILTIN	13

The circuit diagram was used to visualize the connection method of the Arduino board, LED, and Bluetooth module as shown in Figure 4.

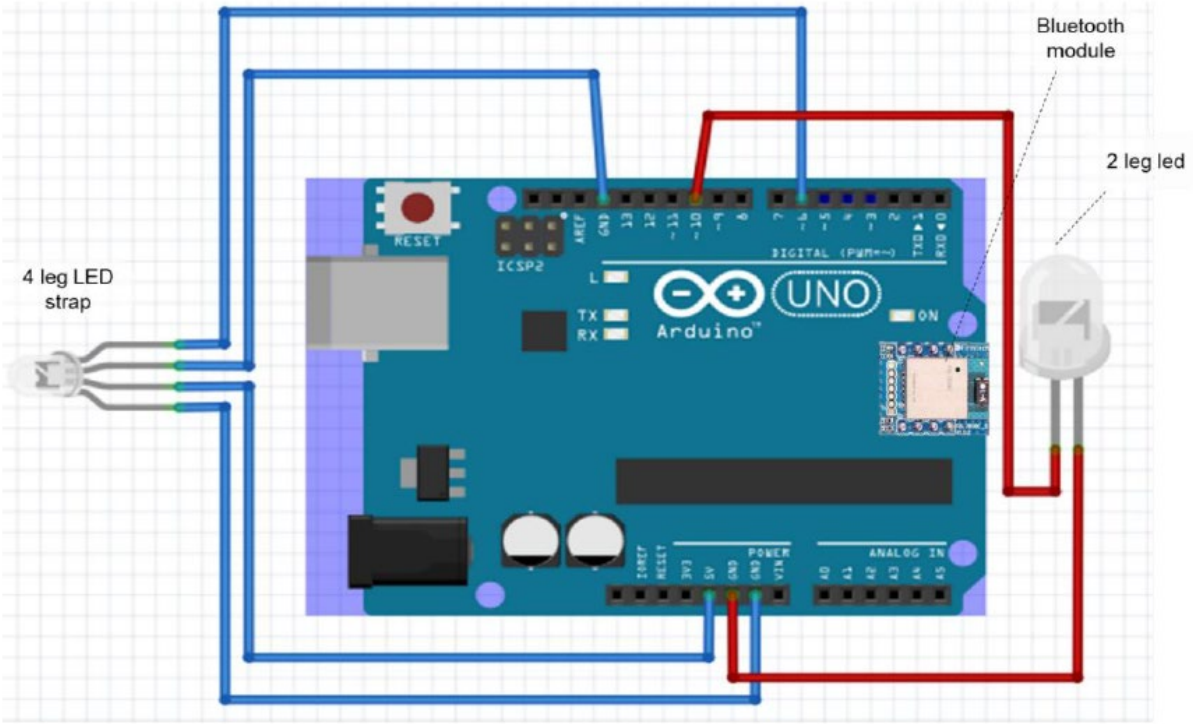


Figure 4. Circuit diagram of Arduino application.

In this study, a smart helmet was developed to develop a wearable personal PWS for mine workers.

The smart helmet was made by combining an Arduino Uno board, Bluetooth BLE module (FBL780BC, Table 3), LED strap, and two-leg LEDs with the safety helmet worn by mining workers.

Table 3. Specifications of Bluetooth module

Item	Value
Model	FBL780BC
Bluetooth specification	Bluetooth4.1Low Energy Support
Communication distance	10 m
Frequency range	2402~2480 MHz ISM Band
Sensitivity	−94 dBm
Transmit power	2 dBm (−3 dBm: Actual value after matching)
Size	15.5 mm × 18.5 mm
Input power	3.3 V
Current consumption	Peripheral: 3 mA (Max), Central: 21 mA (Max: Scanning)
Operating temperature	Min: −10 °C, Max: 50 °C
Communication speed	2400 bps~230,400 bps
Antenna	Chip Antenna
Interface	UART

Figure 5a,b show the exterior shape of the equipment divided into front and rear parts.

The smart helmet provides visual warnings through LED straps (using two-leg LEDs), and receiving power through portable batteries.

The Bluetooth BLE module (FBL780BC) supports Bluetooth Low Energy, a low-power function based on Bluetooth 4.1.

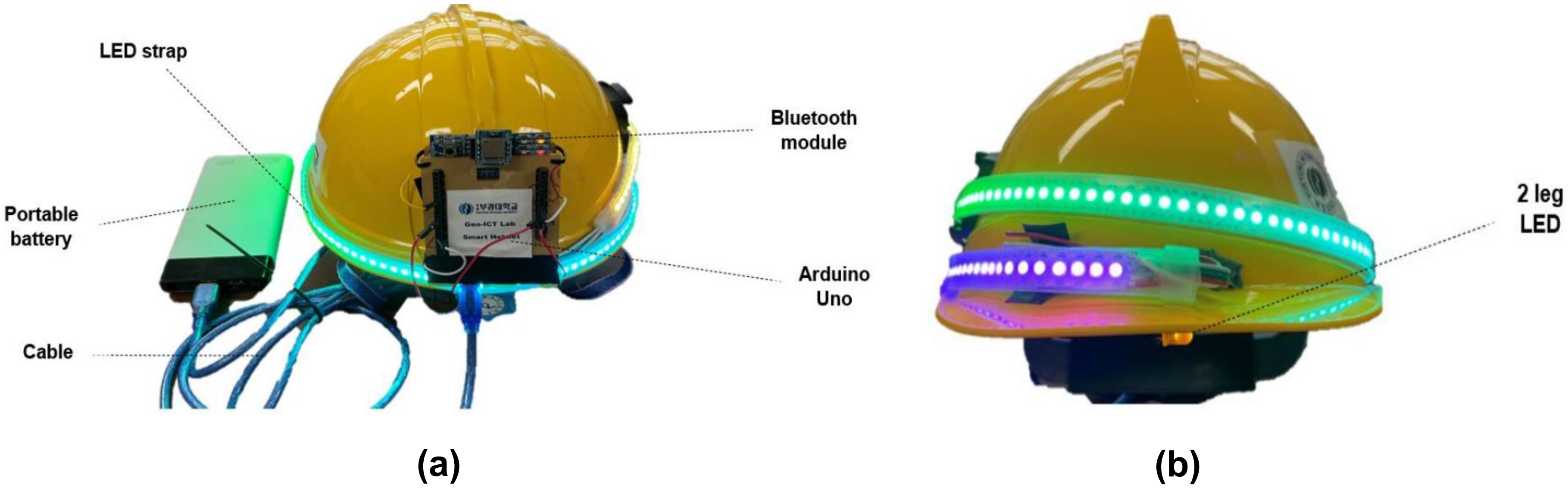


Figure 5. The component of the smart helmet. The rear part (a) and the front part (b) of the helmet

The process of the operating algorithm of the smart-helmet PWS is illustrated in Figure 6.

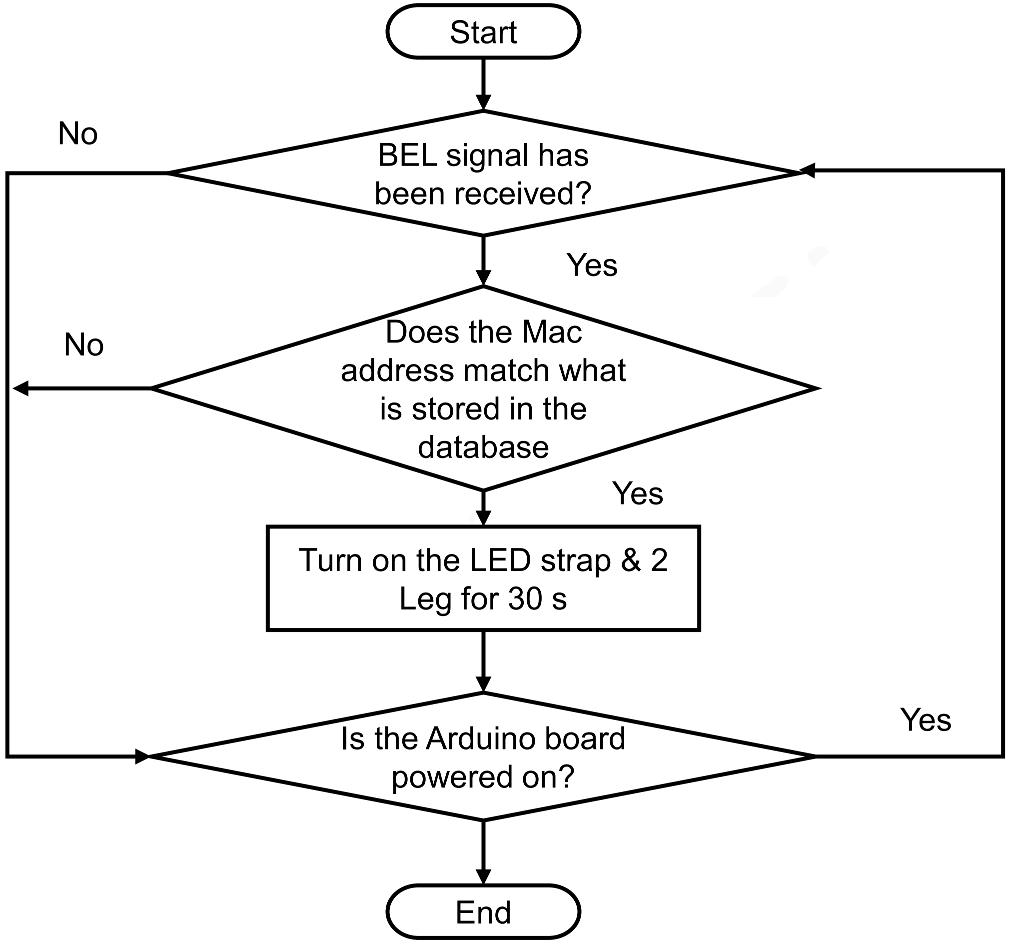
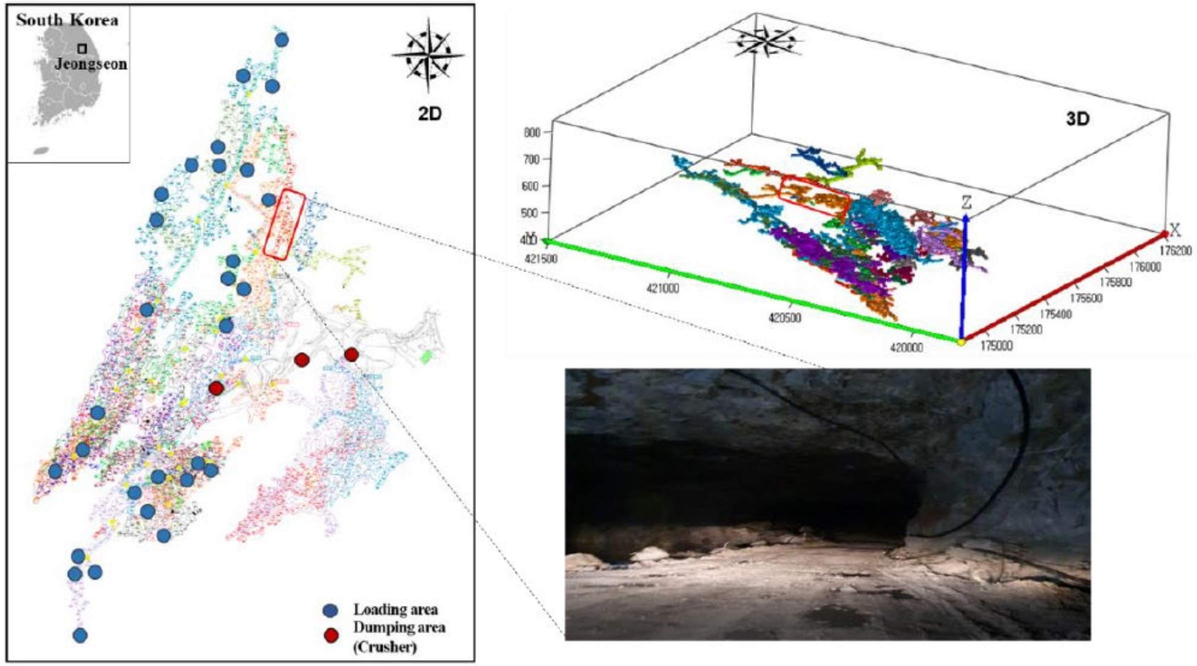


Figure 6. The process of the operating algorithm for the smart helmet-based personal proximity warning system.

Experiment of the Proximity Warning System Based on Bluetooth Beacon and Smart Helmet

A. Performance Evaluation of Personal PWS Based on Smart Helmets



To evaluate the performance of the developed smart helmet-based personal PWS, a field experiment was conducted at the Sungshin Minefield underground limestone mine located in Jeongseon-gun, Gangwon-do, Korea.

Figure 7 shows the tunnels that have been tested in the field on a two-dimensional and three-dimensional map and an actual photograph.

Figure 7. Underground map of the study area (Sungshin Minefield underground limestone mine, Jeongsun-gun, Gangwondo, Korea) in 2- and 3-dimensions, and an actual photograph.

Figure 8 shows the smart helmet measuring the detection distance of receiving the BLE signal for each Tx power.

The Bluetooth module that receives the BLE signal was installed at the rear of the helmet, and the Bluetooth module and Bluetooth beacon attached to the vehicle were arranged to face each other.

The Bluetooth beacon, attached to the truck, approached a pedestrian standing on a mine way transport route 100 m away at a speed of 10–20 km/h.

We then measured the detection distance at which the personal PWS receiving the BLE signal began warning pedestrians. The Tx power was set at 4 dBm intervals from — 12 dBm to 4 dBm and measured 10 times for each Tx rower (50 times total)

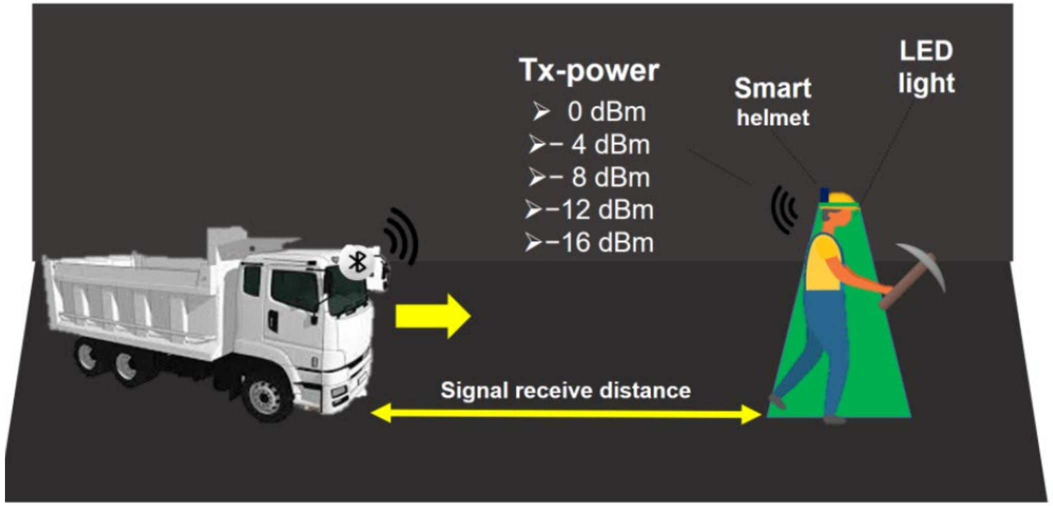


Figure 8. Experimental model of BLE signal detection distance measurement performed by considering the Tx power of the Bluetooth beacon.

Figure 9 shows an experiment that measures the detection distance of a smart helmet receiving a BLE signal via adjusting the angle between the Bluetooth beacon and the smart helmet.

Similar to the above experiment, the truck approached at speeds of 10–20 km/h, and the detection distance at which the warning commenced was measured.

The angles between the smart helmets and beacons were set at 45 intervals—from 0 to 180, and measured 10 times for each angle (50 measurements in total).

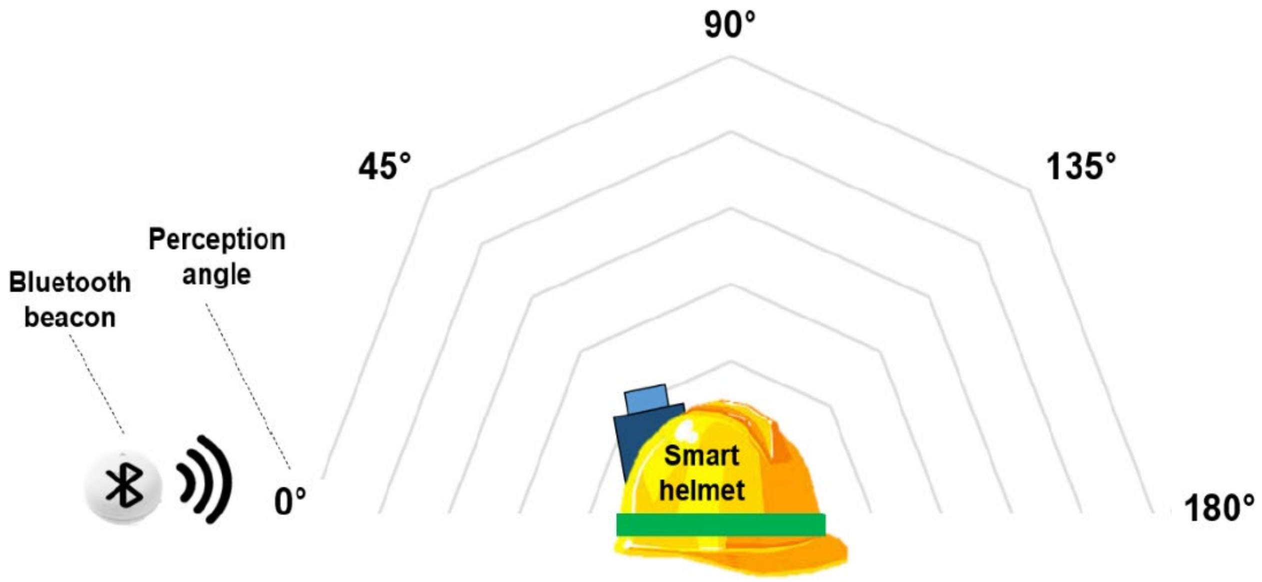


Figure 9. BLE Signal detection distance measurement model according to the perception angle between the Bluetooth beacon and the smart helmet.

B. Subjective Workload Assessment of Smart Helmet-Based Personal PWS

Three equivalent experiments were performed under the same experimental conditions to compare the effect on the subjective workload.

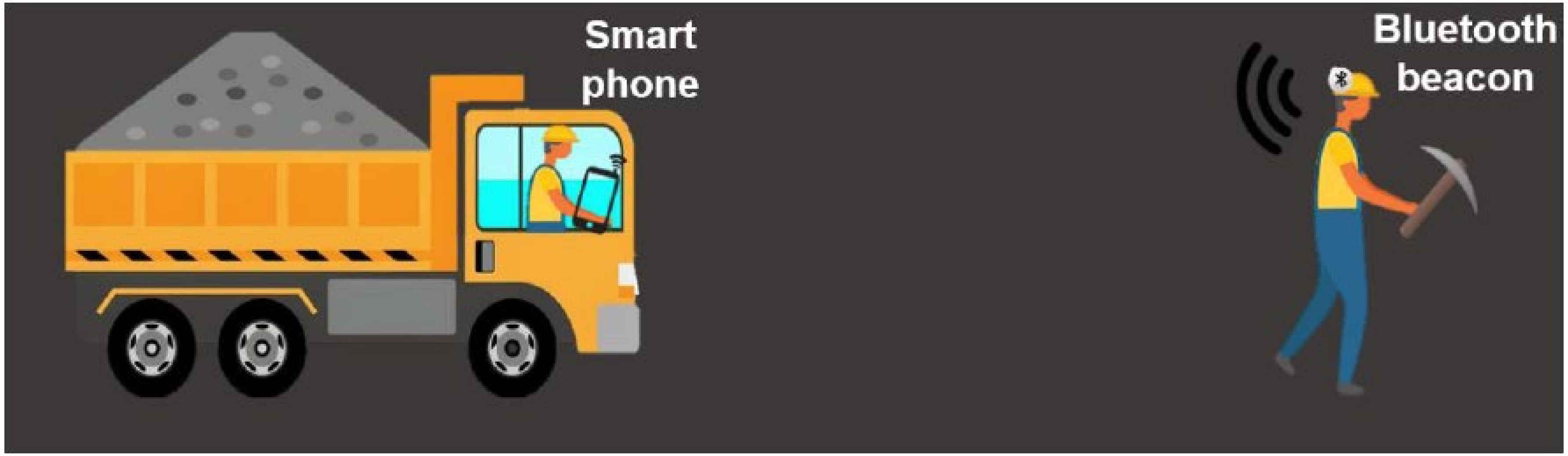
In this study, the subjective workload evaluation was performed on 10 experimental subjects aged 24 to 26 years old (average age was 24.9 years) at the same location where individual PWS performance was evaluated.

More than half (60%) of the test subjects said they had knowledge of smart glasses, and the majority (80%) said they had no knowledge of smart helmets.

The test subjects used (a) a smartphone-based personal PWS (driver's position), (b) a smart glass-based personal PWS (worker's position), and (c) a smart helmet-based personal PWS (worker and driver's position).

In the experiments, the test subject stood at the center of the transport route and examined the condition of the transport route (worker's position) or boarded a truck or loader (driver's position) to approach the subject.

The smartphone provided a proximity warning to the driver with a hazard warning image.



(a)

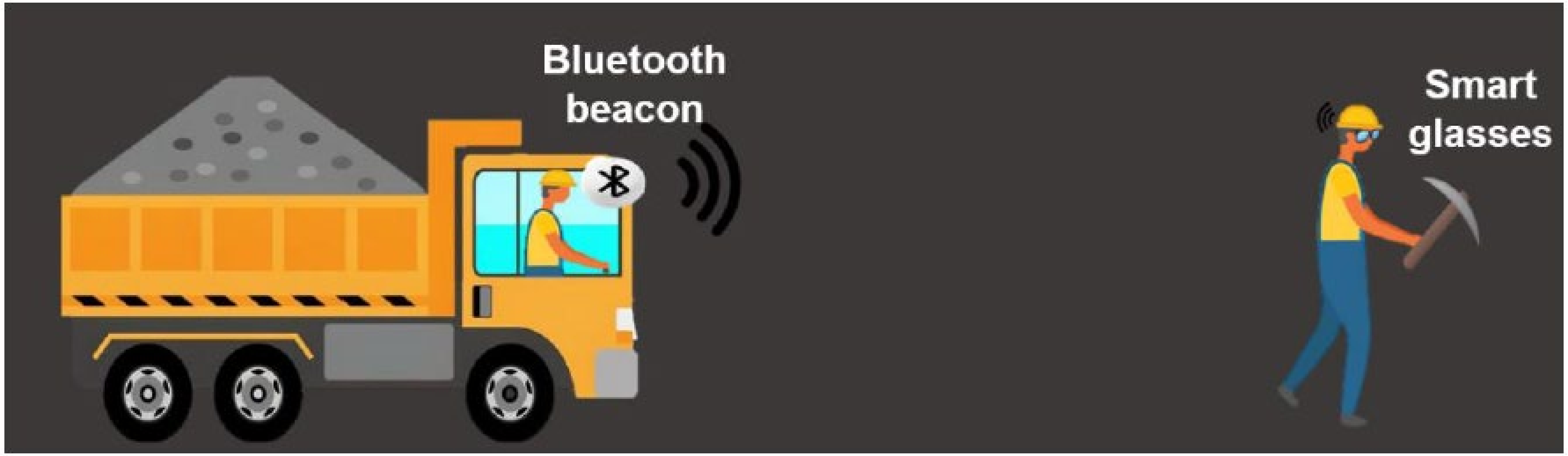
Figure 10. (a) Type 1: truck drivers wearing the smartphone-based PWS.

Smart glass provides a proximity alert to a worker with a hazard warning image.

The smart helmet turned on the LED to provide a visual warning to both the driver and worker.

In one case, the test subject boarded a loader or truck (driver's position) and when the device sensed that the worker was nearby, the vehicle was stopped temporarily.

The worker passed only after confirming the evacuation.



(b)

Figure 10. (b) type 2: pedestrian workers wearing the smart glasses-based PWS.

In another case, the test subject examined the transport route's maintenance status (worker's position), and the operation was stopped when the device sensed that a vehicle was approaching.

The subject evacuated to the side of the transport route, and only after the vehicle had passed did the operation resume.

(c)

Figure 10. (c) type 3: truck drivers and pedestrian workers wearing the smart helmet-based PWS.

(a) (b)

Figure 11. Experimental results showing the performance of the smart-helmet based PWS. (a) Worker wearing the smart helmet when no BLE signal is received; (b) worker wearing the smart helmet when a BLE signal is received.

Results of smart helmet

- Figure 11a shows the worker wearing a smart helmet when a BLE signal is not received, and Figure 11b shows the worker wearing a smart helmet when a BLE signal is received.

- The MAC address of the Bluetooth beacons to be attached to the mining equipment was stored in a personal PWS application program, and the smart helmet PWS was designed to provide visual alerts through LEDs when the BLE signals were received.

- Through the visual alarm, through LEDs, both the worker and driver can recognize the danger in advance and prevent accidents

Figure 12 shows the average detection distance per Tx power as a graph.

The average detection distance is 2.9 m at -12 dBm, 6.0 m at -8 dBm, 27.1 m at -4 dBm, 62.7 m at 0 dBm, and 66.9m at 4 dBm.

As the Tx power increased, the smart helmet's BLE signal detection distance also increased.

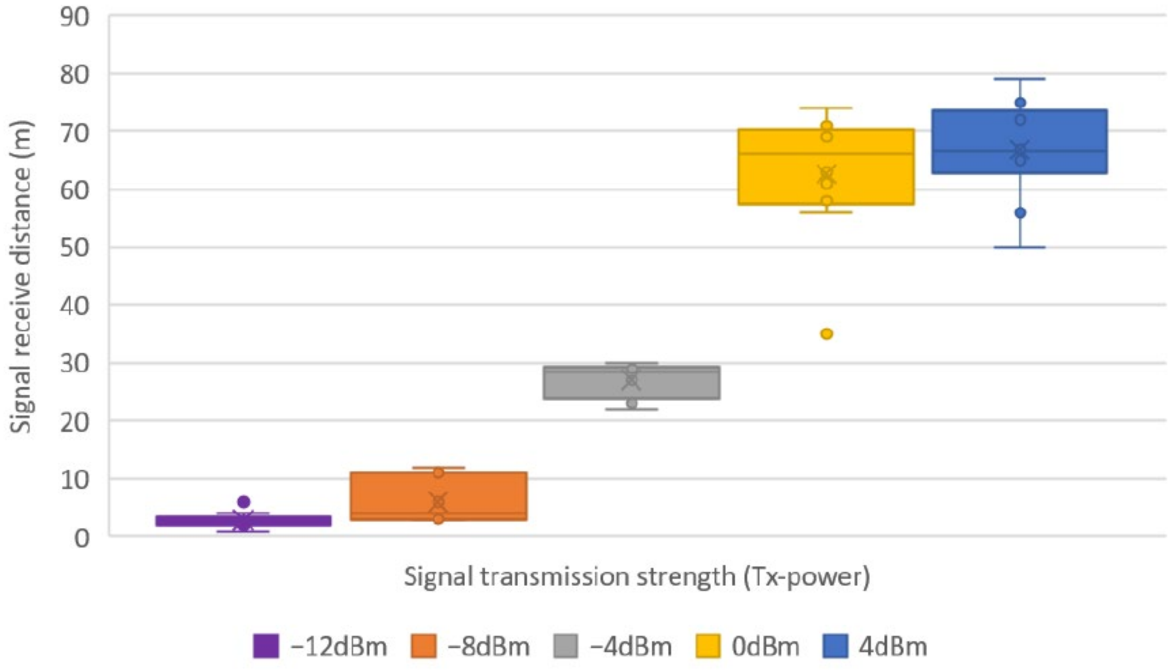


Figure 12. Average BLE signal detection distance of smart helmet according to Tx power of Bluetooth beacon (m).

BLE Signal Propagation in Underground Mines

- **Structural Challenges: 90-degree inclined crossings and curved sections impede line-of-sight.**

- **Environmental Factors: Rough mine walls cause signal diffraction and reflection. Rock mass leads to radio signal attenuation. High humidity and suspended dust affect air quality.**

- **Electromagnetic Interference: Power supply installations create electromagnetic fields. Potential interference with BLE signals.**

- **Testing Objectives: Assess signal stability in complex mine environments. Understand diffraction, reflection, and interference effects.**

- **Testing Importance: Enhance communication reliability in mines. Inform design for robust BLE systems. Improve safety and efficiency.**

Advantages of Smart Helmet-Based PWS

- **Enhanced Alert System: Solves issues of distraction by eliminating the need to check smartphones for warnings. Visual proximity alerts on smart helmets ensure quick identification of danger without disrupting work.**

- **Comfort and Compatibility: Overcomes discomfort caused by smart glasses for workers wearing regular glasses or experiencing slippage. Workers with regular glasses, industrial goggles, and soundproof headsets can use smart helmets comfortably.**

- **Ease of Use: Simplifies operation compared to existing PWSs requiring touchpad controllers. NASA-TLX test indicates users find the smart helmet-based PWS more convenient.**

- **Cost-Effective Implementation: Utilizes Arduino, an open-source hardware, reducing system costs. Allows for the distribution of multiple smart helmets and Bluetooth beacons, making it adaptable to mines of various sizes.**

- **Quick Evacuation Capability: Facilitates rapid evacuation by providing visual proximity alerts without work interruption. Enhances safety by ensuring quick response to dangerous situations.**

- **Broad Applicability: Suitable for diverse workers, including those wearing regular glasses and industrial goggles. Can be implemented across mines of varying sizes due to its cost-effective design.**

REFERENCES

- Kim, Y.; Baek, J.; Choi, Y. Smart Helmet-Based Personnel Proximity Warning System for Improving Underground Mine Safety. Appl. Sci. 2021, 11, 4342. https://doi.org/10.3390/app11104342
- RECO Beacon. Available online: http://reco2.me/
- Bluetooth Module Specification. Available online: http://www.firmtech.co.kr/default/product/bluetooth/fbl780bc.php#01

CONCLUSION

- A proximity sensor is a device that detects the presence or absence of an object or a person within a certain range without any physical contact.

- We have discussed with an example the utility of proximity sensing system to enhance workers safety in the mines using smart helmets.

- The results are optimistic and shows that, it can be customized and mines specific needs may be served well.


THANK YOU

MINE AUTOMATION AND DATA ANALYTICS

MINE AUTOMATION AND DATA ANALYTICS

SWAYAM NPTEL COURSE ON

MINE AUTOMATION AND DATA ANALYTICS

By

Prof. Radhakanta Koner
Department of Mining Engineering
Indian Institute of Technology (Indian School of Mines) Dhanbad

Module 04:
Advanced system in Mining Industry

Lecture 09 A:
Sensing System: Radar Technology

CONCEPTS COVERED

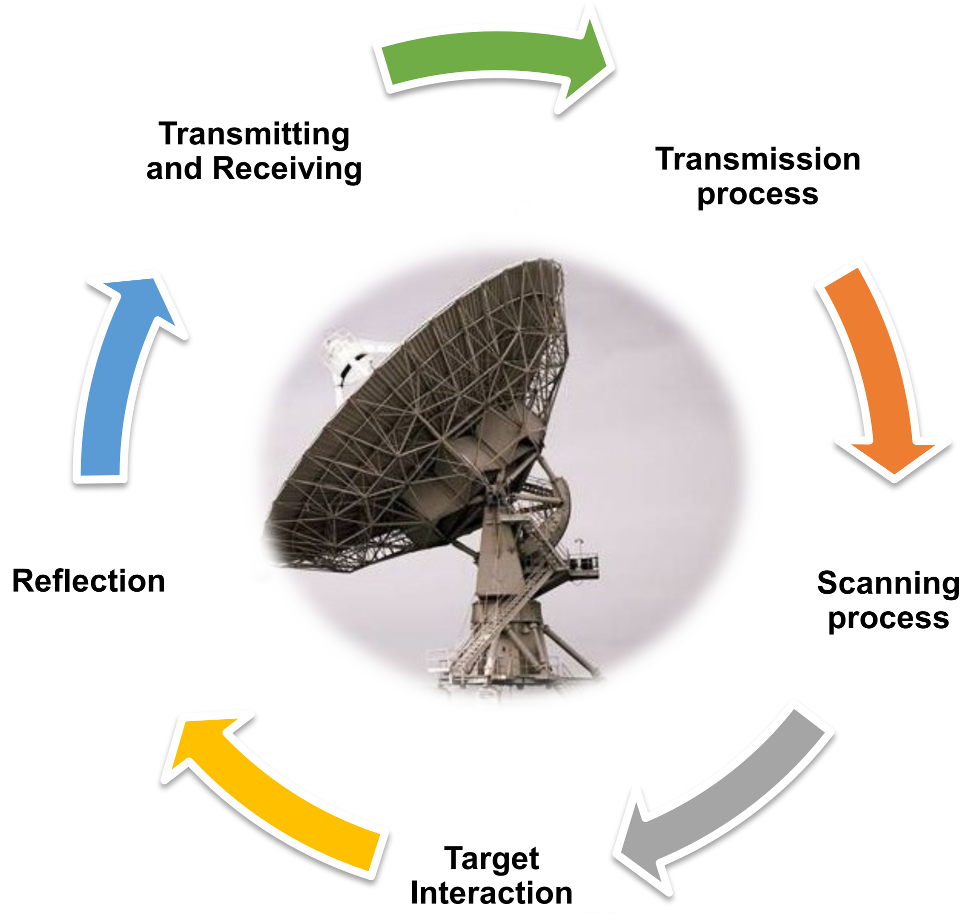
- Introduction to Radar
- Fundamental of Radar
- Types of Radar
- Basics of Radar Technology
- Principle of measurement
- Introduction to slope stability radar(SSR)
- Risk management with SSR
- Case study on radar

Introduction to Radar

It is an electromagnetic sensor used for detecting, locating, tracking, and recognizing objects of various kinds at considerable distances. It operates by transmitting electromagnetic energy toward objects, commonly referred to as targets, and observing the echoes returned from them.

Radar =

Fundamentals of radar



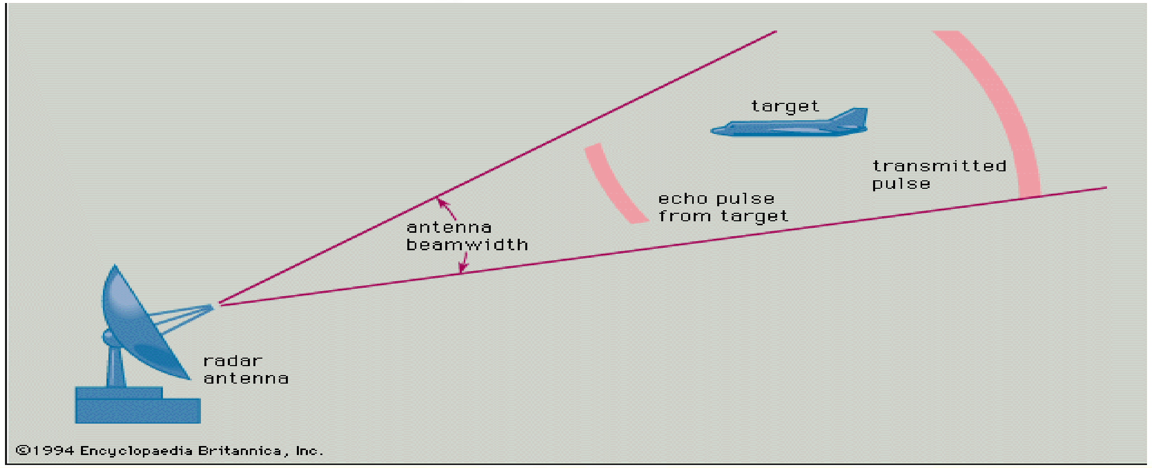
Fundamentals of radar

Transmission process

- Radar involves the transmission of a narrow beam of electromagnetic energy into space. The energy is emitted from an antenna.

Scanning process

- The narrow antenna beam scans a specific region where potential targets are anticipated.



Fundamentals of radar

Target Interaction

- When a target is within the scanned region, it intercepts a portion of the radiated energy.

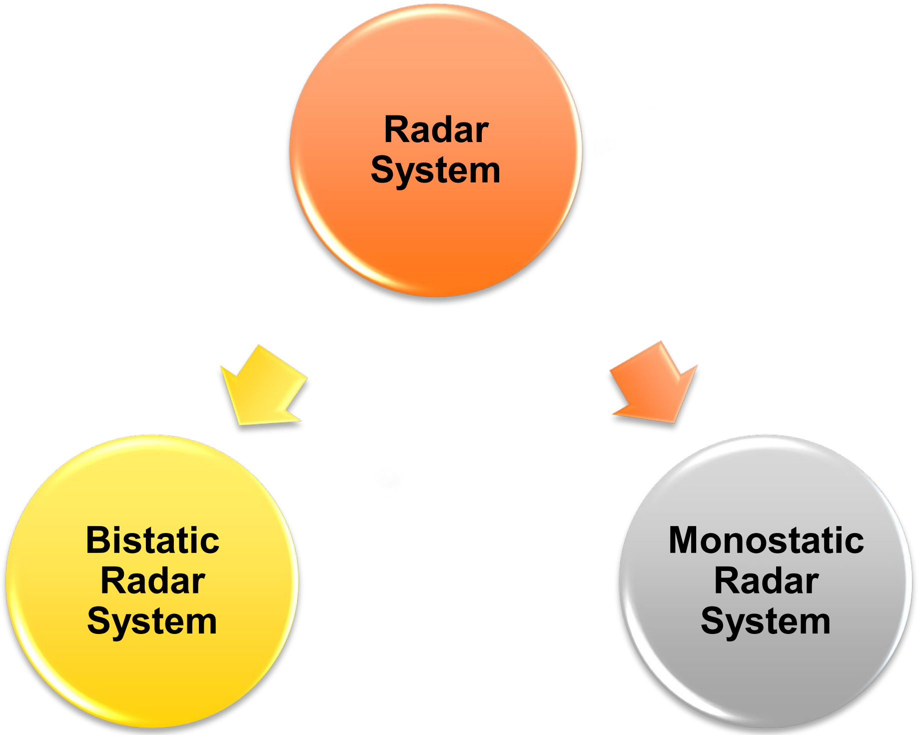
Reflection

- The target reflects a part of the intercepted energy back towards the radar system.

Transmitting and Receiving

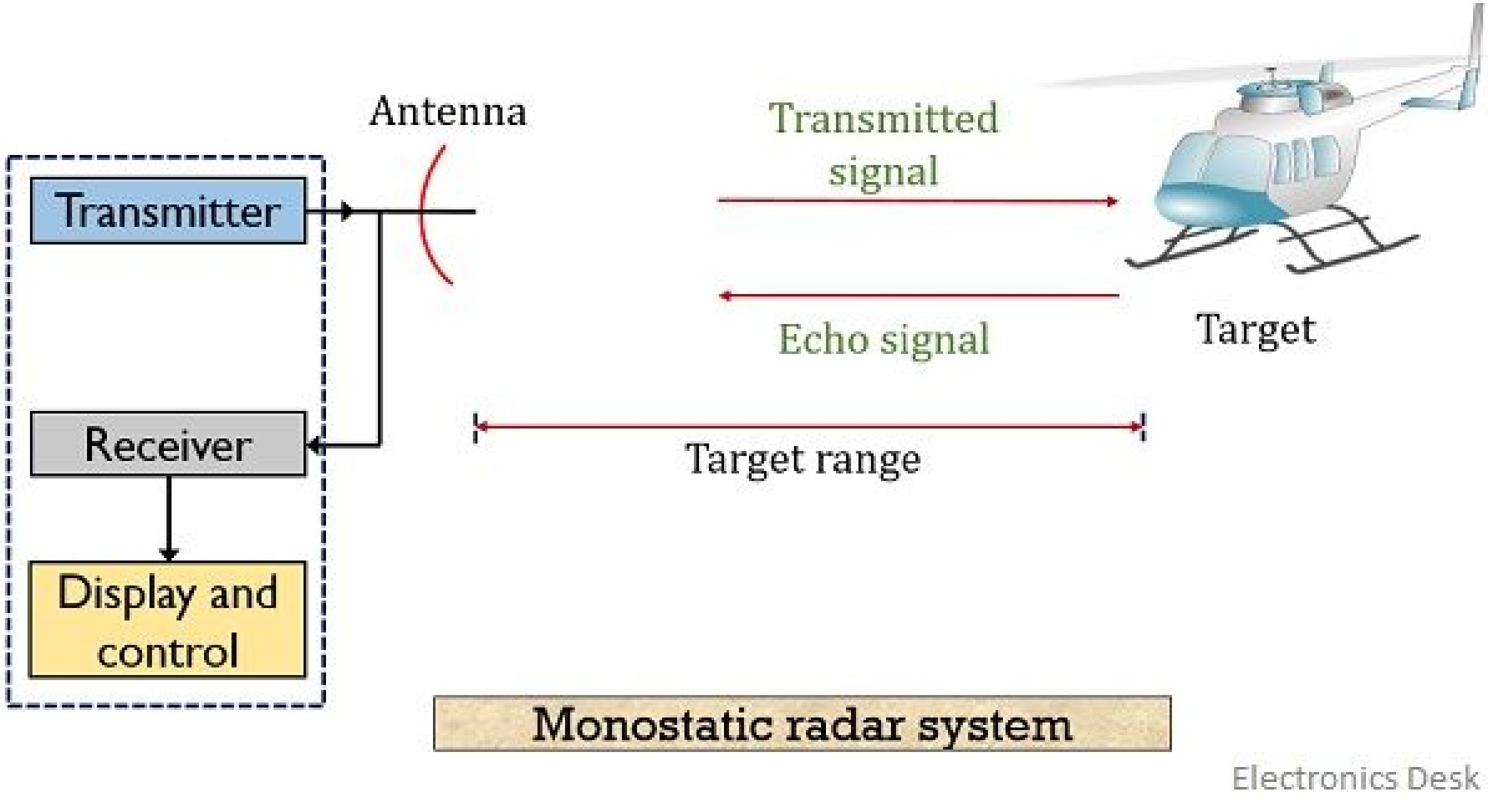
- Most radar systems do not transmit and receive simultaneously. A single antenna is commonly used on a time-shared basis for both transmitting and receiving.

Types of Radar System



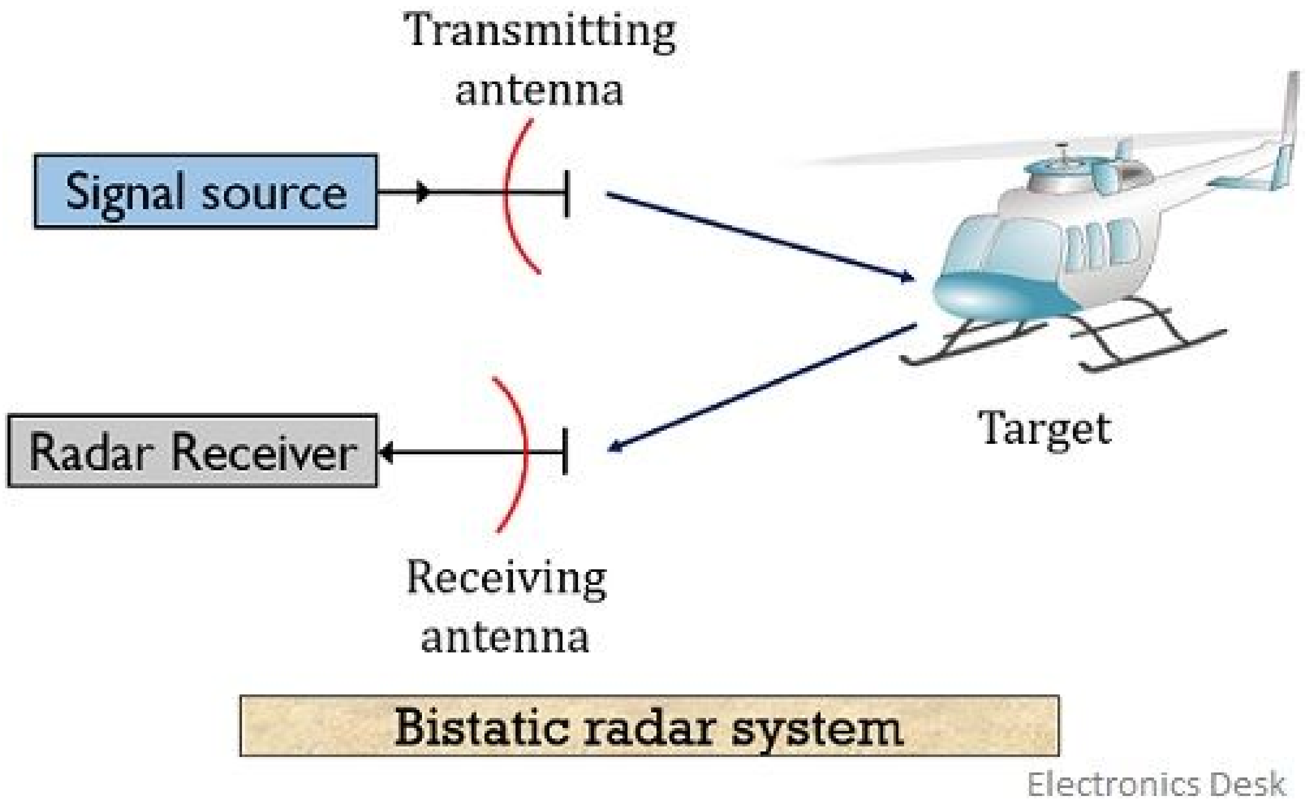
Monostatic Radar System

A monostatic radar system uses a single antenna for transmission as well as reception purposes.

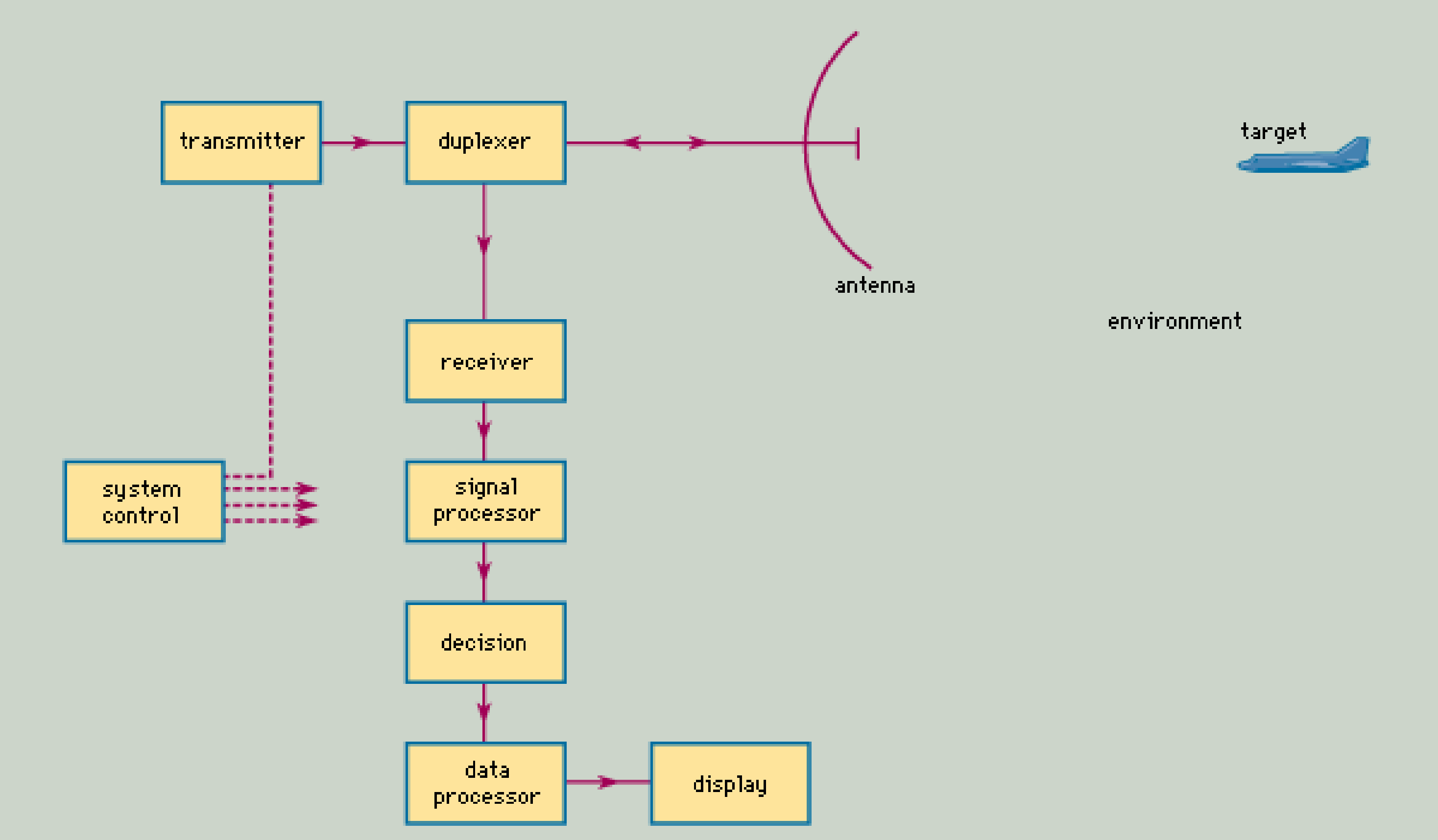


Bistatic Radar System

A bistatic radar system utilizes independent antennas for the transmission and reception of the signal.



Basics of Radar Technology

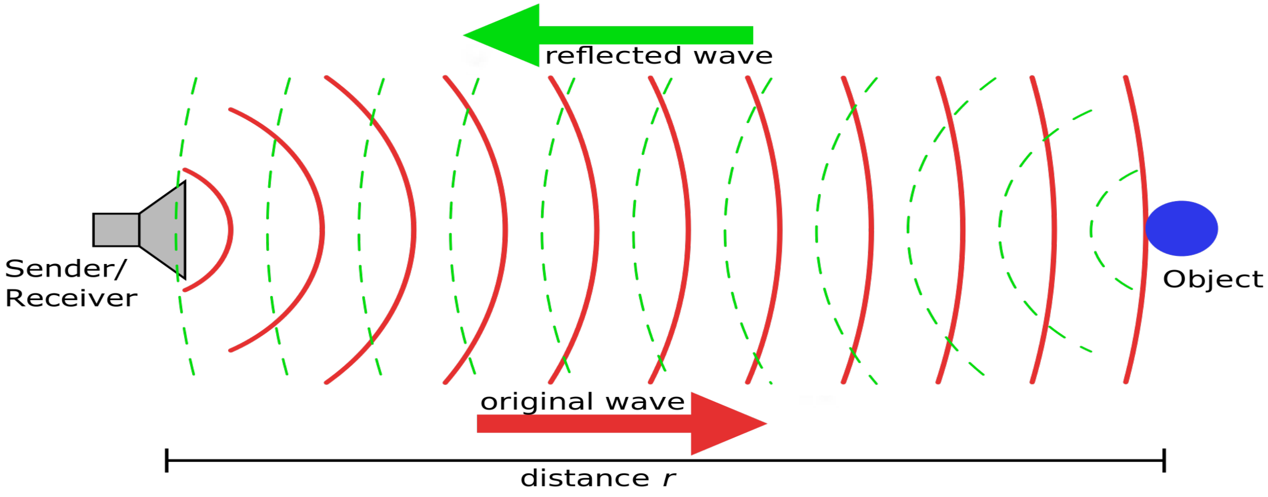


Radar Antenna

- An antenna is a structure that serves as a transition between wave propagating in free space, and the fluctuating voltages in the circuit to which it is connected.
- An antenna receives energy from an electromagnetic field or radiates electromagnetic waves from a high-frequency generator.

Radar Transmitter

- The transmitter of a radar system must be efficient, reliable, not too large in size and weight, and easily maintained, as well as have the wide bandwidth and high power that are characteristic of radar applications.
- In general, the transmitter must generate low-noise, stable transmissions so that extraneous (unwanted) signals from the transmitter do not interfere with the detection of the small Doppler frequency shift produced by weak-moving targets.



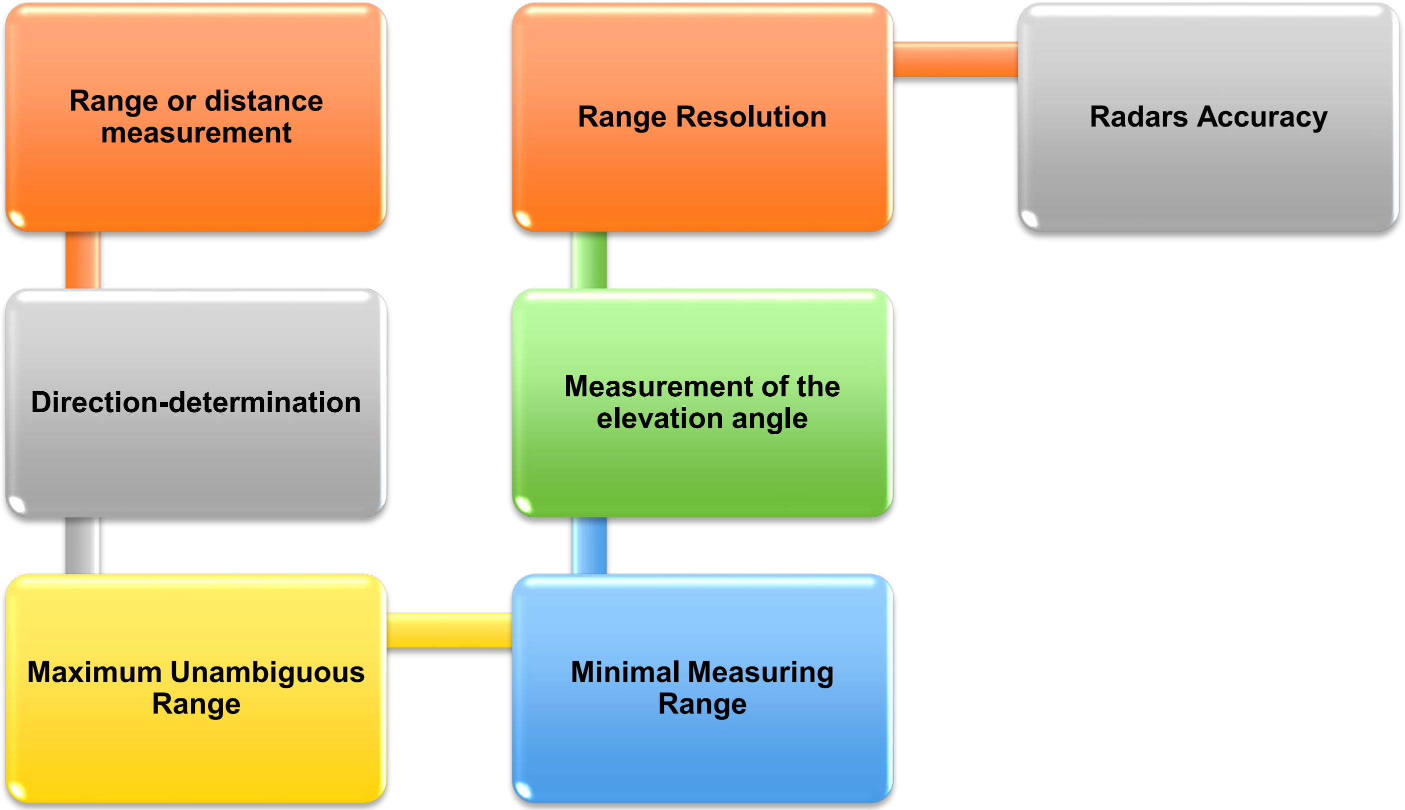
Radar Receiver

- The function of the receiver is to take the weak echoes from the antenna system, amplify them sufficiently, detect the pulse envelope, amplify the pulses, and feed them to the indicator.
- The receivers used in radars can accept weak echoes and increase their amplitudes by a factor of 20 or 30 million. Since radar frequencies are not easily amplified, a superheterodyne receiver changes the radio frequency to an intermediate frequency for amplification.

Radar Signal Processor

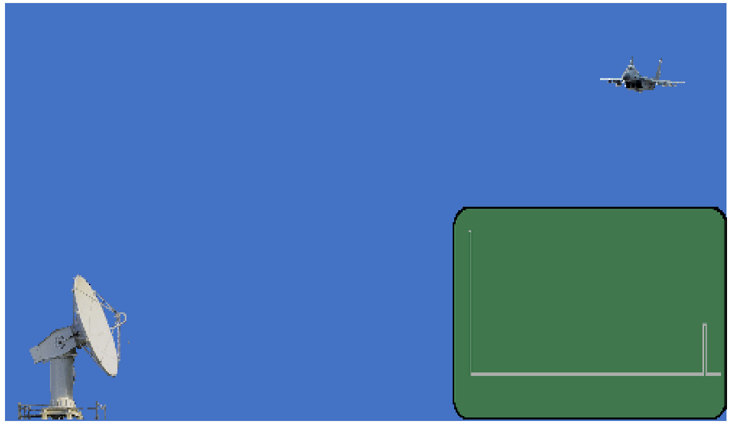
- The signal processor is the part of the receiver that extracts the desired target signal from unwanted clutter. It is not unusual for these undesired reflections to be much larger than desired target echoes, in some cases more than one million times larger.
- Large clutter echoes from stationary objects can be separated from small moving target echoes by noting the Doppler frequency shift produced by the moving targets.
- Most signal processing is performed digitally with computer technology. Digital processing has significant capabilities in signal processing not previously available with analog methods

Principle of Measurement



Range or distance measurement

- Radar calculates the distance to a reflected object by measuring the time between pulses.
- Electromagnetic energy travels in a straight line, allowing calculation of azimuth and elevation.
- Radar sends a signal, and receives a reflected signal (echo) in time T0.
- Based on the constant speed of light, the radar determines the distance (R) to the object.

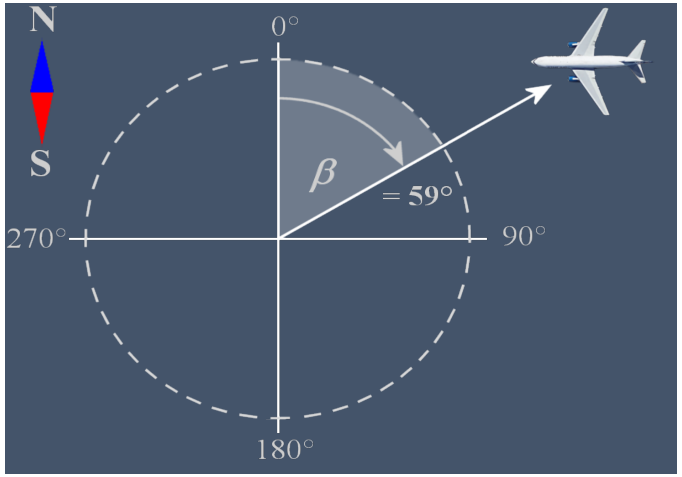


Runtime measurement by radar

$$R_0 = \frac{c * T_0}{2}$$ (c = 300,000 km/s).

Direction-determination

- Angular determination of the target relies on the directivity of the antenna.
- Directivity, also known as directive gain, concentrates transmitted energy in a specific direction.
- An antenna with high directivity is termed a directive antenna.
- By measuring the antenna's direction when receiving the echo, azimuth and elevation angles to the object are determined.
- The accuracy of angular measurement depends on the directivity, linked to the antenna's size.



Direction-determination (bearing

Maximum Unambiguous Range

The maximum unambiguous range *(R_{max})* is the longest range to which a transmitted pulse can travel out to and back again between consecutive transmitted pulses. In other words, R_{max} is the maximum distance radar energy can travel round trip between pulses and still produce reliable information.

Therefore maximum unambiguous range Rmax is the maximum range for which t < T.

$$R_{max} = \frac{c_0 \cdot (T - \tau)}{2}$$

R_{max} = unambiguous Range in [m]

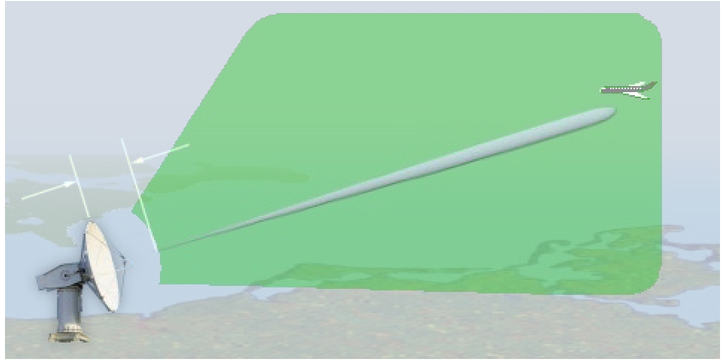
c_0 = speed of light [$3 \cdot 10^8$ m/s]

T = Pulse Repetition Time (PRT) [s]

τ = length of the transmitted pulse [s]

Minimal Measuring Range

Monostatic pulse radar sets use the same antenna for transmitting and receiving. During the transmitting time the radar cannot receive: the radar receiver is switched off using an electronic switch, called duplexer. The minimal measuring range R_{min} ("*blind range*") is the minimum distance which the target must have to be detect. Therein, it is necessary that the transmitting pulse leaves the antenna completely and the radar unit must switch on the receiver. The transmitting time τ and the recovery time $t_{recovery}$ should are as short as possible, if targets shall be detected in the local area.

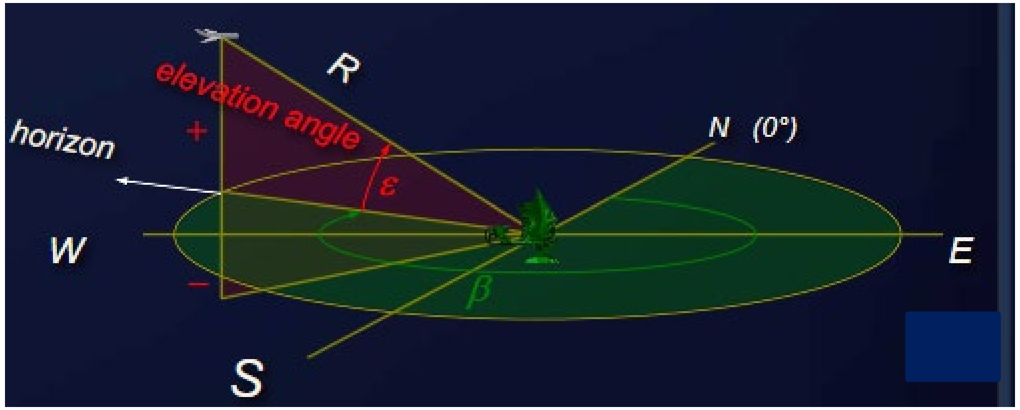


The Radars "blind range"

$$R_{\min} = \frac{c_0 \cdot \left(\tau + t_{recovery}\right)}{2}$$

Measurement of the elevation angle

Elevation angle is the angle between the horizontal plane and the line of sight, measured in the vertical plane. The reference direction (i.e. an elevation angle of zero degrees) is a horizontal line in the direction to the horizon, starting from the antenna. The elevation angle is denoted by the Greek letter ε (epsilon) mostly. It is positive above the horizon but negative below the horizon.



Definition of elevation angle ε

Measurement of the elevation angle

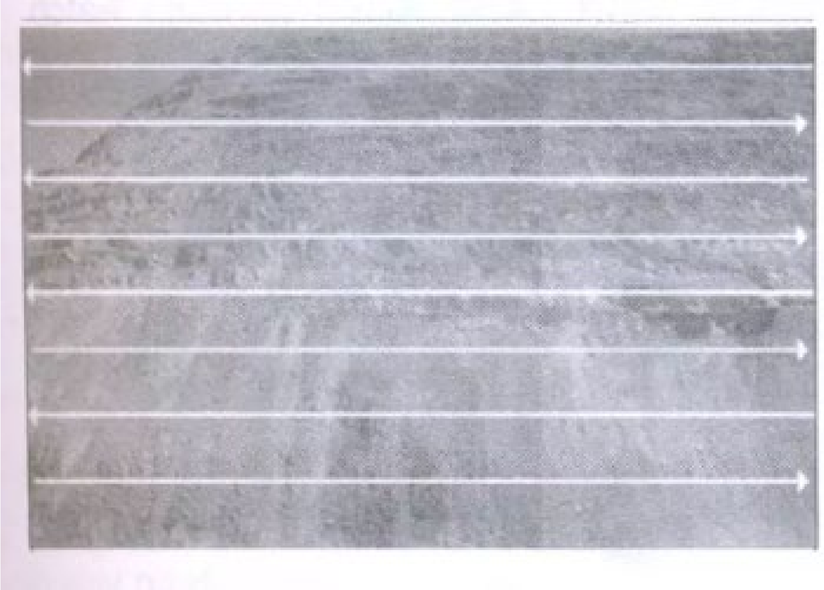
- Altitude- or height-finding radars use a very narrow fan beam in the vertical plane. Height-finding radar systems that also determine bearing must have a narrow beam in the horizontal plane in addition to the one in the vertical plane. The beam is mechanically or electronically scanned in elevation to pinpoint targets. If an echo signal is detected in the receiver, then the current elevation angle is equal to the direction of the antenna pattern.

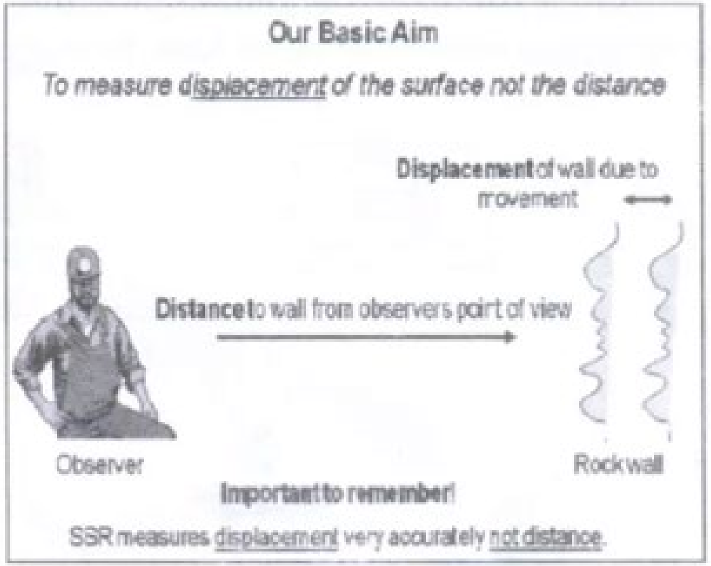
Introduction to Slope Stability Radar (SSR) Technology

- Ground-based radar is a remote sensing technology that uses phase-change interferometry to measure the surface deformation of a slope over time.
- Ground-based SSR systems remotely measure the surface deformation of a slope from a stationary platform without a need for reflectors or prisms.
- A system scans a region of a slope and divides an area into pixels. An amount of movement is measured for each pixel and compared with an amount of movement from the previous scan.
- Using ground-based radar allows for active monitoring of a slope with deformation alerts of a sub-millimeter precision, making the data available for interpretation usually within minutes.

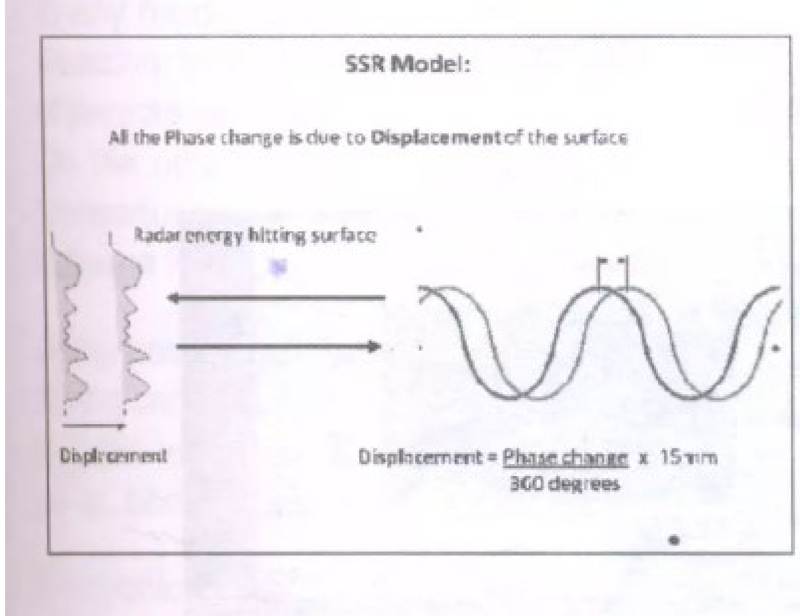
Slope Stability Radar – Operation

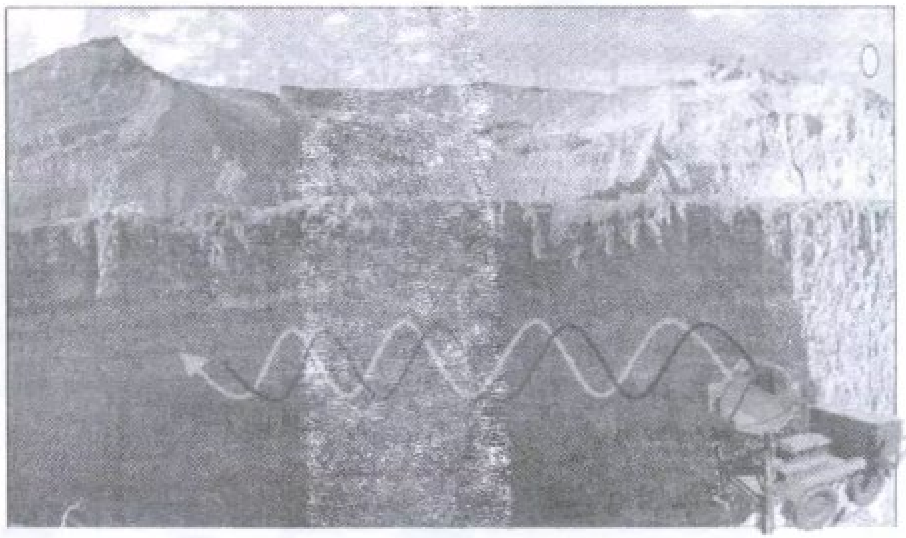
- **Basic aim of this real time monitoring system is measuring the displacement of Pit slope rock. It sent some wave and after hitting on the surface of the front side wall the wave came back on SSR and thus it measured the displacement.**





SSR radar to measure displacement

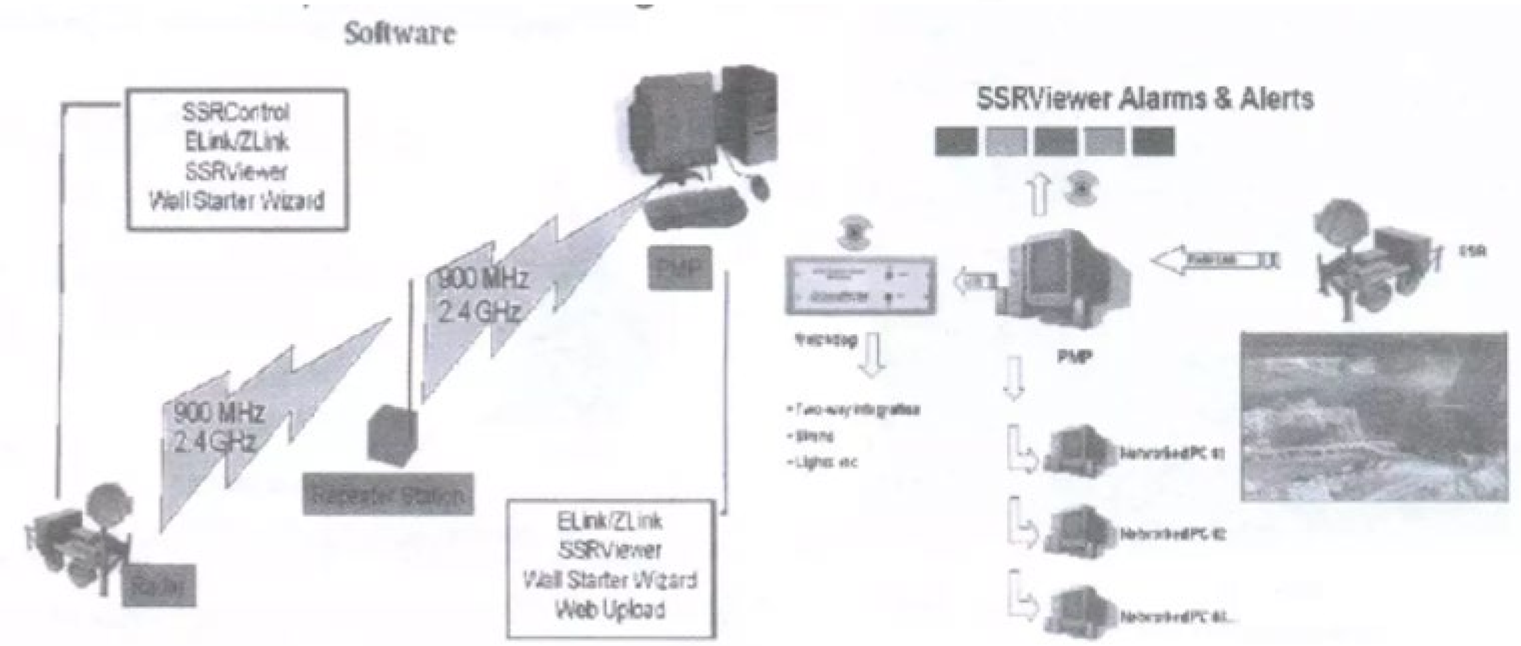




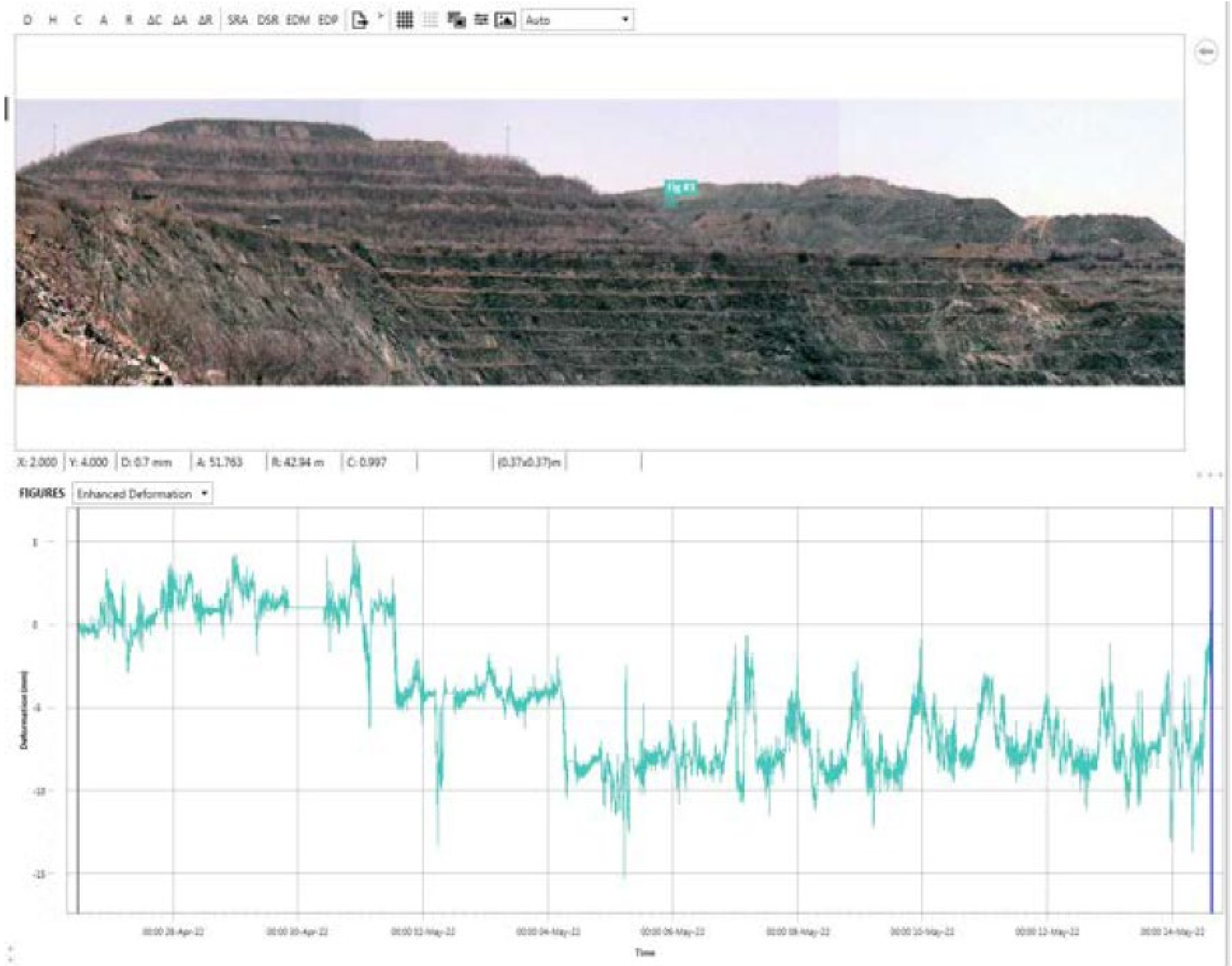
SSR to slope monitoring

Software

- SSR data can be viewed at SSR computer, at primary monitoring point (PMP) computer and Office by using SSR viewer suit software developed by ground probe. Radar data is transmitted through E-link software to PMP. From PMP, it is connected to the Office network. SSR send Alarm and alert through E-mail.



Software to displacement analysis



The rock slope with displacement data screen.

- **SSR is one of the best advanced monitoring systems to monitor pit slope stability and can be easily used for monitoring open-pit slopes.**

- **SSR enables mine managers and geotechnical engineers to make informed decisions, to relate evacuate people and equipment before slope failure.**

Risk Management with SSR

The slope stability radar can be used as an early warning system. In general, an early warning system has a few main aims such as monitoring, which consists of data collection and it transmission, as well as maintenance of the equipment a prediction and an analysis.

An evacuation alarm is one of the alarm types. The mines mostly are using four alarms:

- ## Green Alarm

A small system failure, during which the SSR is close down and the SSR program has to be restarted according to procedures.

- ## Yellow Alarm

A radar system failure, which causes that a pit superintendent to receive an information about the unavailability of a radar, and a geotechnical department is informed to determine a problem with the help of an equipment producer.

- ## Orange Alarm

In other words, “a Geotech alarm”, is an announcement of a ground movement development, which should make a geological department conscious of possible dangers.

- ## Red Alarm

Serious situation in which a pit superintendent must evacuate an area of concern or a whole pit.

Case study-1 at Leveäniemi Open-Pit mines

The SSR unit employed at Leveäniemi Open-Pit mines from the Italian company IDS Georadar. Here's an overview of its features

Detection Capabilities:

- **Remarkable capacity for detecting small movements.**
- **High spatial resolution: 0.5 m x 4.4 m per cell at a 1 km distance.**

Monitoring Area:

- **Covers an expansive area of up to 5 km^2.**

Case study-1 at Leveäniemi Open-Pit mines

Data Acquisition

- Quick acquisition time: Approximately 2 minutes for a single data acquisition at a 1 km range.

Power Options

- Versatile power sources: Wi-Fi, solar panels, or a diesel generator for battery charging.

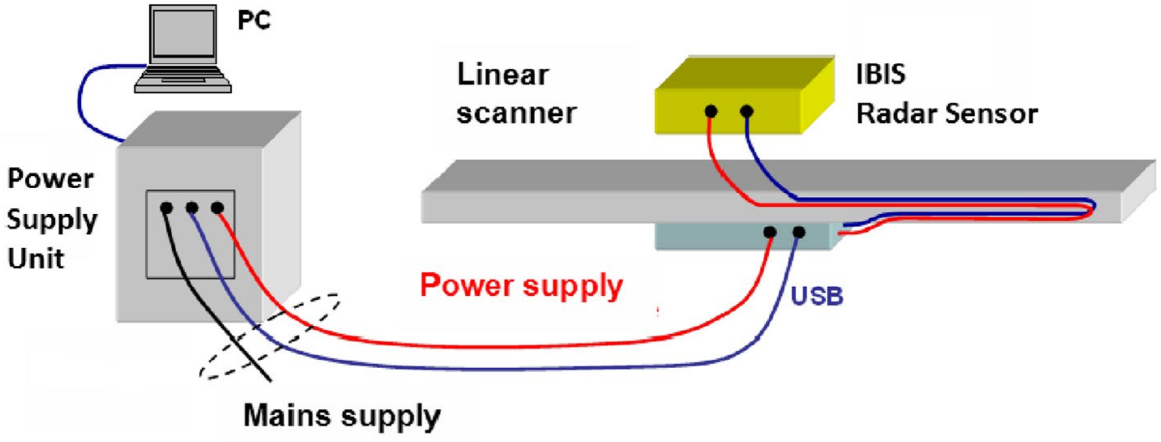
Resilience to Weather Conditions

- Operates in diverse weather conditions.
- Temperature range: -25 °C to +50 °C (-50 °C if placed indoors).

Case study-1 at Leveäniemi Open-Pit mines

Hardware

- The basic hardware (Figure) consists of Radar Sensor (RS), Linear Scanner (LS), Power Supply Unit (PSU) and Field Laptop (FL).
- Additionally, the system can be equipped with: an eagle-vision camera, a weather station, a power generator, solar panels, a Wi-Fi radio or a watchdog.

