राष्ट्रीय भू-सूचना विज्ञान एवं प्रौद्योगिकी संस्थान
भारतीय सर्वेक्षण विभाग
विज्ञान और प्रौद्योगिकी विभाग

National Institute for Geo-Informatics Science & Technology
Survey of India
Department of Science & Technology

Control Survey

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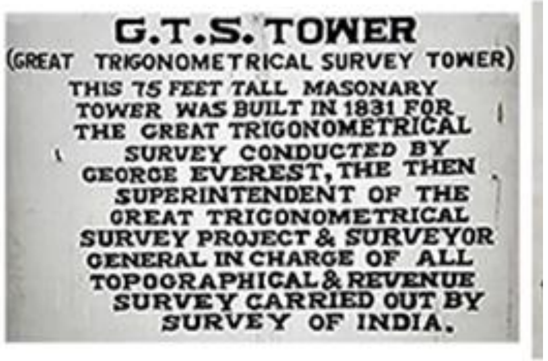
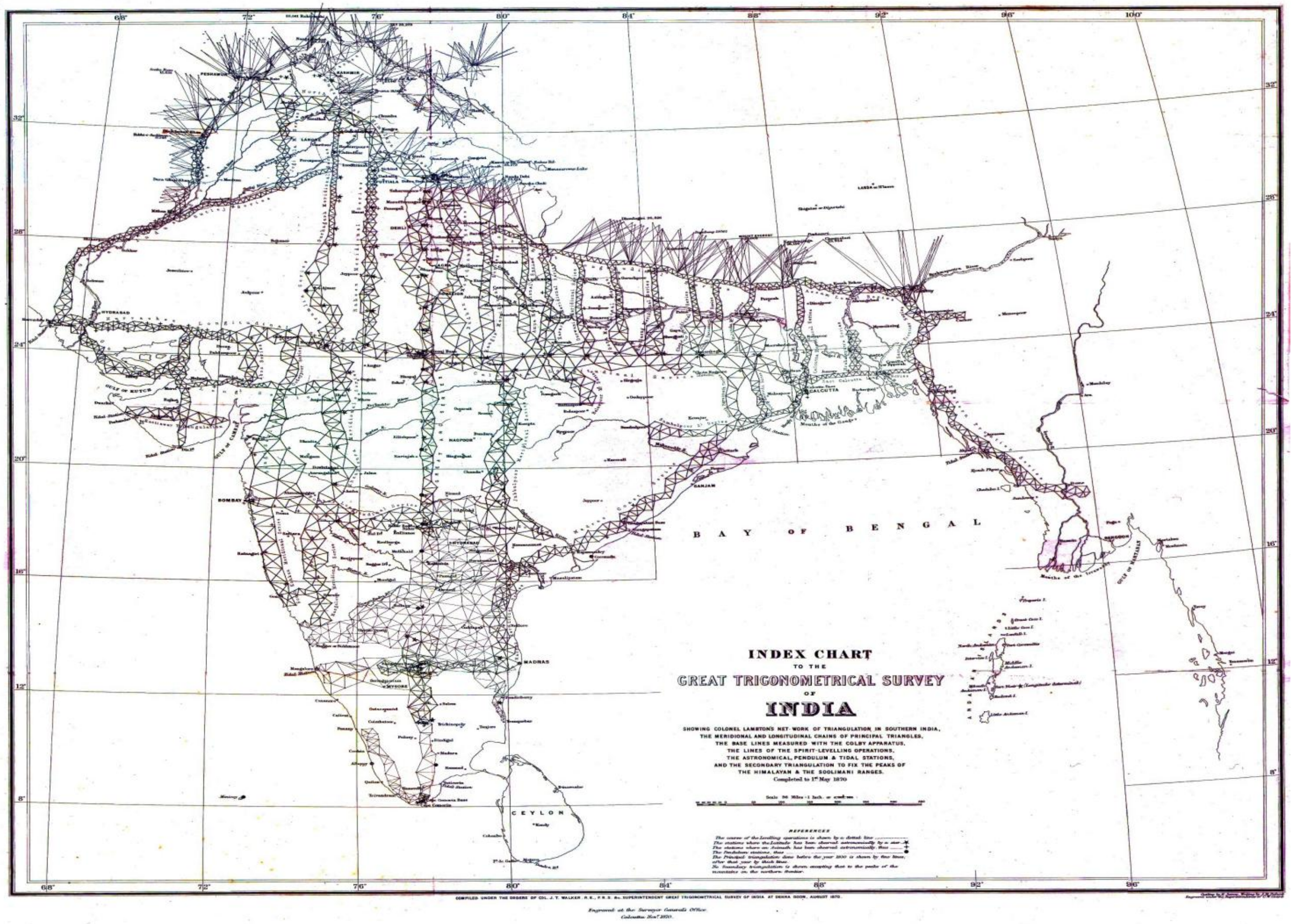
Session Objectives

- **Explain the concept and importance of control surveys** in providing a positional reference framework for surveying and mapping.
- **Describe methods of establishing horizontal control**, including triangulation, trilateration, traversing, and GNSS-based techniques.
- **Understand traverse principles**, including bearings, coordinate computation, misclosure, and adjustment methods.
- **Apply accuracy standards and planning considerations** for selecting appropriate control methods for different projects.
- **Interpret and verify control survey results** through closure checks and adjustment techniques.

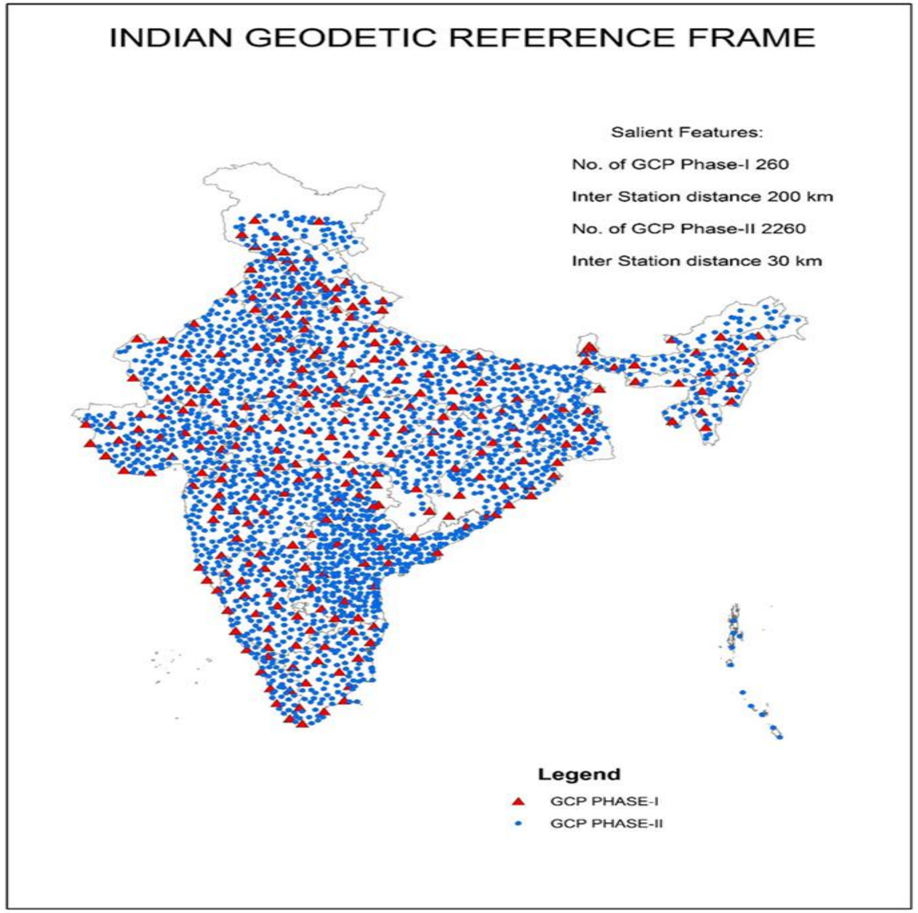
The Great Trigonometrical Survey (GTS) 1802 -39



G.T.S. TOWER
(GREAT TRIGONOMETRICAL SURVEY TOWER)
THIS 75 FEET TALL MASONARY TOWER WAS BUILT IN 1831 FOR THE GREAT TRIGONOMETRICAL SURVEY CONDUCTED BY GEORGE EVEREST, THE THEN SUPERINTENDENT OF THE GREAT TRIGONOMETRICAL SURVEY PROJECT & SURVEYOR GENERAL IN CHARGE OF ALL TOPOGRAPHICAL & REVENUE SURVEY CARRIED OUT BY SURVEY OF INDIA.



