Topic 9. Introduction to Global Positioning Systems (GPS) and Other GNSS Technologies

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Outline

• Overview on GPS and GNSS
  – What is GPS?
  – What is GNSS?

• Basic Concepts of GPS and GNSS
  – Satellite Systems
  – System Components
  – How the system works?
  – GNSS Error Sources

• What you need to know about GNSS
  – Different Grades of GNSS Receivers
  – Signal Accuracies
  – Tricks of the Trade

• GNSS Equipment and Applications

Applications

– Equipment
– Applications
Expected Outcomes

• The students would be able to:
  – Discuss the basic principles of GPS and other GNSS technologies
  – Identify the different types of GPS/GNSS equipment
  – Identify how GPS/GNSS can be used in various applications, particularly in Remote Sensing Image Analysis
What is GPS?

• GPS – Global Positioning System
  – GPS refers to the constellation of navigation satellites associated with the American System (which is a global system).
  – For a long time, GPS was the ‘only game in town’, so everything (satellites, receivers, etc.) was referred to as “GPS”
  – Times are changing... other options (besides GPS) are quickly developing
What is GNSS?

- GNSS – Global Navigation Satellite System
- **GNSS** is an umbrella term that includes any satellite navigation system.
Satellite Systems

• Example of the GNSS Systems/Constellations:
  – GPS (United States)
  – GLONASS (Russia)
  – BeiDuo (China)
  – Galileo (European Union)
  – IRNSS (India)
  – QZSS (Japan)
System Components

- GPS (and GNSS) is a SYSTEM
- It has three major components:
  - Satellites
  - Ground Control Stations
  - Receivers
Satellites

- There are multiple constellations of GNSS satellites orbiting the earth.

- A constellation is simply an orderly grouping of satellites, typically 20-30, in orbits that have been designed to provide a desired coverage.
Satellites

- GNSS satellites orbit well above the atmosphere, about 20,000 km above the earth’s surface.
- They are moving very fast, several kilometres per second.
Ground Controls

- Control stations enable information on Earth to be transmitted to the satellites (updates and fine turning).

- Control stations continuously track satellites, and update the positions of each satellite.

- Without control stations, the accuracy of the system would degrade in a matter of days.
Receivers

- GPS units are referred to as “receivers”.
- They receive information (radio signals) from satellites.
- The GPS receiver knows how long it takes the signal to travel from the satellite to the receiver.
## Signals Received by GPS Receivers

<table>
<thead>
<tr>
<th>Band</th>
<th>Frequency (MHz)</th>
<th>Phase</th>
<th>Original usage</th>
<th>Modernized usage</th>
</tr>
</thead>
<tbody>
<tr>
<td>L1</td>
<td>1575.42</td>
<td>In-phase (I)</td>
<td>Encrypted precision P(Y) code</td>
<td>C/A, L1 Civilian (L1C), and Military (M) code</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Quadrature-phase (Q)</td>
<td>Coarse/acquisition (C/A) code</td>
<td></td>
</tr>
<tr>
<td>L2</td>
<td>1227.60</td>
<td>In-phase (I)</td>
<td>Encrypted precision P(Y) code</td>
<td>L2 Civilian (L2C) code and Military (M) code</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Quadrature-phase (Q)</td>
<td>Unmodulated carrier</td>
<td></td>
</tr>
<tr>
<td>L3</td>
<td>1381.05</td>
<td>Used by Nuclear Detonation (NUDET) Detection System Payload (NDS); signals nuclear detonations/high-energy infrared events. Used to enforce nuclear test ban treaties.</td>
<td>(No transmission)</td>
<td></td>
</tr>
<tr>
<td>L4</td>
<td>1379.913</td>
<td>(No transmission)</td>
<td>Being studied for additional ionospheric correction</td>
<td></td>
</tr>
<tr>
<td>L5</td>
<td>1176.45</td>
<td>In-phase (I)</td>
<td>Safety-of-Life (SoL) Data signal</td>
<td>Safety-of-Life (SoL) Pilot signal</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Quadrature-phase (Q)</td>
<td>(No transmission)</td>
<td></td>
</tr>
</tbody>
</table>
How the System Works?

1. Each satellite broadcasts radio signals with their location, statuses, and precise time information.

2. GPS radio signal travels at the speed of light (~300,000 km/h).

3. GPS device receives radio signals, noting their exact time of arrival and uses these to calculate its distance from each satellite it can see.

4. Once a GPS receiver knows its distance from at least 4 satellites, it uses geometry to determine its exact location on Earth in 3D.
How the System Works?

Illustration:

• A GPS receiver "locks on" to one satellite and calculates the range to be 12,000 miles.

• This fact helps narrow the receiver location down, but it only tells us that we are somewhere on a sphere which is centered on the satellite and has a 12,000 mile radius.

• Many of the locations on that sphere are not on earth, but out in space.
How the System Works?

