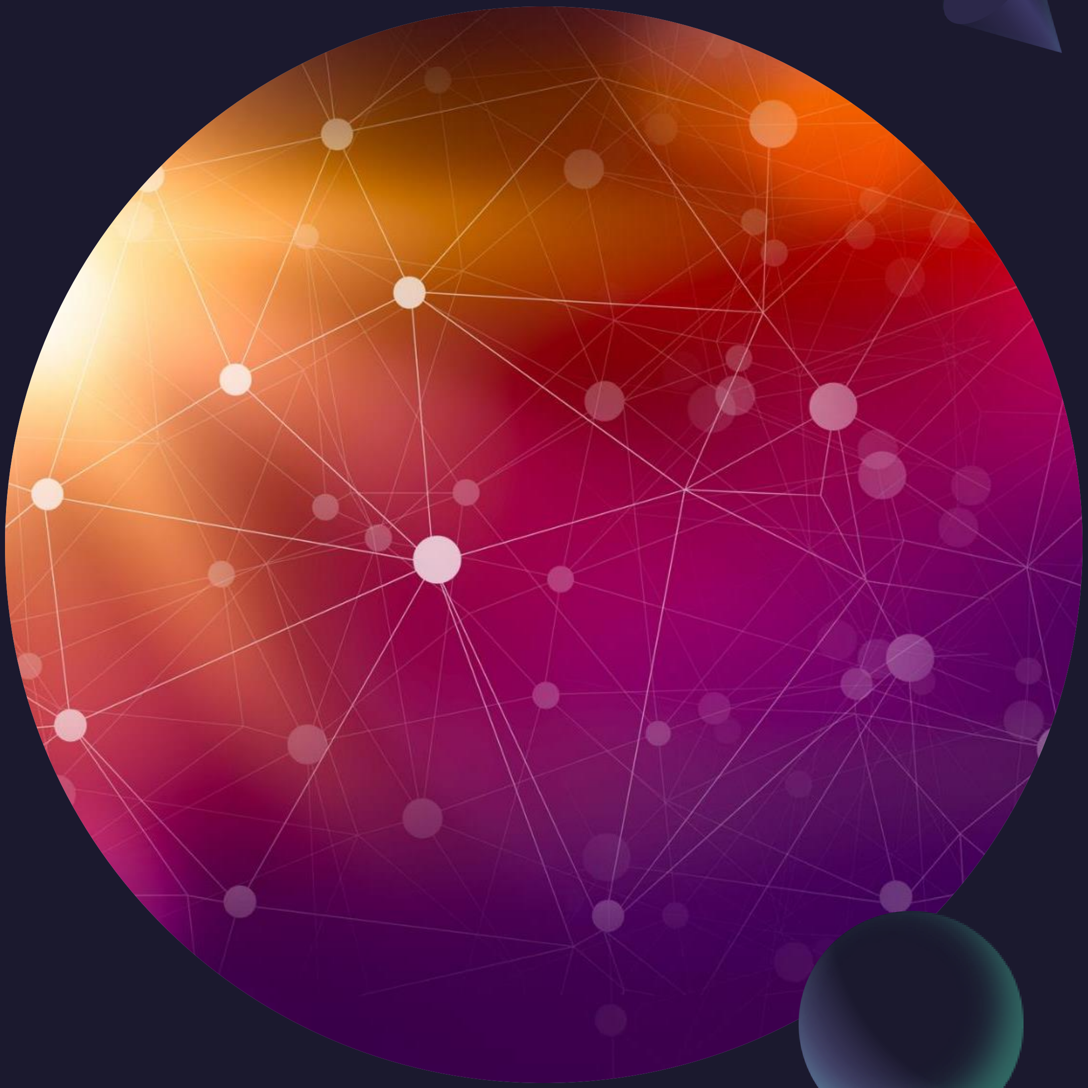
Sharpen Your Precision: Mastering Positional Tolerance

2025 MSS Fall Conference



James M. Shaw, Jr., Prof.L.S.

Reality Capture Deputy Discipline Lead

Johnson, Mirmiran & Thompson, Inc.

- Maryland Professional Land Surveyor (2004)
- 37 Years of Surveying Experience (1988)
- OPUS Projects Manager Certified (2012)
- 20 Years MSS Board Member
  - Past President (2014)
  - Technology, Chair
  - Education, Co-Chair
- 150+ Presentations in 8 States

Positional Tolerance in COMAR

The Minimum Standards of Practice (COMAR 09.13.06)

- .03 G. Accuracy Standards.
- (1) The maximum allowable relative positional precision for boundary surveys shall be 0.07 feet (or 2 centimeters) plus 50 parts per million, based on the direct distance between the two corners being tested.
- (2) The surveyor shall ascertain that the positional uncertainties resulting from the survey measurements do not exceed the allowable relative positional precision.