Erstwhile National Spatial Reference Frame(NSRF)

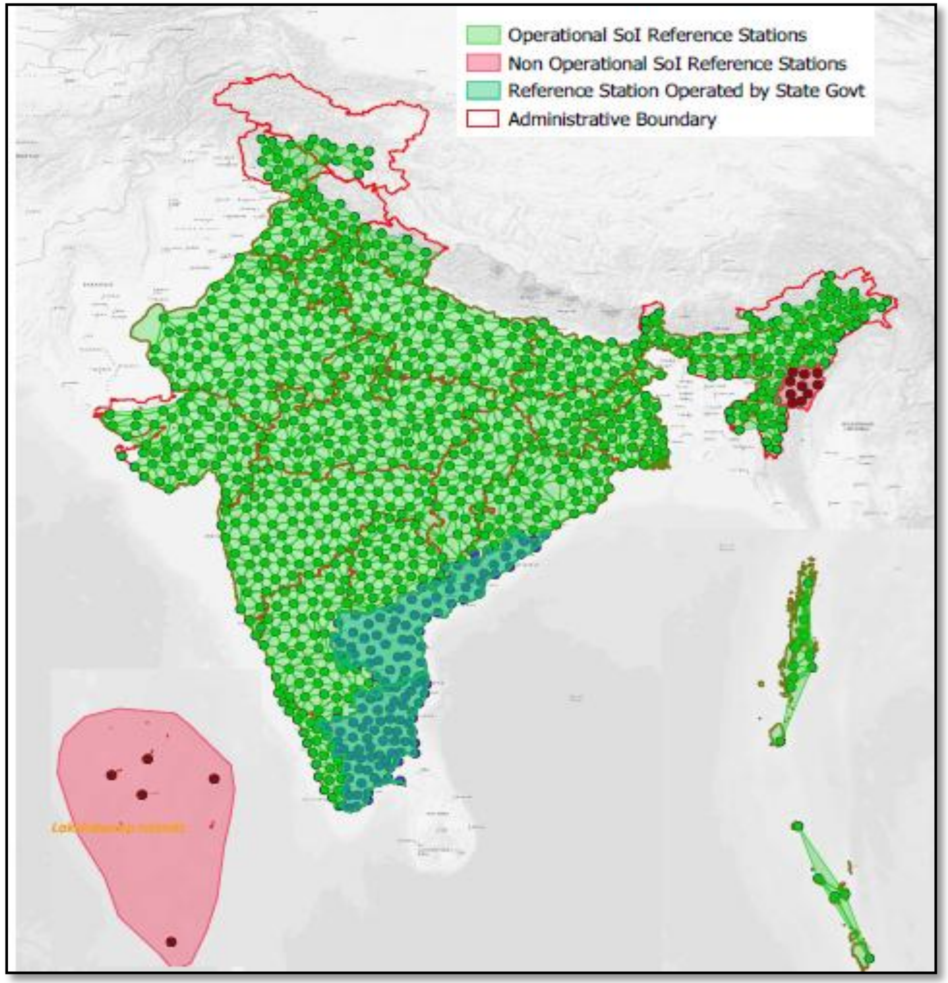


- National Spatial Reference Frame (NSRF) was established through a “passive” network of about 260 well spread Ground Control Points (GCPs) at a spacing of 250-300 km apart across the country during the period from 2006 to 2008.

- The network was further densified with, 2260 precise Ground Control Points at a spacing of 30 to 40 km apart within the framework of NSRF.

- This NSRF is only suited for relative positioning, primarily for mapping applications.

CORS Based updated NSRF



- CORS network would be the Active Ground Reference Marks. It will ultimately replace the Passive Ground Reference Marks (i.e. GCP library)

- This will provide real time positional accuracy of less than 5 cm.

- This will improve the productivity and reliability of Surveying and Mapping.

- The CORS network and its services are available for users across public/ private/ academia fraternity.

- National Spatial Reference Frame (NSRF) will allow layers of data to be spatially registered and integrated within geographic and land information systems (GIS/LIS).

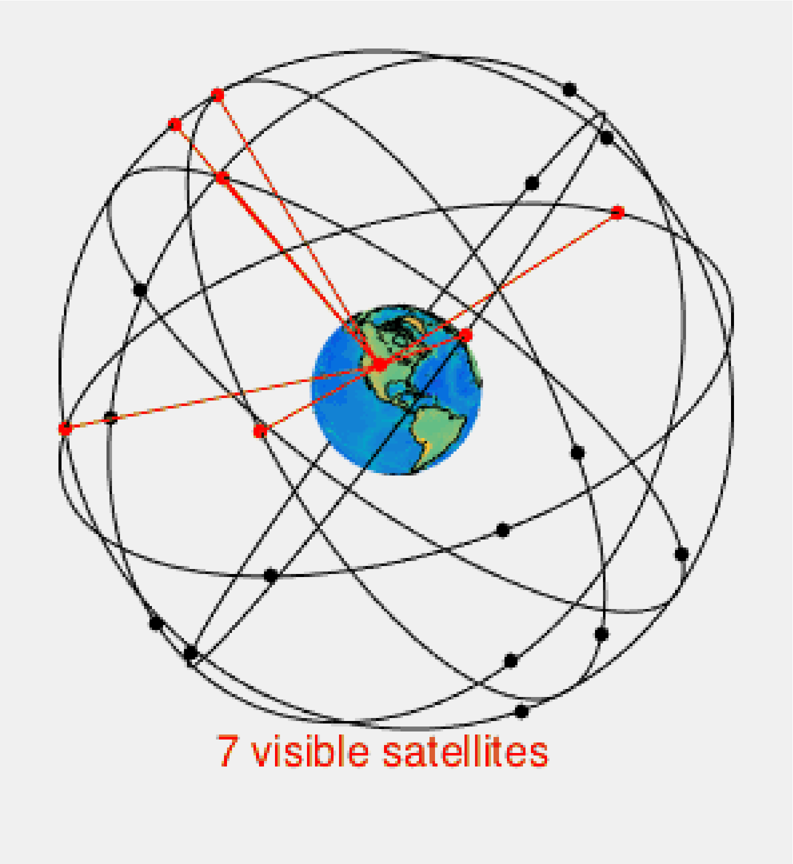
GNSS (Global Navigation Satellite Systems) based realization

- **Global systems**

System	Country	URL
Navigation Signal Timing and Ranging Global Positioning System (NAVSTAR GPS)	U.S.A.	http://www.gps.gov/systems/gps/
GLObal NAvigation Satellite System (GLONASS)	Russia	http://www.glonass-center.ru/en/GPS/
Galileo	European Union	http://www.esa.int/Our_Activities/Navigation/The_future_-_Galileo/What_is_Galileo
Bediou or Compass	China	http://en.beidou.gov.cn/

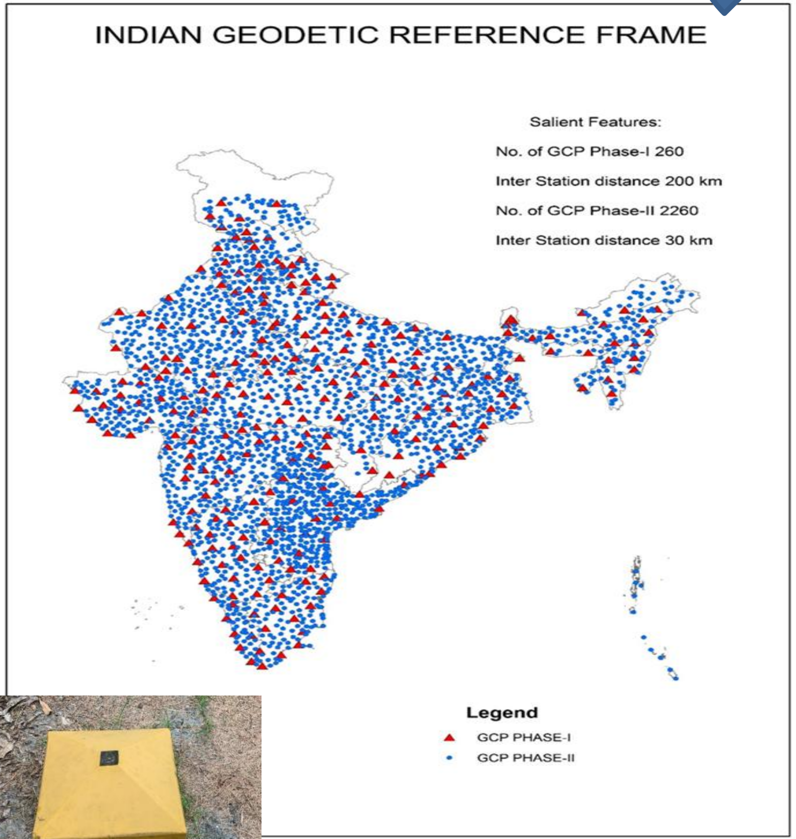
- **Regional systems**

System	Country	URL
Indian Regional Navigation Satellite System (IRNSS)	India	http://www.isro.org/satellites/irnss.aspx
Quasi-Zenith Satellite System(QZSS) or Michibiki	Japan	http://www.qzs.jp/en/



