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:

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

Definition Blocks

```
**Lorem ipsum dolor sit amet**
:   Sed sagittis eleifend rutrum. Donec vitae suscipit est. Nullam tempus
    tellus non sem sollicitudin, quis rutrum leo facilisis.

**Cras arcu libero**
:   Aliquam metus eros, pretium sed nulla venenatis, faucibus auctor ex. Proin
    ut eros sed sapien ullamcorper consequat. Nunc ligula ante.
```

Lorem ipsum dolor sit amet Sed sagittis eleifend rutrum. Donec vitae suscipit est. Nullam tempus tellus non sem sollicitudin, quis rutrum leo facilisis.

Cras arcu libero Aliquam metus eros, pretium sed nulla venenatis, faucibus auctor ex. Proin ut eros sed sapien ullamcorper consequat. Nunc ligula ante.

Definition Blocks + Lists

```
- **Lorem ipsum dolor sit amet**
  :   Sed sagittis eleifend rutrum. Donec vitae suscipit est. Nullam tempus
      tellus non sem sollicitudin, quis rutrum leo facilisis.

- **Cras arcu libero**
  :   Aliquam metus eros, pretium sed nulla venenatis, faucibus auctor ex. Proin
      ut eros sed sapien ullamcorper consequat. Nunc ligula ante.
```

- **Lorem ipsum dolor sit amet** Sed sagittis eleifend rutrum. Donec vitae suscipit est. Nullam tempus tellus non sem sollicitudin, quis rutrum leo facilisis.
- **Cras arcu libero** Aliquam metus eros, pretium sed nulla venenatis, faucibus auctor ex. Proin ut eros sed sapien ullamcorper consequat. Nunc ligula ante.

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

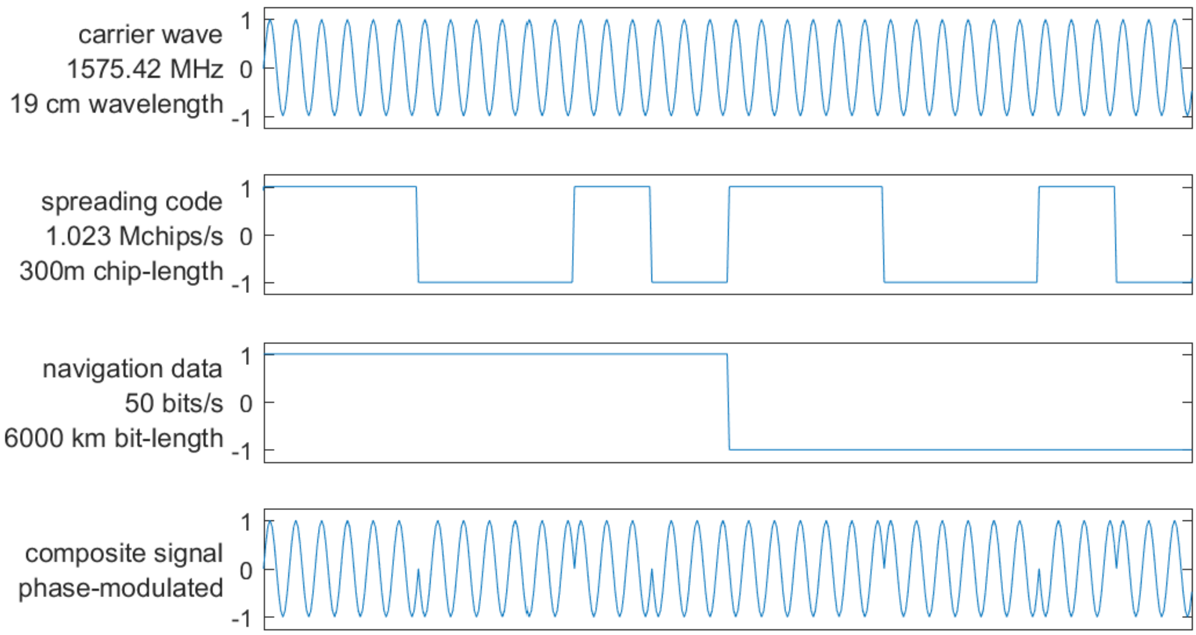

Figure 2: GPS L1 CA-signal (scale is not accurate)

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).

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

There are multiple mays a GNSS signal may be threatened, jamming and spoofing being intentional attacks.

Jamming

By the time GNSS signals arrive at the antennas of a GNSS positioning system, the power level of these signals is very low. This low power level makes the signals susceptible to interference from other signals transmitted in the GNSS frequency range.