The Minimum Standards of Practice (COMAR 09.13.06)

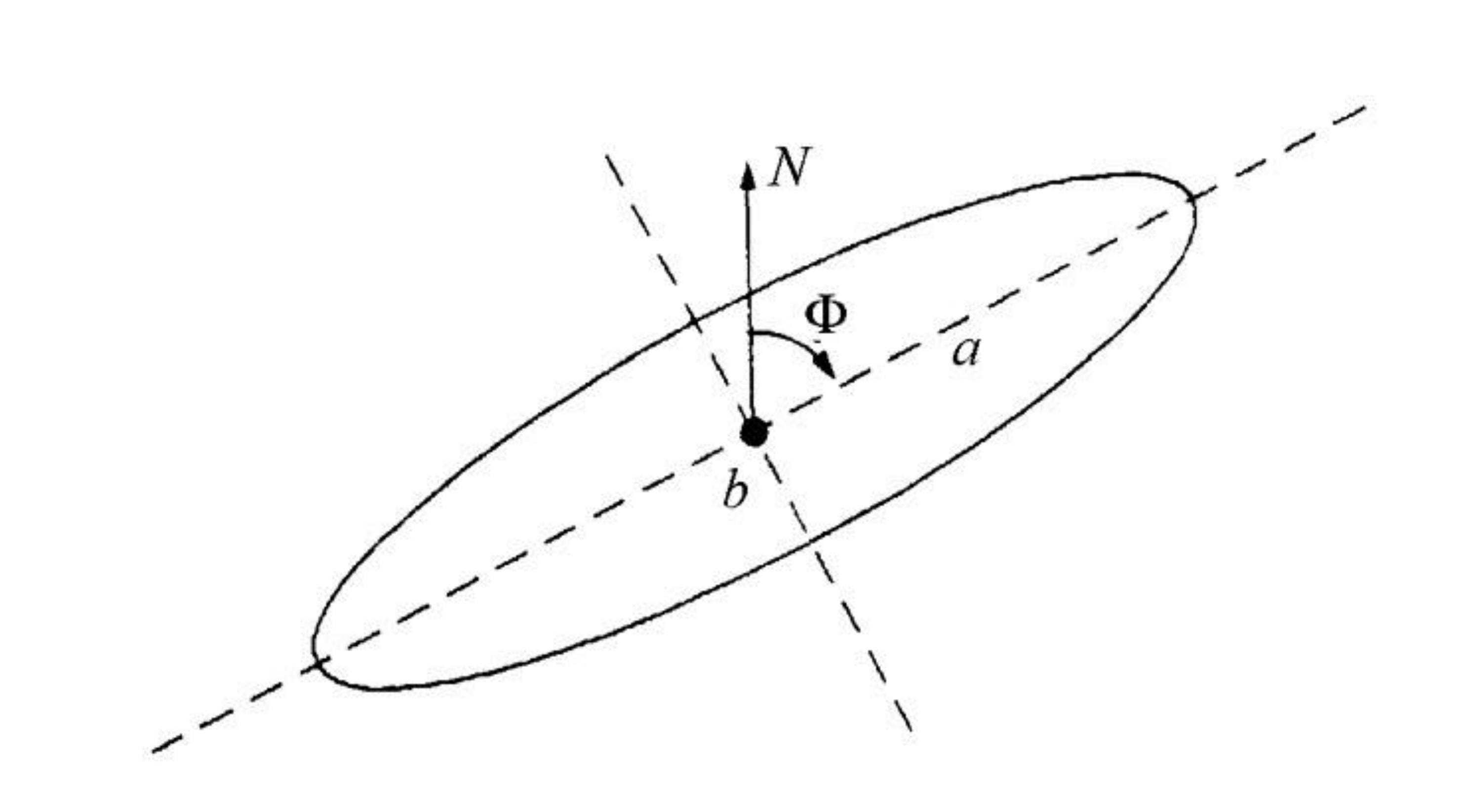
- (4) The surveyor shall, to the extent necessary to achieve the standards set forth in §G of this regulation, compensate or correct for systematic errors, including those associated with instrument calibration.
- (5) The surveyor shall use appropriate error propagation and other measurement design theory to select the proper instruments, field procedures, geometric layouts, and computational procedures to control and adjust random errors to achieve the allowable relative positional precision tolerance.

The Minimum Standards of Practice (COMAR 09.13.06)

- .02 (11) "Relative positional precision" means the length of the semi-major axis expressed in feet or meters, of the error ellipse representing the uncertainty due to random errors in measurements in the location of the property evidence, marking any corner of the surveyed property relative to the property evidence, and marking any other corner of the surveyed property at the 95 percent confidence level (two standard deviations).

