GEO1003 - Shared Notes

Master Geomatics Students

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Introduction

This is the introduction to the notes.

Example

Introduction

The goal of this chapter is just to demonstrate how things should be organized. It will be removed from the notes in the end.

Markdown Basics

Resources and Helpers

A nice cheat sheet about Markdown can be found at this link: https://www.markdownguide.org/cheat-sheet/.

On VS Code, there are some nice extensions that can help you write Markdown files:

- Markdown All in One to provide useful shortcuts and commands
- markdownlint to properly format your Markdown files

Feel free to ask me if you have questions about Markdown.

Comments

```
This <!--This is a comment.--> is
<!--
Comments are not rendered.
They can take multiple lines
-->
a
sentence.
```

This is a sentence.

Headers

```
<!-- Comment the fist headers to avoid messing up the outline of this file -->
<!--
# Level 1

## Level 2

### Level 3
-->

#### Level 4

##### Level 5

###### Level 6
```

Level 4

Level 5 Level 6

Bold and Italic

```
- Normal text
- **Bold text**
- _Italic text_
- **_Bold and italic text_**
```

- Normal text
- **Bold text**
- *Italic text*
- ***Bold and italic text***

Lists

```
*Unordered list:*

- Unordered list item 1
- Unordered list item 2
  - Nested unordered list item

Ordered list:

1. Ordered list item 1
2. Ordered list item 2
   1. Nested ordered list item
```

Unordered list:

- Unordered list item 1
- Unordered list item 2
    - Nested unordered list item

Ordered list:

1. Ordered list item 1
2. Ordered list item 2
    1. Nested ordered list item

Links

```
[Example link](https://www.example.com)
```

Example link

Images

```
![Example image](../../../images/example.jpg){ width="250" }
```

Figure 1: Example image

Blockquotes

```
> This is a blockquote.
```

> This is a blockquote.

Code

```
Inline code: `print("Hello, World!")`

Code block:

```python
def hello_world():
    print("Hello, World!")
```
```

Inline code: `print("Hello, World!")`

Code block:

```python
def hello_world():
    print("Hello, World!")
```

Tables

```
Table: A simple table

| Header 1 | Header 2 |
| -------- | -------- |
| Cell 1   | Cell 2   |
| Cell 3   | Cell 4   |
```

Table 1: A simple table

Header 1	Header 2
Cell 1	Cell 2
Cell 3	Cell 4

Math

```
Inline math: $x^2$ is the square of $x$.

Block math:

$$
\int_0^\infty e^{-x^2} dx = \frac{\sqrt{\pi}}{2}
$$
```

Inline math: x^2 is the square of x.

Block math:

$$\int_0^\infty e^{-x^2} dx = \frac{\sqrt{\pi}}{2}$$

Empty Section

An other section that is empty.

How does GNSS work?

Introduction

GPS (Global Positioning System), also known as NAVSTAR (NAVigation Satellite Time And Ranging) had its first satellite launched in 1978.

GPS segments

The GPS system consists of *three segments*:

1. **Space segment** (satellites with atomic clocks)
2. **Control segment** (ground stations for clock offsets)
3. **User segment** (receivers)

Radio Signal

The GPS radio signal contains:

- the **L-band carrier frequency** between 1 and 2 GHz
- the **Pseudo Random Noise** (PRN, also called the **spreading code**), unique to each satellite, publicly available
- the **navigation message** containing the satellite orbit and clock information

Initialisation

When starting, GPS receivers try to find a particular GPS satellite on *each of their channels* (tens to hundreds). This is done by **overlaying the received signal** with a replica of the **spreading code** and then shifting it until correlation shows a maximum (best fit, or match).