One measurement narrows down our position to the surface of a sphere.
How the System Works?

Now, consider that the receiver picks up a signal from a second satellite and calculates the range between the receiver and the satellite to be 11,000 miles.

- That means we are also somewhere on a sphere with an 11,000 mile radius with the second satellite at the center.

- We must, therefore, be somewhere where these two spheres intersect. When the two spheres intersect, a circle is formed, so we must be somewhere on that circle.
How the System Works?

A second measurement narrows down our position to the intersection of two spheres

12,000 mile radius

11,000 mile radius
How the System Works?

If the receiver picks up another satellite, say at 11,5000 miles away, another sphere is formed, and there are only two points where the three spheres intersect.
How the System Works?

A third measurement narrows down our position to just two points.
How the System Works?

Usually the receiver can discard one of the last two points because it is nowhere near the earth.

So, we're left with one point which is the location of the GPS receiver.

But in practice, a fourth measurement is needed to correct for clock error.
How the System Works?
## GNSS Error Sources

<table>
<thead>
<tr>
<th>Contributing Source</th>
<th>Error Range</th>
</tr>
</thead>
<tbody>
<tr>
<td>Satellite Clocks</td>
<td>±2 m</td>
</tr>
<tr>
<td>Orbit Errors</td>
<td>±2.5 m</td>
</tr>
<tr>
<td>Ionospheric Delays</td>
<td>±5 m</td>
</tr>
<tr>
<td>Tropospheric Delays</td>
<td>±0.5 m</td>
</tr>
<tr>
<td>Receiver Noise</td>
<td>±0.3 m</td>
</tr>
<tr>
<td>Multipath</td>
<td>±1 m</td>
</tr>
</tbody>
</table>

- **Ionosphere**: is defined as the layer of the Earth's atmosphere that is ionized by solar and cosmic radiation. It lies 75-1000 km (46-621 miles) above the Earth.

- **Troposphere**: the lowest region of the atmosphere, extending from the earth's surface to a height of about 3.7–6.2 miles (6–10 km), which is the lower boundary of the stratosphere.
What do you need to know about GNSS?

Different “Grades” of GNSS receivers

- Recreational Grade GNSS
- Mapping Grade GNSS
- Survey Grade GNSS
Recreational Grade

- Recreational grade GPS receivers are sold at most box stores and at many sporting goods and camping stores.

- They are also available widely through Internet retailers.

- These units are the least expensive grade.

- Generally accurate to within +/- 10 m.

- These receivers are the type most often purchased by the general public.
Mapping Grade

- Mapping grade GPS receivers are generally sold by "high end" and licensed resellers.
- These GPS receivers are typically less user-friendly than the recreational GPS, and they cost significantly more.
- Mapping grade GPS are more accurate than recreational units
- Accuracy: commonly 1 to 2 meters.
- Mapping grade GPS receivers are most often used by government agencies, researchers, and other users who require more accurate and dependable coordinate fixes than a recreational GPS can provide.
Survey Grade

- Survey grade GNSS receivers are the most accurate and the most expensive.
- They are accurate to within a **centimeter or less** and can cost in the hundreds of thousands to millions of pesos.
- These receivers are most often used by professional surveyors and excel in high accuracy measurements of fixed positions.
Signal Accuracies

There are 2 types of GPS Signals:

**P-code:** ("Precise" code)
- This is only available to the military and some selected public officials.
- Very precise, not degraded.

**C-code:** ("Civilian" Code).
- Less precise
- Signal can be degraded (by scrambling the signal) especially in times of conflict.
- This is what the GARMIN receivers (and all public GPS receivers) work with.
Things to Consider when using GNSS Receivers

Averaging

- Averaging: A GNSS receiver can collect points continuously for 15-30 seconds or more. The receiver can then average all these locations together.
- This only works when you are standing still!!
- Note that not all GNSS receivers have an averaging capability.

Diagram:
- GNSS Collected Points
- GNSS Averaged Position
- “True” location
Things to Consider when using GNSS Receivers

**Satellite Distribution**

- It is better for your receiver to get a fix on “distributed” satellites, than poorly distributed satellites.

“Positional Dilution of Precision”

- Good Satellite Distribution
- Poor Satellite Distribution
Things to Consider when using GNSS Receivers

**MultiPath Errors**

- Try and stay away from buildings and other structures when using a GNSS receiver
- Satellites may not be visible...
- This can introduce error...
Things to Consider when using GNSS Receivers

**Tracking Satellites**

- GNSS has worldwide coverage...