Positional Uncertainty

- Typically expressed as an error ellipse.
- 95% chance (2 sigma) that the actual position falls within the ellipse



The Father of the Error Ellipse

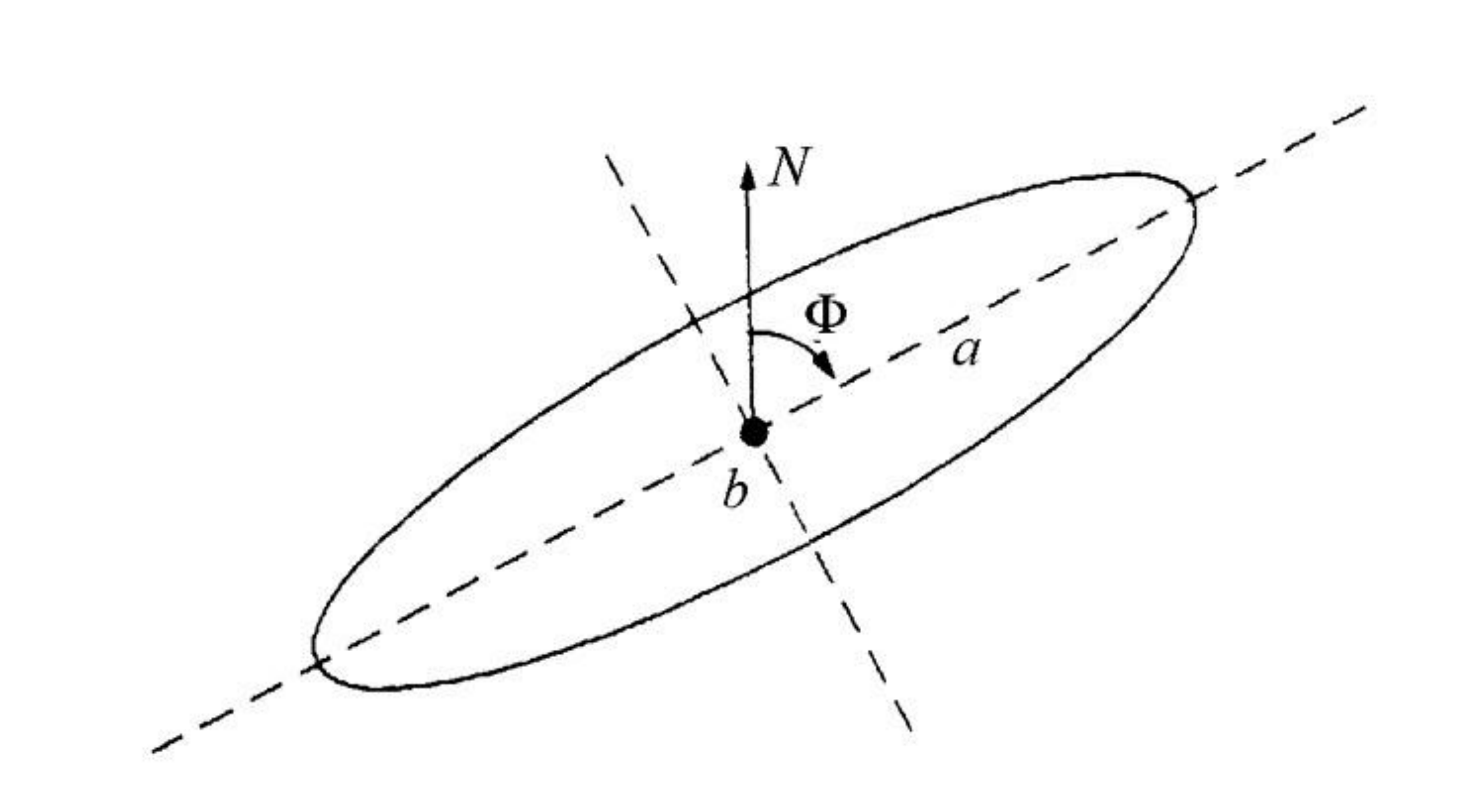
- Auguste Bravais (1811-1863)
- French physicist, astronomer, hydrographer, meteorologist, & mathematician
- 1832 became a naval officer. Performed the hydrographic mapping of the coast of Algeria.
- 1838-1840, participated in the La Recherche Expedition exploring the Faroe Islands, Spitsbergen, and Iceland.
- In 1846 published the paper, 'Mathematical analysis on the probability of errors of a point'. This paper, built on the works of Gauss, was the first to describe the error ellipse.
- Best known for his work in crystalline lattice systems.

The Father of the Modern Least Squares Adjustment

- Johann Carl Friedrich Gauss (1777-1855)
- German mathematician, astronomer, geodesist, & scientist
- Adrien-Marie Legendre (1752-1833) published a least squares method in 1806, before Gauss, as an appendix to his book on the path of comets. Credited with naming the method.
- In 1809 published the 'Theory of the Motion of Heavenly Bodies Moving about the Sun in Conic Sections'. The book included a robust least squares method that Gauss claimed to have developed in 1795. Gauss' method applied the principles of probability and normal distribution.
- In 1828 Gauss developed a figure of the Earth's surface perpendicular to the direction of gravity. This model was later termed the geoid.