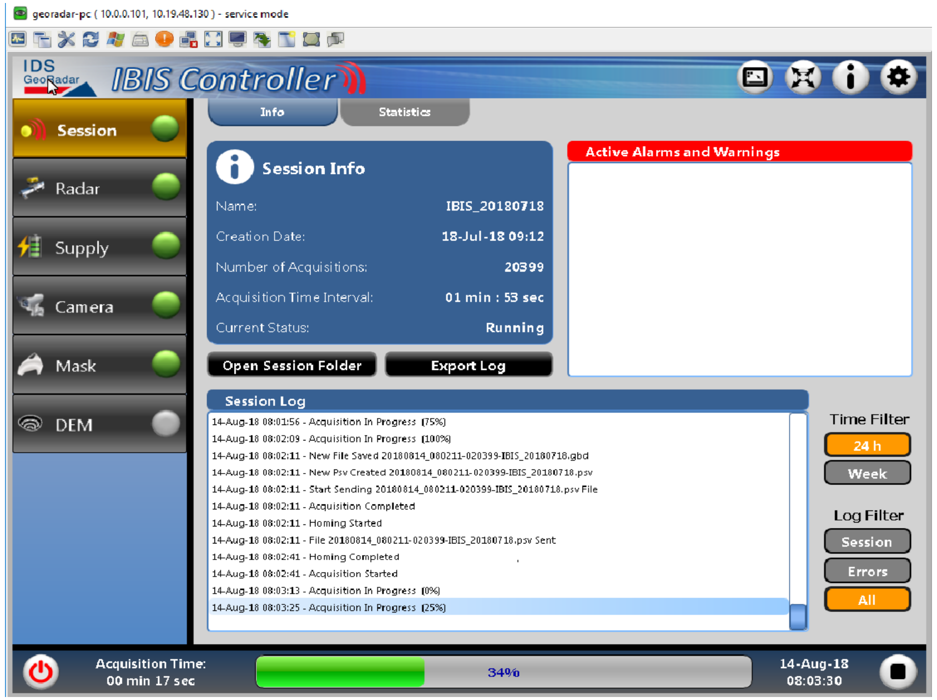


Hardware connection

Case study-1 at Leveäniemi Open-Pit mines

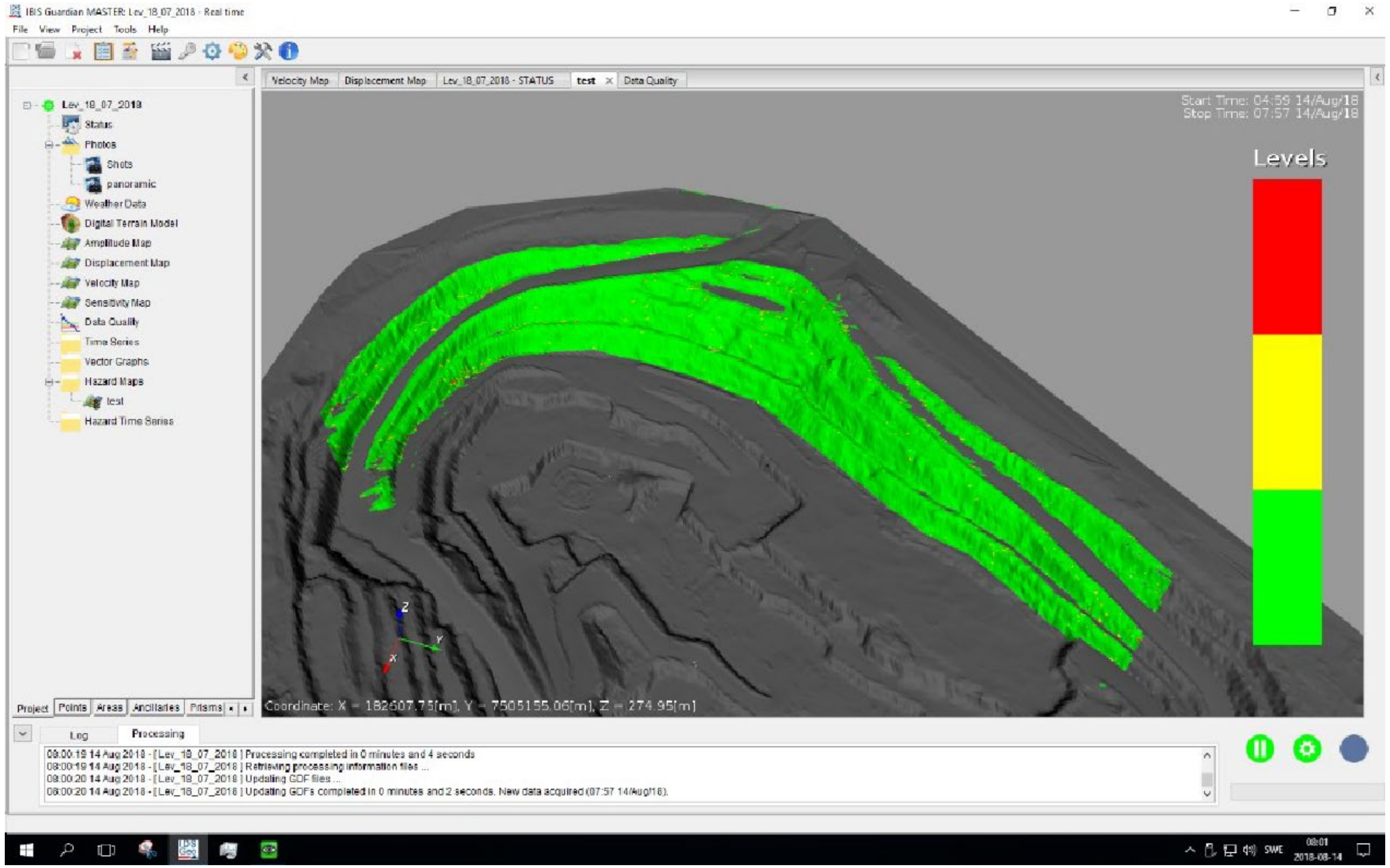
Software

A software of the radar system consisting of two connected between each other programs: IBIS Controller and Guardian.



IBIS Controller

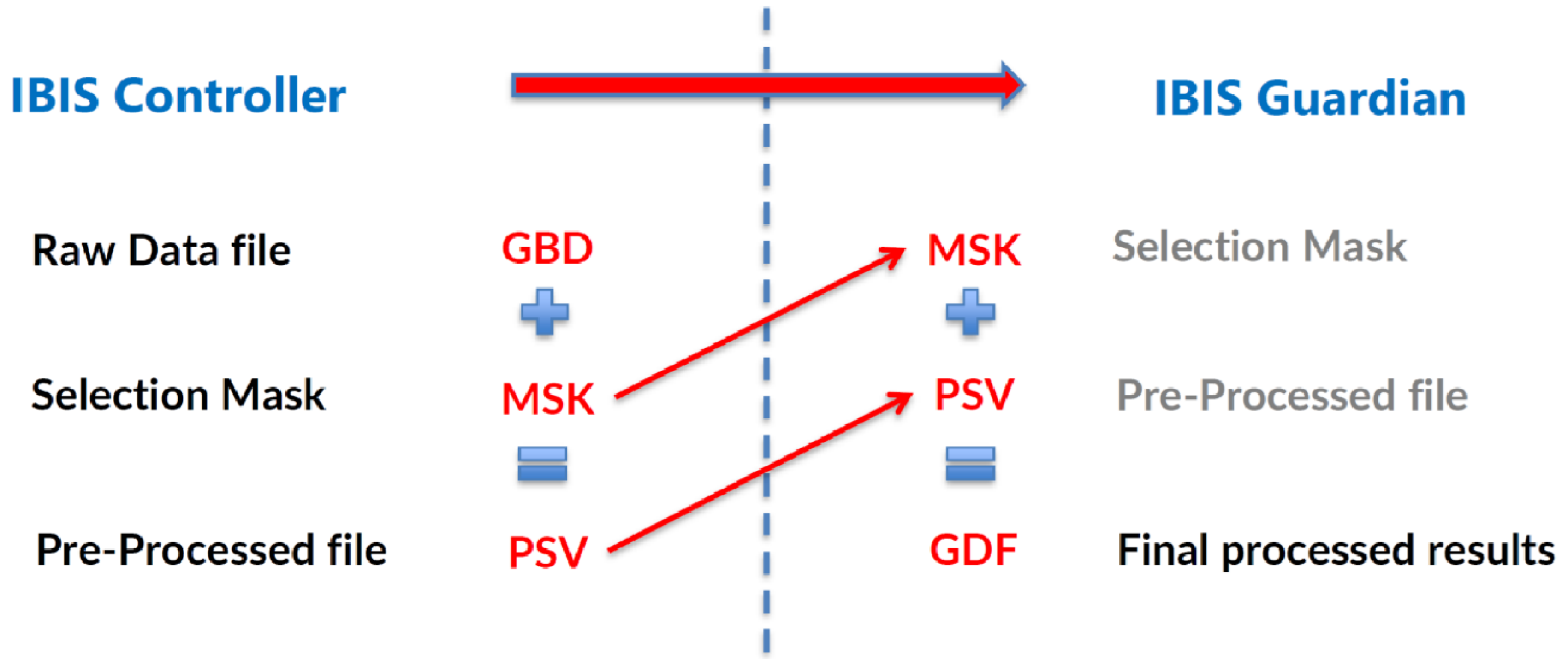
Case study-1 at Leveäniemi Open-Pit mines



The Guardian

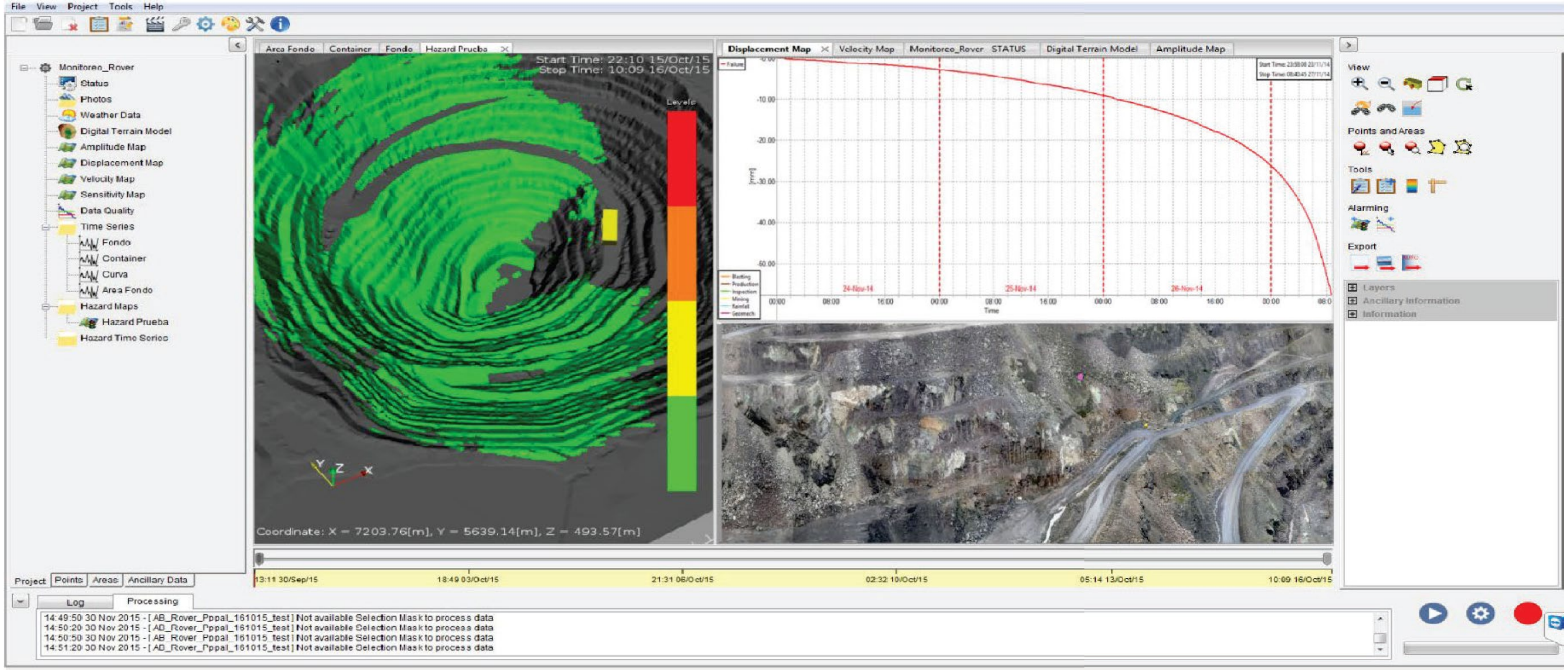
Case study-1 at Leveäniemi Open-Pit mines

The IBIS Controller creates 3 types of files, during each scan: GBD (raw data), MSK (selection mask), and PSV (pre-processed).



Data flow between programs

Case study-1 at Leveäniemi Open-Pit mines



Typical schematic data acquired by SSR in the surface mines and its representation in the slope geometry.

REFERENCES

- Niekrasz, J. (2018). Review of radar system performance and estimation of slope deformation threshold values for the Leveäniemi open pit., https://aaltodoc.aalto.fi/server/api/core/bitstreams/fcfd7da5-21c5-4c62-9069-ee94ba45b89d/content

- Niekrasz, J. (2018). Review of radar system performance and estimation of slope deformation threshold values for the Leveäniemi open pit., https://aaltodoc.aalto.fi/items/5635ed35-0dee-4642-8397-d6abbc4101b3

- https://www.aviationfile.com/cone-of-silence-a-crucial-aspect-in-aviation/
- https://www.aviationfile.com/the-evolution-of-radars-in-aviation/
- https://www.britannica.com/technology/radar/Transmitters

CONCLUSION

- Provided an initial overview of Radar technology.
- Explored the foundational principles underlying Radar systems.
- Examined the various categories and applications of Radar technology.
- Introduced the fundamental concepts and working principles of Radar systems.
- Discussed the methodologies involved in the measurement processes of Radar technology.
- Introduced the specific application of SSR within Radar technology.
- Explored how SSR contributes to risk management, particularly in slope stability scenarios.
- Examined a real-world case study illustrating the application and outcomes of Radar technology in a specific context.


THANK YOU

MINE AUTOMATION AND DATA ANALYTICS

MINE AUTOMATION AND DATA ANALYTICS

SWAYAM NPTEL COURSE ON

MINE AUTOMATION AND DATA ANALYTICS

By

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Module 04:
Advanced system in Mining Industry

Lecture 09 B:
RFID in Mining Engineering

CONCEPTS COVERED

- Introduction to RFID technology
- How does RFID work?
- How Smart Haulage works
- RFID basics
- Working principle
- Main benefits of RFID
- Why RFID in mining
- RFID Applications in Mining Industry
- RFID in mining : Use Cases
- Case study on RFID

Introduction to RFID technology

- It is a wireless technology that uses radio waves to identify and track objects by placing an RFID tag or transponder on them. The tag contains a microchip and an antenna that transmits a unique identifier to a reader device when prompted by the reader's radio signal.
- This technology allows for non-contact, non-line-of-sight identification and tracking of items, which is beneficial for many businesses, including those involved in supply chain management, retail, logistics, and asset management.
- Combining RFID with IoT solutions allows for gathering and analyzing massive amounts of information to optimize and improve business processes and decision-making.

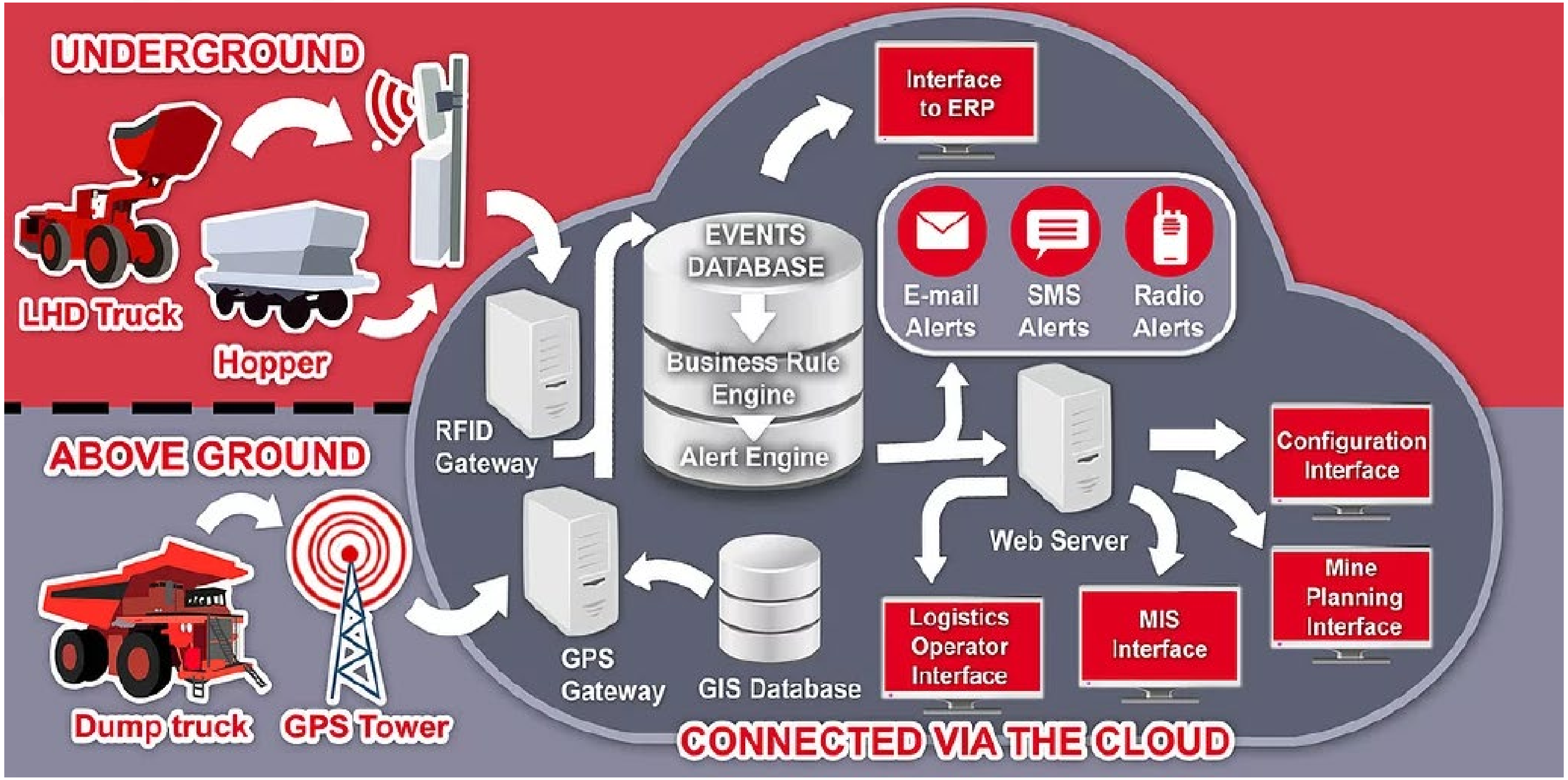
How does RFID work?

- When an RFID reader is activated, it transmits a radio frequency signal to the antenna, which then broadcasts the signal to the surrounding area.
- If an RFID tag is within range of the reader, the radio frequency energy from the reader's signal is absorbed by the tag's antenna, which powers up the microchip on the tag.
- The microchip then uses this energy to transmit the data stored on the tag back to the reader. Each tag responds with a unique number.

How does RFID work?

- The data transmission from the tag to the reader is a one-way communication. The reader receives the data from the tag and decodes it, typically using a microprocessor. The data from the tag is then processed and sent to the host system, which can be a computer, a mobile device, or another type of system.
- There are two main types of RFID tags: passive and active. The passive tag does not have its own power source, and it relies on the energy transmitted from the reader to activate and transmit its data. The active tag has its own power source, typically a battery, and it can transmit data continuously, even when it is not in close proximity to the reader.

How does RFID work?



Schematic of RFID system for underground and surface mine machinery control

How Smart Haulage works:

- The hoppers, LHD trucks and dump trucks are tagged with rugged RFID tags.
- Fixed RFID readers are installed at key points. Movement of haulage equipment is detected by RFID readers and GPS is used to measure the productivity of each vehicle on a second by second basis. This data is sent to the Events Database.
- Smart Haulage will then compare the event data with the rules in the Business Rule Engine. Business rules are initially configured for each mining area as it is specific to the layout of each mine and its operations. The following exceptions can be set to trigger alarms: routes not allowed, min/max travel time between points, min/max waiting time per point, min/max number of visits per shift per point, etc.

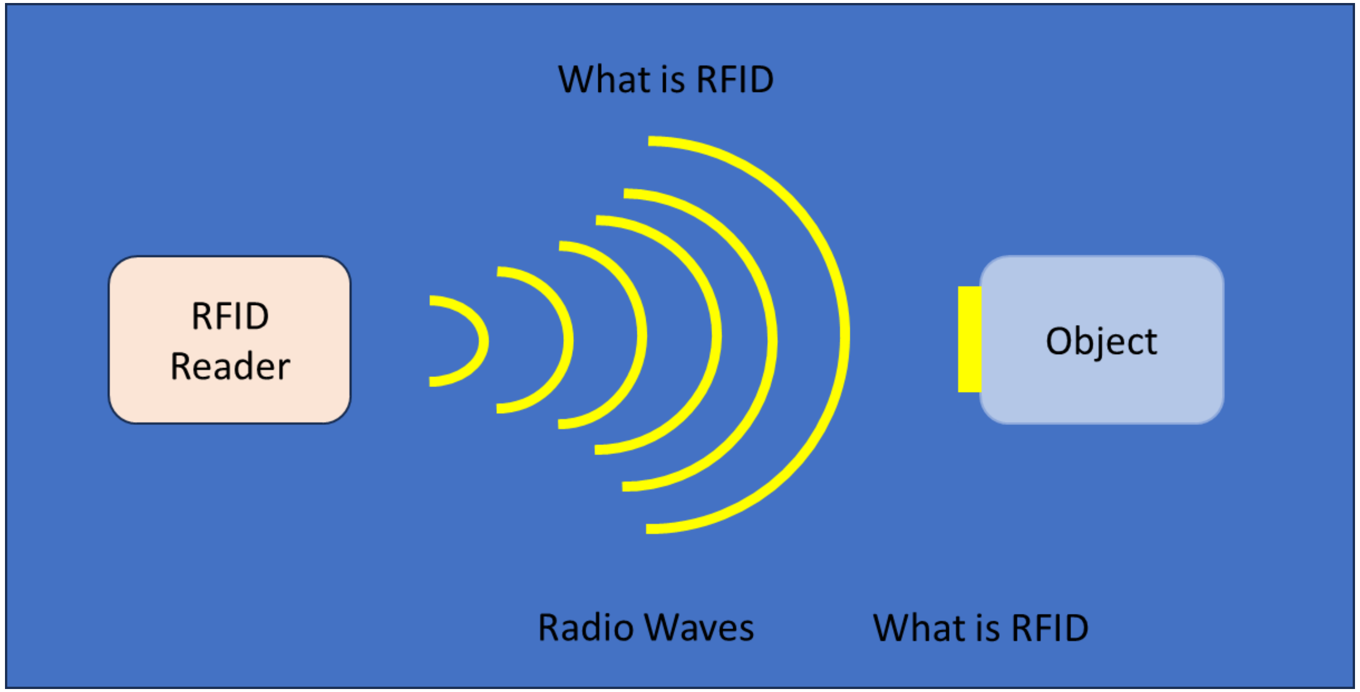
How Smart Haulage works

Smart Haulage working systems

How Smart Haulage works

- When vehicle movement exceeds the parameters set by the Business Rules, alarms are generated on the screen of the Logistics Operator Interface and can also be sent via email, SMS or radio. The control center can then contact the driver and advise the most appropriate action.
- The MIS Interface allows for comprehensive reporting per vehicle per shift with data such as: ROM tonnage moved, ROM tonnage output, ROM cycles completed, % process uptime, % process downtime scheduled, % process downtime unscheduled, % equipment downtime scheduled, and more.
- All data captured and produced by the system will be synchronized and uploaded to the Cloud in real time, where authorized employees can log in to their SmartHaulage accounts at any time to access it.

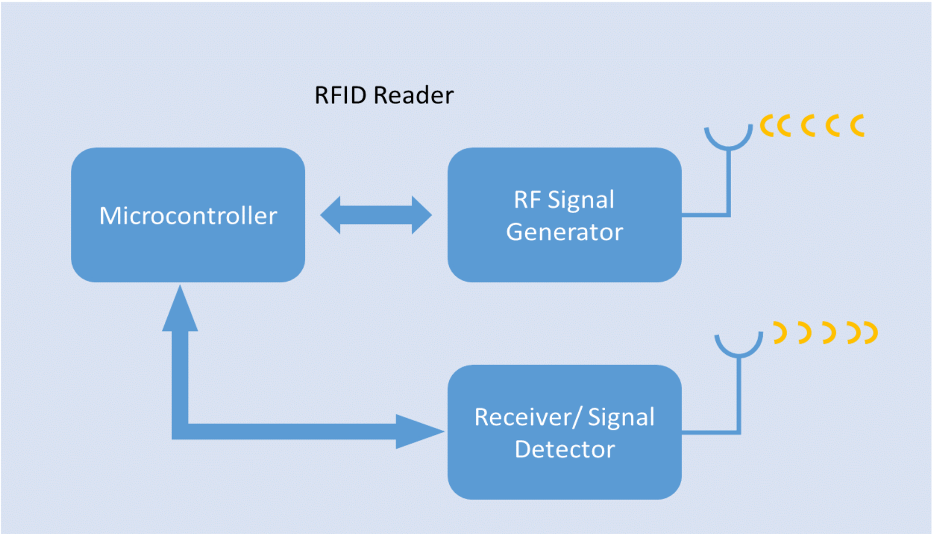
RFID basic



Schematic diagram of RFID System

RFID basic

- RFID System
  - RFID Reader
  - RFID tag
    - Active tag
    - Passive tag
    - Semi Passive tag

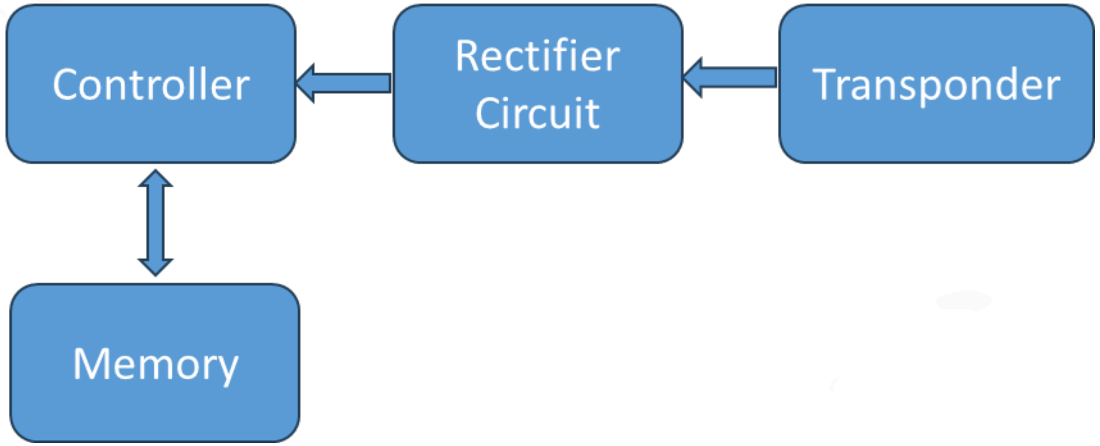


RFID reader

- The LR100 is a rugged long range UHF reader for outdoor applications with integrated Dual Linear Polarized antenna. This is a high performance industrial-class reader and achieves a read range in excess of 30m.

- The LR100 is used for tracking in mining, warehousing, tolling, parking and access control, weigh bridge automation, and more. It also supports the various Cloud Platforms provided by Techsolutions including RFID-Access, SmartAsset, SmartInventory, eFreight, etc.

RFID Tag



P-Apex Tag for Metal Assets

- **P-Apex is a tough and rugged waterproof UHF tag for tracking metal items, assets and equipment such as machinery, parts, containers, railway cars, trolleys, trailers, etc. Dimensions: 150 x 25 x 12mm. It has a read range of up to 9m**

Frequency of Operation

LF	HF	UHF
(Low frequency)	(High frequency)	(Ultra High frequency)
125 kHz or 134 kHz	13.56 MHz	860 - 960 MHz
Range: up to 10 cm	Range: up to 1 m	Range: 10 to 15 m

Working principle

LF and HF RFID Tags: Inductive Coupling (near Field Coupling)

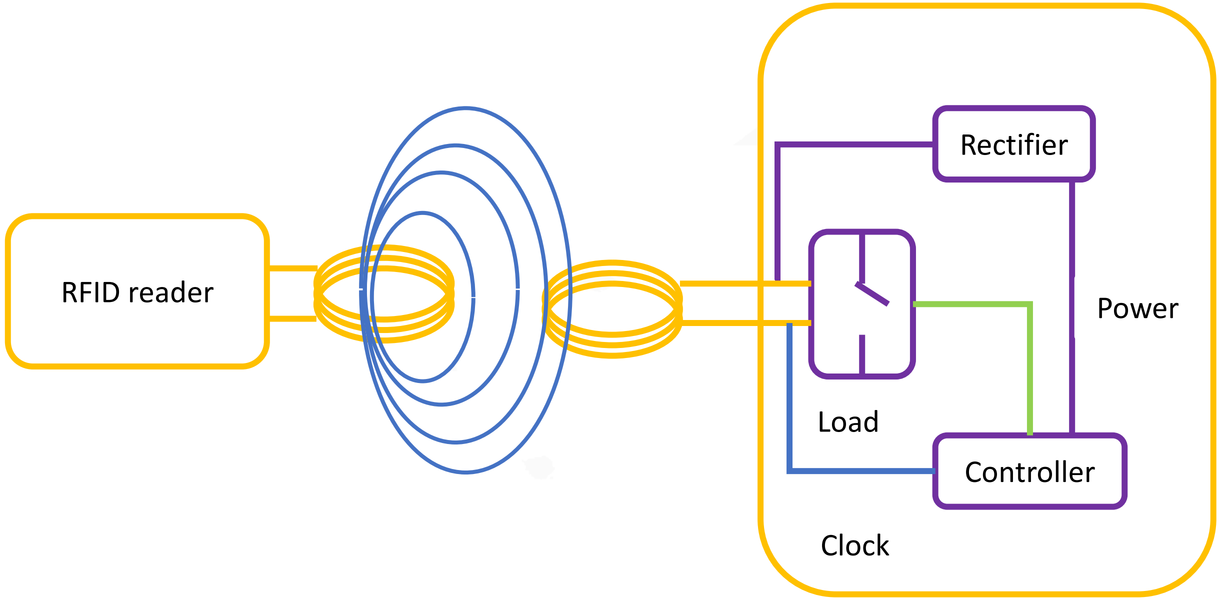
UHF RFID Tags: Electromagnetic Coupling (Far Field Coupling)

Inductive Coupling (near field coupling)

RFID reader

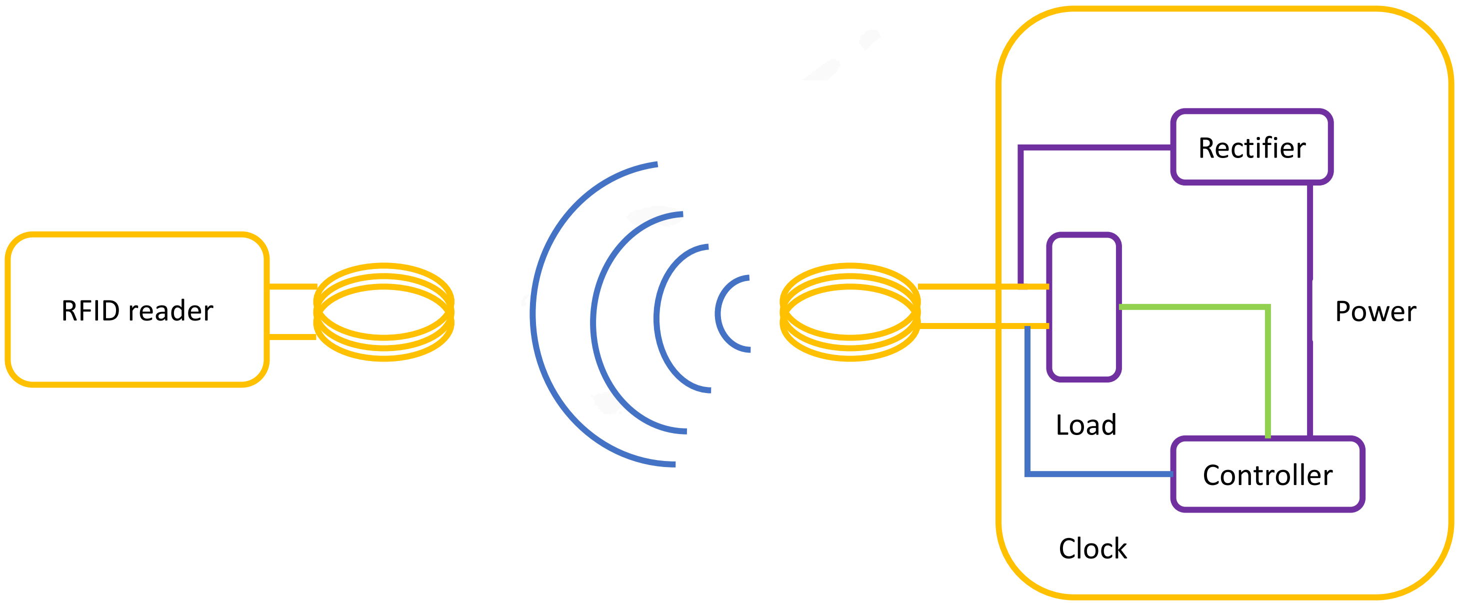
- **Induce enough power into tag**
- **Synchronization clock to tag**
- **Acts as a carrier for return data From tag**

Inductive Coupling (Near field coupling)



LOAD MODULATION

Far field coupling



BACK SCATTER MODULATION

RFID Technology

- ## Overview of RFID:

RFID technology relies on radio frequency range and it work on it.

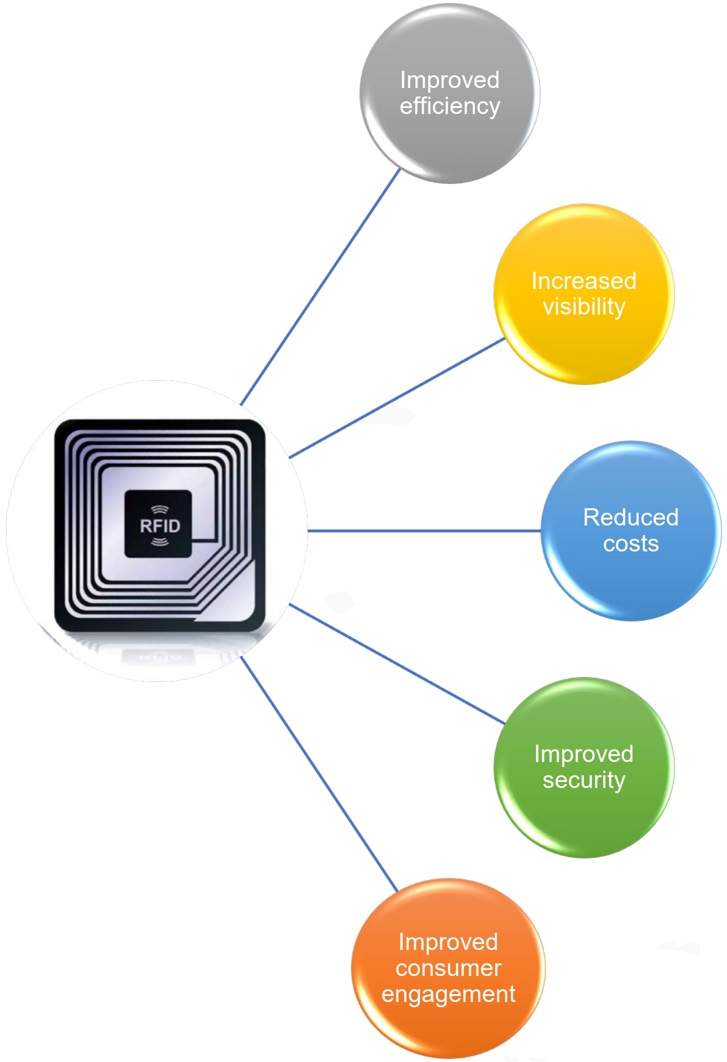
- ## Types of RFID Tags:

Active and passive RFID tags used in mining applications.

- ## RFID Frequencies:

Various RFID frequencies are used based on different mining scenarios.

Main benefits of RFID



Main benefits of RFID

Improved efficiency

RFID technology enables fast and efficient data exchange between an RFID reader and an RFID tag, which can result in improved efficiency and accuracy in various applications, such as inventory management, supply chain management, and asset tracking.

Increased visibility

RFID technology provides real-time data and increased visibility into the movement of goods and assets, enabling organizations to make more informed decisions and respond quickly to changes in demand or other conditions.

Main benefits of RFID

Reduced costs

By automating processes and reducing manual labor, RFID technology can help organizations to reduce costs and improve their bottom line. For example, RFID can help reduce inventory shrinkage and improve asset utilization, both of which can lead to significant cost savings.

Main benefits of RFID

Improved security

RFID technology can be used to enhance security by controlling access to secure areas and facilities and by helping to prevent theft and shrinkage.

Improved consumer engagement

RFID technology can also be applied to create an engaging shopping experience for consumers by providing personalized recommendations, real-time product information, and location-based marketing.

Why RFID in Mining

- The mining industry is one of the most dangerous industries to work in. There are many hazards that workers face on a daily basis, including exposure to toxic chemicals, heavy machinery, and falling debris. In recent years, the industry has been looking for ways to improve safety for workers. One way that mining companies are doing this is by implementing RFID technology.

- RFID stands for "radio frequency identification." This technology uses radio waves to identify and track objects. RFID tags can be attached to equipment, vehicles, or even people. When an RFID reader scans the tag, it can collect information about the object that it is attached.

Why RFID in Mining

- Mining companies are using RFID tags to track equipment and vehicles. This helps them to keep track of where their assets are, and it also helps them to prevent theft. In addition, RFID tags can be used to monitor equipment maintenance. By tracking when equipment is due for servicing, mining companies can minimize downtime and keep their operations running smoothly.

- RFID technology is still relatively new but has already proven valuable for the mining industry. As this technology continues to evolve, even more uses will likely be found in the mining industry.

RFID Applications in Mining Industry

In the mining industry, the effective management and control of assets, personnel, and resources are paramount for ensuring both efficiency and safety. Radio Frequency Identification (RFID) technology has emerged as a powerful tool to address these challenges.

- Machinery tracking and control
- Geo-fencing application
- Human safety and management
- Material quality assessment
- Convery maintenance
- Machinery maintenance

Asset Tracking and Management

- **Asset Identification:**

How RFID is used to uniquely identify and track mining equipment, vehicles, and materials.

- **Real-Time Location Systems (RTLS):**

The implementation of RTLS using RFID for accurate asset location and monitoring.

- **Maintenance and Inventory Control:**

Using RFID for maintenance scheduling, inventory management, and reducing downtime.

Personnel Safety and Monitoring

- **RFID-Based Access Control:**

How RFID enhances security and access control in mining facilities.

- **Personnel Tracking:**

Using RFID for real-time monitoring of personnel, ensuring their safety and compliance.

- **Emergency Response:**

Discussing RFID's role in efficient emergency response and evacuations.

RFID can be more costly

- Whether it be software or hardware, RFID requires more costly equipment that needs to be maintained through the life of the solution.

- Additionally, tags, whether they be Active, Passive or Semi-Passive, can set a business back a ways.

- Although prices have fallen with RFID upgrades since the 1970s, businesses are still taking a pass because of the steep prices.

Trouble with metals and liquids

- RFID has long had a difficult relationship working among liquids and metals, as both make it harder to get proper reads on assets.

- With metal, the problem stems from the radio waves bouncing all over the place.

- Liquids play havoc with RFID in that it can absorb signals sent from a tag.

The RFID collision course:

- In dealing with RFID technology, workers come across reader and tag collisions.

- With reader collision, a worker might come across interference from another reader in the field.

- Tag collision is a little different, in that workers with readers face issues in reading an abundance of tags at one time.

- It happens when more than one tag reflects a signal, and it confuses the reader.

The RFID systems can be easily disrupted

- RFID systems that use the electromagnetic spectrum (Wi-Fi networks as well as cell phones), leading to a collision when you are working on the same frequency and to a lot of delays and inconvenience to consumers who want to Pay and get out of the store.

- In addition to the cards that contain the effective battery that will be questioned continuously at a low level of the battery if no answer.

RFID in Mining: Use Cases

Controlling access to mine sites

RFID can control access to mine sites. By tagging employees' ID badges with RFID tags, companies can track which employees are entering and exiting the site. This information can be used to improve safety by ensuring that only authorized personnel are on site.

Logistic distribution of supplies

RFID tags have many benefits over other tracking methods, such as barcodes. For example, they are more durable, can withstand harsh conditions, do not require a line of sight to be read, and can store more data than barcodes. This makes them ideal for tracking products in the mining industry.

RFID in Mining: Use Cases

RFID tags can provide a wide range of information about the products they are affixed to, making them ideal for tracking in the mining industry. There are two main ways that RFID tags are being used in mining operations:

Open circuit

The same RFID tag that the supplier uses is reused by the mining operation to track the products inside the mine.

Closed circuit

The mining company puts new RFID tags on the products distributed in the mine environment. This allows them to track the products easily and prevents mix-ups.

RFID in Mining: Use Cases

Tracking personnel

RFID tags are used in the mining industry for people localization, as each worker is given an RFID tag. The RFID readers are located at strategic points throughout the mine, such as the main entrance and level entrances. In drifts or ramps of an underground mine, the antennas are located based on readers' range and spacing. The goal is to decrease the personal location uncertainty areas. This allows the rescue and first aid teams to know exactly where everyone is in case of an emergency.

RFID in Mining: Use Cases

Evacuation and rescue

- Safety is of the utmost importance in underground mining. Radio frequency identification (RFID) technology plays an increasingly important role in helping to keep miners safe. It is vital monitoring miners to know each worker's exact location and where the rescue and first aid teams are.
- In an accident, RFID can help first responders locate individuals who may be trapped. It is possible to activate alarms immediately and implement evacuation protocols, monitor and guide rescue teams, do the same with workers and conduct them to safe places or operating lifts, stop truck traffic and stop works affected directly or indirectly by accident.

RFID in Mining: Use Cases

Managing explosives

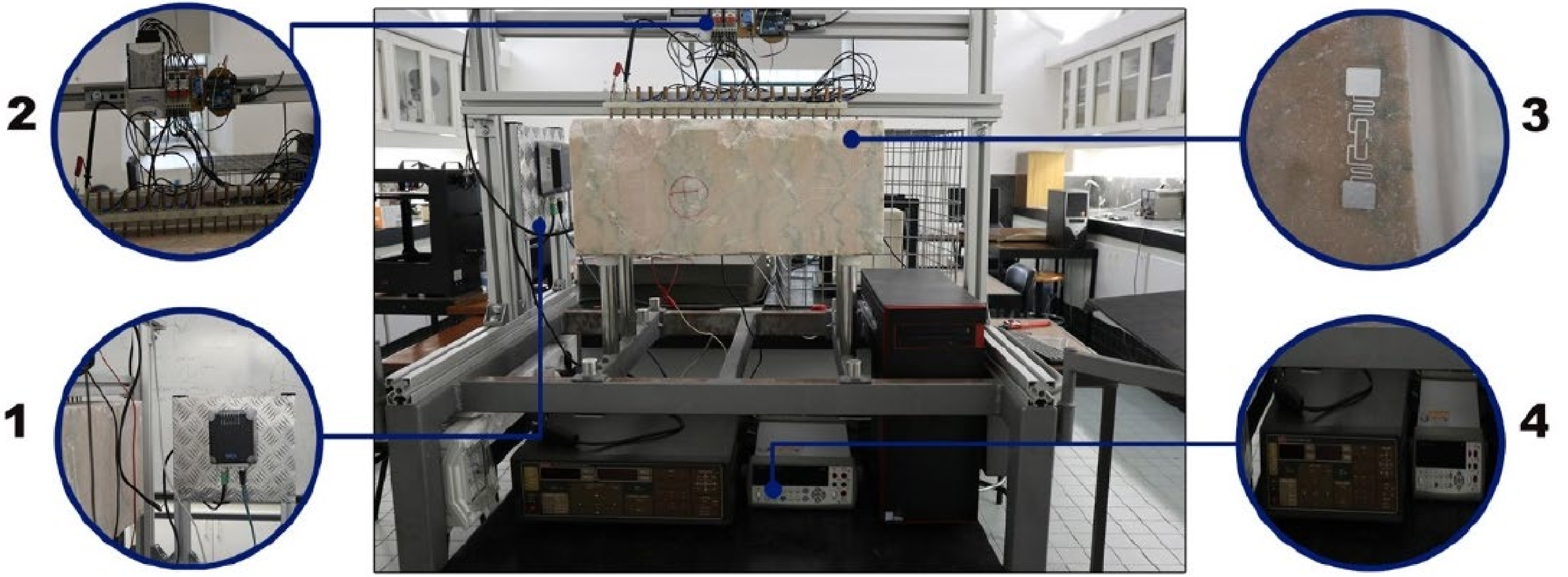
RFID can also be used to track the location of explosives in a mine. This information can improve safety by ensuring that explosives are only used when and where they are supposed to be.

RFID in Mining: Use Cases

Detection areas

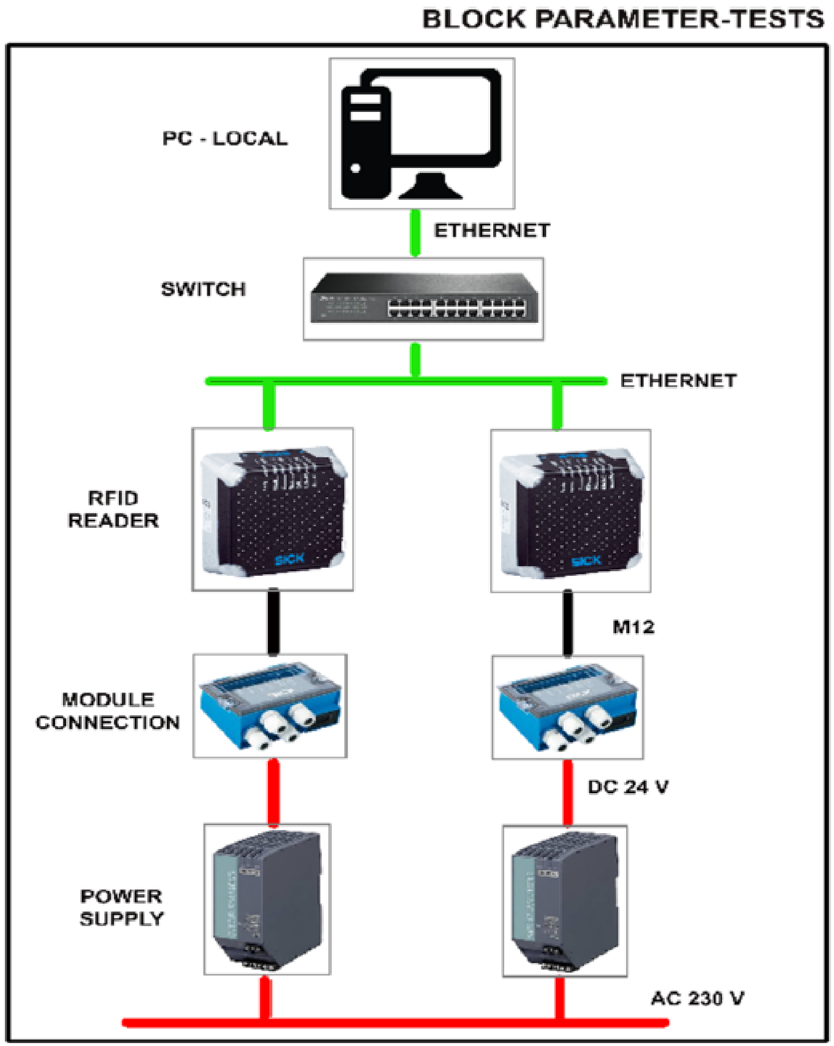
RFID is used in the mining industry for proximity warning systems. These systems use RFID tags to track the location of workers and equipment and then warn the vehicle driver if someone or something is in his proximity. This helps prevent accidents by ensuring the driver is aware of his surroundings. These systems can also be used to track the location of assets and inventory, which can help improve efficiency and productivity in the mining industry.

Case Study



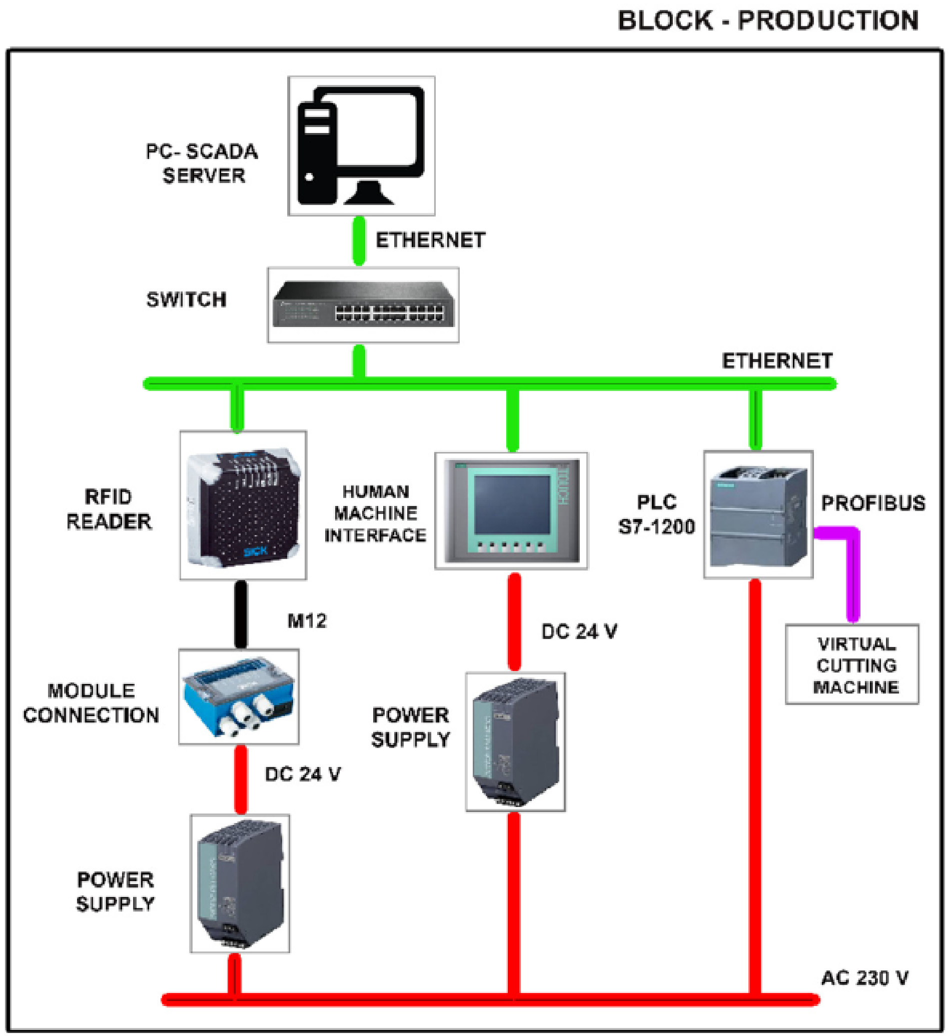
Block-Parameter Tests: Experimental Implementation at University of Evora: 1 = RFID Read/write Sensor and Antenna (SICK RFU620-10100), 2 = Data Acquisition system (NI DAQ-6009), 3 = Passive RFID-tag (Alien H3 EPC Global Gen 2), 4 = Current Source (Keithley 228A) and Digital Multimeter (Agillient 34410A).

Case Study



Schematic layout of RFID-System used in the Block-Parameter Tests.

Case Study



Schematic layout of RFID-System used in the Block-Production Tests.

REFERENCES

- Andrade, L.; Figueiredo, J.; Tlemçani, M. A New RFID-Identification Strategy Applied to the Marble Extraction Industry. Electronics 2021, 10, 491. https://doi.org/10.3390/electronics10040491
- https://www.techsolutions.co.za/rfid-haulage-vehicle-tracking
- https://www.identecsolutions.com/news/rfid-in-mining
- https://iopscience.iop.org/article/10.1088/1757-899X/133/1/012050/pdf

CONCLUSION

- Provided an overview of Radio-Frequency Identification (RFID) technology.
- Explored the operational principles behind RFID technology.
- Examined the application of RFID in the context of smart haulage systems.
- Introduced fundamental concepts and explained the working principle of RFID.
- Discussed the key advantages associated with the use of RFID technology.
- Explored the specific reasons for implementing RFID technology in the mining industry.

CONCLUSION

- Examined diverse applications of RFID technology within mining operations.
- Discussed practical use cases showcasing the application of RFID technology in mining.
- Examined a real-world case study illustrating the implementation and outcomes of RFID technology.


THANK YOU

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Module 04

Virtual boundaries and camera systems

Lecture 10 A

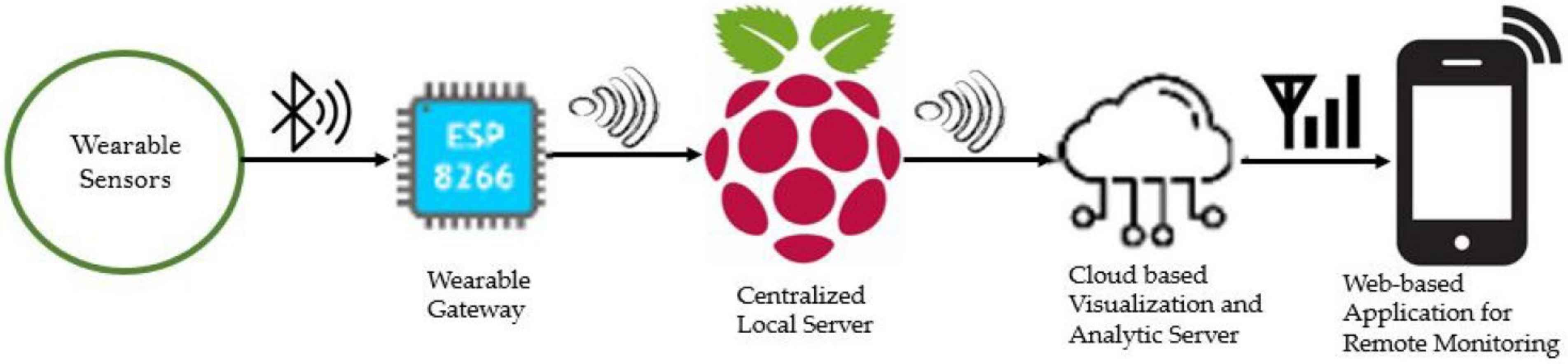
Introduction to Geo-fencing

CONCEPTS COVERED

- Introduction to geofencing
- Geofencing Implementation
- Geofencing Algorithms
- Geofencing keeps miners safe
- Track miners
- Geofencing Application
- Geofencing application use in the mining industry
- Key features of geofencing in mining industry

Introduction to geofencing

Geofencing is a location-based service that enables to detect and monitor when a mobile IoT/M2M device enters, leaves, crosses, or bypasses a precise geographical area delimited by a virtual perimeter, called geofence providing alerts or notifications, usually referred to as geo-notifications.



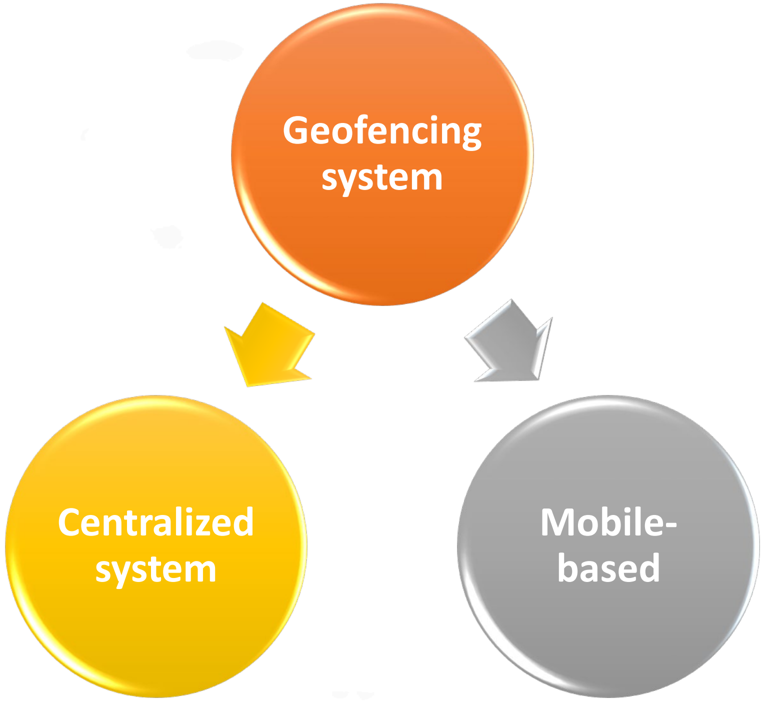
IoT-based framework for Geo-fencing and remote monitoring.

Introduction to geofencing

- **A geofence can be dynamically generated, like a circular area surrounding the current position of a mobile device, or can be made of a predefined set of boundaries, which may be arbitrarily drawn by the user or specific for a place or a building.**
- **Geofencing services can be classified, depending on the geographical references used to check the device's position, in static checks the geographical position of a mobile device with respect to a fixed area, and dynamic operates according to the position of a mobile device with respect to a changing area and peer-to-peer that uses the geographical position of a mobile device with respect to other mobile devices.**

Geofencing Implementation

- One of the most important component in a geofencing system is the Location Monitoring Unit (LMU), which is the component inside the geofencing system infrastructure which is responsible for location processing of the positions of a mobile device and for keeping the geofence scenarios.



Geofencing Implementation

Mobile-based geofencing system

How it works: The device uses satellite-GPS technology to find its position and checks it against a set of geofences right on the device.

Key Feature: This approach is like having a smart device that does most of the work itself.

Consideration: It's good for ensuring trustworthy node positions but can use a lot of battery due to the device doing the geospatial processing.

Geofencing Implementation

Centralized geofencing system

How it works: The mobile device is tracked by the network infrastructure, and the position matching with geofences is done by servers in the geofencing system.

Key Feature: The heavy lifting is done by centralized servers, making it potentially more efficient for the mobile device.

Consideration: This could be a good choice when you want to minimize the impact on the mobile device's battery.

A geofencing can be characterized according to the following features.

- ✓ **Location accuracy**: geofencing accuracy is strictly related to the accuracy of the geographical position provided by the service used to track the location of the mobile device, either satellite/GPS or GSM-based.
- ✓ **Tracking Rate**: expresses the frequency by which the device provides a location update to the server of the proactive LBS.

- ✓ **Device Speed**: the speed of a device determines the period within which the device must provide a location update to be evaluated against eligible events.

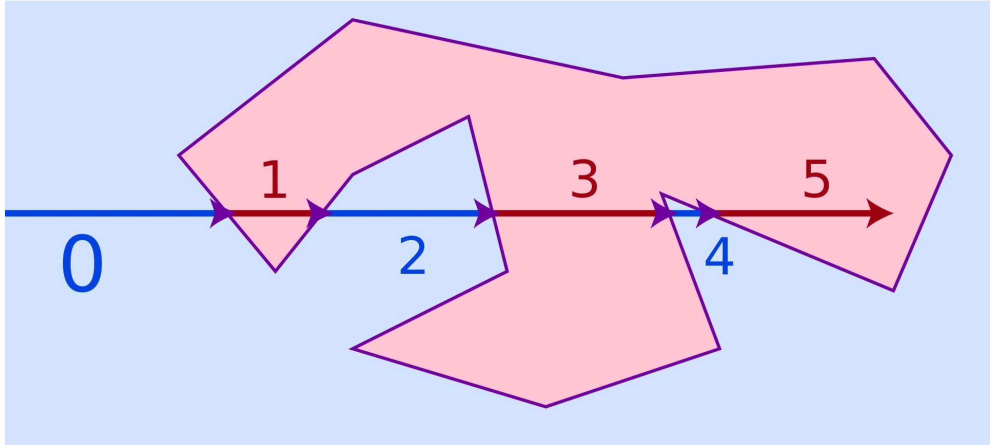
- ✓ **Device Route**: the path a device takes across a geofenced area, affecting the period within which location update must occur.

- ✓ **Geo-notification delivery**: geo-notifications can be delivered to the user only once or every time the mobile device successfully enters, leaves, crosses or bypasses a geofenced area.

Geofencing Algorithms

The "point-in-polygon test" is a geometric algorithm used to determine whether a given point lies inside or outside a polygon. This test is commonly employed in various applications, including geofencing algorithms and geographic information systems (GIS). The fundamental idea is to check whether a specific point's coordinates fall within the boundaries of a polygon.

The number of intersections for a ray passing from the exterior of the polygon to any point: If odd, it shows that the point lies inside the polygon; if even, the point lies outside the polygon. This test also works in three dimensions.



Geofencing Algorithms

PISTON (Parallel In-memory Spatio-temporal Topological Join)Algorithm:

Origin: Developed by the University of Toronto's Computer Science Department.

Design: Parallel, in-memory infrastructure for efficient query execution.

Key Features:

- **Novel parallel, in-memory trajectory index (IR) for high location data update rates.**
- **In-memory spatial index (IS) with a two-level grid approach, optimized for point-in-polygon tests.**
- **Low query response times are suitable for real-time use, even with large geofence datasets.**

Geofencing Algorithms

SLGC-1(Scan-Line Algorithm and Grid Compression) Algorithm

Origin: Created by the Software School of Xiamen University, China.

Purpose: Addresses regional limitations in Internet of Vehicles (IoV) systems with time and storage constraints.

Operation:

- **Spherical grid imposed on the geofence area in preprocessing.**
- **Scan conversion algorithm determines location attributes for each grid cell.**
- **QuadTree compression provides a memory-efficient index structure for geofence area.**
- **Uses Morton Code (MD code) to identify nodes inside the QuadTree structure.**

Geofencing Algorithms

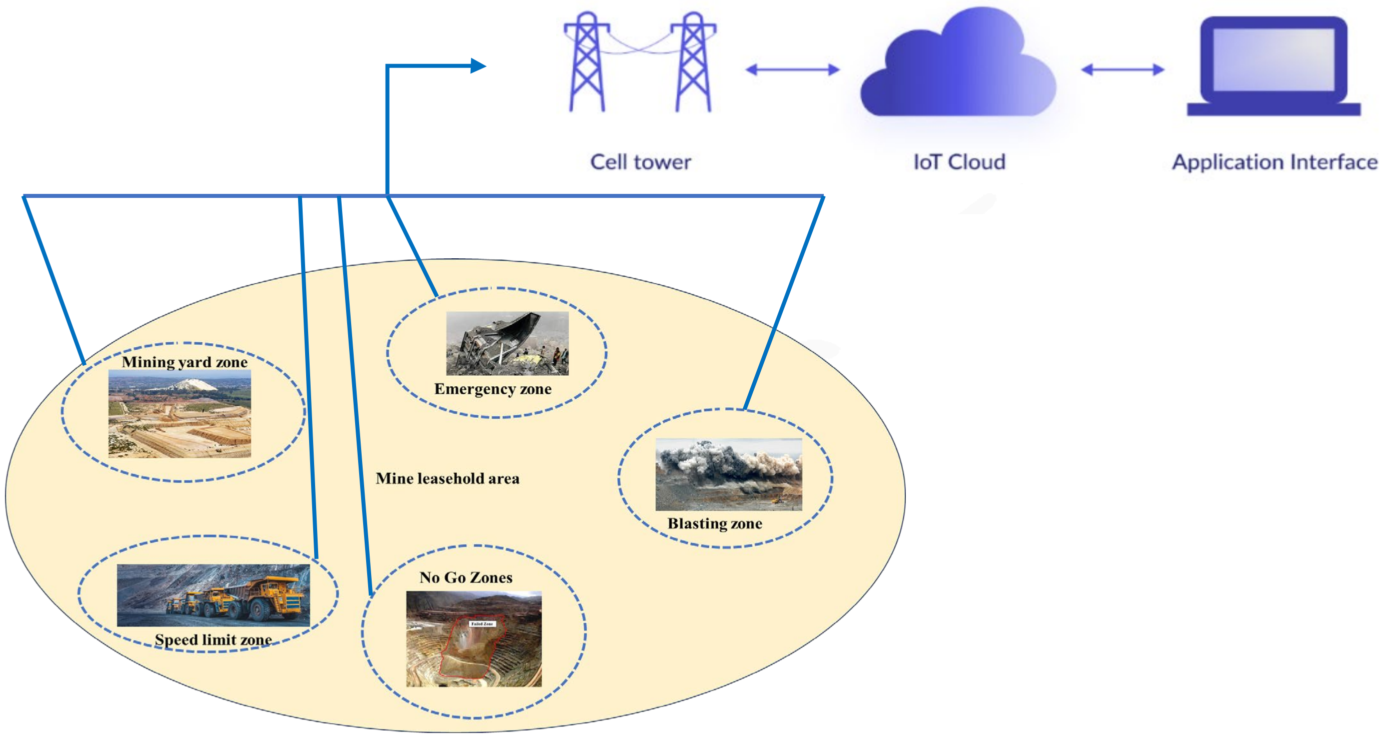
PFLGA (Proactive Fast and Low Resource Geofencing Algorithm)

- **PFLGA employs a tree-based indexing method for geofences, implements a smart trajectory filtering strategy, and provides flexibility with both trajectory-based and point-in-polygon queries. However, its response time for trajectory-based queries may not be the fastest among available algorithms.**

Geofencing keeps miners safe

- Geofencing is a virtual boundary drawn around a dangerous area.
- This can be achieved with GPS and other data signals including cellular, Wi-Fi, and RFID.
- The idea being that a geofencing application responds instantly when a mobile device enters or leaves the fenced area.
- It can limit personnel access to recently blasted areas, for example, or minimize the time for evacuation due to an explosion by determining the best escape routes.
- A geofencing application can be programmed to set off an alarm on a mobile device if a worker or vehicle operates too close to the edge of a dangerous boundary.

Geofencing keeps miners safe



schematic diagram of mining with geo-fencing application.

Geofencing keeps miners safe

- As an extra failsafe, the technology can automatically shut down dangerous equipment or alert site managers so that they can take decisive action quickly.
- Coupled with telematics, geofencing can track the whereabouts of assets and prevent them from leaving a defined area.
- Telematics is the technology used to track individual machines or a fleet. Telematics collects data from vehicles, including location, driver behavior, and vehicle activity
- It can help management keep track of heavy machinery assets and keep them out of hazardous environments, for example. If a machine handler is behaving erratically and endangering the safety of others, an alert can be sent to the site manager.

Track miners

Detecting Dangerous Driving Behavior

- Mining companies nowadays can detect and collect data that indicates truck driver behavior. Data on harsh driving activity can be seen via GPS devices.
- Moreover, mine site managers can easily monitor and detect dangerous driving behavior thanks to the advanced GPS features.
- Yet, once a mine manager detects dangerous driving and operational behavior, straight ahead he can alert drivers on their risky behaviors.

Driver behaviour detecting

Track miners

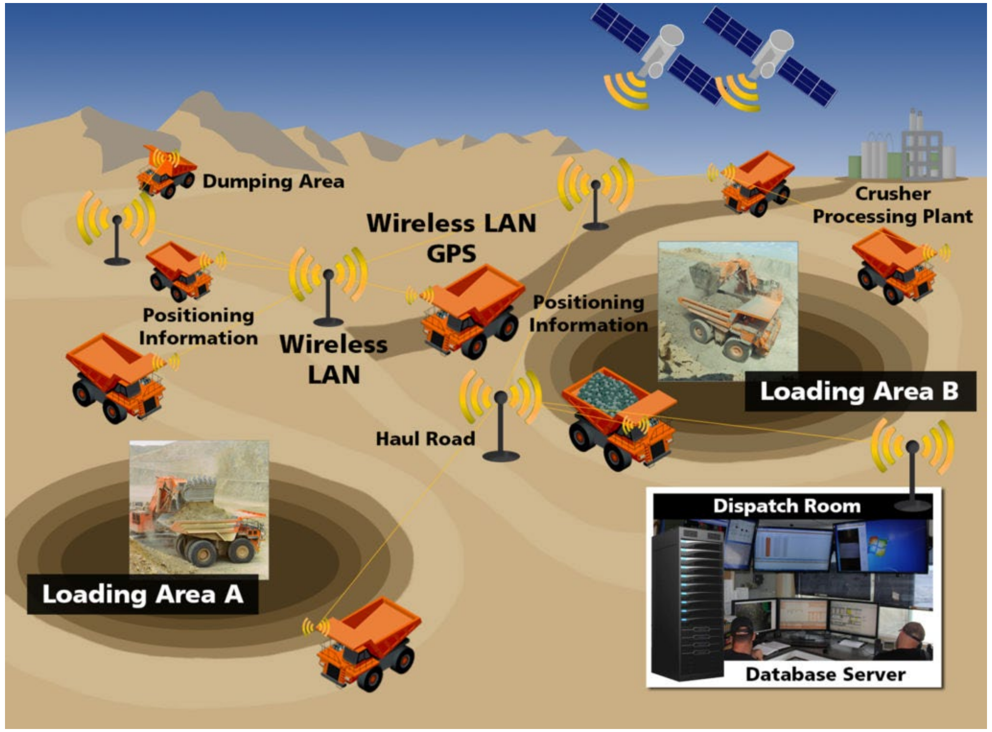
Detecting Dangerous Driving Behavior

- In addition, this application characterization of the GPS features can decrease the chances of accidents or any injury happening on mine sites.
- By that, not only that mining company can decrease the chances of accidents and injuries, but they can as well reduce the wear and tear on the vehicles.
- So, by detecting dangerous driving behaviors via the global positioning system mining companies can improve their overall efficiency.

Track miners

Hazard Avoidance

- **The application characterization of GPS features for mining companies can be seen in the process of hazard avoidance as well. In general, the mining industry is a risky one. Geofencing will add an extra layer of safety for mine workers.**



Geofencing Application

1. Static Virtual-notification

This application works on the geographical position of a mobile user concerning a fixed area.

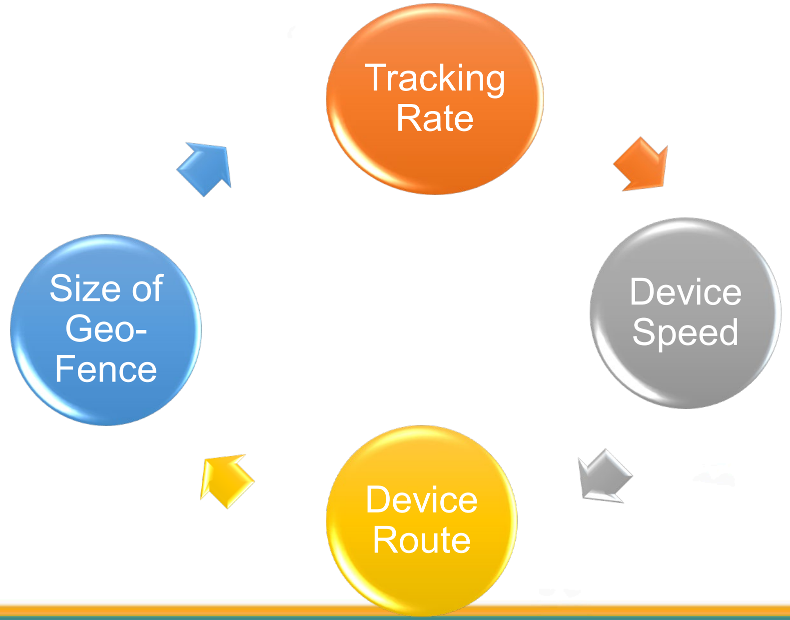
2. Dynamic Virtual-notification

This application is rooted in the geographical location of a mobile user concerning a changing data stream.

Geofencing Application

3. Peer-to-Peer virtual-notification:

- **This application works on the geographical location of a mobile user concerning other users.**
- **Location Accuracy – The device location must be correctly identified to a geo-fence for the action to occur appropriately (i.e., the right user receives a notification)**



How fleet management is used in Geofencing using IoT?

Fleet management can be used in different ways in IoT:

1. Planning trips & Scheduling trips:

Fleet management uses planning trips and Scheduling trips in such a way that owners can plan their trips in a specific manner using Geo tracking and communication with the help of IoT.

2. Fleet management:

When a truck driver diverts from his route, the dispatcher gets an alert. This is used as fleet management using Geo-Fencing.

3. Maintenance:

There are hundreds of vehicles operating on fleet management, so it is crucial to have conservation of these vehicles and the consequences of inappropriate actions.

Geofencing application use in mining industry

Blast Zones

- **When it's time to conduct blasting to loosen iron ore for extraction, for example, obviously you need to be sure no people are in the blast zone, so a geofence can alert the right people if and when this occurs.**

Geo-fencing

Yard and Site

- Should your business involve workers transporting supplies or equipment from a home base (known as a yard) to a temporary work site, creating a geofence can allow you to easily log the times users come and go between each area.
- For example, a concrete truck returning to the yard to fill up, before heading back to the site to drop off its load.

Confinement

- While the applications above have all been about keeping track of who is entering an area, geofences can also be put in place to keep people in who are already there.
- Confinement is where you want someone to stay within an area, and can be set up to send you an alert should they leave the specified zone.

No Go Zones

- Functioning similarly to blast and emergency geofences, this is a solution for areas you don’t want people to go to enter, although not necessarily for safety reasons.
- Security-sensitive areas or environmentally protected zones are good examples.

Emergency

- For use in critical situations, emergency zones can be quickly setup for evacuation and warning zones. An example of this is a fire zone, so when such an event occurs an emergency geofence can be created to cover an area to evacuate.
- As soon as the area is mapped out the system can identify which radio users are in the zone and send out an alert to ensure they leave.

Speed Limiting

- Heavy industrial areas such as mine sites often have certain areas where you are not to exceed a certain speed limit.
- A speed limit geofence can track any incidents of speeding and help you to send any warnings if necessary.

Geofencing application in Open-cast mine

- Geo-fencing, used for miners safety, if miners enter in mining area then the mining office can get a notification.
- In the heavy earth moving machinery tracker, user can get alerts about machinery for example production activity and transportation activity list notification.
- In the mine leasehold boundary area notification.
- Human resource management- An employee smart card or GPS tracking device will send an alert to security if an employee attempts to enter an unauthorized geofence/area.

Geofencing application in Open-cast mine

- **Compliance management- Network logs record all geo-fence crossings to document when the proper use of devices and their compliance with established rules.**
- **Asset management- An RFID tag on a pallet can send an alert or notification if the pallet is removed from the warehouse without authorization.**
- **Law enforcement**

Question 1

How does geofencing technology impact the mining industry?

A) It has no impact on the mining industry.

B) It creates physical perimeters around designated areas.

C) It relies solely on GPS for real-time monitoring.

D) It revolutionizes the industry by enabling virtual perimeters and automated responses.

E) It only monitors assets, not people, within the virtual fences.

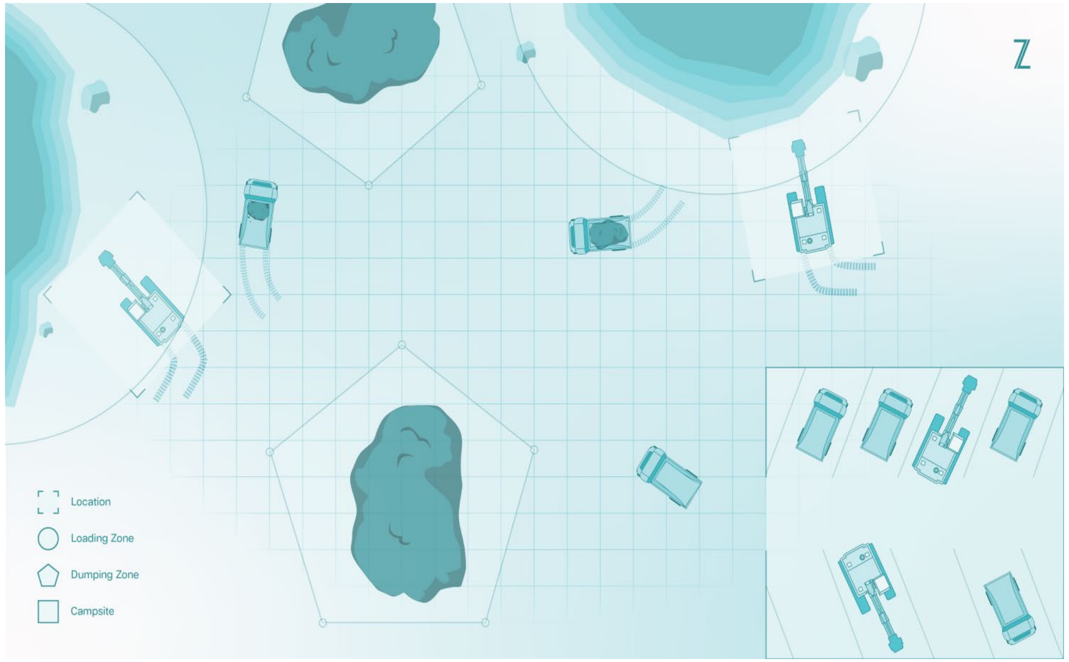
Answer: D) It revolutionizes the industry by enabling virtual perimeters and automated responses.

Key features Geofencing Application in the mining industry

- Geofencing and Access Control
- Real-Time Tracking and Visualization
- Intelligent Routing and Dispatch Management
- Automated Alerts and Notifications
- Driver and Fleet Mapping
- Performance Analytics and Reporting
- Emergency Response Integration

Geofencing and Access Control:

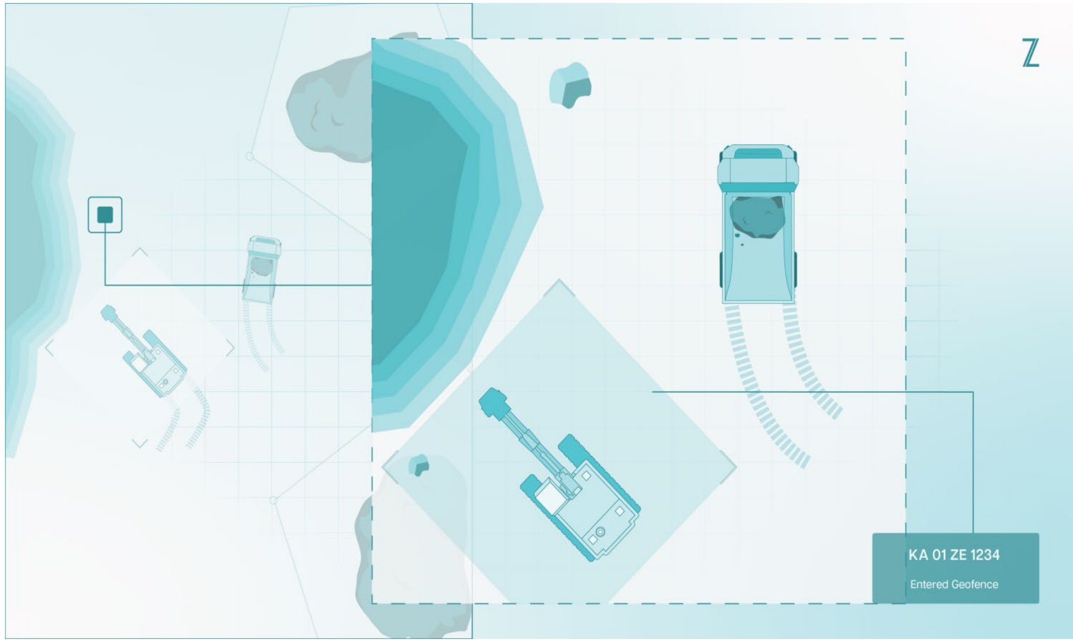
- Implementation of geofencing technology to create virtual boundaries around excavation zones. Only authorized vehicles and equipment can enter specific areas, preventing accidental encroachments, ensuring a safer work environment.



Geo-Fencing of Areas in the Mining Site

Real-Time Tracking and Visualization:

- The system integrates GPS and RFID technologies to track the location and movement of all excavators and vehicles in real time. A user-friendly interface displays the mining site layout with color-coded zones, enabling operators to monitor activities and detect any unauthorized entry.



Real-Time Tracking of fleet movements and notification of event on Geo-Fenced Area access

Intelligent Routing and Dispatch Management:

- The system employs predictive analytics and AI algorithms to recommend optimal routes for each vehicle and excavator.
- This minimizes traffic congestion, reduces turnaround times, and enhances overall operational efficiency.
- Dispatch managers receive real-time suggestions to make informed decisions.
- Additionally, manual route planning can be implemented with geofencing to assist drivers in adhering to the designated route.
- Any deviations from the planned route within the geofenced areas can be tracked in real time.
- So, whenever an event of geofence breach occurs, a real-time alert can be generated and reported.

