Science and Technology Class 02

Previous Class Topic

- **Scientific method**: The concept and significance of the scientific method, especially its openness to change based on new data and its difference from acquiring knowledge through authority or tradition.
- **Space technology**: Introduction to space technology, types of satellites (especially communication and Earth observation satellites), and an initial mention of remote sensing techniques.

Scientific Method and Nature of Scientific Knowledge

- The scientific method operates by questioning claims and confirming knowledge through experiment and evidence, rather than accepting statements from authority.
- Scientific understanding is continually refined through successive approximations based on new experiments or data.
- Physics is highly dependent on mathematics, but differs as it possesses no axioms taken on faith; every theory remains subject to observational testing.
- Fundamental scientific theories like the conservation of energy remain valid only until contradicted by evidence; if anomalies arise, better theories are sought.
- The core of science is its willingness to accept and accommodate new findings, rendering it distinct from other knowledge systems.

Interdependence of Science, Technology, Engineering, and Economics

- Scientific knowledge alone is not sufficient for technology; engineering translates scientific principles into technological devices.
- Economic considerations are vital in transforming scientific discoveries into practical technologies accessible for societal use.

Types and Applications of Satellites

Communication Satellites

- Facilitate radio, TV, and modern communication services (*e.g., Dish TV, FM radio*).
- Operate best at high altitudes (geostationary orbits preferred) to maximise the coverage area on Earth's surface.
- Lower altitude satellites provide smaller coverage, while higher ones cover broader areas.

Earth Observation Satellites

- Supply data for atlases, maps, and various spatial information products.
- Employ remote sensing instruments to gather information on Earth's surface, including land, vegetation, and water features.
- Fundamental for resource assessment, urban planning, agriculture, forestry, and natural disaster monitoring.

Electromagnetic Radiation and Information

Nature of Light and Information Carried

- Light, as an electromagnetic wave, contains information about color, distance, physical, chemical, and even biological properties of objects.
- The visible spectrum is only a small part of the electromagnetic spectrum; light also includes IR (infrared), UV (ultraviolet), X-ray, microwave, and radio waves.
- Human senses are adapted to visible light but not other frequencies, yet these can be detected using technology.

Remote Sensing Satellites: Techniques

Remote Sensing: Basic Concept

- Involves acquiring information about objects or surfaces from a distance, typically using satellite or airborne sensors.
- Allows access to information which cannot be directly perceived by human senses, especially non-visible electromagnetic radiation.

Sequence of Techniques

1. **Optical Imaging**

- Captures images using visible light (red, green, blue).
- Operates similarly to digital cameras but with higher resolution and much wider coverage.
- Useful for monitoring land cover, urban development, and basic mapping.

2. **Infrared Imaging (Thermal Imaging)**

- Records IR radiation to measure surface temperatures and observe thermal phenomena.
- Used in night vision, measuring human body temperature (*e.g., during COVID-19 checks*), and identifying heat-emitting sources such as volcanoes, urban heat islands, and melting ice (cryosphere).
- Thermal imaging aids in tracking areas affected by volcanic eruptions, urban warming, ocean surface changes, and environmental stress., Melting of Cryosphere.
- Image colours in thermal images do not reflect real colours; instead, they visually represent temperature differences.

-> Optical and Thermal imaging are Passive sensing which means we do not use our own light to detect images and we can see also that in optical imaging already existing lights we are capturing and in thermal imaging infrared rays are emitting.

-> RADAR and LIDAR are Active sensing i.e. we are using our own light to detect image.

3. **Radar Imaging**

/ micro wave

- **RADAR** (Radio Detection and Ranging) emits radio waves and records their reflections to map surfaces.
- Works regardless of lighting conditions or cloud cover, effective at night and in poor weather.
- Can penetrate some obstacles (like clouds or forest canopy) which block visible/infrared light.

4.

Synthetic Aperture Radar (SAR) and LiDAR

Table: Key Features of SAR and LiDAR

Technique	Principle	Wavelength Used	Applications	Special Features
SAR	Moving radar antenna	Radio waves	High-resolution surface mapping	Works day/night; penetrates clouds, provides detailed images
LiDAR	Pulsed laser ranging	Visible (laser) light	Mapping, driverless cars, cave surveys	Generates 3D maps; sensitive to small surface variations

- SAR achieves very high resolution by synthesising a large antenna using the satellite's motion.
- LiDAR emits laser pulses and measures reflected light to map surfaces in detail, especially vertical structure.

5. **Hyperspectral Imaging**

- Captures a series of images at hundreds or thousands of narrow frequency bands across the visible, infrared, and sometimes ultraviolet spectrum.
- Stack these images and analyse variations to determine subtle differences in chemical or physical properties.
- Useful for revealing information undetectable by normal imaging (*e.g., plant health, minerals, toxins*).
- Analysis is based on the unique way different substances absorb and reflect various frequencies.