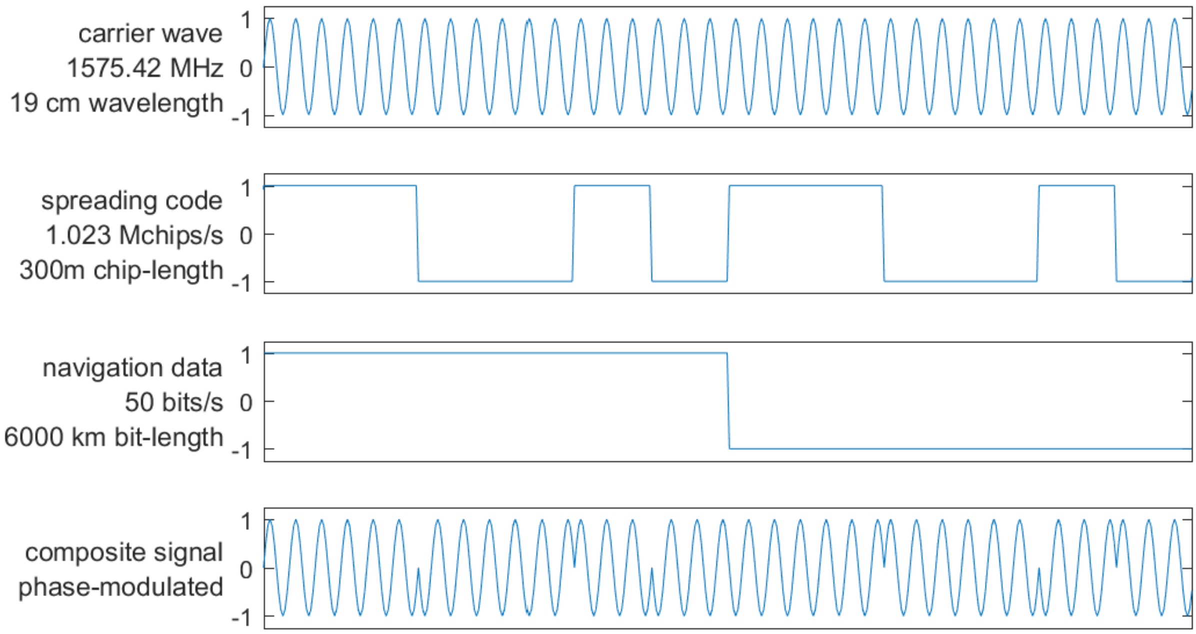

Figure 2: GPS L1 CA-signal (scale is not accurate)

Pseudorange Measurement

The **pseudorange** $p_{r,s}$ is calculated by multiplying the travel time $\tau_{r,s}$ by the speed of light c:

$$p_{r,s} = c \cdot \tau_{r,s} \text{ where } \tau_{r,s} = t_r - t_s$$

Carrier Phase Measurement

Carrier Phase Measurement:

- Measures **fractional phase difference** between the received *carrier wave* from the satellite and a locally generated *replica*.
- Provides a **very precise distance** measure (satellite to receiver)
- Needs to be **initialized** by finding the initial number of carrier wave cycles.
- Is much more precise than pseudorange code measurement. thanks to the **carrier period** being **much smaller** than code chip duration (in L1 CA-code signal, *1540 carrier periods* fit in one PRN spreading code chip).

Jamming and Spoofing

GPS Jamming

GPS Spoofing

GNSS performance

Introduction

Error Sources

Pseudorange Calculation

Multiple issues affect the calculation of the pseudorange:

- **satellite clock offset** (known).
- **receiver clock offset** (unknown).
- **ionosphere delay** (unknown).
- other errors, such as *multipath* (unknown).

The calculation is very sensible since $c \approx 3 \times 10^8$ m/s, and a **1 µs** error will cause a **300 m** error in the calculated distance.

Ionosphere Delay

Ionospheric delay:

- Is due to **free electrons** in the ionosphere.
- Is highly variable (depends on **time** and **space**).
- Ranges from *a few meters to hundreds of meters.*
- Is maximum near geomagnetic equator, around local noon and during solar maxima.
- Is proportional to 1/frequency^2.
- Can be estimated using two frequencies. This is why satellites emit at **L1** (1575.42 MHz) and **L2** (1227.60 MHz).

Accuracy and Precision

The quality of the measurement can be assessed through the carrier-to-noise-density ratio C/N_0 (signal strength).