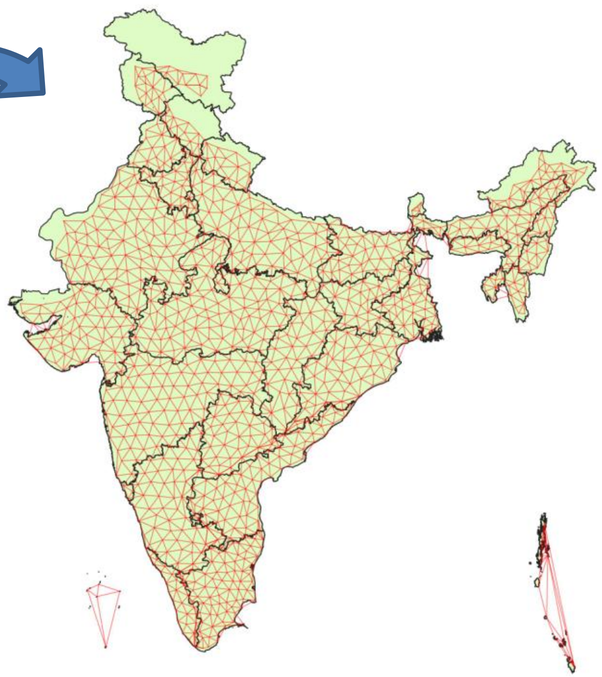
NSRF Realization

Passive GCP based IGRF



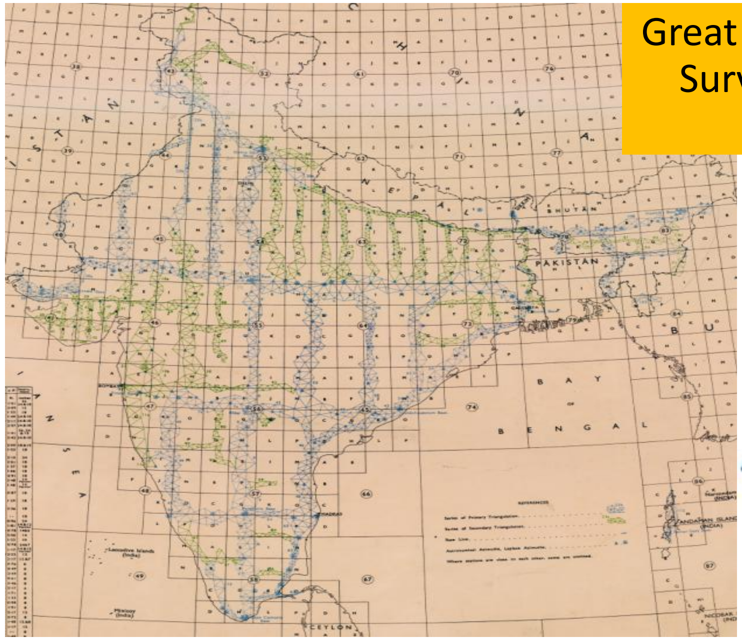
Active CORS based NSRF

CORS Network

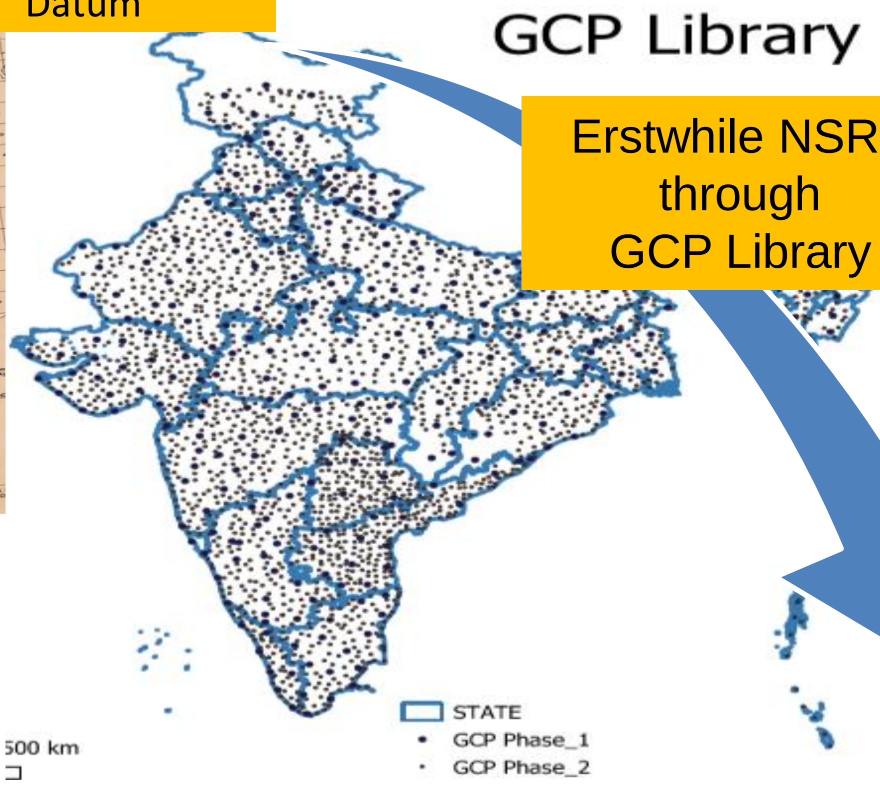


- One of mandated deliverable of NGP 2022 is the development of Geodetic Reference Frame for the Nation.
- One among these is the Horizontal Reference Frame.
- Survey of India has established well distributed 1042 CORS stations across the nation, which will be used for the realization of NSRF.

National Spatial Reference Frame

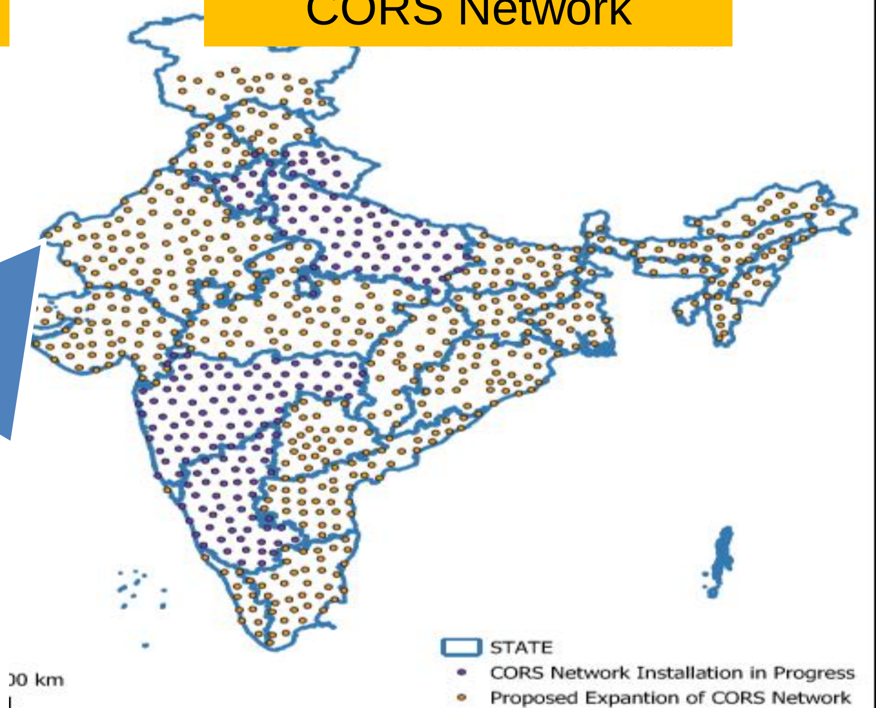


Great Trigonometric Survey , Everest Datum



Erstwhile NSRF through GCP Library

Active Reference Frame through CORS Network



Control Survey

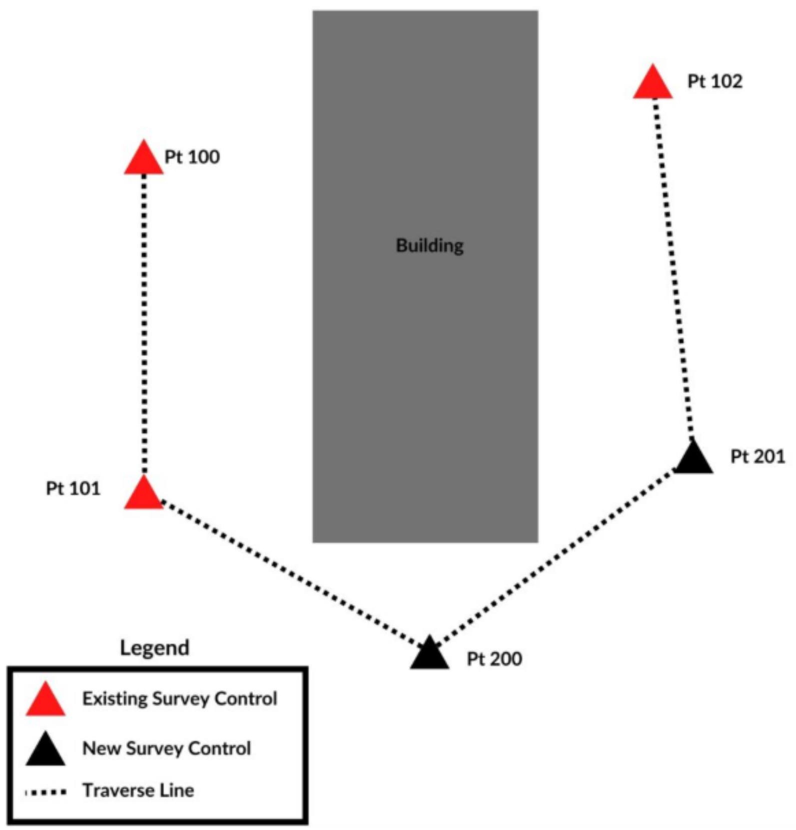
Control Survey provides a network of accurately located reference points on the Earth's surface. These points serve as the **framework for all detailed surveying and mapping**

Aspect	Horizontal Control	Vertical Control
Defines	Location (X, Y)	Elevation (Z)
Datum Used	Ellipsoid or Plane Coordinate System	Mean Sea Level (MSL)
Measured By	Triangulation, Traverse, GNSS	Levelling, Trigonometrical
Instrument	Theodolite, Total Station, GNSS	Level, Digital Level, GNSS,TS
Purpose	Position control	Height control
Output	Control points (X, Y)	Benchmarks (Z)

Horizontal Control

Horizontal control refers to the establishment of a network of **accurately positioned control points** whose **horizontal coordinates (X, Y)** are known with respect to a defined datum and coordinate system.