Automated Alerts and Notifications:

- When a vehicle or excavator enters a restricted or active excavation zone, the system triggers automated alerts to relevant stakeholders, including operators, supervisors, and drivers.
- These alerts prompt immediate corrective actions and prevent safety hazards and resource wastage.

Driver and Fleet Mapping:

- Enabling an access control system that links drivers to specific vehicles facilitates the process of assigning vehicles and aligning drivers with their designated shifts.
- This system ensures that access is granted exclusively to vehicles that have been pre-approved and onboarded by the fleet manager.
- Moreover, this access control mechanism serves the vital purpose of restricting unauthorized personnel from entering vehicles located in hazardous areas.
- Only individuals who have undergone specialized training are permitted to access and operate these specific vehicles.
- It's important to note that vehicle operation is only allowed once a trip has been officially assigned; otherwise, alerts can be generated for such events to enable quick preventive action.

Performance Analytics and Reporting:

- The system collects data on vehicle movements, operational patterns, and efficiency metrics.
- Detailed reports are generated such as Fleet utilization reports, Delay/ Miss reports in trip plan, incident report, Total KMs Covered report, Driver-wise report and customized reports based on operational requirements, providing insights into performance trends, potential bottlenecks areas for improvement.

Emergency Response Integration:

- The system includes an emergency override feature that allows operators to remotely halt vehicles and equipment in case of a safety threat.
- This ensures swift action to prevent accidents or hazardous situations.

REFERENCES

- Hulwan, N., 2018. Geo-fencing Application For Natural Disaster And Student Tracker. International Journal Of Advanced Research In Computer Science, 10(6).
- Https://Www.Fueloyal.Com/10-most-important-practices-of-gps-features-for-mining-companies/
- Https://Www.Wencomine.Com/Post/Hitachi-wenco-join-forces-revolutionize-mining-industry
- Https://Www.Linkedin.Com/Pulse/Harnessing-data-success-zeliots-condense-iot-platform-solution/
- Schelle, A.; Völk, F.; Schwarz, R.T.; Knopp, A.; Stütz, P. Evaluation Of A Multi-mode-transceiver For Enhanced UAV Visibility And Connectivity In Mixed ATM/UTM Contexts. Drones 2022, 6, 80. Https://Doi.Org/10.3390/Drones6040080

REFERENCES

- P. W. Modica, M. P. Loria, M. Toja, V. Carchiolo and M. Malgeri, "A Geofencing Algorithm Fit for Supply Chain Management," 2018 Federated Conference on Computer Science and Information Systems (FedCSIS), Poznan, Poland, 2018, pp. 737-746. https://ieeexplore.ieee.org/document/8511158

CONCLUSION

- Provided an overview of the concept of geofencing.
- Explored the practical application and integration of geofencing technology
- Discussed the algorithms employed in geofencing systems to define and manage virtual boundaries.
- Explored the role of geofencing in enhancing safety measures for miners.
- Discussed how geofencing is utilized to track and monitor the movements of miners.
- Examined the practical application of geofencing technology.

CONCLUSION

- Explored specific use cases of geofencing technology within the mining sector.
- Highlighted essential features that make geofencing valuable for enhancing safety and monitoring in mining operations.


THANK YOU

MINE AUTOMATION AND DATA ANALYTICS

MINE AUTOMATION AND DATA ANALYTICS

SWAYAM NPTEL COURSE ON

MINE AUTOMATION AND DATA ANALYTICS

By

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Module 04:
Virtual boundaries and camera systems

Lecture 10 B
CCD camera in Mine safety and management

CONCEPTS COVERED

- Introduction to image sensors
- CCD Technology
- Basics operation in CCD technology
- CMOS Technology
- Main differences between CCD vs CMOS
- Data collection methods
- CCD Camera use in mining industry
- Examples- CCD Cameras use in mining

Introduction to image sensors

- When an image is being captured by a network camera, light passes through the lens and falls on the image sensor. The image sensor consists of picture elements, also called pixels, that register the amount of light that falls on them. They convert the received amount of light into a corresponding number of electrons.
- The stronger the light, the more electrons are generated. The electrons are converted into voltage and then transformed into numbers by means of an Analog to Digital converter.
- The signal constituted by the numbers is processed by electronic circuits inside the camera

Introduction to image sensors

Presently, there are two main technologies that can be used for the image sensor in a camera, i.e. CCD (Charge-coupled Device) and CMOS (Complementary Metal-oxide Semiconductor).

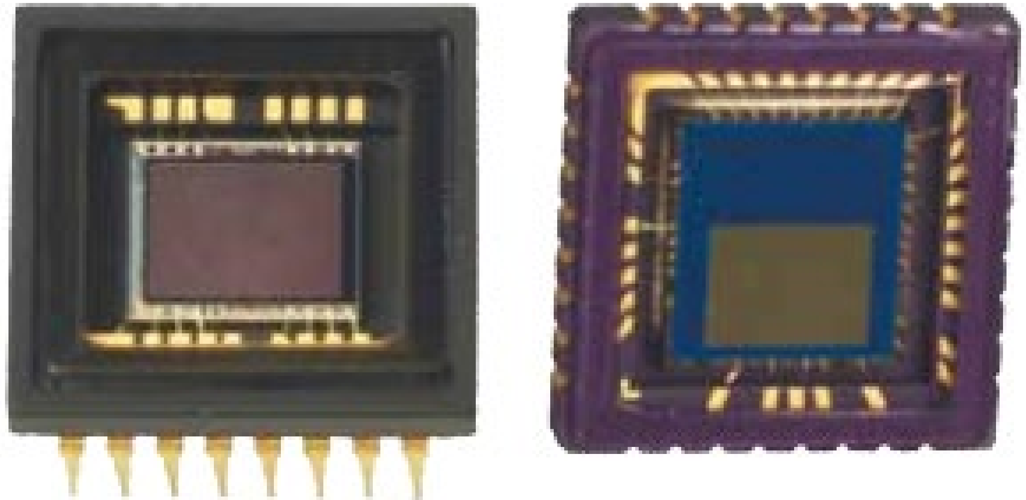
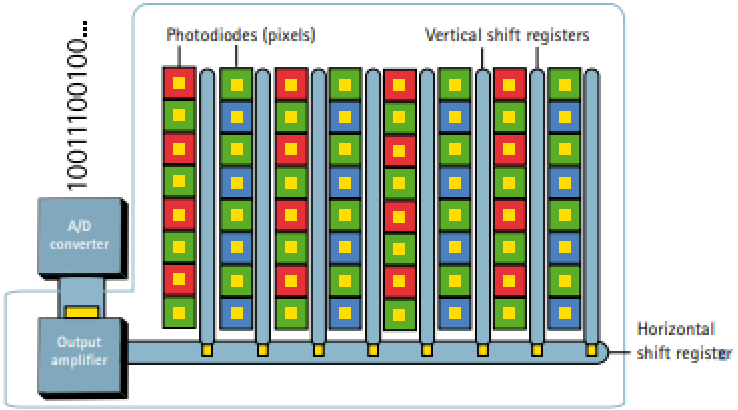


Image sensors: CCD (left) and CMOS (right)

CCD Technology

- In a CCD sensor, the light (charge) that falls on the pixels of the sensor is transferred from the chip through one output node or only a few output nodes.
- The charges are converted to voltage levels, buffered, and sent out as an analog signal. This signal is then amplified and converted to numbers using an Analog to Digital converter outside the sensor



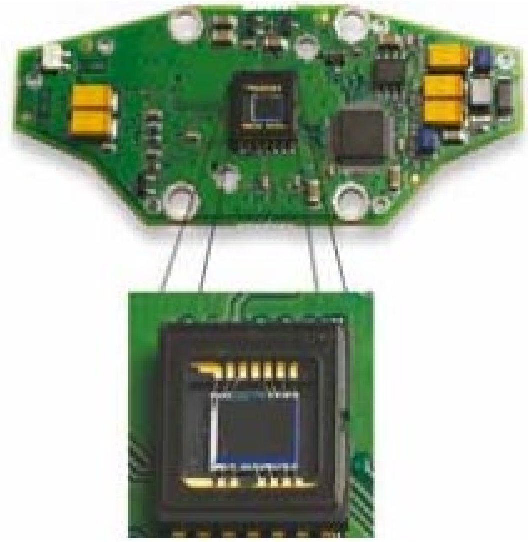
CCD operation (video-type CCD)

CCD Technology

- The CCD technology was developed specifically to be used in cameras, and CCD sensors have been used for more than 30 years. Traditionally, CCD sensors have had some advantages compared to CMOS sensors, such as better light sensitivity and less noise.
- The disadvantages of CCD sensors are that they are analog components that require more electronic circuitry outside the sensor, they are more expensive to produce, and can consume up to 100 times more power than CMOS sensors.

CCD Technology

- The increased power consumption can lead to heat issues in the camera, which not only impacts image quality negatively, but also increases the cost and environmental impact of the product.
- CCD sensors also require a higher data rate, since everything has to go through just one output amplifier, or a few output amplifiers.

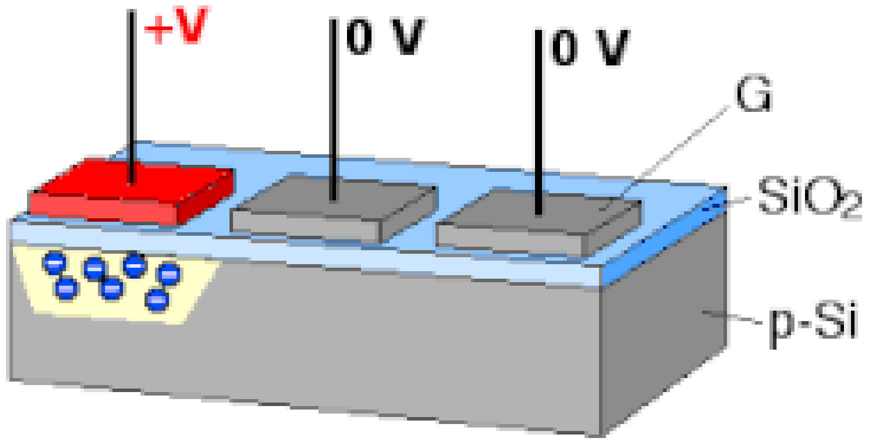


CCD sensor mounted on a PCB

Basics operation in CCD technology

- In a CCD for capturing images, there is a photoactive region (a layer of silicon), and a transmission region made out of a shift register (the CCD).
- An image is projected through a lens onto the capacitor array (the photoactive region), causing each capacitor to accumulate an electric charge proportional to the light intensity at that location. A one-dimensional array, used in line-scan cameras, captures a single slice of the image, whereas a two-dimensional array, used in video and still cameras, captures a two-dimensional picture corresponding to the scene projected onto the focal plane of the sensor.

Basics of operation in CCD technology



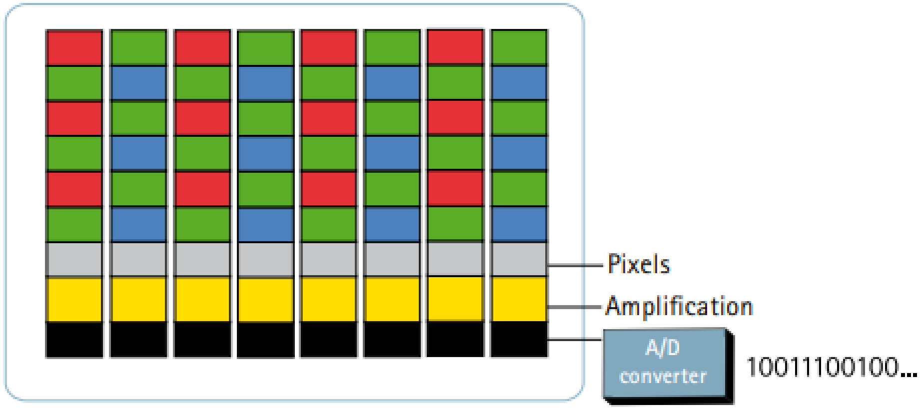
- **Once the array has been exposed to the image, a control circuit causes each capacitor to transfer its contents to its neighbour (operating as a shift register). The last capacitor in the array dumps its charge into a charge amplifier, which converts the charge into a voltage.**

Basics of operation in CCD technology

- By repeating this process, the controlling circuit converts the entire contents of the array in the semiconductor to a sequence of voltages.
- In a digital device, these voltages are then sampled, digitized, and usually stored in memory in an analog device (such as an analog video camera), they are processed into a continuous analog signal (e.g. by feeding the output of the charge amplifier into a low-pass filter), which is then processed and fed out to other circuits for transmission, recording, or other processing.

CMOS technology

Early on, ordinary CMOS chips were used for imaging purposes, but the image quality was poor due to their inferior light sensitivity. Modern CMOS sensors use a more specialized technology and the quality and light sensitivity of the sensors have rapidly increased in recent years.



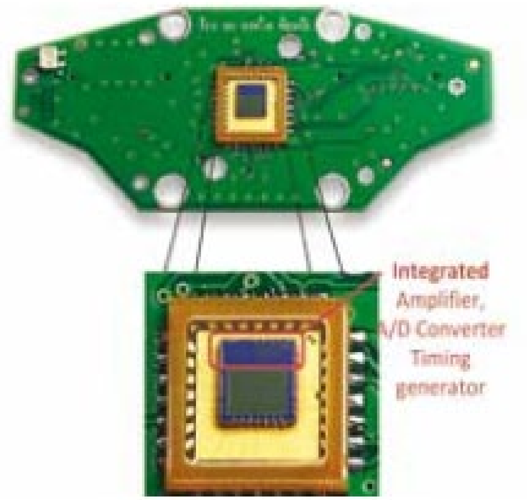
CMOS sensor

CMOS technology

- CMOS chips have several advantages. Unlike the CCD sensor, the CMOS chip incorporates amplifiers and A/D-converters, which lowers the cost for cameras since it contains all the logics needed to produce an image.
- Compared to CCD sensors, CMOS sensors have better integration possibilities and more functions. However, this addition of circuitry inside the chip can lead to a risk of more structured noise, such as stripes and other patterns.

CMOS technology

- **CMOS sensors also have a faster readout, lower power consumption, higher noise immunity, and a smaller system size.**
- **Calibrating a CMOS sensor in production, if needed, can be more difficult than calibrating a CCD sensor. But technology development has made CMOS sensors easier to calibrate, and some are nowadays even self-calibrating.**



CMOS sensor mounted on a PCB

Main differences between CCD vs CMOS

- **A CMOS sensor incorporates amplifiers, A/D-converters and often circuitry for additional processing, whereas in a camera with a CCD sensor, many signal processing functions are performed outside the sensor.**
- **CMOS sensors have a lower power consumption than CCD image sensors, which means that the temperature inside the camera can be kept lower.**
- **Heat issues with CCD sensors can increase interference, but on the other hand, CMOS sensors can suffer more from structured noise**

Main differences between CCD vs CMOS

- A CMOS sensor allows ‘windowing’ and multi-view streaming, which cannot be performed with a CCD sensor.
- A CCD sensor generally has one charge-to-voltage converter per sensor, whereas a CMOS sensor has one per pixel.
- The faster readout from a CMOS sensor makes it easier to use for multi-megapixel cameras.

Question 1

How do CMOS sensors differ from CCD sensors in terms of power consumption?

a) CMOS sensors consume more power.

b) CMOS sensors have lower power consumption.

c) Both sensors consume the same amount of power.

d) CMOS sensors have no power consumption.

e) None of these.

Answer: b) CMOS sensors have lower power consumption.

Enhancing Mining Safety and Management with CCD Cameras

- **Cameras are employed in a variety of industries to allow the driver to navigate a blind spot region in real-time through a display in the driver's cab.**

CCD camera

RGB Camera

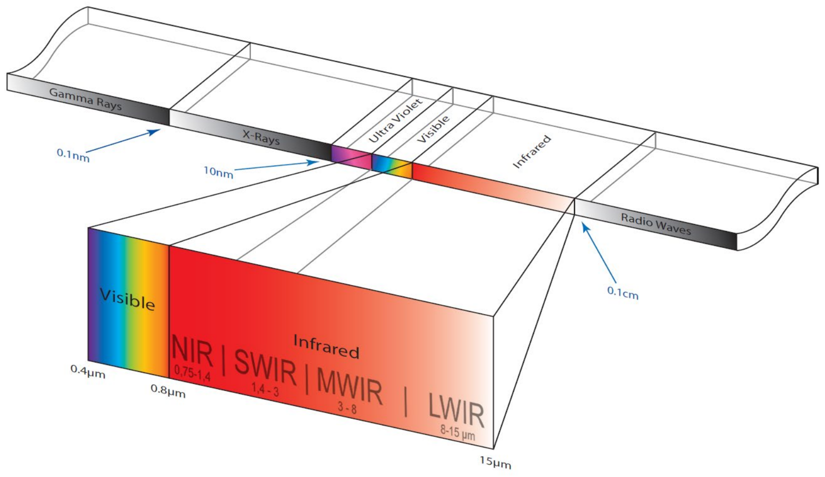
- An RGB (red, green, blue) camera can be employed for multiple purposes, including surveying and mapping, stockpiling volume calculations, traffic and security surveillance, inspection, and more.
- To provide depth assessment at a large number of pixels, RGB cameras employ either active stereo or time-of-flight sensing technology.
- The camera must be carefully chosen, taking into account the drone's power consumption.
- For fixed-wing drones, a tiny camera is preferred because bulky gadgets cannot be carried.

The use of RGB camera with Spotlight LED. (a) RGB camera; (b) spotlight LED.

Infrared Camera

- A thermal camera is a type of camera that uses heat-sensing technology to detect and display the temperature of objects in the area of vision.
- Thermal cameras work by detecting the infrared (IR) radiation emitted by objects and converting that information into an image that can be displayed on a screen.

Thermal camera



Thermal range

Infrared Camera

- This allows thermal cameras to “see” through darkness, fog, and other forms of visual obstruction, as well as detect hot and cold spots that may not be visible to the naked eye.
- There are several applications for thermal cameras, including security, search and rescue, military, industrial maintenance, and building energy efficiency.

Stereoscopic Camera

- A camera capable of capturing three-dimensional pictures is referred to as a stereoscopic camera, which utilizes a combination of at least two lenses, much like the human visual system.
- Stereo cameras use their distinct image sensors to create three-dimensional pictures.
- Stereo cameras offer the benefits of high precision and high-quality resolution in a controlled environment.
- Under smoke, fog, or dust, however, it performs poorly because light waves are warped in these situations.

Stereoscopic camera

Data Collection Method

Researchers have conducted various experiments using four hardware systems:

- **Unmanned aerial vehicles (UAVs)**
- **Unmanned ground vehicles (UGVs)**
- **Mobile machines, such as load–haul–dump (LHD) vehicles, and fixed cameras such as surveillance cameras**

Data Collection Method

Drones

- Drones, or unmanned aerial vehicles (UAVs), can also be used in underground and open-cast mines as a way to improve safety, efficiency, and productivity.
- These drones are typically equipped with sensors and cameras and are controlled remotely by a human operator or through autonomous programming.

Drone

Data Collection Method

Unnamed Ground Vehicle

- Unmanned ground vehicles (UGVs) are becoming increasingly popular in underground mines as a way to improve safety, efficiency, and productivity.
- These vehicles are equipped with sensors and cameras and are typically controlled remotely by a human operator or through autonomous programming.

Unmanned ground vehicle

Data Collection Method

Mobile Machines

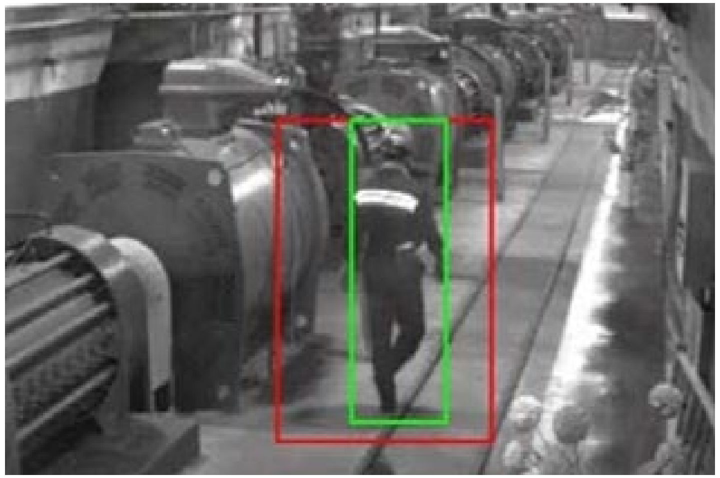
- A load–haul–dump (LHD) is a type of underground mining vehicle that is used to load, haul, and dump material within an underground mine. LHDs are typically used to transport materials, such as ore, waste rock, and coal, within the mine.
- The material is then transported to a designated dumping location, where it is unloaded using the bucket or a conveyor belt.
- LHDs are commonly used in underground mines to improve efficiency and productivity.

Load–haul–dump: (a) load–haul–dump (LHD); (b) view from fixed camera on LHD.

Data Collection Method

Surveillance Cameras

- Surveillance cameras can be used in underground mines to monitor and assess the condition of equipment, infrastructure, and the environment within the mine.
- These cameras can be placed in strategic locations throughout the mine and can be used to transmit real-time video footage to a central monitoring station.
- There are several potential benefits to using surveillance cameras in underground mines: improved safety, enhanced productivity, and improved communication.



View from a surveillance camera.

Algorithmic Part

Table 1 illustrates the algorithm and its uses.

Algorithm	Data Type	Purpose
Yolo (v2,v3, v4 and v5)	RGB Images, Thermal Images	Pedestrian detection, electric locomotives and stones falling
HOG	RGB Images, Thermal Images	Pedestrian detection
SVM	RGB Images, Thermal images	Enhancing underground visual place, pedestrian detection
Image segmentation and Thresholding	RGB Images, Thermal images	Overhead boulders detection, pedestrian detection
Navigation and mapping	RGB Images, Stereoscopic images, thermal images from LIDAR	Anti-collision, exploration path planning solutions, road signs recognition, location estimation method, trajectory controller

CCD camera use in the mining industry

Surveillance and Monitoring

Site Security

- CCD cameras can be strategically placed around the mining site to monitor entrances, exits, and perimeter areas for unauthorized access.
- Equipment Monitoring: Cameras can be installed on heavy machinery and equipment to monitor their operation and identify any potential issues or malfunctions.

CCD camera use in the mining industry

Emergency Response

Incident Documentation

CCD cameras can capture real-time footage of any incidents or emergencies, providing valuable documentation for incident investigations and improving the overall response to emergencies.

CCD camera use in the mining industry

Safety Compliance

Personnel Safety

Cameras can monitor work zones to ensure that employees are following safety protocols and wearing the required protective gear.

Regulatory Compliance:

Video footage can be used to verify compliance with safety regulations and standards, helping mining companies avoid fines and penalties.

CCD camera use in the mining industry

Training and Education

Training Material

Recorded footage from CCD cameras can be used as training material for new employees, helping them understand and adhere to safety procedures.

Simulation

Video feeds from cameras can be used in simulated training scenarios to prepare workers for emergency situations.

CCD camera use in the mining industry

Environmental Monitoring

Site Conditions

CCD cameras can be equipped with sensors to monitor environmental conditions such as dust levels, air quality, and temperature, helping to ensure a safe working environment for miners.

CCD camera use in the mining industry

Remote Monitoring and Management:

Centralized Control

CCD cameras can be integrated into a centralized monitoring system, allowing for real-time remote monitoring of multiple locations within the mining site.

Data Analysis

Video analytics can be applied to detect patterns, anomalies, and trends, providing valuable insights for optimizing mining operations and improving overall management.

Question 2

How can recorded footage from CCD cameras contribute to training and education?

a. Only as documentation for safety procedures

b. Only for live monitoring of employees

c. Only for creating simulation scenarios

d. As training material for new employees to understand and adhere to safety procedures

e. Only for surveillance purposes

Answer: d. As training material for new employees to understand and adhere to safety procedures"

CCD camera use in the mining industry

Record Keeping

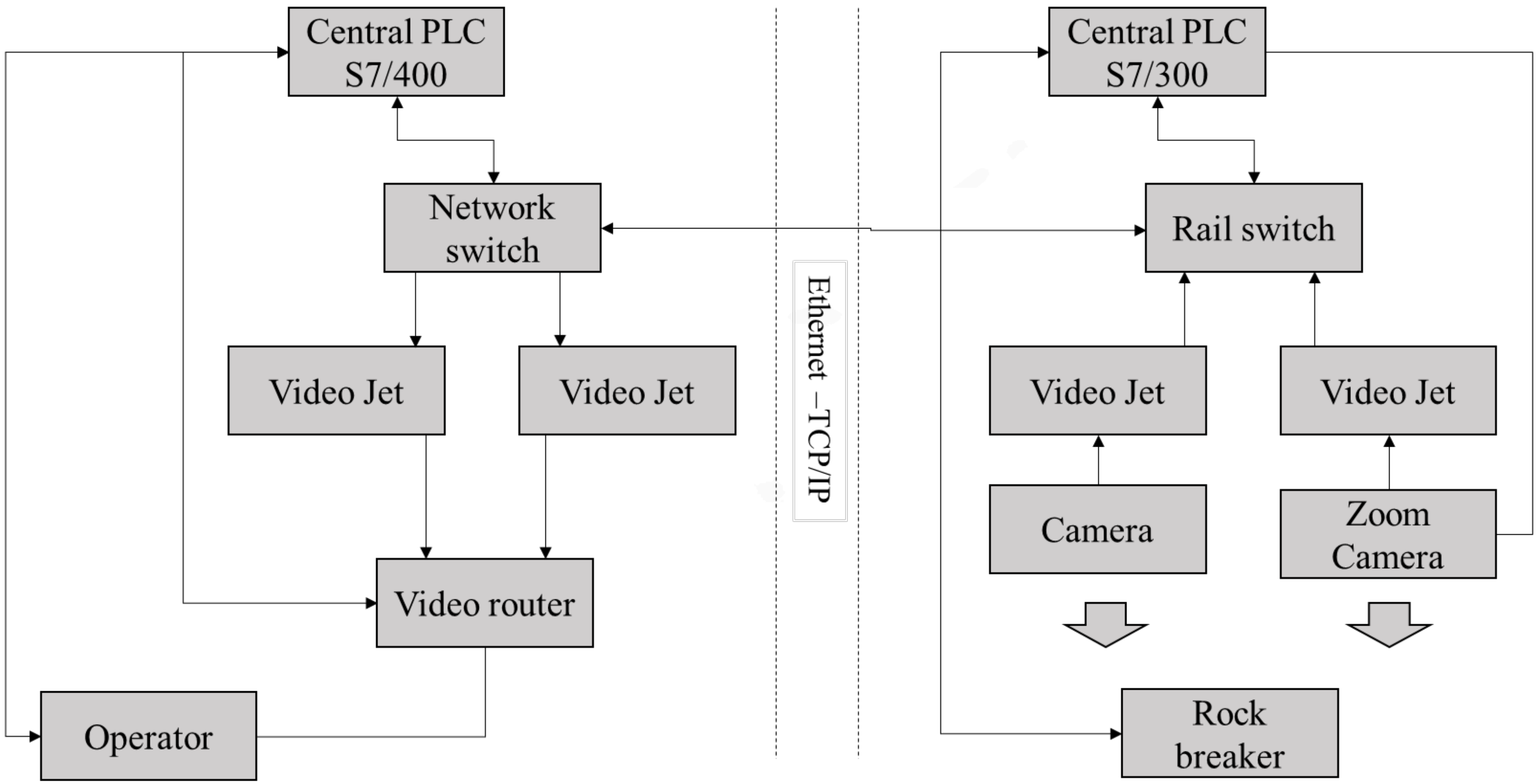
Incident Investigation

Recorded footage can be used for detailed investigations into incidents, accidents, or near misses, helping identify root causes and prevent future occurrences.

Audit Trails

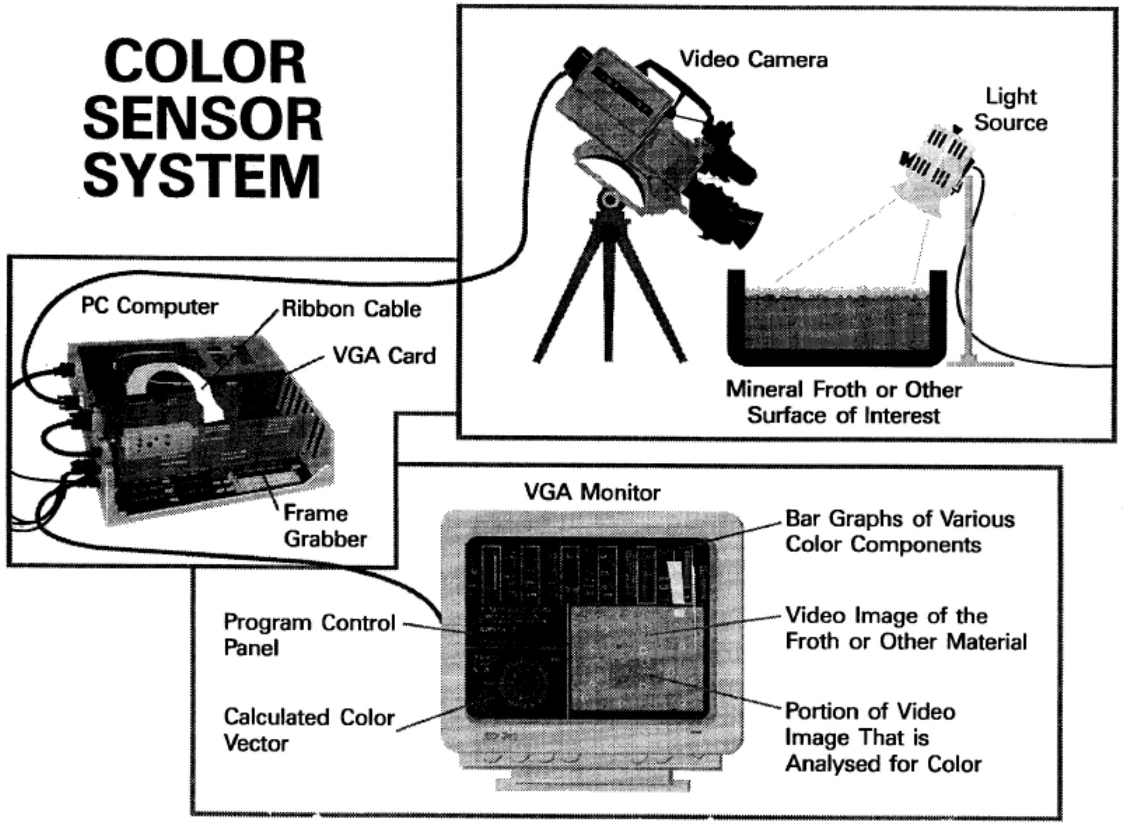
Having a comprehensive record of activities through video footage can assist in audits and compliance checks.

CCD camera use in the mining industry



CCD Camera schematic system for mining application

CCD camera use in the mining industry



Schematic of color sensor for measuring composition of mineralized flotation froths and other mineral mixtures.

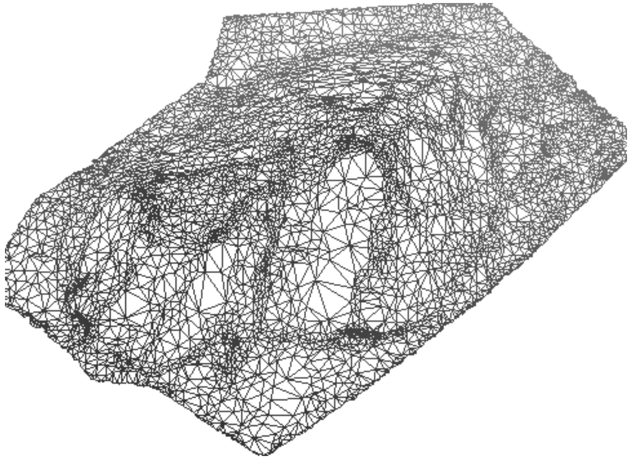
CCD camera use in the mining industry

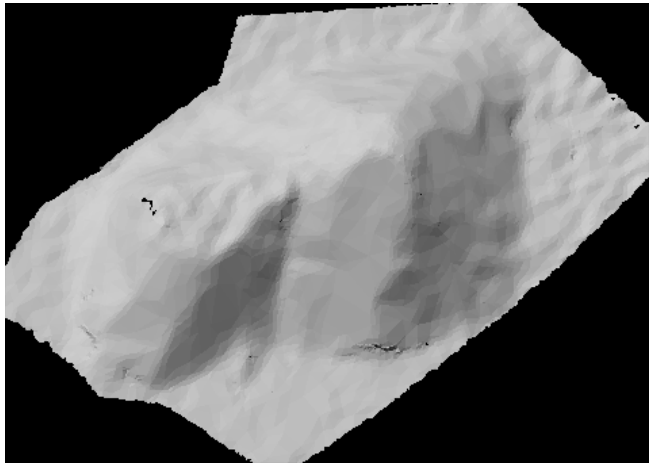
Pile volume measurement by range imaging camera in an indoor environment

The volume measurement of the gravel pile by SR4000 camera

CCD camera use in the mining industry

Pile volume measurement by range imaging camera in an indoor environment

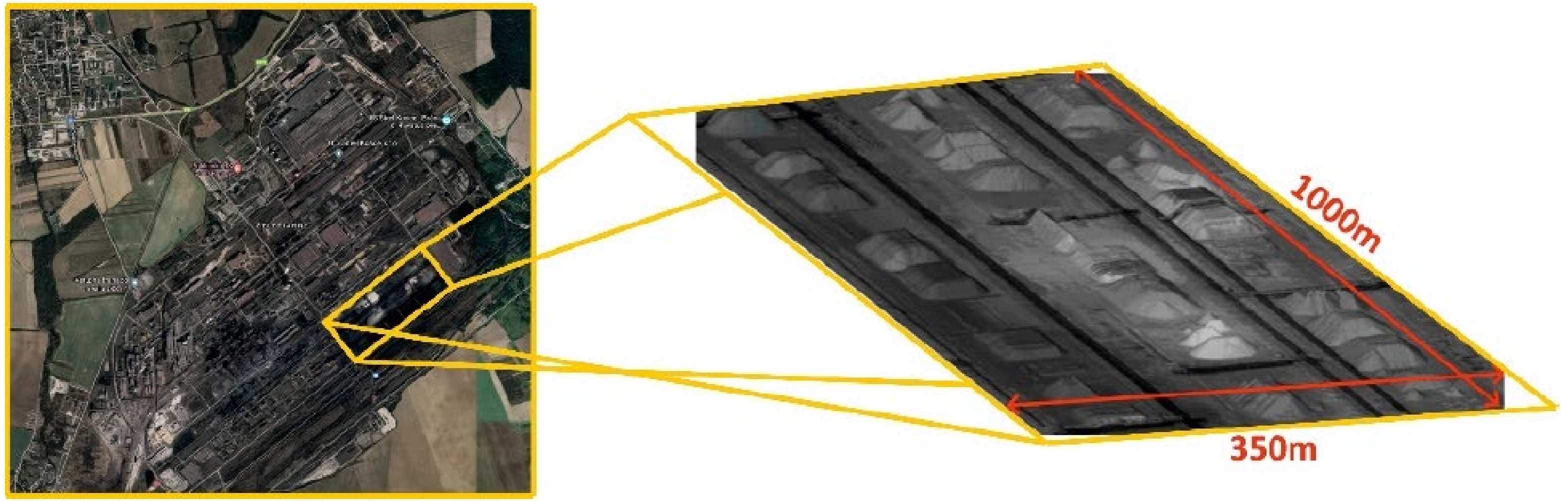




The triangulated and mesh models of the gravel pile. The reference plane was created by three points selected from the ground interactively

CCD camera use in the mining industry

Aerial Photogrammetry for Dump Documentation and Volume Determination in Large Areas



surveyed heaps

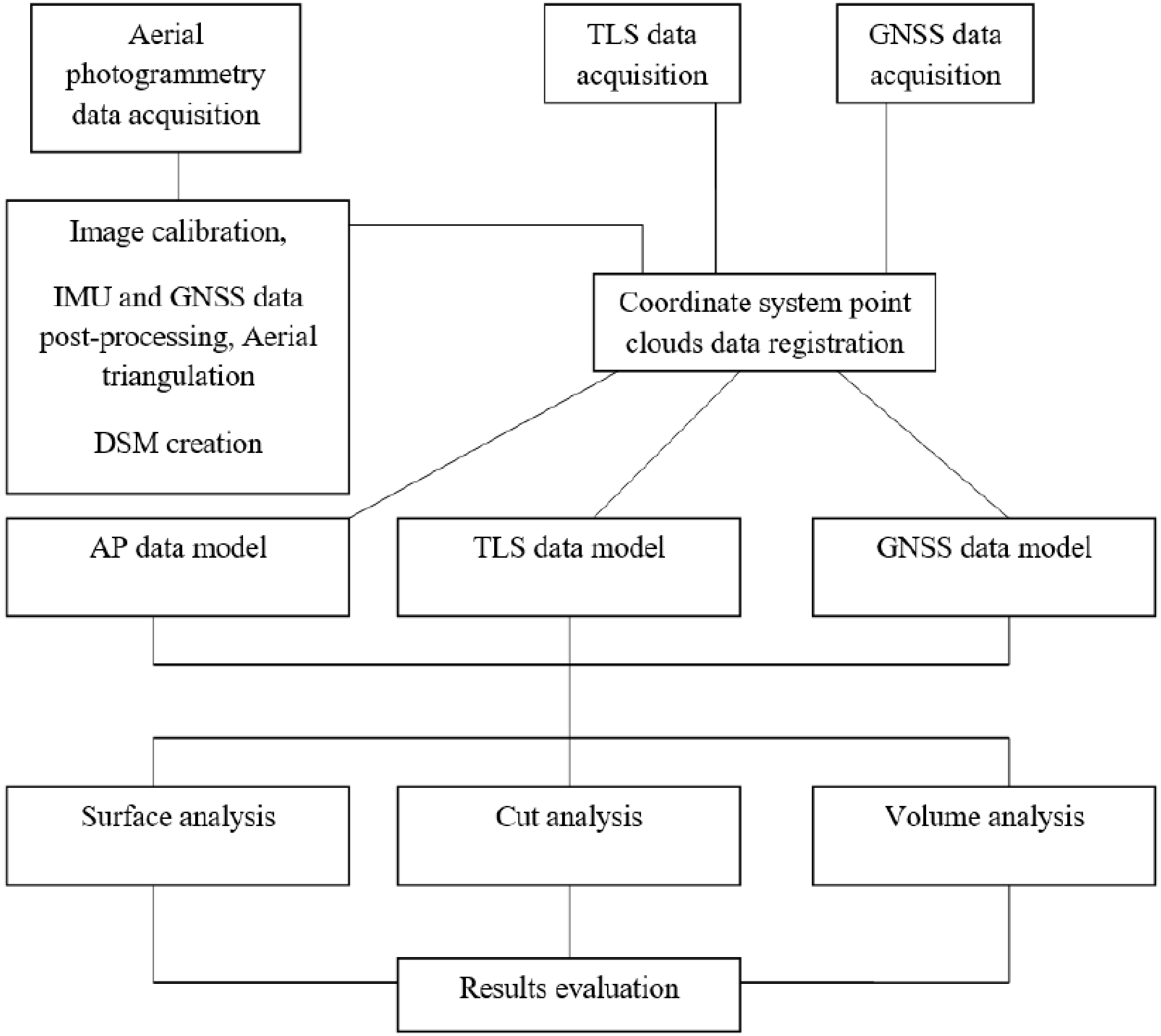
CCD camera use in the mining industry

- Aerial Photogrammetry for Dump Documentation and Volume Determination in Large Areas

(a)

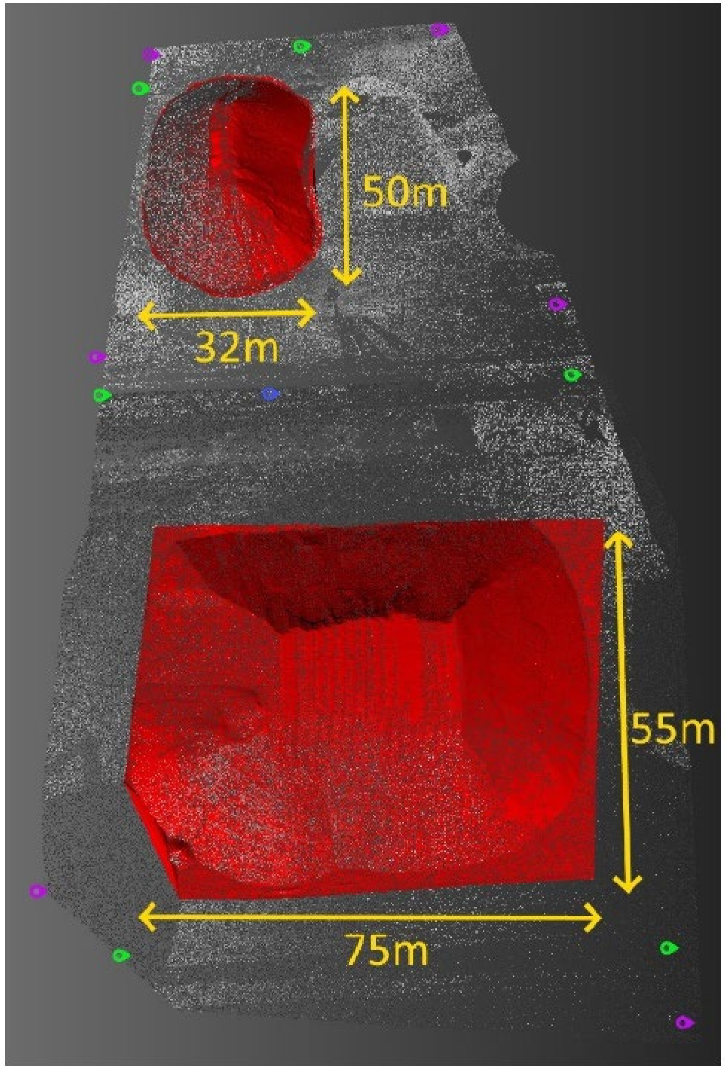
(b)

Arial equipment: (a) Camera Microsoft UltracamLP; (b) Aircraft Tecnam MMA.

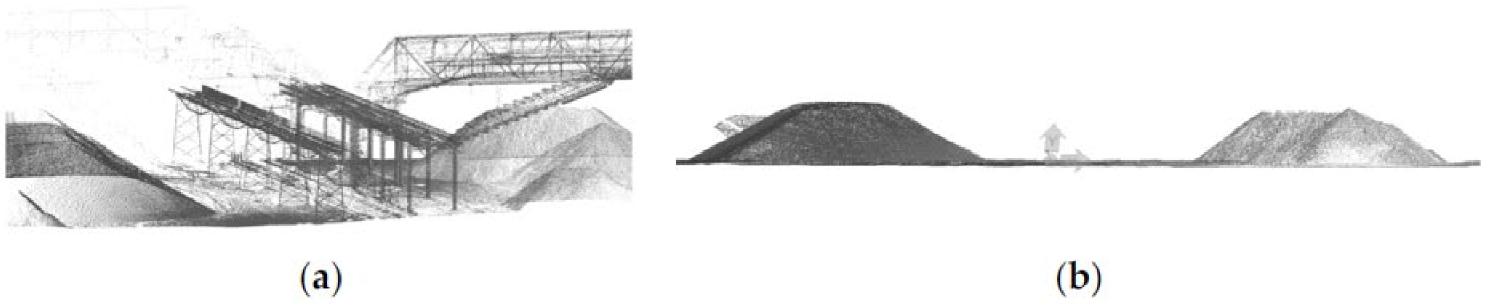


Workflow diagram

JAN 2024



Dump 3D model.



(a) raw point cloud data (b) classified point cloud data

Activity Estimation of Excavation Processes for Productivity Assessment

Point clouds of excavation site before and after video recording

REFERENCES

- Altuntas, C., 2014. Pile volume measurement by range imaging camera in indoor environment. The International Archives of the Photogrammetry, Remote Sensing and Spatial Information Sciences, 40, pp.35-39., https://isprs-archives.copernicus.org/articles/XL-5/35/2014/

- Imam, M.; Baïna, K.; Tabii, Y.; Ressami, E.M.; Adlaoui, Y.; Benzakour, I.; Abdelwahed, E.h. The Future of Mine Safety: A Comprehensive Review of Anti-Collision Systems Based on Computer Vision in Underground Mines. Sensors 2023, 23, 4294. https://doi.org/10.3390/s23094294

REFERENCES

- Sun, E., & Zhang, X. (2011, December). 3D Assisted driving system for haul trucks in surface mining. In Proceedings 2011 International Conference on Transportation, Mechanical, and Electrical Engineering (TMEE) (pp. 363-366). IEEE. https://doi.org/10.1109/TMEE.2011.6199218
- https://www.axis.com/files/whitepaper/wp_ccd_cmos_40722_en_1010_lo.pdf
- https://en.wikipedia.org/wiki/Charge-coupled_device#:~:text=A%20charge%2Dcoupled%20device%20(CCD,technology%20used%20in%20digital%20imaging.

CONCLUSION

- Provided an overview of image sensor technology.
- Explored Charge-Coupled Device (CCD) technology as a type of image sensor.
- Introduced Complementary Metal-Oxide-Semiconductor (CMOS) technology as another type of image sensor.
- Discussed the key distinctions between CCD and CMOS technologies.
- Examined the methods employed for data collection using image sensors.
- Explored the application of CCD cameras in mining operations.
- Provided specific instances and use cases of CCD cameras within the mining industry.


THANK YOU

MINE AUTOMATION AND DATA ANALYTICS

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SWAYAM NPTEL COURSE ON

MINE AUTOMATION AND DATA ANALYTICS

By

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Module 05

Satellite system in mining application

Lecture 11 A

GNSS in Mining

CONCEPTS COVERED

- Introduction to GNSS
- Primary uses of GNSS
- Basics of GNSS Trilateration
- GNSS Components
- GNSS signals
- Reference systems

CONCEPTS COVERED

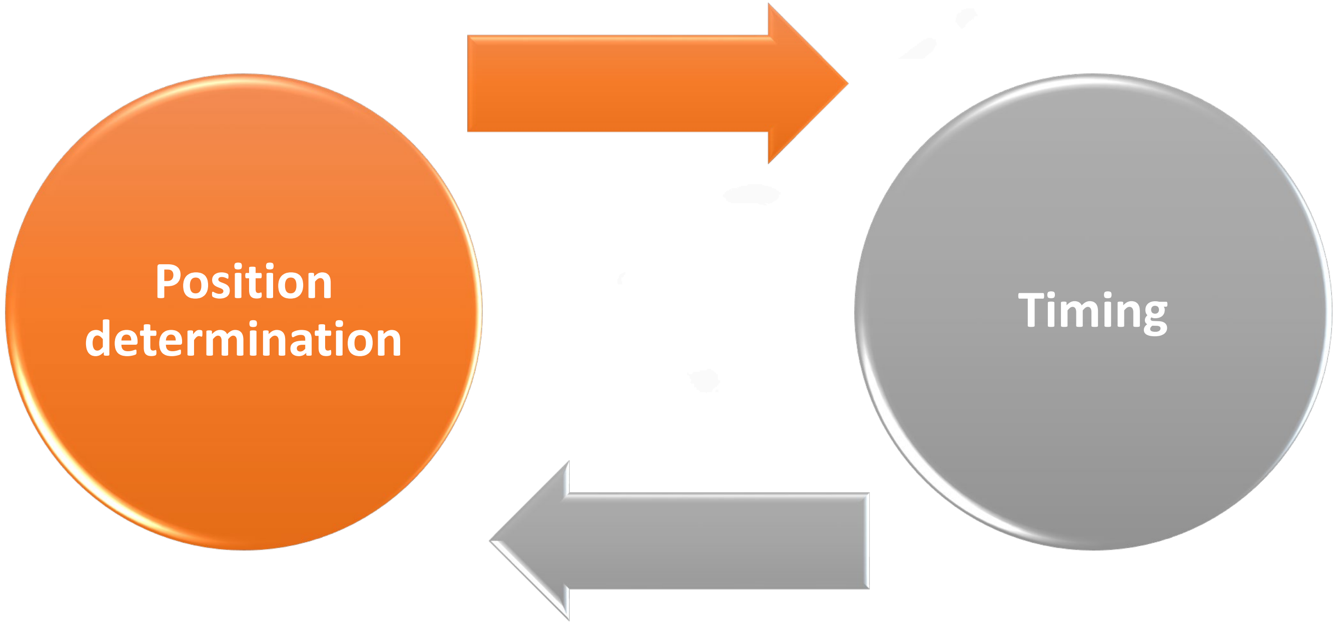
- Observation techniques
- GNSS positioning techniques
- Concept of GNSS
- Current and Developing status of GNSSs
- GNSS Applications

Global Navigation Satellite System (GNSS)

- GNSS stands for global navigation satellite system. A Global Navigation Satellite System (GNSS) consists of a constellation of satellites orbiting the Earth in very specific trajectories. For global coverage, it is estimated that a constellation requires 18 to 30 satellites.
- Navigation satellites provide orbit information and accurate timing (and other services) to radio receivers specifically designed to receive those satellite signals and decode the signal message contents. With the contents of the messages from at least four “visible” satellites, the position on or near most of the Earth’s surface can be calculated using a mathematical process known as trilateration.

Primary uses of GNSS

There are two primary uses for GNSS



Primary uses of GNSS

Position determination

Position of an object is its latitude (distance from the equator), longitude (distance from the Greenwich meridian in the UK) and elevation above (or below) mean sea level. This is known as "absolute position". The absolute position of a GNSS receiver can be determined when the signal from four (or more) GNSS satellites can be clearly received at the same time.

Primary uses of GNSS

Timing

- The signals, sent over radio waves, from GNSS satellites have extremely accurate time stamps (and other information) encoded into them. This is enabled by the use of incredibly accurate (and very high cost) atomic clocks on board each satellite.
- Once the GNSS receiver has determined its position, the GNSS receiver synchronizes its internal (much less accurate) clock with the satellite clocks. By maintaining that synchronization, the GNSS receiver clock is then considered to have a very accurate timing source.

Basics of GNSS Trilateration

- The signal from a single satellite provides a general location of a point around the perimeter of a circular area that covers approximately 35% of the Earth's surface.

- When a second satellite can be seen, the coverage of that satellite will overlap part of the first satellite coverage. This means that the GNSS receiver is at one of the two points of intersection of the perimeters of the coverage areas.

Basics of GNSS Trilateration

Basics of GNSS Trilateration

- When a third satellite can be seen, the point of intersection of all three coverage area perimeters will be the location of the GNSS receiver. That is, an accurate two-dimensional (longitude – X and latitude – Y coordinates) position of the GNSS receiver on the Earth's surface.

- When a fourth satellite can be seen, elevation or altitude can be determined with trigonometry using the X-Y coordinate

GNSS Components

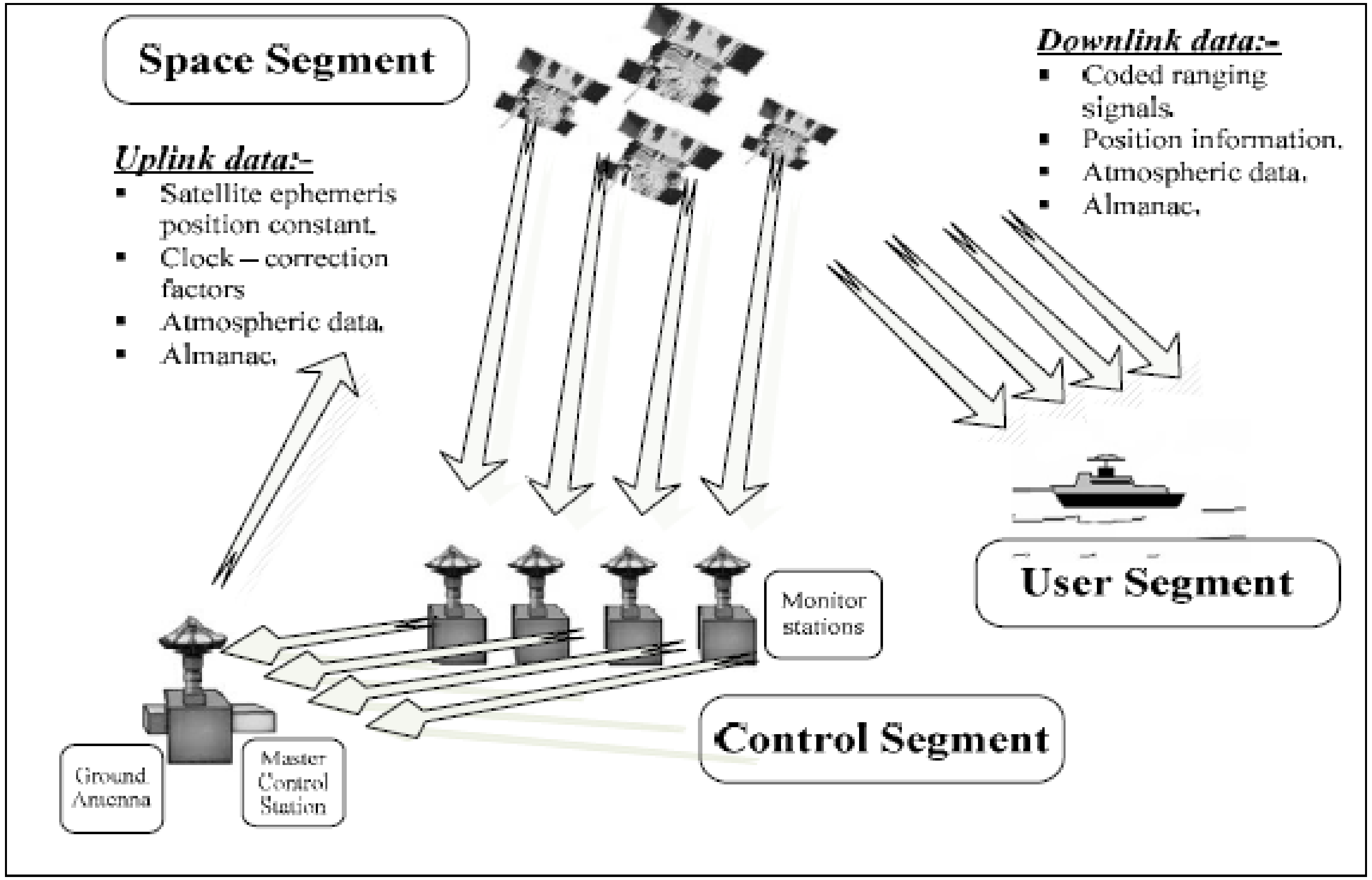
The GNSS consists of three main satellite technologies: GPS, Glonass, and Galileo. Each of the consists mainly of three segments: (a) space segment, (b) control segment, and (c) user segment. These segments are almost similar in the three satellite technologies, which are all together make up the GNSS.

space segment

control segment

user segment

Global Positioning System



GPS segments

Global Positioning System

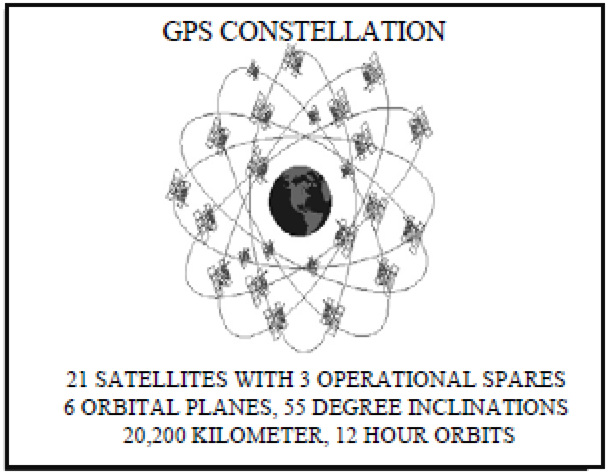
The United States Department of Defence (DoD) has developed the Navstar GPS, which is an all-weather, space-based navigation system to meet the needs of the USA military forces and accurately determine their position, velocity, and time in a common reference system, anywhere on or near the Earth on a continuous basis

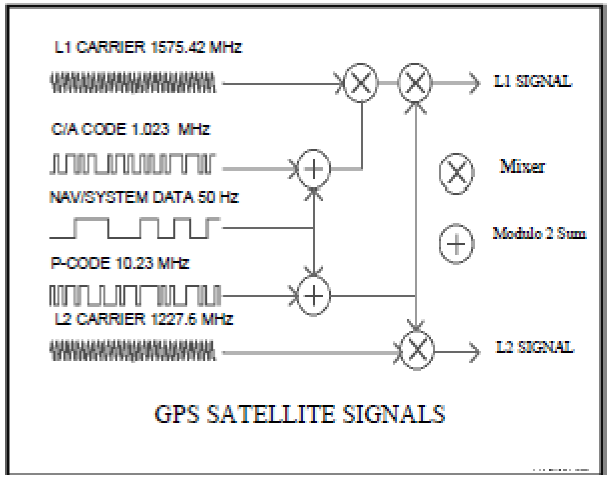
Global Positioning System

GPS comprises three main components

Space segment

- **The Space Segment of the system consists of the GPS satellites.**
- **These space vehicles (SVs) send radio signals from space as shown in the figure below.**





GPS Constellation and GPS Satellite Signals

Global Positioning System

Control segment

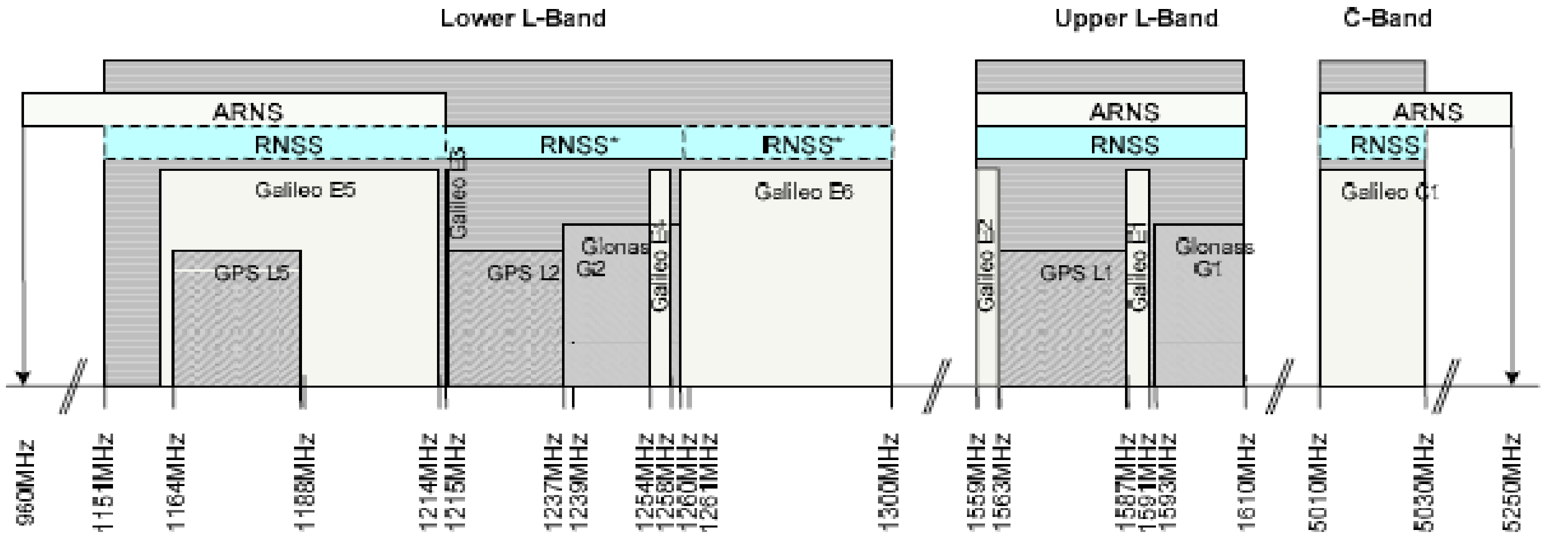
- The Control Segment consists of a system of tracking stations located around the world.
- The Master Control facility is located at Schriever Air Force Base (formerly Falcon AFB) in the State of Colorado, USA.

User segment

- The GPS User Segment consists of the GPS receivers and the user community. GPS receivers convert space vehicle (SV) signals into position, velocity, and time estimates.

GNSS SIGNALS

Each satellite system has specific signal characteristics, but each system attempts to be compatible with the others in order to prevent the interferences and attenuation between the signals. It is important to consider that the processing of all signals should be performed using the same receiver, thus a complex receiver design is supposed to be designed and built.



Reference Systems

Coordinate system

The definition of reference coordinate system is crucial for the description of satellite motion.

In satellite geodesy, two reference systems are required

(a) Space-fixed, inertial reference system for the description of satellite motion, and

(b) Earth-fixed, terrestrial reference system for the positions of the observation stations

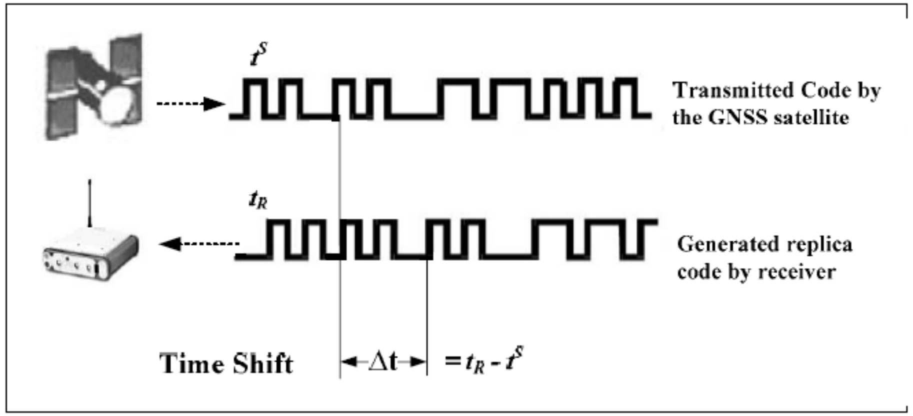
Reference Systems

Coordinate system

The position of the receiver is calculated with respect to the instant position of the satellite. By considering the range vector relation between satellite and receiver, the coordinate of the satellite and receiver should be expressed in the same coordinate system.

Observation Techniques

The basic concept of GNSS is to measure the signal traveling time between an artificial satellite and a receiver. By multiplying this time by the light velocity (c), we get the range between the satellite and the receiver.



$$Range = c.(t_R - t^S) = \Delta t_R^S \cdot c$$

Observation Techniques

The time or phase measurement performed by the receiver is based on the comparison between the received signal at the antenna of the receiver and the generated reference signal by the receiver. The two signals are affected by the clock's errors. Therefore, the range measured is not true and it is called pseudorange. Since the signal travels through the atmospheric layers, further noise should be modelled in order to compute the precise range.

GNSS observable errors

The code and phase measurements are affected by noise and errors due to the propagation of signals through atmospheric layers and due to the noise measurements.

- Satellite clock error
- Orbital error
- Ionospheric error
- The troposphere
- Receiver clock error
- Multipath

GNSS Positioning Techniques

There are two main types of positioning techniques in GNSS measurements are single point positioning and differential positioning.

Single Point Positioning

The basic concept of point position depends on the trilateration between the receiver and satellite. Range measurements from 4 satellites are needed to determine the four unknown X, Y, Z, and receiver clock offsets ($\Delta\delta$).

GNSS Positioning Techniques

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Single Point Positioning

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GNSS Positioning Techniques

The analytical solution for receiver A and 4 satellites could be written as below.

$$R_A^1(t) = \sqrt{\left(X^1(t) - X_A\right)^2 + \left(Y^1(t) - Y_A\right)^2 + \left(Z^1(t) - Z_A\right)^2} + c \cdot \Delta\delta$$

$$R_A^2(t) = \sqrt{\left(X^2(t) - X_A\right)^2 + \left(Y^2(t) - Y_A\right)^2 + \left(Z^2(t) - Z_A\right)^2} + c \cdot \Delta\delta$$

$$R_A^2(t) = \sqrt{\left(X^3(t) - X_A\right)^2 + \left(Y^3(t) - Y_A\right)^2 + \left(Z^3(t) - Z_A\right)^2} + c \cdot \Delta\delta$$

$$R_A^4(t) = \sqrt{\left(X^4(t) - X_A\right)^4 + \left(Y^4(t) - Y_A\right)^2 + \left(Z^4(t) - Z_A\right)^2} + c \cdot \Delta\delta$$

GNSS Positioning Techniques

Observable difference

By considering all the systematic and random errors on the observation, we can write the math model for observable differences in code and phase measurements, respectively, as below.

$$R_A^1(t_0) = \rho_A^1(t_0) + \Delta\rho_A^1(t_0) + c\delta^1(t_0) - c\delta_A(t_0) + I_A + T_A + \varepsilon$$

$$\lambda\phi_A^1(t_0) = \rho_A^1(t_0) + \Delta\rho_A^1(t_0) + \lambda N_A^1 + c\delta^1(t_0) - c\delta_A(t_0) - I_A + T_A + \varepsilon$$

Where Δp_R^S is the orbital error, I is the ionosphere error, T is the troposphere error and ε is the other types of noise and errors such as the ones due to multipath.

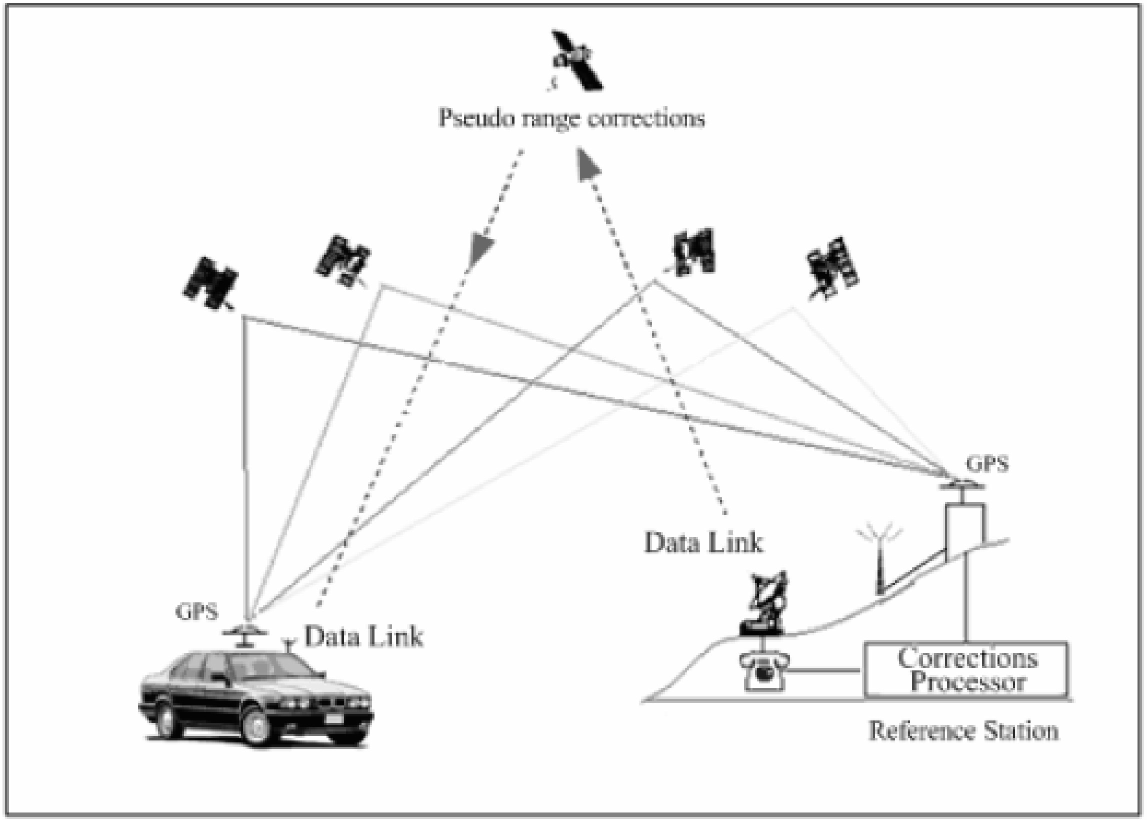
GNSS Positioning Techniques

Differential position

- There is an increase interest in differential positioning due to the numerous advantages of wireless communications and networks. Most of the errors that affect GNSS are common between the receivers, which observe the same set of satellites. Thus, by making differential measurements between two or more receivers, most of these errors could be cancelled.
- The basic concept of differential position is the calculation of position correction or range correction at the reference receiver and then sending this correction to the other receiver via a radio link. This way most of the errors are cancelled.

GNSS Positioning Techniques

Differential position



GNSS Positioning Techniques

Wide Area Differential GNSS (WADGNSS)

- WADGNSS is a scheme that would allow the user to perform differential positioning and obtain reliable position with high accuracy in real time over a sizeable region. WADGNSS consists of a master control station and number of local or Global monitor stations and communication link.

- The monitor stations gather the data from the GNSS satellite, and then send them to the master control station. The master control estimates the ionosphere parameter, troposphere parameters, satellite ephemeredes, and clock errors. All these corrections are transmitted to the user via the Internet, wireless communications, or satellite communications.

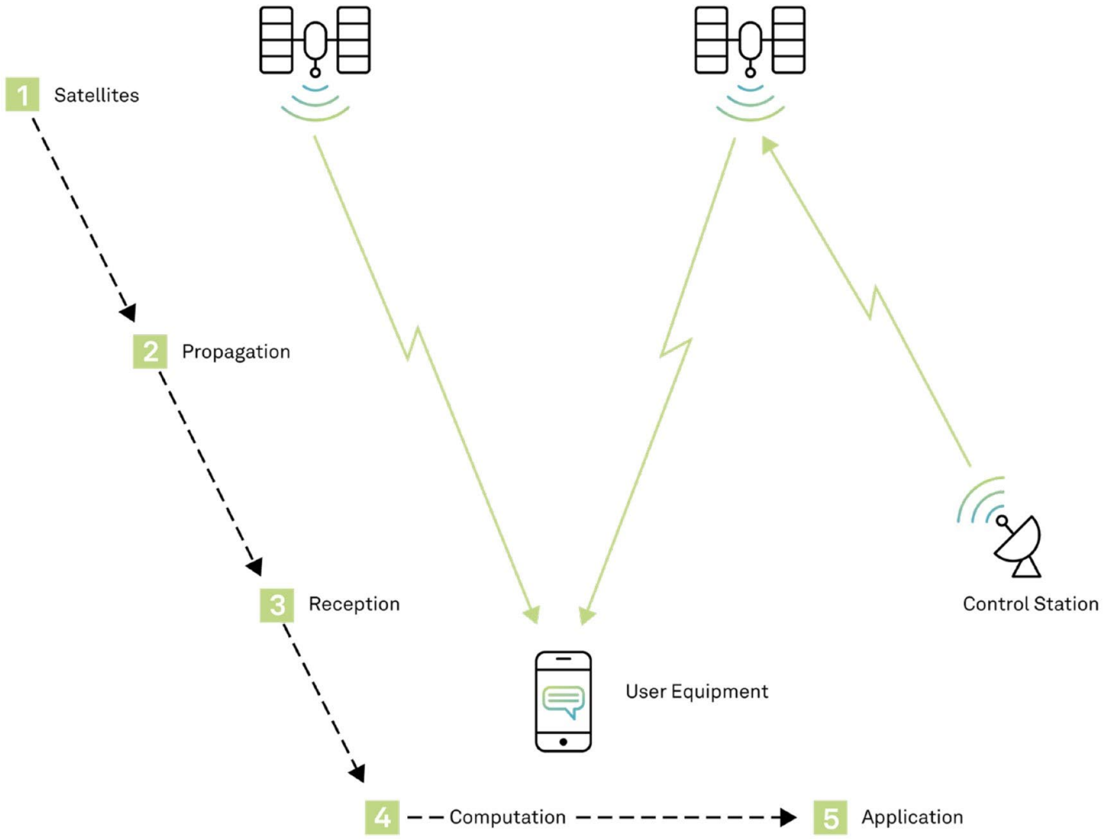
GNSS Positioning Techniques

Wide Area Augmentation System (WAAS)

- Wide Area Augmentation System (WAAS) is a new augmentation to the United States Department of Defense's (DoD) Global Positioning System (GPS) that is designed to enhance the integrity and accuracy of the basic GPS capability

- The WAAS uses geostationary satellites to receive data measured from many ground stations, and it sends information to GPS users for position correction. Since WAAS satellites are of the geostationary type, the Doppler frequency caused by their motion is very small. Thus, the signal transmitted by the WAAS can be used to calibrate the sampling frequency in a GPS receiver. The WAAS signal frequency is at 1575.42 MHz. The WAAS services will be available on both L1 and L5.

GNSS concepts



STEP 1 — SATELLITES

GNSS satellites orbit the Earth. The satellites know their orbit ephemerides (the parameters that define their orbit) and the time very accurately. Ground-based control stations adjust the satellites’ ephemerides and time, when necessary.

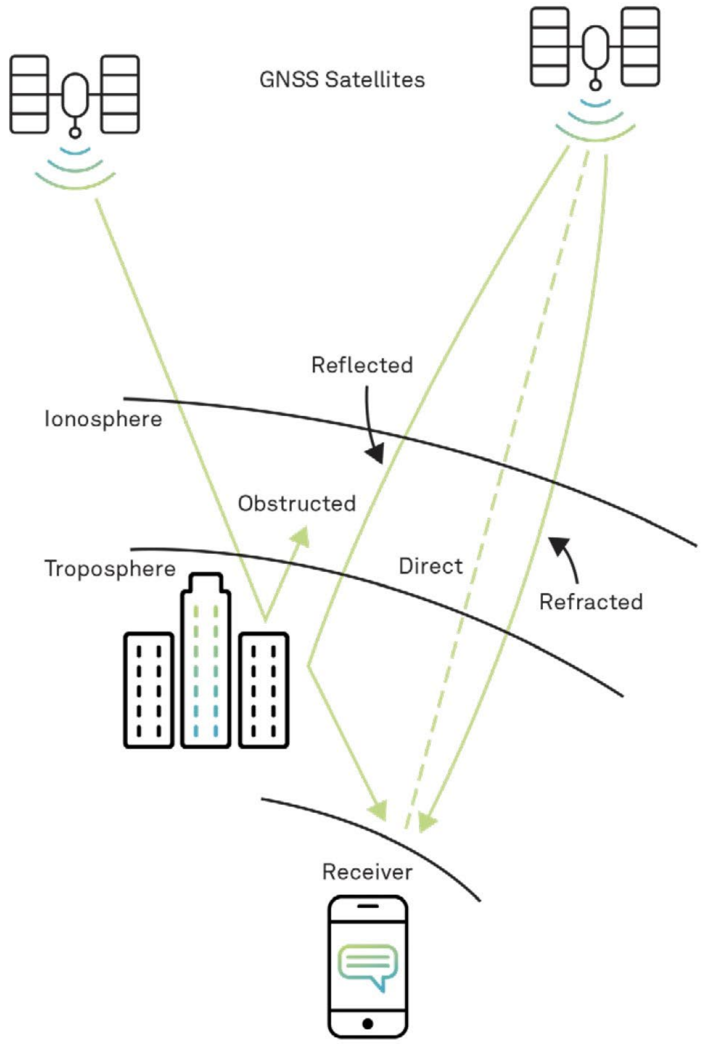
GPS satellite

Satellite orbits

- GNSS satellites orbit well above the Earth's atmosphere. GPS and GLONASS satellites orbit at altitudes close to 20,000 km (12,500 miles). BeiDou and Galileo satellites orbit higher, around 21,500 to 36,000 km (13,400 to 22,400 miles) for BeiDou and 23,000 km (14,300 miles) for Galileo. GNSS orbits are more or less circular, highly stable, and predictable.

STEP 2 — PROPAGATION:

- GNSS satellites regularly broadcast their ephemerides and time, as well as their status. GNSS radio signals pass through layers of the atmosphere to the user equipment.

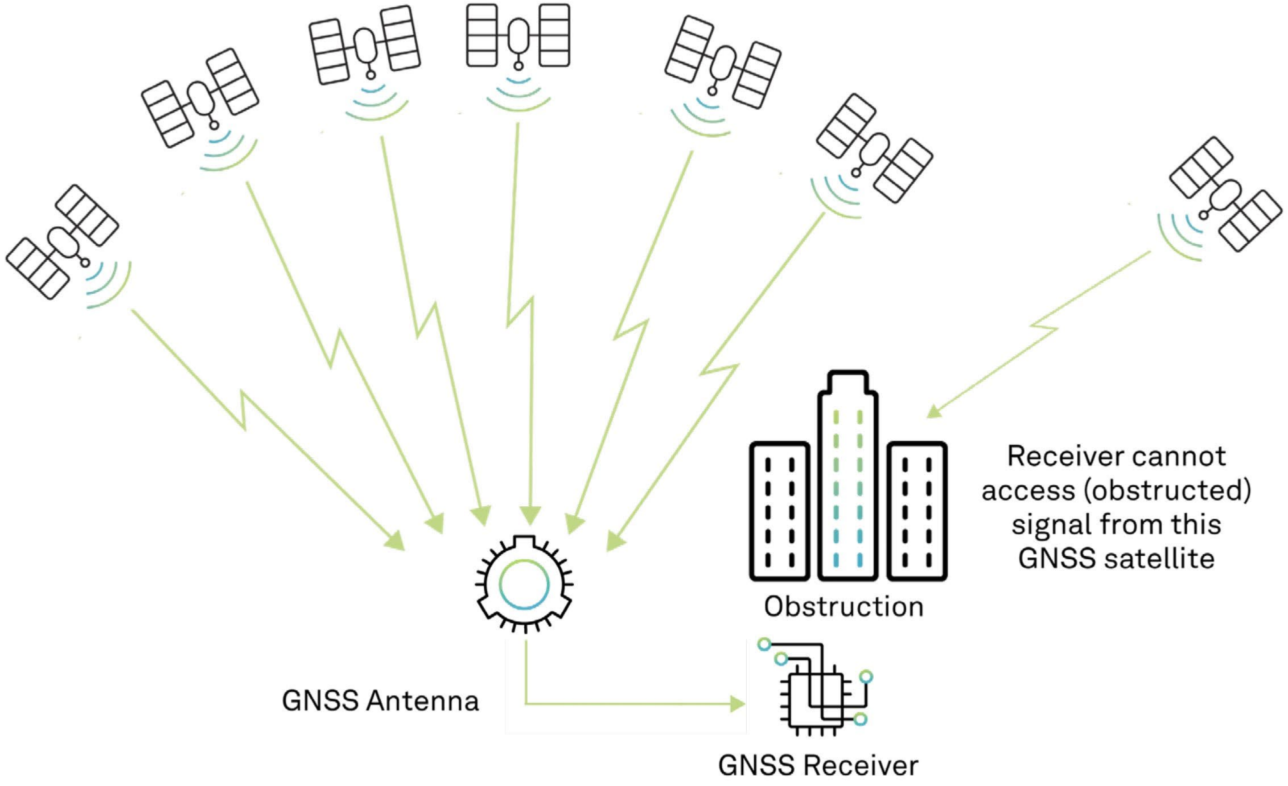


STEP 3 — RECEPTION:

- GNSS user equipment receives the signals from multiple GNSS satellites and, for each satellite, recovers the information that was transmitted and determines the time of propagation (the time it takes the signals to travel from the satellite to the receiver).

- To determine a position and time, GNSS receivers need to track at least four satellites from one of the GNSS constellations. This means there needs to be a line of sight between the receiver's antenna and the four satellites.

STEP 3 — RECEPTION



GNSS reception

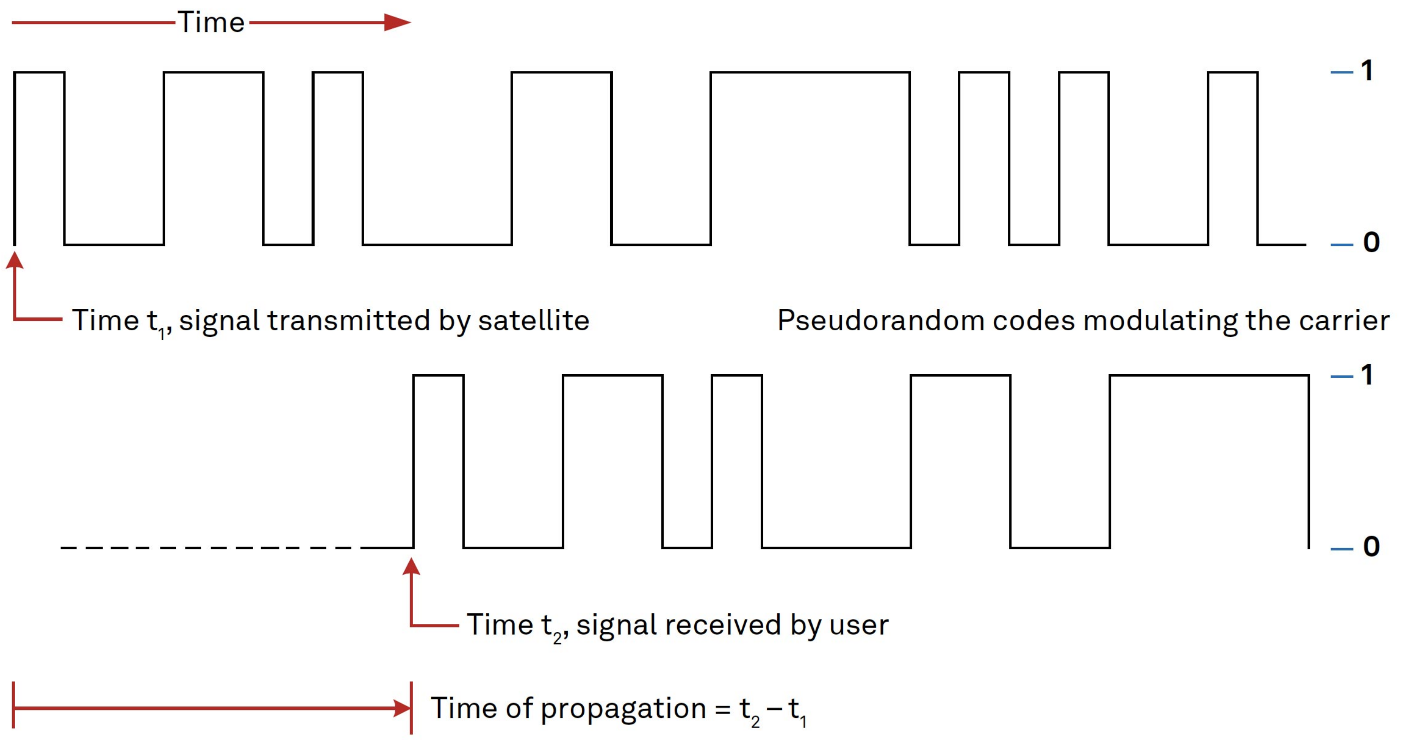


Figure illustrates the transmission of a pseudorandom code, a series of zeroes and ones. Since the receiver knows the pseudorandom code for each satellite, it can determine the time it received the code from a particular satellite. By comparing the time the signal was received with the transmission time stored in the satellite message, the receiver can determine the time of propagation.