The precision of the measurement depends on the method used:

Table 2: Precision of GNSS measurements

	Pseudorange	Carrier Phase
Precision	Few meters to few decimeters	Few centimeters to millimeter

Dilution of Precision

Availability, Continuity and Integrity

Availability

Continuity

Integrity

PPP-RTK

Abbreviations

- **SV**: space vehicles or orbiting space vehicles
- **RTK**: Real-Time Kinematic
- **PPP**: Precise Point Positioning
- **PPP-RTK**: Hybrid of PPP and RTK
- **CORS**: Continuously Operating Reference Station
- **NRTK**: Network RTK
- **OSR**: Observation State Representation
- **SSR**: State Space Representation

PPP

- **PPP** achieves decimetre-level or better accuracy by leveraging corrections transmitted via satellite or the internet.
- It utilises the **SSR** message format for efficient data transmission.
- **PPP** is suitable for global applications due to its independence from regional base stations.
- The primary limitation of **PPP** is its long convergence time, typically ranging from 5 to 30 minutes.
- **PPP** primarily corrects for orbit errors, clock errors, and biases to achieve its positioning solution.
- **PPP** offers a trade-off between accuracy and coverage, providing moderate accuracy over a wide area.
- Variations like PPP-AR and A-PPP exist, offering enhanced accuracy or specialized capabilities.

RTK

- **RTK** provides centimetre-level accuracy, achieving the highest precision among the discussed technologies.
- **RTK** relies on the **OSR** message format, which requires a two-way communication channel between the base station and the rover.
- The coverage area of **RTK** is limited to a short range (30-50 km) due to signal degradation with distance.
- **RTK** boasts a near-instantaneous convergence time, typically under 5 seconds.

- **RTK** corrects for various errors, including orbit errors, clock errors, bias, ionospheric delay, and tropospheric delay.
- **RTK** is widely adopted in applications demanding high accuracy within a limited area, such as surveying and agriculture.
- Developments like Network RTK (NRTK) address range limitations by incorporating networks of base stations.

PPP-RTK

- **PPP-RTK** combines the strengths of PPP and RTK, offering high accuracy, global coverage, and fast convergence.
- **PPP-RTK** achieves centimetre-level accuracy comparable to RTK while offering global coverage.
- **PPP-RTK** employs the efficient **SSR** message format, enabling broadcast corrections and lower bandwidth requirements.
- **PPP-RTK** utilises a network of CORS stations for precise atmospheric and clock corrections.
- **PPP-RTK** converges significantly faster than PPP, typically within 1-10 minutes, and potentially seconds under ideal conditions.
- It effectively corrects for orbit errors, clock errors, bias, ionospheric delay, and tropospheric delay, allowing for integer ambiguity resolution.
- **PPP-RTK** gracefully degrades to standard PPP performance when outside the range of the CORS network.

Comparing RTK, PPP, and PPP-RTK

Feature	RTK	PPP	PPP-RTK
Accuracy	**cm-level** (up to 1 cm + 1 ppm)	**dm-level or better** (less than 10 cm)	**cm-level**, similar to RTK
Coverage Area	**Limited range** (typically 30-50 km from the base station)	**Global**	**Global** with graceful degradation to standard PPP outside the range of the CORS network
Message Format	**OSR** (Observation Space Representation)	**SSR** (State Space Representation)	**SSR** (State Space Representation)
Transmission Channel	**Two-way communication** between base station and rover	Corrections delivered via **satellite or the internet**	Corrections **broadcast to users**, enabling a large number of users to connect simultaneously
Convergence Time	**Near instantaneous** (typically less than 5 seconds)	**Relatively long** (typically 5-30 minutes)	**Fast** (typically 1-10 minutes, potentially within seconds under ideal conditions)