- **Objectives**
  - Provide a reliable positional reference framework
  - Ensure uniformity and consistency in surveys
  - Transfer accuracy from control to detail surveys



Orders of Horizontal Control

- Horizontal control networks are classified into **orders** based on **accuracy, extent, and purpose**.
- **First-Order Control**
  - Highest precision
  - Covers large areas (national / regional)
  - Established using precise geodetic methods
- **Second-Order Control**
  - Derived from first-order control
  - Regional or project-level framework
- **Third-Order Control**
  - Derived from second-order control

Accuracy Standards for Horizontal Control

Order of Control	Typical Relative Accuracy
First Order	1 : 1,000,000 or better
Second Order	1 : 100,000 – 1 : 250,000
Third Order	1 : 5,000 – 1 : 20,000

Standards specify

Permissible angular misclosure

Permissible linear misclosure

Observation procedures and redundancy

Purpose of standards

Ensure uniform quality

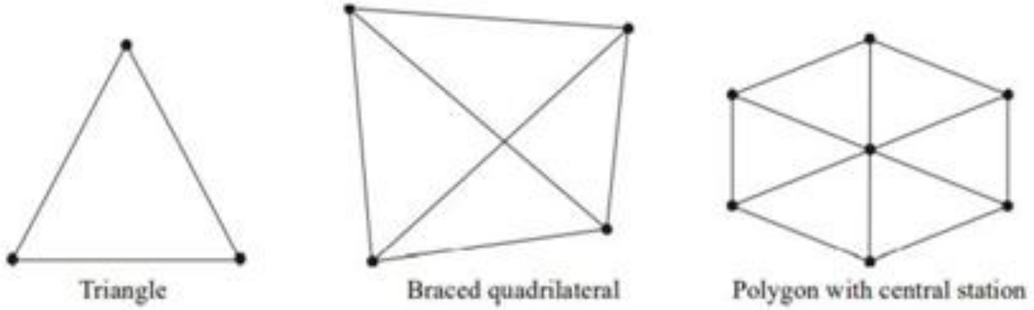
Enable comparison and integration of surveys

Planning of Horizontal Control

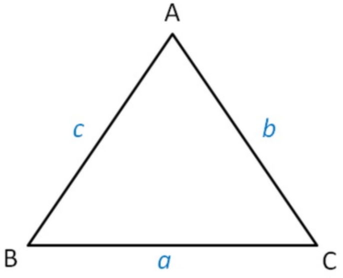
- **Planning Considerations**
  - Purpose and scale of the survey
  - Required order and accuracy
  - Terrain conditions and accessibility
  - Choice of method (GNSS, traverse, triangulation, trilateration)
- **Good Planning Practices**
  - Establish control from higher to lower order
  - Use well-conditioned network geometry
  - Provide redundant observations
  - Select stable, permanent, and intervisible stations
- Horizontal control is the fundamental positional framework of

Methods of establishing horizontal control

- **Trigonometric Basis**
- If the **three angles of a triangle** and the **length of one side (base)** are known, the remaining sides can be computed.
- By forming a **chain of connected**
  measurement of one accurately measured
  line) and all angles allows determination
  side lengths.



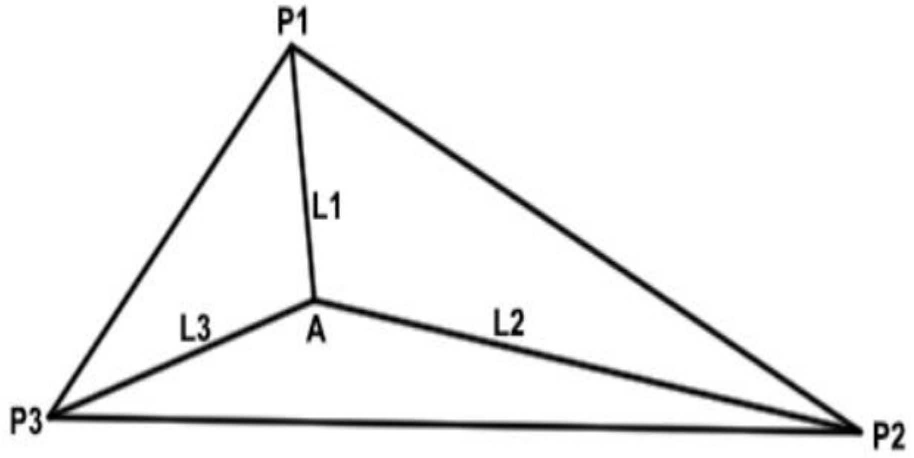
- **Core Principles**
- **Working from Whole to Part**
  - Large triangles are first established
    accuracy
  - Smaller triangles are later subdivided
    accuracy
  - Prevents accumulation and spread of errors



sinA/a=sinB/b=sinC/c
b=c×sinA/sinC
a=cx sinB/sinC

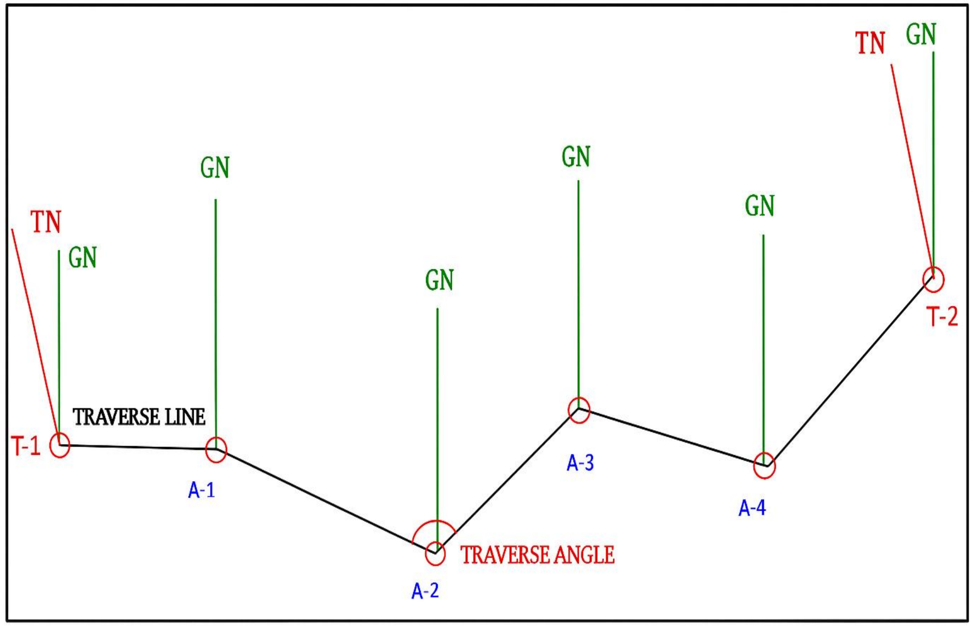
Trilateration

- **Control is established by measuring all sides (distances)** of a network of triangles
- **Angles are computed** mathematically from the measured distances
- Relies on **Electronic Distance Measurement (EDM)** technology for high precision
- Minimizes angular observation errors
- Provides **higher accuracy than classical triangulation** where distance measurement is reliable



Introduction

- A **traverse** in surveying is a method of establishing control by measuring a series of **connected straight lines** whose **lengths** and **directions** are accurately observed. These lines are called **traverse legs**, and the endpoints are **traverse stations**.
- A traverse provides the geometric framework needed to compute the **horizontal positions** (coordinates) of points on the ground using bearings and distances.

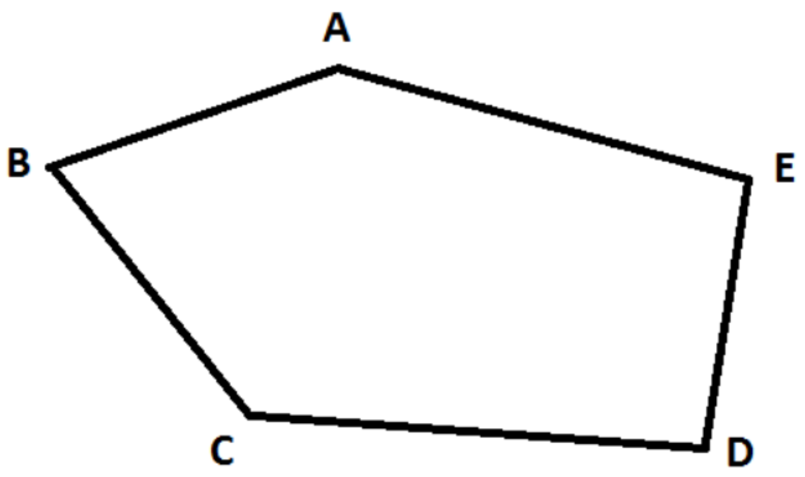


Purpose of Traverse

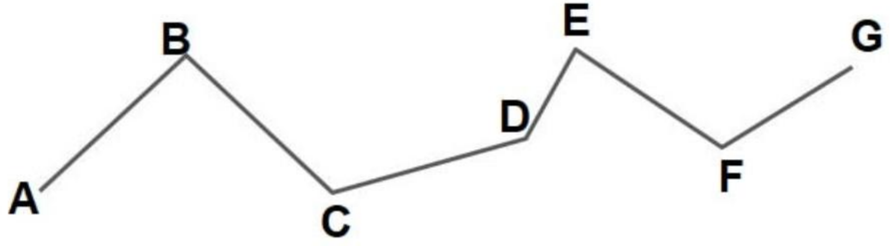
- To establish control points for detail survey and other ground verification survey.
- To fix the course or route of a proposed road, administrative boundary or the course of a river with high accuracy.
- To fix or re-locate the boundary pillars on the ground in numerical terms
- To supplement the controls in the area not suitable for GNSS using the known controls of higher accuracy.

