Chapter 14: GNSS Survey

14.1 Introduction to GNSS

The **Global Navigation Satellite System (GNSS)** refers to a constellation of satellites providing signals from space that transmit positioning and timing data to GNSS receivers. These systems enable users on the ground to determine their location (longitude, latitude, and height) at any time and in all weather conditions.

GNSS includes multiple satellite systems:

- **GPS** (Global Positioning System) – USA
- **GLONASS** – Russia
- **Galileo** – European Union
- **BeiDou** – China
- **NavIC** – India
- **QZSS** – Japan

GNSS plays a significant role in **civil engineering**, especially in surveying, mapping, navigation, and infrastructure development.

14.2 Components of GNSS

GNSS comprises three primary segments:

14.2.1 Space Segment

- Consists of satellites orbiting Earth.
- Typically includes 24–30 satellites in medium Earth orbit (MEO) per constellation.
- Satellites continuously transmit signals containing time and orbital data.

14.2.2 Control Segment

- Ground stations that monitor, control, and manage satellite health and orbits.
- Includes Master Control Station and monitoring stations spread globally.
- Responsible for synchronization and integrity of satellite data.

14.2.3 User Segment

- Consists of GNSS receivers used by individuals or devices.
- These receivers calculate position by triangulating signals from at least four satellites.

- Can be single-frequency or dual-frequency receivers depending on accuracy needs.

14.3 Working Principle of GNSS

GNSS positioning relies on a concept called **trilateration**:

1. A satellite transmits a signal with time and orbital data.
2. The GNSS receiver calculates how long it took the signal to arrive.
3. Distance to the satellite = speed of light × signal travel time.
4. With signals from 4+ satellites, the receiver calculates its 3D position and clock offset.

For precise positioning, receivers use:

- **Pseudorange**: Approximate distance to satellite.
- **Carrier phase**: More accurate, based on the phase of the signal's carrier wave.

14.4 Types of GNSS Surveys

14.4.1 Static GNSS Survey

- Used for high-precision applications like control surveys.
- Involves prolonged observation (up to several hours) at fixed stations.
- Post-processing is required to determine relative positions.

14.4.2 Kinematic GNSS Survey

- Includes **Real-Time Kinematic (RTK)** and **Post-Processed Kinematic (PPK)**.
- Used for topographic mapping, construction, and mobile surveys.
- Provides high accuracy in real time using base and rover setup.

14.4.3 Differential GNSS (DGNSS)

- Uses a base station to provide corrections to a mobile receiver.
- Enhances accuracy by compensating for atmospheric and other errors.
- Accuracy of up to 1 meter or better.

14.5 GNSS Signals and Frequencies

Each GNSS satellite transmits signals on multiple frequencies:

- **GPS**: L1 (1575.42 MHz), L2 (1227.60 MHz), L5 (1176.45 MHz)

- **GLONASS**: L1 (1602 MHz + freq. offset), L2 (1246 MHz)
- **Galileo**: E1, E5a, E5b, E6
- **BeiDou**: B1, B2, B3

These signals carry:

- **Navigation message**: Satellite position, clock data, health info.
- **Ephemeris data**: Precise orbit of the satellite.
- **Almanac data**: Status and orbit of all satellites in constellation.

14.6 Sources of GNSS Errors

Several factors affect GNSS accuracy:

14.6.1 Satellite Clock Errors

- Imperfect satellite clocks cause small time errors, leading to position errors.

14.6.2 Ionospheric and Tropospheric Delays

- Signals slow down in atmospheric layers, introducing delays.

14.6.3 Multipath Effects

- Signal reflections from surfaces like buildings or water bodies create errors.

14.6.4 Receiver Noise

- Internal noise from the receiver's electronics can distort measurements.

14.6.5 Orbital Errors

- Imperfect satellite ephemeris data leads to inaccuracies.

14.6.6 Geometry of Satellite Constellation

- Poor geometry (satellites clustered together) increases **Dilution of Precision (DOP)**.

14.7 GNSS Surveying Equipment

14.7.1 GNSS Receiver

- Single or dual frequency, with capabilities for static/kinematic mode.

14.7.2 Antenna

- External antenna for better signal reception, often placed on tripod.

14.7.3 Controller/Data Logger

- Stores survey data and allows field control.

14.7.4 Base and Rover Configuration

- Base station: Fixed position, provides corrections.
- Rover: Mobile unit used to collect data in the field.

14.8 GNSS Positioning Techniques

14.8.1 Absolute Positioning

- Uses only one receiver.
- Accuracy: ~5–10 meters.
- Suitable for navigation, not for precise surveying.

14.8.2 Differential Positioning

- Uses a base station to provide corrections.
- Increases accuracy to ~1 meter or better.

14.8.3 RTK (Real-Time Kinematic)

- Provides centimeter-level accuracy in real-time using corrections.

14.8.4 PPP (Precise Point Positioning)

- Global, single-receiver solution with high precision.
- Requires long observation time and accurate satellite products.

14.9 GNSS Applications in Civil Engineering

- **Topographic Surveys**: For mapping contours and land features.
- **Construction Layout**: Positioning structures with precision.
- **Monitoring Infrastructure**: Detecting movement in dams, bridges, buildings.
- **Road and Railway Alignment**: Accurate centerline and profile surveys.
- **Flood and Disaster Mapping**: Quick data collection post-disaster.
- **Urban Planning**: GIS base map generation with positional accuracy.

14.10 Advantages of GNSS Surveying

- High accuracy (especially with RTK/PPK).
- Time-efficient and requires fewer personnel.
- All-weather, day-and-night operation.
- Wide-area coverage with minimal ground control.
- Direct integration with GIS and CAD systems.