STEP 4 — COMPUTATION

GNSS equipment uses the recovered information to compute time and position.

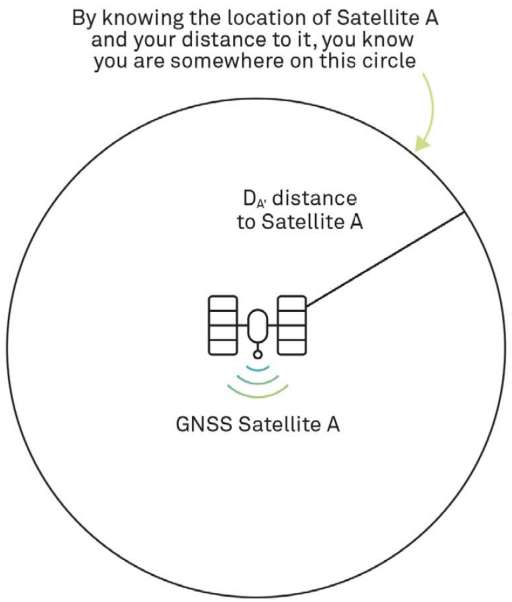
- If we knew the exact position of three satellites and the exact range to each of them, we would geometrically be able to determine our location. We have suggested that we need ranges to four satellites to determine position.

- **For each satellite being tracked, the receiver calculates how long the satellite signal took to reach it, as follows:**

Propagation Time = Time Signal Reached Receiver – Time Signal Left Satellite

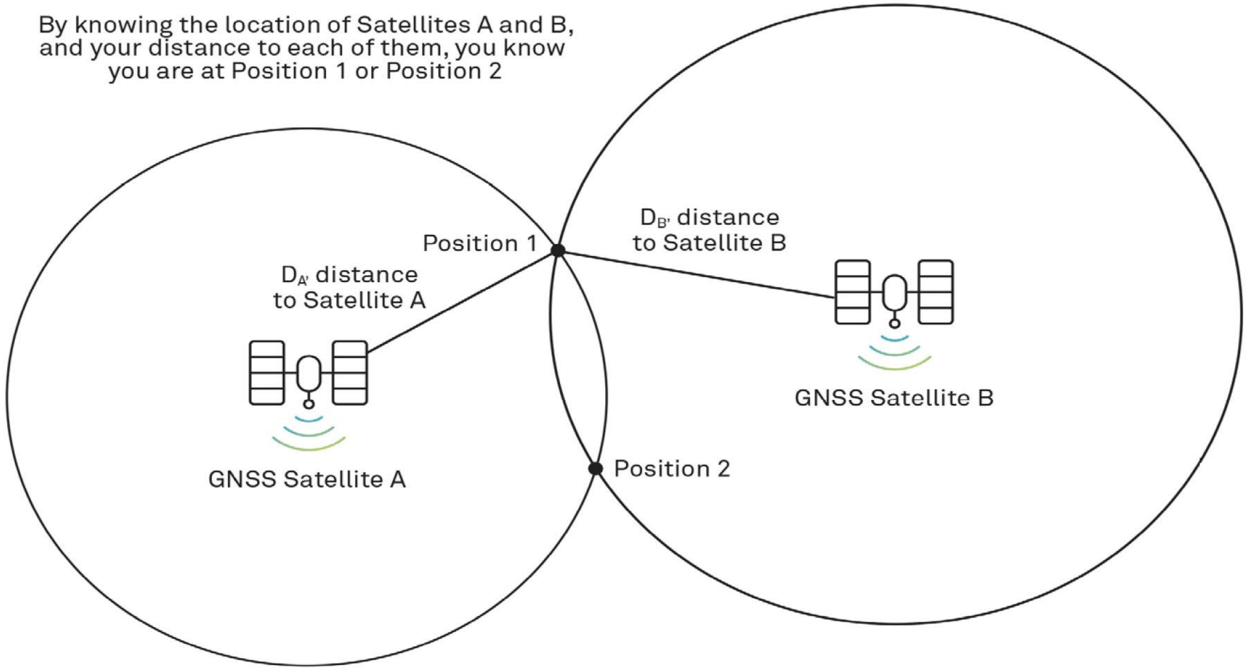
- Multiplying this propagation time by the speed of light gives the distance to the satellite.

- By determining the amount of time it took for the signal from Satellite A to arrive at the receiver and multiplying this time by the speed of light.
- Satellite A communicated its location (determined from the satellite orbit ephemerides and time) to the receiver, so the receiver knows it is somewhere on a circle with a radius equal to the range and centered at the location of Satellite A, as illustrated in Figure.



Ranging to first satellite

- The receiver also determines its range to a second satellite, Satellite B. Now the receiver knows it is at the intersection of two circles, at either Position 1 or 2, as shown in Figure.



Ranging to second satellite

STEP 5 — APPLICATION

- GNSS user equipment provides the computed position and time to the end-user application for use in navigation, surveying, mapping and more.

- Once the errors have been accounted for in the GNSS equation, the receiver can determine its position and time and pass this information on to the end-user application.
- The GNSS technology market is a ubiquitous, multi-billion-dollar industry.
- Applications range from simple hand-held meter-level (yard-level) navigation aids to robust, centimeter-level (inch-level) positioning solutions for survey, military and autonomous applications.

Concept of GNSS Positioning

GNSS Measurements

- **Pseudo-range:**

Measures the difference between the receiver clock at signal reception and the satellite clock at signal transmission, scaled by the speed of light. It reflects the satellite-receiver distance with precision in the range, considering clock asynchrony and other delays.

- **Doppler:**

The Doppler effect-induced change in received frequency indicates range-rate or line-of-sight velocity. This provides valuable information about the velocity component along the line of sight.

Concept of GNSS Positioning

GNSS Measurements

- **Carrier Phase:**

Measures the instantaneous beat phase and accumulated zero-crossings after mixing with a reference signal. Changes in carrier phase over time reflect (pseudo)range changes with exceptional precision, approximately two orders higher than the pseudo-range. Interrupted tracking may lead to cycle slips in measurements.

Current and Developing GNSSs

GNSSs and regional navigation satellite systems (RNSSs) commonly consist of three components:

- The space segment comprises a constellation of satellites orbiting above the Earth's surface that transmit ranging signals on at least two frequencies in the microwave part of the radio spectrum.

- The control segment is responsible for maintaining the health of the system by monitoring the broadcast signals and computing and uploading to the satellites required navigation data. It consists of a group of globally (or locally)-dispersed monitoring stations, ground antennas for communicating with the satellites, and a master control station with a backup facility at a different location.

Currently, there are six GNSSs/RNSSs in operation. The four GNSSs are: GPS (US), GLONASS (Russia), BeiDou (China), and Galileo (EU); and the two RNSSs: QZSS (Japan) and IRNSS/NavIC (India). For an overview summary, see Table.

System	GPS	GLONASS	BeiDou	Galileo	QZSS	NavIC
Owner	USA	Russia	China	European union	Japan	India
Coverage	Global	Global	Global	Global	Regional	Regional
Orbit	MEO	MEO	MEO,GSO,GEO	MEO	GSO,GEO	GSO,GEO
Nominal no.of satellites	24	24	35(27MEO,3GSO, 5GEO)	24	4(3GSO,1GEO) 7 in the future	8(5GSO,3GEO)
Precision	5m(no DGPS or WAAS)	4.5-7.4m	1m(public) 0.01m(Encrypted)	1m(public) 0.01m(Encrypted)	1m(public) 0.01m(Encrypted)	1m(public) 0.01m(Encrypted)

BEIDOU NAVIGATION SATELLITE SYSTEM (BDS)

- **BeiDou, or BDS, is a regional GNSS owned and operated by the People's Republic of China. China is currently expanding the system to provide global coverage with 35 satellites by 2020. BDS was previously called Compass.**

GALILEO

- **Galileo is a global GNSS owned and operated by the European Union. The EU declared the start of Galileo Initial Services in 2016 and plans to complete the system of 24+ satellites by 2020.**

GLONASS

It is a global GNSS owned and operated by the Russian Federation. The fully operational system consists of 24+ satellites.

Indian Regional Navigation Satellite System (IRNSS) / Navigation Indian Constellation (NAVIC)

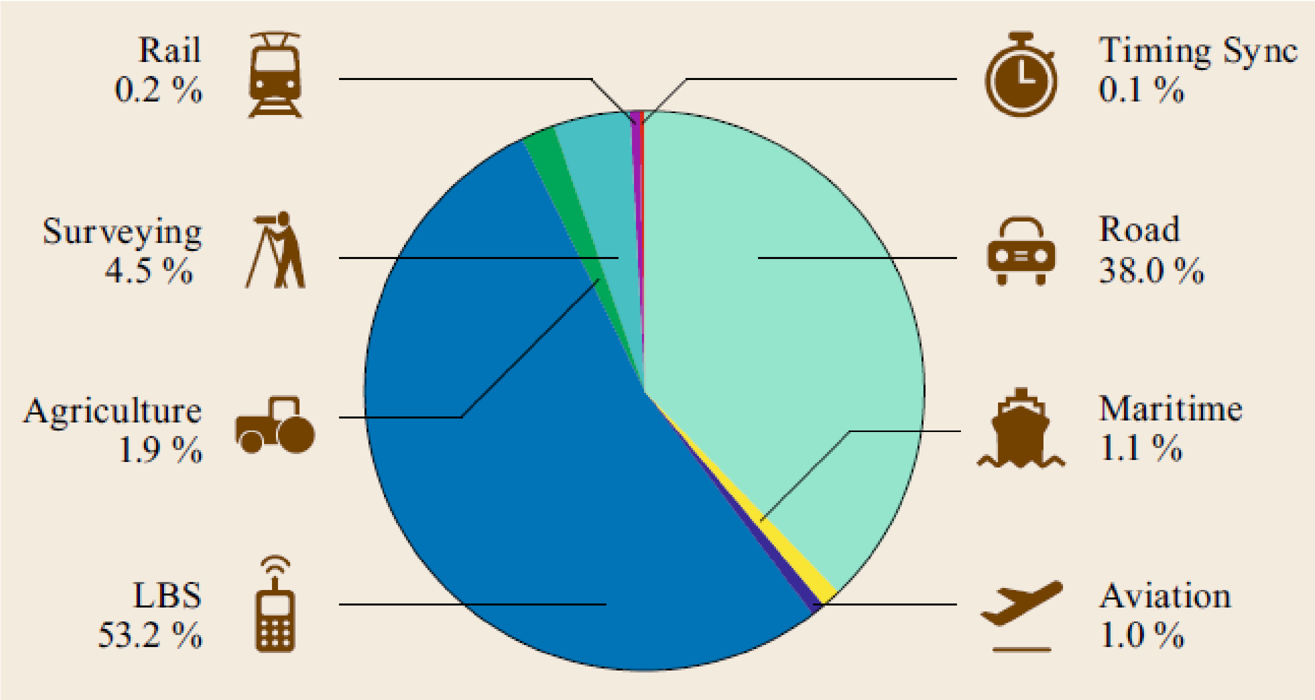
IRNSS is a regional GNSS owned and operated by the Government of India. IRNSS is an autonomous system designed to cover the Indian region and 1500 km around the Indian mainland. The system consists of 7 satellites and should be declared operational in 2018. In 2016, India renamed IRNSS as the Navigation Indian Constellation (NavIC, meaning "sailor" or "navigator").

QUASI-ZENITH SATELLITE SYSTEM (QZSS)

- **QZSS is a regional GNSS owned by the Government of Japan and operated by QZS System Service Inc. (QSS). QZSS complements GPS to improve coverage in East Asia and Oceania. Japan plans to have an operational constellation of 4 satellites by 2018 and expand it to 7 satellites for autonomous capability by 2023.**

GNSS for Science and Society at Large

GNSS is used for many types of applications, covering the mass market, professional and safety-critical applications as well as a whole range of scientific applications.



Distribution of cumulative global revenue from GNSS chipset sales projected for 2013–2023 period

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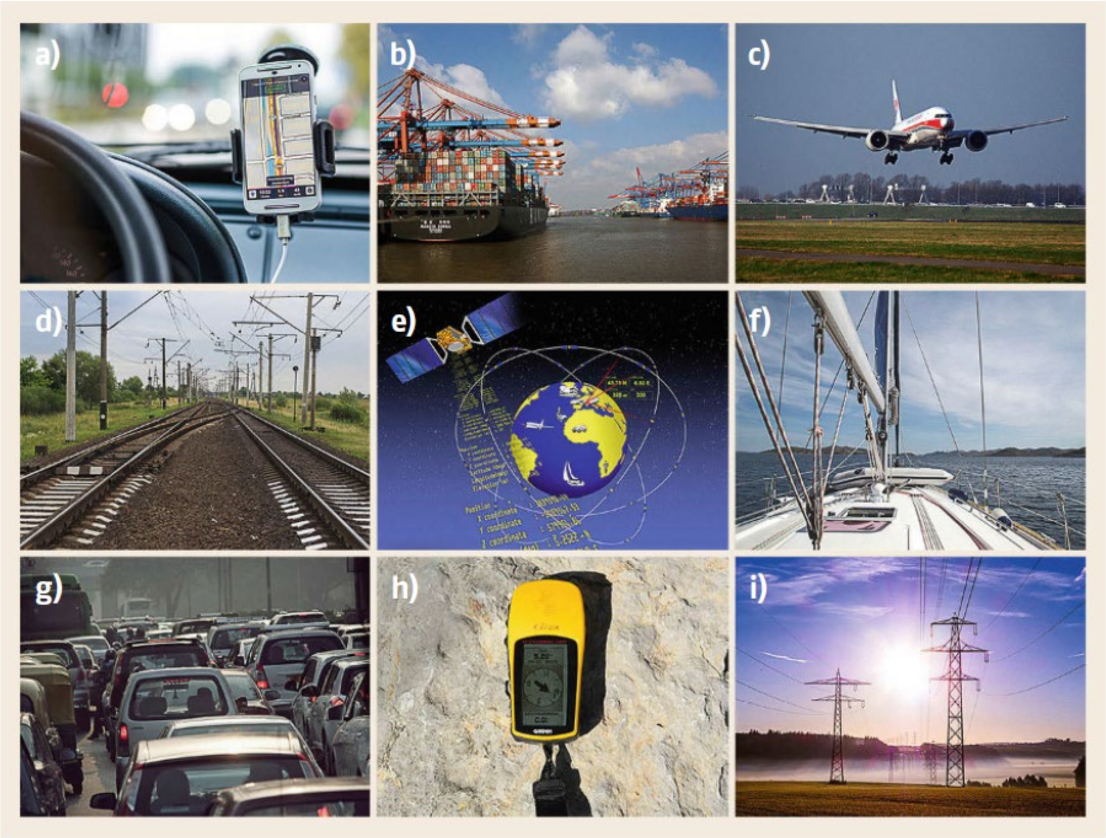


Examples of everyday GNSS applications.

REFERENCES

- https://novatel.com/an-introduction-to-gnss/basic-concepts/application
- FontShen, N.; Chen, L.; Liu, J.; Wang, L.; Tao, T.; Wu, D.; Chen, R. A Review of Global Navigation Satellite System (GNSS)-Based Dynamic Monitoring Technologies for Structural Health Monitoring. Remote Sens. 2019, 11, 1001. https://doi.org/10.3390/rs11091001
- Hofmann-Wellenhof, B.; Lichtenegger, H.;Wasle, E. GNSS–Global Navigation Satellite Systems: GPS, GLONASS, Galileo, and More; Springer Science & Business Media: Berlin/Heidelberg, Germany, 2007; pp. 161–191.

REFERENCES

- Shrestha, R. and Awasthi, E.B., A Scientific Report on “How Nepal can be benefitted from different GNSS systems available worldwide”.
- Teunissen, P.J. and Montenbruck, O. eds., 2017. Springer handbook of global navigation satellite systems (Vol. 10, pp. 978-3). Cham, Switzerland: Springer International Publishing.
- https://www.advancednavigation.com/tech-articles/global-navigation-satellite-system-gnss-and-satellite-navigation-explained/
- https://www.princeton.edu/~alaink/Orf467F07/GNSS.pdf

CONCLUSION

- Provided an introduction to Global Navigation Satellite Systems (GNSS).
- Explored the primary use of GNSS technology.
- Discussed the fundamental principle of trilateration used in GNSS for determining positions.
- Explored the key components that constitute a GNSS system.
- Explored the signals transmitted by Global Navigation Satellite Systems (GNSS) for positioning and navigation.
- Discussed the reference systems utilized in GNSS technology for accurate positioning measurements.

CONCLUSION

- Explored the methodologies and techniques employed to observe and analyze GNSS signals for navigation and positioning purposes.
- Provided an overview of the fundamental concept of GNSS technology, which enables precise positioning and navigation using satellite signals.
- Introduced the concept of determining precise positions using GNSS technology.
- Discussed existing and emerging GNSS systems.
- Explored the diverse practical applications of GNSS technology across various industries.


THANK YOU

MINE AUTOMATION AND DATA ANALYTICS

MINE AUTOMATION AND DATA ANALYTICS

SWAYAM NPTEL COURSE ON

MINE AUTOMATION AND DATA ANALYTICS

By

Prof. Radhakanta Koner

Department of Mining Engineering

Indian Institute of Technology (Indian School of Mines) Dhanbad

Module 05:
Image Processing

Lecture 12B:
Basics of Digital Image Processing

CONCEPTS COVERED

- What is a digital image?
- What is digital image processing?
- State-of-the-art examples of digital image processing
- Image acquisition
- What is sampling?
- What is spatial resolution?
- What is quantization?
- What is grey-level resolution?
- Contrast enhancement
- Histogram processing

Image – Digital Image

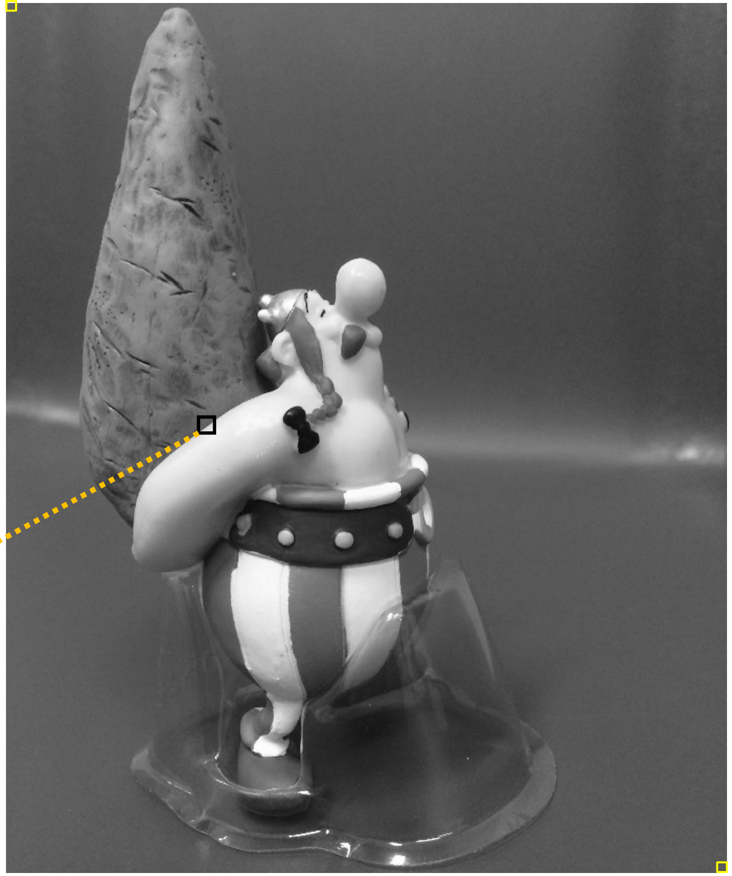
An image is a two-dimensional function f(x,y), where x and y are the spatial (plane) coordinates, and the amplitude of f at any pair of coordinates (x,y) is called the intensity of the image at that level.

If x,y and the amplitude values of f are finite and discrete quantities, we call the image a digital image. A digital image is composed of a finite number of elements called pixels, each of which has a particular location and value.

Consider the following image (2724x2336 pixels) to be 2D function or a matrix with rows and columns

Pixel intensity value

$\underbrace{f(1,1)}_{\text{Pixel location}} = 103$



$f(2724,2336) = 88$

rows columns

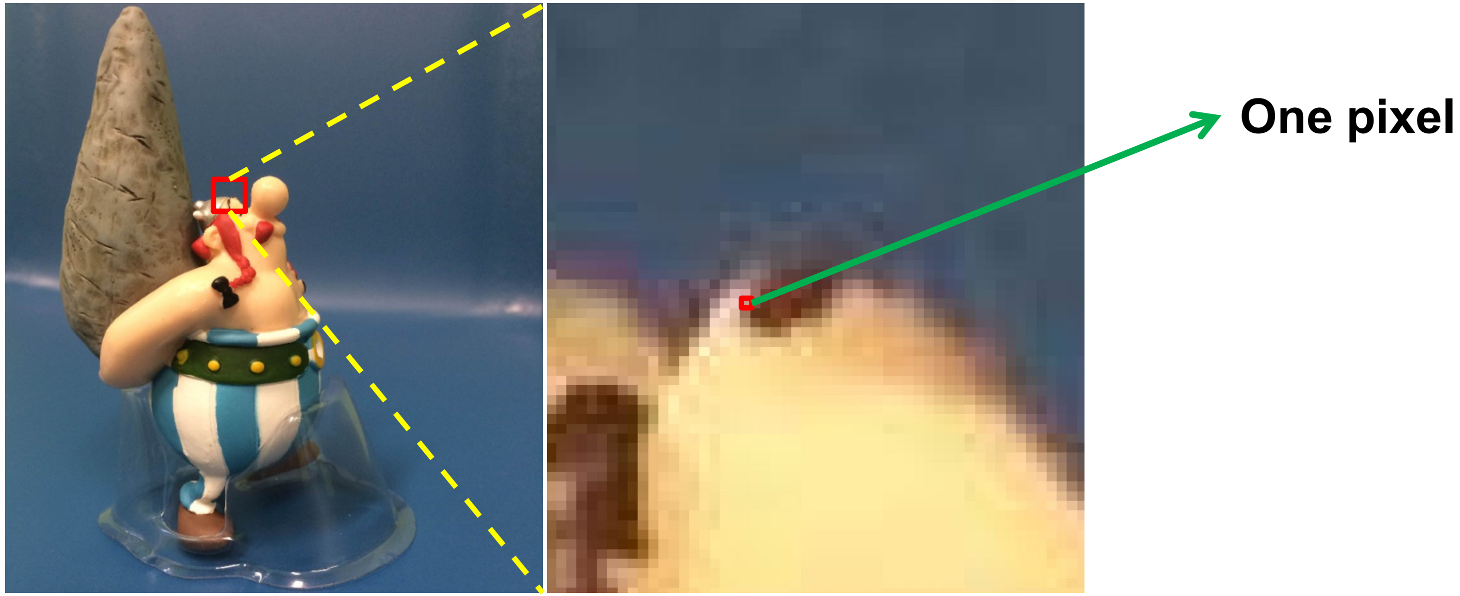
83	82	82	82	82	82
82	82	82	81	81	81
82	82	81	81	80	80
82	82	81	80	80	79
80	79	78	77	77	77
80	79	78	78	77	77

In 8-bit representation

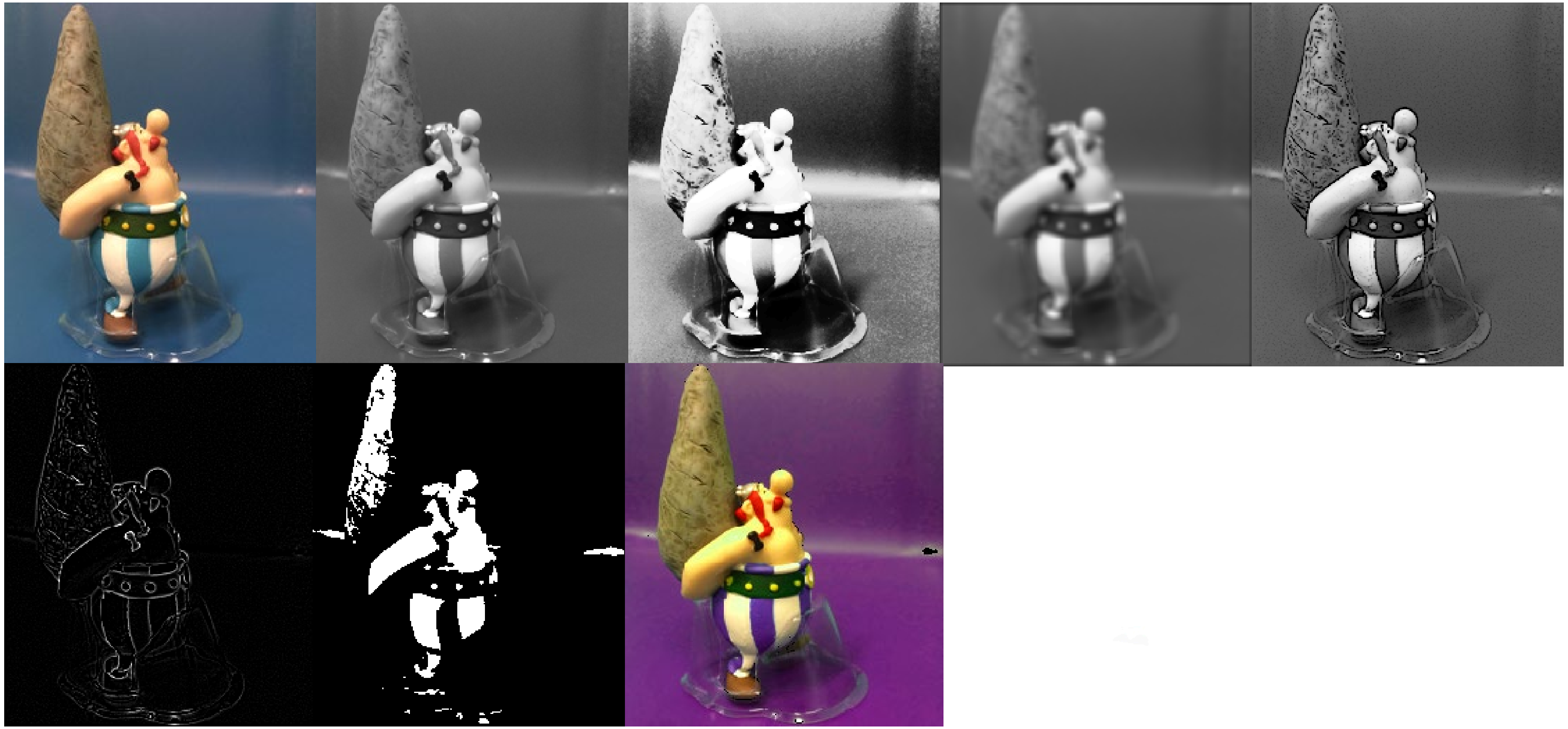
Pixel intensity values change between 0 (Black) and 255 (White)

Digital Image

Remember *digitization* implies that a digital image is an *approximation* of a real scene

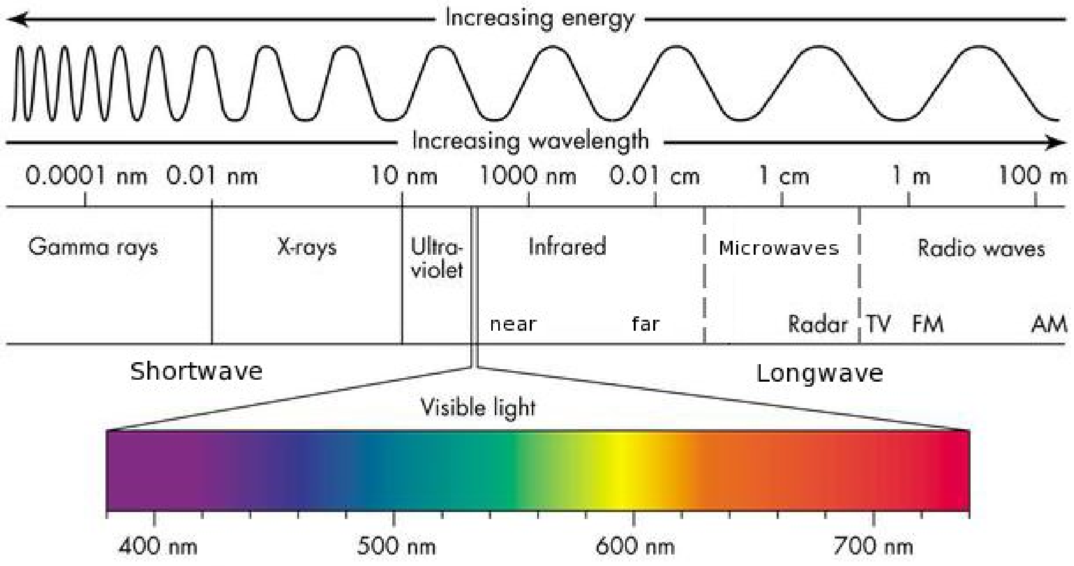


Digital Image Processing

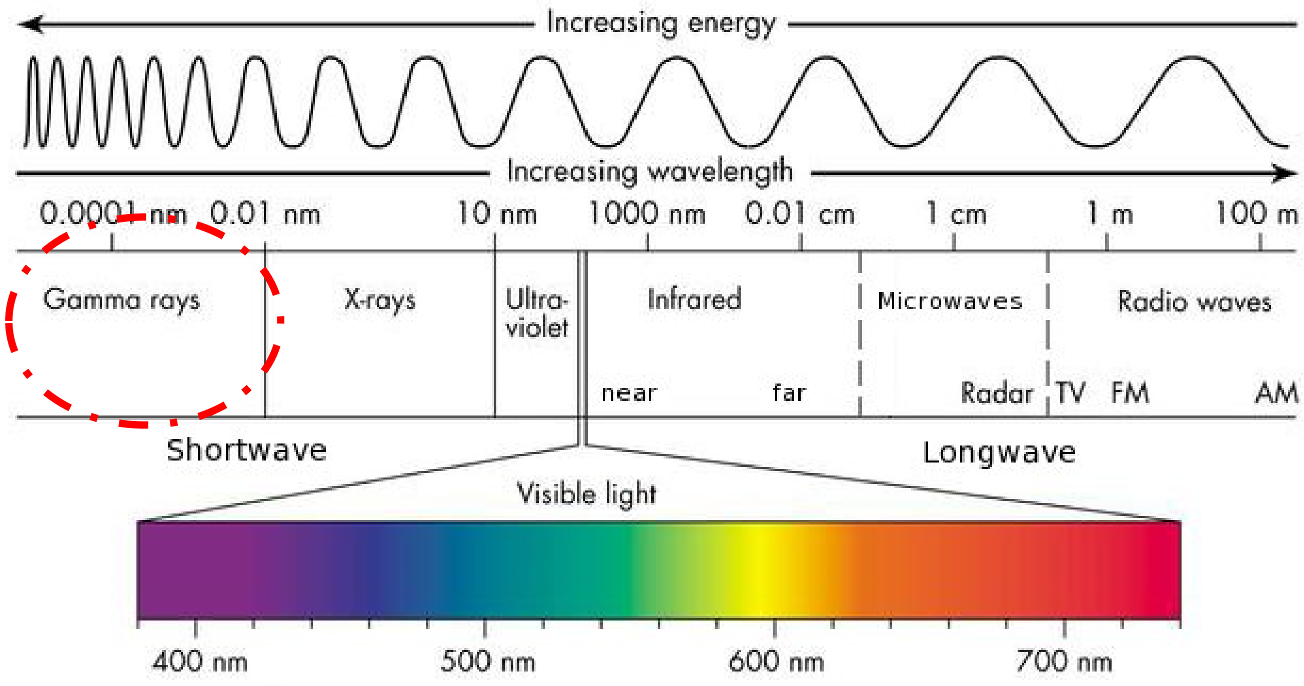


Sources of Digital Images

The principal source for the images is the electromagnetic (EM) energy spectrum.



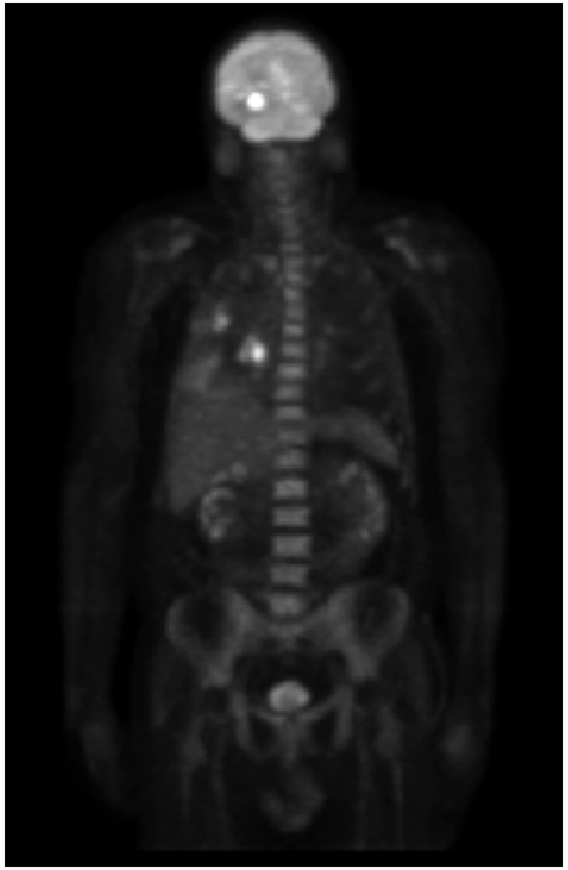
Gamma Rays



JAN 2024

Gamma Rays

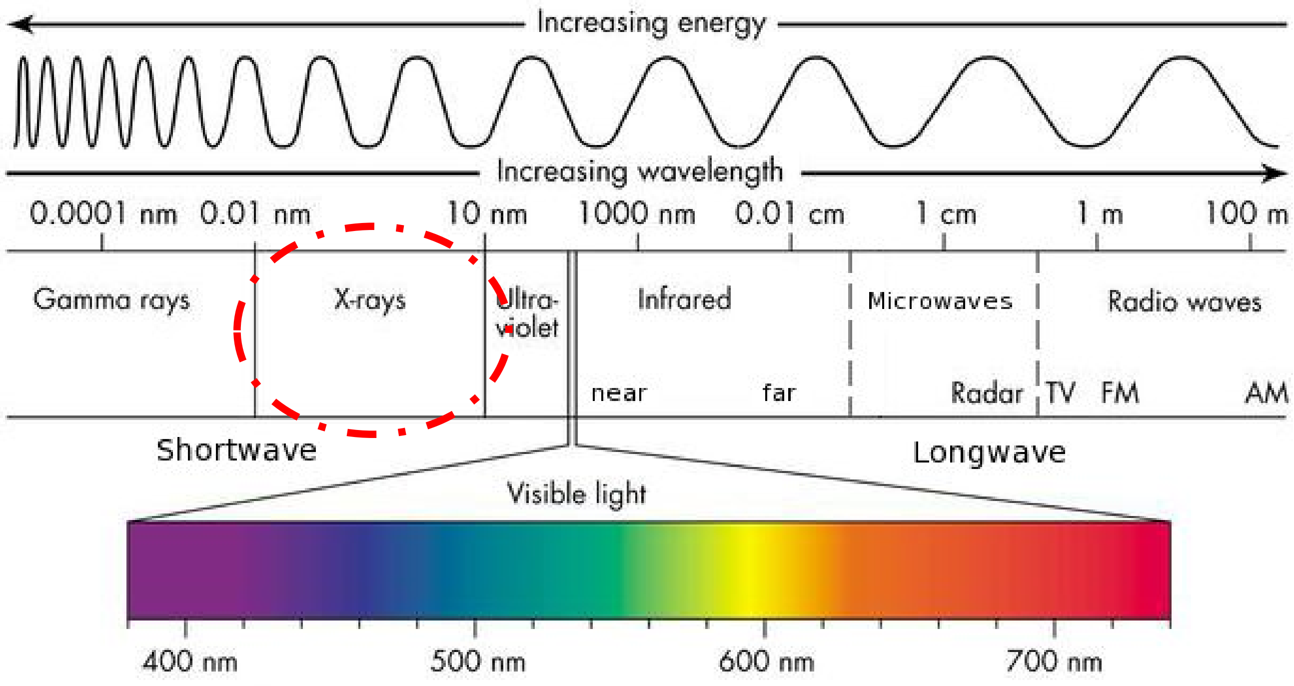
Gamma-Ray Imaging Cherenkov Telescope



Gamma-Ray Imaging İn nuclear medicine

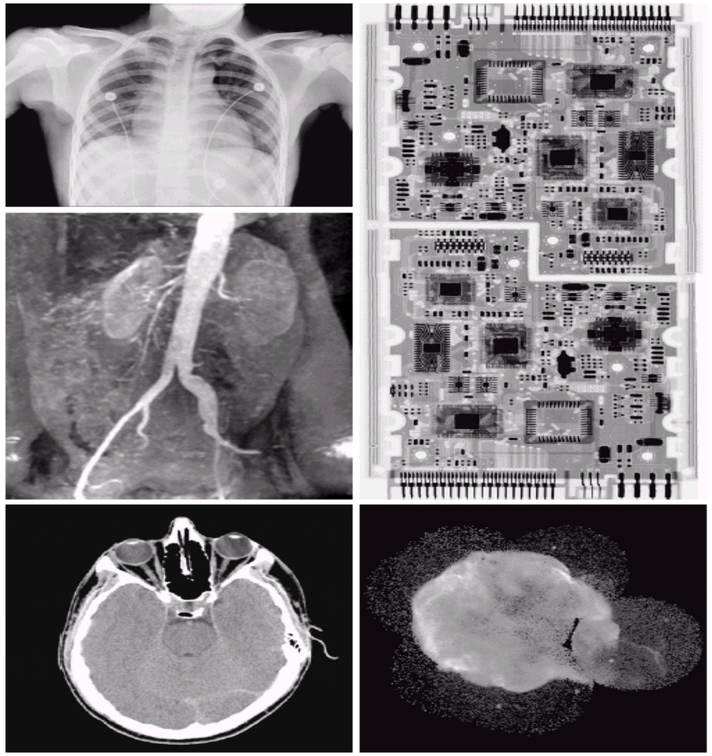
Gamma-Ray imaging of A starburst galaxy about 12 million light-years away

X-Rays

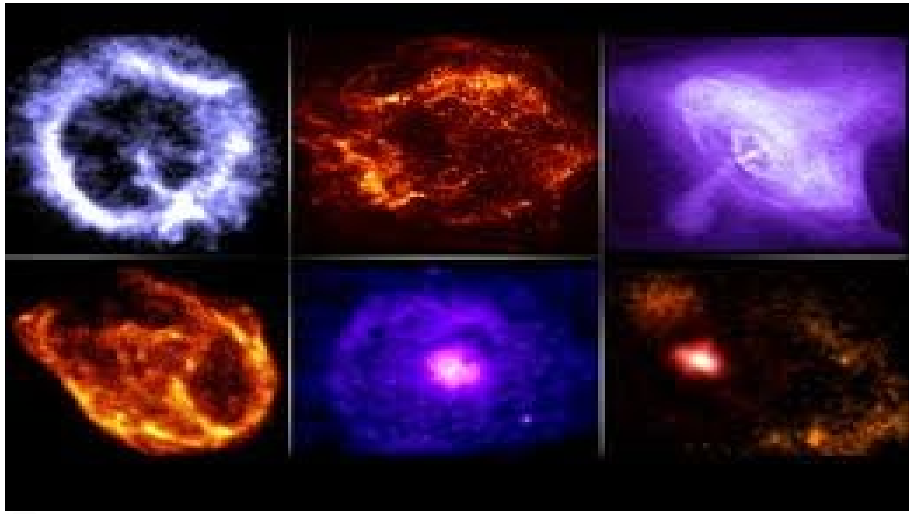


Increasing energy
Increasing wavelength
0.0001 nm
0.01 nm
10 nm
1000 nm
0.01 cm
1 cm
1 m
100 m
Gamma rays
X-rays
Ultra-violet
Infrared
near
far
Microwaves
Radar
Radio waves
TV
FM
AM
Shortwave
Longwave
Visible light
400 nm
500 nm
600 nm
700 nm

X-Rays

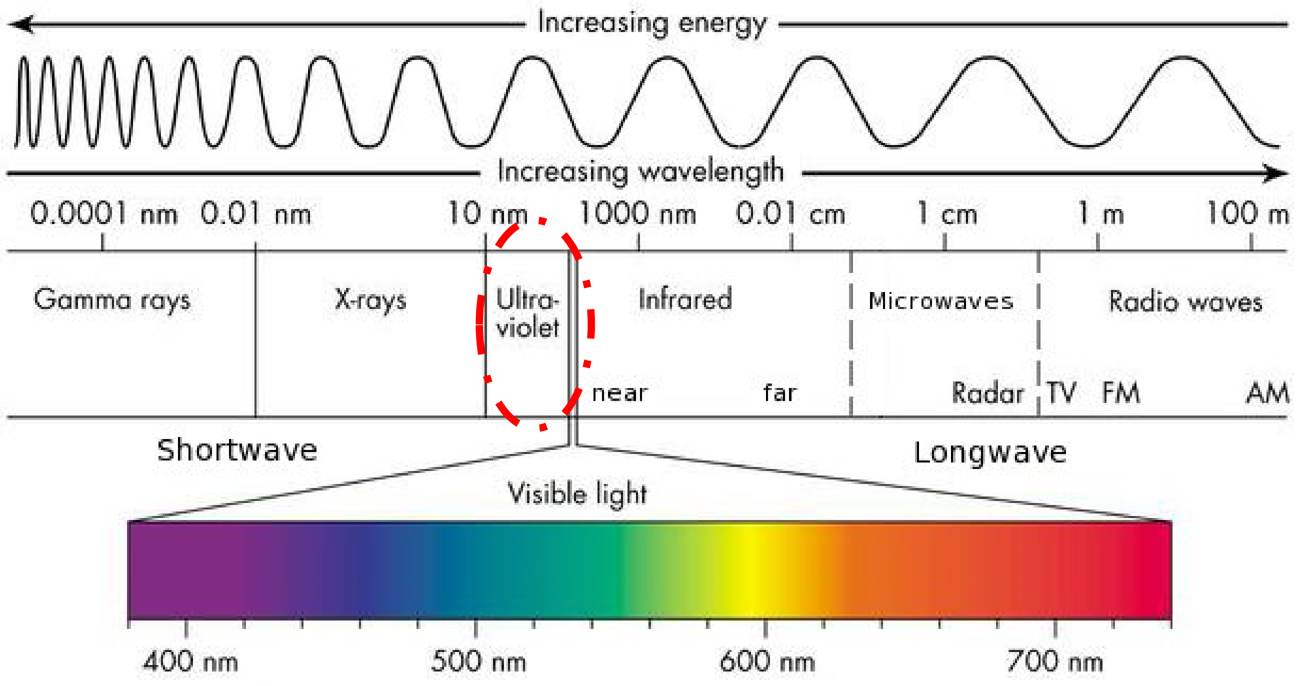


Examples of x-rays imaging

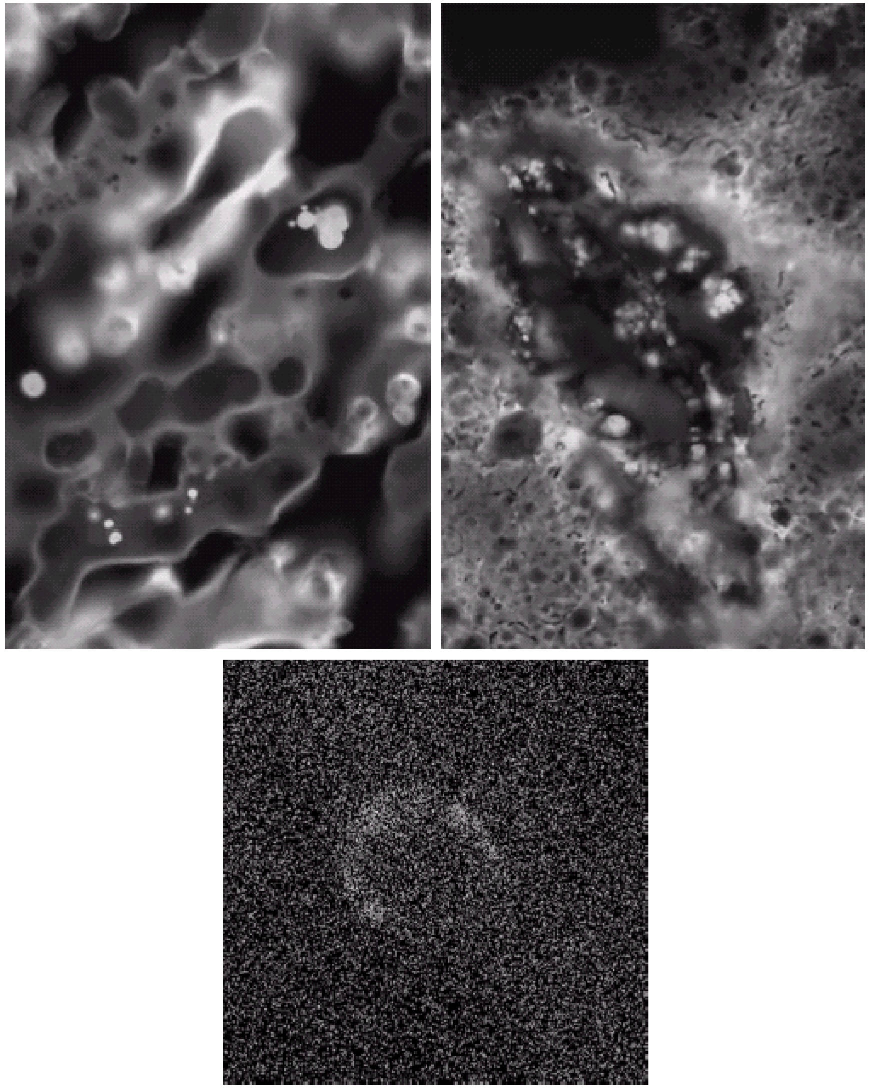


X-ray images from the space
The Chandra X-Ray Observatory

Ultra-Violet



Ultra-Violet



Examples of ultraviolet imaging

(a) Normal corn

(b) Smut corn

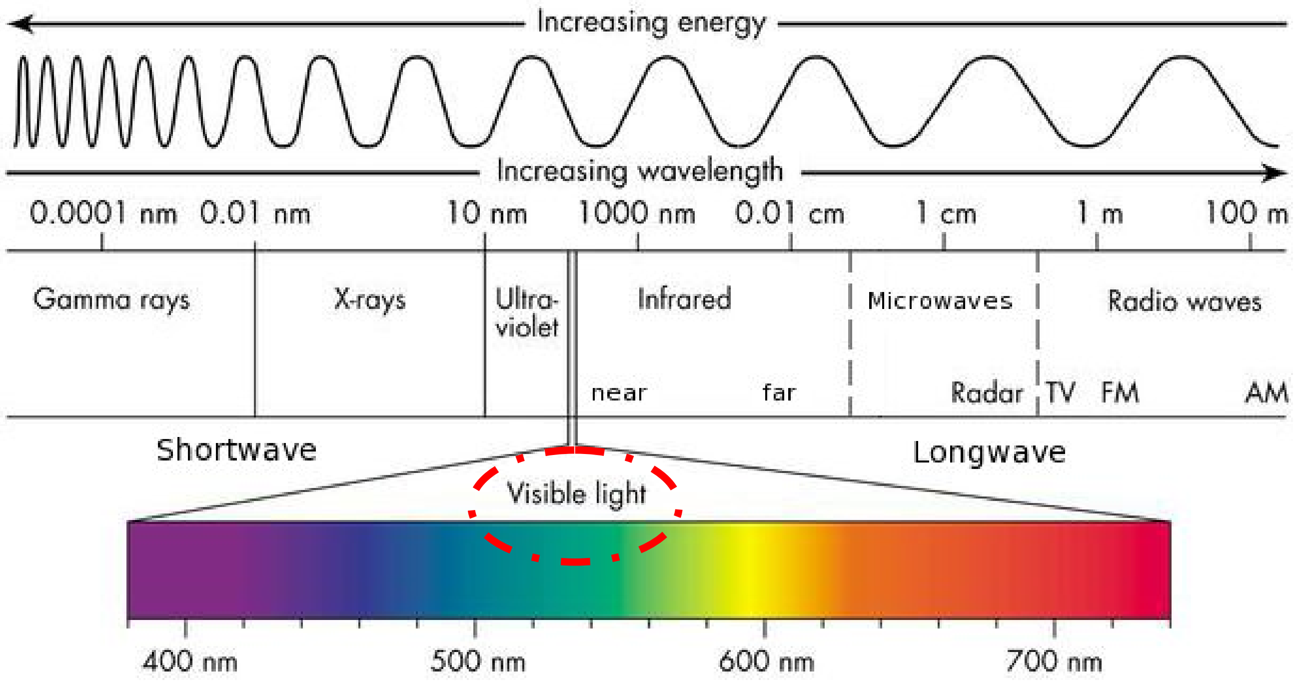
(c) Cygnus Loop

(Images courtesy of (a) and (b)

Dr Michael W. Davidson,

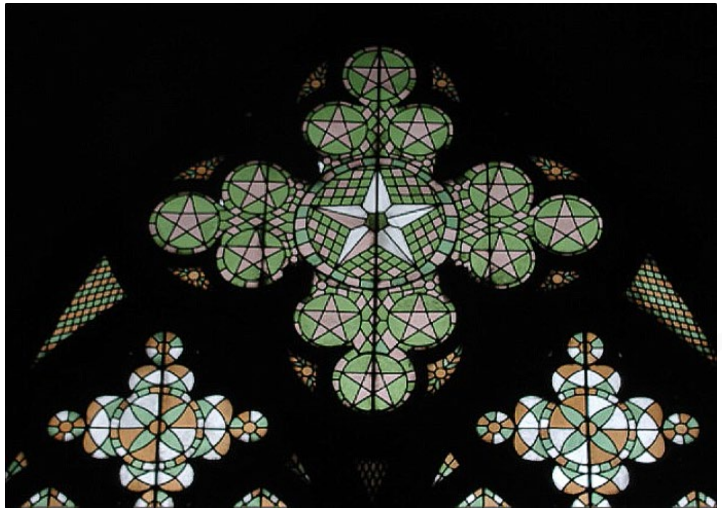
Florida State University, (c) NASA.)

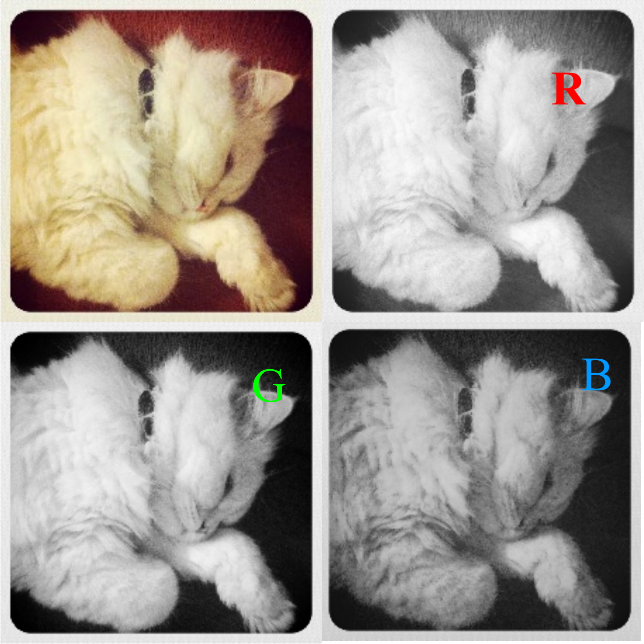
Visible Light

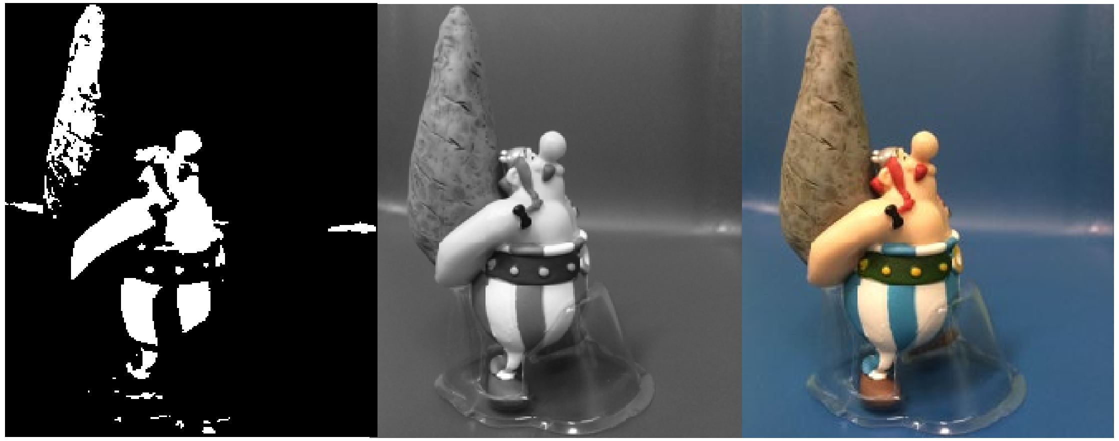


JAN 2024

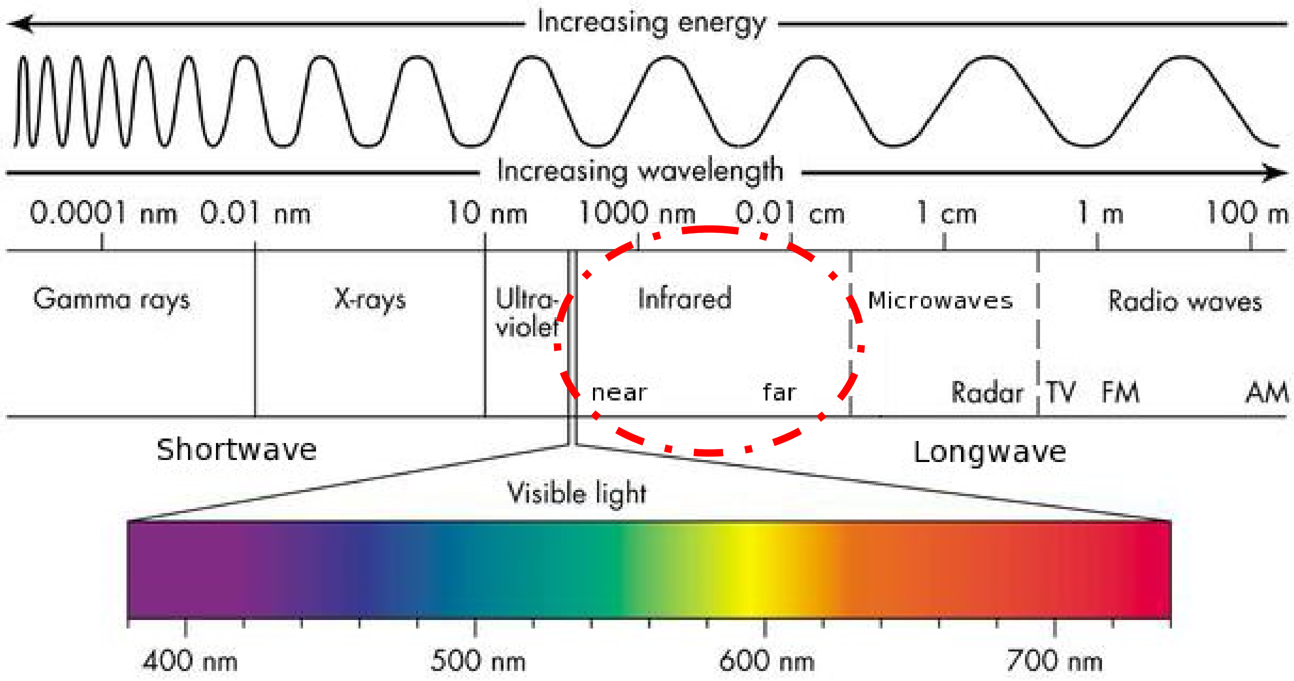
Visible Light



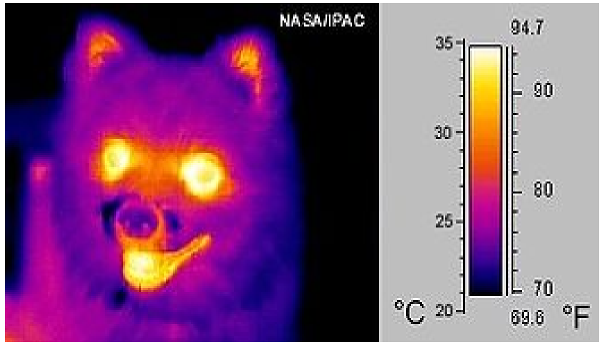




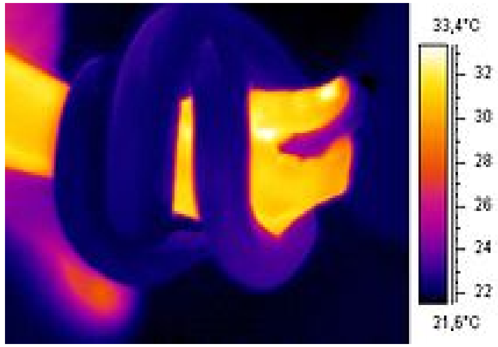
Infrared


Increasing energy
Increasing wavelength
0.0001 nm
0.01 nm
10 nm
1000 nm
0.01 cm
1 cm
1 m
100 m
Gamma rays
X-rays
Ultra-violet
Infrared
Microwaves
Radio waves
near
far
Radar
TV
FM
AM
Shortwave
Longwave
Visible light
400 nm
500 nm
600 nm
700 nm

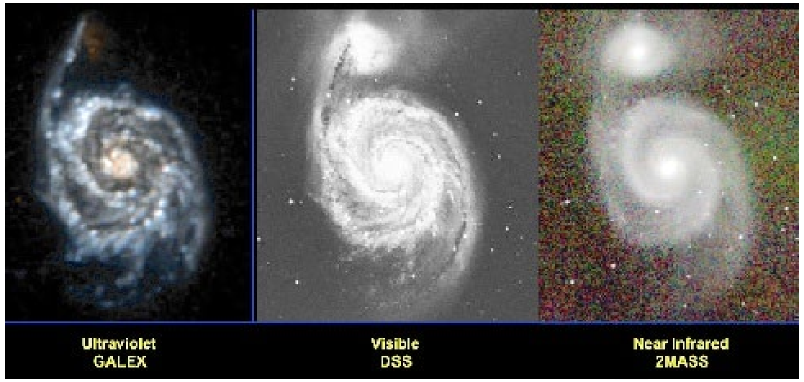
Infrared



infrared ("thermal") image

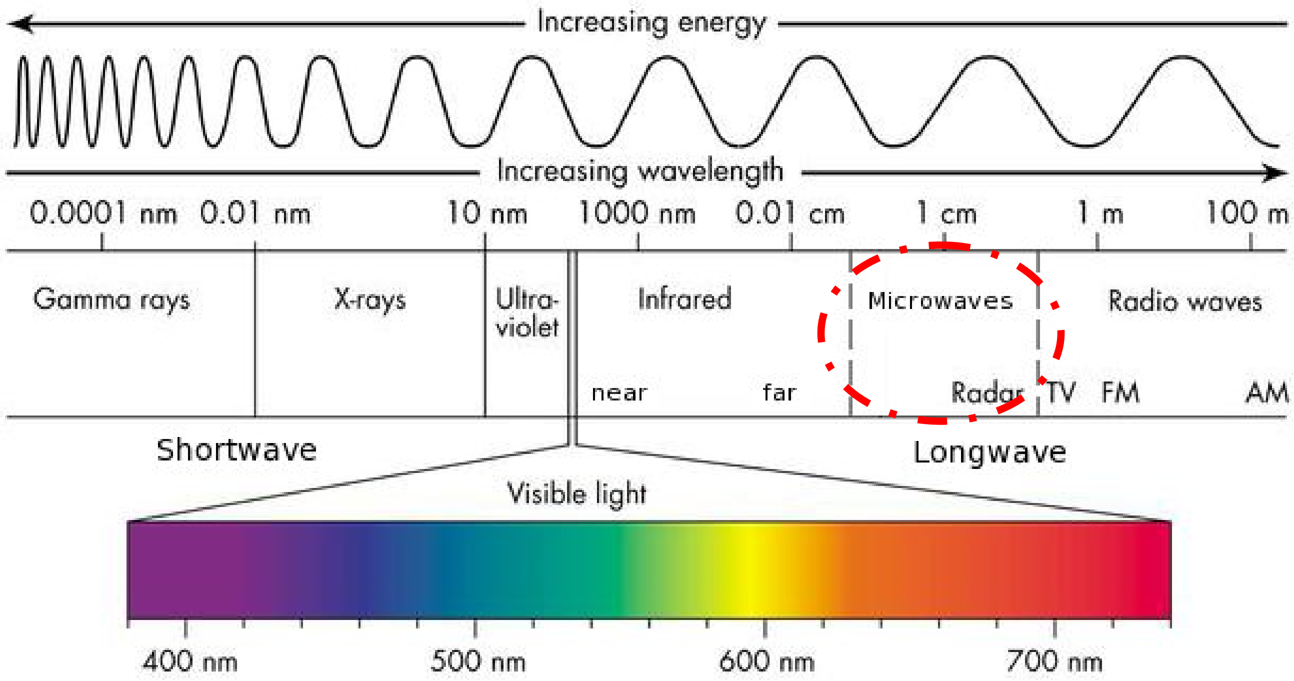


Snake around the arm



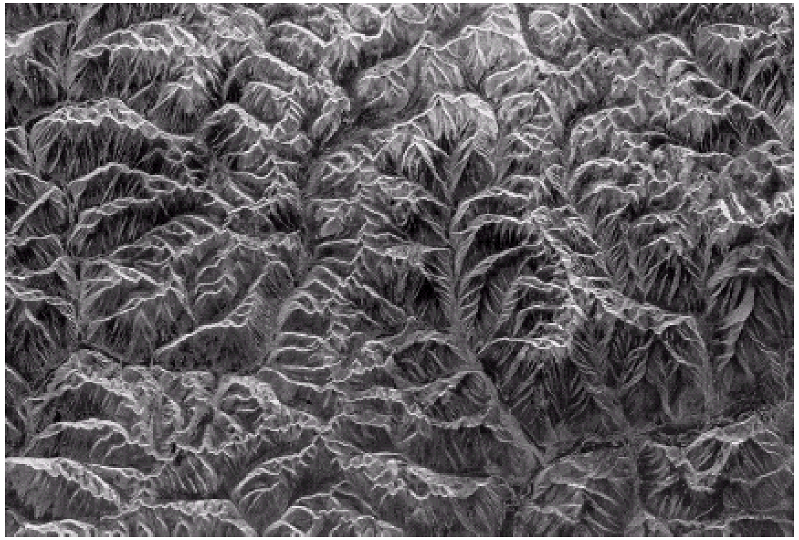
Messier 51 in ultraviolet (GALEX), visible (DSS), and near infrared (2MASS). *Courtesy of James Fanson.*

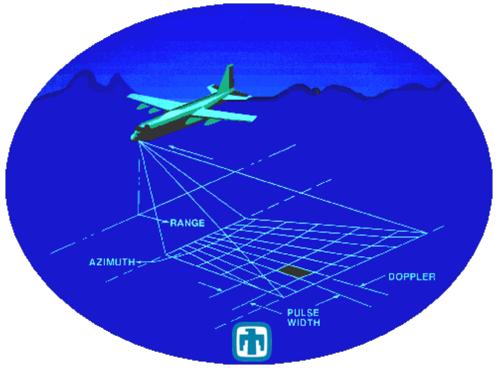
Microwaves



Increasing energy
Increasing wavelength
0.0001 nm
0.01 nm
10 nm
1000 nm
0.01 cm
1 cm
1 m
100 m
Gamma rays
X-rays
Ultra-violet
Infrared
Microwaves
Radio waves
near
far
Radar
TV
FM
AM
Shortwave
Longwave
Visible light
400 nm
500 nm
600 nm
700 nm

Microwaves

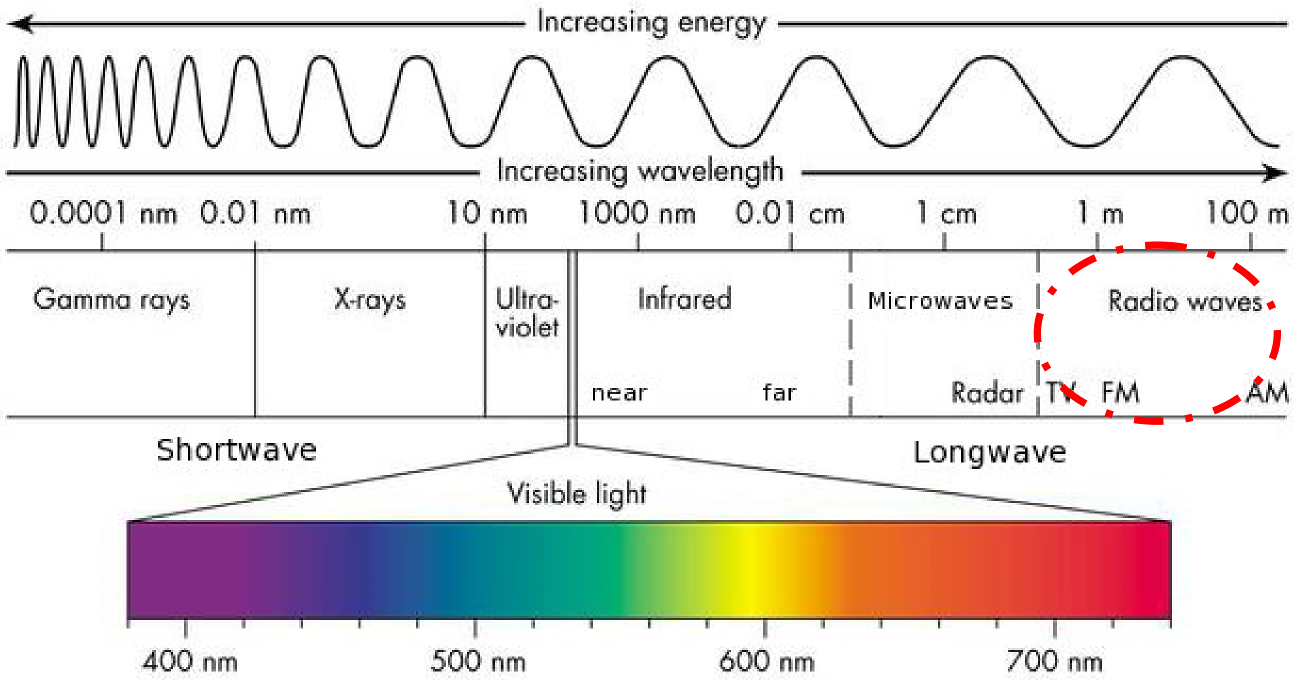




Synthetic Aperture Radar System

Spaceborne radar image of mountains in southeast Tibet (Courtesy of NASA)

Radio Waves



Increasing energy
Increasing wavelength
0.0001 nm
0.01 nm
10 nm
1000 nm
0.01 cm
1 cm
1 m
100 m
Gamma rays
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Ultra-violet
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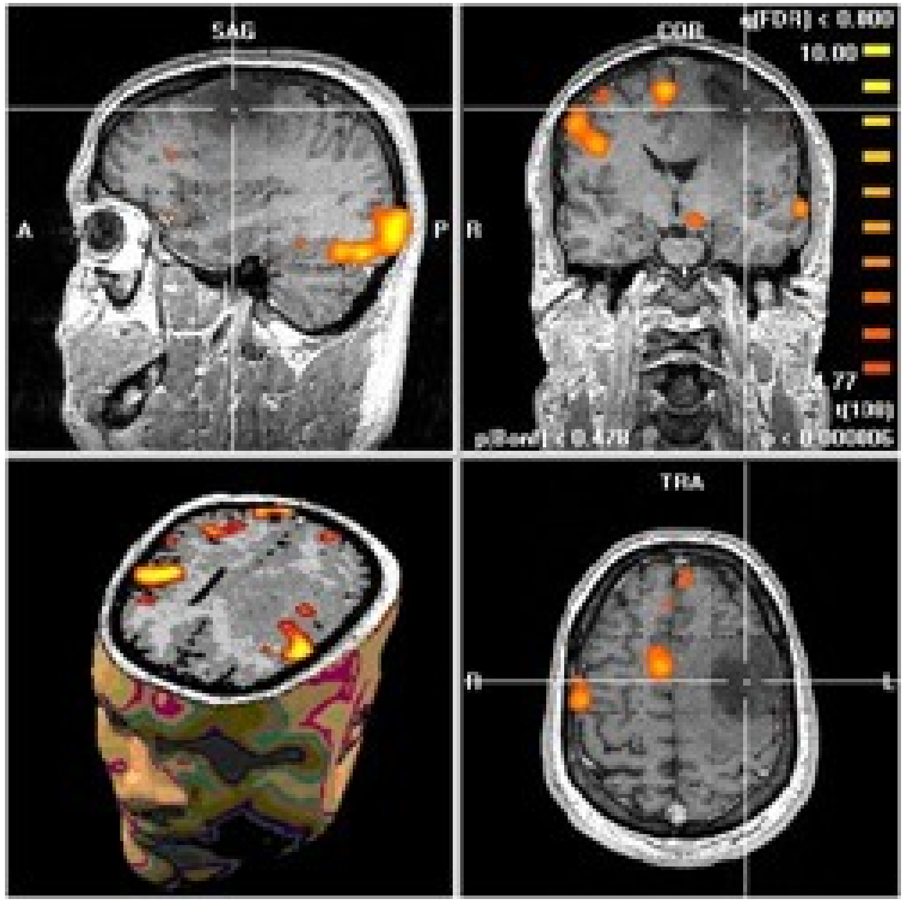
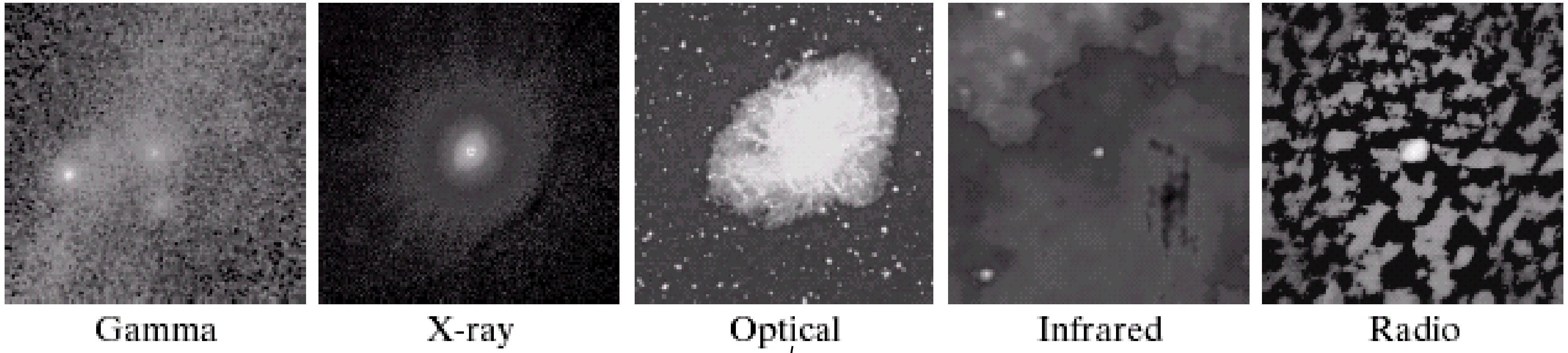
Radio Waves



MRI image slices from the brain

Digital Images based on the EM Spectrum

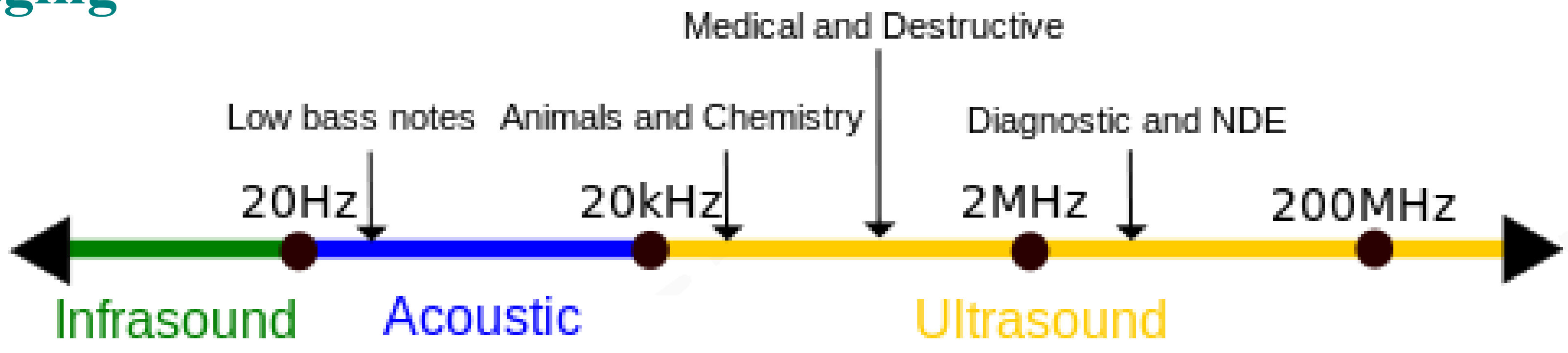
An example showing Imaging in all of the bands



Images of the Crab Pulsar (in the centre of images) covering the EM spectrum

Visible light

Ultrasound Imaging



Ultrasonic spectrum

Ultrasonic Baby image during pragnancy

Ultrasound image acquisition device

Levels of Image Processing

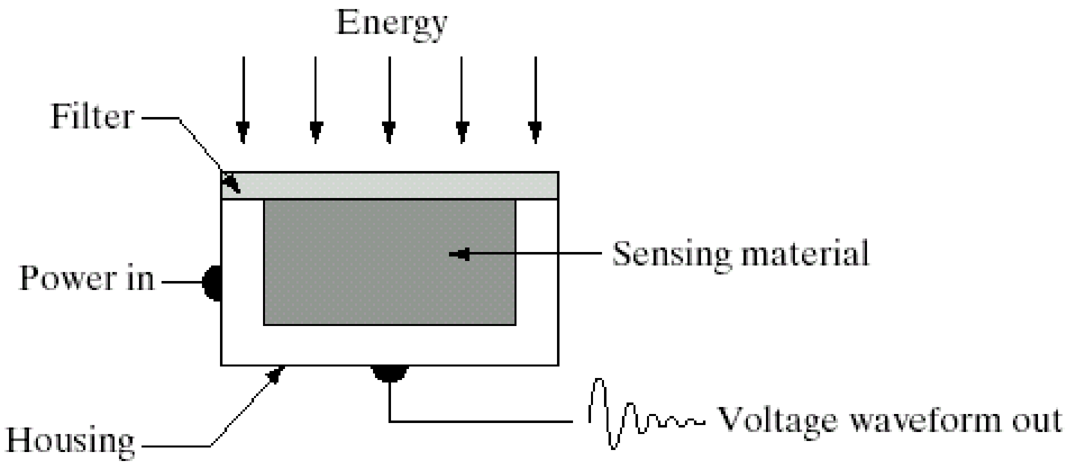
The continuum from image processing to computer vision can be broken into low--, mid- and high-level processes.

Low Level Process	Mid Level Process	High Level Process
Input: Image Output: Image	Input: Image Output: Attributes	Input: Attributes Output: Understanding
Examples: Noise removal, image sharpening	Examples: Object recognition, segmentation	Examples: Scene understanding, autonomous navigation

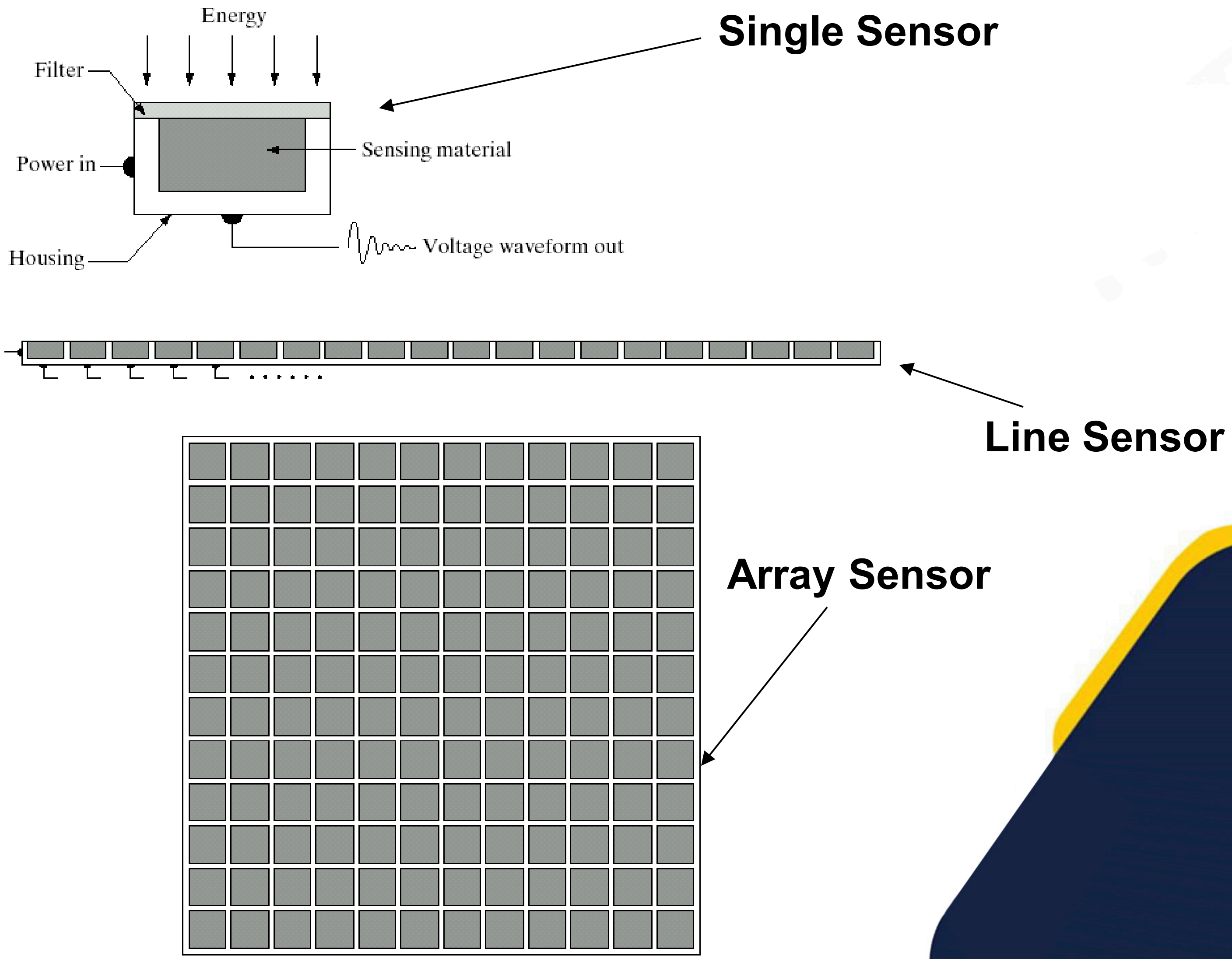
Acquisition of Images

The images are generated by the combination of an *illumination source* and the reflection or absorption of energy from that source by the elements of the *scene* being imaged.