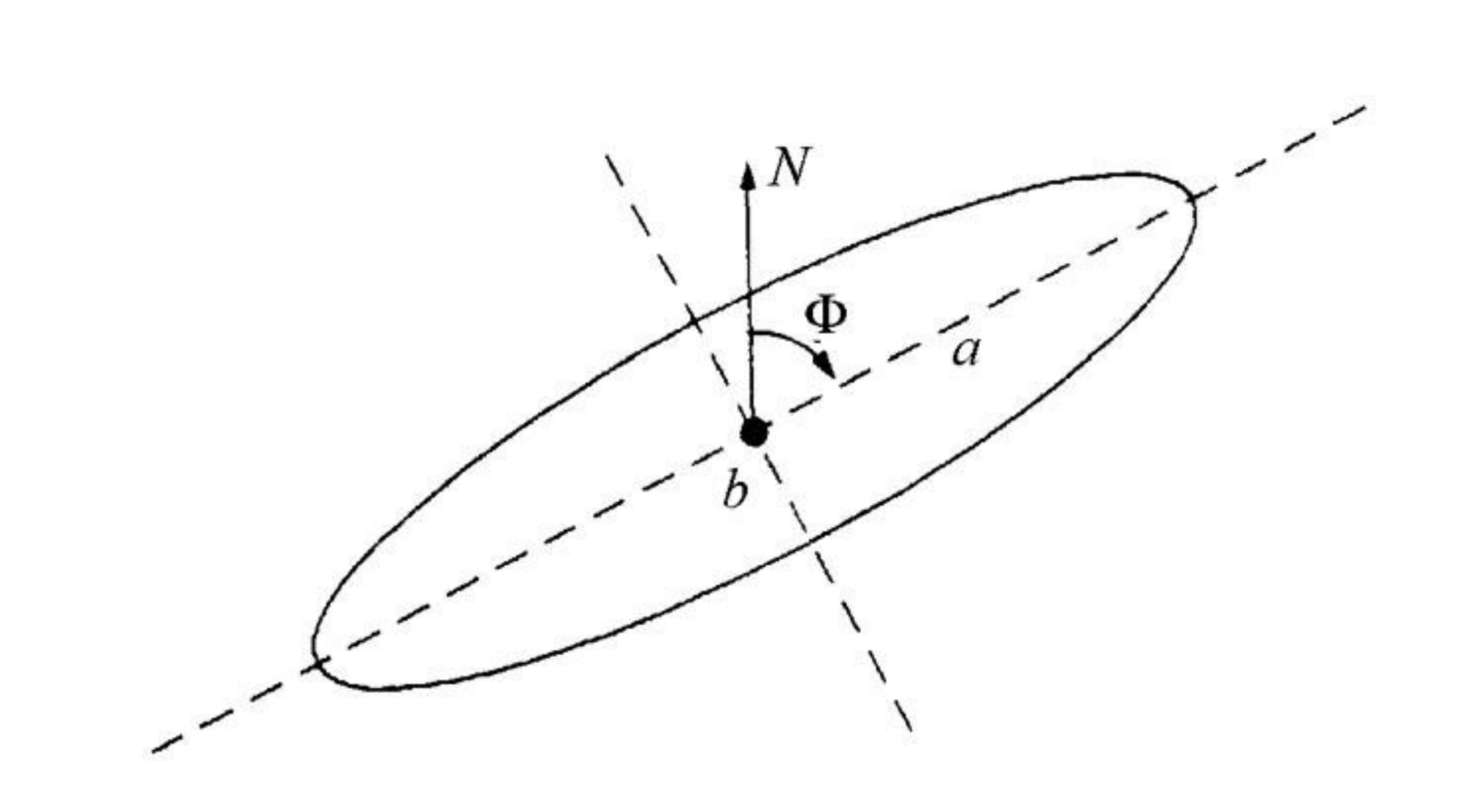
Positional Uncertainty

- Typically expressed as an error ellipse.
- 95% chance (2 sigma) that the actual position falls within the ellipse



Positional Uncertainty

- The maximum allowable relative positional precision for boundary surveys shall be 0.07 feet (or 2 centimeters) plus 50 parts per million.
- 95% chance (2 sigma) that the actual position falls within the ellipse



Surveyor's Reference Coin

- Diameter = 21.21mm (0.021m or 0.070 feet)
- Thickness = 1.95mm (0.006 feet)

Sidebar: Three Decimal Places

The average thickness of a business card is 0.001 USft.