14.11 Limitations of GNSS Surveying

- Signal blockage in dense urban or forest areas.
- Errors due to atmospheric conditions and multipath.
- Requires clear sky visibility.
- Initial cost of equipment is high.
- Power dependency and equipment calibration needs.

14.12 Future Trends in GNSS Surveying

- **Multi-GNSS Receivers**: Using multiple constellations for better accuracy and availability.
- **Integration with UAVs/Drones**: For aerial surveys and 3D mapping.
- **GNSS + Inertial Navigation System (INS)**: For uninterrupted positioning in tunnels or urban canyons.
- **Crowdsourced GNSS Data**: Real-time, large-scale data collection for smart cities.
- **5G Integration**: Enhancing real-time accuracy and communication.

14.13 Integration of GNSS with Other Surveying Technologies

In modern geospatial workflows, GNSS is increasingly integrated with other technologies to improve data richness, redundancy, and reliability.

14.13.1 GNSS + Total Station

- Used in **hybrid surveys**.
- GNSS helps establish control points over large areas quickly.
- Total stations provide **precise angular and distance measurements** for fine detailing in congested or obstructed environments.

14.13.2 GNSS + LiDAR

- GNSS provides positional control for **airborne and mobile LiDAR systems**.
- Used for corridor mapping, power line surveys, forest canopy analysis, and 3D modeling of terrain.

14.13.3 GNSS + UAV/Drone Platforms

- Drones equipped with **PPK/RTK GNSS modules** collect highly accurate aerial imagery.
- Applications: road design, open-pit mine surveys, volumetric calculations, and crop monitoring.
- Improves speed and accessibility in **hazardous or remote areas**.

14.13.4 GNSS + GIS

- GNSS provides spatial data for real-time mapping and decision-making.
- Used extensively in **asset management**, **urban infrastructure**, and **transport networks**.
- Enables **real-time updates** to GIS layers in field mapping applications.

14.14 Legal and Policy Framework for GNSS Surveying in India

14.14.1 Surveying Regulations

- Governed by **Survey of India (SoI)** and **National Mapping Policy**.
- Use of high-precision GNSS equipment for surveys above a certain accuracy level may require **licensing** and **clearance** from Ministry of Defence.

14.14.2 Use of NavIC in National Projects

- India's indigenous **NavIC** (Navigation with Indian Constellation) is being promoted for use in civil engineering and transportation projects.
- Efforts are ongoing to integrate NavIC into mobile chips and commercial GNSS receivers.
- Supports **real-time positioning services (RTPS)** and **Standard Positioning Service (SPS)**.

14.14.3 Data Security and Ethics

- GNSS-based data collection must comply with:
  - **National Geospatial Policy**
  - **Remote Sensing Data Policy**
  - **Personal Data Protection norms** when mapping populated areas.

14.15 GNSS Data Processing and Software

Raw GNSS data requires proper **processing and correction** to derive usable positions. This involves:

14.15.1 Post-Processing Software

- **Trimble Business Center (TBC)**
- **Leica Geo Office (LGO)**
- **Topcon Magnet Tools**
- **RTKLIB** (open-source)
- Features include:
  - Baseline computation
  - Differential correction
  - Coordinate transformation
  - Time synchronization

14.15.2 Cloud-Based GNSS Processing

- Platforms like **OPUS (NOAA)**, **CSRS-PPP (Canada)** allow users to upload raw GNSS logs and receive corrected positions.
- Useful in academic and resource-constrained setups.

14.15.3 Integration with CAD/GIS Software

- Survey output (e.g., DXF, SHP, KML) is easily imported into:
  - AutoCAD Civil 3D
  - QGIS
  - ArcGIS
  - Google Earth

14.16 Real-Time GNSS Correction Services in India

To support real-time high-accuracy GNSS surveying, several **correction networks** are in operation or development.

14.16.1 GAGAN

- GPS Aided GEO Augmented Navigation.
- Developed by ISRO and AAI.
- Improves GPS accuracy for aviation and navigation.

- Expected to support **land-based RTK applications** in future.

14.16.2 NRTK Services by Private Vendors

- Trimble VRS Now, Leica SmartNet, and others offer **virtual reference station (VRS)** services.
- Provide RTK corrections over the internet.
- Reduces need for on-site base stations.

14.16.3 ISRO's Differential Correction Services

- Under trials using **NavIC + GPS dual-frequency receivers**.
- Targets **centimeter-level positioning** for agriculture, roads, mining, and smart cities.

14.17 Advanced Applications of GNSS in Civil Projects

14.17.1 Deformation Monitoring

- Continuous GNSS measurements detect millimeter-level movements.
- Applied in:
  - Dam safety monitoring
  - Bridge displacement tracking
  - Landslide-prone zone assessment

14.17.2 Machine Control in Construction

- GNSS integrated with construction machinery for automated control.
- Used in:
  - Grading and excavation
  - Road paving
  - Canal alignment
- Increases speed, reduces manual error, and enables **BIM integration**.

14.17.3 GNSS in Hydrology and Flood Mapping

- Provides real-time water level and station position.
- Supports **hydrologic modeling**, **disaster risk mitigation**, and **infrastructure planning**.

14.18 Career and Research Prospects in GNSS for Civil Engineers

- **Survey Engineer** – Specialized in RTK surveys, construction layout, cadastral surveys.
- **Geospatial Analyst** – Working in GIS/GNSS integration and spatial decision-making.
- **UAV Surveyor** – Using GNSS for drone-based terrain modeling.
- **Academic Research** – GNSS signal modeling, error correction algorithms, integration with AI/ML.
- **Smart City Planning** – GNSS-based real-time asset tracking and mobility infrastructure.