Types of Traverse

- A traverse that starts from a known station and closes either on the same known station or on another station of known coordinates



- A traverse which starts from a known station and does not close on to another known station or on to the station but left hanging is called open traverse.

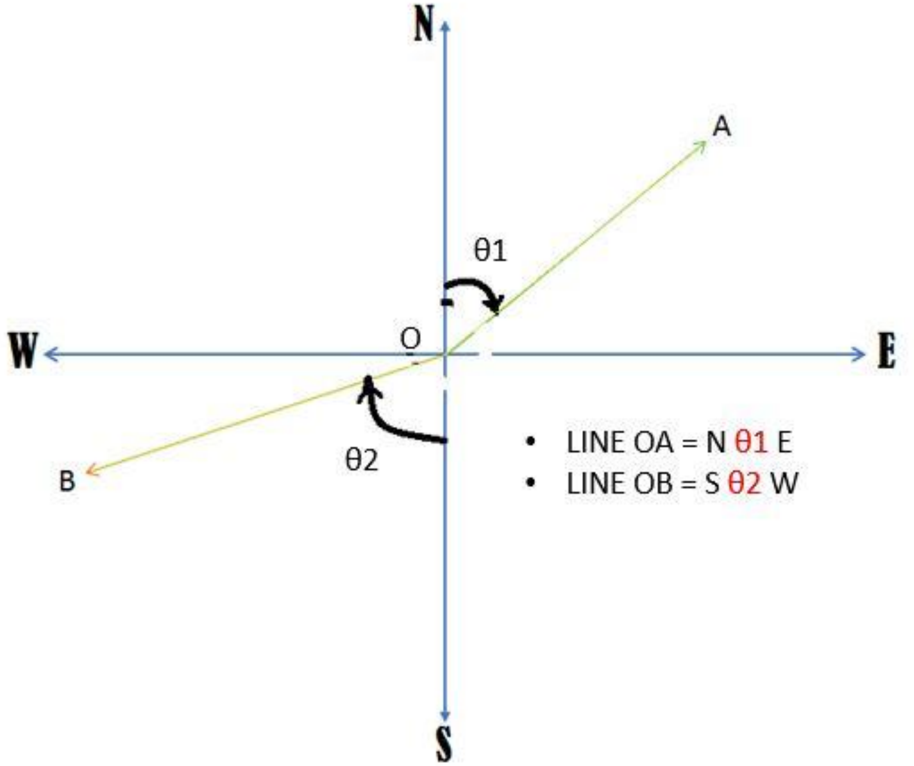


Control by Traversing - Procedures

- **Planning** - establish requirements for accuracy, density and location of control points. Time and resources available.
- **Reconnaissance** - nature of terrain, access, location of points.
- Station marking - type of mark, reference, protection.
- Angular Measurement- targets, reading and booking procedure.
- Linear Distance –Measuring and applying the following corrections- standardization correction, slope correction, temperature correction and booking procedure.
- Computations
- **Reduction of field data:** corrections to linear measurements, abstract of angles, angle misclosure and adjustment - sketch of reduced data.

Bearing in Surveying

- Bearing is the horizontal angle measured between a reference meridian (usually north or south) and the line connecting two survey points.
- Bearings are expressed in degrees, minutes, and seconds, and always measured clockwise from the reference meridian.



Bearing in Surveying

Type	Reference Meridian	Range	Format	Example
Whole Circle Bearing (WCB)	North	$0^\circ - 360^\circ$	Clockwise angle from north	$145^\circ\ 20'$
Quadrantal Bearing (QB) / Reduced Bearing (RB)	North or South	$0^\circ - 90^\circ$	N/S θ E/W	S $35^\circ\ 20'$ E
True Bearing	True (geographical) meridian	Depends	Angle from true north	Based on Earth's axis
Magnetic Bearing	Magnetic meridian	Depends	Angle from magnetic north	Compass reading
Grid Bearing	Grid meridian (map projection)	Depends	Angle from grid north	Used in UTM, GNSS
Arbitrary Bearing	Assumed meridian	Depends	Angle from chosen direction	User-defined

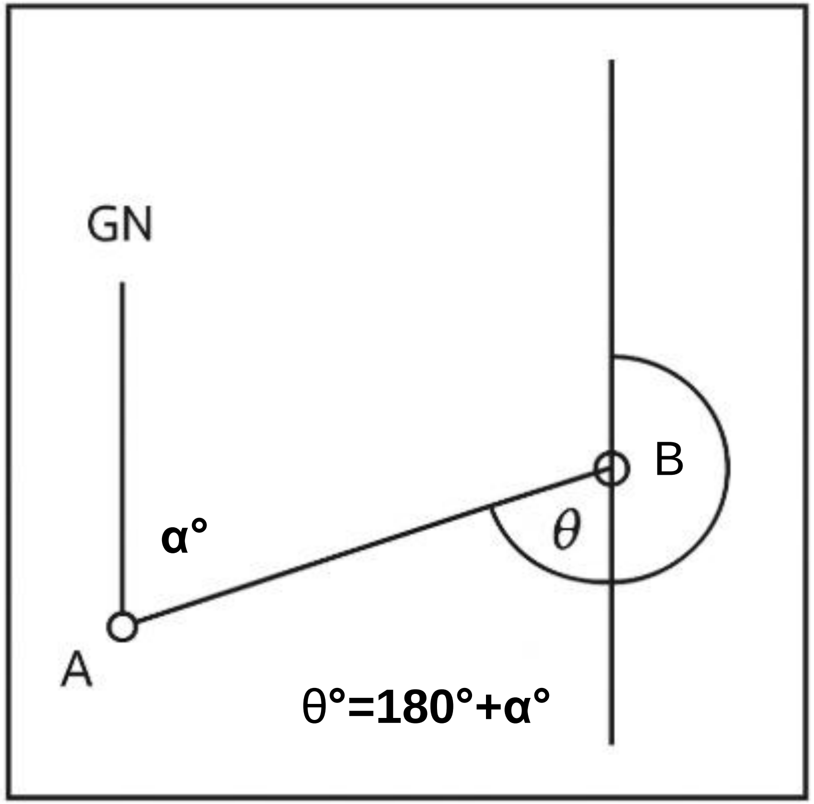
Reciprocal Bearing

Reciprocal Grid Bearing

- If Grid Bearing of **AB** at point **A** = **α°**
  Then the reciprocal bearing at **B** of **A =180°+α°**
  If the sum exceeds 360° → subtract 360°.
- Grid meridians are **parallel** → **no meridian convergence**.

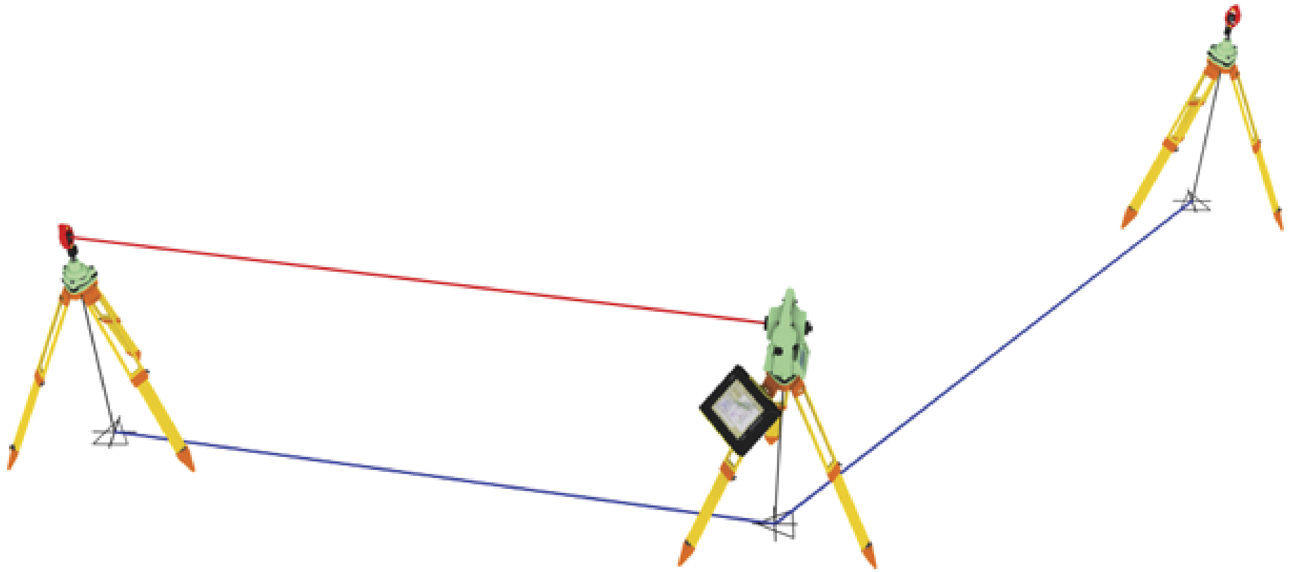
Reciprocal True Bearing (Azimuth)

- If True Bearing (Azimuth) of **AB** at **A** = **β°**
  Then reciprocal true bearing at **B** of **A** = β±(180∘+ε) Where the **meridian convergence**:$\varepsilon = \Delta\lambda \cdot \sin\phi$
- $\Delta\lambda$ = Difference in longitude between A and B
- ϕ = Mean latitude of AB



Data necessary for starting traverse work

- Two known stations with known coordinates separated by considerable distance.
- Azimuth/Bearing of the starting traverse leg.