Feature	RTK	PPP	PPP-RTK
Errors Solved	Orbit errors, clock errors, bias, **ionospheric delay, tropospheric delay**	Orbit errors, clock errors, bias	Orbit errors, clock errors, bias, **ionospheric delay, tropospheric delay**, enabling **integer ambiguity resolution**
Key Strengths	High accuracy, very fast convergence time	Global coverage, no reliance on local base stations	High accuracy, fast convergence time, global coverage, lower bandwidth requirements compared to RTK, graceful degradation outside CORS range
Key Limitations	Limited range, high bandwidth requirements, reliance on local base stations	Long convergence time, lower accuracy compared to RTK	Still requires a CORS network (though less dense than RTK) and may degrade to standard PPP with increasing distance from CORS station

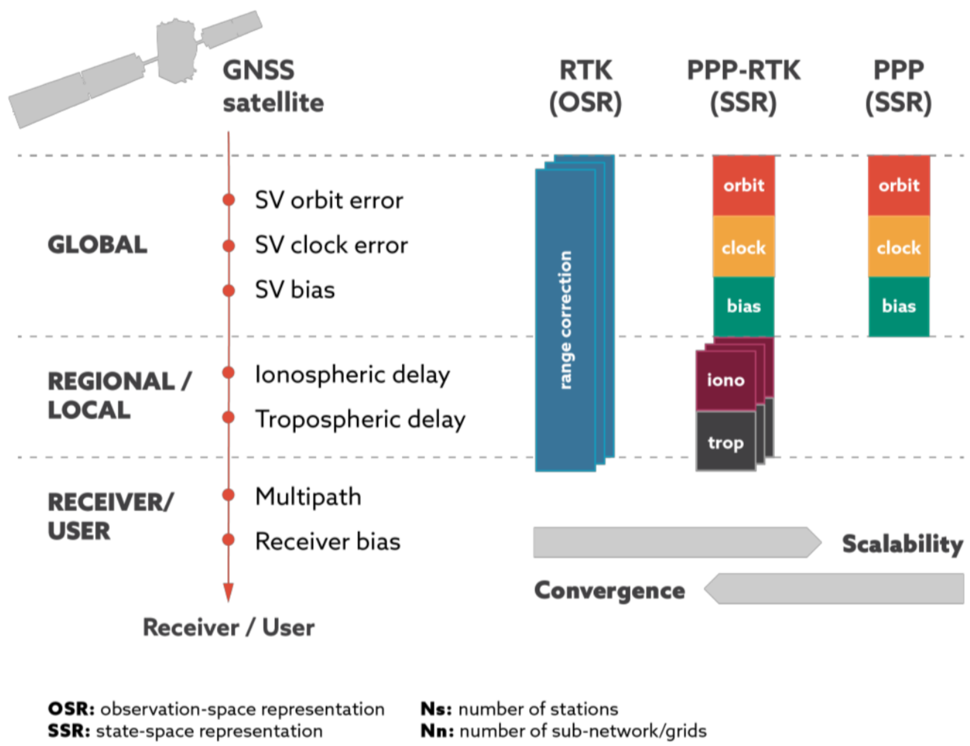

Figure 3: difference in message format and resolved errors

DGNSS

GNSS in the built environment (outdoor, indoor and in between)

Introduction

Multipath

Urban Canyon

Shadow Matching

CRS

Introduction

Coordinate Systems

Ellipsoids

Geocentric Coordinate Systems

Topocentric Coordinate Systems

Coordinate Reference Systems (CRS)

Terrestrial Reference Systems and Frames

Terrestrial Reference Systems

ITRS

ETRS

Terrestrial Reference Frames

ITRF

ETRF

Datum and Transformations

Datums

Transformations

Conversions

Map Projection

RDNAP

Rijksdriehoeksmeting (RD)

Normaal Amsterdams Peil (NAP)

Wi-Fi-monitoring / Fingerprinting

Introduction

Wi-Fi-Based Approaches

Wi-Fi Monitoring

Wi-Fi Fingerprinting

Radio Signal Based Techniques

Received Signal Strength (RSS)

Time of Arrival (ToA)

Time Difference of Arrival (TDoA)

Angle of Arrival (AOA)

Path-Loss

Fine Timing Measurement (FTM)

Radio Frequency Identification (RFID)

Hybrid and Other Techniques

Trilateration

Inertial Navigation Systems (INS)

Visual Based Indoor Localisation

Isovists