***Imaging sensors* are used to transform the *illumination energy* into digital images.**



Types of Image Sensors



(a) Single imaging sensor,

(b) Line sensor,

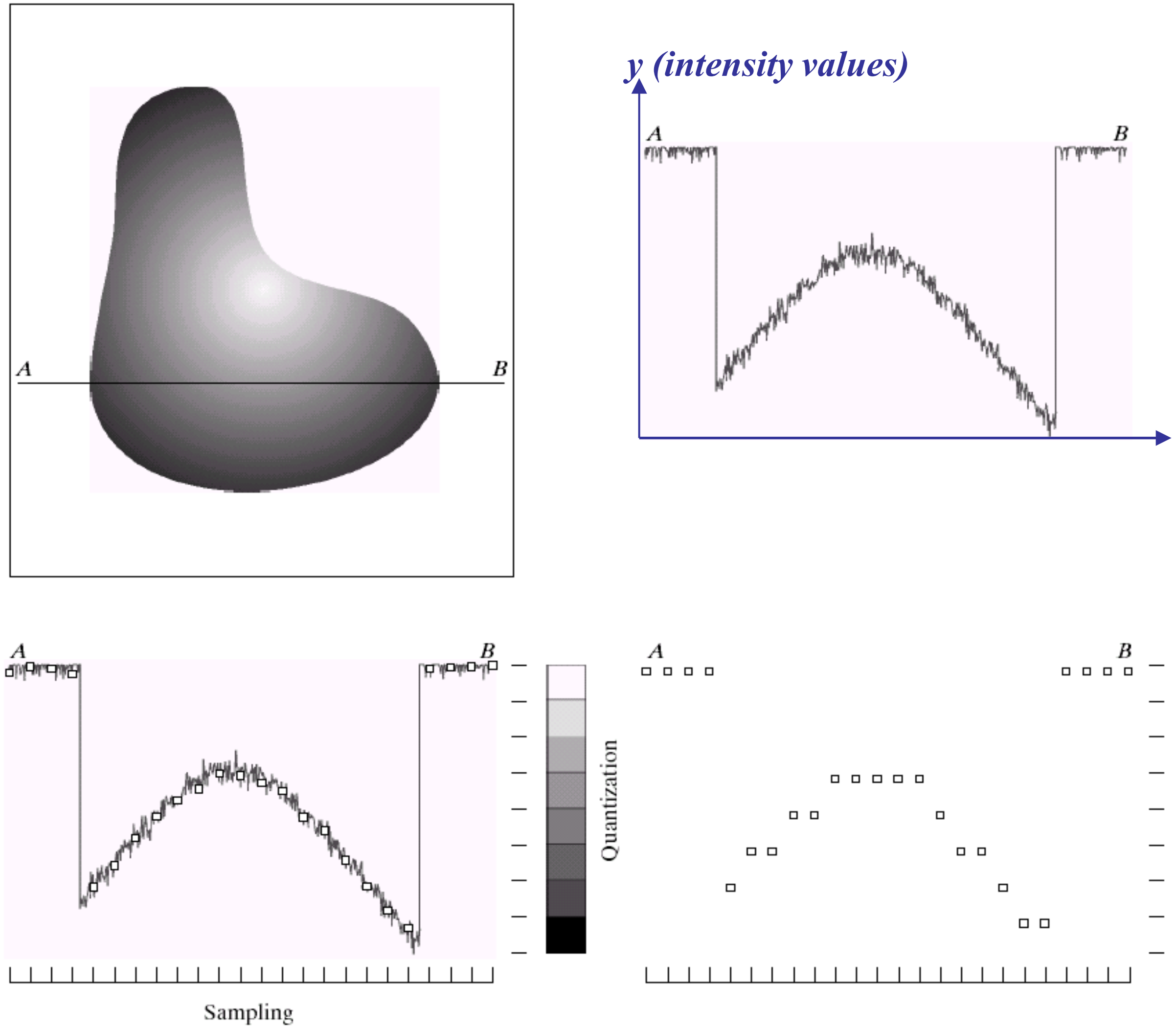
(c) Array sensor

Key stages in digital image processing

Sampling : related to coordinates values

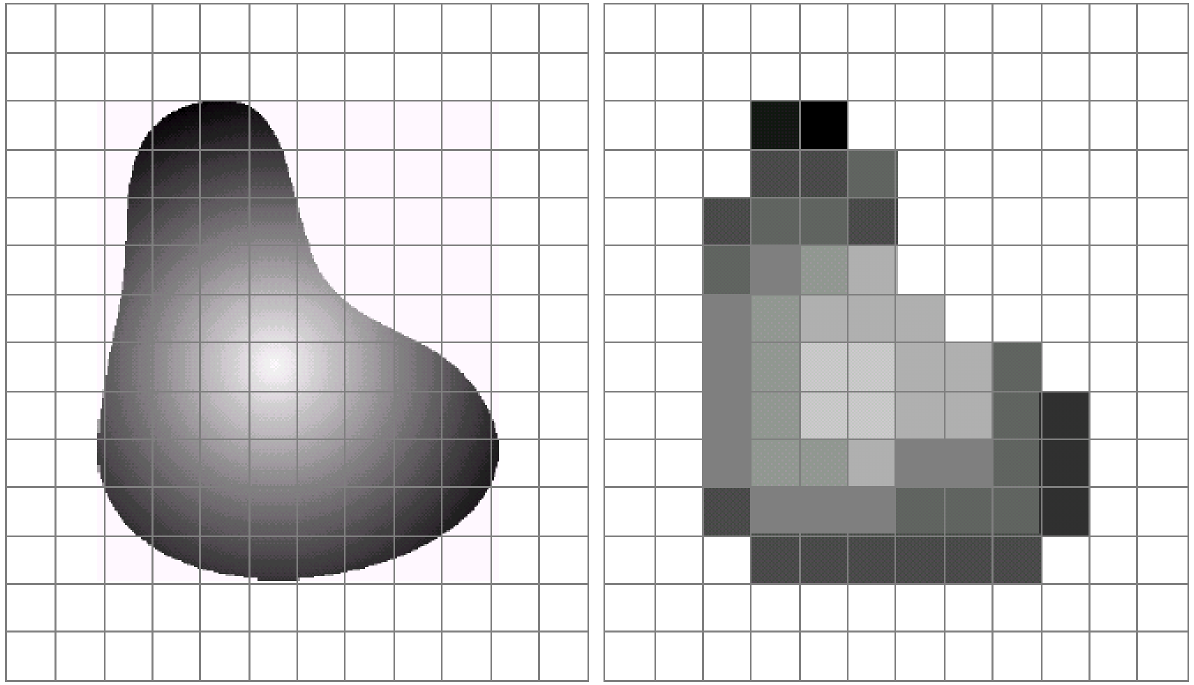
(Nyquist frequency)

Quantisation : related to intensity values



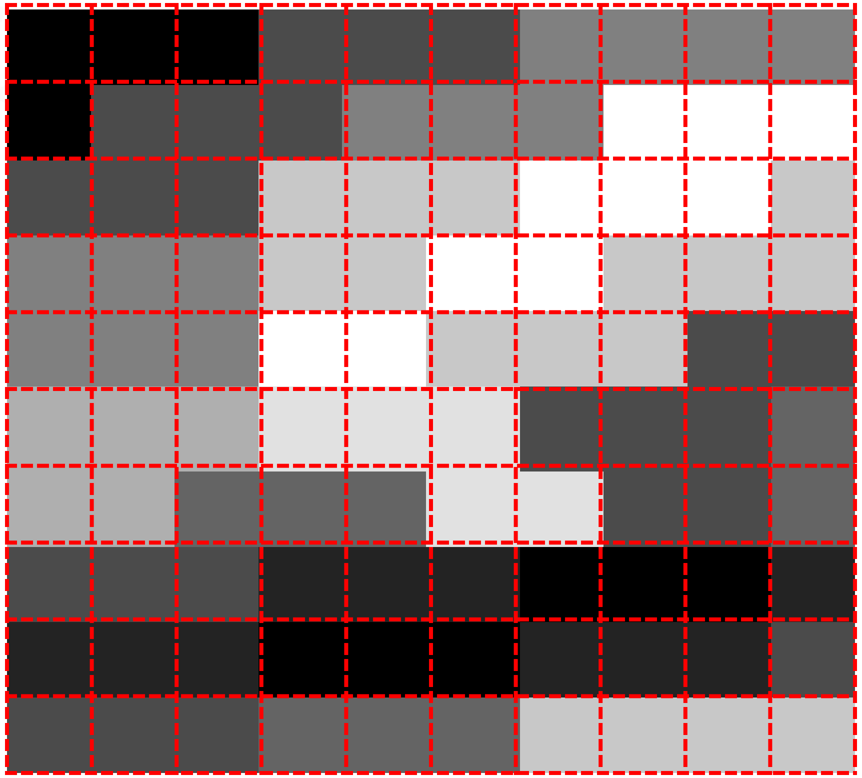
a	b
c	d

Generating a digital image. (a) Continuous image. (b) A scaling line from A to B in the continuous image illustrates the concepts of sampling and quantisation. (c) sampling and quantisation. (d) Digital scan line.



a **b**

(a) Continuous image projected onto a sensor array. (b) Result of image sampling and quantization.



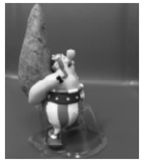
0	0	0	75	75	75	128	128	128	128
0	75	75	75	128	128	128	255	255	255
75	75	75	200	200	200	255	255	255	200
128	128	128	200	200	255	255	200	200	200
128	128	128	255	255	200	200	200	75	75
175	175	175	225	225	225	75	75	75	100
175	175	100	100	100	225	225	75	75	100
75	75	75	35	35	35	0	0	0	35
35	35	35	0	0	0	35	35	35	75
75	75	75	100	100	100	200	200	200	200

Sampling

1024

512

256



128

64

32

Sampling


1024


512


256


128


64


32

Quantisation

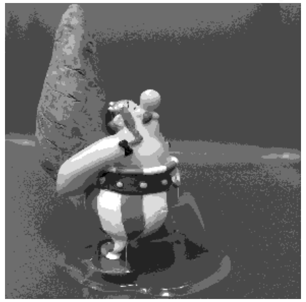
8-bit

7-bit

6-bit

5-bit

4-bit



3-bit

2-bit

1-bit

Image Enhancement

Spatial Domain Methods: manipulates the pixel of a given image for enhancement.

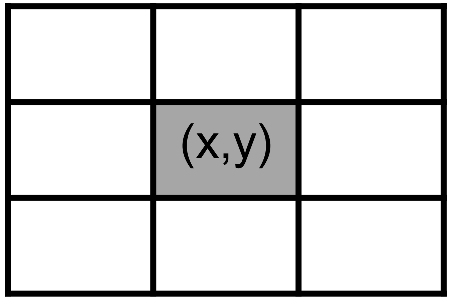
Frequency Domain Methods: manipulates the Fourier transform of a given image for enhancement.

$$g(x,y)=T[f(x,y)]$$

f(x,y) : input

g(x,y) : output

T : transformation function



3x3 neighborhood (mask)

Image Enhancement in Spatial Domain

Point Processing: enhancement at any point in an image depends only the gray-level at that point.

Mask Processing/Filtering: where the values of the mask coefficients determine the nature of the process.

Contrast Stretching

Contrast: is the difference in visual properties making an object/image distinguishable from other objects and the background.

Resizing Images

Zooming : Creating new pixel locations

Assigning gray-level values to these locations

Solution: Interpolation

3 main type of 2D Interpolations :

Nearest neighbor interpolation

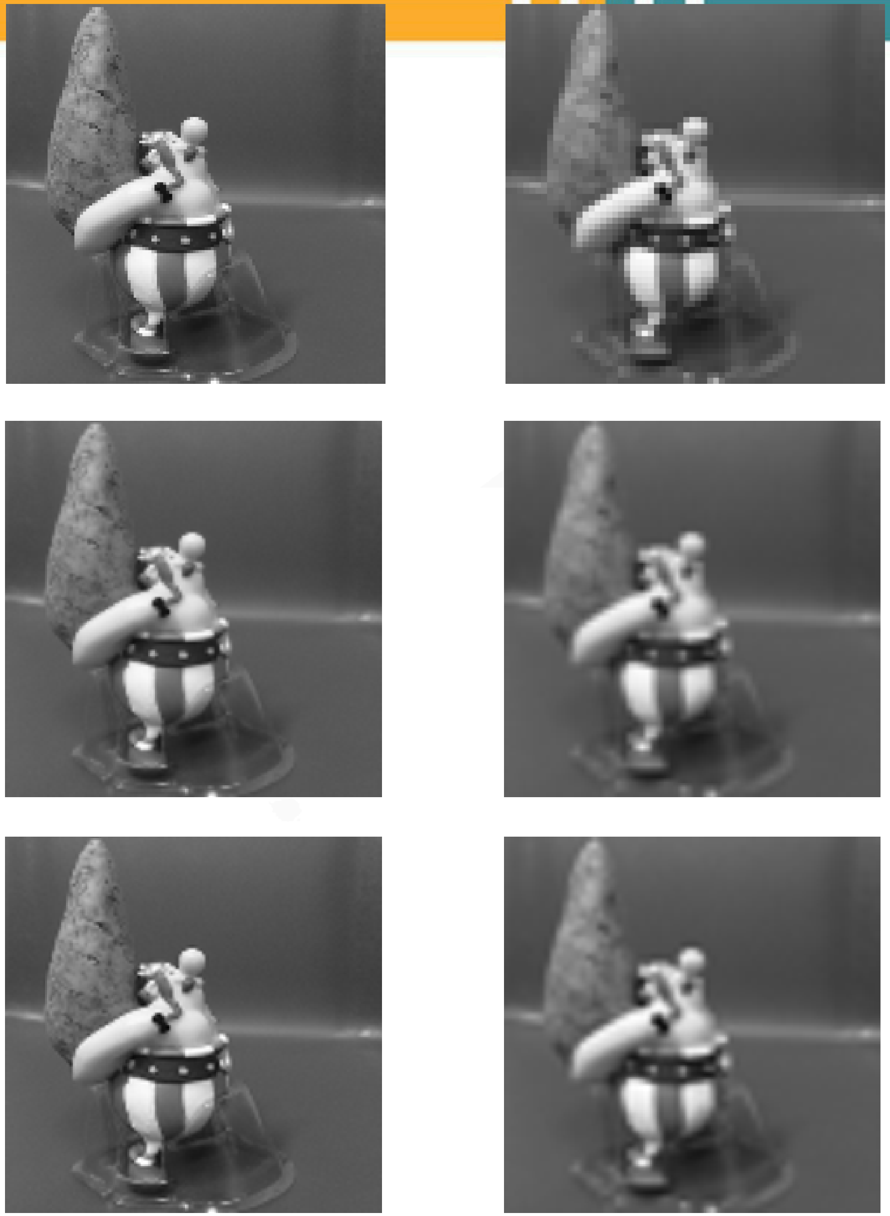
Bilinear interpolation

Bicubic interpolation

Nearest Neighbor

Bilinear

Bicubic

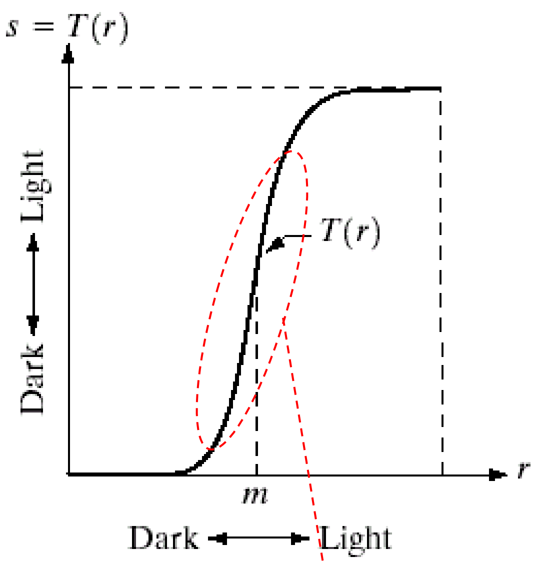


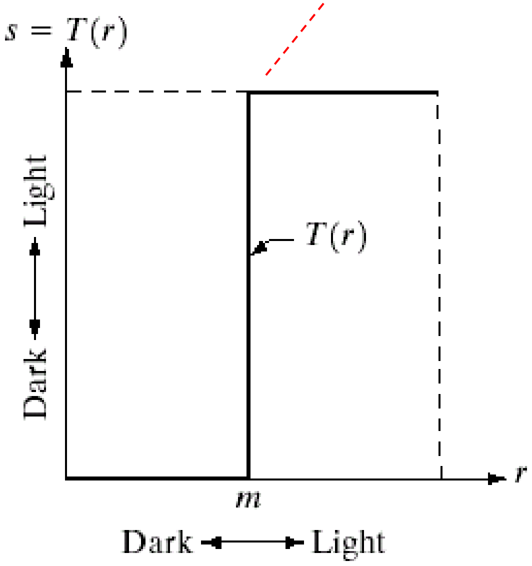
128 → 1024   64 → 1024

Contrast Enhancement

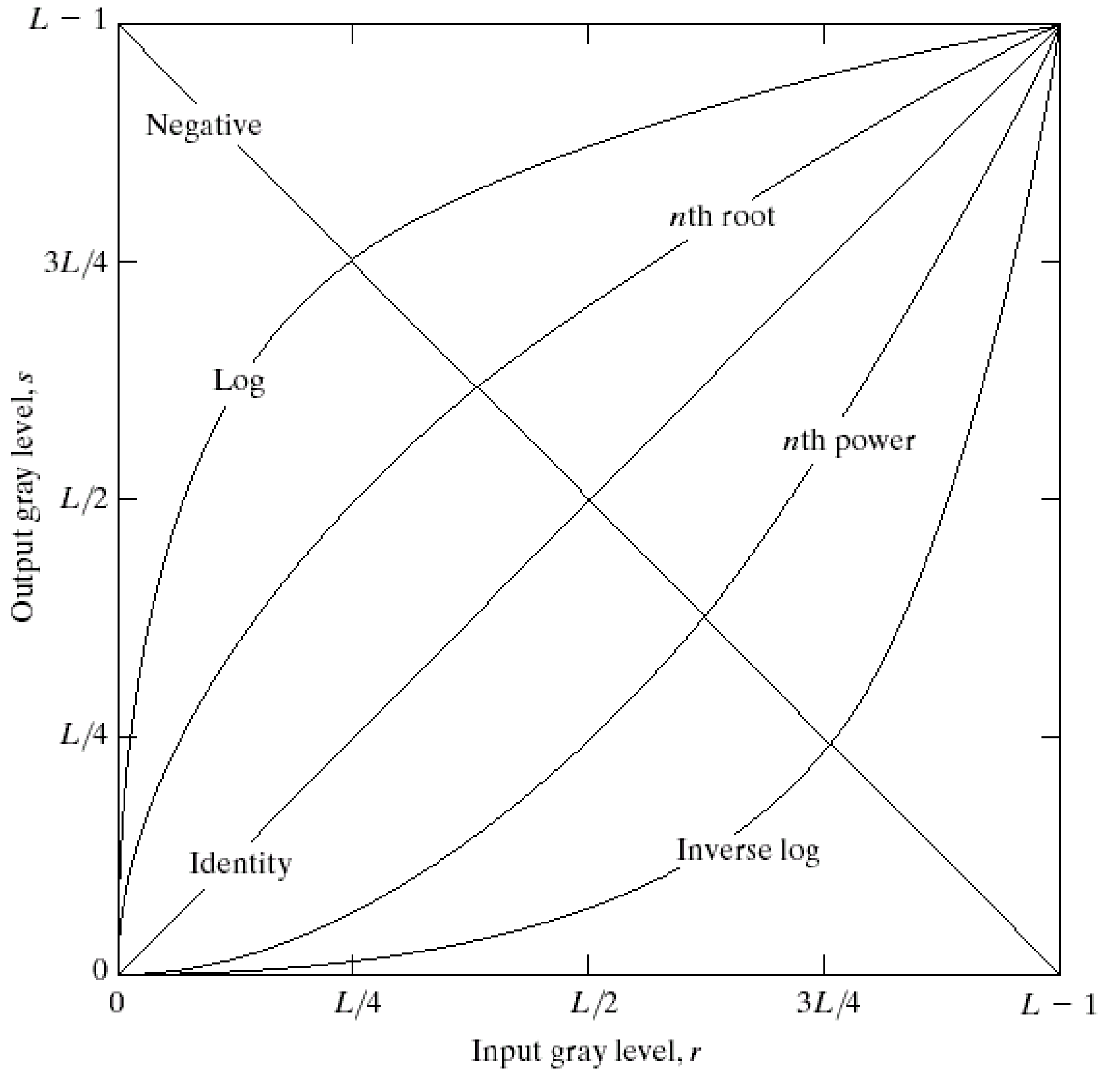
Contrast Stretching: improves the contrast in an image by stretching the range of intensity values to span a desired range of values.

Converts to black & white





Linear Part contributes to the contrast stretching



Some basic grey-level transformation functions used for contrast enhancement

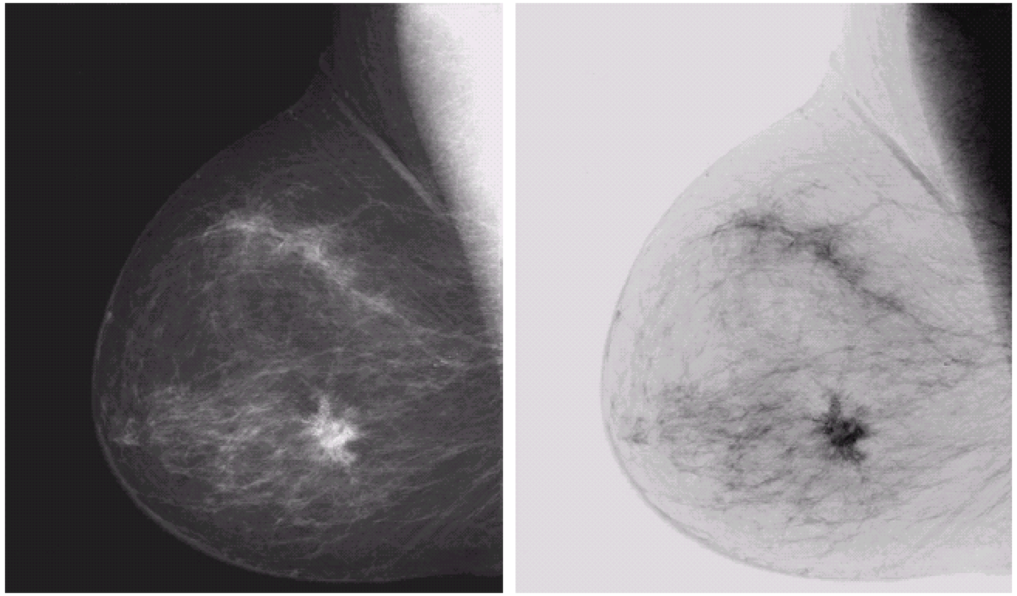
L=2k

k: number of bits used to represent each pixel

Image Negatives

$$s = (L - 1) - r$$

s is the pixel value of the output image and r is the pixel value of the input image.

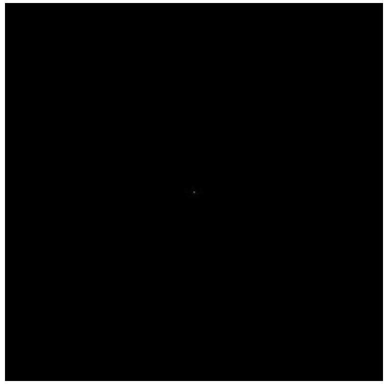


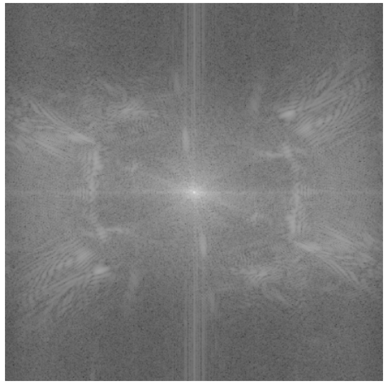
(left) Original digital mammogram. (right) Negative image obtained using the negative transformation

Logarithmic Transformations

$$s = c \log(1 + r)$$

s is the pixel value of the output image and r is the pixel value of the input image.



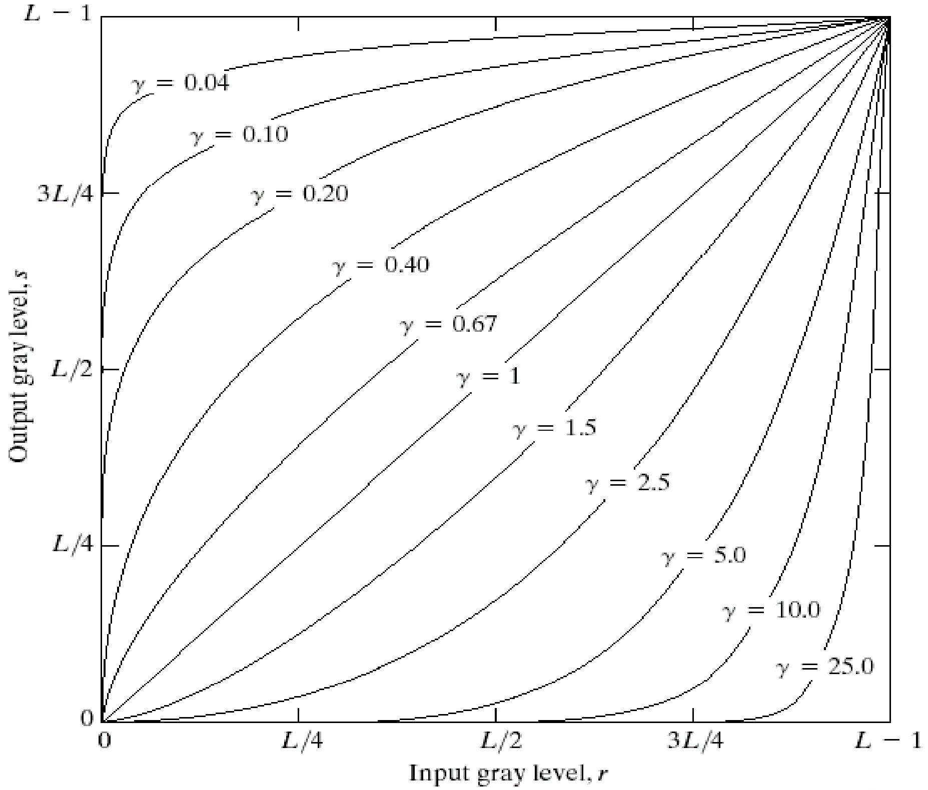


(left) Fourier spectrum of Barbara's image. (right) Result of applying the log transformation

Logarithmic Transformations

$$s = c\ r^{\gamma}$$

s is the pixel value of the output image and r is the pixel value of the input image. ($\gamma \geq 0$ and $0 \leq r \leq 1$)



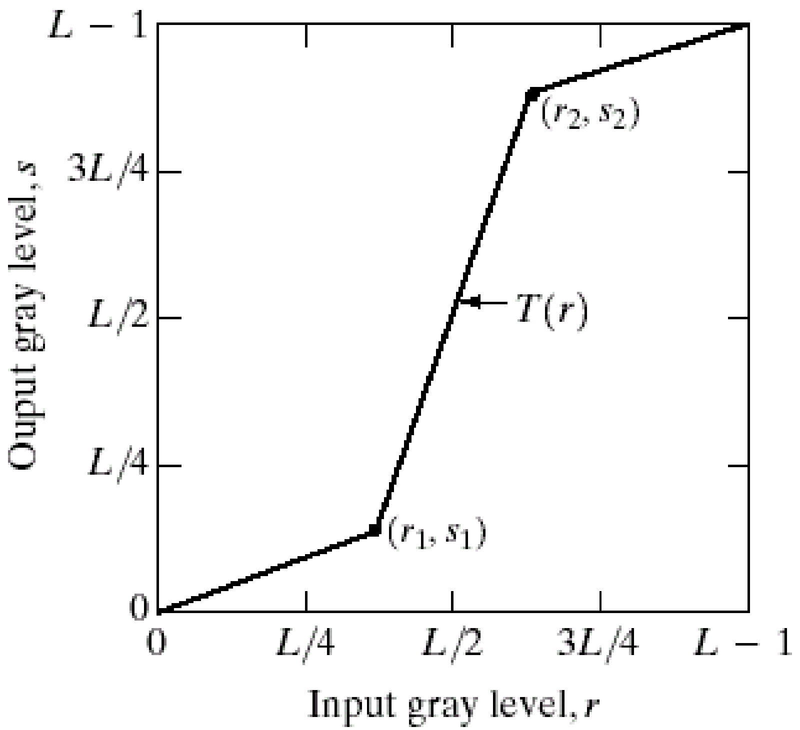
Plots for various values of γ (c=1)

Logarithmic Transformations

a	b
c	d

(a) original image. (b) γ = 0.5 .
(c) γ = 0.3 . (d) γ = 0.7.

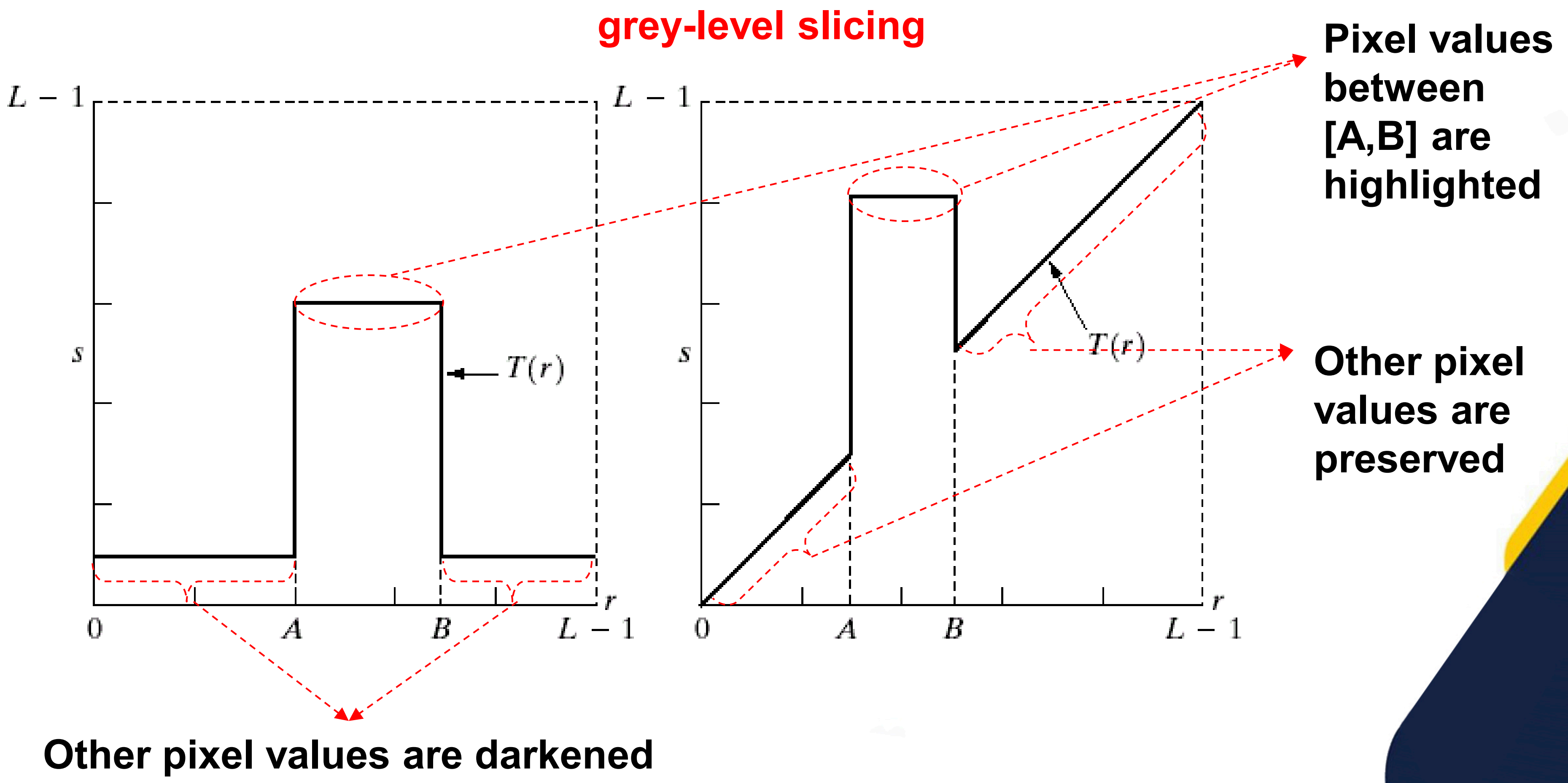
Piecewise-Linear Transformations



An example of piecewise linear transformation function

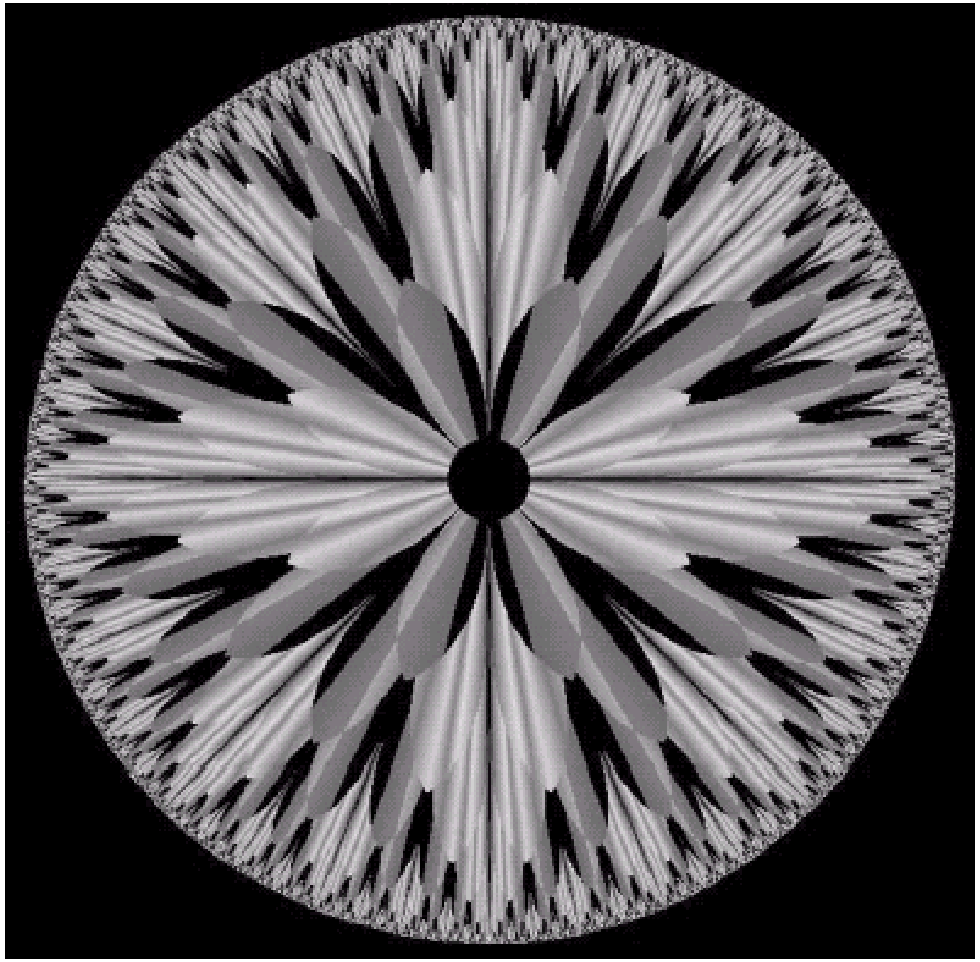
Piecewise-Linear Transformations

grey-level slicing



Piecewise-Linear Transformations

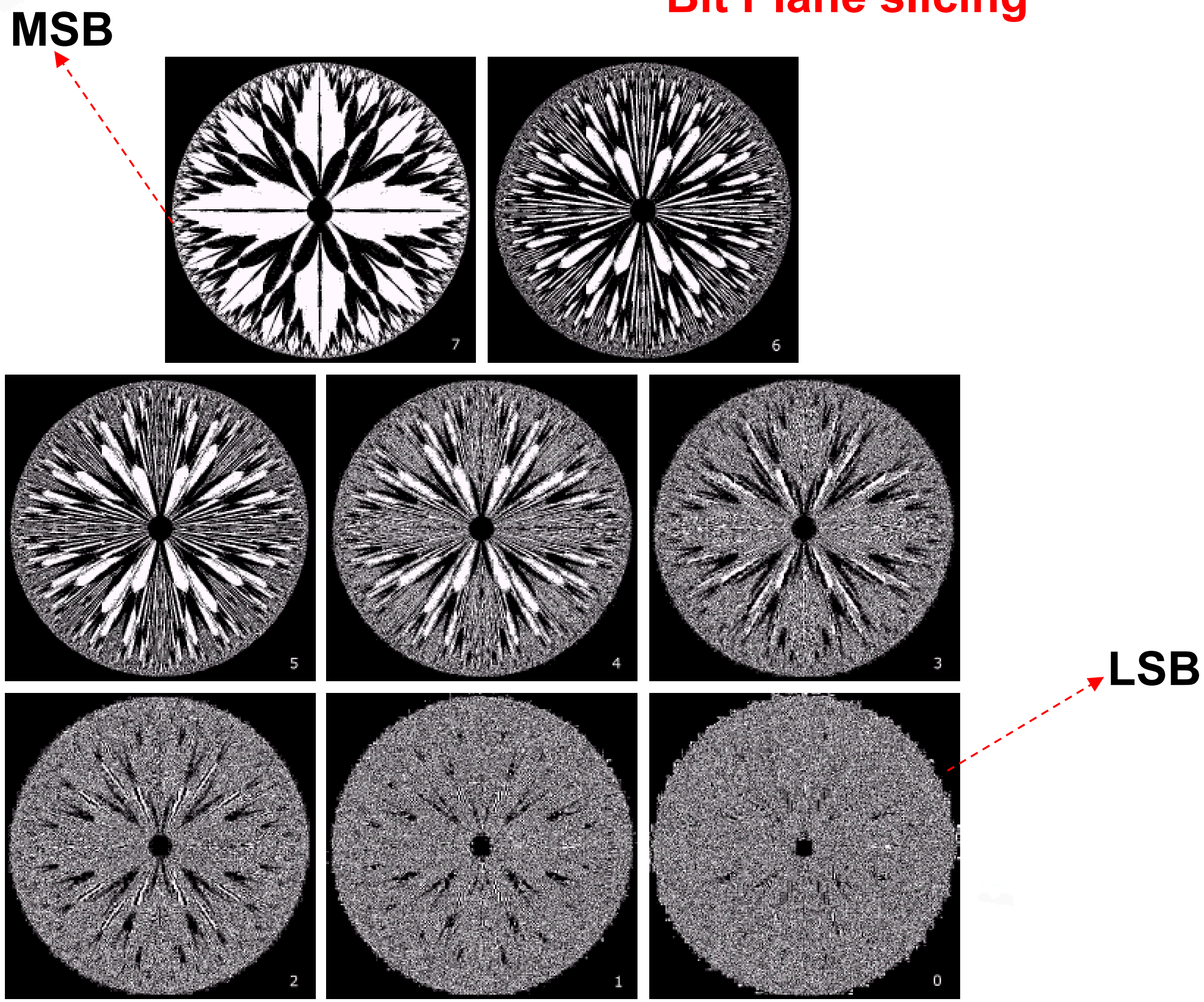
Bit Plane slicing



An 8-bit fractal image

Piecewise-Linear Transformations

Bit Plane slicing

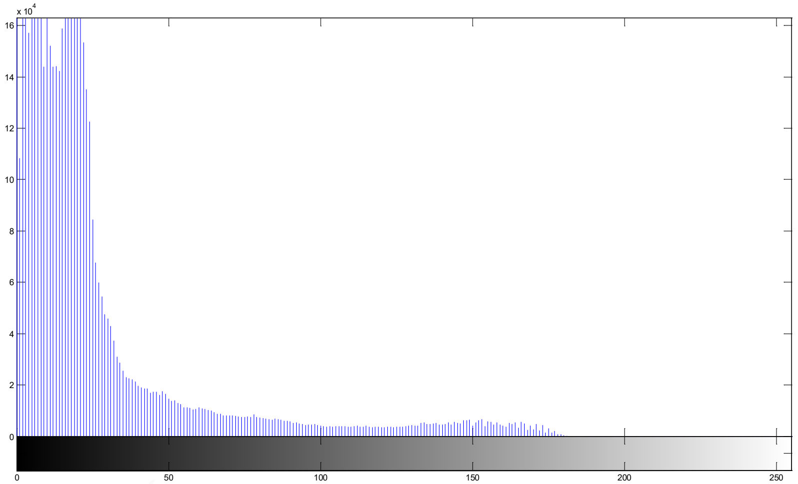


Histogram Processing

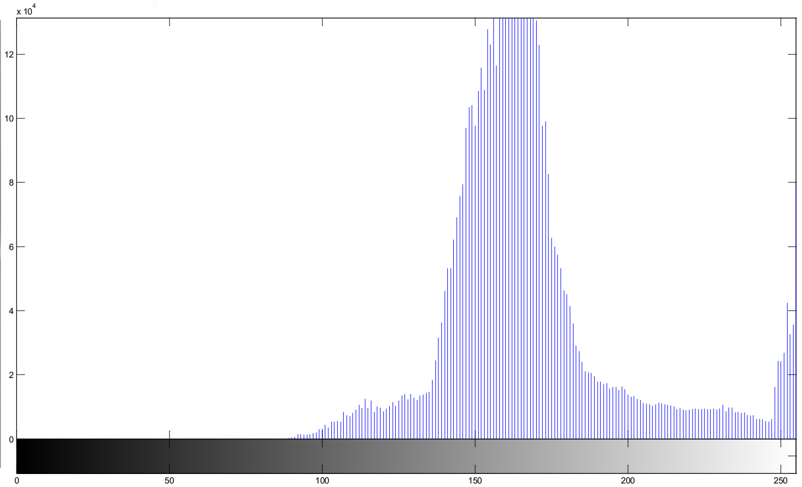
Histogram : is the discrete function $h(r_k)=n_k$, where r_k is the k^{th} gray level in the range of [0, L-1] and n_k is the number of pixels having gray level r_k.

Normalized histogram : is $p(r_k)=n_k/n$, for $k=0,1,\ldots,L-1$ and $p(r_k)$ can be considered to give an estimate of the probability of occurrence of ray level r_k.

Histogram of 4 basic grey-level characteristics

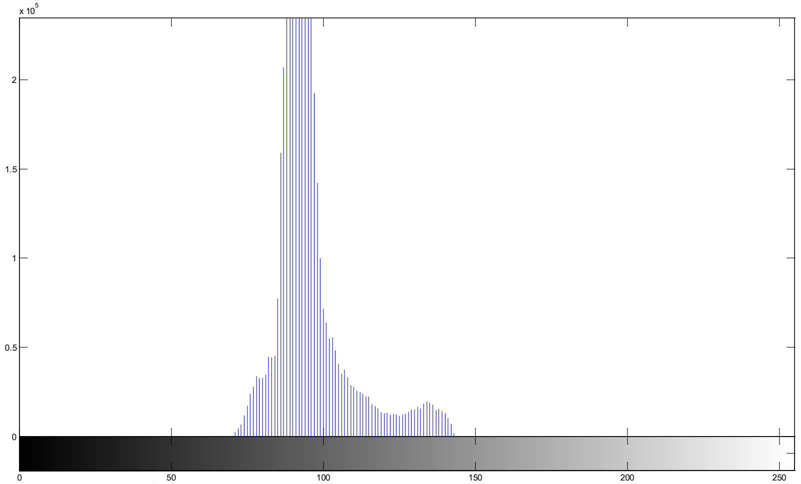


Dark image

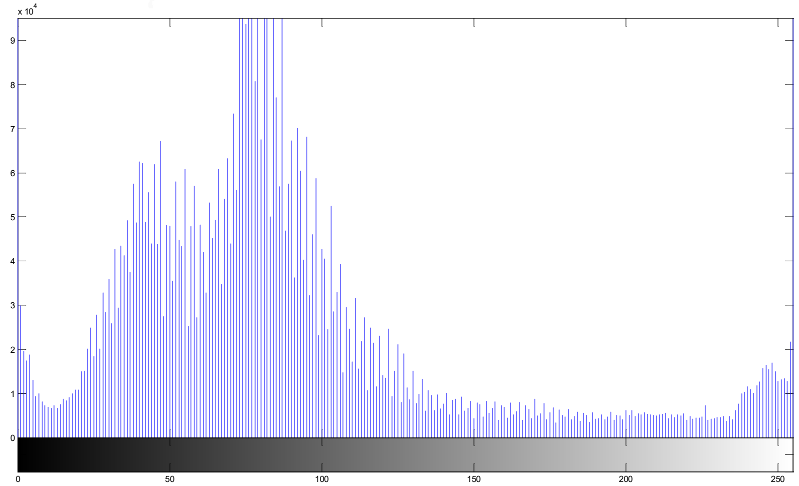


Bright image

Histogram of 4 basic grey-level characteristics



Low contrast image



High contrast image

Question 1

01. What are the types of images you know?

A. Binary

B. Black and white

C. Grayscale

D. Color

E. All of these

Answer E. All of these

Question 2: Fill the blanks

02. A color image has _____, _____, and _____ pixels.

Answer. Red, green, and blue

Question 3

03. The size of each pixel in a binary image is _____.?

A. One bit

B. Two bit

C. Four bit

D. Eight bit

E. Sixteen bit

Answer A. One bit

You may note it

Storage requirements for all the image types

- **Binary – 1 bit per pixel.**
- **Black and white – 8 bits per pixel.**
- **Grayscale – 8 bits per pixel.**
- **Color – 24 bits per pixel (R, G, and B channels together).**

REFERENCES

- Gonzalez, R. C., Woods, R. E. (2008). Digital image processing. Upper Saddle River, N.J.: Prentice Hall. ISBN: 9780131687288 013168728X 9780135052679 013505267X
- A Baskar, Muthaiah Rajappa, Shriram K Vasudevan, and T S Murugesh (2023) Digital Image Processing, First edition published 2023 by CRC Press, ISBN: 9781003217428 (ebk), DOI: 10.1201/9781003217428
- https://sisu.ut.ee/imageprocessing/avaleht

CONCLUSION

- **Basics of Digital Image**
- **Image Acquisition**
- **Image Processing**
- **Image Enhancement**


THANK YOU

MINE AUTOMATION AND DATA ANALYTICS

MINE AUTOMATION AND DATA ANALYTICS

SWAYAM NPTEL COURSE ON

MINE AUTOMATION AND DATA ANALYTICS

By

Prof. Radhakanta Koner
Department of Mining Engineering
Indian Institute of Technology (Indian School of Mines) Dhanbad

Module 05
Automated Tracking and Communication Technologies

Lecture 13 A
Image Processing and Analysis in Remote Sensing

CONCEPTS COVERED

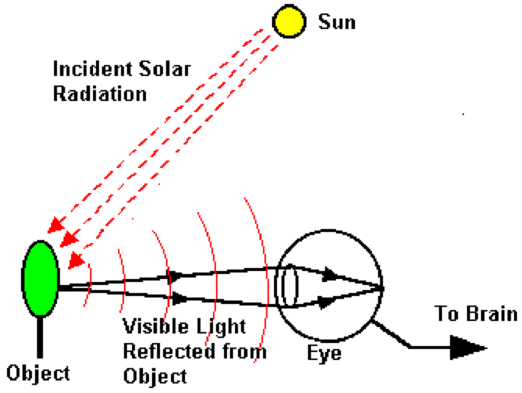
- Introduction to Remote sensing
- Techniques in remote sensing
- Imaging: Images are captured using optical, infrared, and microwave technologies.
- Processing of Images
- Restoration of Images
- Images Analysis

Introduction to Remote sensing

- **Generally, Remote sensing refers to the activities of recording/observing/perceiving (sensing) objects or events at far away (remote) places.**
- **In remote sensing, the sensors are not in direct contact with the objects or events being observed. The information needs a physical carrier to travel from the objects/events to the sensors through an intervening medium.**
- **The electromagnetic radiation is normally used as an information carrier in remote sensing.**

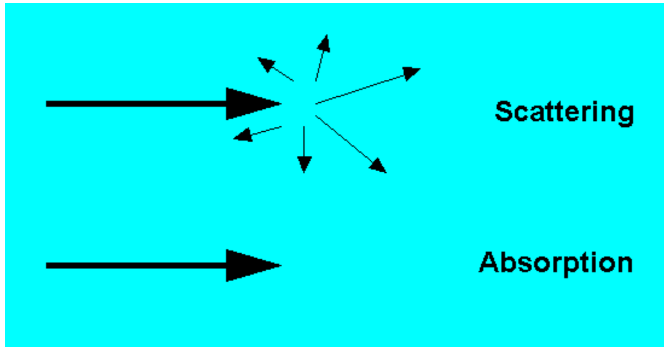
Introduction to Remote sensing

- The output of a remote sensing system is usually an image representing the scene being observed.
- A further step of image analysis and interpretation is required in order to extract useful information from the image. The human visual system is an example of a remote sensing system in this general sense.



Effects of Atmosphere

- Satellite remote sensing involves sensors observing Earth through the atmosphere.
- Understanding atmospheric effects of electromagnetic radiation is crucial.
- Atmospheric constituents cause wavelength-dependent absorption and scattering.
- These effects degrade image quality.
- Some atmospheric effects can be corrected prior to further analysis

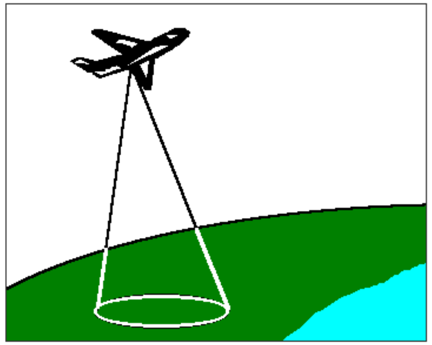


Effects of Atmosphere

- Certain wavelength bands are strongly absorbed by the atmosphere.
- Regions of the electromagnetic spectrum usable for remote sensing are determined by atmospheric transmission windows.
- Remote sensing systems are designed to operate within these windows.
- Transmission windows exist in the microwave, some infrared, visible, and near ultraviolet regions.
- X-rays and gamma rays, although transparent to the atmosphere, are not commonly used in remote sensing of Earth.

Airborne Remote Sensing

- Airborne remote sensing uses sensors mounted on aircraft to capture images of Earth's surface.
- Advantages include very high spatial resolution (20 cm or less).
- Disadvantages include low coverage area and high cost per unit area.
- Airborne remote sensing is not cost-effective for mapping large areas.
- Earth observation satellites allow continuous monitoring.



A high resolution aerial photograph over a forested area. The canopy of each individual tree can be clearly seen. This type of very high resolution imagery is useful in identification of tree types and in assessing the conditions of the trees.

Airborne Remote Sensing

- Common techniques include analog aerial photography, videography, and digital photography.
- Synthetic Aperture Radar imaging is also conducted on airborne platforms.
- Analog photography offers high spatial resolution and visual interpretation by experienced analysts.
- Analog photographs may be digitized for computer-assisted analysis.
- Digital photography enables real-time data transmission for immediate analysis and computer-aided interpretation

Another example of a high resolution aerial photograph over a residential area.

Spaceborne Remote Sensing

In spaceborne remote sensing, sensors are mounted on-board a spacecraft (space shuttle or satellite) orbiting the earth. At present, there are several remote sensing satellites providing imagery for research and operational applications. Spaceborne remote sensing provides the following advantages:

- **Large area coverage;**
- **Frequent and repetitive coverage of an area of interest;**
- **Quantitative measurement of ground features using radiometrically calibrated sensors;**
- **Semiautomated computerized processing and analysis;**
- **Relatively lower cost per unit area of coverage.**

Digital Image

- An image is a two-dimensional representation of objects in a real scene.
- Remote sensing images are representations of parts of the earth surface as seen from space.
- The images may be analog or digital. Aerial photographs are examples of analog images while satellite images acquired using electronic sensors are examples of digital images.

Multilayer Image

- Different types of measurements can be made from the ground area covered by a single pixel.
- Each measurement forms an image carrying specific information about the area.
- Stacking these images together forms a multilayer image, with each component image as a layer.
- Multilayer images can also be formed by combining images from different sensors and other data.
- For example, a multilayer image may include layers from SPOT multispectral images, ERS synthetic aperture radar images, and digital elevation maps of the area.

Multispectral Image

Multispectral images consist of multiple layers, each representing a specific wavelength band. Examples include SPOT HRV (3 bands), IKONOS (4 bands), and Landsat TM (7 bands).

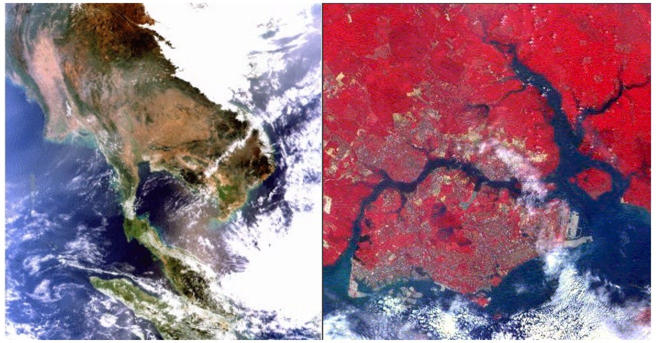
Superspectral Image

- **Modern satellite sensors like MODIS on NASA's TERRA satellite have many more wavelength bands.**
- **MODIS consists of 36 spectral bands covering a wide range from visible to thermal infrared.**
- **These sensors capture finer spectral characteristics with narrower bandwidths.**
- **Such sensors are termed "superspectral."**

Hyperspectral images

- **Hyperspectral images consist of over a hundred contiguous spectral bands.**
- **These images capture the characteristic spectrum of each pixel.**
- **The precise spectral information enables better target characterization and identification.**
- **Hyperspectral imagery finds applications in precision agriculture and coastal management.**
- **Currently, no commercially available hyperspectral imagery from satellites.**
- **Experimental satellite sensors like NASA's Hyperion and ESA's CHRIS acquire hyperspectral imagery for scientific investigation.**

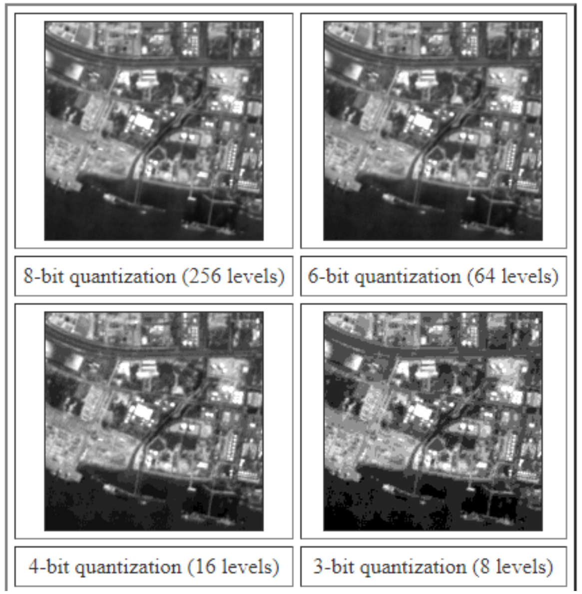
Spatial Resolution



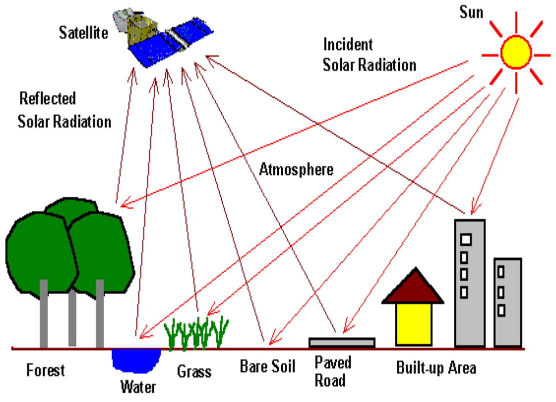
- Spatial resolution is the smallest object size that can be resolved on the ground.
- In digital images, resolution is limited by pixel size.
- Intrinsic resolution is determined by the sensor's instantaneous field of view (IFOV).
- Other factors like improper focusing, atmospheric scattering, and target motion can degrade intrinsic resolution.
- A "High Resolution" image refers to one with a small resolution size. Fine details can be seen in a high-resolution image. On the other hand, a "Low Resolution" image is one with a large resolution size, i.e. only coarse features can be observed in the image.

Radiometric Resolution

Radiometric Resolution refers to the smallest change in intensity level that can be detected by the sensing system. The intrinsic radiometric resolution of a sensing system depends on the signal to noise ratio of the detector. In a digital image, the radiometric resolution is limited by the number of discrete quantization levels used to digitize the continuous intensity value.



Optical and Infrared Remote Sensing

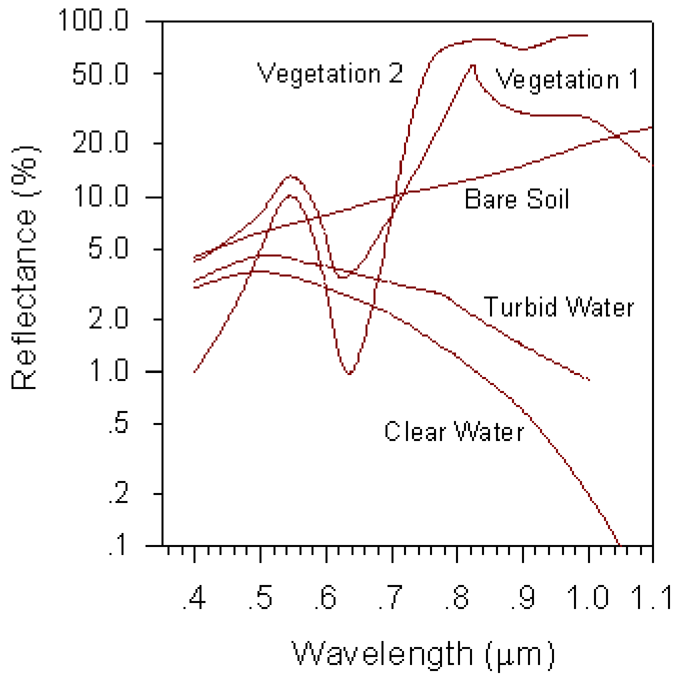


- **Optical remote sensing uses sensors to detect solar radiation reflected or scattered from Earth.**
- **The wavelength region extends from visible and near-infrared (VNIR) to short-wave infrared (SWIR).**
- **Different materials reflect visible and infrared light differently.**
- **Interpretation of optical images requires knowledge of spectral reflectance signatures.**
- **Infrared sensors measure thermal radiation emitted from Earth, enabling temperature derivation of land or sea surfaces.**

Spectral Reflectance Signature

When solar radiation hits a target surface, it may be transmitted, absorbed or reflected. Different materials reflect and absorb differently at different wavelengths. The reflectance spectrum of a material is a plot of the fraction of radiation reflected as a function of the incident wavelength and serves as a unique signature for the material. In principle, a material can be identified from its spectral reflectance signature if the sensing system has sufficient spectral resolution to distinguish its spectrum from those of other materials. This premise provides the basis for multispectral remote sensing.

The following graph shows the typical reflectance spectra of five materials: clear water, turbid water, bare soil, and two types of vegetation.



Reflectance Spectrum of Five Types of Landcover

Interpreting Optical Remote Sensing Images

Four main types of information contained in an optical image are often utilized for image interpretation

- Radiometric Information (i.e. brightness, intensity, tone),
- Spectral Information (i.e. color, hue),
- Textural Information,
- Geometric and Contextual Information.

Interpreting Optical Remote Sensing Images

Panchromatic Images

A panchromatic image consists of only one band. It is usually displayed as a grey scale image, i.e. the displayed brightness of a particular pixel is proportional to the pixel digital number which is related to the intensity of solar radiation reflected by the targets in the pixel and detected by the detector. Thus, a panchromatic image may be similarly interpreted as a black-and-white aerial photograph of the area. The Radiometric Information is the main information type utilized in the interpretation.

Interpreting Optical Remote Sensing Images

True Color Composite

If a multispectral image consists of the three visual primary color bands (red, green, blue), the three bands may be combined to produce a "true color" image. For example, the bands 3 (red band), 2 (green band), and 1 (blue band) of a LANDSAT TM image or an IKONOS multispectral image can be assigned respectively to the R, G, and B colors for display. In this way, the colors of the resulting color composite image resemble closely what would be observed by the human eyes.

Interpreting Optical Remote Sensing Images

Vegetation Indices

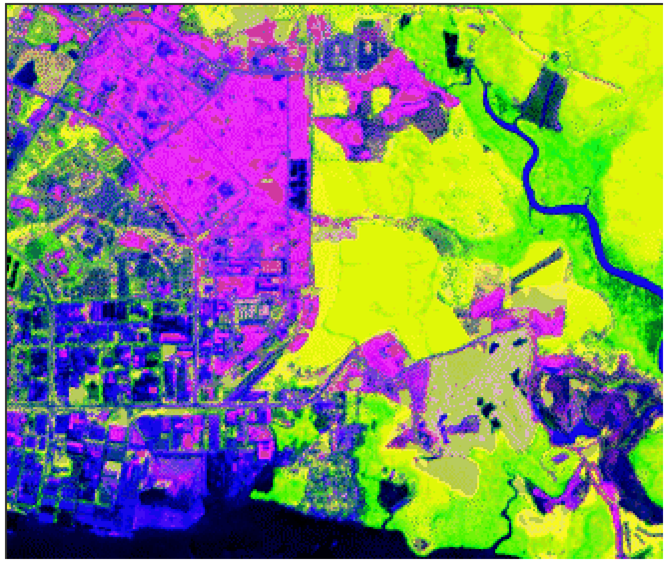
Different bands of a multispectral image may be combined to accentuate the vegetated areas. One such combination is the ratio of the near-infrared band to the red band. This ratio is known as the <u>Ratio Vegetation Index (RVI)</u>

RVI = NIR/Red

Since vegetation has high NIR reflectance but low red reflectance, vegetated areas will have higher RVI values compared to non-vegetated aeras. Another commonly used vegetation index is the Normalized Difference Vegetation Index (NDVI) computed by

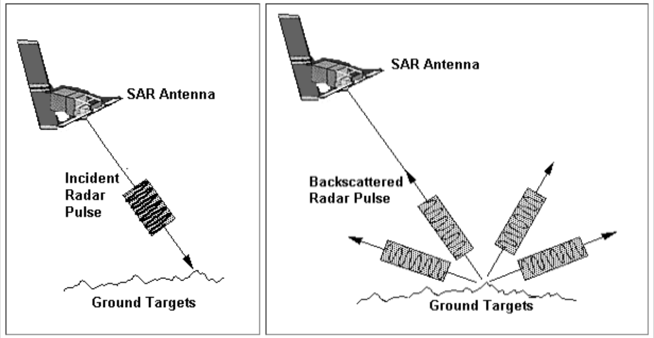
NDVI = (NIR - Red)/(NIR + Red)areas

In the NDVI map shown, the bright areas are vegetated while the non vegetated areas (buildings, clearings, river, sea) are generally dark. Note that the trees lining the roads are clearly visible as grey linear features against the dark background.



The NDVI band may also be combined with other bands of the multispectral image to form a color composite image which helps to discriminate different types of vegetation. One such example is shown.

Microwave Remote Sensing



A radar pulse is transmitted from the antenna to the ground

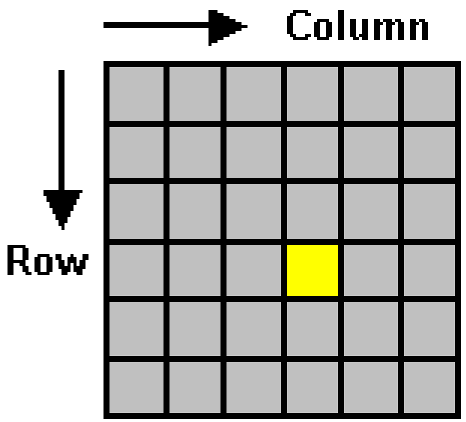
The radar pulse is scattered by the ground targets back to the antenna.

- Some remote sensing satellites carry passive or active microwave sensors.
- Active sensors emit pulses of microwave radiation to illuminate areas for imaging.
- Images are formed by measuring microwave energy scattered back to the sensors.
- These satellites operate like "flashlights," emitting microwaves to illuminate targets.
- Microwave imaging allows acquisition of images day and night, and can penetrate clouds.
- Synthetic Aperture Radar (SAR) is a high-resolution microwave imaging system.
- SAR image intensity depends on microwave backscatter received by the antenna.
- Interpretation of SAR images requires understanding how microwaves interact with targets.

Microwave Remote Sensing

- Electromagnetic radiation in the microwave wavelength region is used in remote sensing to provide useful information about the Earth's atmosphere, land, and ocean.
- A microwave radiometer is a passive device that records the natural microwave emission from the earth. It can be used to measure the total water content of the atmosphere within its field of view.
- A radar altimeter sends out pulses of microwave signals and records the signal scattered back from the earth’s surface. The height of the surface can be measured from the time delay of the return signals.
- A wind scatterometer can be used to measure wind speed and direction over the ocean surface. it sends out pulses of microwaves along several directions and records the magnitude of the signals backscattered from the ocean surface.

Remote Sensing Images

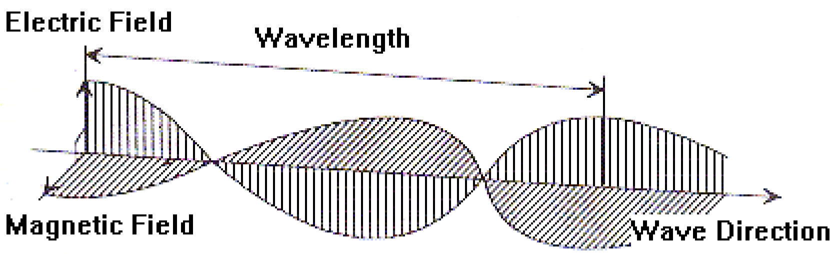


- Remote sensing images are typically in digital form.
- Image processing techniques are used to extract useful information.
- Techniques include enhancement, correction, and restoration of images.
- Methods depend on specific problem requirements.
- Image segmentation and classification algorithms are commonly used.
- These algorithms delineate different areas into thematic classes. Thematic maps are produced as a result. Thematic maps can be combined with other databases for further analysis.

Electromagnetic Radiation

Electromagnetic waves are energy transported through space in the form of periodic disturbances of electric and magnetic fields. All electromagnetic waves travel through space at the same speed, c = 2.99792458 x 10^8 m/s, commonly known as the speed of light. An electromagnetic wave is characterized by a frequency and a wavelength. These two quantities are related to the speed of light by the equation,

$$\text{speed of light} = \text{frequency} \times \text{wavelength}$$

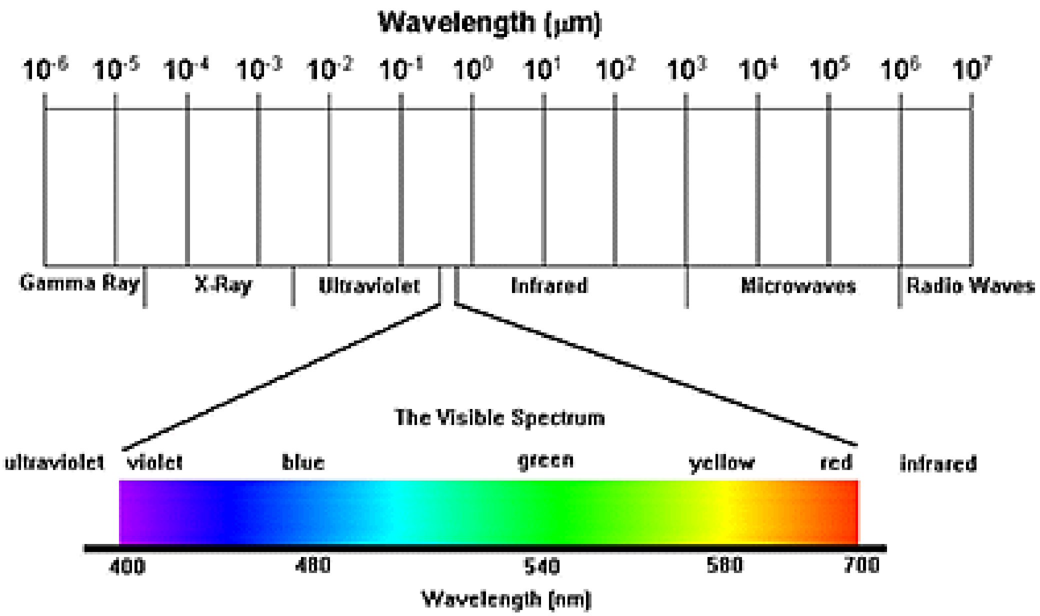


Electromagnetic Radiation

The frequency of an electromagnetic wave depends on its source. There is a wide range of frequency encountered in our physical world, ranging from the low frequency of the electric waves generated by the power transmission lines to the very high frequency of the gamma rays originating from the atomic nuclei. This wide frequency range of electromagnetic waves constitutes the Electromagnetic Spectrum.

Electromagnetic Spectrum

- The electromagnetic spectrum comprises various wavelength (frequency) regions.
- Only a narrow band from about 400 to 700 nm is visible to human eyes.
- Boundaries between these regions are approximate and can overlap.
- There is no sharp boundary between adjacent regions.



Wavelength units: 1 mm = 1000 µm; 1 µm = 1000 nm.

Image Pre-Processing

- Once an image is acquired it is generally processed to eliminate errors

Geometric correction

Radiometric correction

Geometric Correction

Sources of distortion

- Variations in altitude
- Variations in velocity
- Earth curvature
- Relief displacement
- Atmospheric refraction
- Skew distortion from earth’s eastward rotation

Geometric Correction

Raw digital images contain two types of geometric distortions are systematic and random

- **Systematic sources are understood and can be corrected by applying formulas.**

- **Random distortions, or ‘residual unknown systematic distortions are corrected using multiple regression of ground control points that are visible from the image.**

Radiometric Correction

Radiance measured at a given point is influenced by

- **Changes in illumination**
- **Atmospheric conditions (haze, clouds)**
- **Angle of view**
- **Instrument response characteristics**
- **Elevation of the sun (seasonal change in sun angle)**
- **Earth-sun distance variation**

Image enhancement

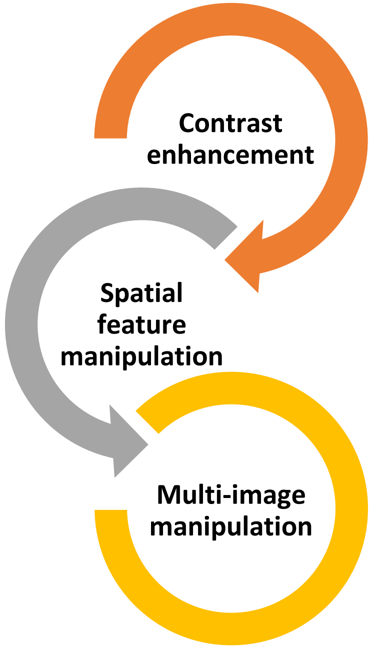
- Improving image quality, particularly contrast It includes a number of methods used for enhancing subtle radiometric differences so that the eye can easily perceive them.

Two types: point and local operations

- Point: modify the brightness value of a given pixel independently
- Local: modify pixel brightness based on neighborhood brightness values

Image enhancement

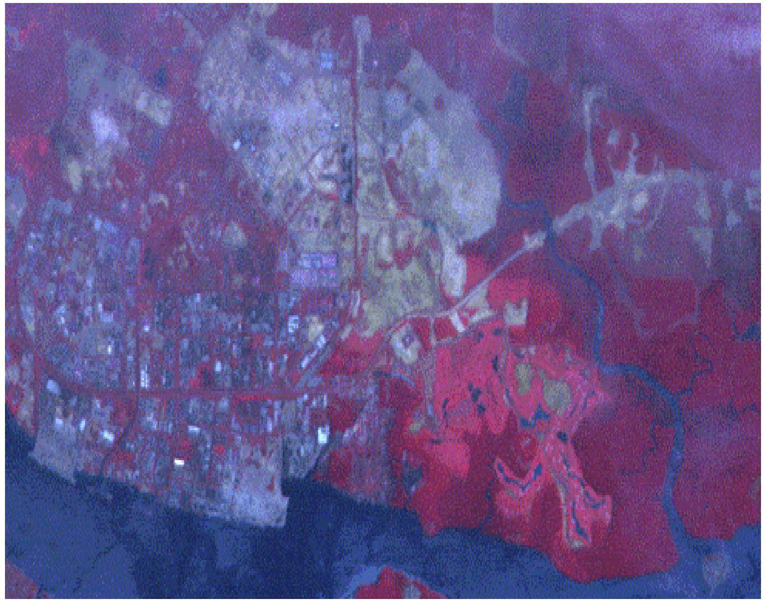
Three types of manipulation are



- **Methods include gray level thresholding, level slicing and contrast stretching.**
- **Methods include spatial filtering, edge enhancement and Fourier analysis.**
- **Methods include multispectral band rationing and differencing, principal components, canonical components, vegetative components, decorrelation stretching, and others.**

Contrast enhancement

The image on the left is hazy because of atmospheric scattering; the image is improved (right) through the use of Gray level thresholding. Note that, If there is more contrast and features can be better extracted.



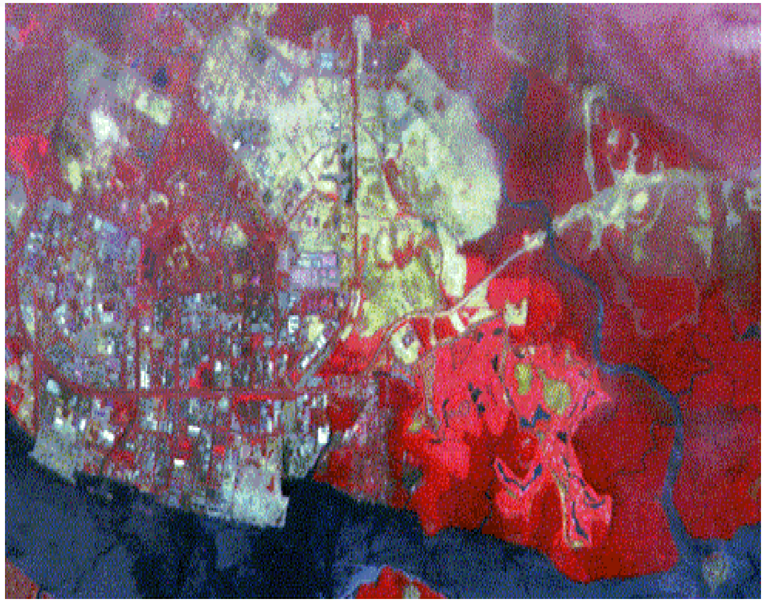
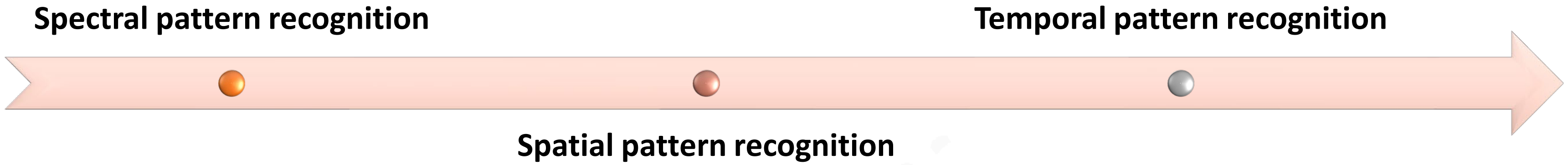


Image classification



- **Spectral pattern recognition classifies a pixel based on its pattern of radiance measurements in each band: more common and easy to use**
- **Spatial pattern recognition classifies a pixel based on its relationship to surrounding pixels: more complex and difficult to implement**
- **Temporal pattern recognition: looks at changes in pixels over time to assist in feature recognition**

Spectral Classification

Two types of classification

- **Supervised:**

The analyst designates on-screen "training areas" known land cover type from which an interpretation key is created, describing the spectral attributes of each cover class. Statistical techniques are then used to assign pixel data to a cover class, based on what class its spectral pattern resembles.

Spectral Classification

- **Unsupervised:**

Automated algorithms produce spectral classes based on natural groupings of multi-band reflectance values (rather than through designation of training areas), and the analyst uses reference data, such as field measurements, DOQs or GIS data layers to assign areas to the given classes.

Spectral Classification

Unsupervised:

- Computer groups all pixels according to their spectral relationships and looks for natural spectral groupings of pixels, called spectral classes
- Assumes that data in different cover classes will not belong to the same grouping
- Once created, the analyst assesses their utility

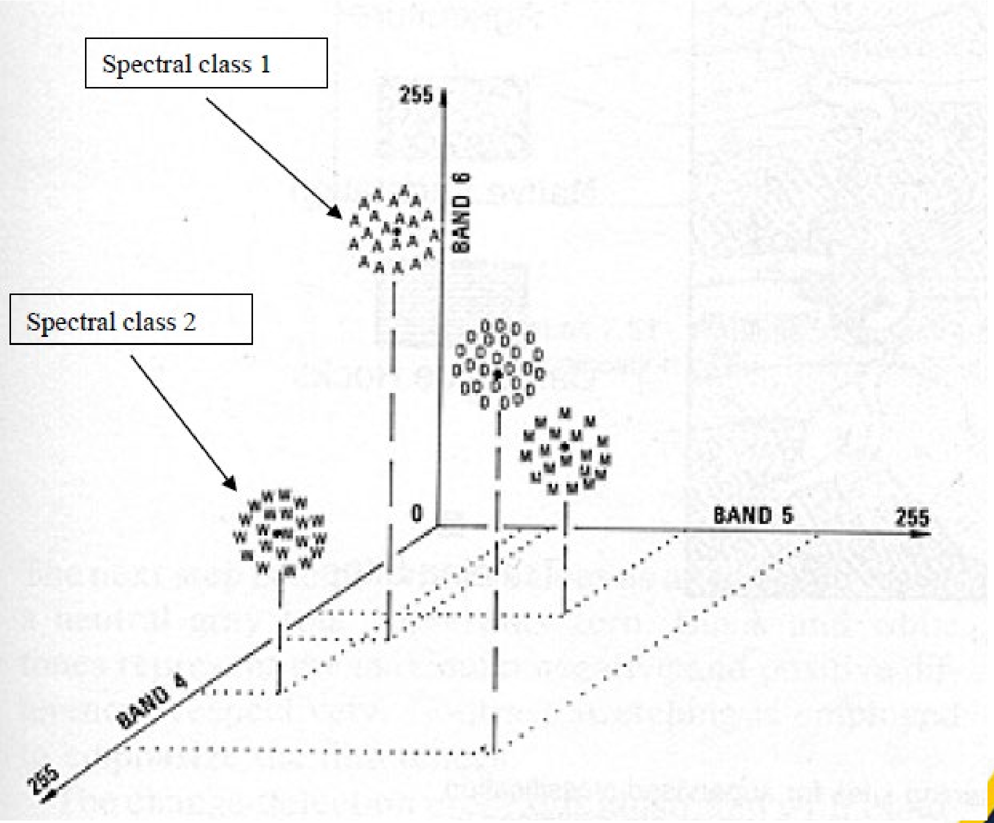


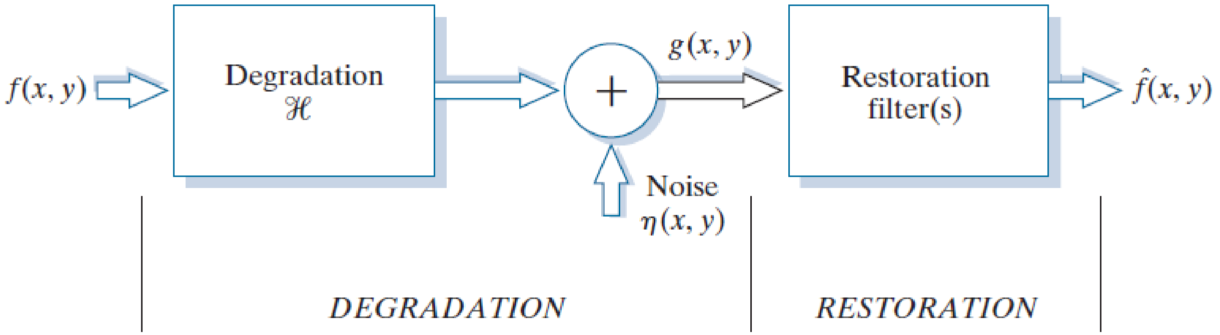
Image Restoration

Restoration techniques are oriented toward modeling the degradation and applying the inverse process in order to recover the original image.

Noise Models

- Digital images can be affected by noise during image acquisition or transmission.
- Imaging sensors' performance is influenced by environmental factors during acquisition and the quality of sensing elements.

- Factors like light levels and sensor temperature can impact the amount of noise in images captured with a CCD camera.
- Transmission channels can introduce interference, corrupting images during transmission.
- Examples of interference during transmission include disturbances like lightning or atmospheric conditions in wireless networks.