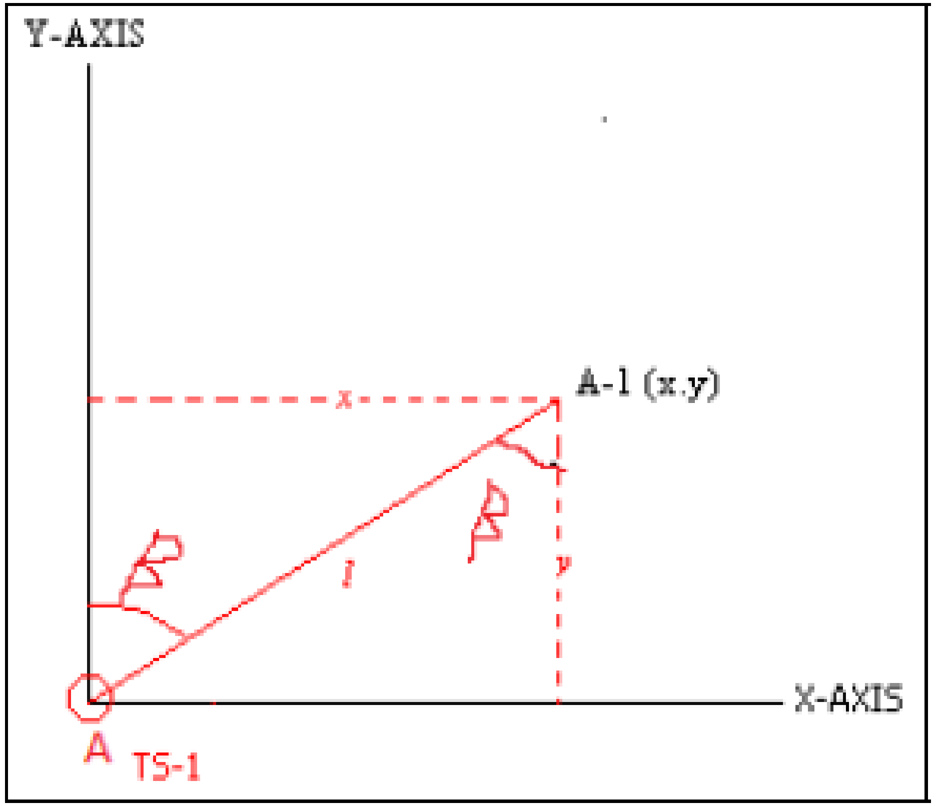


Procedure for Running a Traverse

- Set up the instrument at the known starting station
- Sight the back station to establish bearing (True/Grid)
- Observe traverse angles at intermediate stations
- Measure distances of all traverse legs
- Close the traverse at another known station
- Verify angular accuracy using $\pm\sqrt{n} \times$ least count
- Compute misclosure in Easting/Northing (Latitude/Departure)
- Adjust traverse using Bowditch (Compass) Rule

Principle

- If coordinates of one station(A-1) and the true/grid bearing of the connected leg are known, the next station(TS-1)'s coordinates are computed using:
- ΔLatitude=lcosθ
- ΔDeparture=lsinθ
- Northing(TS-1)=Northing(A-1)+Δlatitude
- Easting(TS-1) =Easting(A-1)+ΔDeparture



Classification of Traverse

Based on accuracy or the quality of the results

Primary traverse or 1st order traverse:-

- Accuracy = 1:50,000 and above in total length of the traverse
- 1 ppm = 1 part per million , 1 km = 1000 m
- (1mm) =10,00000 mm, 1 m = 100 cm
- = 10^6 mm 1 cm = 10 mm
- = 1 km. 1 km = 10^6 mm
- **Secondary or 2nd order traverse:-**
- Accuracy = from 1/20,000 to 1/50,000 achieved in the total length of the traverse.

Tertiary or 3rd order traverse:-

Types of Control / Traverse, Instruments Used and Order

Type of Control / Traverse	Instruments Used (Modern Description)	Order of Control
Classical Theodolite Traverse (Legacy Method)	Optical / glass-arc theodolite (1″ or 0.1″ least count) with steel band or chain for distances	**Tertiary Control**
EDM-Based Traverse (Transitional Method)	Precision theodolite (T2 / T3 class) for angles and short-to medium-range EDM for distances	**Secondary Control**
Total Station Traverse (Contemporary Classical Method)	Integrated electronic theodolite and EDM with on-board microprocessor, data storage, and processing capability	**Secondary Control**
GNSS Geodetic Control (Modern Practice)	Multi-frequency GNSS receivers (L1/L2/L5) using static, network, or CORS-based observations to derive geodetic coordinates and azimuths	**Primary (First-Order) Control**

Classification of Traverse

Traverse based on purpose

- Route survey
- Administrative Boundary Survey
- Forest boundary survey
- Relocation and re-fixing of boundary pillars
- Road Alignment survey.
- Rail Alignment Survey.
- Transmission Line Survey.

Accuracy Standards for Traverse

Quantity	Zero Order Control	Primary Control	Secondary Control	Tertiary Control
Nature of control	National geodetic framework	Major mapping & regional control	Densification control	Local survey control
Predominant technology (latest)	GNSS (Static / CORS)	GNSS + ETS	ETS / GNSS-RTK	ETS
Instrument angular accuracy (ETS)	≤ 0.5″	1″–2″	≤ 5″	≤ 10″
Instrument least count / resolution	0.1″–0.2″	0.5″–1″	1″	1″–5″
Permissible error in horizontal angle	±1″	±2″	±5″	±10″
Average angular / loop misclosure (max)	≤ 0.5″	≤ 2″	≤ 5″	≤ 10″
Number of angle repetitions (zeros)	GNSS-based	8–10	4	1
Azimuth determination	GNSS-derived	Astronomical / GNSS	Astronomical / GNSS	Occasional
Maximum azimuth misclosure per station	≤ 0.5″	≤ 1″	≤ 2″	≤ 5″
Stations between azimuth controls	Continuous GNSS	6–8	8–10	10–15
Distance measurement accuracy	GNSS baseline RMS	±(5 mm + 1 ppm)	±(5 mm + 2 ppm)	±(5 mm + 5 ppm)
Distance & reciprocal distance agreement	√2 × (5–6 mm + 1 ppm)	–	–	–

Transmission Line Control Survey Accuracy Standards (Latest trends)

Quantity	Primary Control	Secondary Control	Tertiary Control
Purpose	Corridor orientation, river & long-span control	Alignment fixing, angle points	Tower spotting & foundation
Typical technology	GNSS (Static / CORS)	GNSS (RTK) + ETS	ETS / RTK
Horizontal position accuracy	±10–20 mm	±20–30 mm	±50 mm
Vertical accuracy (heights)	±15–20 mm	±25–40 mm	±50 mm
Instrument angular accuracy (ETS)	≤ 1″–2″	≤ 5″	≤ 7″–10″
Permissible error in horizontal angle	±2″	±5″	±10″
Traverse closing error (plan)	GNSS-based	1 : 20,000	1 : 5,000
Maximum azimuth misclosure per station	≤ 1″	≤ 2″	≤ 5″
Stations between azimuth controls	GNSS continuous	8–10	10–15
Distance measurement accuracy	±(5 mm + 1 ppm)	±(5 mm + 2 ppm)	±(5 mm + 5 ppm)
Angle repetitions (zeros)	≥ 8	≥ 4	≥ 1–2
Reciprocal distance agreement	√2 × (5 mm + 1 ppm)	–	–

Traverse Adjustment

1. Why Adjust a Traverse?

- Remove accumulated measurement errors
- Achieve a *mathematically consistent* framework
- Obtain accurate coordinates for all traverse stations
- Improve reliability of angles, distances, and heights

2. Pre-Adjustment Checks (Using ETS)

- **Instrumental Checks**
- Collimation error
- Trunnion (horizontal) axis error
- Vertical index error
- EDM constant, prism constant, atmospheric parameters

Observational Checks

FL/FR angular agreement
FB/BB bearing agreement
Repeat distance checks
Correct HI/HT entries, proper centering and leveling

3. Blunder Detection

Wrong point sighting
Recording errors
Prism not vertical
Incorrect station orientation
Only error-free data should enter adjustment.

