GEO1003 - Shared Notes

Master Geomatics Students

2024-12-07

Contents

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" }
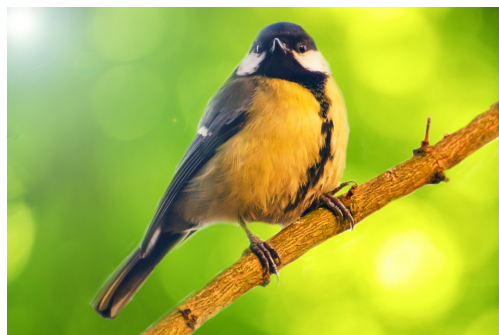
Figure 1: Example image

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

This section gives more information about the empty section.

How does GNSS work?

Introduction

The Global Positioning System (**GPS**), also known as the NAVigation Satellite Time And Ranging (**NAVSTAR**) system had its first satellite launched back in February 1978. GPS is a *one-way* radio ranging system which provides realtime knowledge of one's Position and Velocity, and a very accurate Time reference as well (all together referred to as **PVT**).

GPS segments

The GPS system consists of three segments:

1. The **space segment**, consisting of 24 or more satellites, with accurate atomic clocks on board, continuously transmitting ranging signals to Earth.
2. The **control segment**, consisting of a number of ground stations, which monitors the satellites, computes their orbits and clock offsets, and uploads this information to the satellites, which in turn encode this information on the ranging signal (the so-called navigation data).
3. The **user segment**, simply consisting of many GPS receivers, which each track four or more GPS satellites, and compute their own position.

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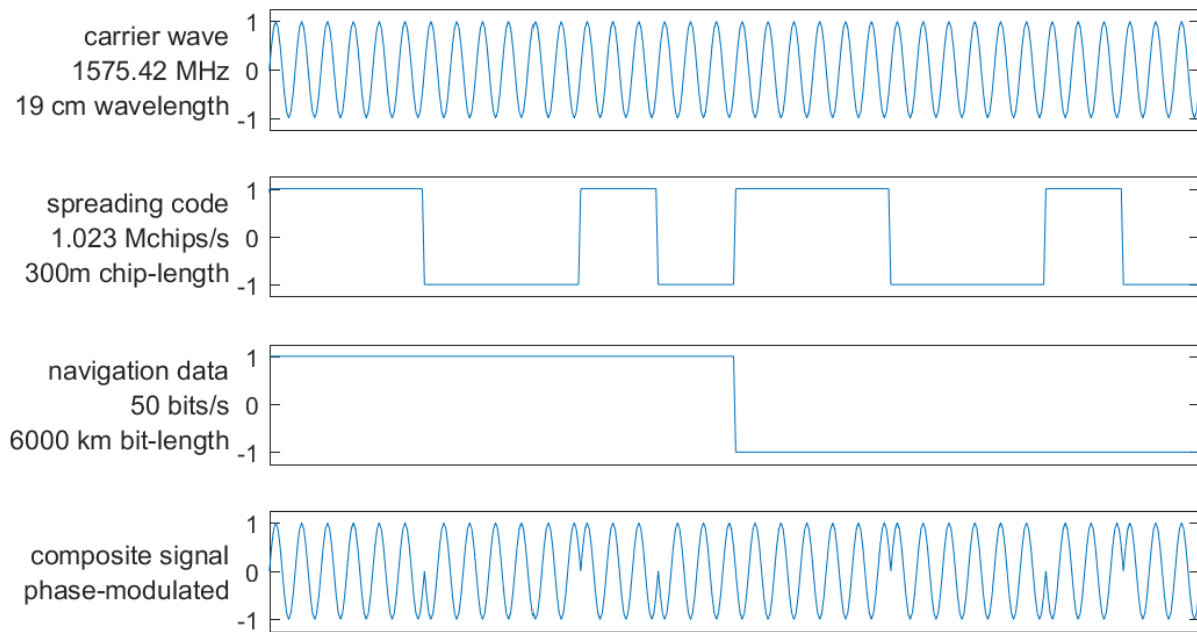
Figure 2: GPS L1 CA-signal (scale is not accurate)

Initialisation

A GPS receiver typically consists of tens to hundreds of so-called **channels**, and will allocate each of these to a specific GPS (GNSS) satellite. When a GPS receiver first starts up, it will begin to *search for a particular GPS satellite on each of its channels*, by trying to scan for the corresponding **spreading codes** at different *Doppler offsets* and *time delays*. This is done by overlaying the received signal with a *local copy or replica of the same code* and then (time) shifting it until correlation shows a maximum (best fit, or match).

Pseudorange Measurement

Once the receiver is locked on to a satellite's spreading code, it will continue to track it by *continuously adjusting the time delay and Doppler offset* to keep the correlation at a maximum. The time delay is then used to calculate the **pseudorange** $p_{r,s}$ to the satellite, which is (theoretically) the travel time $\tau_{r,s}$ multiplied by the speed of light c:

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

See Error Sources for more information on the errors in the pseudorange measurement.

Carrier Phase Measurement

A GPS receiver may measure the **fractional phase difference** between the received *carrier wave* from the satellite and a locally generated copy (replica). The carrier wave measurement is a **very precise measure** of the distance between the satellite and the receiver, but the initial number of carrier wave cycles is *unknown*, and needs to be estimated before the carrier phase measurements can be effectively used.

The much better precision of the carrier phase measurement with respect to the pseudorange code measurement can be explained by **much smaller period** of the carrier compared to the code chip duration (for the L1 CAcode signal, 1540 periods of the carrier fit in one chip of the Pseudo Random Noise (PRN) spreading code).

Jamming and Spoofing

GPS Jamming

GPS Spoofing

GNSS performance

Introduction

Error Sources

There are a few issues with this calculation:

- the **satellite clock** has an **offset**, which is *known* (part of the navigation message)
- the **receiver clock** has an **offset**, which is *unknown*
- the **ionosphere** causes a delay (due to a lower speed of light), which is *unknown*
- there might be other errors, such as multipath, which are unknown

Any of these issues will cause the calculated pseudorange to be **inaccurate**. 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

One of the *major error sources* in GPS is due to the **ionosphere**, which contains *free electrons* that cause the speed of light to be lower than in vacuum.

The ionospheric delay may be **highly variable**, as a function of both **time** and **space**. In terms of distance ranging, it can go from *a few meter to hundreds of meters*, and is maximum round the geomagnetic equator around local noon, and during solar maxima.

The ionosphere delay scales, to a very good approximation, with the **inverse of the square of the radio frequency** of the signal, so using two different frequencies allows to create the so-called *ionosphere-free range measurements*. This is why GPS satellites were originally designed to transmit ranging signals on both the **L1** (1575.42 MHz) and **L2** (1227.60 MHz) frequency.

Accuracy and Precision

The receiver can measure the received **signal strength**, through the so-called carrier-to-noise-density ratio C/N_0, which gives an indication of the **quality of the measurement** (larger signal strength yields more precise measurement).

The **pseudorange measurement** precision is typically at the *one or few meter* level for low-cost, mass-market equipment, and can get down to the *few decimeter level* for professional highend equipment.

The **carrier phase measurement** precision ranges from the *few centimeter to the millimeter level*. The carrier phase is an ambiguous measurement of distance, but it is more precise than the pseudorange, typically by **two orders of magnitude**.

Dilution of Precision

Availability, Continuity and Integrity

Availability

Continuity

Integrity

PPP-RTK

PPP

RTK

DGNSS

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

Introduction

Multipath

Urban Canyon

Shadow Matching

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