Sidebar: Four Decimal Places

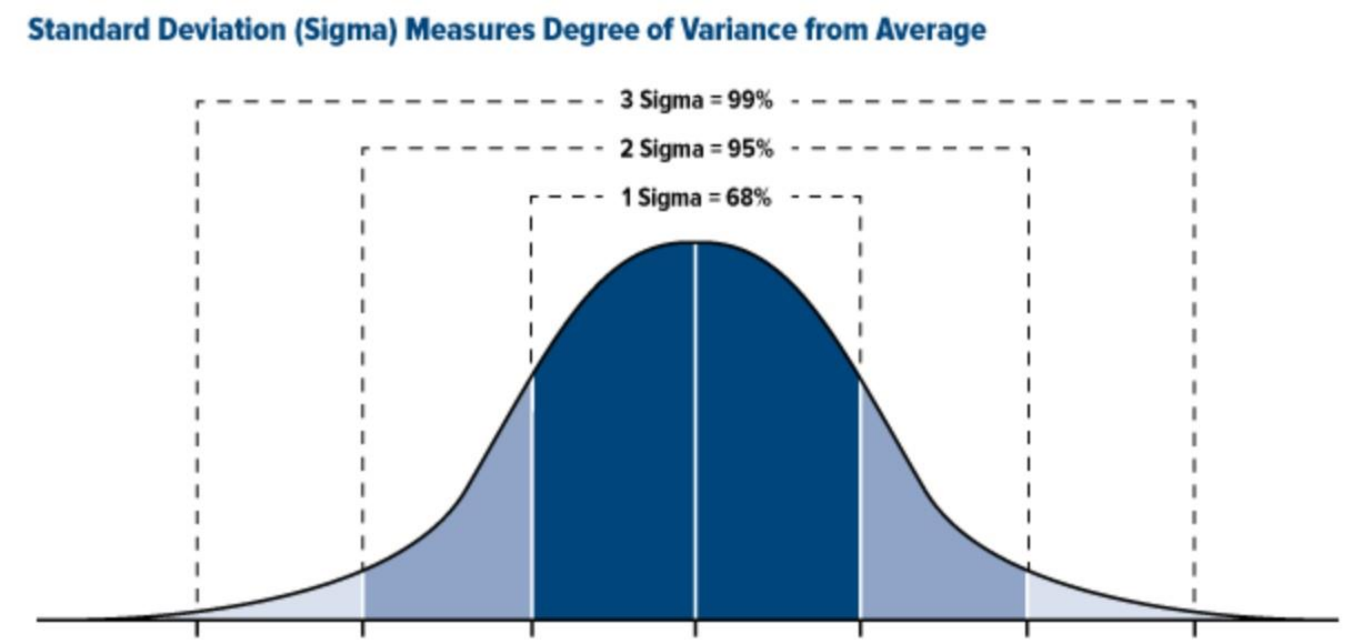
The average thickness of human hair is 0.00016 Usft and can be as thick as

0.0005 USft.

Positional Uncertainty

- The maximum allowable relative positional precision for boundary surveys shall be 0.07 feet (or 2 centimeters) plus 50 parts per million.
- 95% chance (2 sigma) that the actual position falls within the ellipse

Adjustment target = 2 Sigma



Remember me?

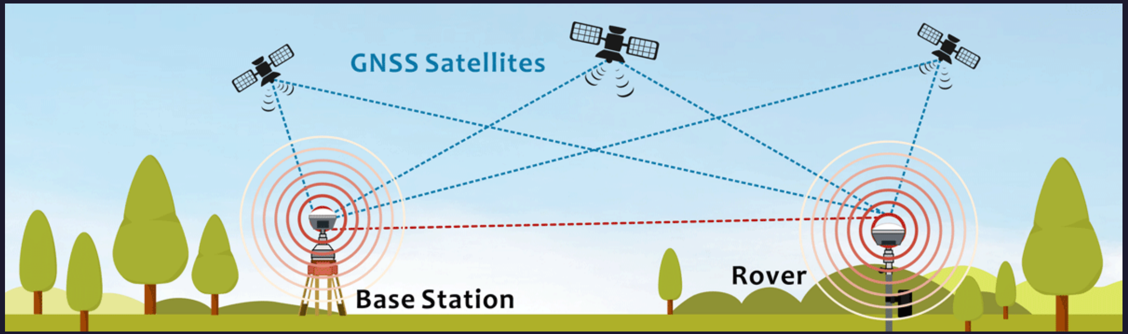
50 Parts Per Million Visualized

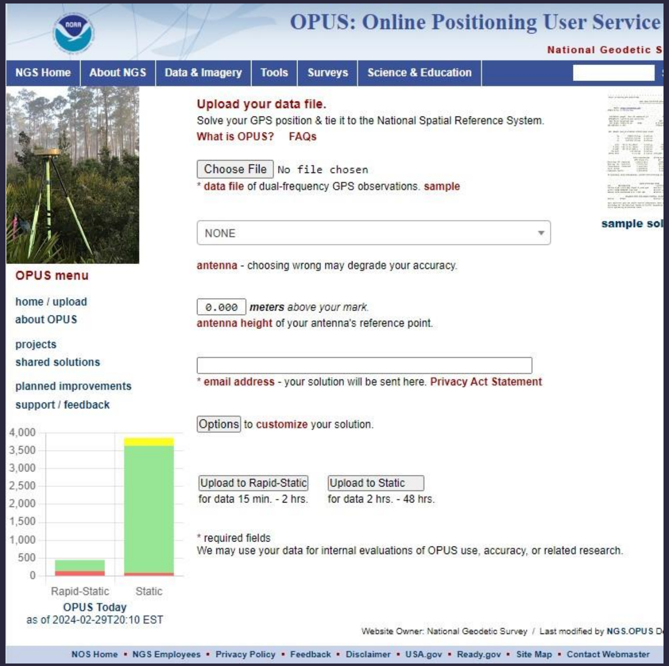
- U.S. Quarter is 24.26mm (0.080’) in diameter.
- 50/1,000,000 = 0.00005
- 24.26mm – 21.21mm = 3.05mm
- 3.05/0.00005 = 61,000mm or 61.000 meters
- 61.000 meters = 200.131 U.S. feet