Mean Filters

Arithmetic Mean Filter

The arithmetic mean filter computes the average value of the corrupted image, g(x, y), in the area defined by S_{xy}. The value of the restored image f̂ at point (x, y) is the arithmetic mean computed using the pixels in the region defined by S_{xy}.

$$\hat{f}(x,y) = \frac{1}{mn} \sum_{(r,c)\in S_{xy}} g(r,c)$$

Mean Filters

Geometric Mean Filter

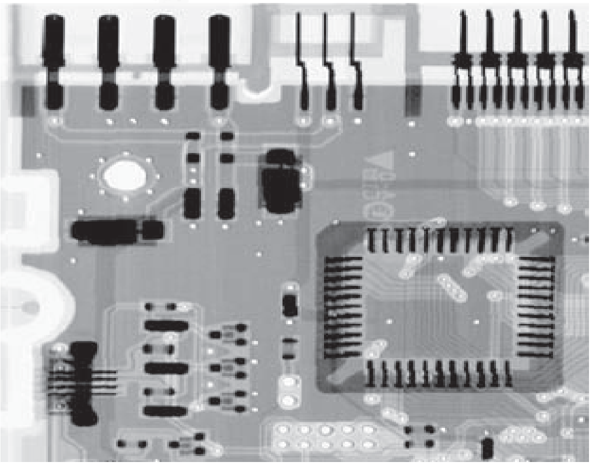
$$\hat{f}(x,y) = \left[\prod_{(r,c) \in S_{xy}} g(r,c) \right]^{\frac{1}{mn}}$$

Harmonic Mean Filter

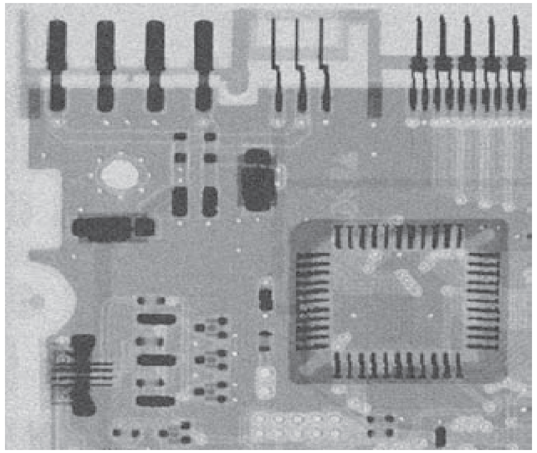
$$\hat{f}(x,y) = \frac{mn}{\sum_{(r,c) \in S_{xy}} \frac{1}{g(r,c)}}$$

Contraharmonic Mean Filter

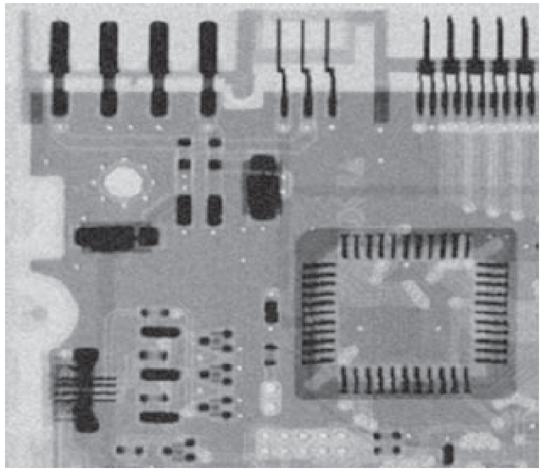
$$\hat{f}(x,y) = \frac{\sum_{(r,c) \in S_{xy}} g(r,c)^{Q+1}}{\sum_{(r,c) \in S_{xy}} g(r,c)^{Q}}$$



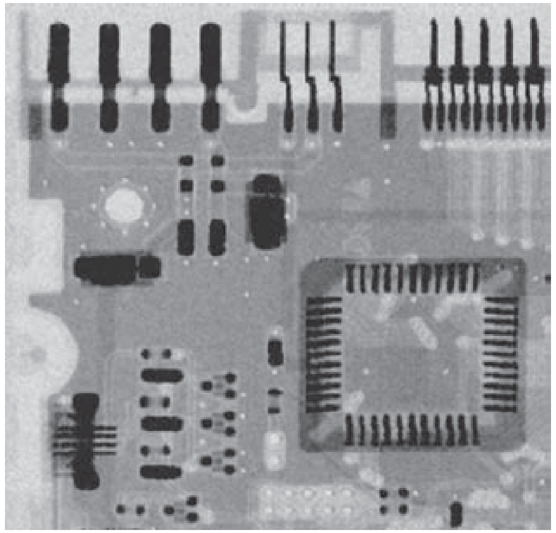
(a) X-ray image of circuit board.



(b) Image corrupted by additive Gaussian noise.



(c) Result of filtering with an arithmetic mean filter of size 3 × 3.



(d) Result of filtering with a geometric mean filter of the same size.

Image Compression

For transferring images to other devices or due to computational storage constraints, images need to be compressed and cannot be kept at their original size.

Morphological Processing

Image components that are useful in the representation and description of shapes need to be extracted for further processing or downstream tasks. For example, erosion and dilation operations are used to sharpen and blur the edges of objects in an image, respectively.

Image Segmentation

This step involves partitioning an image into different key parts to simplify and/or change the representation of an image into something that is more meaningful and easier to analyze. Image segmentation allows for computers to put attention on the more important parts of the image, discarding the rest, which enables automated systems to have improved performance.

REFERENCES

- https://crisp.nus.edu.sg/~research/tutorial/rsmain.htm
- Gonzalez, R. C., Woods, R. E. (1992). Digital image processing. United Kingdom: Addison-Wesley.,https://www.google.co.in/books/edition/Digital_Image_Processing/C_FRAAAAMAAJ?hl=en&gbpv=0&bsq=Image%20processing

CONCLUSION

- Provided an overview of the remote sensing technology.
- Explored various methods and approaches employed in remote sensing applications.
- Discussed the capture of images using optical, infrared, and microwave technologies in remote sensing.
- Introduced the process of manipulating and enhancing remote sensing images for analysis.
- Explored techniques for improving the quality of degraded or damaged remote sensing images.
- Discussed methodologies for interpreting and extracting meaningful information from remote sensing images.


THANK YOU

MINE AUTOMATION AND DATA ANALYTICS

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SWAYAM NPTEL COURSE ON

MINE AUTOMATION AND DATA ANALYTICS

By

Prof. Radhakanta Koner
Department of Mining Engineering
Indian Institute of Technology (Indian School of Mines) Dhanbad

Module 06
Automated tracking and VR systems

Lecture 13 B
Automated communication and tracking technologies: Image processing

CONCEPTS COVERED

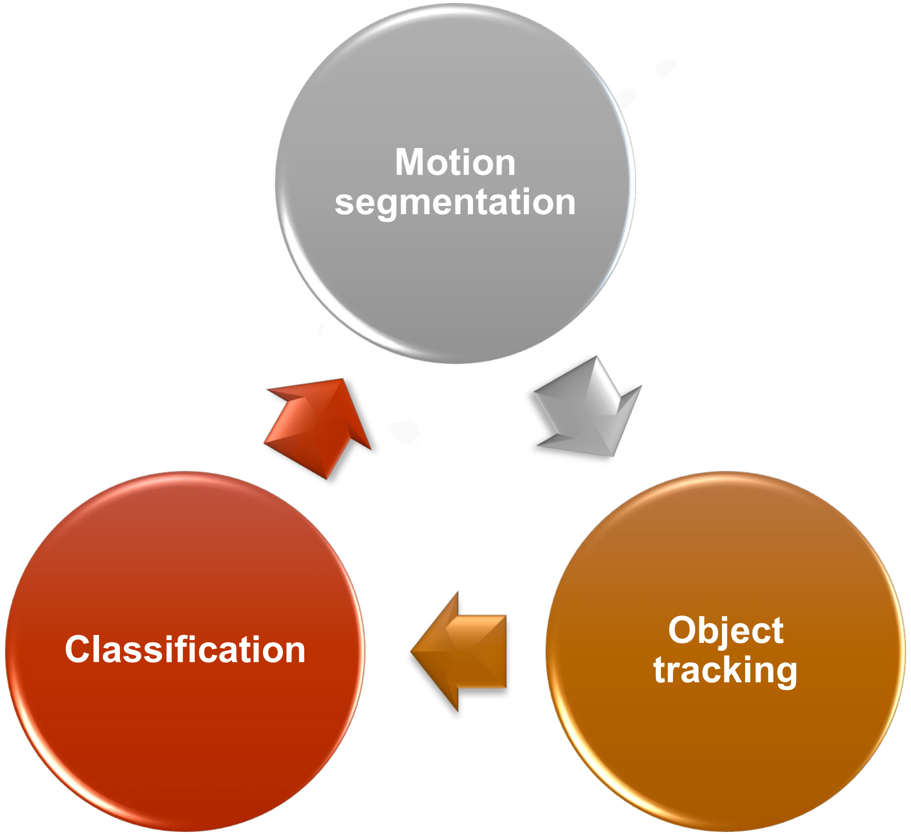
- Introduction to Automated Communication and Tracking Technology
- Case study: Real-Time Object Detection and Tracking for Unmanned Aerial Vehicles Based on Convolutional Neural Networks

Automated Communication and Tracking Technology

- Image processing is a form of processing with input as image such as photograph or video frame and output can be characteristics or parameters related to image.
- Computer vision is an area that consists of methods for incorporating, analyzing and visualizing images.
- Surveillance stands for monitoring the behaviour, activities, and other changing information, usually of people for the purpose of influencing, directing and protecting them.

- **The process of locating moving object using a camera is video tracking.**
- **In simple terms, tracking means associate target objects in consecutive video frames.**
- **Difficulties arise especially when objects are moving rapidly as compared to frame rate or when the tracked object changes direction over time.**
- **A sequential flow of object detection, object tracking, object identification and its behavior completes the process framework of tracking.**

Object tracking in video surveillance is a very important aspect of computer vision and pattern recognition. The common architecture of classification consists of three main steps are



Step-1 Motion segmentation

- Object detection is a computer vision technology that deals with identifying instances of objects such as humans, vehicles, animals or birds and other moving objects. Object detection is one of the initial steps for object tracking.
- A video surveillance system for stationary cameras generally includes some part of motion detection.

Background Subtraction

Temporal Differencing

Optical Flow

Step-2 Object classification

Classification is a process in which individual items like objects, patters, image regions, pixels, etc. are grouped based on the similarity between the item and the description of the group. In general, object classification in video surveillance are

- Shape-Based Classification
- Motion-Based Classification
- Color-Based Classification
- Texture-Based Classification

Step-3 Object tracking

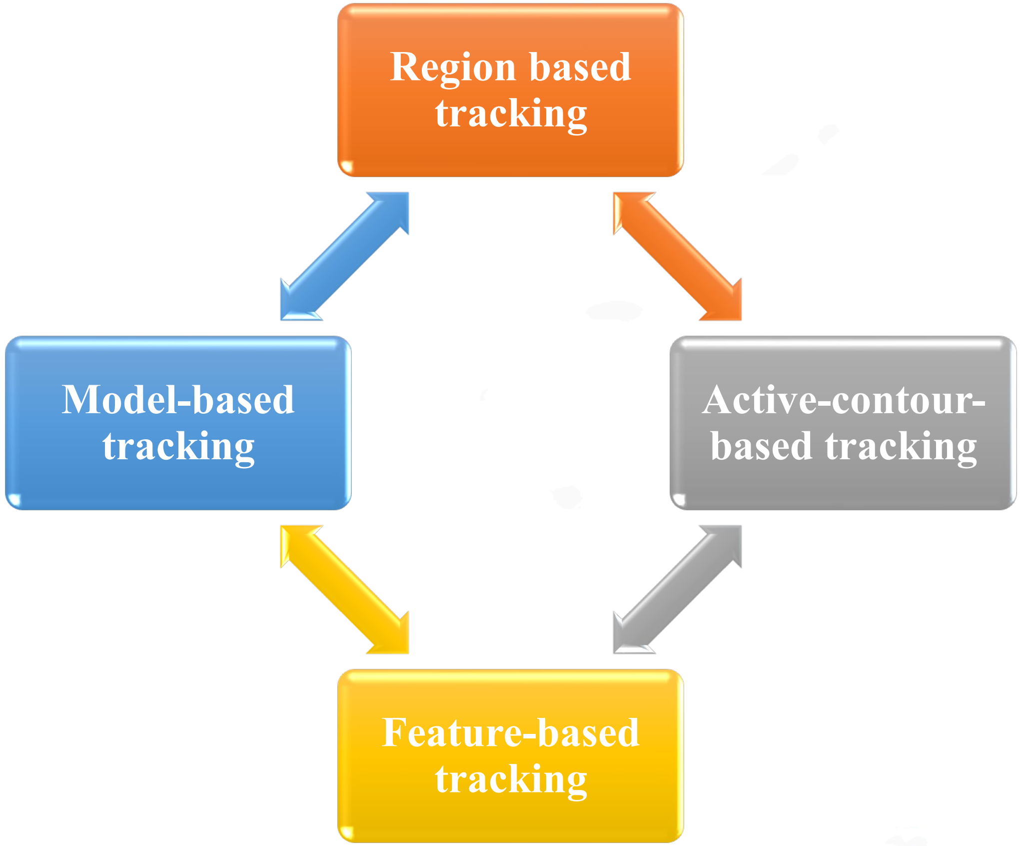
- In simple terms tracking is the problem of estimating the trajectory of an object in the image plane as it moves around a scene.

- Depending upon tracking domain, method and algorithm, a tracker can also provide object centric information like area, orientation and shape of an object. Once objects are detected, the next task in video surveillance process is to track the objects from one frame to another.

- Tracking objects can be complex due to complex object shapes, object motion, non-rigid nature of object, scene illumination changes, partial or full object occlusions, etc.

Step-3 Object tracking

Tracking procedures are mainly divided into four types



Real-Time Object Detection and Tracking for Unmanned Aerial Vehicles Based on Convolutional Neural Networks

- In this work, the target object for detection is a person.
- In this study, utilize the ROS (Robot Operating System) to implement image detection and tracking for controlling UAVs.
- Hardware required laptop, lightweight models.
- For the object detector, train a convolutional neural network based on the YOLOv4 architecture.

- This study employ the pruned version of the YOLOv4 object detector and the SiamMask monocular object tracker to detect and track the target person captured by the camera of the drone.

- This object detection system consists of four main components:

I. Object detection

II. Target tracking

III. Proportional Integral Derivative (PID) control

IV. The UAV driver package

- This study utilize the Tello drone for implementing the object detection and tracking system.
- During the tracking process, the UAV control parameters include the roll, pitch, yaw, and altitude, all of which are controlled using PID controllers.
- These PID controllers take the position and distance of the target object as inputs.
- The position and distance are calculated using the monocular front-facing camera of the UAV.

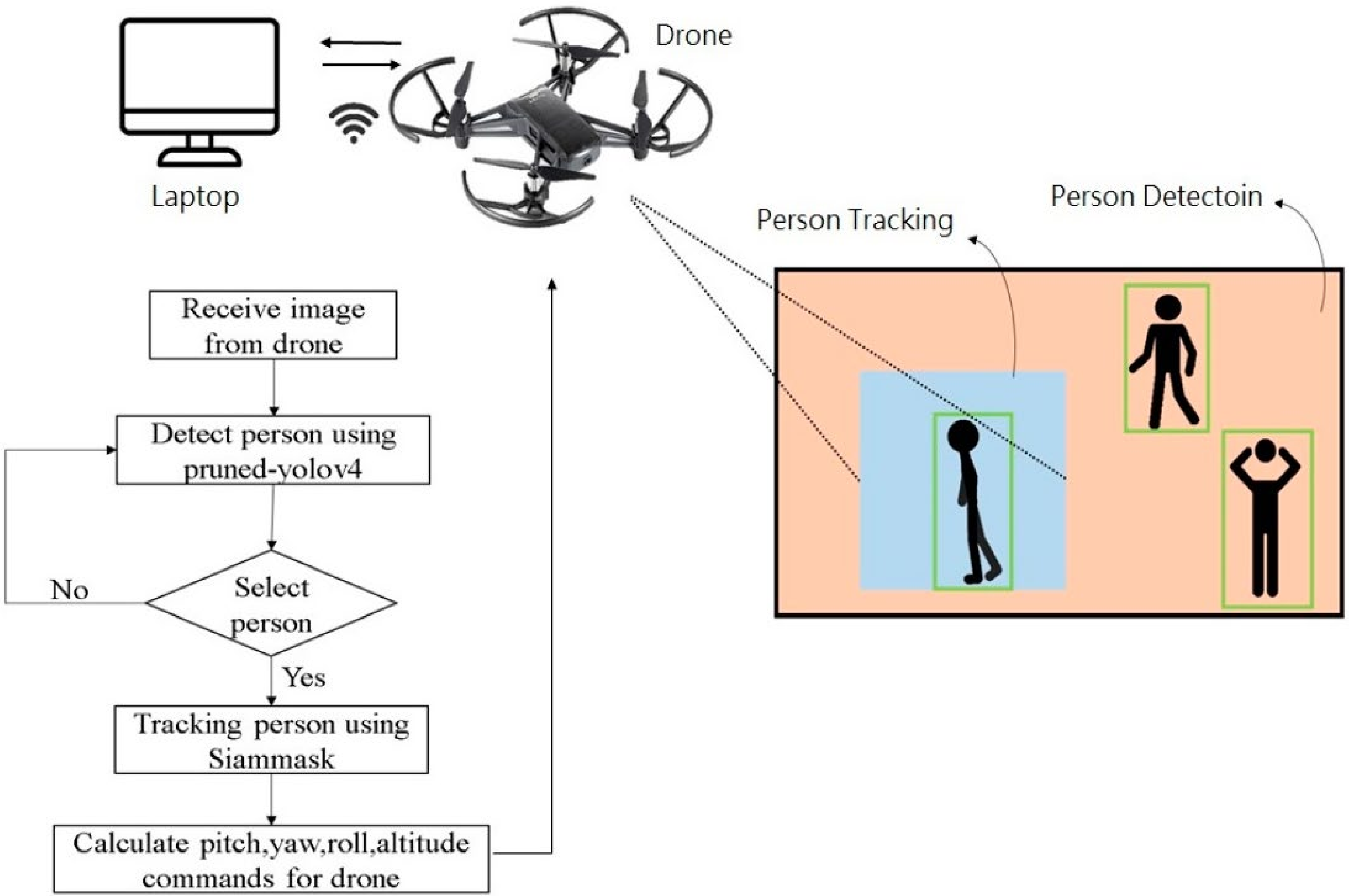
Approach

Introduction to Framework Methods

- **Proposed framework- object detection, model pruning, and visual tracking.**

System Setup and Communication

- **A laptop computer (PC) communicates with the Tello drone via Wi-Fi.**
- **The drone transmits images at a constant frequency of 30 Hz, processed using a pruned version of the YOLOv4 algorithm for object detection.**


Drone
Laptop
Person Tracking
Person Detectoin
Receive image from drone
Detect person using pruned-yolov4
Select person
No
Yes
Tracking person using Siammask
Calculate pitch,yaw,roll,altitude commands for drone

Object Detection and User Interaction

- Users can select bounding boxes based on their requirements for object detection.
- Pruned-YOLOv4 is utilized for person detection, with detected bounding boxes displayed on the screen.

Object Tracking with SiamMask

- The system employs the Siamese network, SiamMask, for object tracking.
- A tracking algorithm based on a PID controller estimates roll, pitch, yaw, and altitude based on the tracked object's position and distance.

User Interaction and Object Selection

- Users can select a specific object of interest by clicking on its bounding box.
- The system extracts the person within that bounding box as a template frame for the SiamMask network to enable subsequent tracking.

Flight Commands Generation

- The tracking algorithm calculates the error between the target and the center of the frame.
- This error serves as input for the PID controller to generate flight commands for yaw, roll, and altitude adjustments.

Handling No Target Detection

- If no target is detected, the drone maintains its position until a target appears in the image feed.
- This ensures stability and prevents unnecessary movements when no object of interest is present.

Hardware Specifications

Introduction to DJI Tello Drone

- The DJI Tello drone is a small and easy-to-control consumer-grade drone suitable for both indoor and outdoor use.
- It has dimensions of approximately 98 × 92 cm and weighs around 80 g.

Drone Features

- Equipped with various sensors including a 3-axis gyroscope, a 3-axis accelerometer, a 3-axis magnetometer, a pressure sensor, and an ultrasonic altitude sensor.
- Features a front-facing camera with a resolution of 1280 × 720, capable of capturing video at 30 frames per second.

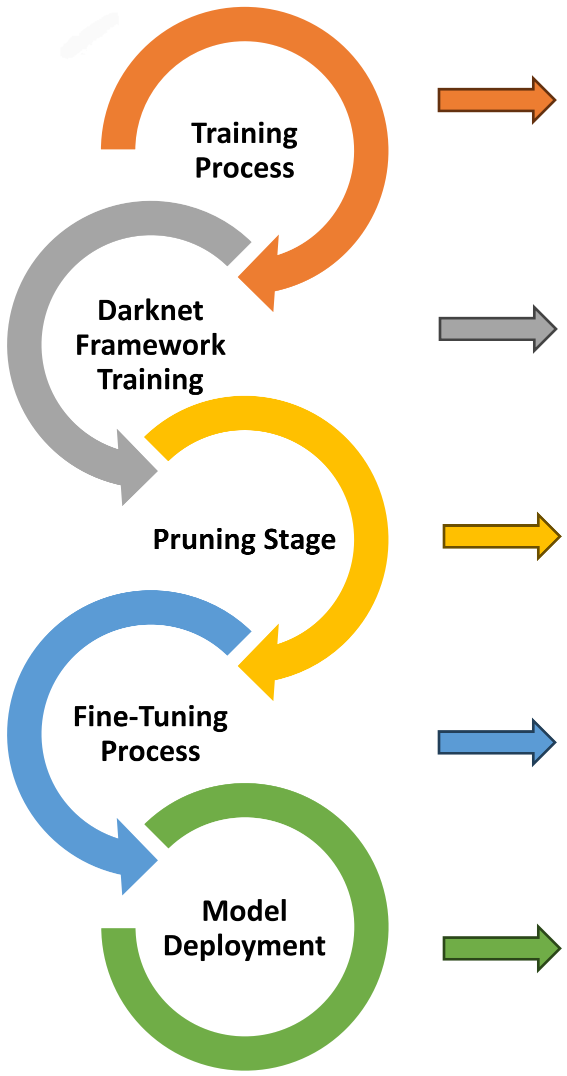
Communication and Connectivity

- The Tello drone can communicate with other devices such as smartphones or laptops via a Wi-Fi network.

Usage in Study

- In this particular study, a PC was used for communication with the Tello drone.
- This setup allows for data exchange and control of the drone's functions during experiments or applications.

Detection Model Pruning and Object Detection



The object detection process begins with the training of the model

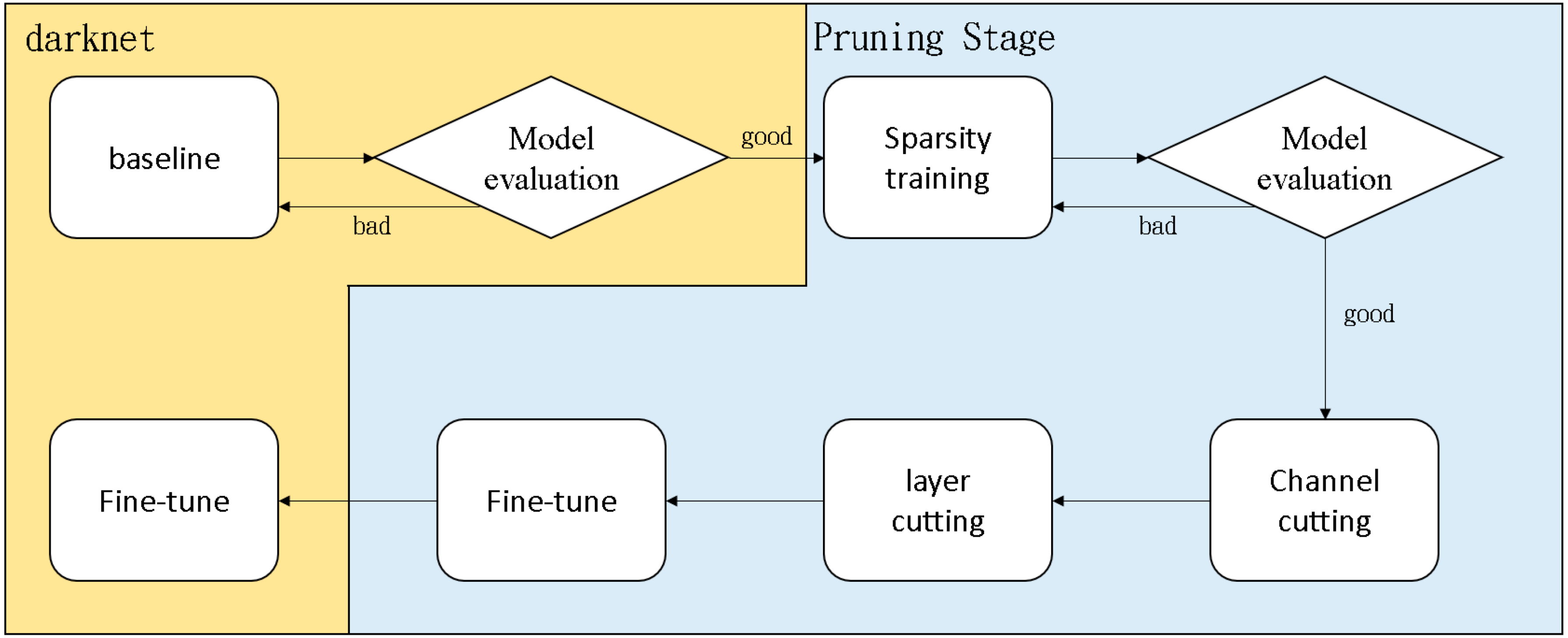
Initially, the Darknet framework is employed to train the YOLOv4 base model

Various techniques such as sparse training, channel pruning, layer pruning, and fine-tuning are applied to the base model using the Darknet framework.

Fine-tuning helps in optimizing the model's performance and accuracy further.

This deployment allows for real-world applications of the trained model in detecting objects efficiently.

Detection Model Pruning and Object Detection



Darknet Training

Training with Darknet Framework and YOLOv4

- The Darknet framework is utilized for training the YOLOv4 model, with adjustments made to various hyperparameters to enhance accuracy and performance.

Adjusting Input Size

- One crucial hyperparameter adjusted is the input size of the network, impacting the model's ability to detect small objects.
- Increasing the input size aids in detecting small objects but may slow down inference speed and consume more GPU memory.

- The YOLOv4 network downsamples the input size by a factor of 32, necessitating input width and height to be multiples of 32.
- In this study, the input size is set to 416 × 416 to ensure compatibility with the network.

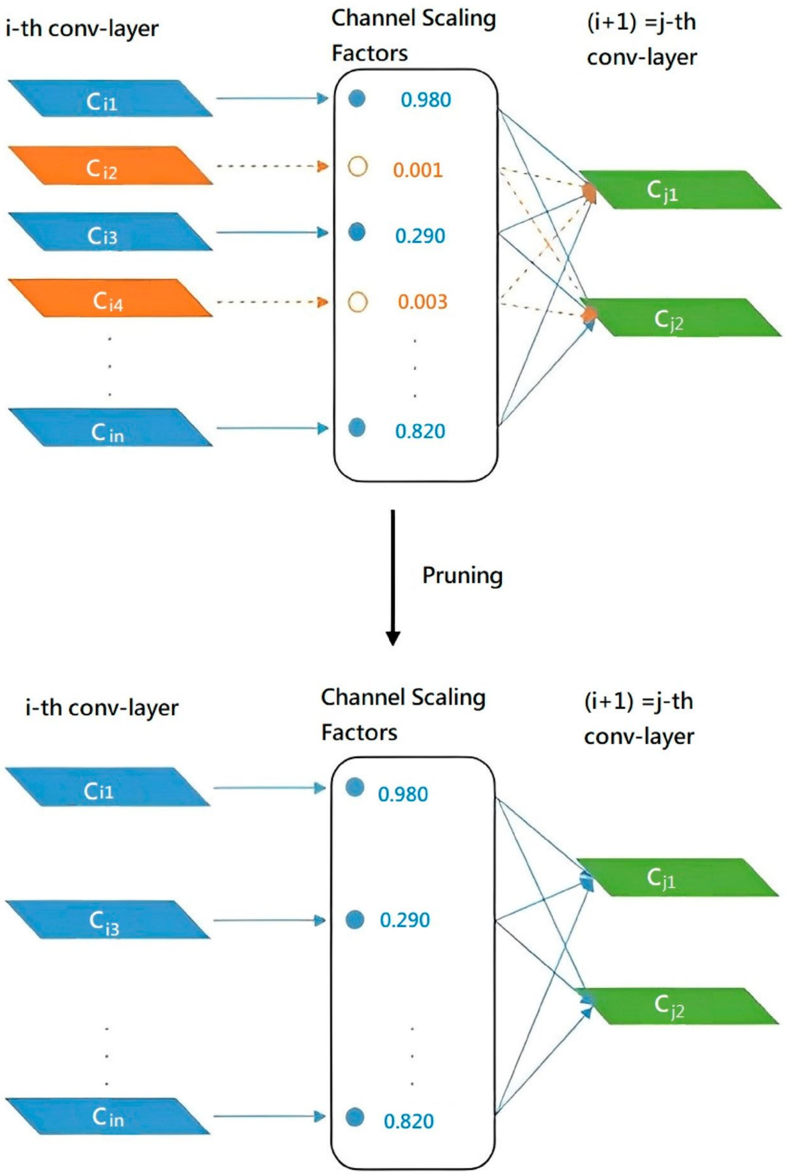
Batch Size and Subdivisions

- The batch size and subdivisions hyperparameters are adjusted based on GPU performance.
- Batch size represents the number of images loaded during training, typically set to 64.
- If GPU memory is insufficient, each batch is subdivided into smaller sub-batches to fit into memory.

- In this study, the batch size is set to 64, with subdivisions set to 8, optimizing GPU memory usage.

Number of Iterations

- Training in the Darknet framework is measured in iterations, not epochs.
- Each object class should ideally have at least 2000 iterations for effective training.
- With only one class, the number of iterations is set to 2200 to ensure sufficient training for higher accuracy and performance.



Pruning Stage

Basic Training and Pruning Strategy

- **Before pruning, weights from the Darknet framework undergo basic training.**
- **The pruning strategy is employed for model pruning, focusing on achieving channel sparsity in deep models.**

Sparse Training and Channel Pruning

- **Sparse training is conducted on the model, with L1 regularization applied to scaling factors associated with each channel in convolutional layers.**

- This regularization helps identify unimportant channels, which are subsequently pruned based on their scaling factor values.

Compact Model Generation

- After pruning, a compact model is obtained, potentially sacrificing some less important channels for reduced model size and complexity.
- This compact model is then fine-tuned to achieve comparable or even higher accuracy compared to the fully trained network.

Sparsity Training

Introduction to Batch Normalization (BN) Layer

A Batch Normalization (BN) layer is added after each convolutional layer in YOLOv4 to expedite convergence and enhance generalization.

Normalization Process

The BN layer normalizes convolutional features using batch statistics, represented by the equation

$$y = \gamma \times \frac{x - \bar{x}}{\sqrt{\sigma^2 + \varepsilon}} + \beta$$

Here, $\bar{X}$ and $\sigma 2$ represent the mean and variance of the input features in the mini-batch, respectively. γ and β represent the trainable scale factor and bias in the BN layer.

Indicator of Channel Importance

The scale factor (γ) in the BN layer is utilized as an indicator of channel importance. L1 regularization is applied to γ to facilitate channel-level sparse training, distinguishing between important and unimportant channels effectively.

Sparse Training Loss Function

The loss function for sparse training incorporates L1 regularization on γ and is expressed as

$$L = loss_{yolo} + \alpha \sum_{\gamma \in \Gamma} f(\gamma)$$

Here, f(γ) represents the L1 norm applied to γ, and α is the penalty factor balancing the two loss terms.

Benefits of Sparse Training

- Pruning effectiveness relies on the sparsity of the model.
- Sparse training compresses most γ values in the BN layer towards zero, leading to two benefits:
    1) Improved model efficiency through network pruning and compression, reducing computational complexity.
    2) Identification and pruning of parameters with minimal impact on network performance by sparsifying weights close to zero

Channel cutting

- Following the completion of sparse training, the process of channel cutting is initiated to further optimize the model.
- The total number of channels in the backbone is computed to establish the basis for channel cutting.
- Corresponding γ values are extracted and stored in a variable, then sorted in ascending order.
- The decision of which channels to retain and which to prune is based on a predefined pruning rate.
- The pruning rate, typically a value between 0 and 1, determines the proportion of channels to be pruned. A higher pruning rate signifies a greater degree of pruning.

Fine-tuning

Necessity of Fine-Tuning

- In cases where pruning adversely affects model accuracy, fine-tuning becomes essential to restore the pruned model's accuracy.
- Fine-tuning plays a crucial role in mitigating accuracy loss caused by pruning, thereby enhancing the overall performance of the pruned model.

Importance of Fine-Tuning

- Fine-tuning allows for the adjustment of model parameters and optimization of the pruned model for improved accuracy.

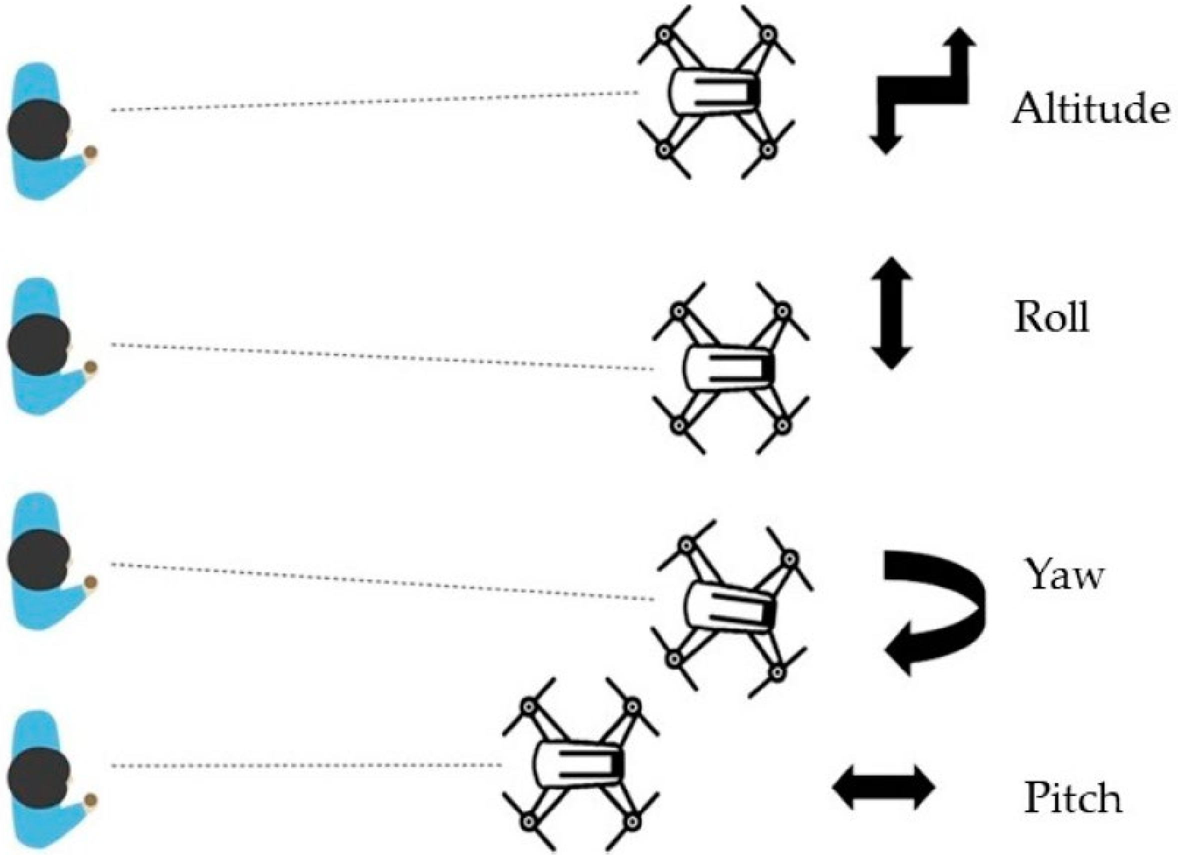
- **It ensures that the pruned model maintains its effectiveness in performing its intended task, such as object detection.**

- ## Experimental Approach

- **In the conducted experiments, the Pruned-YOLOv4 model was retrained using the same training hyperparameters as the normal training process for YOLOv4.**

- **This approach ensures consistency and facilitates comparison between the pruned and original models, enabling a comprehensive evaluation of their performance.**

Fundamental maneuvers of a drone



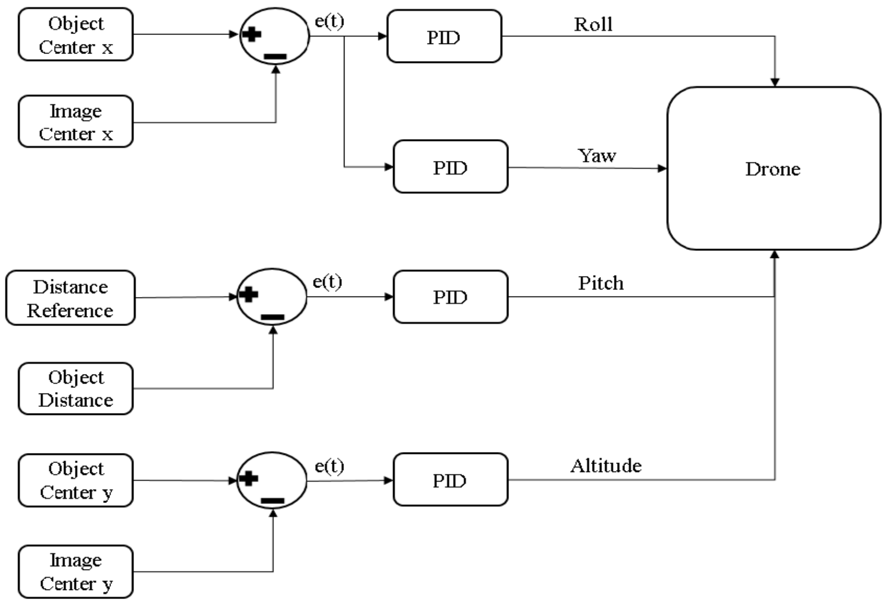
Control scheme for the drone

Error Calculation for X-Axis

- By comparing the center point of the tracked object with the center point of the screen, the error in the X-axis is determined.
- This error corresponds to the drone's roll for lateral movement and yaw for clockwise or counterclockwise rotation.

X-Axis Error Handling

If the drone detects lateral movement of the object, adjustments can be made to the drone's heading to face the object or perform lateral movements to maintain alignment.



Error Calculation for Pitch Axis

- The pitch axis involves forward and backward movements.
- By comparing the distance between the drone and the real object with the desired ideal distance, the distance error is calculated to control the drone's forward or backward movements accordingly.

Pitch Axis Error Handling

Adjustments are made based on the calculated distance error to control the drone's forward or backward movements and maintain desired proximity to the tracked object.

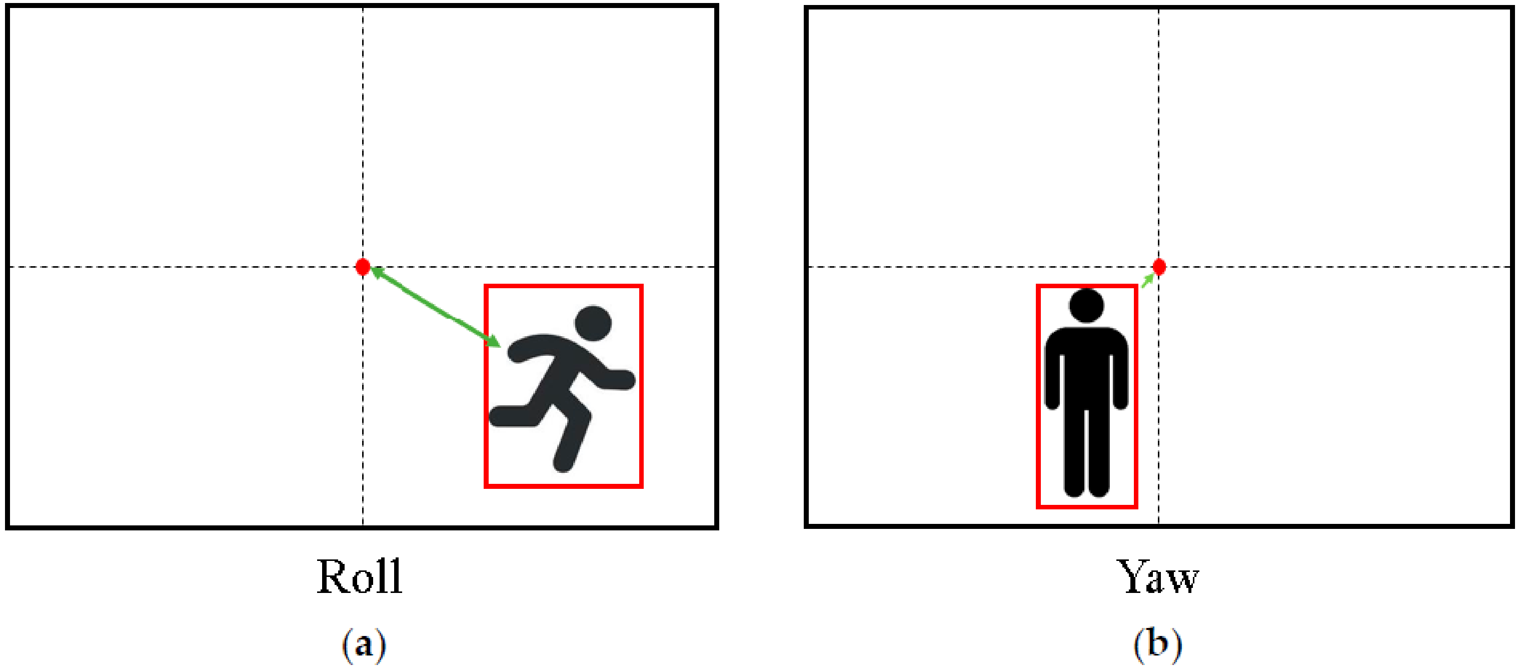
Error Calculation for Y-Axis

- The error in the Y-axis is obtained by comparing the Y-coordinate of the tracked object with the Y-coordinate of the screen center.
- This error is used to calculate the necessary altitude adjustments for the drone's vertical ascent or descent

Y-Axis Error Handling

Altitude adjustments are made based on the calculated error to control the drone's vertical movement and maintain the desired altitude relative to the tracked object.

If the tracked object does not exhibit significant movement, the yaw option is selected, which only requires adjusting the drone’s heading to follow the target, represented by the green arrow illustrated in Figure.



Examples of object movement (a) Roll (b) Yaw

Detection Model Pruning and Object Detection

- This study trained the baseline YOLOv4 model using the coco2014 dataset.
- The Tiny version of YOLOv4 is specifically designed as a lightweight variant for devices with lower computational resources.
- To achieve this goal, a series of experiments to simulate the exploration needs of drones in real environments and require the drones to successfully track target objects automatically.

To evaluate the performance of the object detector, we applied the following four metrics:

(1)Precision:

- It measures the proportion of true positives among all the detections made by the system. A higher precision indicates that the system can accurately identify target objects, reducing the likelihood of false alarms.

(2)Recall:

- It measures the proportion of true positives among all the actual target objects. A higher recall indicates that the system can successfully detect a larger portion of the target objects, reducing the risk of missed detections.

(3)BFLOPs

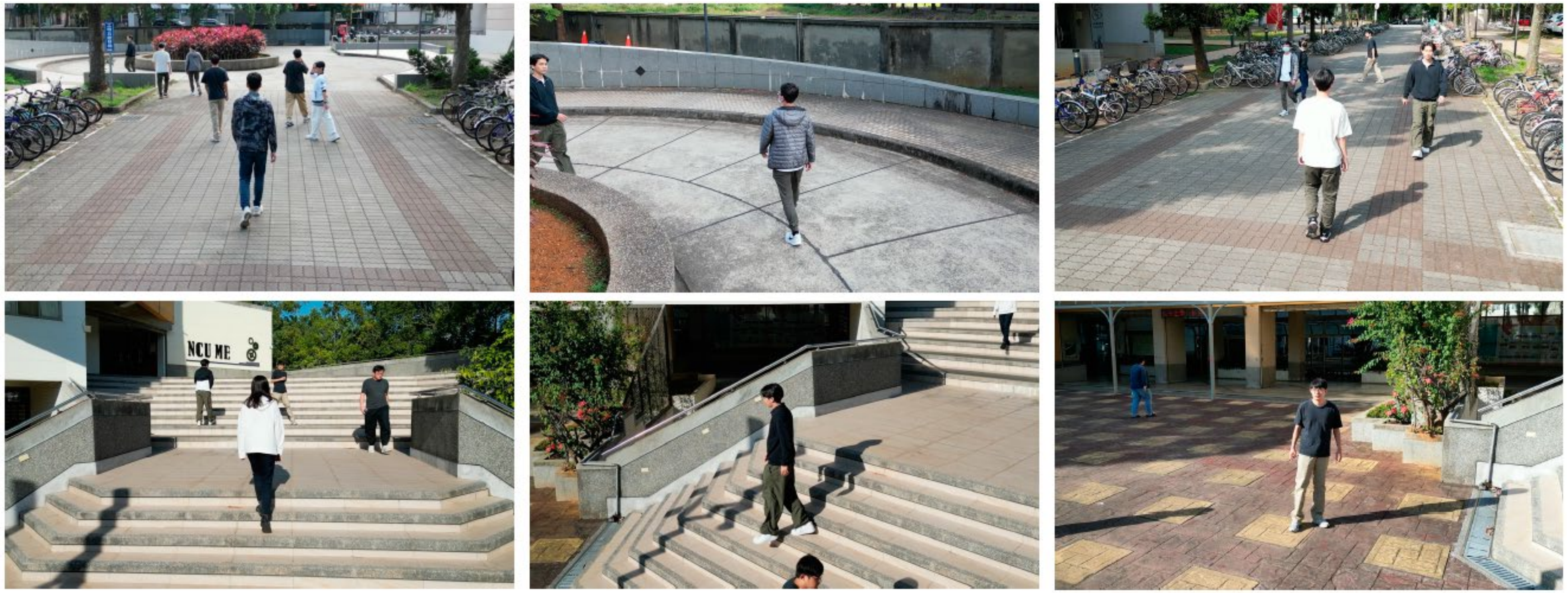
- BFLOPs is a metric used to measure the computational efficiency of a computer system or machine-learning model. It is a commonly used metric for evaluating the computational efficiency and speed of systems or models.

(4) mAP@0.5 (mean Average Precision at IoU 0.5)

- mAP@0.5 is a commonly used evaluation metric in object detection. It measures the average precision at an Intersection over Union (IoU) threshold of 0.5 across different classes.

Subject Tracking and Drone Control

- Figures below are the selected outdoor scenes and indoor scenes in the experimental videos, respectively.
- The subjects being tracked include ten different people.
- Each person is tracked for 50 to 90 s in outdoor and indoor environments five times.
- During the tracking process, a random number of 0 to 7 other people would appear as passersby in the scene.

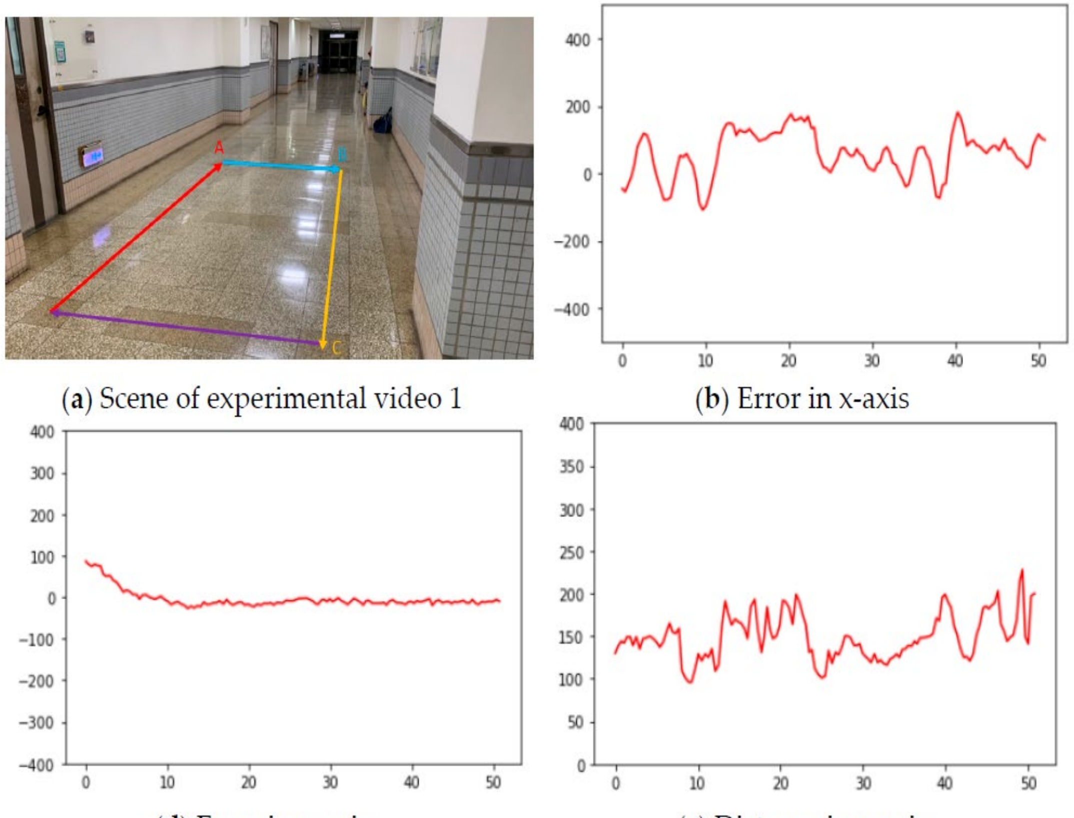


Selected scenes in outdoor environments

Selected scenes in indoor environments.

B. Analysis of PID control for drone

- In the video-1, the tracked subject walks on a flat surface, as shown in figure (a). The four directions that the subject moves are represented as the red, blue, yellow, and purple arrows in figure (a)



(a) Scene of experimental video 1

(b) Error in x-axis

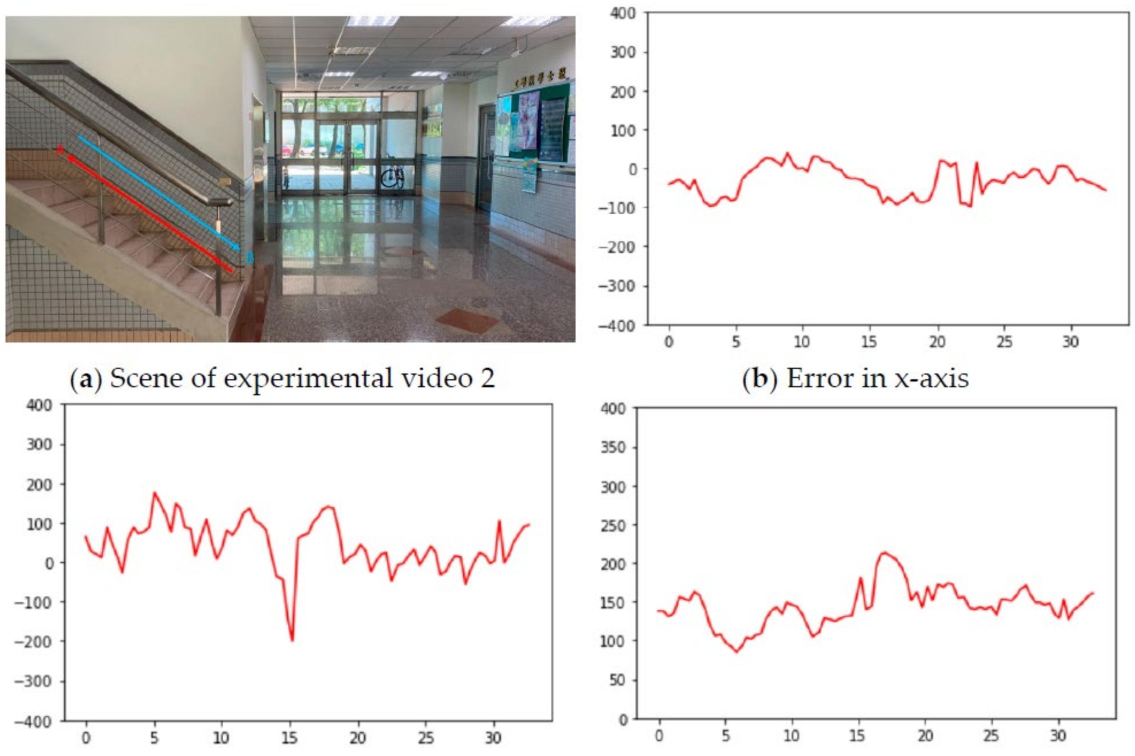
(d) Error in y-axis

(c) Distance in z-axis

- The response of the PID control to the error in the *x*-axis position of the tracked object in video-1 is plotted in figure (b).
- For the error in *y*-axis, since the subject in video-1 does not undergo significant changes in height, we can observe from Figure (c) that there is not a significant variation in the y-axis error.
- Figure (d) plots the response of the PID control to the error in the *z*-axis position of the tracked object in the selected video.

Response of the PID control to the errors in different directions for video-1.

- In video 2, the tracked subject moves upstairs and downstairs, as shown in Figure (a).
- The red arrow and blue arrow represent the directions moving up and down the stairs.
- Figure a–c show the response of the PID control to the error in the x-axis and y-axis positions and the distance in the z-axis position of the tracked object in video 2.



(a) Scene of experimental video 2
(b) Error in x-axis
(d) Error in y-axis
(c) Distance in z-axis

Response of the PID control to the errors in different directions for video 2.

Figure demonstrates that the PID control continuously adjusts the x-axis and y-axis errors to approach zero as the subject moves forward and backward while ascending or descending the stairs.

REFERENCES

- Yang, S. Y., Cheng, H. Y., & Yu, C. C. (2023). Real-Time Object Detection and Tracking for Unmanned Aerial Vehicles Based on Convolutional Neural Networks. Electronics, 12(24), 4928. https://doi.org/10.3390/electronics12244928

CONCLUSION

- **Real-time human tracking and detection can be possible using the image process and drone technology.**
- **The technology not only improves the quality control measures but also contributes to cost-effectiveness and sustainability in industrial operations.**


THANK YOU

MINE AUTOMATION AND DATA ANALYTICS

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SWAYAM NPTEL COURSE ON

MINE AUTOMATION AND DATA ANALYTICS

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Lecture 14 A
Automated Communication and Tracking Technologies: SCADA

Module 06
Automated tracking and VR systems

CONCEPTS COVERED

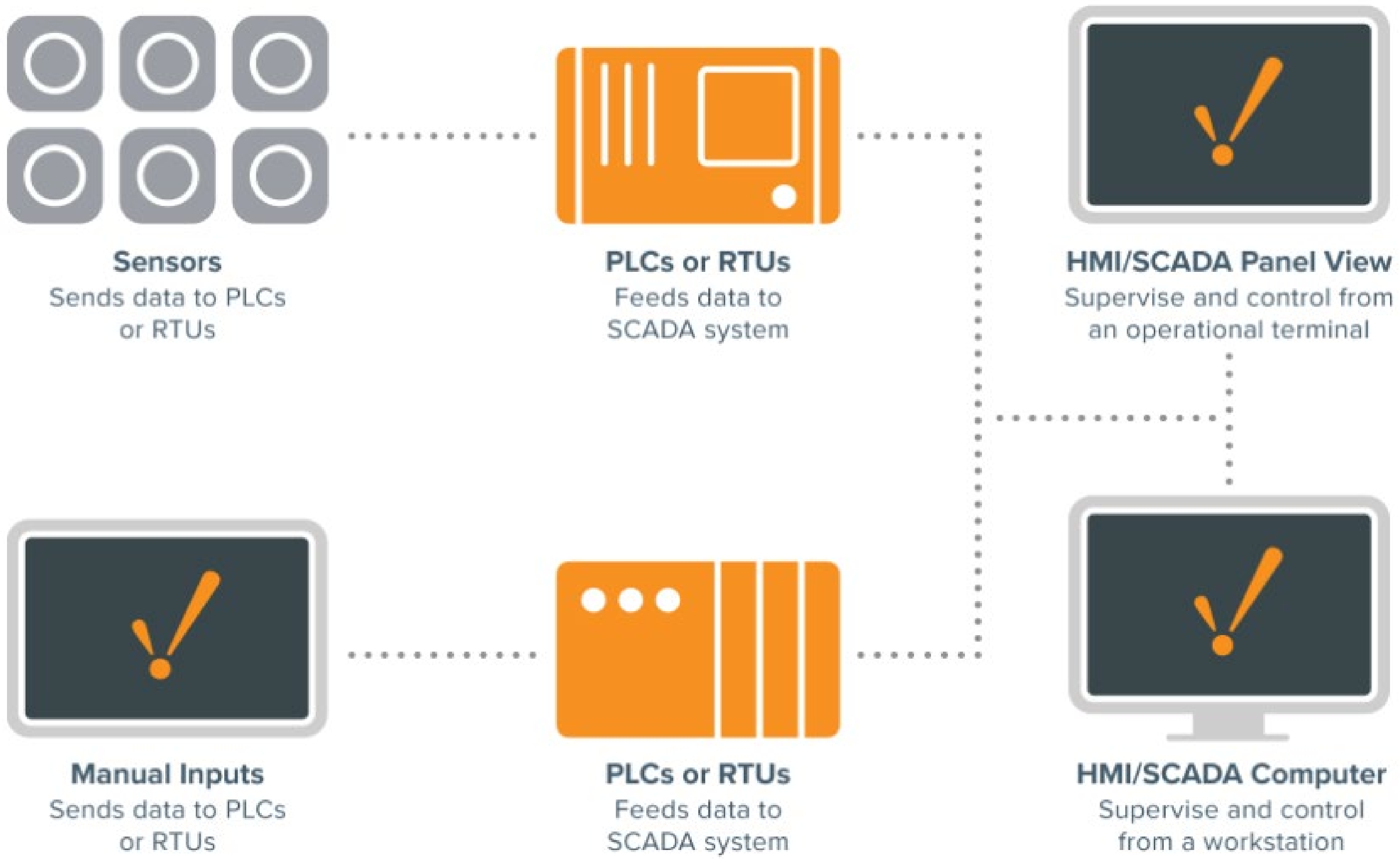
- Introduction to SCADA
- SCADA Architecture
- Evolution of SCADA
- SCADA Components
- SCADA Communication Protocols
- Fundamental of Control of SCADA System

Introduction

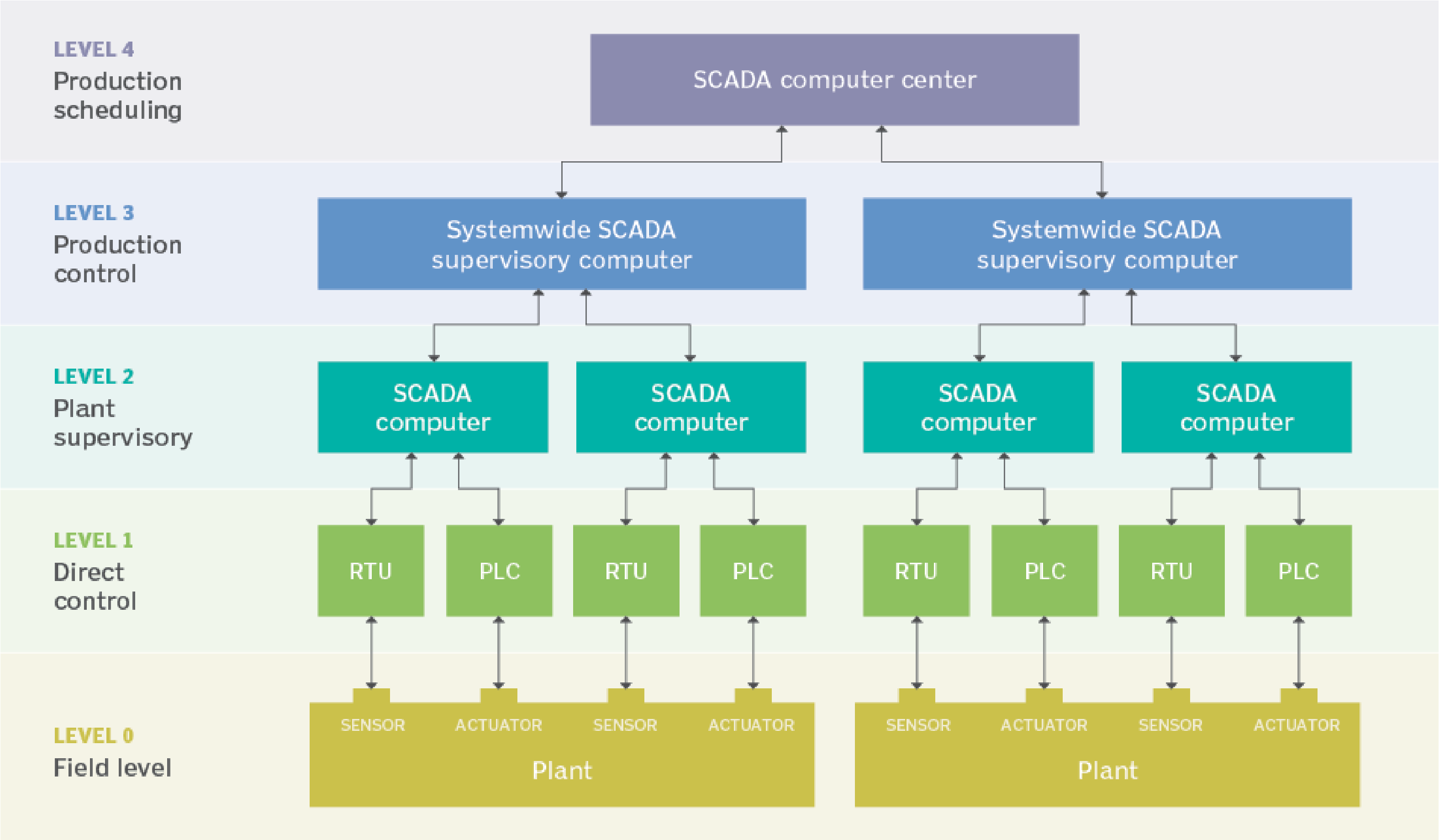
Supervisory control and data acquisition (SCADA) is a system of software and hardware elements that allows industrial organizations to

- Control industrial processes locally or at remote locations
- Monitor, gather, and process real-time data
- Directly interact with devices such as sensors, valves, pumps, motors, and more through human-machine interface (HMI) software
- Record events into a log file

A Basic SCADA Diagram



SCADA Architecture



Level 0

The field level includes field devices, such as sensors, used to forward data relating to field processes and actuators used to control processes.

Level 1

The direct control level includes local controllers, such as PLCs and RTUs, that interface directly with field devices, including accepting data inputs from sensors and sending commands to field device actuators.

Level 2

The plant supervisory level includes local supervisory systems that aggregate data from level controllers and issue commands for those controllers to carry out.

Level 3

The production control level includes systemwide supervisory systems that aggregate data from Level 2 systems to produce ongoing reporting to the production scheduling level, as well as other site or regionwide functions, like alerts and reporting.

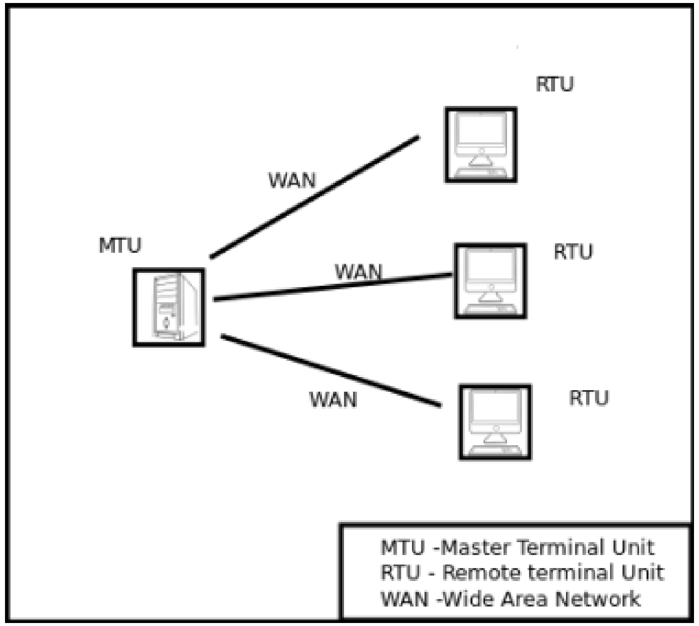
Level 4

The production scheduling level includes business systems used to manage ongoing processes.

Evolution of SCADA

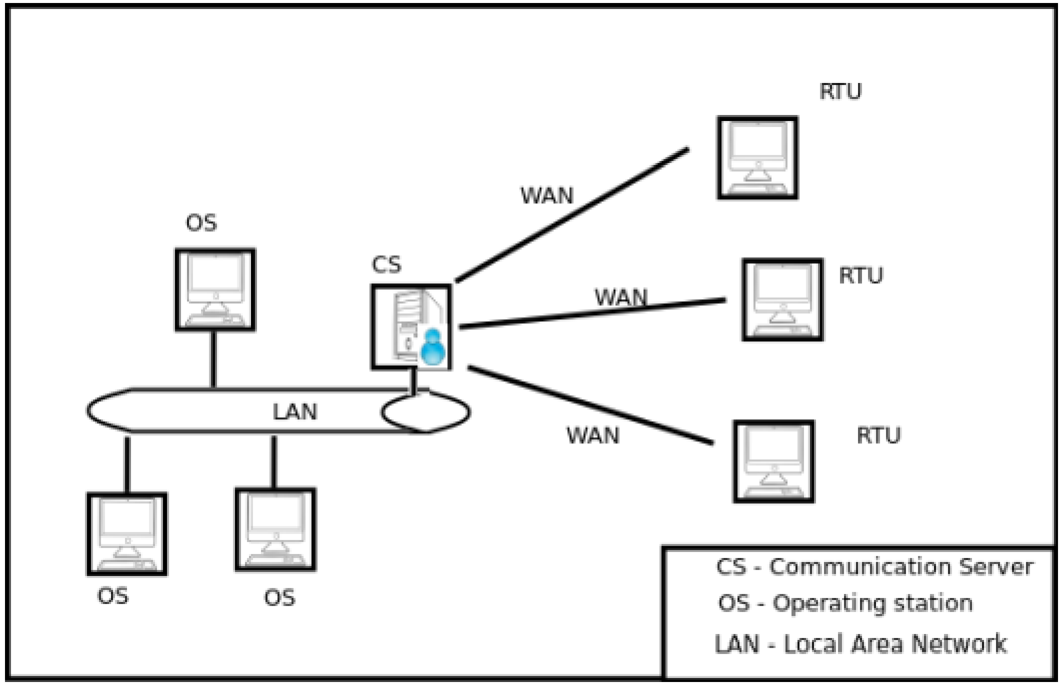
First generation: Monolithic systems

SCADA systems implemented in the 1960s and 1970s usually incorporated RTUs at industrial sites connected directly to mainframe or minicomputer systems, usually also on-site or connected over a wide area network.



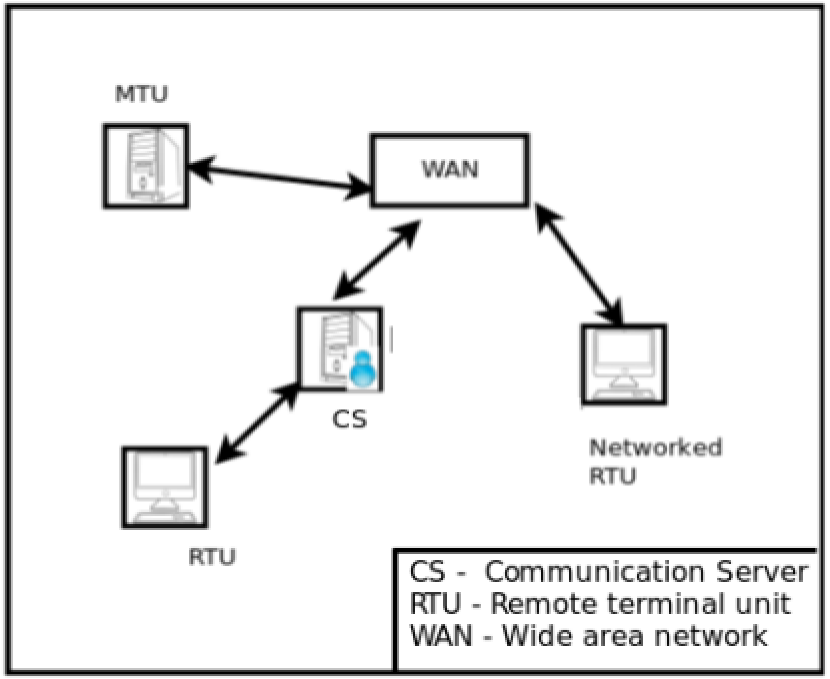
Second generation: Distributed systems

SCADA systems took advantage of wide availability of proprietary local area networks and smaller, more powerful computers during the 1980s to enable greater sharing of operational data at the plant level and beyond. However, the lack of open networking standards prevented interoperability across SCADA product vendors.

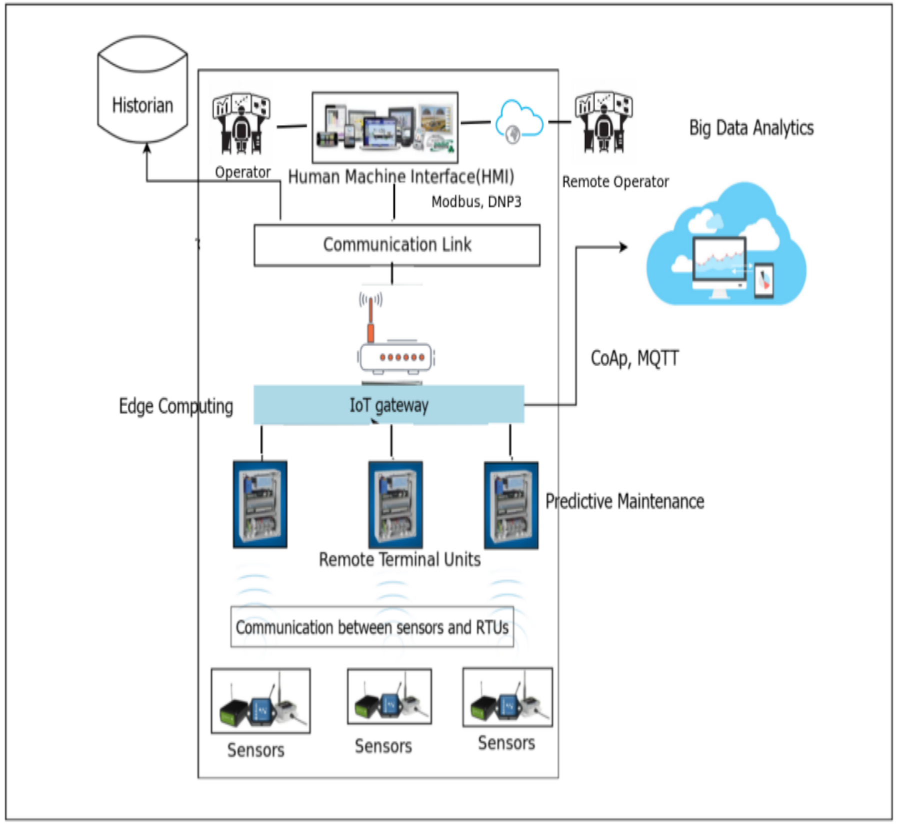


Third generation: Networked systems

SCADA systems depended on greater interoperability provided by industry acceptance and incorporation of standard network protocols during the 1990s. SCADA systems could be scaled more easily, as enterprises were able to integrate systems across their own industrial infrastructure while using a wider variety of devices and systems.

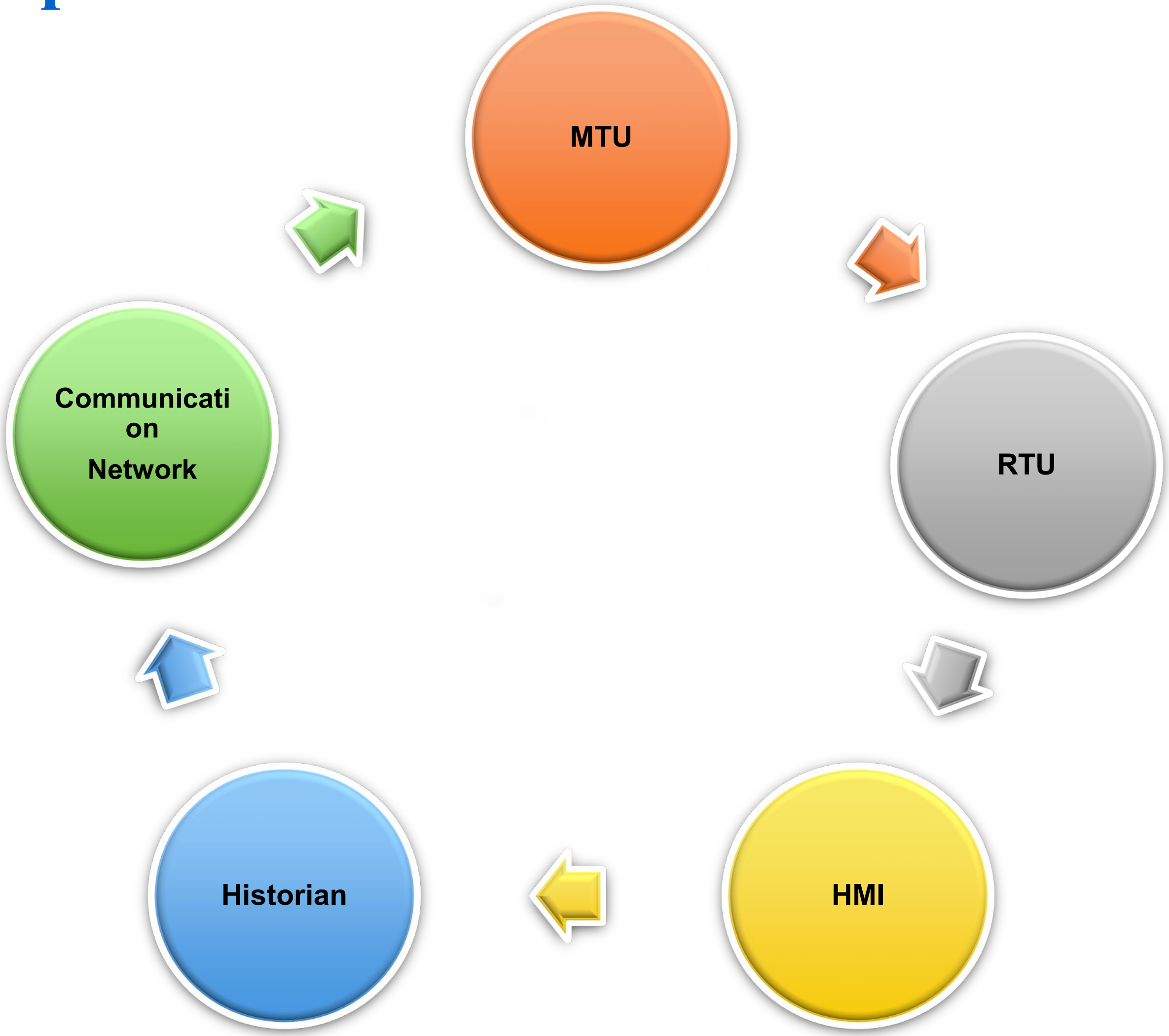


Fourth generation: Web or IIoT-based systems



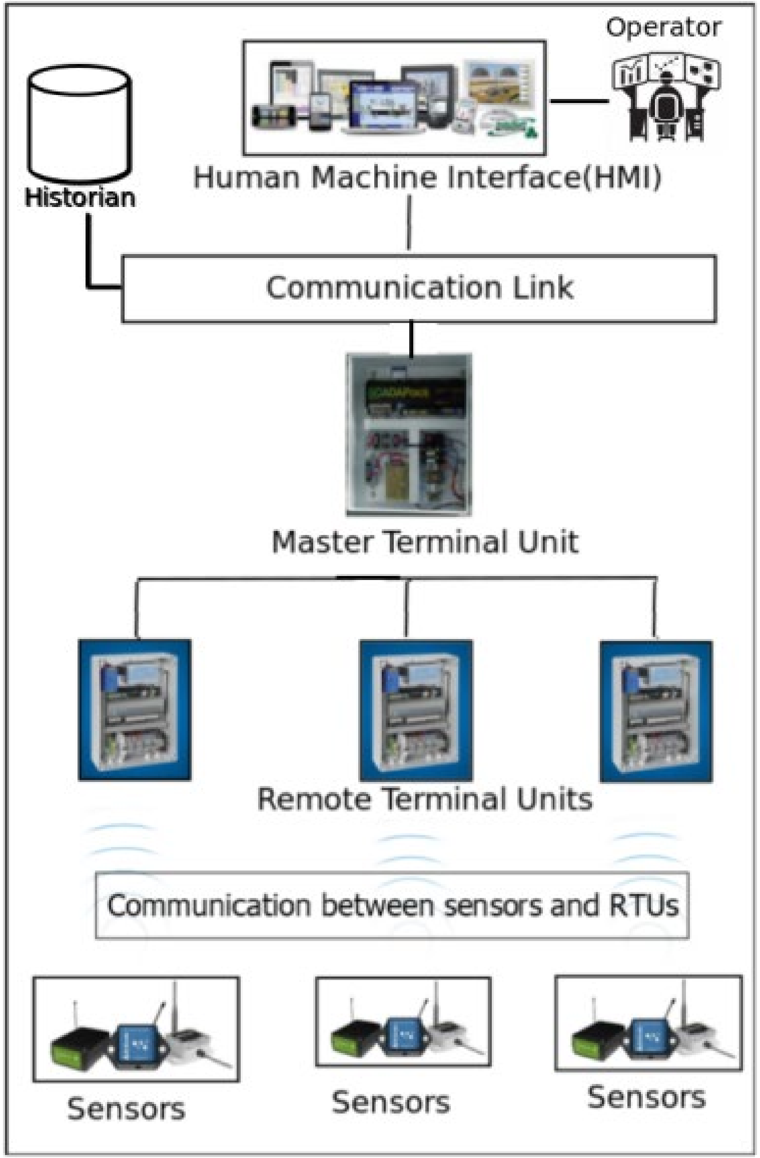
SCADA systems began appearing in the early 2000s as SCADA vendors embraced web software development tools to enable transparent interoperability and access via universally available interfaces, like web browsers running on handheld devices, laptops, and desktop computers.

SCADA Components



Remote Terminal Units (RTU)

1) RTU is responsible for collecting real-time data and information from sensors that are connected to the physical environment using link LAN/WAN.
2) RTUs forward information to MTU.
3) These are additionally in charge of conveying the present status data of physical devices associated with the system.



Master Terminal Unit (MTU)

1) MTU is the central monitoring station.

2) It is in charge of controlling and commanding the RTU machine over communication links.

3) It also responds to messages from RTU and processes and stores them for succeeding communication.

Human Machine Interface (HMI)

1) HMI provides a communication interface between SCADA hardware and software components.

2) It is responsible for controlling SCADA operational information, for example, controlling, observing, and communication between several RTU and MTU in the form of text, statistics, or other comprehensible content.

Central database (Historian)

1) Historian is used for accumulating two-way communication data, events, and alarms between SCADA control centers.

2) It can be described as a centralized database or a server located at a distant location.

3) The historian is queried to populate graphical trends on the HMI.

Communication network

1) The communication network provides communication services between various components in the SCADA network framework.

2) The medium utilized can be either wireless or wired. Presently, wireless media is generally utilized as it interfaces geologically circulated areas and less available zones to communicate effortlessly.

SCADA Communication Protocols

Modbus

- Modbus transmission protocol developed by Gould Modicon for their Modicon programmable controller.
- Most commonly used protocol for connecting electronic devices due to being openly published and easy to use.
- Used for interactions between MTU and RTUs.
- Modbus/TCP is an enhanced variation focusing on reliable communication over the Internet and Intranet.
- Modbus Plus protocol proposed to overcome master terminal vulnerability issues.

Distributed Network Protocol (DNP)

- Distributed Network Protocol (DNP) is based on the Enhanced Performance Architecture (EPA) model, which is a streamlined type of OSI layer architecture developed by Harris, Distributed Automation Products.
- DNP3 protocol was developed to achieve open and standards-based interoperability between RTUs, MTU, and Programmable Logic Controllers (PLCs).

Distributed Network Protocol (DNP)

- **Core components of the DNP3 protocol include data link layer conventions, transport functions, application conventions, and a data link library.**
- **A user layer is added to the EPA architecture responsible for tasks such as multiplexing, data fragmentation, prioritization, and error checking.**

IEC 60870-5 Protocol

- **The International Electro-Technical Commission (IEC) 60870-5 protocol also follows the Enhanced Performance Architecture (EPA) model.**
- **An additional top layer representing the application layer is included in the EPA architecture to indicate functions related to the telecontrol framework.**
- **Variations of the telecontrol framework, such as T101, T102, T103, T104, define diverse specifications, data objects, and function codes at the application convention level.**
- **For efficient transmission, the DNP3 layer stack adds a pseudo-transport layer, but it is not utilized in IEC 60870-5.**

Foundation Fieldbus Protocol

- Foundation Fieldbus utilizes a four-layer stack comprising the user, application, data link, and physical layers.
- Foundation Fieldbus architecture follows the OSI layer model, with the user layer added as an additional top layer of the application layer.
- The user layer serves as a gateway between software programs and field devices, facilitating easy process integration.
- Foundation Fieldbus offers features such as multifunctional devices, open standards, and decreased wire costs, setting it apart from other protocols.