6. **Spectroscopy**

- Focuses on measuring and analysing particular frequencies (wavelengths) of light as they interact with materials.
- Determines composition, temperature, and structure of substances via absorption, reflection, and emission spectra.
- Enables detection of specific molecules (*e.g., chlorophyll in plants, dyes in fabrics*) and is employed in environmental monitoring and archaeology.

Applications of Remote Sensing Satellites

1. **Agricultural Monitoring**

- Assesses soil conditions, crop types, vegetation health, and stress factors.
- Provides information for improved yield prediction, management, and resource allocation.

2. **Forestry and Wildfire Management**

- Monitors wildfires, tracks deforestation, and maps forest cover changes over time.
- Assesses forest health and supports sustainable management.

3. **Resource Exploration**

- Identifies and maps mineral deposits by analysing spectral signatures.
- Supports exploration for resources like uranium, potash, and groundwater reservoirs (aquifers).

4. **Water Resource Monitoring**

- Observes lakes, rivers, reservoirs, and groundwater via spectral analysis.
- Guides water conservation strategies and resource allocation.

5. **Oceanography**

- Monitors ocean currents, temperature patterns, and changes in ocean surface conditions.
- Supports disaster response (*e.g., tsunamis, storms*) and resource management.

6. **Geomorphology**

- Studies Earth's surface processes, landforms, and rock distributions and transformations.
- Aids in natural hazard assessment and geological research.

7. **Weather Forecasting and Disaster Management**

- Provides timely data for storm, cyclone, and flood forecasting.
- Tracks changes in landscapes due to disasters and assists in effective response.

8. **Urban Governance and Scheme Implementation**

- Monitors progress of infrastructure projects (*e.g., low-cost housing, roads*).
- Enhances transparency and accountability in scheme implementation by tracking real-world changes via satellite imagery.

9. **Intelligence and Defence**

- Plays a crucial role in reconnaissance and surveillance.
- Military "spy satellites" gather intelligence on strategic targets, although not publicly acknowledged as such.

Principles of Light and Colour in Remote Sensing

- Colours perceived from objects result from the selective reflection or emission of certain wavelengths, closely related to atomic and molecular composition.
- Spectroscopy can identify specific chemicals (*e.g., dyes, minerals, organic residues*) based on unique spectral fingerprints.
- Colour is an emergent property arising from the collective reflection of many molecules' spectra, not an absolute trait.

10. Spy Satellites.

Remote Sensing satellites of ISRO -
1. Cartosat series (Carto is short from of Cartography in which we make map from remote sensing data)
2. RISAT (launched to explore resources.)
3. Oceansat (launched to do oceanographic studies)
4. HYSIS (Hyper Spectral Image Sensing)
5. EOS Series.

Remote sensing satellites are generally places in Low Earth Orbits, Polar Orbits, Polar sun-synchronous orbits and orbits such as geo-stationary orbit.

Radar and Object Differentiation

- Radar systems, much like human vision, distinguish between objects by their reflective characteristics.
- Advanced sensors process small variations in reflection time and intensity to produce high-resolution differentiation.

Specialised Orbits for Satellites

- Remote sensing satellites are often placed in Low Earth Orbit (LEO), Polar Orbit, or Polar Sun-Synchronous Orbit, and sometimes Geostationary Orbits.
- LEO and Polar Orbits help cover different parts of Earth as the planet rotates and the satellite moves, ensuring global coverage over time.

Remote Sensing in Archaeology

- Remote sensing can identify large-scale site features, but detailed analysis of small sites typically requires direct excavation.
- Spectroscopy is extensively used to analyse material composition at archaeological sites (*e.g., identifying grains in pottery*).

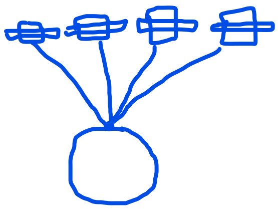
Satellite and Orbit Classifications

Definitions of Celestial Objects

- Planets, satellites (moons), asteroids, and dwarf planets are defined based on their orbital properties and relationships (*e.g., satellites orbit planets, planets orbit stars*).

Satellite Orbits

- The concept of the national airspace ends at a defined altitude; satellites operate over 200 km up, in domains considered global commons.



Navigational Satellites

Function and Importance

- Navigational satellites provide accurate location (latitude, longitude, altitude) to receivers on Earth.
- Essential for guiding vehicles, mapping, disaster response, precision agriculture, and numerous digital services.

Triangulation Principle

- To resolve an object’s exact position, a receiver requires data from at least four satellites owing to geometric triangulation in three dimensions.

Methods of Determining Position

- Positioning is calculated by the time delay between satellite signal emission and its receipt at the receiver, using the speed of light.