Jamming is a special case of signal interference where an attacker tries to block the incoming GNSS signal to a specific person/area.

GNSS receivers can use several methods to protect against interference and jamming:

- Signal filtering
- Multiple navigation sensors. For short-term interference, other sensors can help the receiver bridge brief periods of GNSS outage.
- Multi-frequency/multi-constellation GNSS makes it much harder to jam a signal on multiple different frequencies at once.
- Anti-jam antennas use multiple antenna elements to control the amount of signal received from a particular direction. When an anti-jam system senses interference from a direction, it turns down the antenna gain for it.

Spoofing

Unlike interference where GNSS is denied by overpowering the satellite signal, spoofing tricks the receiver into reporting an incorrect position. Spoofing is done by first jamming the GNSS receiver and then providing a false satellite signal that is either created by a signal generator or is a rebroadcast of a pre-recorded GNSS signal. Unlike interference, spoofing is always an intentional attack.

To protect against spoofing the same methods apply as against interference. Additionally, one of the most effective ways to protect against spoofing is to track encrypted signals that are broadcast by several of the GNSS constellations. Access to the encrypted signals is restricted and not available to all users.

Signal blockage

The GNSS signal can be blocked by many objects like trees or buildings, especially in urban areas. The main protection is again using multiple constellations and using additional sensors like an IMU.

Constellation failure

Although it is extremely unlikely that an entire constellation will fail, receivers that can track more than one constellation protect against this unlikely scenario.

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)
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

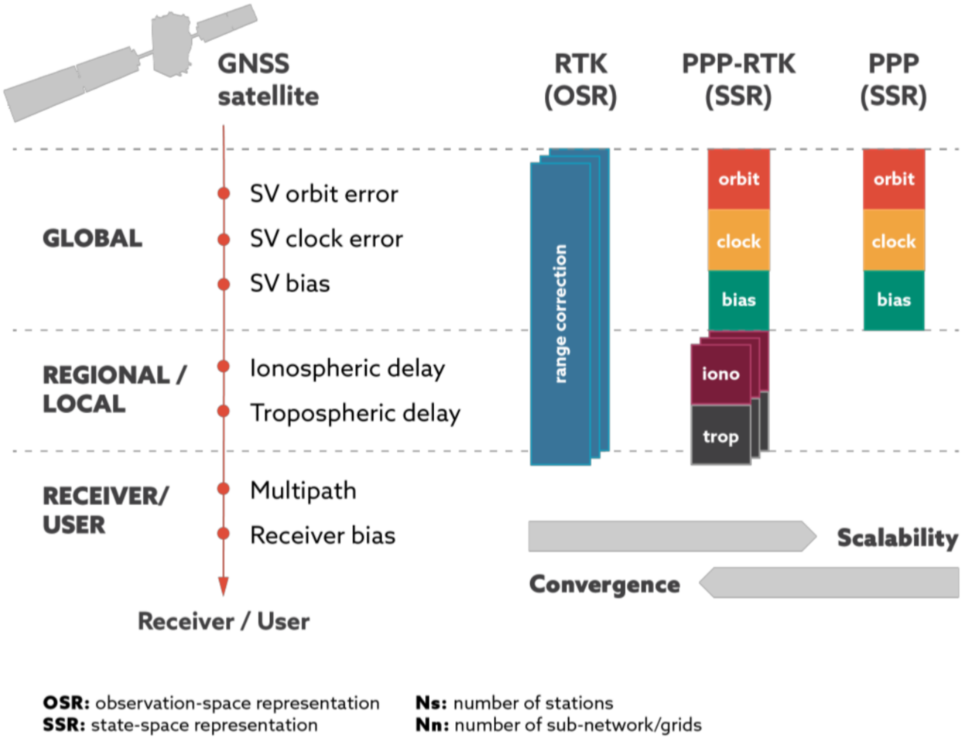

Figure 3: difference in message format and resolved errors

DGNSS

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

Introduction

Multipath

Urban Canyon

Shadow Matching

CRS

Introduction

Coordinate Systems

Coordinate Reference Systems

Geographic Coordinate Reference Systems

Projected Coordinate Reference Systems

Linear Reference Systems

Terrestrial Reference Systems and Frames

Datum and Transformations

Transformations and conversions

Datums

Map Projections

RDNAP

Coordinate Systems

Official 3D coordinate system of the Netherlands and Europe: European Terrestrial Reference System 1989 (ETRS89). ETRS89 is linked to the International Terrestrial Reference System (ITRS) by a time-dependant coordinate transformation.
National coordinate systems in Europe are linked to ETRS89.