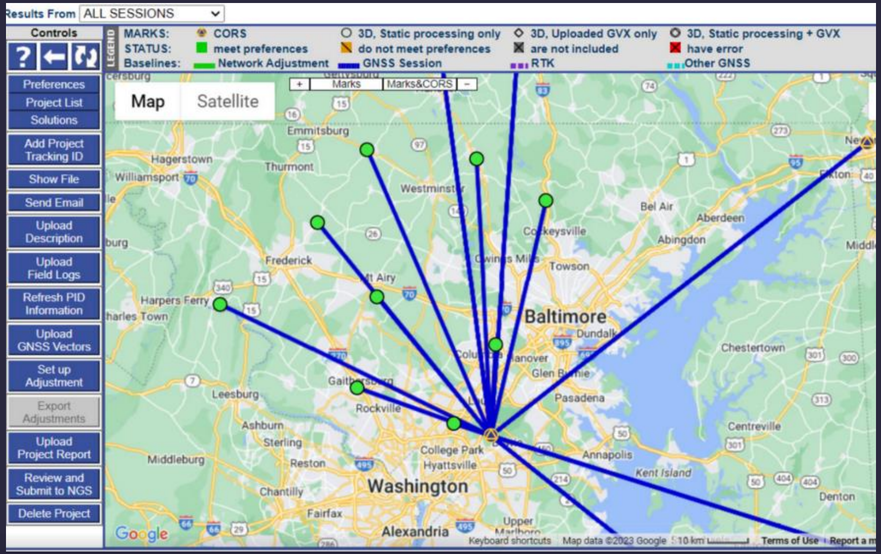
0.07' + 50ppm at 1,000 Feet

As the distance between two points increases, the allowable error ellipse increases.

Satellite-Based Positioning







Understanding the Spec Sheet

Trimble R980

Positioning performance[3]		
STATIC GNSS SURVEYING		
High-Precision Static	Horizontal	3 mm + 0.1 ppm RMS
	Vertical	3.5 mm + 0.4 ppm RMS
Static and Fast Static	Horizontal	3 mm + 0.5 ppm RMS
	Vertical	5 mm + 0.5 ppm RMS
REAL TIME KINEMATIC SURVEYING		
Single Baseline < 30 km	Horizontal	8 mm + 1 ppm RMS
	Vertical	15 mm + 1 ppm RMS
Network RTK[4]	Horizontal	8 mm + 0.5 ppm RMS
	Vertical	15 mm + 0.5 ppm RMS
	RTK start-up time for specified precisions[5]	2 to 8 seconds
TRIMBLE INERTIAL PLATFORM (TIP) TECHNOLOGY		
TIP Compensated Surveying[6]	Horizontal	RTK + 3mm + 0.15mm/°tilt (up to 40°) RMS
	Horizontal	RTX + 3mm + 0.15mm/°tilt (up to 40°) RMS
IMU Integrity Monitor	Bias monitoring	Temperature, age and shock
Operation	IMU alignment	Calibration-free and immune to magnetic interference