**HOWEVER**...

- You can lose satellite coverage (or received degraded signals) in areas with dense foliage, in “urban canyons”, etc.
- You may also lose satellite coverage (or receive degraded signals) in deep valleys or gorges.
GNSS Equipment

- As illustrated, GNSS equipment consists of receivers, antennas and supporting software, in varying levels of integration and performance.
GNSS Equipment

- Depending on the application, the antenna and receiver may be separate entities, or they may be integrated into a single package, as in a handheld GNSS receiver.
- GNSS equipment may be further integrated with application equipment such as a survey or hydrographic instrumentation or a transport vessel.
Example: Integrating GNSS Equipment with Echosounder
GNSS Equipment: Considerations about Accuracy

• Applications such as survey may require centimetre-level accuracy.

• Others, such as positioning for hiking, may only require accuracy to within tens of metres.

• Some applications require absolute accuracy; that is, position defined accurately, relative to an actual reference point or location.

• Others may require accuracy relative to a previous position.

• If high-precision accuracy is obtained through the application of differential GNSS, it may be desirable that the differential service be integrated in the same package as the GNSS receiver.
GNSS Applications

- Some common applications
  - Consumer
  - Transportation
  - Precision Agriculture
  - Construction
  - Mining
  - Surveying
GNSS Applications

Consumer

• GNSS technology has been adopted by the consumer market, in an ever-increasing range of products.
• GNSS receivers are now routinely integrated into smartphones, to support applications that display maps showing the location of and best route to stores and restaurants.
• Portable navigation devices give drivers directions on road or off.
• Currently, most GNSS consumer products are based on GPS, but this will change as more GNSS constellations are implemented.
GNSS Applications

**Transportation**

- In rail transportation, GNSS is used in conjunction with other technologies, to track the location of locomotives and rail cars.
- In aviation, GNSS is being used for aircraft navigation from departure, en route, to landing.
- GNSS facilitates aircraft navigation in remote areas that are not well served by ground-based navigation aids, and it is a significant component of collision avoidance systems, and of systems used to improve approaches to airport runways.
- In marine transportation, GNSS is being used to accurately determine the position of ships when they are in open sea and also when they are maneuvering in congested ports.
- In surface transportation, vehicle location and in-vehicle navigation systems are now being used throughout the world.
GNSS Applications

Precision Agriculture

- In precision agriculture, GNSS-based applications are used to support farm planning, field mapping, soil sampling, tractor guidance, and crop assessment.

- GNSS applications can automatically guide farm implements along the contours of the earth in a manner that controls erosion and maximizes the effectiveness of irrigation systems.

- Farm machinery can be automatically operated at higher speeds, day and night, with increased accuracy. This increased accuracy saves time and fuel, and maximizes the efficiency of the operation.
GNSS Applications

Construction

• GNSS information can be used to position the cutting edge of a blade (on a bulldozer or grader, for example) or a bucket (excavator), and to compare this position against a 3D digital design to compute cut/fill amounts.

• Automatic systems for bulldozers/ graders use the cut/fill information to drive the hydraulic controls of the machine to automatically move the machine’s blade to grade.
GNSS Applications

Surface Mining

- GNSS information is being used to efficiently manage the mining of an ore body and the movement of waste material.
- GNSS equipment installed on shovels and haul trucks provides position information to a computer-controlled dispatch system to optimally route haul trucks to and from each shovel.
- Position information is also used to track each bucket of material extracted by the shovel, to ensure that it is routed to the appropriate location in the mine (crusher, waste dump, leach pad).
GNSS Applications

Surveying

• GNSS-based surveying reduces the amount of equipment and labour required to determine the position of points on the surface of the Earth, when compared with previous surveying techniques.

• Using GNSS, surveyors can now set up an RTK base station over an existing survey point and an RTK rover over the new point, then record the position measurement at the rover.

• This simplification shows why the surveying industry was one of the early civilian adopters of GNSS technology.
Basic Applications of GPS/GNSS in Remote Sensing Image Interpretation and Analysis

• Geometric correction of satellite images
• Image classification accuracy assessment
Basic Applications of GPS/GNSS in Remote Sensing Image Interpretation and Analysis

• **Geometric Correction of Satellite Images:**
  – Use of GPS/GNSS equipment to determine coordinates of Ground Control Points
  – Type of recommended equipment to use depends on the spatial resolution of image:
    • **Survey-grade Equipment** → for very high spatial resolution images (pixel size < 1 m)
    • **Mapping grade** → for medium resolution images (e.g., pixel size > 1 to <= 30 m; e.g., Landsat images)
    • **Recreational grade** → not usually recommended for use in GCP collection for geometric correction
**Image Classification Accuracy Assessment:**
- Use of GPS/GNSS equipment to determine coordinates of Ground Control Points and their actual land-cover types
- Type of recommended equipment to use depends on the spatial resolution of image:
  - **Survey-grade Equipment** → for very high spatial resolution images (pixel size < 1 m)
  - **Mapping grade** → for medium resolution images (e.g., pixel size > 1 to ≤ 30 m; e.g., Landsat images)
  - **Recreational grade** → can be used as long as the receiver’s accuracy is less than half the pixel size.
• Questions or clarifications?