Major Global and Regional Navigation Systems

Table: Major Navigational Satellite Systems

System	Country/Region	Number of Satellites	Coverage	Orbits Used
GPS	USA	30+	Global	Medium Earth Orbit (MEO)
GLONASS	Russia	Multiple	Global	MEO
Galileo	Europe	Multiple	Global	MEO
BeiDou	China	Multiple	Global	MEO/GEO/IGSO
QZSS	Japan	4+	Asia-Pacific	Quasi-Zenith
NavIC	India	7 (planned)	India + 1500 km	Geostationary/GeoSync

GNSS (Global Navigational Satellite System)

- NavIC (Navigation with Indian Constellation) is India's regional navigation system, consisting of three geostationary and four geosynchronous satellites.
- Developed for strategic autonomy, especially after access to GPS was restricted during a military conflict.

Positioning Services

Navigational Satellites provide 2 types of services -

- **Standard Positioning Service**: For civilian use; typically accurate to 5-10 meters.
- **Restricted or Precise Positioning Service**: For military/defence; accuracy often 1-3 meters.

Distinctions Between Systems

- GPS is global, large-scale, and placed in MEO, whereas NavIC is regional and mainly covers India and adjoining regions.
- NavIC is cost-effective and suited to national needs.

Application of Navigational satellites -
a) Terrestrial, Aerial, Marine navigation.
b) Integration with mobile phones.
c) Vehicle tracking.
d) Banking.
e) Geospatial data.
-> Geographical information / Remote sensing + Navigational data.
f) Toll collection.

Role of Atomic Clocks

- Precise time measurement is crucial, as small timing errors can mean large positional inaccuracies.
- Atomic clocks are standard aboard satellites for unparalleled time accuracy, essential for high-precision navigation.

Applications of Navigational Satellites

General Use Cases

- Enable terrestrial, aerial, marine, and personal navigation.
- Integrate with mobile phones, logistic tracking, and vehicle monitoring.
- Used in public transportation and for emergency evacuation planning.

Banking and Financial Synchronisation

- Used for secure tracking and timing of transactions, especially in large banking networks to ensure synchronised operations across multiple locations.

Toll Collection and Transportation

- Support automated toll collection via GPS-based systems, with planned upgrades replacing physical toll booths entirely.

Disaster Management and Geospatial Data

- Provide critical geospatial data (location-tagged information) for efficient disaster response, infrastructure planning, and public policy interventions.

Geospatial Data

- Combines geographical features and precise location information (latitude, longitude, altitude).
- Enables mapping, analysis, and decision-making across sectors such as epidemiology, environmental monitoring, and governance.

Characteristics of Space and The Karman Line

- Space is commonly defined as the region above the **Karman line**, 100 km above Earth's mean sea level in the thermosphere.
- Anything above the Karman line is considered to be in outer space, which is not subject to any national jurisdiction.

Historical Development of Orbital Mechanics

Ancient Astronomy

- Indian and Greek astronomers understood Earth's rotation and revolution; Aryabhatta is particularly noted for such insights.
- European knowledge of heliocentric models was temporarily lost but later revived.

Copernicus and the Heliocentric Model

- Proposed that Earth and other planets orbit the Sun in circular paths, opposing geocentric views.

Tycho Brahe and Johannes Kepler

- Brahe collected extensive planetary position data; Kepler analysed it, discovering the three laws of planetary motion.

Kepler's Laws of Planetary Motion

- Orbits are ellipses with the Sun at one focus, not perfect circles.
- The concept of aphelion (farthest point) and perihelion (nearest point) describes the location of planets' elliptical paths.
- A mathematical relationship exists between a planet's distance and its orbital period.
- Satellites orbiting the Earth also generally follow nearly circular (low eccentricity) orbits.

Newtonian Physics and Gravitation

- Newton formulated the laws of motion, establishing the principle that an object remains at rest or in uniform, straight-line motion unless acted upon by a force.
- Introduced the principle that force equals mass times acceleration.
- Action-reaction law: For every action, there is an equal and opposite reaction.
- Gravitational attraction is proportional to the product of masses and inversely proportional to the square of the distance between them ($F = GM1M2/R^2$).
- For ordinary-sized objects, gravity's effect is negligible, but with larger masses (e.g., Earth), gravity is significant.

Circular and Curved Motion

- Objects travelling in circles require an inward-acting centripetal force; in daily life (*e.g., cycling*), friction provides this force by opposing the tendency to slip outward.
- Every day movement (walking, stopping) depends critically on friction.

Newton's Thought Experiments and Escape Velocity

- Posed the question: If objects are thrown at gradually increasing velocities, is there a speed at which they never return to Earth?
- Escape velocity from Earth is about 11.2 km/s; at or above this speed, objects can leave Earth's gravitational pull.

Launching Artificial Satellites

- Newton conceptualised satellites remaining in orbit at sufficient velocities; technological advancements in the 20th century finally made this possible.
- Rockets achieve orbit by expelling mass downward (action) to propel upward or forward (reaction), embodying Newton's third law.

Topic to be Discussed in the Next Class

- Details and mechanics of satellite launching and orbital motion, including differentiating geostationary and geosynchronous orbits.
- Applications of GPS in power grids and timing services, as well as further foundational discussion on orbits and satellite technology.