HxGN SmartNet

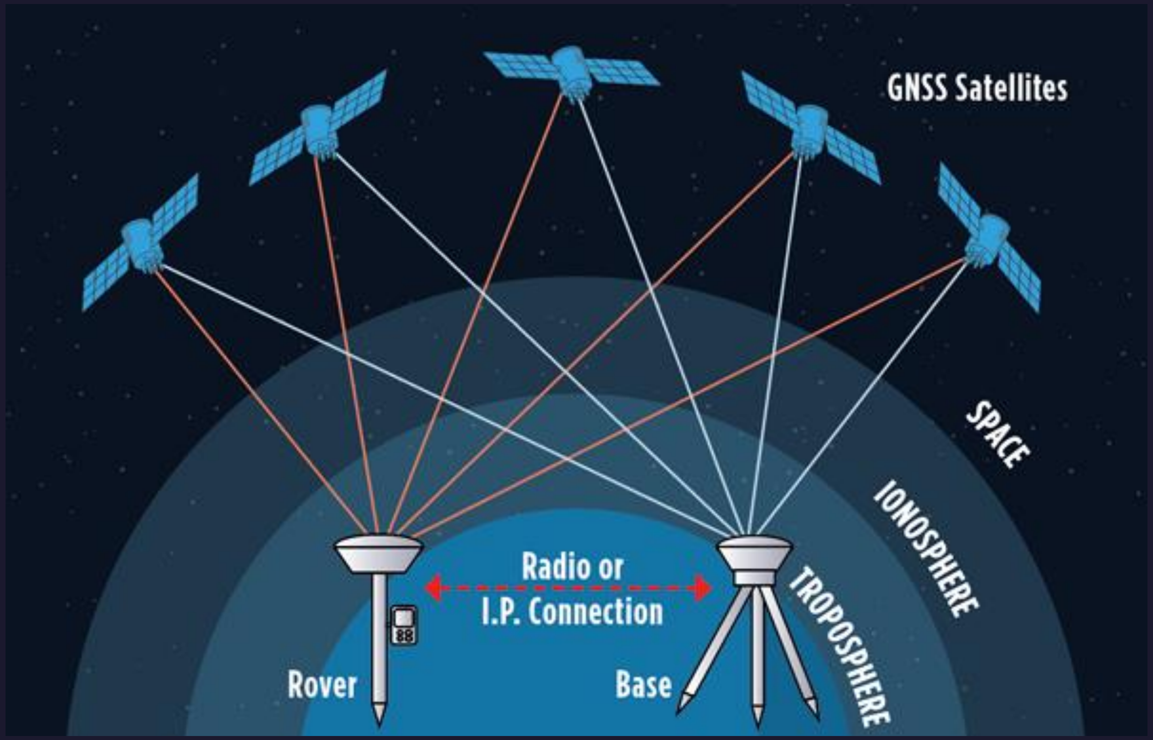
NETWORK RTK | TECHNICAL SPECIFICATIONS

Data access	Mobile Internet via NTRIP	Single Access Point via NTRIP (v1 & v2)
Coordinate reference frame		Local reference frame Global reference frame: ITRF2020 / North America ITRF2014
Correction data formats		RTCM 3.x (MSM from RTCM 3.2)
Correction Types		Network RTK: VRS, i-MAX RTK: Nearest (Single Base)
Satellite Constellation Support		GPS, GLONASS, Galileo, BeiDou, QZSS
Positioning quality	Quality of the positioning in accordance with the terms of use specified in the HxGN SmartNet Terms and Conditions	Leica Geosystems GS Sensors / Other GNSS devices Horizontal: 0.8 cm (+ 0.5 ppm) / ca. 1-3 cm (+ 0.5 ppm) Vertical: 1.5 cm (+ 0.5 ppm) / ca. 2-5 cm (+ 0.5 ppm)
Data rate	Data rate of the RTK correction data:	1 Hz
Supported Products	Services: HxGN SmartNet | NRTK HxGN SmartNet | Pro HxGN SmartNet | +	Devices: Open to all GNSS devices Leica Geosystems GS Sensors Leica Geosystems GS Sensors
Country availability	According to Coverage Map	https://hxgnsmartnet.com/coverage-map

Note: Accuracies listed are at one-sigma.

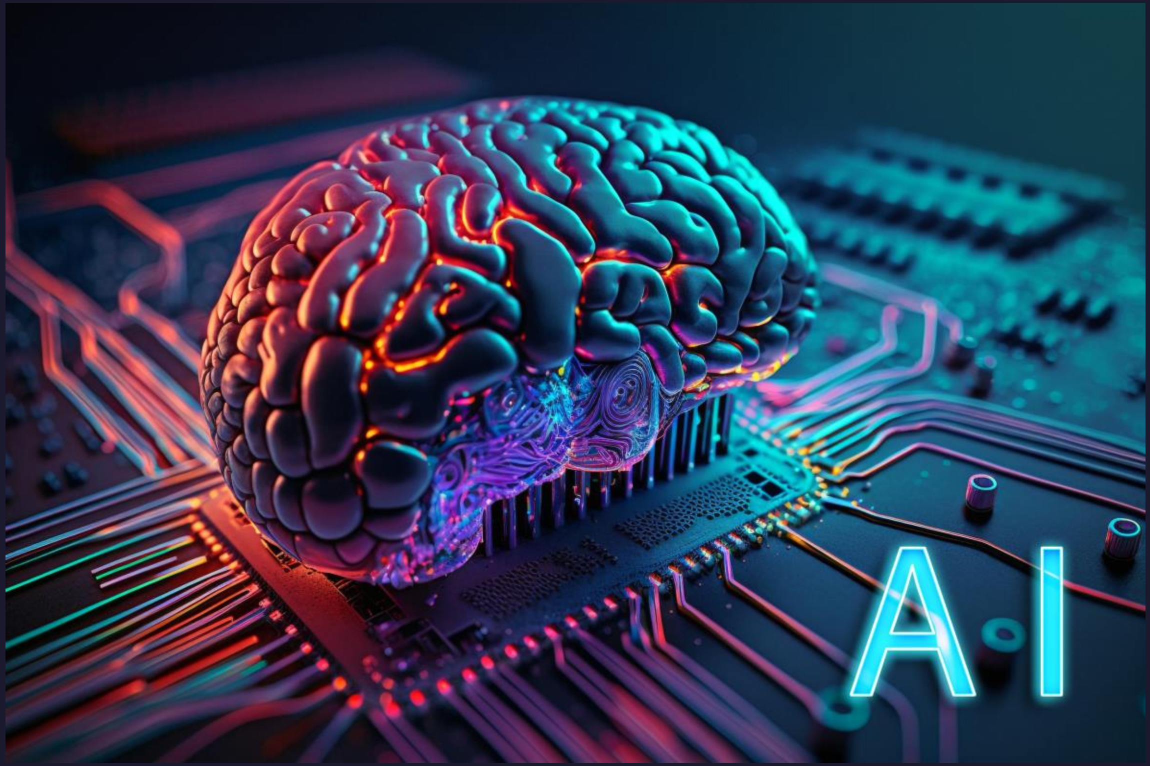
GNSS Scenario

- Trimble R980 in RTK mode.
  - 16 mm + 1.0 ppm
- HxGN SmartNet non-Leica receiver
  - 1-3 cm + 0.5 ppm
- Our raw positional error can be as high as 4.6cm or 0.150 feet before PPM.
- Minimal distance = 3,000 feet to ensure COMAR compliance.