Bowditch(Compass Rule)

Assumption

- Probable errors in length and bearing produce equal displacements at the end of the leg.
- Probable errors of linear measurements are proportional to the square roots of the lengths of the leg.

The rule is …….

- Correction to Latitude /Departure =

  Closing error in Latitude /Departure X Length of corresponding leg

  ----

  Total length of Traverse

TRANSIT RULE

- This method of adjusting the consecutive co-ordinate of theodolite traverses, may be conveniently employed where angular measurements are more accurate than the linear measurements (e.g. more precise theodolites)
- **Assumption:** The correction to latitude (or departure) of any traverse leg should be proportional to the latitude (or departure) instead of the length of the traverse leg itself.
- Correction to Latitude /Departure) of a traverse leg =

Total error in Latitude/Departure) X Latitude /Departure of that traverse leg

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LEAST SQUARES ADJUSTMENT

1. Why Least Squares?

- Statistically optimal adjustment
- Handles mixed observations: angles + distances + heights
- Provides accuracy estimates (covariance matrix)
- Identifies weak stations and outliers
- Essential for high-precision work (tunnels, metro, monitoring)

2. Least Squares Principle

- Minimize:
- $\mathbf{v^T W v}$
- **v** = residuals
- **W** = weights (based on ETS precision)

3. LS Adjustment Workflow

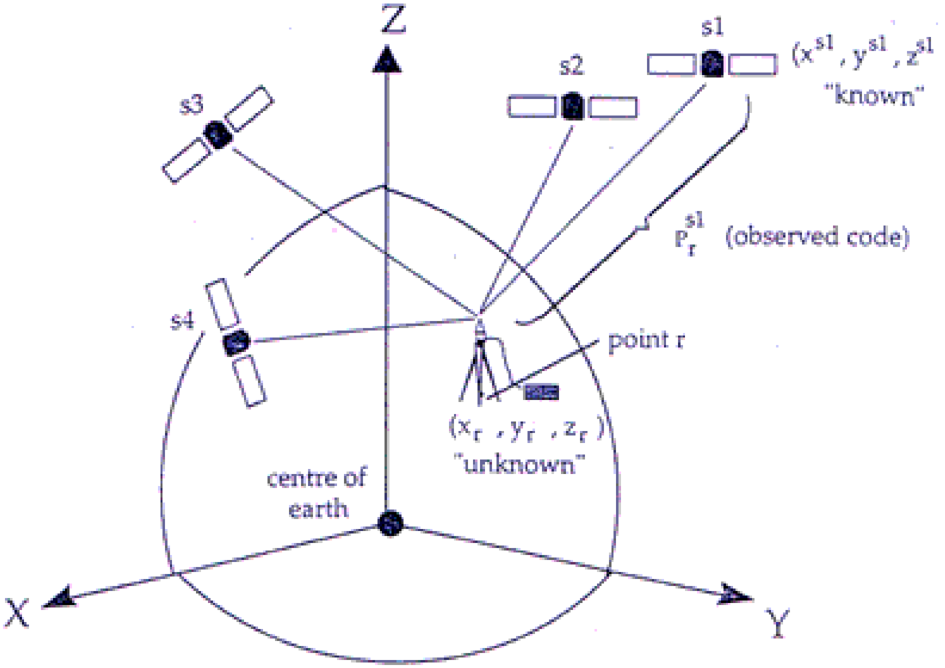
- Form observation equations
- Linearize angular/distance equations
- Build coefficient matrix (A)
- Apply weights (W)
- Solve normal equations
  $(A^TWA)x=A^TWl$
- Compute adjusted coordinates
- Inspect residuals and statistical tests

4. Output of LS Adjustment

- Fully adjusted coordinates (E, N, Z)
- Error ellipses for each station
- Statistical diagnostics
- High-confidence control network

GNSS / GPS-Based Control

- Control points are established using **satellite-based positioning systems**
- Provides coordinates directly in a **global or national reference frame**
- Suitable for:
  - – Primary and secondary control
  - – Large and inaccessible areas
- Accuracy depends on:
  - – Observation method (static, rapid stat
  - – Satellite geometry and corrections



How many satellites are required in GPS/GNSS to find position?

- **With two satellites:**
  - Insufficient to determine a unique position
  - Multiple solutions exist
  - Position and time **cannot be uniquely resolved**
- **With three satellites:**
  - Can determine **X, Y and T** *if* the receiver height (Z) is **known or constrained**
  - Used in special cases such as **2D positioning** or surface navigation
- **With four satellites:**
  - Can determine **X, Y, Z and T simultaneously**
  - Provides a **unique 3D position and clock correction**

- There are **four unknowns** (X, Y, Z, T)

Pseudo range equation
(Code Observable)

$p = \rho + d_p + c(dt - dT) + d_{ion} + d_{trop} + \epsilon_{mp} + \epsilon_p$

where:

p = the pseudorange measurement

ρ = the true range

d_ρ = satellite orbital errors

c = the speed of light

dt = satellite clock offset from GPS time

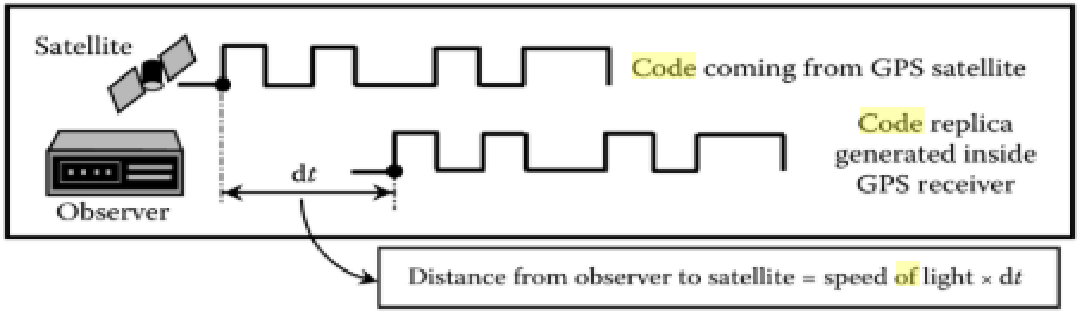
dT = receiver clock offset from GPS time

d_{ion} = ionospheric delay

d_{trop} = tropospheric delay

ϵ_{mp} = multipath

ϵ_p = receiver noise



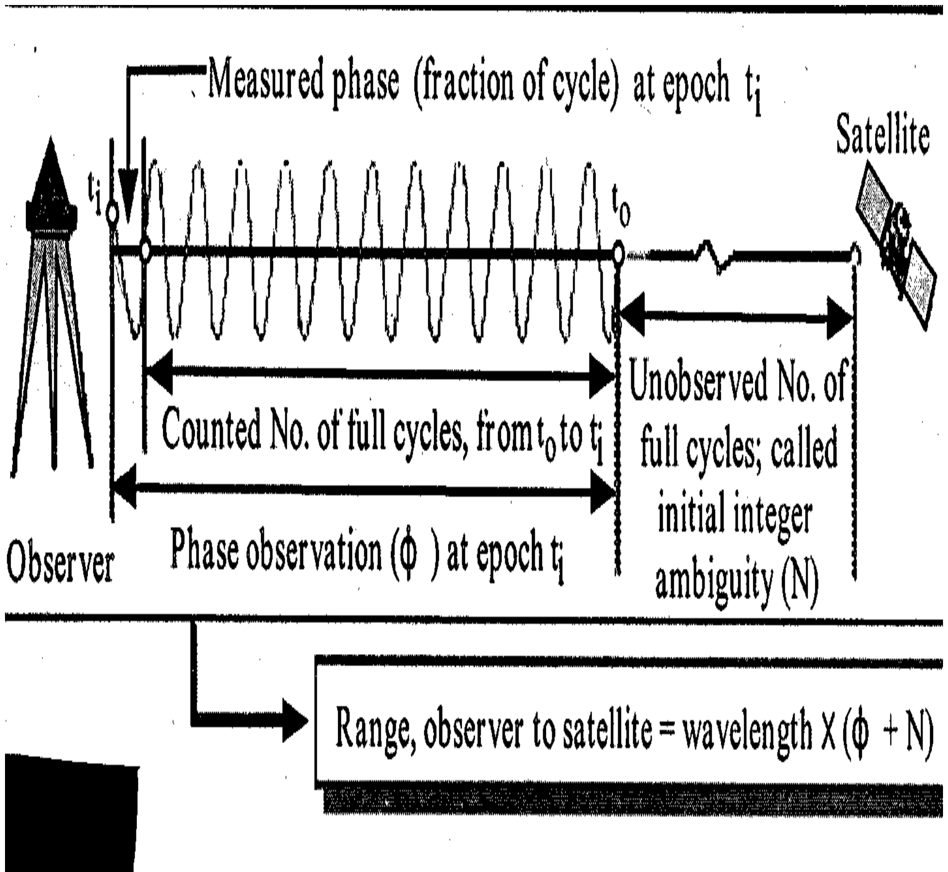
The principle of obtaining a range measurement using PRN codes.