Apart from these traditional communication protocols, in IIoT-based SCADA other IoT protocols are

Zigbee

- Zigbee, an IEEE 802.15.4 based communication protocol, was developed by the Zigbee Alliance and standardized in 2003, with a revision in 2006.
- The communication range of Zigbee is between 10 to 100 meters line-of-sight, depending on environmental characteristics.

- Zigbee architecture comprises three types of devices: Fully Functional Devices (FFDs) which act as routers, Reduced Functional Devices (RFDs), and a coordinator.
- Zigbee enables Wireless Personal Area Networks (WPAN) and provides a communication protocol with low-power digital radios.
- It operates as a low data rate, low-power, and low communication range wireless ad hoc network, secured by 128-bit symmetric encryption keys, with a data rate of 250 kbps.

Bluetooth Low Energy (BLE)

- Bluetooth Low Energy (BLE) aims to decrease power consumption compared to classic Bluetooth technology.
- BLE shares the same protocol stack as classic Bluetooth but supports quick transfer of small data packets with a 1 Mbps data rate. It does not support data streaming.
- BLE follows a master-slave architecture, where the master acts as a central device connecting to multiple slaves, making the devices power-efficient.

- Energy is conserved by keeping the slave nodes in sleep mode by default and waking them periodically to send data packets to the master node and receive control packets from the slave node.
- BLE is reported to be 2.5 times more energy efficient than Zigbee.

LORA

- LoRa, a long-range communication protocol, was initially developed by Cycleo of Grenoble, France, and later acquired by Semtech in 2012.
- It supports long-range communication up to 10 km and data rates less than 50 kbps while maintaining low power consumption.
- LoRa is particularly suitable for non-real-time applications that require fault tolerance.
- It operates in the physical layer combined with Long Range Wide Area Network (LoRaWAN) in the upper layers.

Fundamental of Control

SCADA systems make extensive use of electronic technology, the technology cycles are very short, and recommendations regarding specific types of hardware, software, communications protocols, etc. needs to upgrade as and when technology advances.

General control

Control consists of monitoring the state of a critical parameter, detecting when it varies from the desired state, and taking action to restore it. Control can be discrete or analog, manual or automatic, and periodic or continuous.

- The process variable is the parameter that is to be controlled
- Devices that measure process variables are transducers or sensors
- The setpoint is the desired value of the process variable.
- The control output

The process variable is the parameter that is to be controlled

- Examples of process variables in deep metal mine system are the temperature, humidity, air velocity etc.
- To be controlled, the process variable must be capable of being measured and that measurement converted into a signal that can be acted on by the controller.

Devices that measure process variables are transducers or sensors

In many cases, the process variable sensor consists of a direct measurement device, called an element and a separate signal processor called a transmitter. An example of this would be temperature measurement using a resistive temperature detector (RTD), as the element and a temperature transmitter, which converts the varying resistance value of the RTD into a current or voltage proportional to the temperature.

The setpoint is the desired value of the process variable

- Normally preset into the control system by an operator, or derived as an output of another control calculation.
- The error signal is the difference between the process variable and the setpoint and is the basis for control action.
- The controller is the device that processes the error signal, determines the required control action, and provides a control output to the process.

The control output

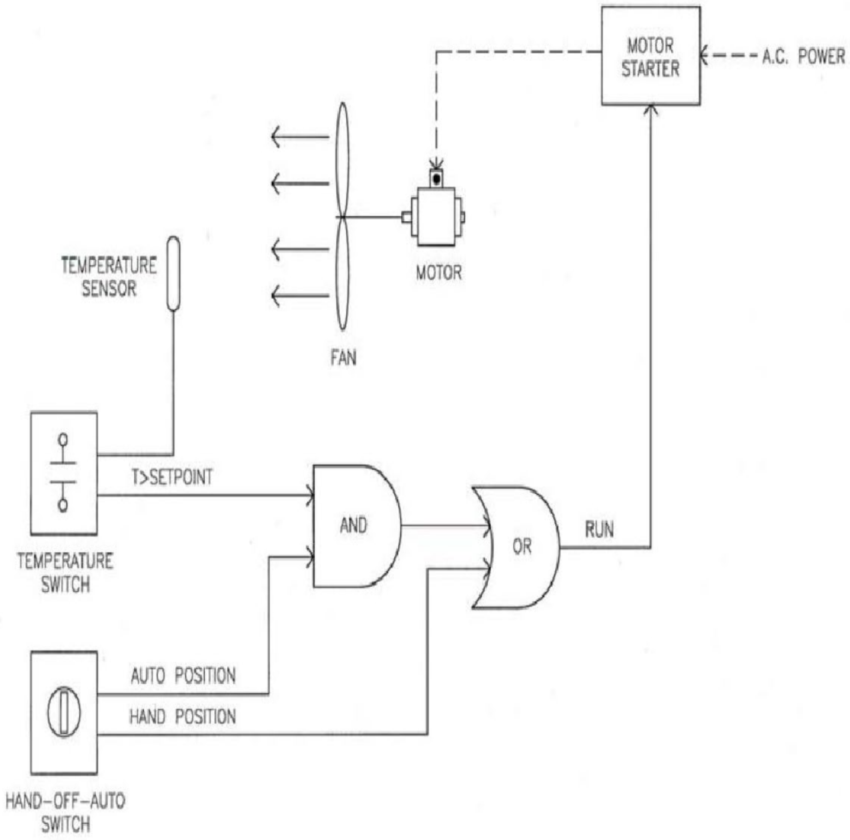
- usually must act on the system through another device to effect the desired control action, such as varying the position of a valve, the speed of a motor, or the current through a heating element.

- The device that converts the control output into control action is the actuator.

Discrete control

Discrete control deals with systems in which each element can only exist in certain defined states. An example of discrete control would be starting an exhaust fan when the temperature in a space exceeds a preset value and stopping the fan when the temperature falls below a lower preset value. The temperature (process variable) is either within the acceptable range, or outside of it.

The fan control relay (actuator) is either on or off. This type of control is implemented with logic diagrams and circuits. In discrete control, even though some of the parameters actually have a continuous range of values, the only information used by the control system is whether their value is greater than, less than, or equal to some desired value.



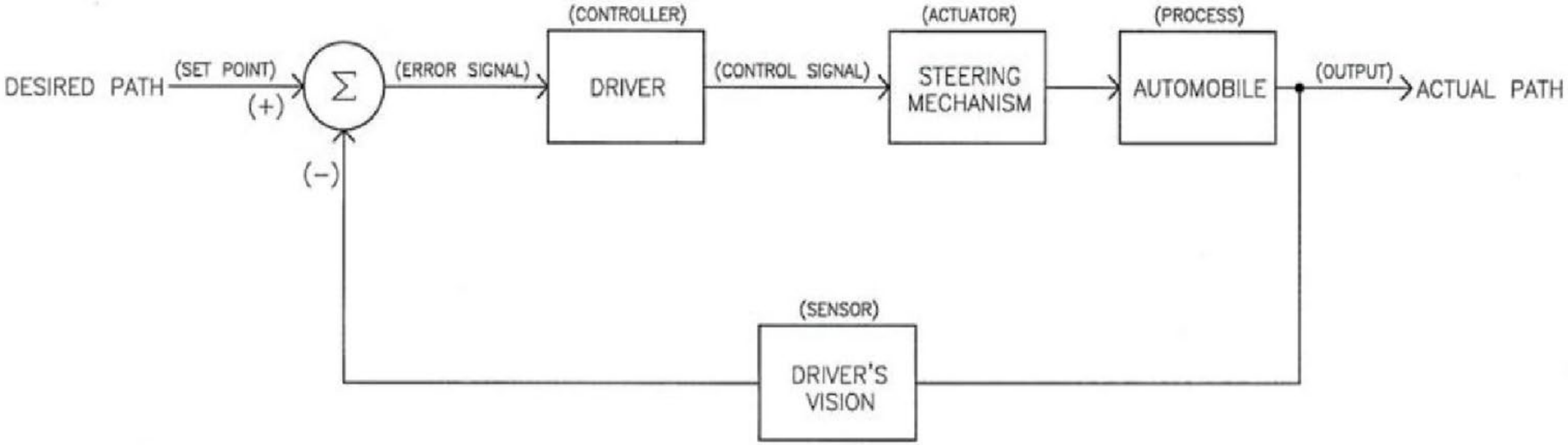
- **The devices used to sense system conditions in discrete control are typically electrical switches, with contacts that are open when the variable is in one state and closed when it is in the other.**

- **Similarly, the control action is typically produced by control relays, which open or close contacts in the control circuits of motors, valve actuators, or other devices.**

Analog control

Analog control deals with systems in which variables can have a continuous range of values, rather than simply discrete states. Basic analog control consists of the process of measuring the actual output of a system, comparing it to the desired value of that output, and taking control action based on the difference to cause the output to return to the desired value.

This process can be as simple as the driver of an automobile comparing the speedometer reading (process variable) to the speed limit (setpoint) and adjusting the position of the accelerator pedal (control action) to speed up or slow down the vehicle accordingly.



Analog control system block diagram

Classes of analog controllers

Analog controllers can be classified by the relationship between the error signal input to them and the control action they produce:

A. Proportional (P)

- Controllers in proportional (P) control systems generate an output proportional to the error signal.
- An essential feature of P control is that the error signal must remain non-zero to prompt a control action.
- Consequently, P control alone cannot restore the process to the setpoint after an external disturbance.

- The steady-state offset, a non-zero error signal inherent in P controllers, is a defining characteristic.
- The adjustable parameter determining the proportionality of the controller's response is known as the gain.
- Higher gains result in larger control actions for a given error signal and faster system response.

B. Proportional plus Integral (PI)

- Controllers in proportional-integral (PI) control systems generate a control action proportional to the error signal plus the integral of the error signal.

- The addition of the integrator enables the controller to eliminate steady-state offset and return the process variable to the setpoint value.

- The adjustable parameter controlling the integration constant of the PI controller is known as the reset, as it effectively resets the error signal to zero.

- An engine governor operating in isochronous mode, maintaining a constant RPM over the full load range, utilizes PI control to achieve this control behaviour.

C. Proportional plus Integral plus Derivative (PID)

- Controllers in proportional-integral-derivative (PID) control systems incorporate a component of control action proportional to the derivative of the error signal, representing the rate of change of the error signal.

- This control mode enables the controller to anticipate changes in the process variable by increasing control action for rapid changes, which is particularly beneficial for systems requiring fast response times or those inherently unstable without control.

- The adjustable parameter controlling the derivative component in a PID controller is known as the rate.

Control loops

- The complete control scheme required to control a single process variable or a group of related process variables is called a control loop.
- The control loop includes the relevant part of the process, the process variable sensor and associated transmitter(s), the input signals, the controller, the control output signal, and the actuator.
- The process of adjusting the gain, reset, and rate parameters to obtain effective and stable response of the system to changes in the setpoint or external disturbances is called loop tuning, and is an essential aspect of control system startup and commissioning.

Types of controllers

- Control can be implemented using either individual standalone controllers, known as single-loop controllers, or by combining multiple control loops into a larger controller.

- Single-loop controllers have provisions for a process variable input signal, a control output signal, setpoint adjustment, tuning of the PID control parameters, and typically include some type of display of the value of the process variable and the setpoint.

REFERENCES

- Army - Coe Technical Manuals (Tm) Tm 5-601 Supervisory Control And Data Acquisition (Scada) Systems For Command, Control, Communications, Computer, Intelligence, Surveillance, And Reconnaissance (C4isr) Facilities.
- https://www.techtarget.com/whatis/definition/SCADA-supervisory-control-and-data-acquisition
- Yadav, Geeta & Paul, Kolin. (2020). Architecture and Security of SCADA Systems: A Review, https://www.researchgate.net/publication/338500163_Architecture_and_Security_of_SCADA_Systems_A_Review

CONCLUSION

- Provided an overview of Supervisory Control and Data Acquisition (SCADA) systems.
- Explored the structural framework of SCADA systems, including hardware and software components.
- Traced the historical development and advancements in SCADA technology over time.
- Discussed the key elements that comprise a SCADA system, such as sensors, actuators, and control interfaces.
- Explored the various protocols used for communication between SCADA components.
- Introduced the basic principles and methodologies involved in controlling SCADA systems for monitoring and management purposes.


THANK YOU

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Module 06
Automated tracking and VR system

Lecture 14 B
SCADA and its Application in Mining

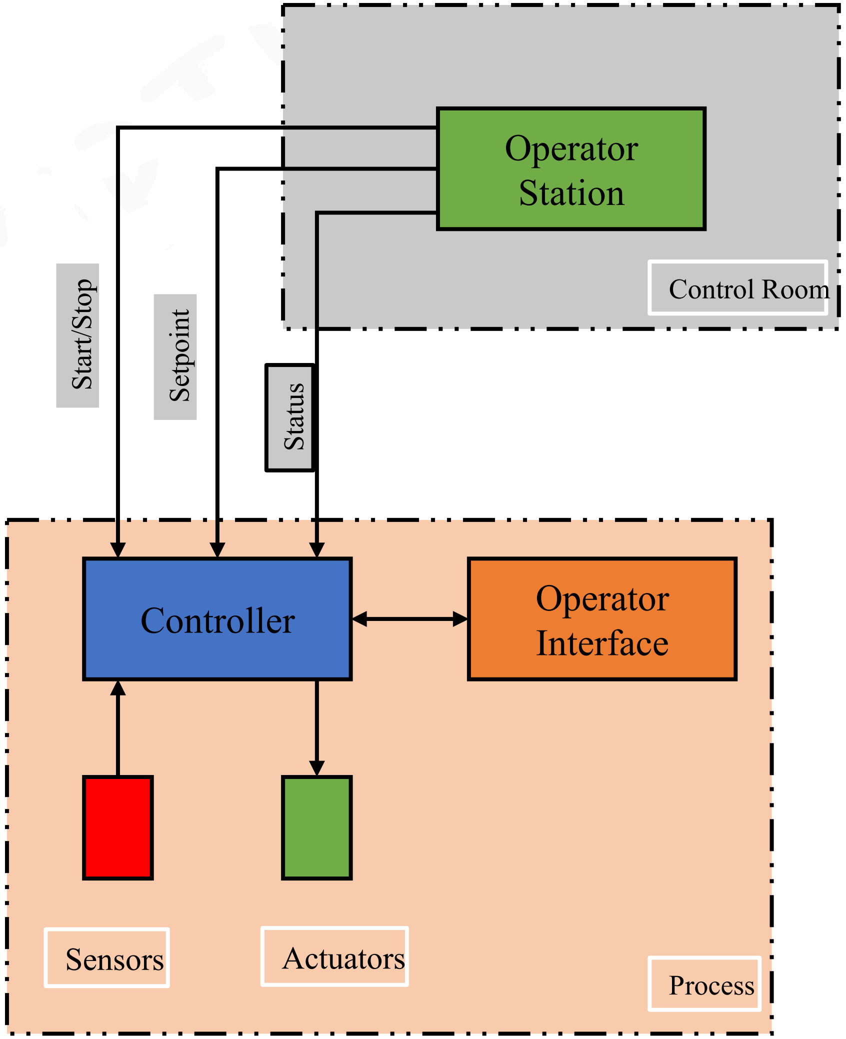
CONCEPTS COVERED

- Different control in SCADA systems
- Programmable logic controller (PLC)
- Redundant PLCs
- SCADA System Implementation
- Recent advances in SCADA
- Case study - Smart Energy Management System: Design of a Monitoring and Peak Load Forecasting System for an Experimental Open-Pit Mine

Different control in SCADA systems

Local control

- It is a system architecture where sensors, controllers, and controlled equipment are in close proximity, with each controller having jurisdiction over a specific system or subsystem.
- Local controllers are typically capable of receiving inputs from a supervisory controller to initiate or terminate locally-controlled automatic sequences or adjust control setpoints. However, the control action itself is determined within the local controller.



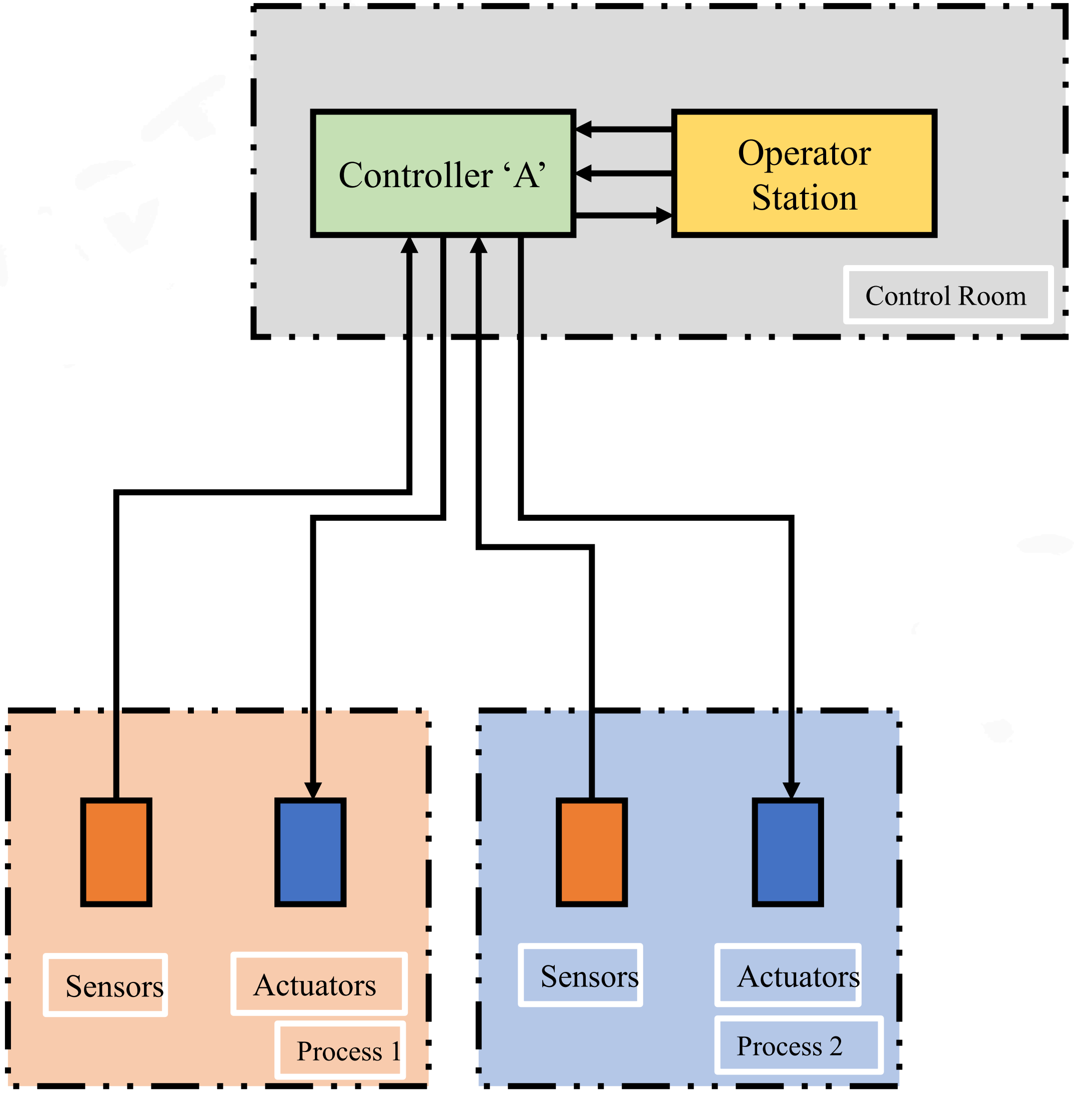
Local control system architecture

- Operator interfaces and displays necessary for system operation are also local, providing a significant advantage for troubleshooting but requiring operators to move around the facility to monitor systems or respond to contingencies.
- Examples of local control include packaged control panels accompanying chillers or skid-mounted pump packages.

Centralized control

- Centralized control refers to a system where all sensors, actuators, and equipment within a facility are connected to a single controller or group of controllers situated in a common control room.
- This setup enhances operator understanding of system conditions and facilitates rapid response to contingencies by consolidating controls, operator interfaces, and indicators in one location.

- Centralized control was prevalent in facilities like power plants using single-loop controllers or early digital controls. However, it has been largely replaced by distributed control due to the high cost associated with routing and installing all control system wiring to a central location.
- Centralized control systems may still be suitable for small C4ISR (Command, Control, Communications, Computers, Intelligence, Surveillance, and Reconnaissance) facilities but require fully redundant processors.

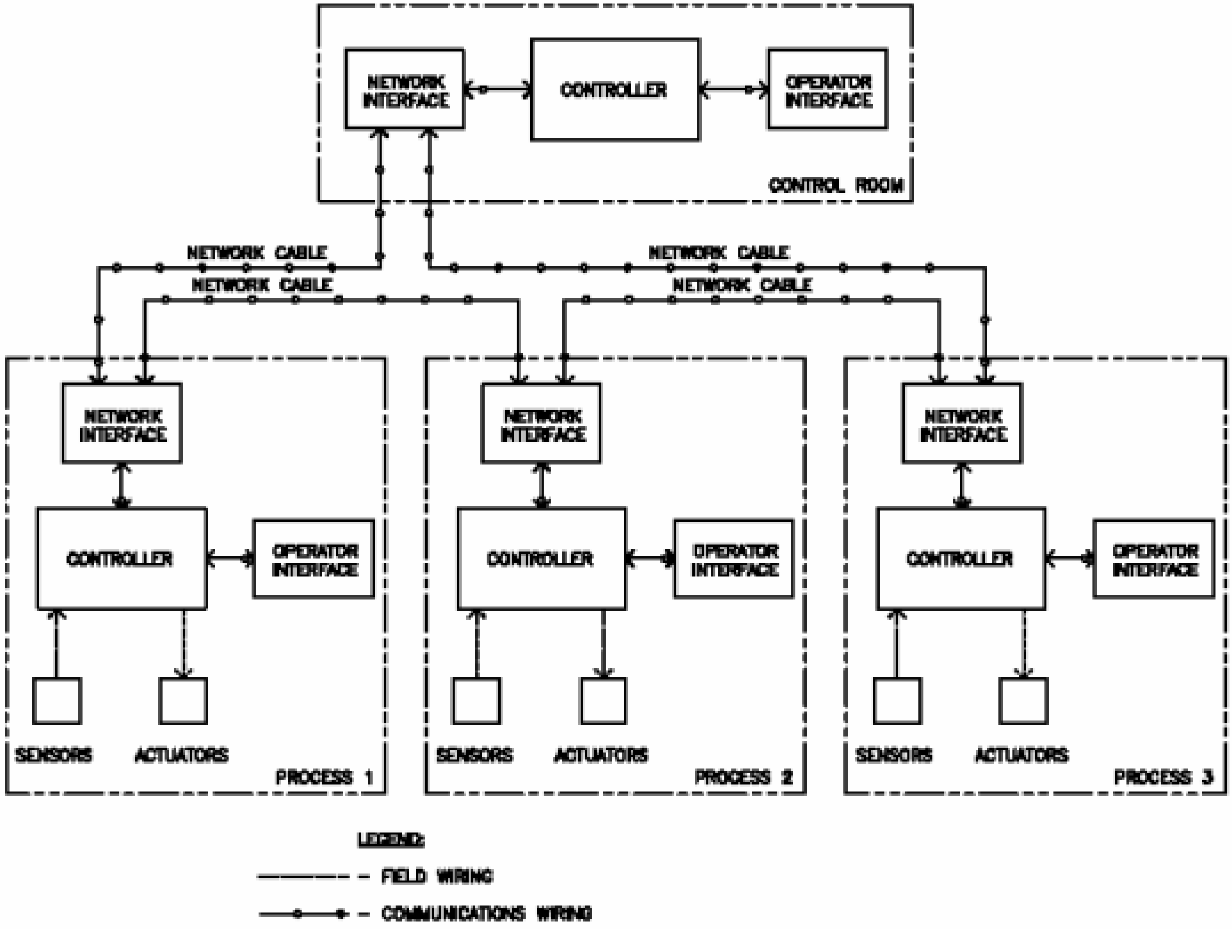


Centralized control system architecture

- In centralized control systems with redundancy, segregated wiring pathways are essential to ensure that control signals to and from redundant equipment or systems are not susceptible to common failure from electrical faults, physical damage, or environmental hazards.

Distributed control

- Distributed control system architecture, combines the advantages of both local and centralized control.
- In a distributed control system, controllers are situated locally to systems or groups of equipment but are interconnected to one or more operator stations in a central location via a digital communication circuit.


NETWORK INTERFACE
CONTROLLER
OPERATOR INTERFACE
CONTROL ROOM
NETWORK CABLE
NETWORK CABLE
NETWORK CABLE
NETWORK CABLE
NETWORK INTERFACE
CONTROLLER
OPERATOR INTERFACE
SENSORS
ACTUATORS
PROCESS 1
NETWORK INTERFACE
CONTROLLER
OPERATOR INTERFACE
SENSORS
ACTUATORS
PROCESS 2
NETWORK INTERFACE
CONTROLLER
OPERATOR INTERFACE
SENSORS
ACTUATORS
PROCESS 3
LEGEND:
– FIELD WIRING
– COMMUNICATIONS WIRING

- Control actions for each system or subsystem occur within the local controller, while the central operator station maintains full visibility of the status of all systems and input/output data in each controller.
- Additionally, the central operator station possesses the capability to intervene in the control logic of local controllers if necessary, providing enhanced control and monitoring capabilities across the entire system.

There are a number of characteristics of distributed control architecture which enhance reliability

1) Input and output wiring runs are short and less vulnerable to physical disruption or electromagnetic interference.

2) A catastrophic environmental failure in one area of the facility will not affect controllers or wiring located in another area.

3) Each local controller can function on its own upon loss of communication with the central controller.

There are also specific threats introduced by distributed control architecture that must be addressed in the design of the system:

1) **Networks used for communication may become electronically compromised from outside the facility.**
2) **Interconnection of controllers in different locations can produce ground loop and surge voltage problems.**
3) **If the central controller is provided with the ability to directly drive the output of local controllers for purposes of operator intervention, software glitches in the central controller have the potential to affect multiple local controllers, compromising system redundancy.**

Types of distributed control systems

Plant distributed control system (DCS)

- Distributed control system architecture, combines the advantages of both local and centralized control.
- In a distributed control system, controllers are situated locally to systems or groups of equipment but are interconnected to one or more operator stations in a central location via a digital communication circuit.

Direct digital control (DDC)

Purpose:

DDC systems are utilized in the commercial building HVAC industry to oversee and regulate environmental conditions.

Components:

I. DDC systems consist of local controllers.
II. These controllers are linked to a network.
III. A central station, typically PC-based, is part of the setup.

Functionality of Central Station:

I. The central station offers capabilities for monitoring.
II. It allows for reporting.
III. Data storage is included.
IV. Programming capabilities are provided.

Optimization:

I. **The controllers are designed for cost-effective HVAC system control.**

II. **They prioritize efficiency over fast execution speeds.**

Proprietary Nature:

I. **Both hardware and control software are proprietary.**

II. **Network communication may employ either proprietary or open protocols.**

Remote terminal unit (RTU) based SCADA

Application

RTU-based systems are prevalent in the electric, gas, and water distribution industries, especially for monitoring and controlling operations across vast geographical areas.

Purpose of RTUs:

I. **RTUs are primarily developed to enable monitoring and control functions at remote and unattended sites.**
II. **Typical deployment sites include substations, metering stations, pump stations, and water towers.**

Communication:
RTUs communicate with a central station using various means such as telephone lines, fiber optics, radio, or microwave transmission.

Functionality at Monitored Sites:

I. **Monitored sites are relatively small in size.**

II. **RTUs are primarily used for monitoring purposes, with limited control capabilities.**

Proprietary Nature:

I. **Both hardware and software in RTU-based systems are proprietary.**

II. **Data transmission to the central station may utilize either proprietary or open protocols.**

Programmable logic controller (PLC)

The recommended controller for SCADA systems is the programmable logic controller (PLC). PLCs are general-purpose microprocessor-based controllers that provide

Logic

Timing

Counting

analog control with network communications

PLCs are recommended for the following reasons:

a. They were developed for the factory floor and have demonstrated high reliability and tolerance for heat, vibration, and electromagnetic interference.

b. Their widespread market penetration means that parts are readily available and programming and technical support services are available from a large number of control system integrators.

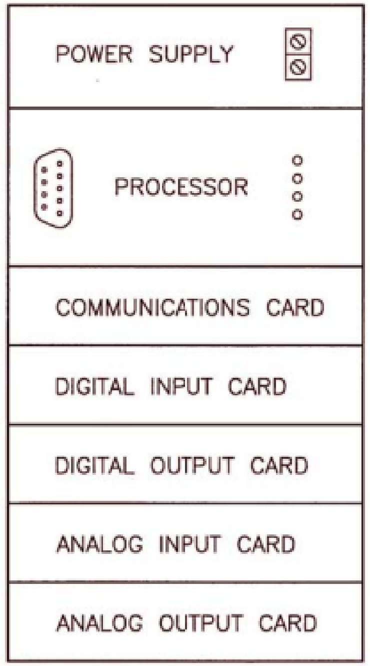
c. They provide high-speed processing, which is important in generator and switchgear control applications.

d. They support hot standby and triple-redundant configurations for high-reliability applications.

A PLC consists of the required quantities of the following types of modules or cards, mounted on a common physical support and electrical interconnection structure known as a rack. A typical PLC rack configuration is shown in the figure

Power supply

- The power supply converts facility's electrical distribution voltage, such as 120 VAC or 125 VDC to signal level voltage used by the processor and other modules.



Typical PLC rack

Processor

The processor module contains the microprocessor that performs control functions and computations, as well as the memory required to store the program.

Input/Output (I/O)

These modules provide the means of connecting the processor to the field devices.

Communications

Communications modules are available for a wide range of industry-standard communication network connections. These allow digital data transfer between PLCs and to other systems within the facility. Some PLCs have communications capability built-in to the processor, rather than using separate modules.

Redundant PLCs

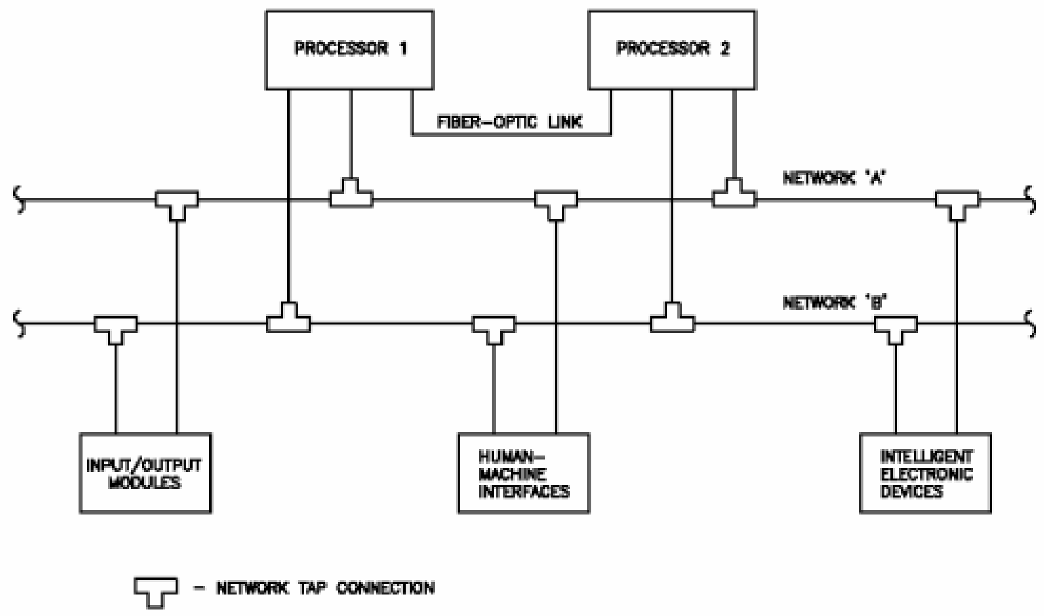
I. Redundant PLC systems may utilize a warm standby, hot standby, or voting configuration.

II. Both processors have continuous access to I/O over redundant buses or networks.

III. Register data and status information are exchanged over a dedicated fiber optic link.

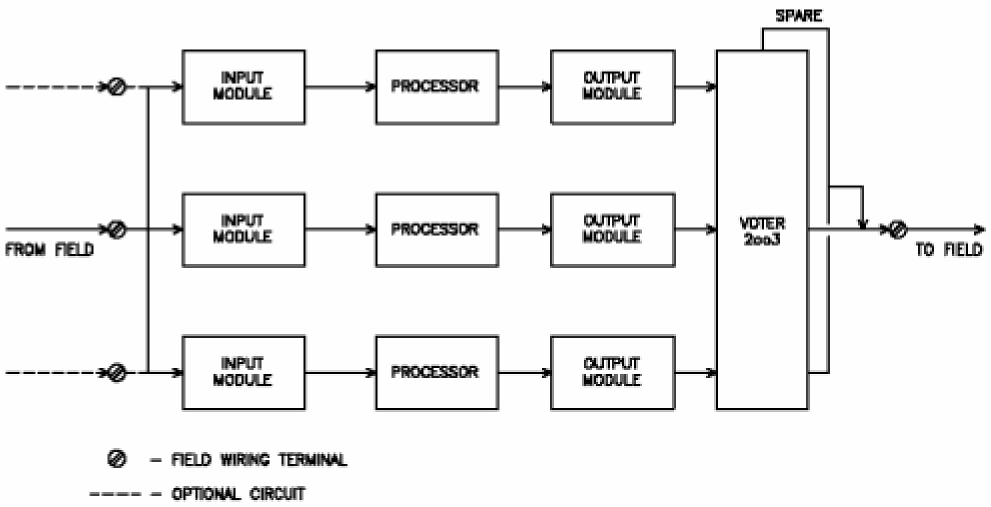
IV. In a warm standby configuration, the primary processor runs the program and controls output states. Upon primary processor failure, the standby processor takes over and runs the program.

- In a hot standby configuration, both processors run continuously with synchronized program scans over the fiber optic link. If one processor fails, the other takes control without changing output states.



Typical redundant PLC configuration

- The hot standby configuration is recommended for most SCADA applications.
- For highly critical applications, a triple-redundant voting scheme may be used.
- Three processors run continuously with synchronized scans, using shared or independent input data from redundant sensors.



Triple-redundant PLC configuration

SCADA System Implementation

Approaches to SCADA System Implementation

- **Physical replication: Creating exact physical copies of SCADA systems.**
- **Virtual-physical replication: Simulating SCADA systems in virtual environments that closely resemble physical setups.**
- **Virtual replication: Completely simulating SCADA systems in virtual environments.**
- **Hybrid replication: Combining physical and virtual elements in SCADA system replication.**

Recent advances in SCADA

Challenges in Traditional SCADA Frameworks

- Current SCADA frameworks combine characteristics of old and new features, which may compromise their security.
- Traditional SCADA systems are often inflexible, static, and centralized, limiting interoperability and exposing vulnerabilities.
- Sensor cloud-based SCADA infrastructure has been proposed as a solution to overcome these limitations, but it introduces new security concerns due to its larger exposed space.

New Approaches and Technologies

- Researchers have introduced new cloud-based frameworks capable of virtualizing sensing frameworks, processing data, and managing large amounts of sensor data.
- Proposals such as VS-Cloud focus on virtual SCADA architectures with features like dynamic sensing services management, scalability, fault tolerance, and privacy.

Integration of IoT with SCADA

- Industrial IoT (Internet of Things) is revolutionizing industrial sectors by providing enhanced automation and information sharing.
- Integrating IoT with SCADA using cloud computing services offers benefits such as predictive maintenance and fault tolerance but also introduces security vulnerabilities.
- Traditional SCADA systems integrated with IoT are more vulnerable to security threats due to the lack of proper security measures.

Concerns and Considerations

- Advantages of cloud services for SCADA include real-time monitoring, cost-effectiveness, and easy maintenance and upgrades.
- Security and performance issues are major concerns with cloud-based SCADA systems, including tracking of hackers, information leakage, latency, and privacy issues.
- Traditional communication protocols like Modbus/TCP and DNP3 lack adequate protection, increasing the risk of attacks.

- **Reliance on cloud communication exposes SCADA systems to additional security risks and vulnerabilities.**
- **Commercial off-the-shelf solutions are often used instead of proprietary solutions, further complicating security measures.**

Smart Energy Management System: Design of a Monitoring and Peak Load Forecasting System for an Experimental Open-Pit Mine

- Digitization in the mining industry and machine learning applications have improved the production by showing insights in different components.
- Energy consumption is one of the key components to improve the industry's performance in a smart way that requires a very low investment.
- This study represents a new hardware, software, and data processing infrastructure for open-pit mines to overcome the energy 4.0 transition and digital transformation.

- The main goal of this infrastructure is adding an artificial intelligence layer to energy use in an experimental open-pit mine and giving insights on energy consumption and electrical grid quality.
- The achievement of these goals will ease the decision-making stage for maintenance and energy managers according to ISO 50001 standards.
- In the mining industry, technological advancements are being successfully applied to enhance the productivity and performance using the industry 4.0 concept.
- However, energy management and efficiency have not kept pace with these changes, which is a key element to directly optimize energy consumption and increase profitability.

- The objective of this work is to design a new architecture for a smart energy management system according to ISO 50001 standard for mining industry.

- The application was oriented to an experimental open-pit mine respecting all requirements and needs.

- The study presents a full design and architecture for applying a smart energy management system in mining industry regardless the situation and the technology of the control system adapted because the use of OPC data transmission this system can be implemented in different types of open pit mines.

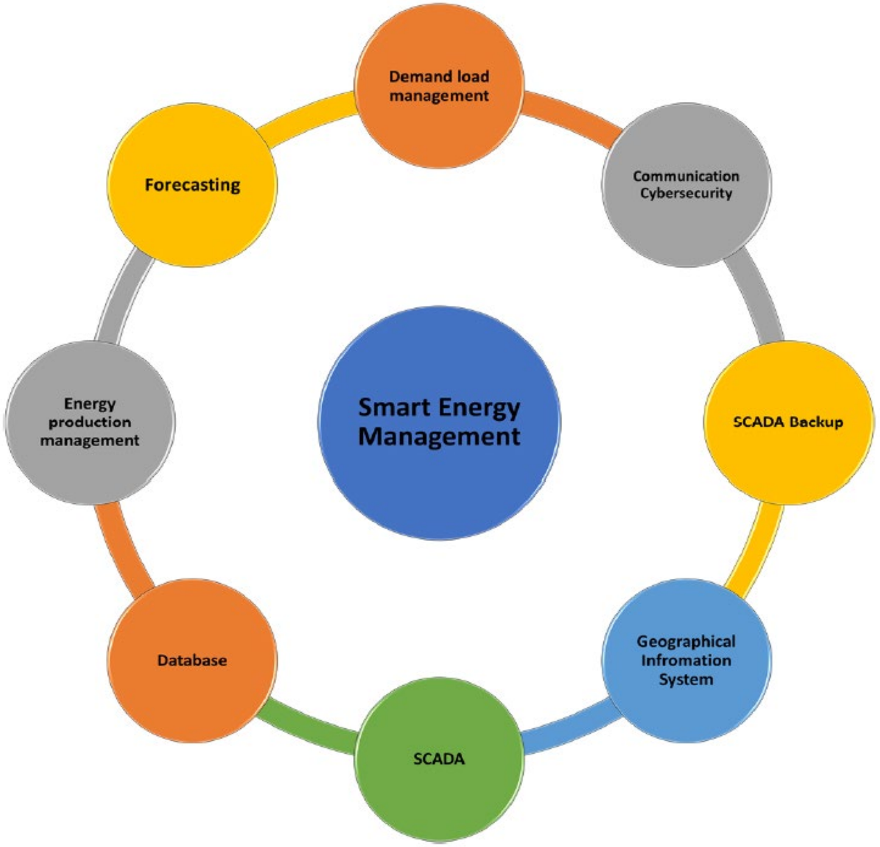
The Challenges of the Implementing the Smart Energy Management System in the Open-Pit Mine

The experimental open-pit mine was initially designed for a required function: to extract mining products and maximize the production, regardless of energy consumption and grid quality monitoring.

- **Monitoring All Different Loads and Supplies.**
- **Feeding the Supervisors by Real-Time Energy Data on the Same Process SCADA View.**
- **Parallel Integrating Hardware Solutions to the Same Process Control System.**

- **Predict the Energy Demand Response Based on the State of Different Historical Scenarios**
- **Finding Correlations between the KPIs of Energy Consumption and Mine Production Process**
- **Giving Insights on the Electrical Grid Quality**
- **Real-Time Energy Consumption Feedback Tarrif**
- **Cybersecurity and Data Sharing**

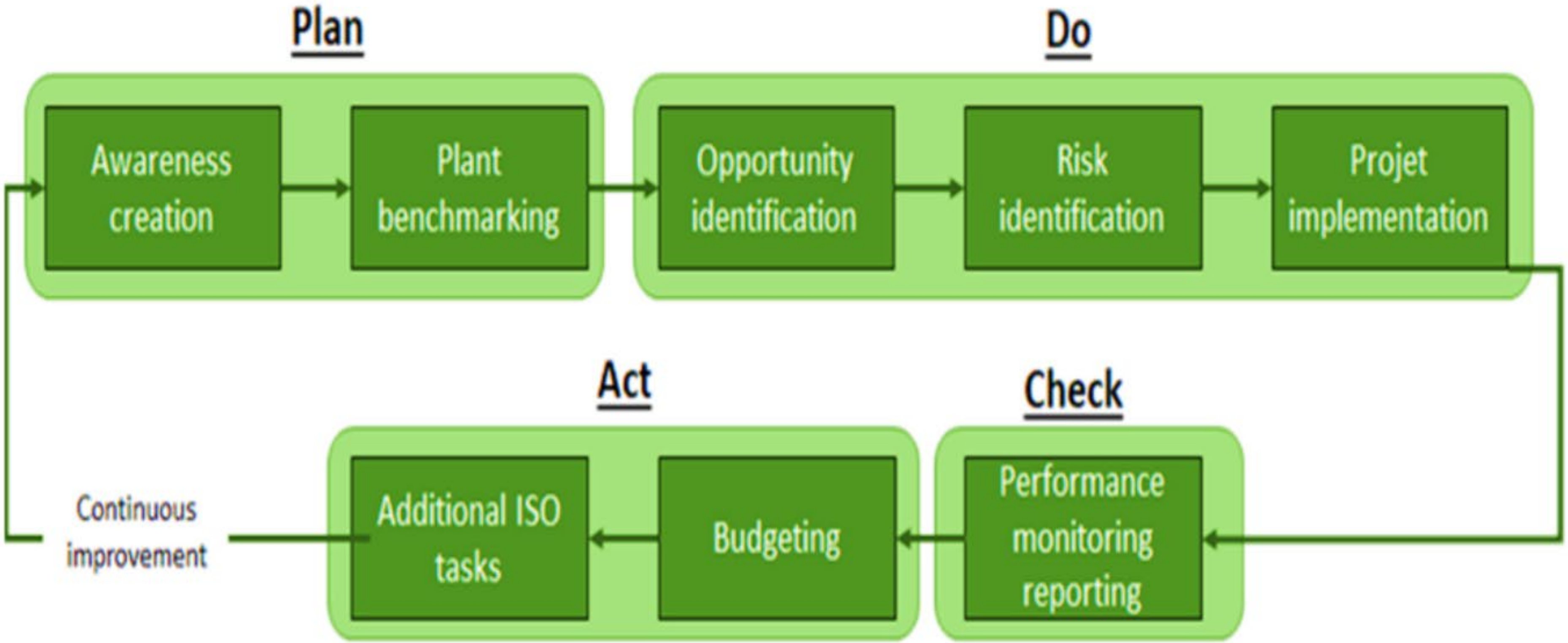
Methodology of the Integrated Smart Energy Management System



A smart energy management system general schematic.

The smart energy management system (SEMS), as shown in slide before, is a dataflow of energy consumption, generation data, between SCADA, SCADA back up for redundancy, the database, and the supervision dashboard, which shows the forecasted and predicted energy profile and demand response of the different components of the open-pit mine electrical grid.

A general PDCA schematic of the smart energy management system approach.



A scheme describing the result increasing profitability using the plan-do-check-act approach of ISO 50001.

State of Art of the Smart Energy Management Systems

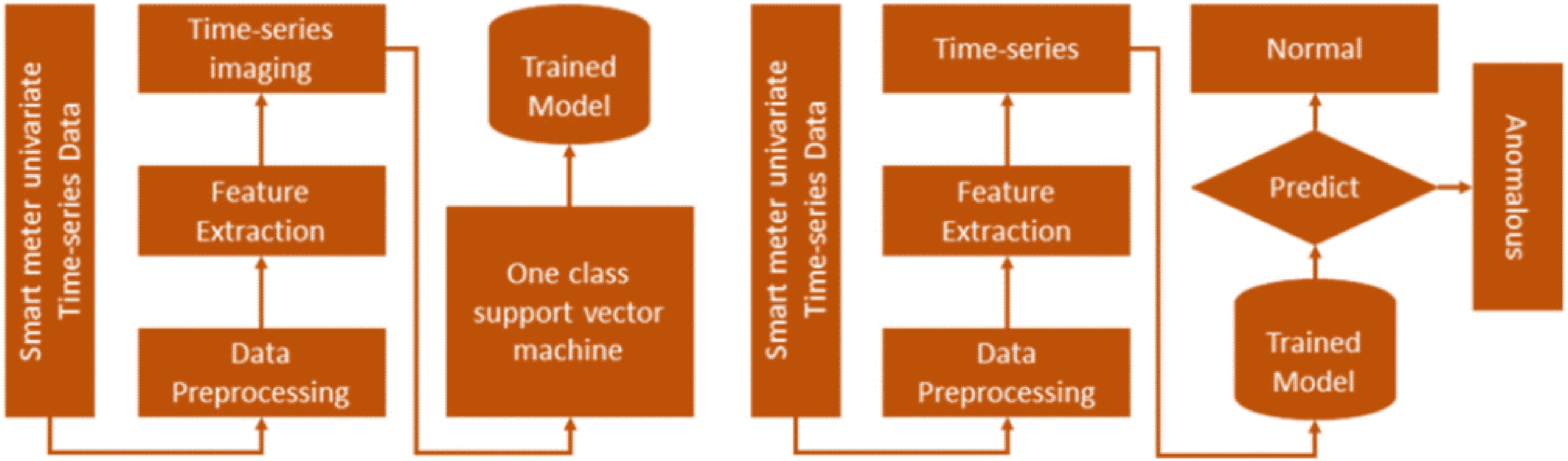
Peak Load Forecasting Models

The energy consumption prediction and peak load forecasting is an important feature in the proposed design. After collecting the data and completing the integration of hardware with the SCADA system is the phase to choose the best peak load forecasting model to validate the POC.

Model	Application	Year	Accuracy
Quantile regression	Electricity demand	2021	0.99
Neuro-fuzzy inference time series	Campus	2020	0.98
SVM	Hotel	2020	0.94
ANN	Ships in green ports	2020	0.85
Quantile regression	Industry	2019	0.95
Quantile regression	Grid demand load	2018	0.99

Comparative study of peak load forecasting models

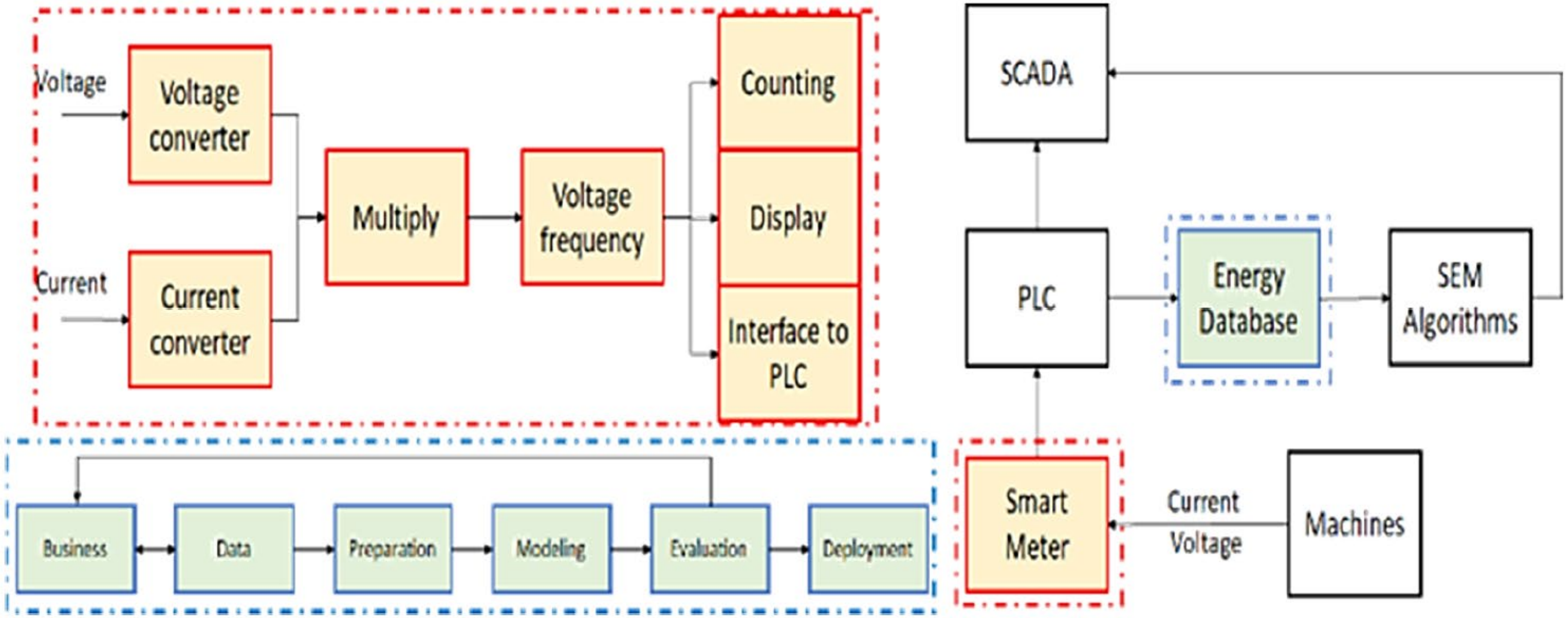
The goals, as shown in Figure, were collecting time series data from smart meters, processing the data and extracting the principal features, training the model using support vector machine, and then predicting the abnormal energy consumption behavior of each open-pit equipment.



Training and testing model to predict the normal and abnormal energy consumption for a residential smart building.

Smart Energy Meter

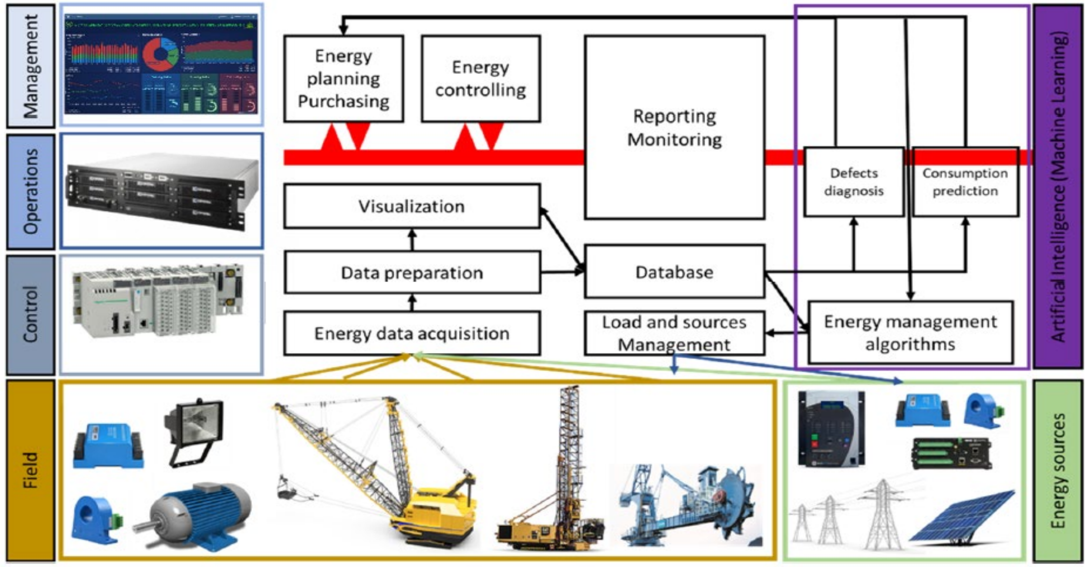
The key component in the proposed SEMS architecture in the open-pit mine application is the energy meter. In this section, we select the best energy meter that can fit perfectly with the existing SCADA architecture. We used PM8000 Schneider energy meters, which can communicate easily with the PLCs through the Modbus protocol.



A scheme of energy metering, storing, predicting and real-time monitoring for industry.

Smart Energy Management System Architecture

- The design is based on an architecture proposed in recent work, where the Smart Energy Management System (SEMS) is depicted as a data flow from various open-pit sections.
- In the field, machines and equipment like draglines, bucket wheel reclaimers, and conveyors are monitored and instrumented with current and voltage sensors.
- Sensor selection is based on factors such as accuracy, drift, linearity, phase shift, integration, and price.



Physical, software and artificial intelligence layers implementation scheme in a mining industry.

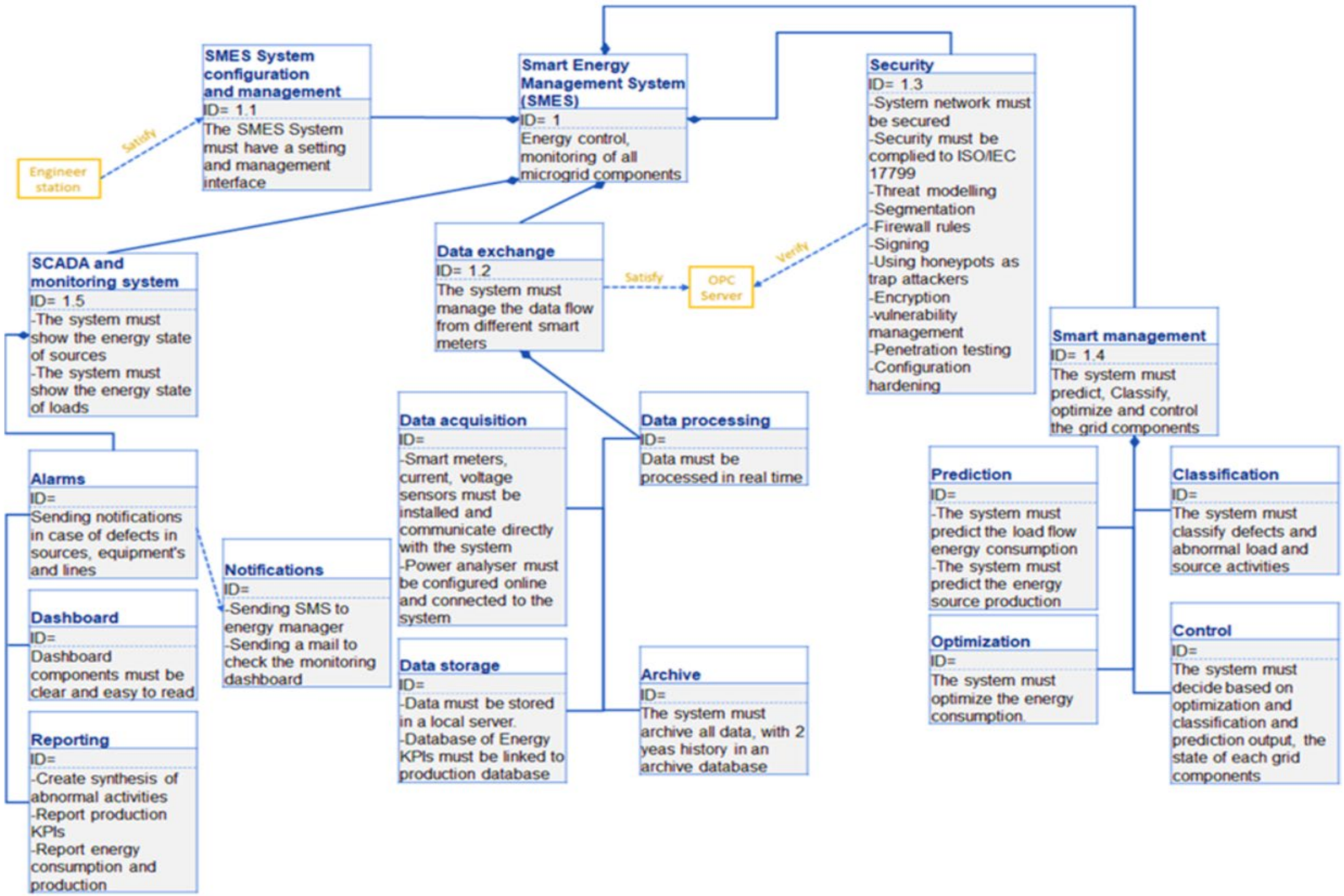
- These sensors interface with power meters, which communicate directly with Programmable Logic Controllers (PLC) in the control layer.
- The PLCs interface with the SCADA system to collect, store, and visualize the data.
- In the artificial intelligence layer of the SEMS, the database feeds algorithms for defect diagnosis and load forecasting.

Smart Energy Management System Requirements for the Open-Pit Mine

- To implement a smart energy management system in mining industry, the requirements of the system must meet the ISO 50001, ISO 50006, IEC 61557-12, IEC 62974-1 and ISO IEC 17799 standards requirements, the schematic represents the requirements diagram for this system, and it proposes a methodology on how making it smart.

- The requirements for a smart energy management system considering five important parts: SCADA and the monitoring system which contains alarms for sending notifications in case of a defects or an abnormal behavior of the grid components, a dashboard that shows the different KPIs and results of the microgrid, and a reporting system that summarize the results and generates reports automatically.

- The data exchange between different smart meters, power analyzers and the communication system, where the data acquisition processing and storage must be in real-time and automatic.



The requirements diagram for smart energy management system for mining industry.

Open-Pit Mine Application

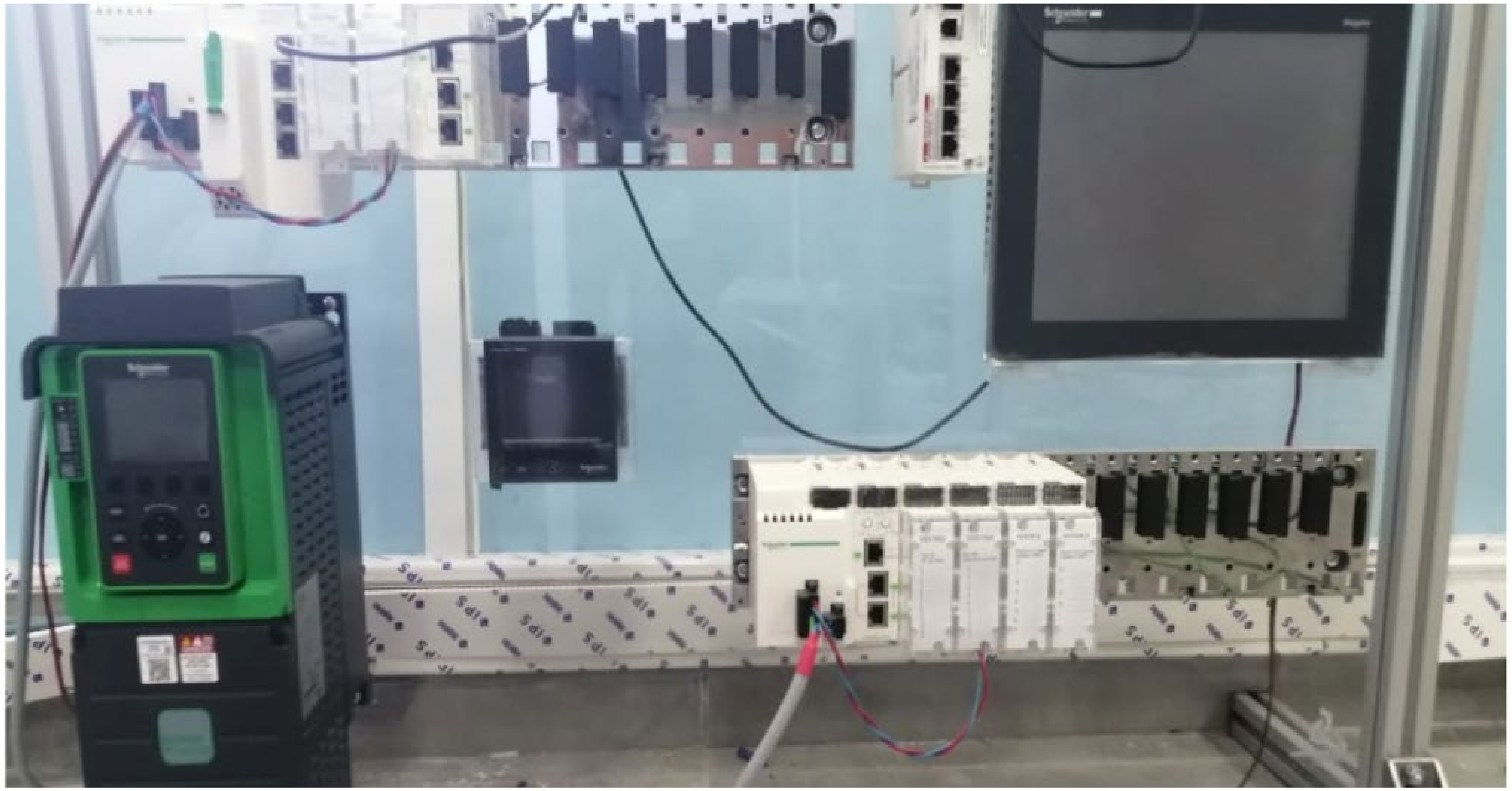
- After the design and requirements study, this section presents the current state of the smart energy management system's proof of concept at the experimental open-pit mine.
- Before implementing the architecture in the field, a test bench was designed in order to test the communication protocols, the database connection, the SCADA system, and the prediction algorithm.

Industrial Application in the Open-Pit Mine SEMS Architecture and Designed Test Bench

- Figure represents the test bench adding an HMI to visualize the data. The program is tested and built on the same PLC using Unity Pro Xl software.

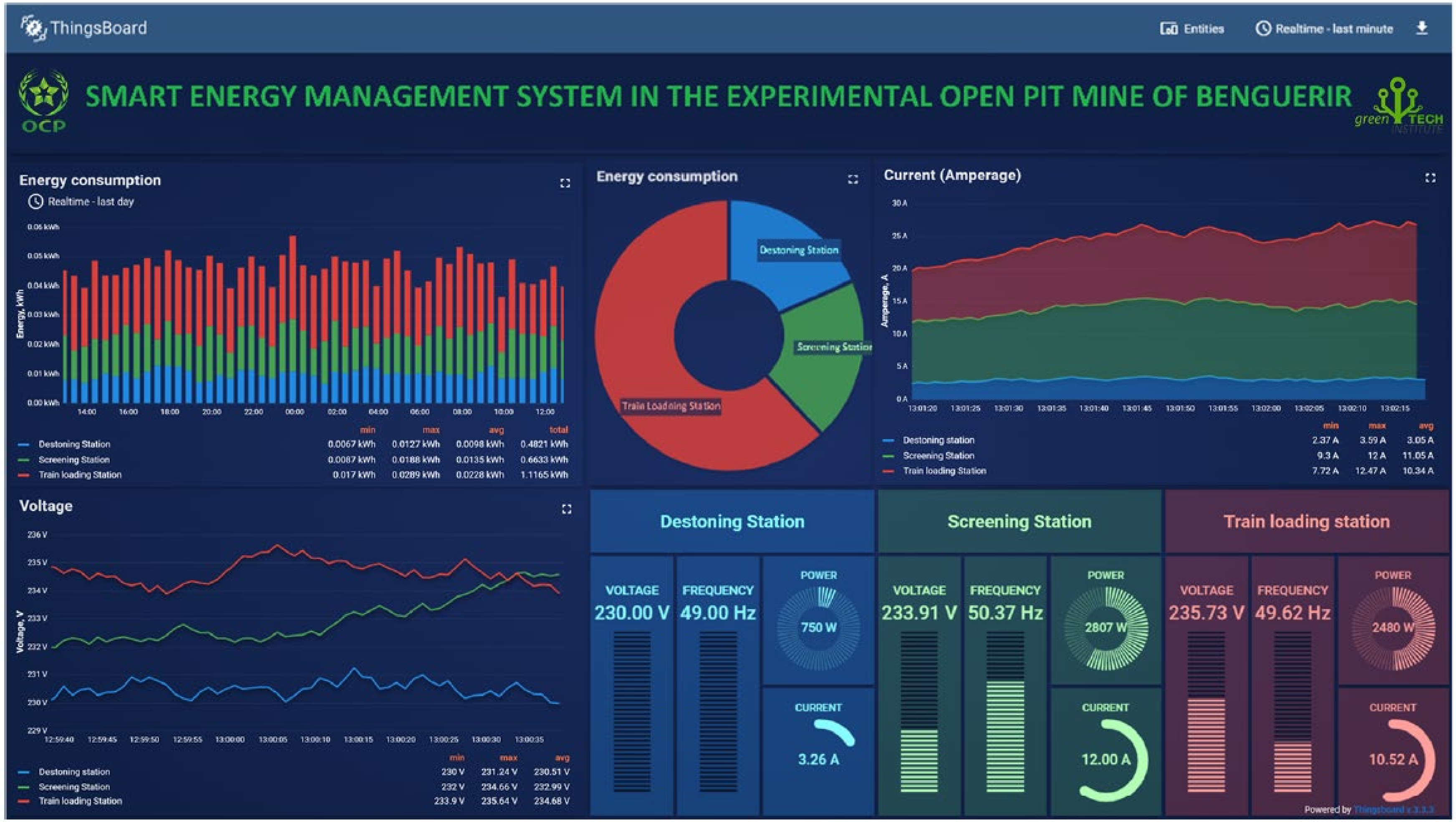
The PLC is connected to a server that contains the database, using the Python program that retrieves data from the PLC Modbus protocol and inserts them into tables as a time series dataset, which is connected to both SCADA views using Citect SCADA software and to Things Board for web browser connection.

Industrial Application in the Open-Pit Mine SEMS Architecture and Designed Test Bench



Communication test bench set up.

SCADA Views



Things Board view under design.

- These power meters interface with programmable logic controllers (PLCs) and distributed control systems (DCS) to directly control motors and optimize energy consumption.
- Similar power meters are connected to renewable energy sources such as photovoltaic panels, wind turbines, electric vehicles, or other energy storage systems for a comprehensive monitoring system.
- A smart microgrid dedicated to the mining industry's open-pit operations is developed, integrating different communication protocols and managing energy flow.

REFERENCES

- Army - Coe Technical Manuals (Tm) Tm 5-601 Supervisory Control And Data Acquisition (Scada) Systems For Command, Control, Communications, Computer, Intelligence, Surveillance, And Reconnaissance (C4isr) Facilities.
- Jämsä-Jounela, SL., Baiden, G. (2009). Automation and Robotics in Mining and Mineral Processing. In: Nof, S. (eds) Springer Handbook of Automation. Springer Handbooks. Springer, Berlin, Heidelberg. https://doi.org/10.1007/978-3-540-78831-7_57
- Laayati, O.; Bouzi, M.; Chebak, A. Smart Energy Management System: Design of a Monitoring and Peak Load Forecasting System for an Experimental Open-Pit Mine. Appl. Syst. Innov. 2022, 5, 18. https://doi.org/10.3390/asi5010018

CONCLUSION

- Explored the various control mechanisms employed within SCADA systems for monitoring and managing industrial processes.
- Introduced PLCs as a key component of SCADA systems, responsible for executing control logic.
- Discussed the use of redundant PLCs to enhance reliability and fault tolerance in SCADA setups.
- Explored the process of implementing SCADA systems, including hardware setup, software configuration, and integration
- Examined the latest developments and innovations in SCADA technology, including advancements in hardware, software, and communication protocols.
- Case Study - Smart Energy Management System


THANK YOU

MINE AUTOMATION AND DATA ANALYTICS

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SWAYAM NPTEL COURSE ON

MINE AUTOMATION AND DATA ANALYTICS

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Module 06
Automated Tracking and VR Systems

Lecture 15 A
Introduction to VR Systems

CONCEPTS COVERED

- What is Virtual Reality
- I^3 of virtual reality
- Types of Virtual Reality
- Applications of VR
- Hardware components of VR systems

CONCEPTS COVERED

- Field of View and Visual
- Overview of Micro-displays
- Benefits of Virtual Reality
- Future of Virtual Reality
- Technical Considerations for Virtual Reality

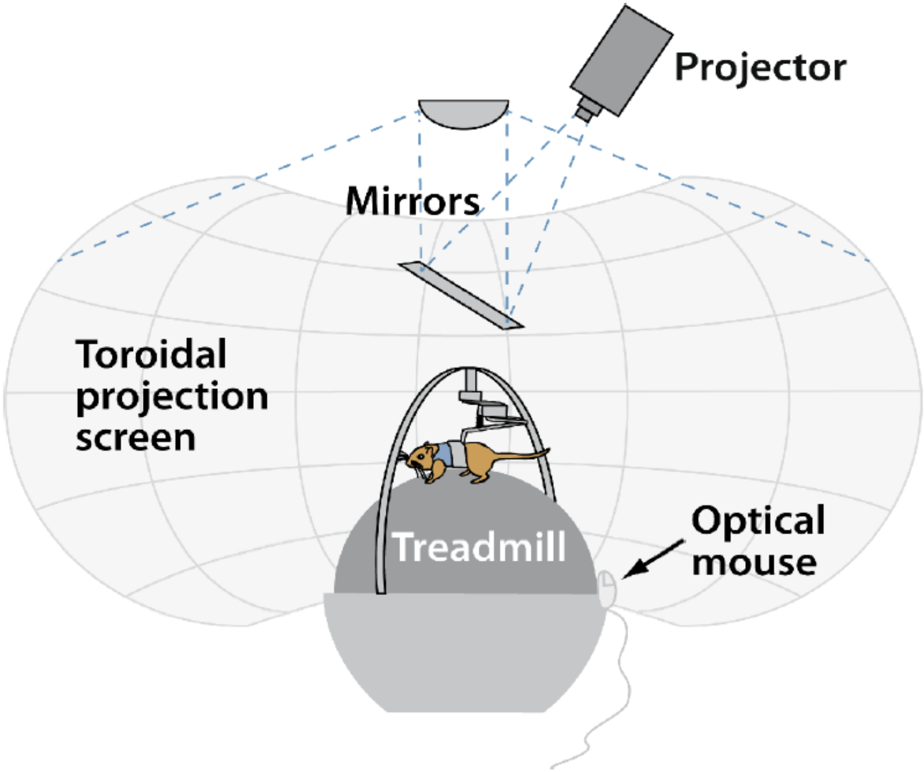
What is Virtual Reality?

Virtual Reality (VR) refers to a computer-generated simulation of an environment or situation that immerses users in a three-dimensional, interactive experience. In a virtual reality environment, users can interact with the simulated world using specialized hardware and software. The goal of virtual reality is to create a sense of presence, making users feel as if they are physically present in the virtual space.

Examples:

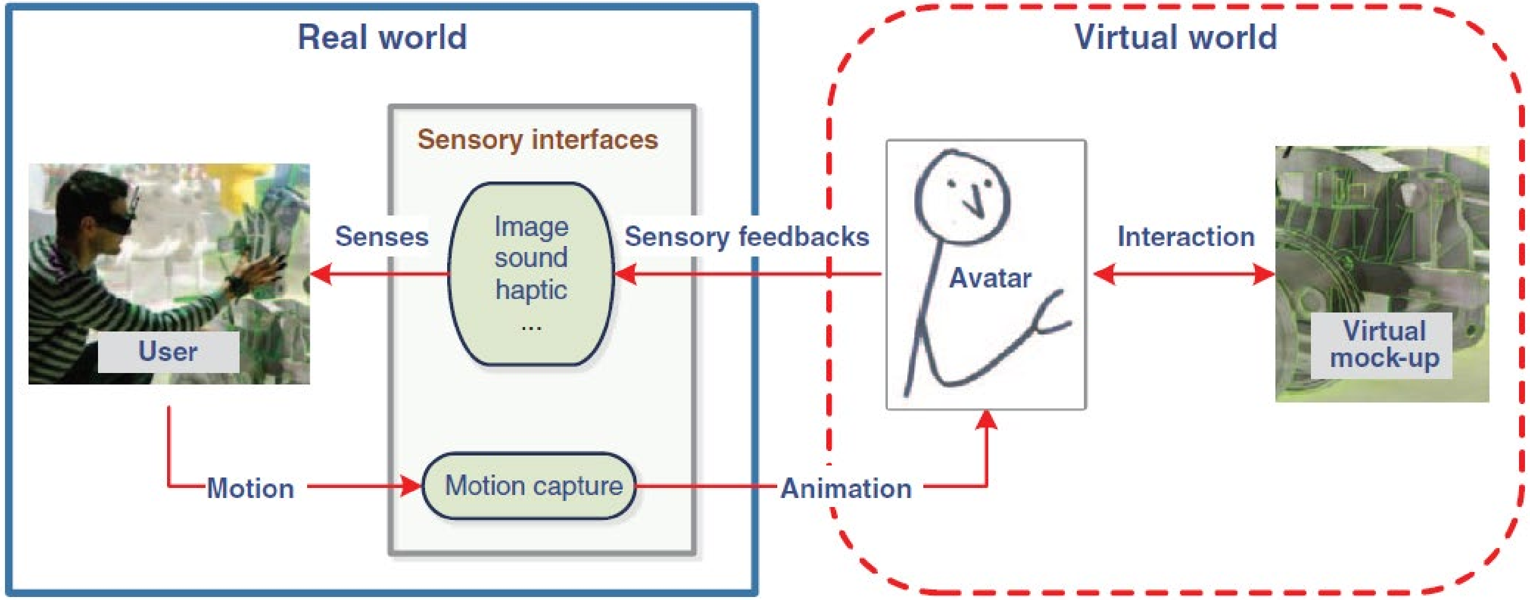
1. A human has an experience of flying over virtual San Francisco by flapping his own wings as shown in figure below. The user, wearing a VR headset, flaps his wings while flying over virtual San Francisco. A motion platform and fan provide additional sensory stimulation. The figure on the right shows the stimulus presented to each eye.

2. A mouse running on a freely rotating ball while exploring a virtual maze that appears on a projection screen around the mouse. An experimental setup used by neurobiologists at LMU Munich to present visual stimuli to rodents while they run on a spherical ball that acts as a treadmill

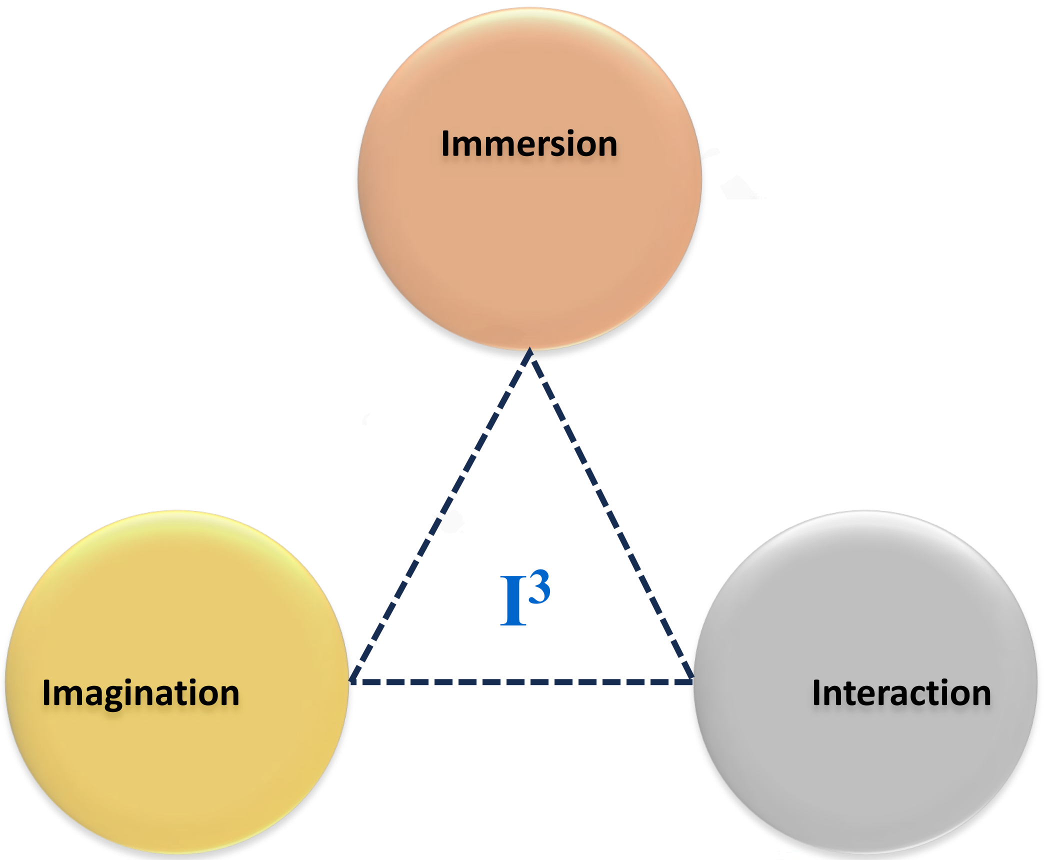


Principle of Virtual Reality

The principle is to create a relationship between the user and a virtual environment. For that, software technologies (computer graphics, real-time computing) as well as hardware technologies (human-computer interfaces) are required.



I^3 of virtual reality



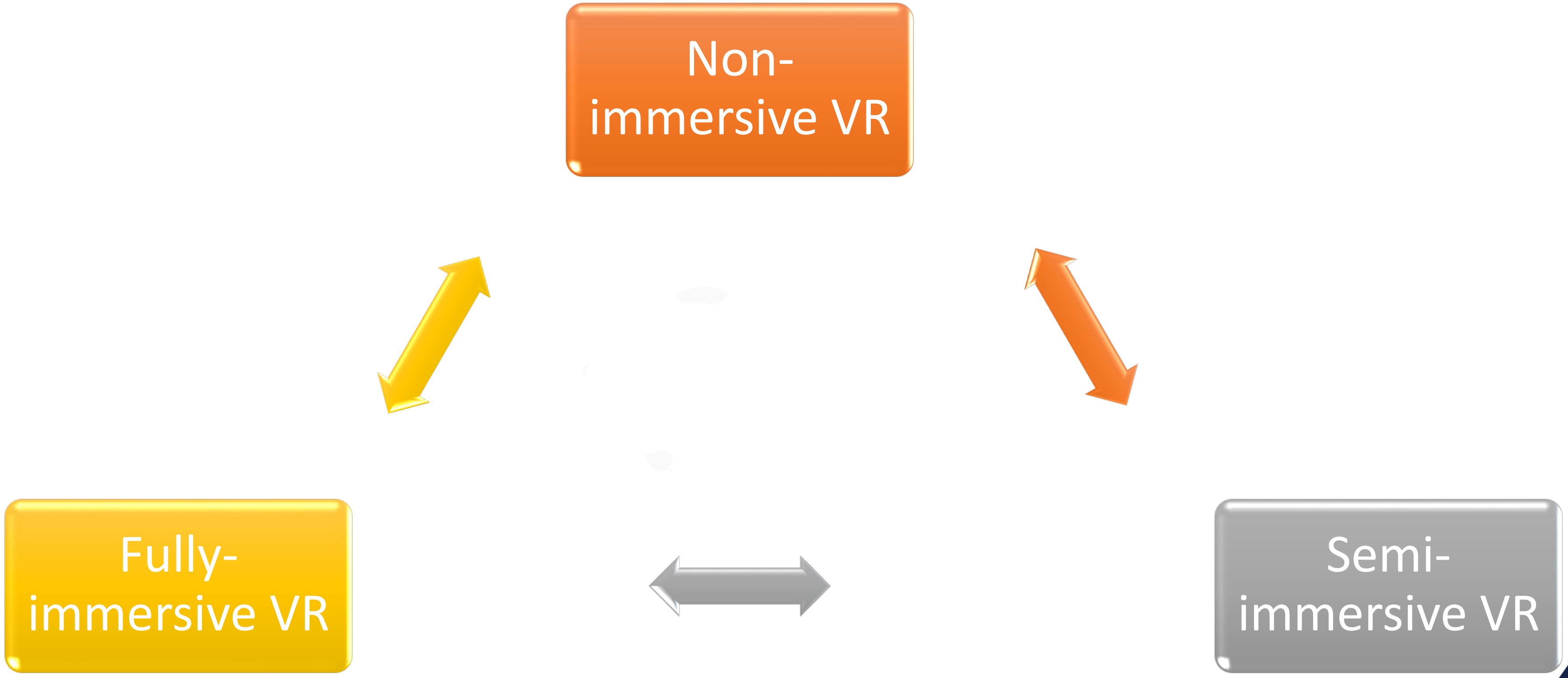
Immersion: It means that users focus on the experience in virtual scenes and forget the real environment, which is the key to virtual simulation.

Interaction: The experiencer participates in the virtual environment and gets information feedback from the virtual environment, which is the core of human-computer interaction. Users can interact with virtual objects in various forms.

Imagination: It is the purpose of virtual simulation that the experiencer conceives various sensory effects beyond reality, improves rational or perceptual knowledge and expands people's imagination space.

With the development and evolution of virtual reality technology, its theory and system are becoming more and more mature. Artificial intelligence technology will also be included in the basic characteristics of VR, and its " I^3 " feature will develop into " I^4 " feature.