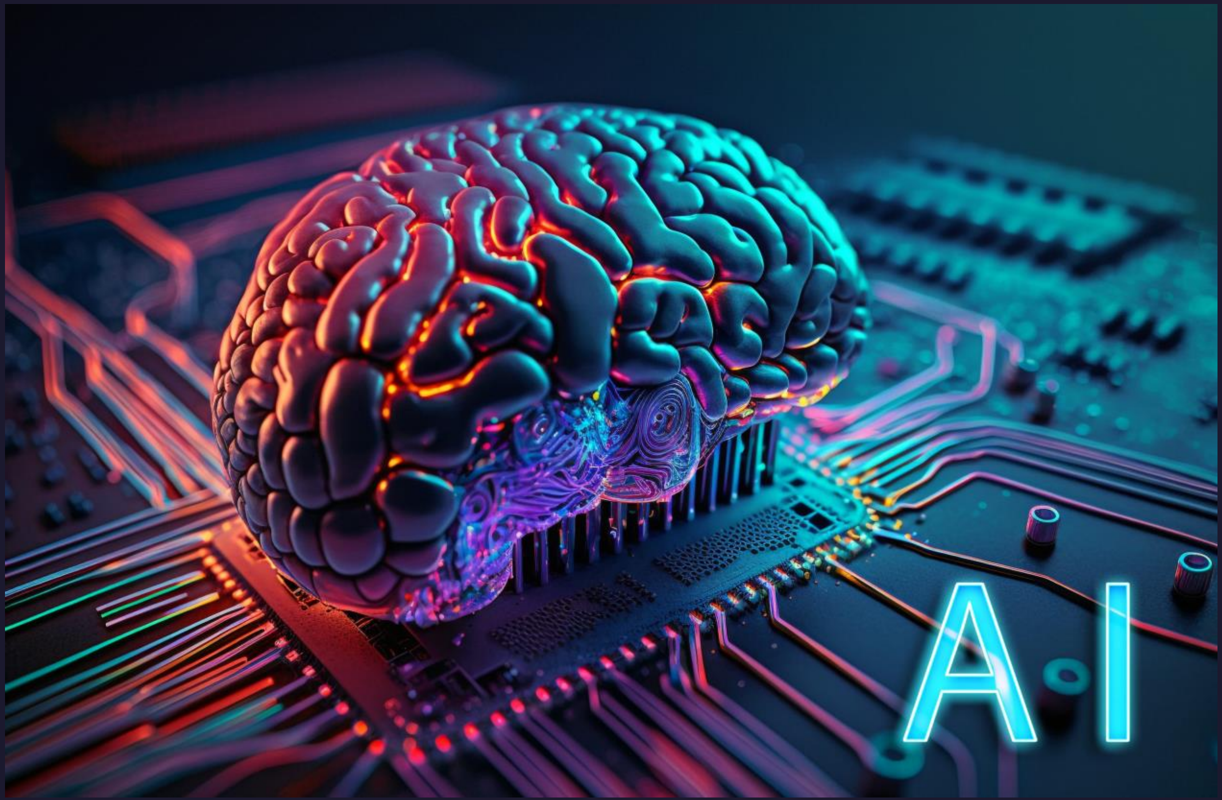


Let's Ask A.I.

- Q: What method is used to determine relative positional accuracy?
- A: Statistical analysis. This method uses a minimally constrained, correctly weighted least-squares adjustment to statistically analyze the collected survey data.



Let’s Ask A.I.



How it works:

- A surveyor collects more measurements than are strictly necessary (known as redundant measurements). This redundancy allows the least-squares adjustment to find the most probable values for the unknown coordinates while also quantifying the precision of those coordinates.

Result:

- This process produces an "error ellipse," which represents the positional uncertainty of a point relative to other points in the survey at a specified confidence level, such as 95%.

(Answer from Gemini, 10/2025)

Minimally Constrained Adjustment

- Minimize the number of knowns to the smallest amount.
- One known point and one fixed bearing is best.
- Review the amount of movement from known values.

Weighing the Observations

Not All Data is Created Equal

Sources of Uncertainty

- Precision of the Instrument
- Centering of the Instrument
- Centering of the Target
- Environment
- Maintenance

Blunders / Errors

- Misnaming the Point
- Incorrect Heights
- Off Center
- Incorrect Datum
- Site Calibrations
- Over-Constrained

Direct Measurements

- Direct measurements between two points are preferable to indirect measurements.
- Occupying boundary evidence has two primary benefits:
  - It provides direct measurements on the evidence when evaluating the positional tolerance.
  - It reduces the monuments in the ground that might cause confusion for future surveyors.

The most likely coordinates?

A least squares adjustment attempts to find the closest approximation of a truth that can never be known.

Thank You

James M. Shaw Jr., Prof.L.S.

jshaw@jmt.com

www.jmt.com