Observable in Carrier Phase

- The carrier phase observable (expressed in cycles) can be written as:

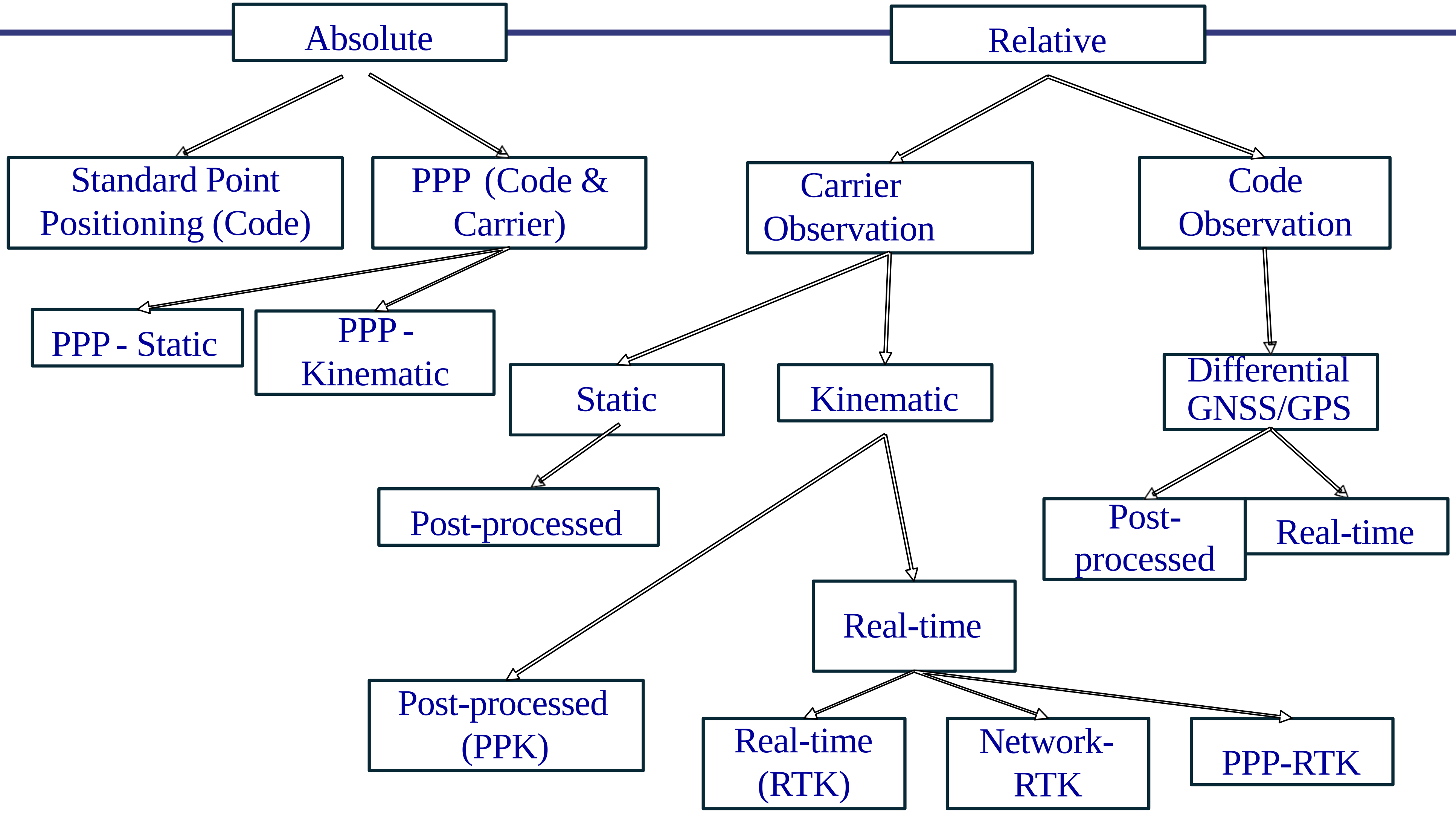
$$\Phi = \rho + c\,(dtr - dTs) - I + T + \lambda N + d\Phi + \epsilon$$

- Where:
  - Φ is the measured carrier phase in meters
  - ρ is the geometric range between the satellite and receiver
  - c is the speed of light
  - dtr, dTs are the receiver and satellite clock errors
  - I and T are ionospheric and tropospheric delays
  - λN represents the initial phase ambiguity multiplied by the wavelength
  - $d\Phi$ includes hardware-related phase center offset corrections
  - ϵ is the measurement noise



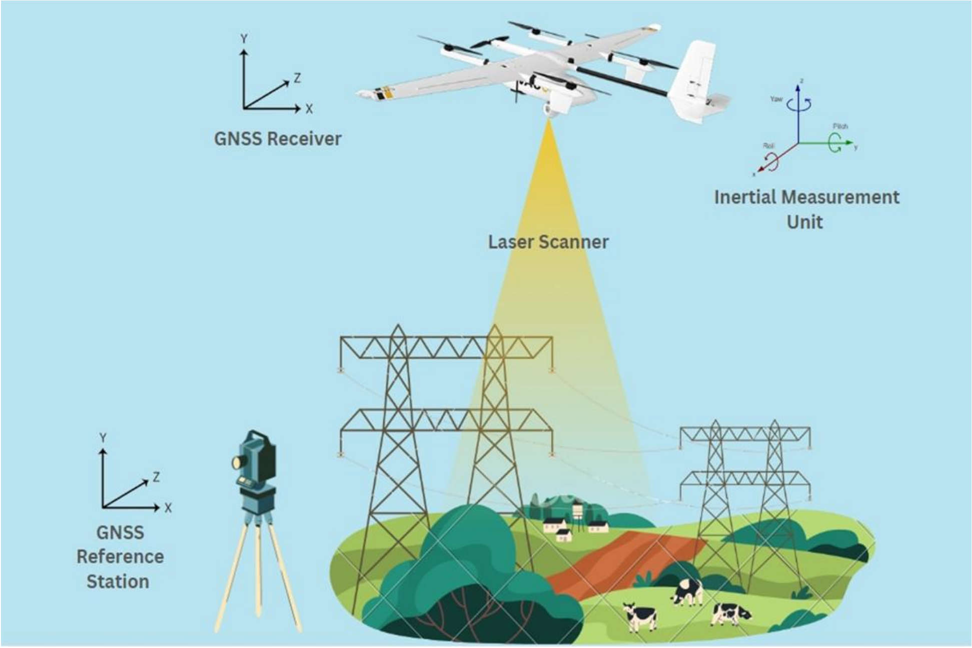
Phase (carrier) range determination using GPS phase measurement.

GNSS Surveying Methods



LiDAR

- **LiDAR (Light Detection and Ranging)** is an active remote sensing technique used to determine ground elevations and surface features by measuring the **time taken by laser pulses** to travel from a sensor to the target and back.
- **Key Characteristics**
- Uses **laser pulses** emitted from airborne or terrestrial platforms
- Measures **distance based on time-of-flight principle**
- Produces dense **3D point clouds (X, Y, Z)**



UAV (Unmanned Aerial Vehicle)

- **UAV (Unmanned Aerial Vehicle) survey** involves capturing high-resolution aerial data using drones equipped with **cameras or LiDAR sensors**, combined with photogrammetric or LiDAR processing.
- **Key Characteristics**
- Low-altitude, high-resolution data capture
- Uses **photogrammetry and/or LiDAR**
- Requires **ground control points (GCPs)** for accuracy
- Rapid deployment and cost-effective for small to medium areas

Exercise

Problem 1:

A 220 kV transmission line is proposed between control stations A and E. A closed traverse A–B–C–D–E–A is run along the proposed alignment.

Given Data:

Coordinates of Control Station A:

A : Easting = 5000.000 m, Northing = 10000.000 m

Traverse Leg	Bearing (WCB)	Distance (m)
A–B	$045^\circ\ 30'00''$	850.00
B–C	$110^\circ\ 15'00''$	920.00
C–D	$195^\circ\ 45'00''$	780.00
D–E	$280^\circ\ 30'00''$	890.00
E–A	$350^\circ\ 00'00''$	420.00

Task:

Compute latitude and departure of each traverse leg.
Determine the angular and linear misclosure.
Adjust the traverse using the Bowditch (Compass) Rule.
Compute adjusted coordinates of stations B, C, D, and E.
Comment on the suitability of the traverse accuracy for transmission line tower spotting.

Exercise

Problem 2: GNSS–Traverse Integrated Control for Transmission Line

A 400 kV transmission line corridor passes through forest and river-crossing areas. Two GNSS control points are established using CORS-based RTK.

Station	Easting (m)	Northing (m)
G1	25000.000	40000.000
G2	26250.000	41780.000

A traverse is run between G1 and G2 through intermediate stations T1 and T2.

Traverse Leg	Bearing (WCB)	Distance (m)
G1–T1	$038^\circ\ 20'00''$	1240.00
T1–T2	$095^\circ\ 10'00''$	980.00
T2–G2	$162^\circ\ 40'00''$	1350.00

Tasks:

Compute the coordinates of T1 and T2.

Check the coordinate misclosure at G2.

Adjust the traverse using the Bowditch Rule.

Assess whether the achieved accuracy is acceptable for tower location and ROW demarcation.

Summary

End of Session – Thank You!