Types of Virtual Reality

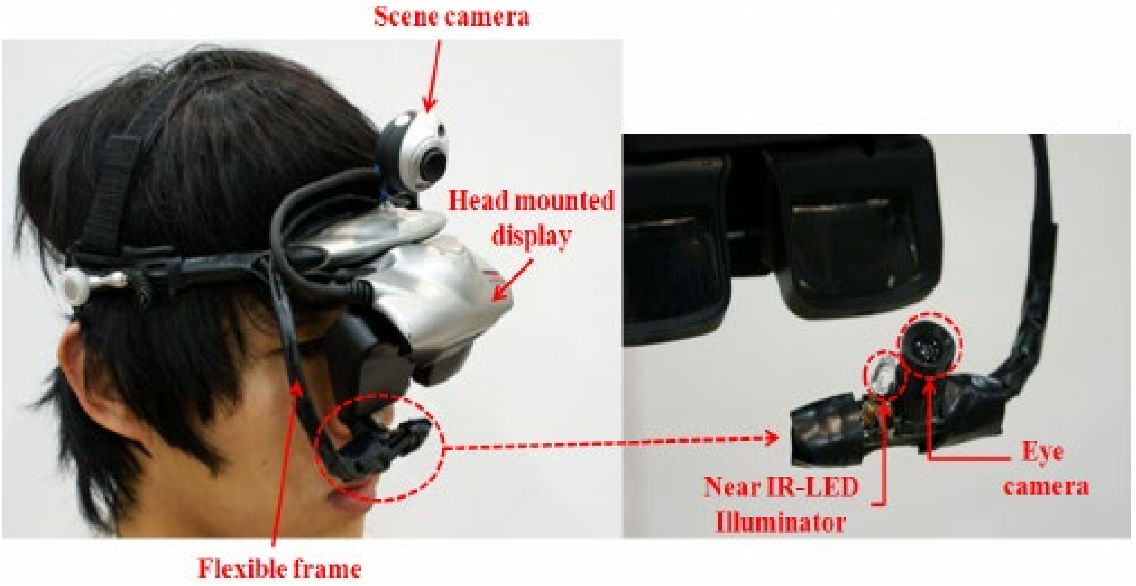


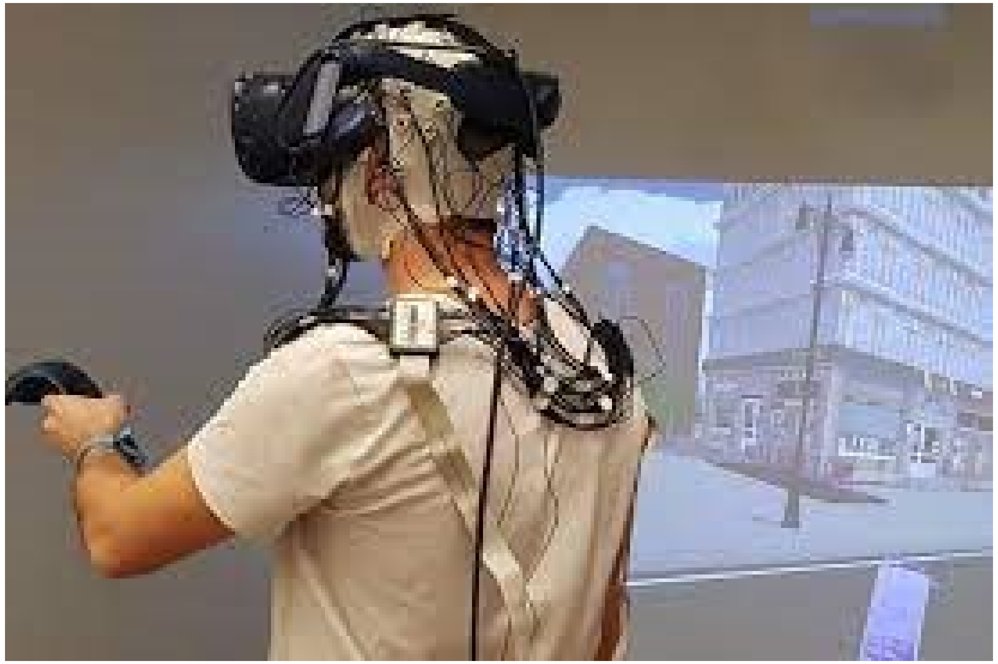
Non-immersive VR

1. Non-immersive VR, also known as desktop or 3D VR, is a basic form of virtual reality.
2. Users experience virtual environments through a computer screen or handheld devices like smartphones or tablets.
3. With non-immersive VR, users can view the virtual world on a screen while simultaneously observing their real-world surroundings.
4. Examples of non-immersive VR include virtual tours, 360-degree videos, and flight or driving simulators.

Semi-immersive VR

- Semi-immersive VR provides a more immersive experience than non-immersive VR but doesn't fully immerse users in a virtual environment.
- Users typically wear a head-mounted display (HMD) covering only part of their field of view.
- The HMD may include motion tracking, enabling users to look around the virtual space by moving their head.





- However, body movements are not fully tracked, which may limit immersion.
- Applications of semi-immersive VR include gaming experiences and training applications where users can interact with virtual environments through head movements.

Fully-immersive VR

- Fully immersive VR offers the highest level of immersion and presence, providing a realistic and seamless virtual experience.
- Users wear special head-mounted displays (HMDs) or VR goggles that cover their eyes and ears.
- These devices allow for a 360-degree view and sound, creating a real sense of presence within the virtual world.
- High-resolution screens for each eye enhance depth perception.

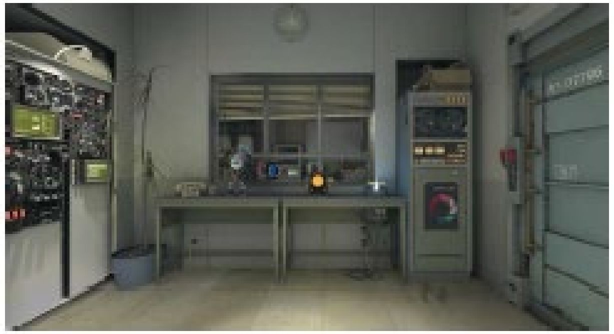
- Users can interact with the virtual environment using both head and body movements.
- Additional accessories like motion controllers or haptic feedback devices may be included to enhance the experience.
- Examples of fully immersive VR include high-end gaming experiences, virtual simulations for medical and pilot training, and advanced architectural visualization tools allowing users to navigate virtual buildings

Applications of VR

- Entertainment: Games
- Augmented Reality – Superimposing display
- Training
- Remote Robotics
- Distributed Collaboration
- Virtual prototyping

Applications

Entertainment: Games



(a)

(b)

(c)

(d)

Augmented Reality

The Microsoft Hololens, 2016, uses advanced see-through display technology to superimpose graphical images onto the ordinary physical world, as perceived by looking through the glasses.

Training

A flight simulator in use by the US Air Force. The user sits in a physical cockpit while being surrounded by displays that show the environment.

Remote Robotics

Examples of robotic avatars

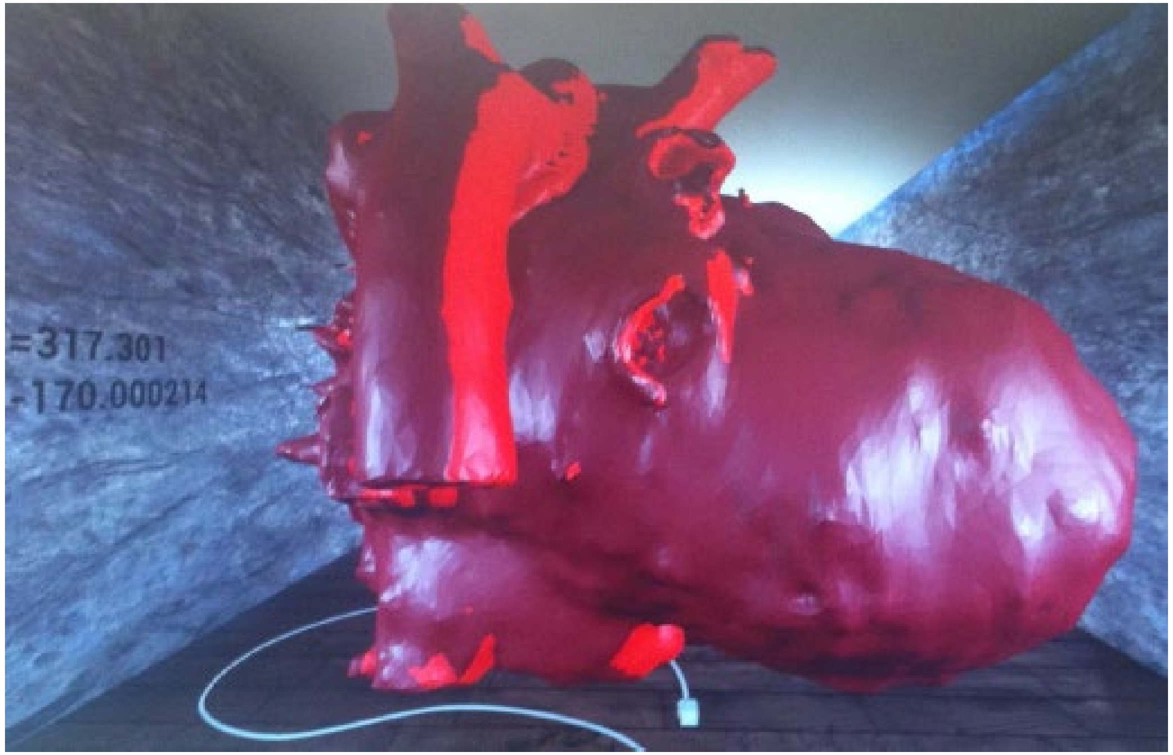
- **The DORA robot from the University of Pennsylvania mimics the users head motions, allowing him to look around in a remote world while maintaining a stereo view (panoramas are monoscopic).**
- **The Plexidrone, a flying robot that is designed for streaming panoramic video.**

(a)

(b)

Health care

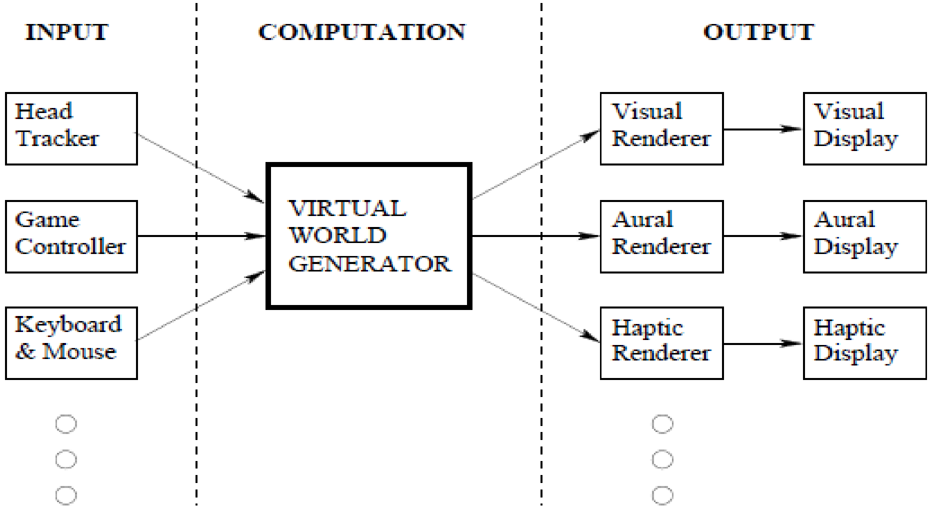
A heart visualization system based on images of a real human heart. This was developed by the Jump Trading Simulation and Education Center and the University of Illinois.



Virtual prototyping

Architecture is a prime example of where a virtual prototype is invaluable. This demo, called Ty Hedfan, was created by IVR-NATION. The real kitchen is above and the virtual kitchen is below.

Hardware components of VR systems



Displays (output)

Devices that each stimulate a sense organ.

Sensors (input)

Devices that extract information from the real world.

Computers

Devices that process inputs and outputs sequentially.

Field of View and Visual

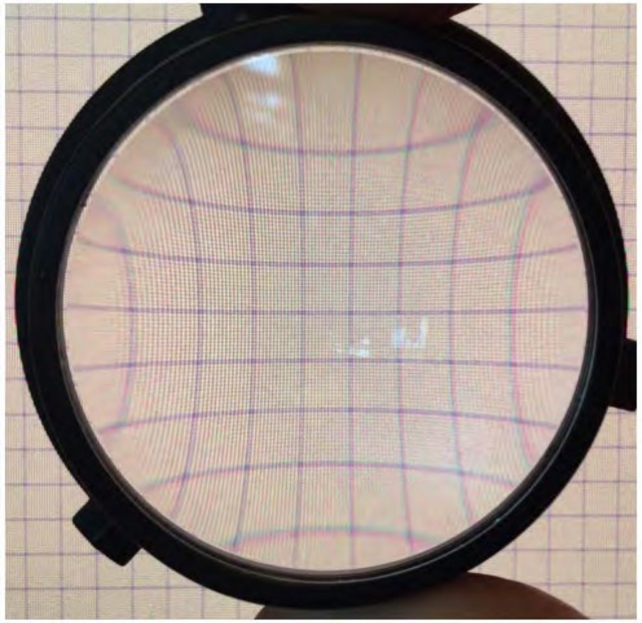
Lens Distortion Correction

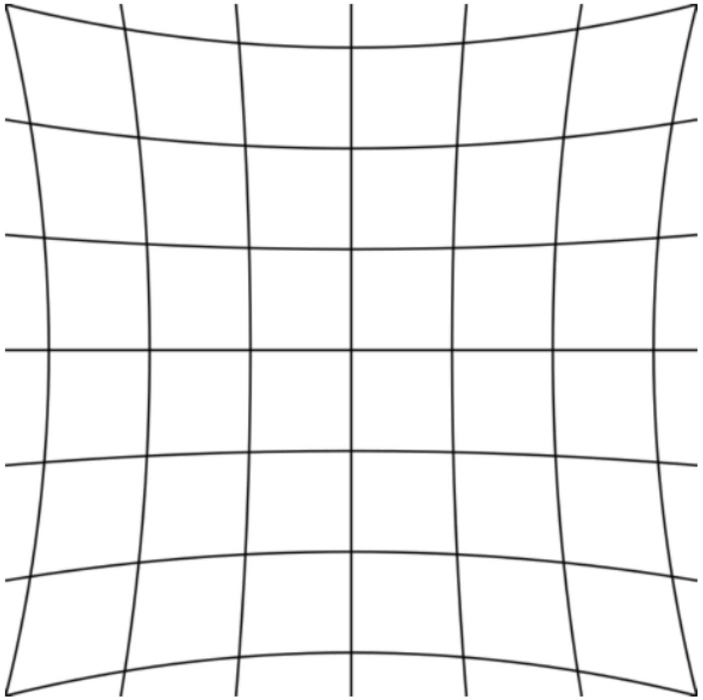
All lenses introduce image distortion, chromatic aberrations, and other artifacts – we need to correct for them as best as we can in the software

Lens Distortion

- grid seen through HMD lens
- lateral (xy) distortion of the image
- chromatic aberrations:

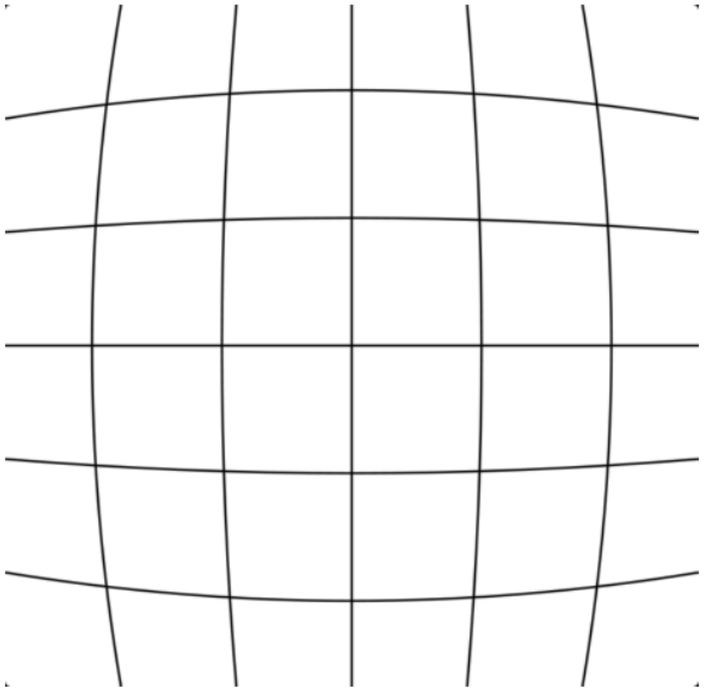
distortion is wavelength-dependent





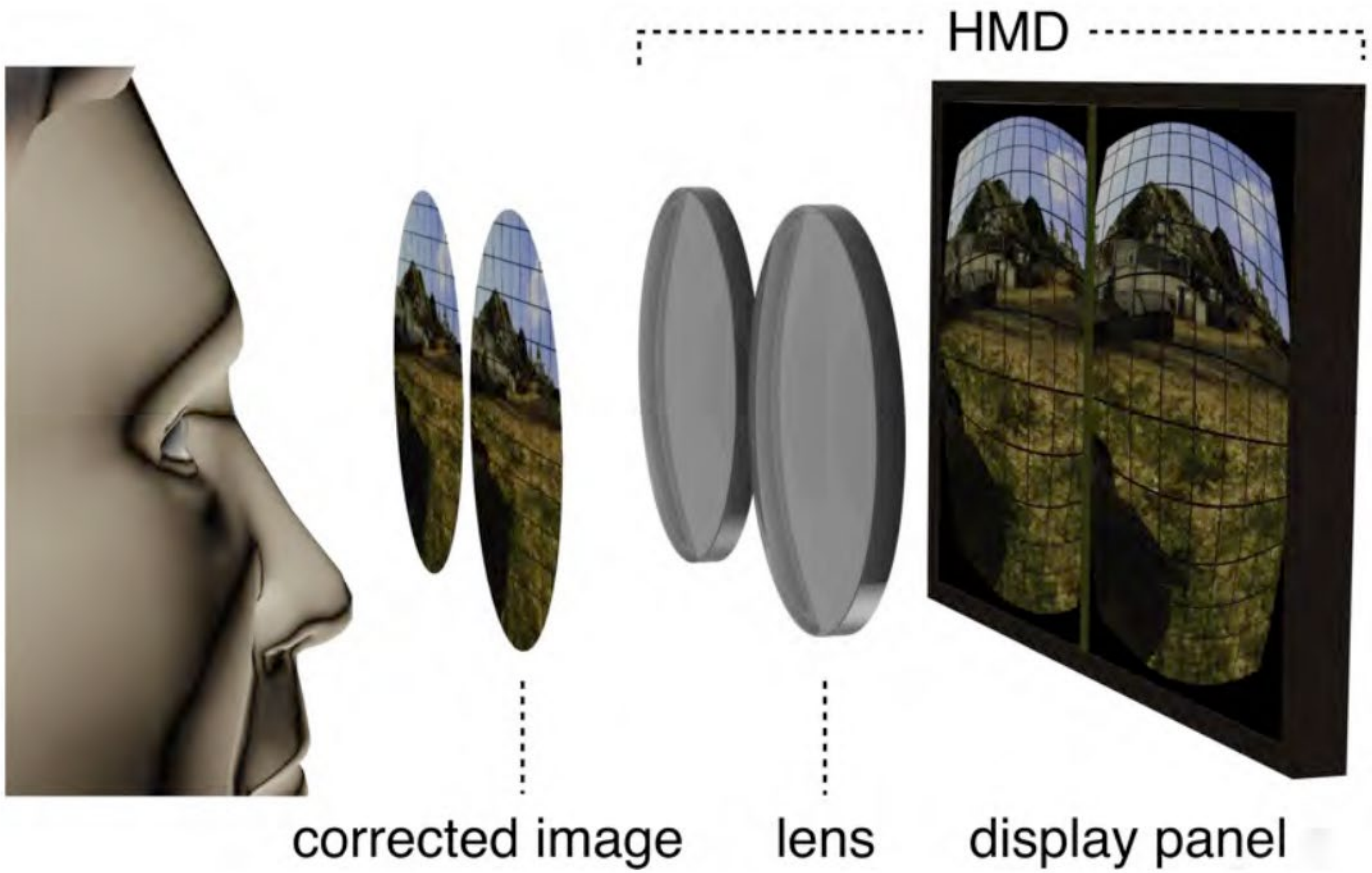
Pincussion Distortion

<u>optical</u>

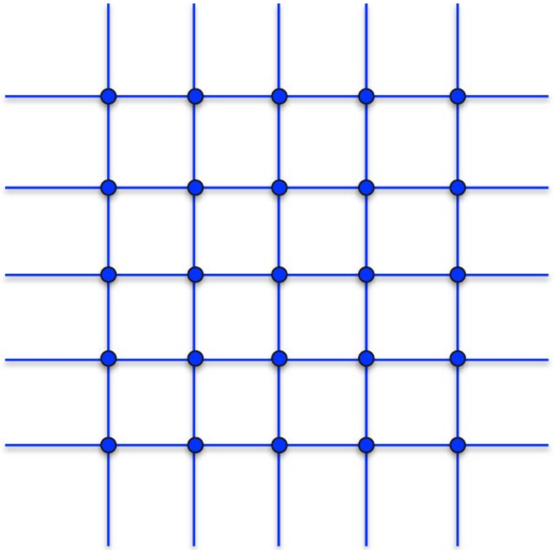


Barrel Distortion

<u>digital correction</u>


HMD
corrected image
lens
display panel

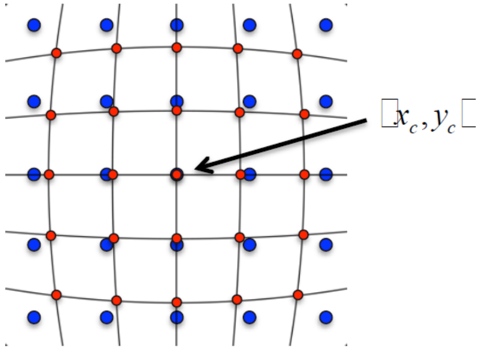
- x_u , y_u **undistorted point**



- x_u, y_u undistorted point
- $x_d \approx x_u(1 + K_1 r^2 + K_2 r^4)$

  $y_d \approx y_u(1 + K_1 r^2 + K_2 r^4)$

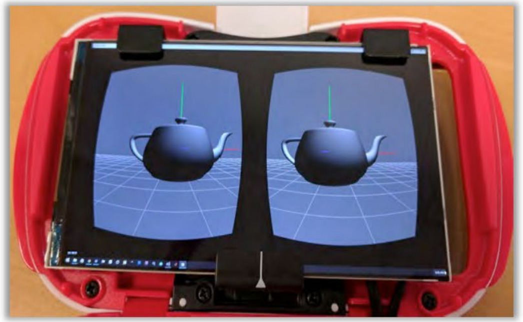
x_d, y_d	distorted point coordinates
K_1, K_2	distortion coefficients
r	normalized distance from center
x_c, y_c	center of optical axis

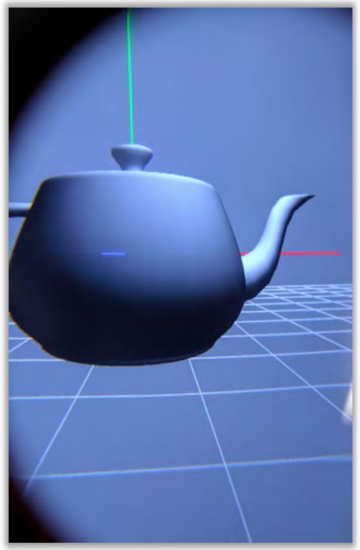


Barrel Distortion

digital correction

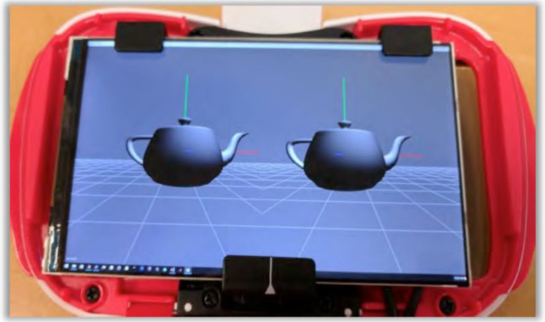
Lens Distortion Correction Example

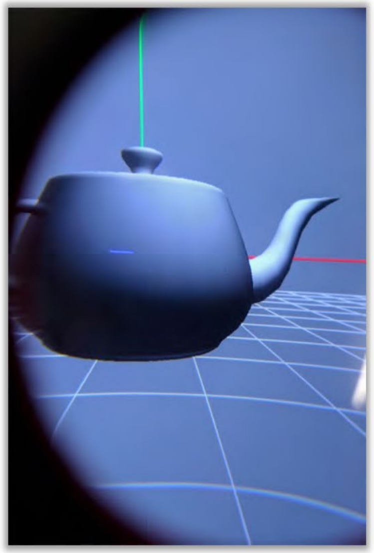




stereo rendering with lens distortion correction

Lens Distortion Correction Example

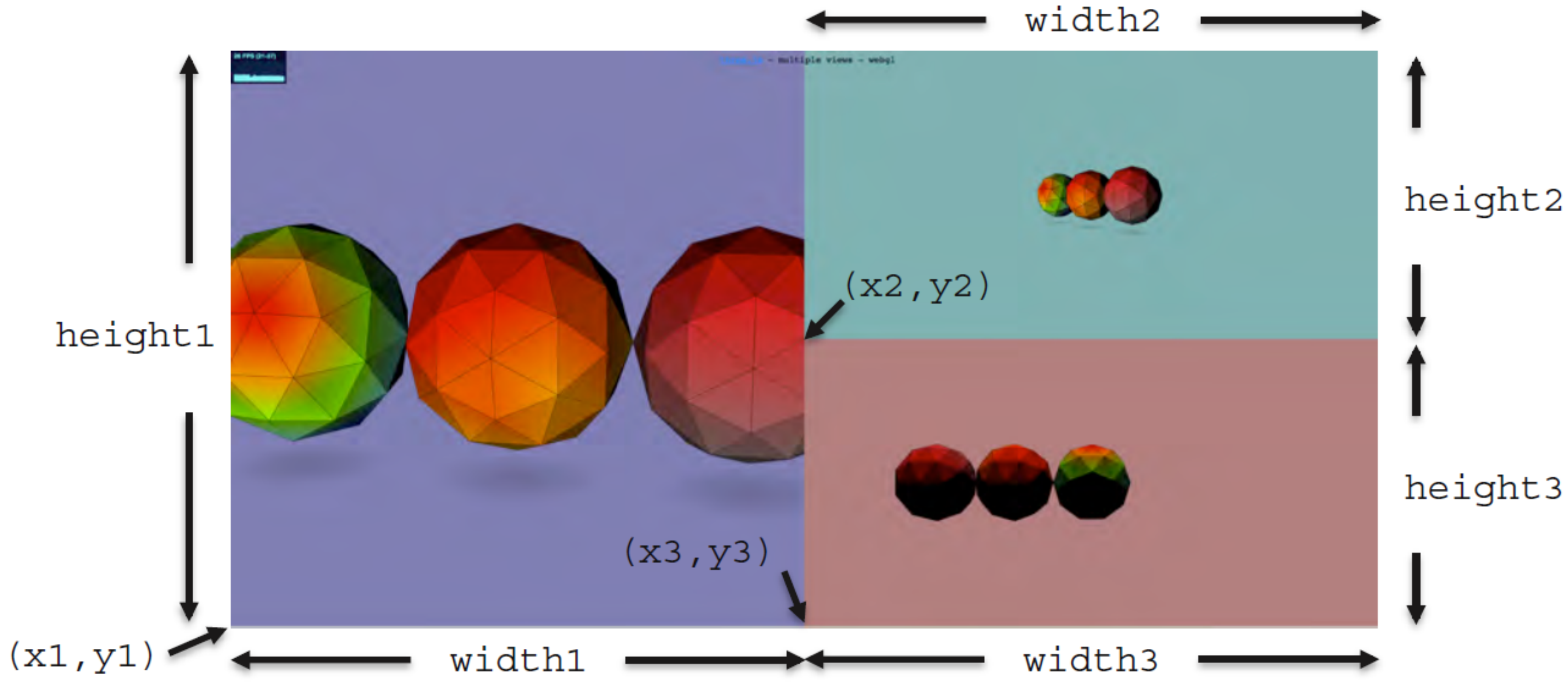




stereo rendering without lens distortion correction

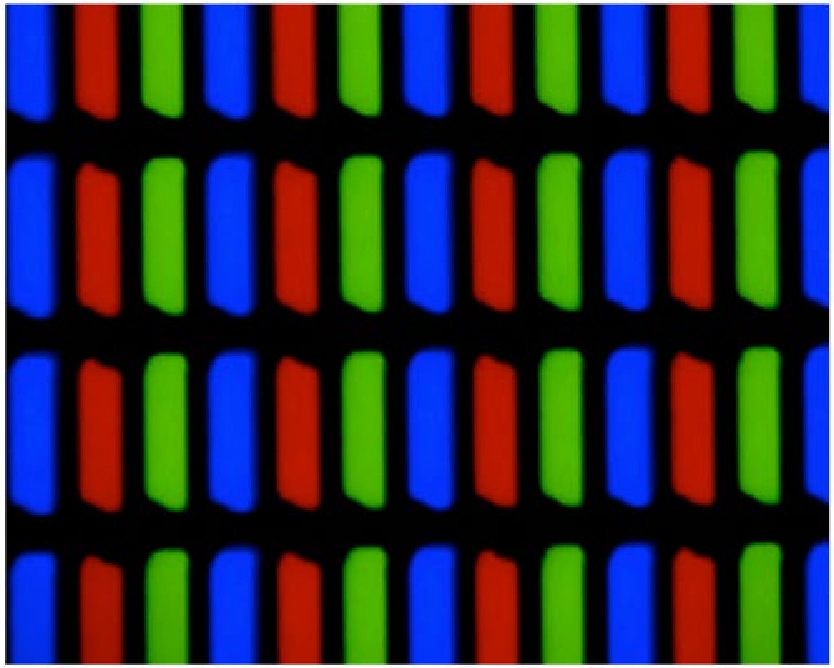
How to Render into Different Parts of the Window?

- `WebGLRenderer.setViewport(x,y,width,height)`
- `x,y` lower left corner; width, height viewport size

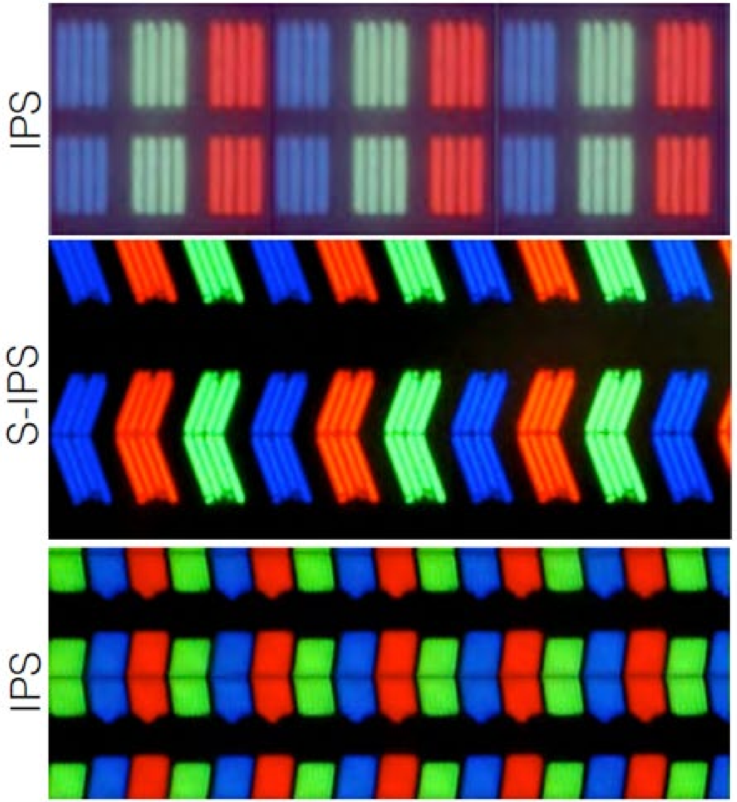


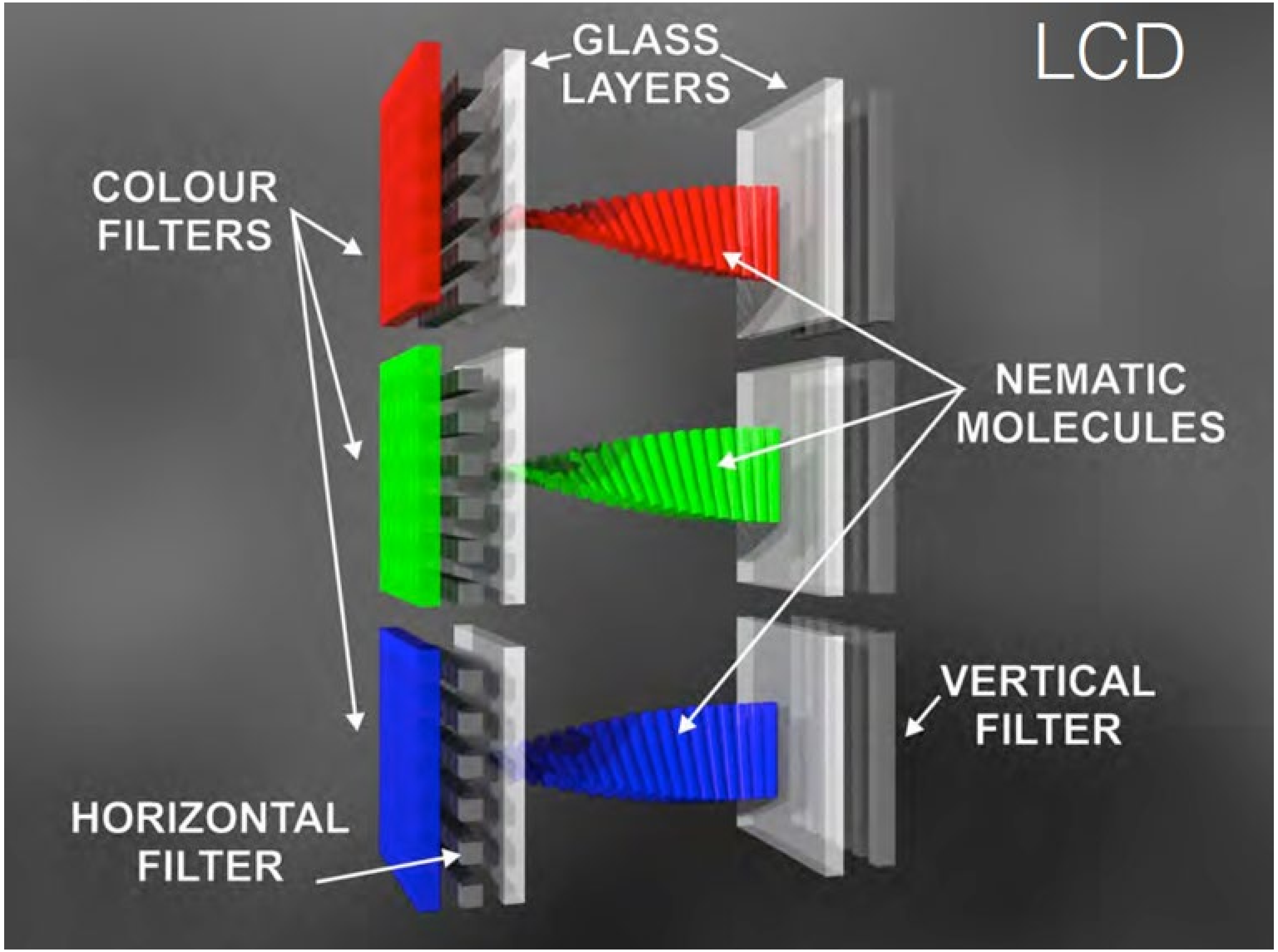
Overview of Micro-displays

Liquid Crystal Display (LCD) - Subpixels

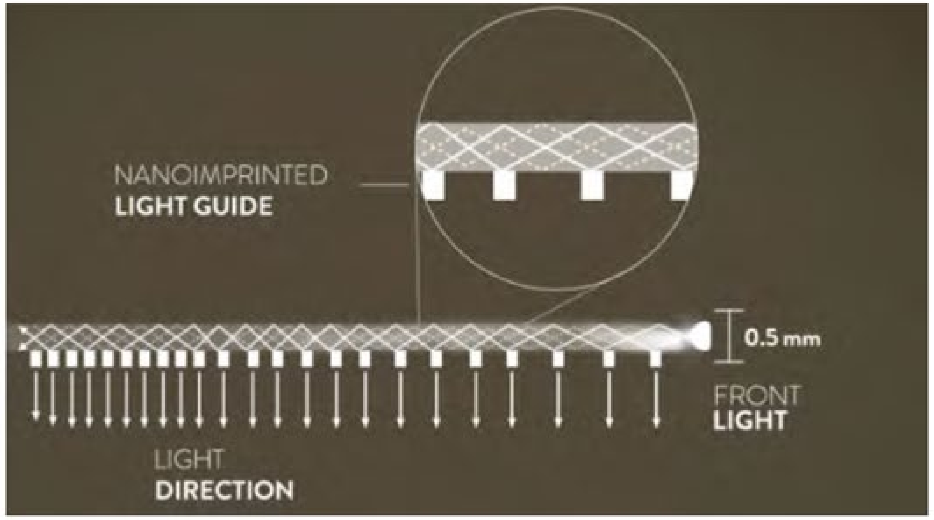


TN subpixels

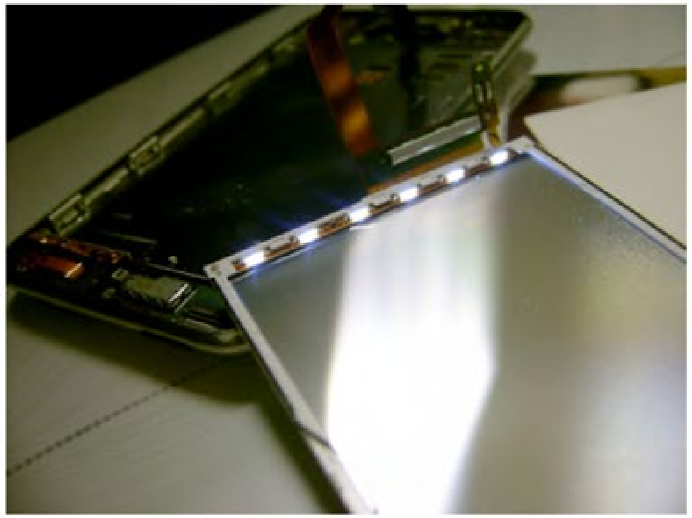



LCD
GLASS
LAYERS
COLOUR
FILTERS
NEMATIC
MOLECULES
VERTICAL
FILTER
HORIZONTAL
FILTER

LCD Backlight

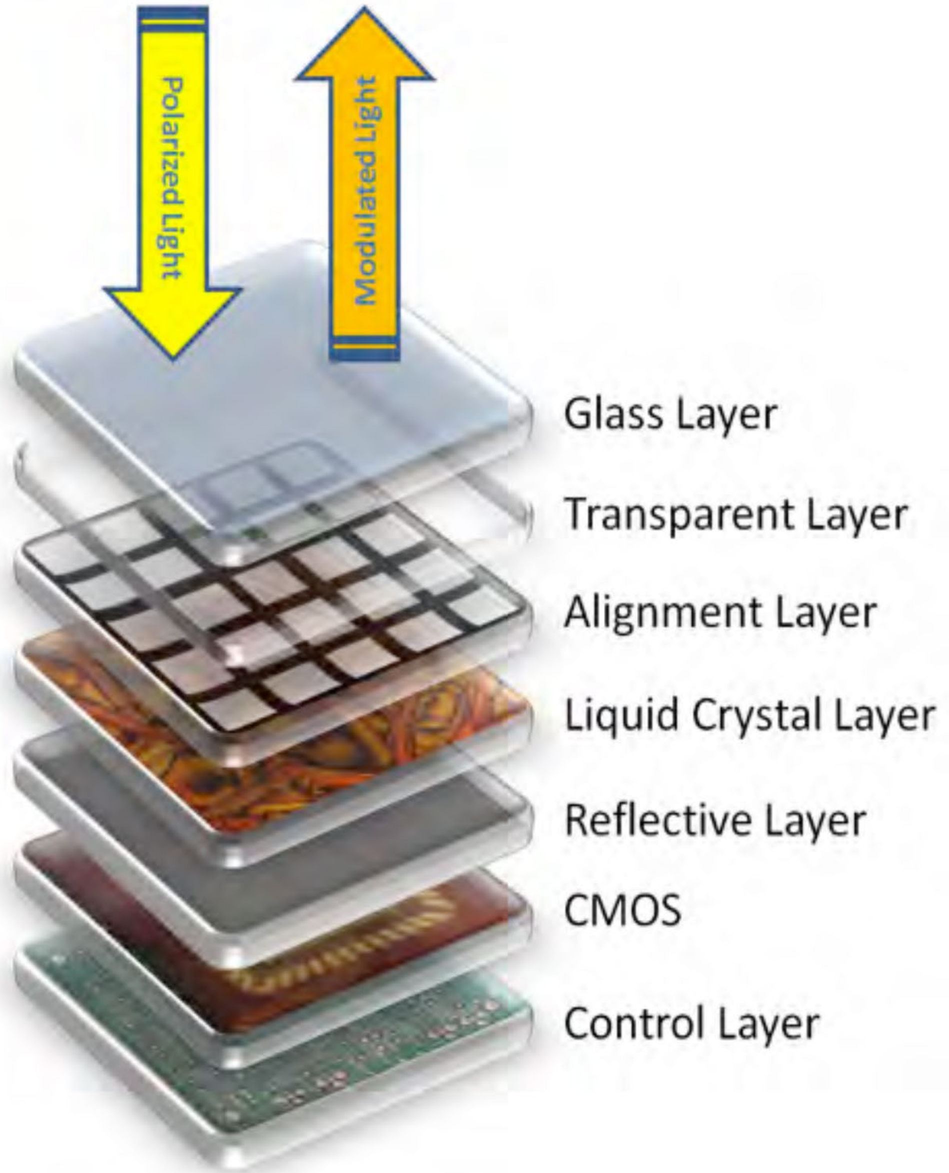


wikipedia

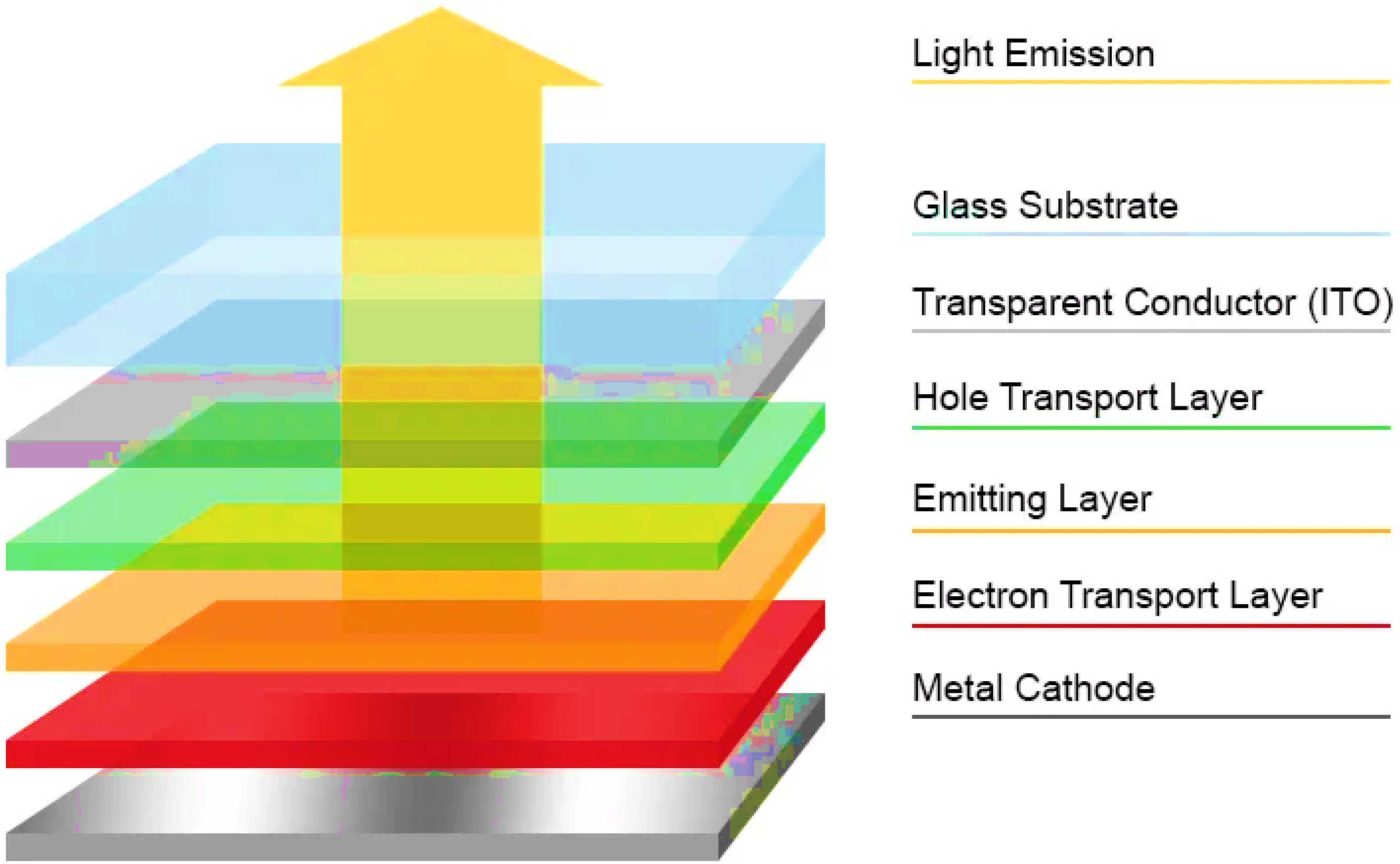


Liquid Crystal on Silicon (LCoS)

- basically a reflective LCD
- standard component in projectors and head-mounted displays
- used e.g. in google glass

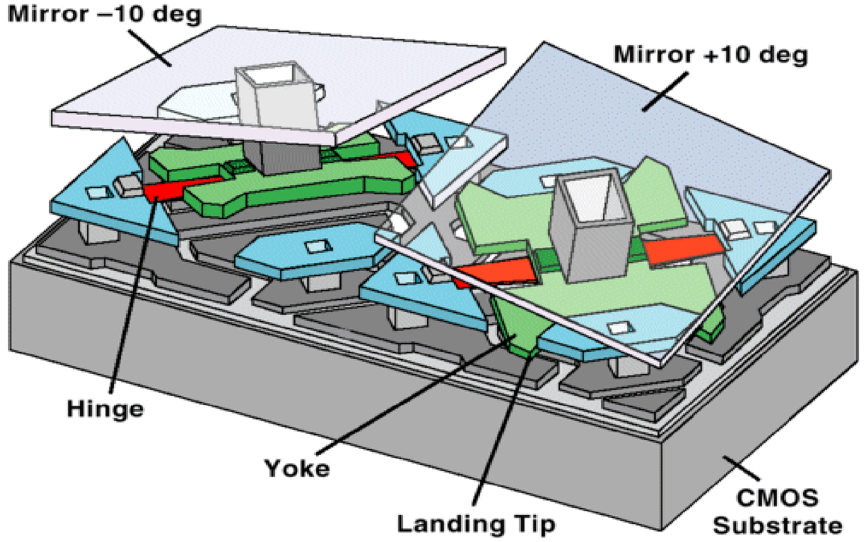


Organic Light Emitting Diodes (OLED)



Digital Micromirror Device (DMD)

- developed by Texas Instruments
- MEMS device
- binary states (e.g. +/- 10 degrees)
- gray-level through pulse width modulation (PWM)



Texas Instruments

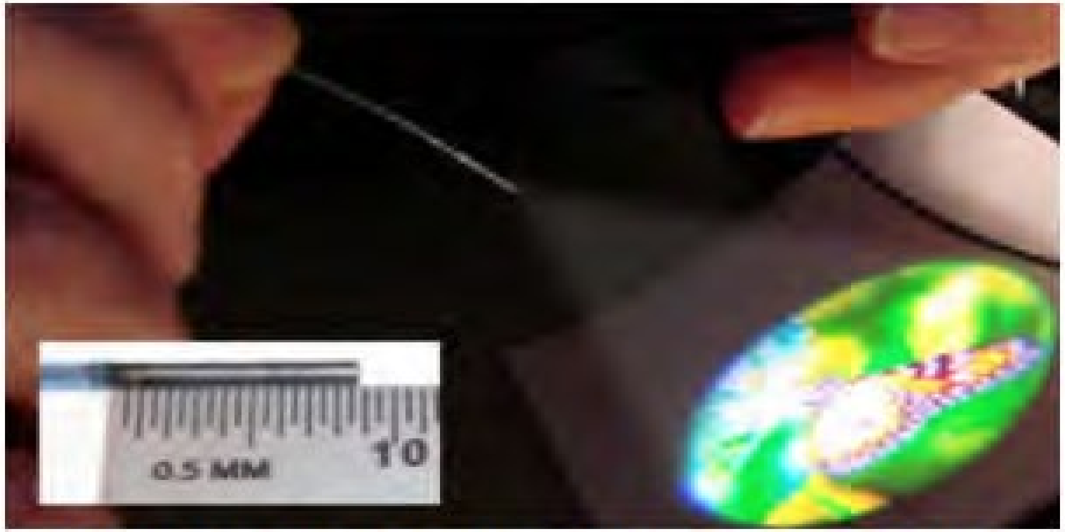
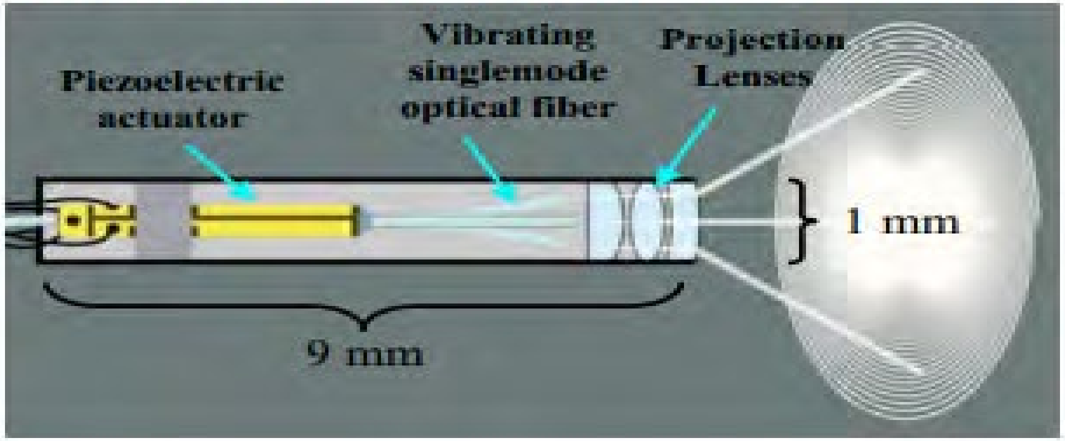


Figure 1. 1 mm x 9 mm scanning fiber projector.



3D Displays Using Scanning Laser Projection.

Benefits of Virtual Reality

- It provides high-quality visualization with countless sensations.
- A fully immersive VR can simulate potentially menacing real-world situations like flight operations or surgery.
- As a tourist, virtual reality technology helps you decide if any upcoming trip is worth it or not.
- The types of VR provide consumers with an engaging experience.

Benefits of Virtual Reality

- Virtual reality is of great help to pilots, firefighters, astronauts, and police officers to practice in a safe environment before getting into a jeopardized situation.
- This technology is handy in day-to-day activities.
- It makes watching more enjoyable, thereby creating interest.
- Virtual reality can effectively overcome language barriers.

Future of Virtual Reality

AI and VR integration

Artificial Intelligence (AI) will play a significant role in creating dynamic and adaptive VR experiences. AI algorithms can personalize content based on user behaviour, preferences, and real-time interactions, making VR applications more engaging and tailored to individual users.

Expanded applications in education and training

It is likely that VR will find broader applications in education and professional training. It will be used not only for medical simulations and pilot training but also for soft skills development, team-building exercises, and language learning.

Entertainment and gaming

VR gaming will continue to grow, with more sophisticated and interactive experiences and scenarios becoming available. Game developers are likely to invest in VR titles, pushing the boundaries of storytelling, graphics, and gameplay.

Enhanced hardware

In terms of the hardware used, future VR devices will probably become more lightweight, comfortable, and user-friendly. Advancements in display technology may lead to higher resolutions, wider field-of-view, and reduced motion sickness.

Technical Considerations for Virtual Reality

Accuracy

VR application development requires significant attention to detail with respect to stimulus generation, internal calculations, and outcome data. For example, in research, it is necessary to generate a consistent, repeatable stimulus. Additionally, the sequence of when physics (e.g., positions, forces) are computed, applied, and rendered can vary depending on the application.

Flexibility

Flexible VR architectures for research need to be both modular and scalable, and the underlying framework should support further development. For example, strategic development of base VR features should be platform agnostic. Though user interfaces would need to change based on a final use case, minimizing the need for content adaptation increases the utility. To this end, a VR application could easily be made for an HMD or a large-scale theater.

REFERENCES

- S. M. Lavalle. Virtual Reality. Cambridge University Press, 2023. 2
- https://www.optimum.com/articles/internet/the-realities-of-virtual-reality
- https://dl.acm.org/doi/fullHtml/10.1145/3482632.3482643
- image from: https://www.slideshare.net/Mark_Kilgard/nvidia-opengl-in-2016
- Organic Light Emitting Diodes (OLED), https://images.app.goo.gl/jiWpPKAf3EmoFKMj7

CONCLUSION

- Provided an overview of the concept of Virtual Reality (VR) technology.
- Introduced the three main components of VR: immersion, interaction, and imagination.
- Explored different classifications or categories of VR technology based on usage and implementation.
- Discussed various practical applications of VR technology across different industries and fields.
- Examined the essential hardware components required for VR systems, including headsets, controllers, and sensors.

CONCLUSION

- Explored the importance of field of view and visual in Virtual Reality (VR) experiences.
- Provided an introduction to micro-displays and their role in VR technology.
- Discussed the advantages and positive impacts of VR technology in various domains.
- Explored potential advancements and developments expected in the future of VR technology.
- Examined key technical factors and considerations relevant to the design and implementation of VR systems.


THANK YOU

MINE AUTOMATION AND DATA ANALYTICS

MINE AUTOMATION AND DATA ANALYTICS

SWAYAM NPTEL COURSE ON

MINE AUTOMATION AND DATA ANALYTICS

By

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Department of Mining Engineering

Indian Institute of Technology (Indian School of Mines) Dhanbad

Module 7 : Descriptive Statistics

Lecture 17A : Introduction - I

CONCEPTS COVERED

1. Types of data – classify data as categorical or numerical data.

2. Visual Representation of numerical data and interpretation shape of the distribution

3. Compute and Interpret numerical Summaries of Data

- Compute and Interpret measures of central tendency: Mean, Median, Mode
- Compute and Interpret measures of dispersion: Range

What is Statistics?

Definition

Statistics is the art of learning from data. It is concerned with the collection of data, its subsequent description, and its analysis, which often leads to the drawing of conclusions.

- **Major Branches of Statistics**
  - **Descriptive Statistics**
  - **Inferential Statistics**

Major Branches of Statistics

1. Description

Descriptive statistics is the part of statistics concerned with the description and summarization of data.

2. Inference

The part of statistics concerned with drawing conclusions from data is called inferential statistics.

- To draw a conclusion from the data, we must consider the possibility of chance – introduction to probability.

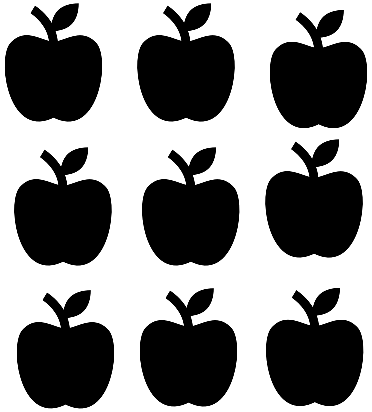
Population and Sample

Definition

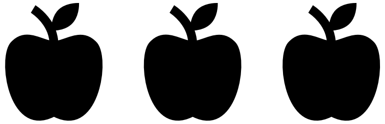
- The total collection of all the elements we are interested in is called a **population**.

Definition

- A subgroup of the population that will be studied in detail is called a **sample**.



Population



Sample

Purpose of Statistical Analysis

- If the purpose of the analysis is to examine and explore information for its own intrinsic interest only, the study is descriptive.
- If the information is obtained from a sample of a population and the purpose of the study is to use that information to draw conclusions about the population, the analysis is inferential.
- A descriptive study may be performed on a sample or population.
- When an inference is made about the population based on the sample's information, then the study become inferential.

What is data ?

To learn something, we need information

Definition

Data are the facts and figures collected, analyzed, and summarized for presentation and interpretation.

Variables and Cases

- A variable that "varies," and in formal definition, it is a characteristic or attribute that varies across all units.
- Case (Observation): A unit from which data are collected
- Rows represent cases: The same attribute is recorded for each case.
- Columns represent variables: The same type of value for each case is recorded for each variable.

Sample data:

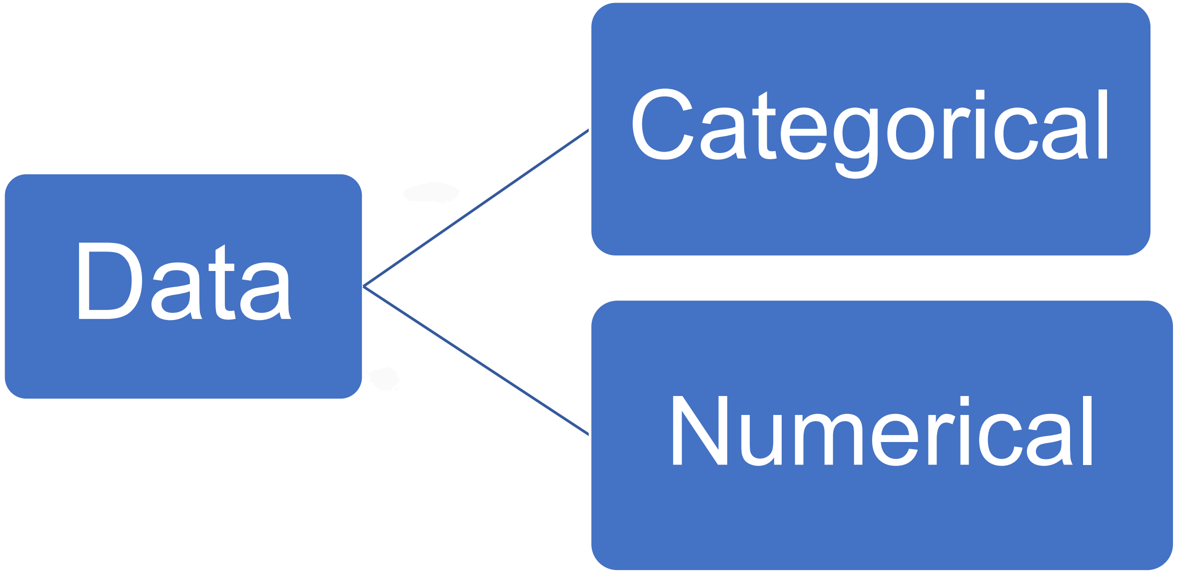
Variable

Sl No	Student Name	English Marks	Science Marks
1	Radha Krishna	93	85
2	Sai Raj	89	91

Case/Observation

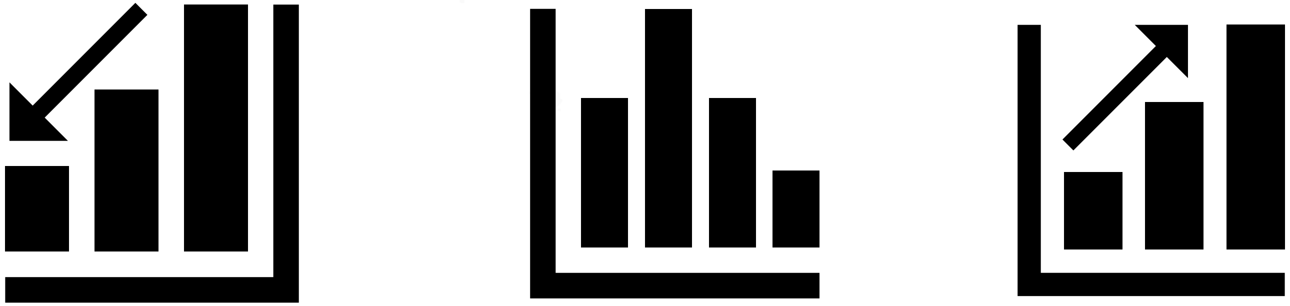
- Each variable must have its own column
- Each observation must have its own row

Classification of Data
Categorical and Numerical



Visual Representation

- Visual representation of numerical data is a crucial aspect of data analysis, and it provides insights into the distribution and characteristics of the data.
- Histogram is one of the standard methods for visualizing the numerical data.

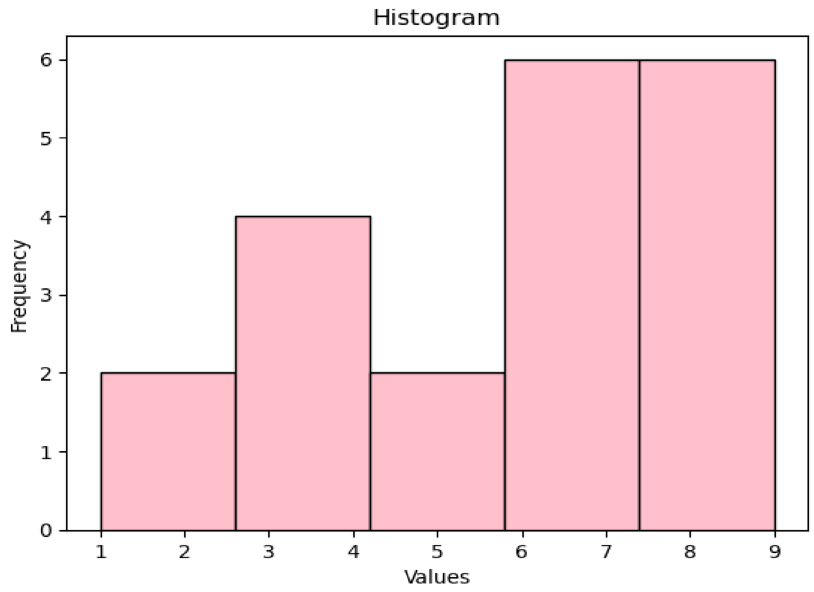


Histogram

A histogram is a graphical representation of the distribution of a dataset.

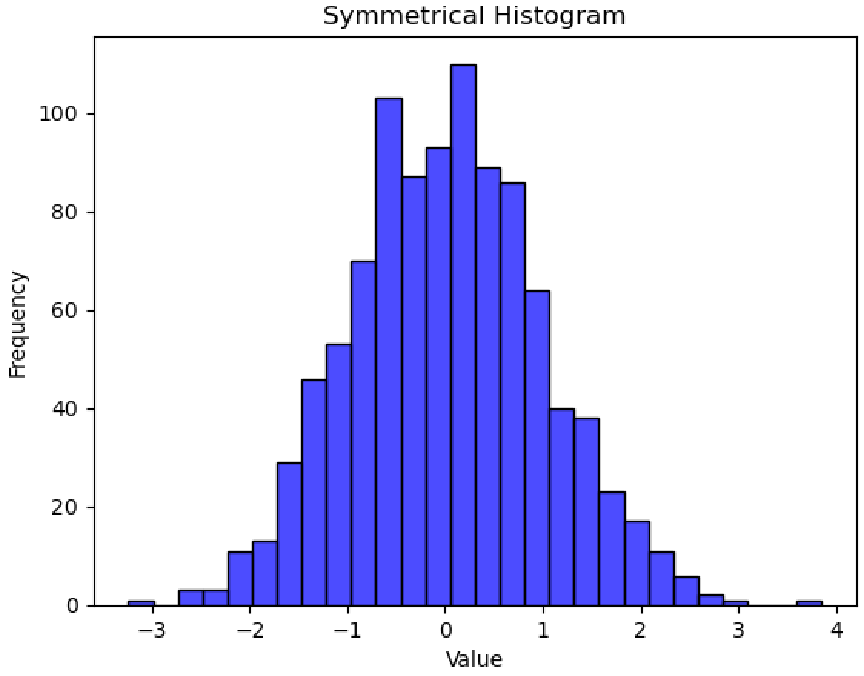
It consists of bars, where each bar represents a range of values (called a bin), and the height of the bar corresponds to the frequency of observations within that bin.

Data = [1, 2, 3, 4, 4, 4, 5, 5, 6, 6, 6, 6, 7, 7, 8, 8, 8, 9, 9, 9]



Symmetric Distribution

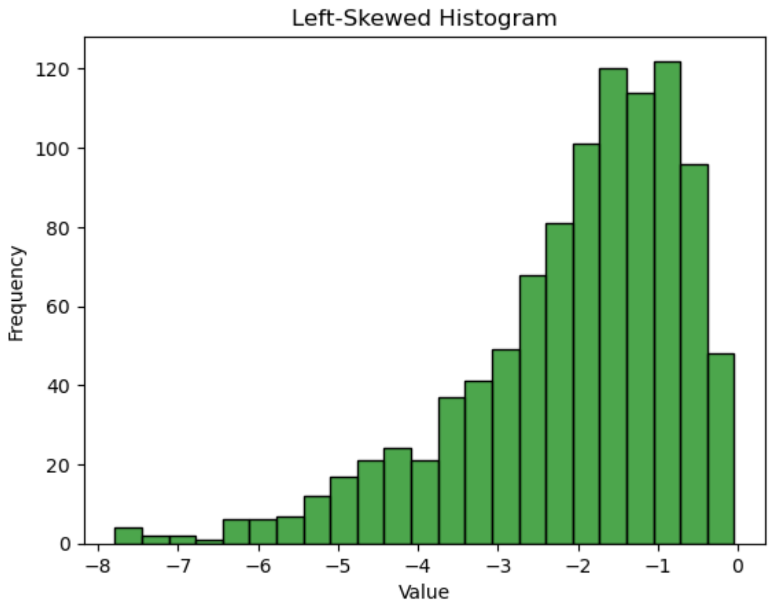
If the histogram is roughly symmetrical, it suggests that the data is evenly distributed around the mean.

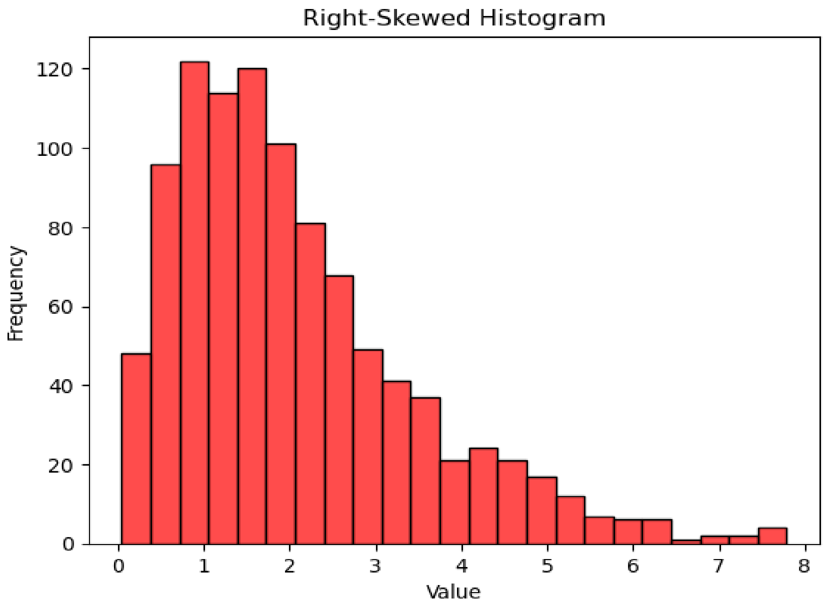


Skewed Distribution

If the histogram is skewed to the right (positively skewed), it indicates that the data has a tail on the right side.

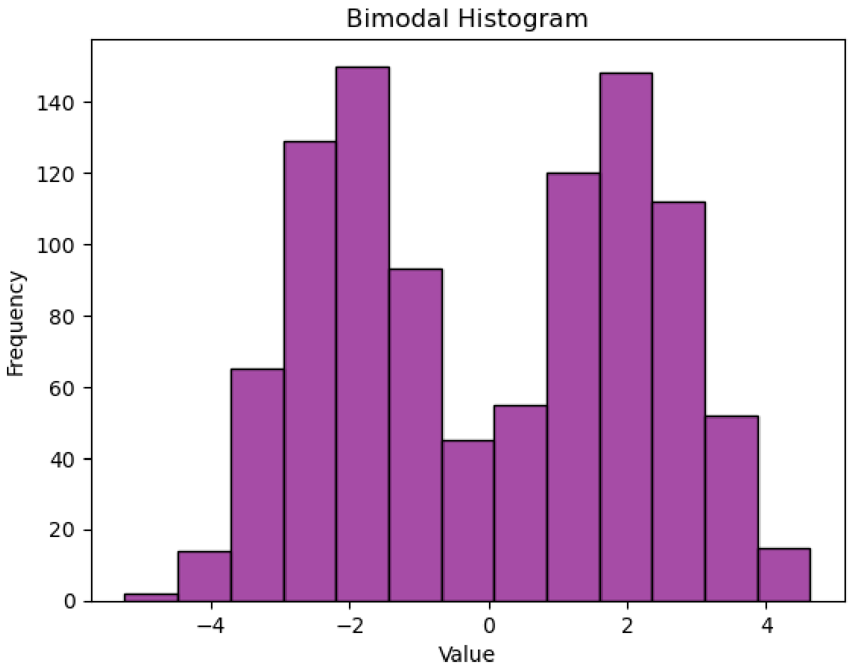
Similarly, if it's skewed to the left (negatively skewed), there's a tail on the left side.





Bimodal Distribution

If there are two distinct peaks, it suggests that the data may have two underlying subgroups.



Descriptive Measures

Most commonly used descriptive measures can be categorized as

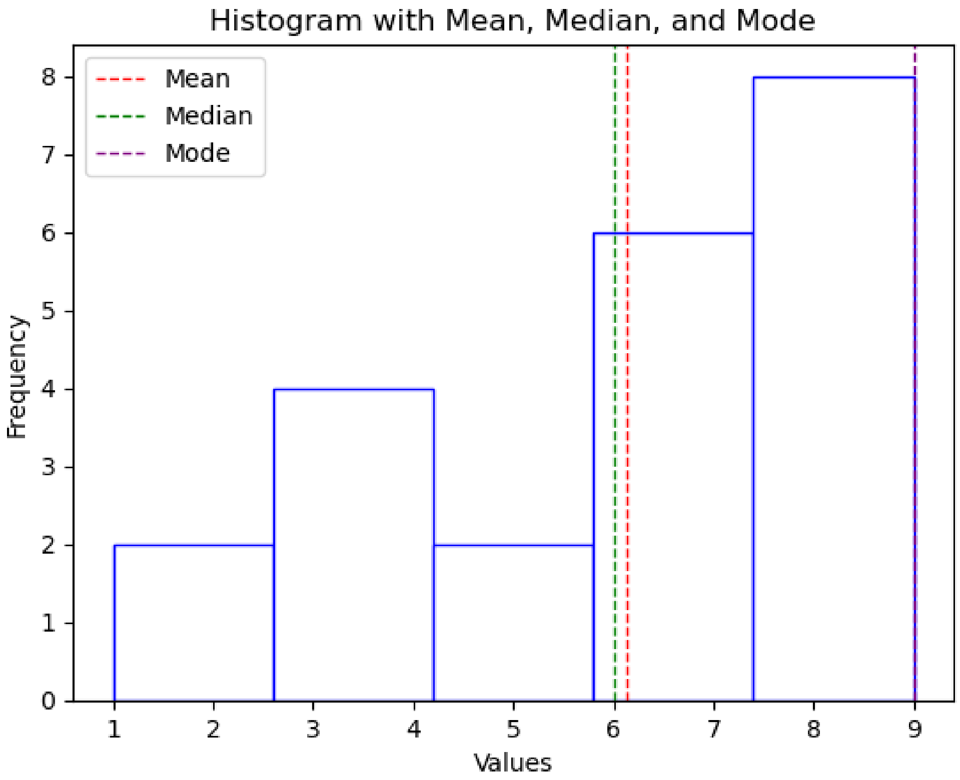
Measures of central tendency: These are measures that indicate the most typical value or center of a data set.

Measures of dispersion: These measures indicate the variability of a dataset.

Measures of Central Tendency

- **Mean**
- **Median**
- **Mode**

Data = [1, 2, 3, 4, 4, 4, 5, 5, 6, 6, 6, 6, 7, 7, 8, 8, 8, 9, 9, 9, 9, 9]



Mean: 6.136
Median: 6.0
Mode: 9

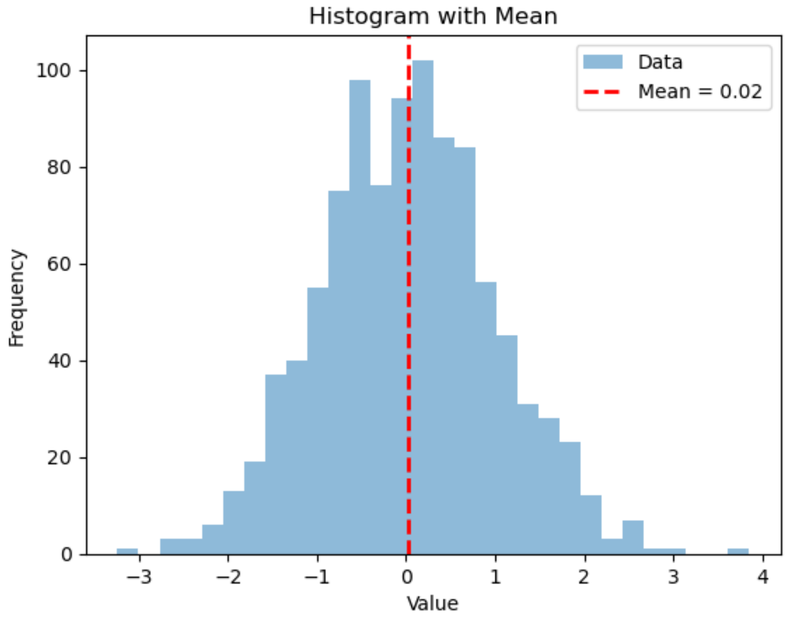
The Mean

The most commonly used measure of central tendency is the mean.

Definition

The mean of a data set is the sum of the observations divided by the number of observations

- **The mean is usually referred to as average.**
- **For discrete observations:**
- **Sample mean:** $\bar{x} = \frac{x_1 + x_2 + \dots + x_n}{n}$
- **Population mean:** $\mu = \frac{x_1 + x_2 + \dots + x_N}{N}$



Example:

1. The winning scores in the U.S masters golf tournament in the years from 2004 to 2013 were as follows: 280,278,272,276,281,279,276,281,289,280. Find the sample mean of these scores.

Sample mean: $\bar{x} = \frac{x_1 + x_2 + \ldots + x_n}{n}$

$= \frac{276 + 281 + 279 + 276 + 281 + 289 + 280 + 280 + 278 + 272}{10}$

= 279.2

Adding/Multiplying a constant

- Let $y_i = x_i + c$ where c is a constant then $\bar{y} = \bar{x} + c$
- Let $y_i = x_i * c$ where c is a constant then $\bar{y} = \bar{x} * c$

Example : the marks of students : 88,74,86,67,90,49

The mean of above marks is 75.67.

Let us suppose that you have decided to add 5 marks as bonus marks to each student,

then the data becomes : 93, 79, 91, 72, 95 , 54

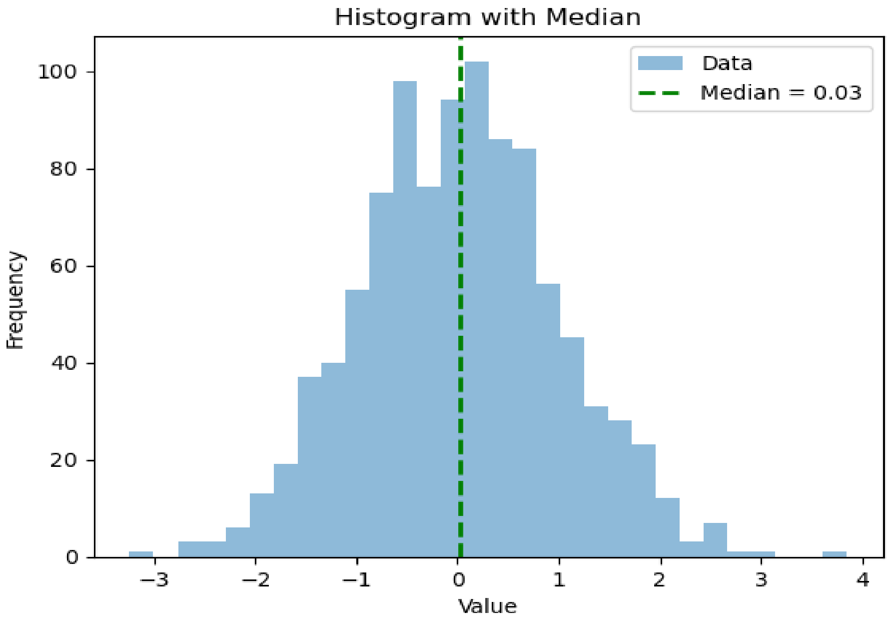
The mean of the new data set is 80.67 = 75.67 + 5

The Median

- **Another frequently used measure of center is the median. Essentially, the median of a data set is the number that divides the bottom 50 % of the data from the top 50%.**

Definition

The median of a data set is the middle value in its ordered list.



Steps to obtain median

1.Arrange the data in increasing order. Let n be the total number of observations in the dataset.

2. If the number of observations is odd, then the median is the observation exactly in the middle of the ordered list, i.e. $\frac{n+1}{2}$ observation

3. If the number of observations is even, then the median is the mean of the two middle observations in the ordered list, i.e. mean of $\frac{n}{2}$ and $\frac{n}{2}+1$ observation.

Examples of median

Scores = [75, 82, 90, 65, 88, 72, 91, 78, 85, 79]

Median = 80.5

Numbers = [11, 22, 15, 29, 33, 15, 17, 22, 19, 25, 27]

Median = 22

Outliers Effect

Example 1: 1 2, 12, 5, 7, 6, 7, 3

Sample Mean = 6 , Sample Median = 6

Example 2: 2, 117, 5, 7, 6, 7, 3

Sample Mean = 21 , Sample Median = 6

The sample mean is sensitive to outliers , whereas the sample median is not sensitive to outliers.

Adding/Multiplying a constant

- Let $y_i = x_i + c$ where c is a constant then $new\,median = old\,median + c$
- Let $y_i = x_i * c$ where c is a constant then $new\,median = old\,median * c$

Mode

Another measure of central tendency is the sample mode

Definition

The mode of a dataset is its most frequently occurring value.

Steps to obtain mode

- If no value occurs more than once, then the dataset has no mode.
- Else, the value that occurs with the greatest frequency is a mode of the data set.

Example 1: 2 , 12 , 5 , 7 , 6 , 7 , 3

7 occurs twice, hence 7 is mode

Example 2: 2 , 105 , 5 , 7 , 6 , 3

No mode

Adding/Multiplying a constant

- Let $y_i = x_i + c$ where c is a constant then $new\,mode = old\,mode + c$
- Let $y_i = x_i * c$ where c is a constant then $new\,mode = old\,mode * c$

Relationship of Mean, Median, and Mode

- **In statistics, for a moderately skewed distribution, there exists a relation between mean, median and mode.**
- **This mean median and mode relationship is known as the "empirical relationship" which is defined as Mode is equal to the difference between 3 times the median and 2 times the mean.**

$$\boxed{\text{Mode} = 3\ \text{Median} - 2\ \text{Mean}}$$

Measures of dispersion

- To measure the amount of variation, or spread , in a data set.
- Measures of dispersion are also known as measures of variation or spread.

Measures of dispersion

- Range
- Variance
- Standard Deviation
- Interquartile Range

Range

Definition

- The range of a data set is the difference between its largest and smallest values.

$$Range = Max - Min$$

Where Max and Min denote the maximum and minimum observations, respectively.

- Range is sensitive to outliers.

REFERENCES

- Introduction to Probability and Statistics for Engineers and Scientists, Sixth Edition, Sheldon M. Ross
- Statistical Methods Combined Edition (Volume I& II), N G Das

CONCLUSION

1. Types of data – identifying the data type
- categorical data or
- numerical data

2. Visual Representation of numerical data and interpreting the shape of the distribution
- Symmetric Distribution
- Skewed Distribution
- Bimodal Distribution

3. Computed and Interpreted the numerical Summaries of Data
- Compute and Interpret measures of central tendency: Mean, Median, Mode
- Compute and Interpret measures of dispersion: Range


THANK YOU


MINE AUTOMATION AND
DATA ANALYTICS