Rijksdriehoeksmeting (RD) Coordinates in the Dutch Stelsel van de Rijksdriehoeksmeting (RD) are the most-frequently used 2D coordinates on land and internal waters. RD coordinates are defined by the official transformation from ETRS89 coordinates. Maintaining reference points for ETRS89 and the transformation to RD coordinates are legal responsibilities of Kadaster.

Normaal Amsterdams Peil (NAP) Heights relative to Normaal Amsterdams Peil (NAP) are the official and the most-frequently used heights on land and internal waters. The NAP is a legal responsibility of Rijkswaterstaat Ellipsoidal heights in ETRS89 can be transformed with the quasi-geoid model to NAP with a precision higher than ETRS89 coordinates obtained with most GNSS measurements.

Coordinate transformation RDNAPTRANS™

The official coordinate transformation between European ETRS89 coordinates and Dutch coordinates in RD and NAP is called RDNAPTRANS™

The recommended ETRS89 realisation is ETRF2000 at epoch 2010.50 (AGRS2010). When using RDNAPTRANS™2018 it is important to use this realisation and epoch, especially for the height. For applications demanding high accuracy, it is recommended to obtain the NAP height of the point of interest by levelling to nearby NAP benchmarks.

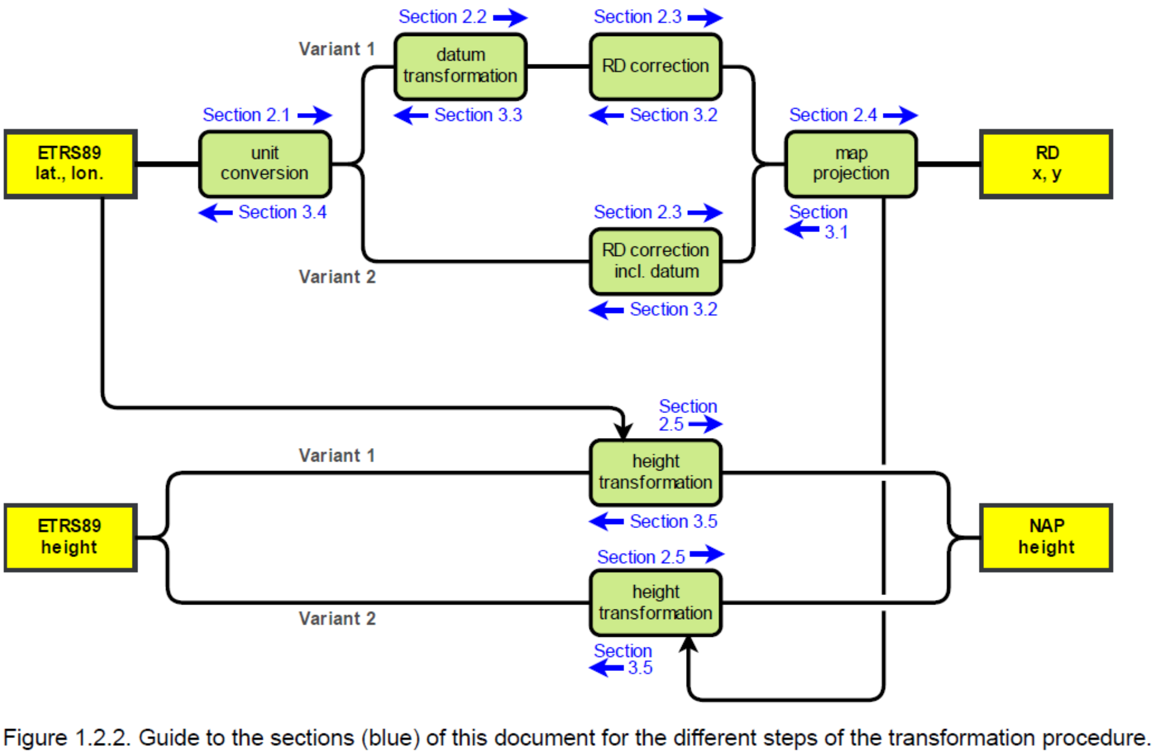

Figure 4: Figure 1.2.2

There are two variants for the implementation of the horizontal component of RDNAPTRANS™2018 and two variants for the vertical component (Figure 1.2.2).

Implementation variant 1 applies the datum transformation as a separate step using a 3D similarity transformation.
The advantage of implementation variant 1 is that it has no strict bounds for the area where horizontal coordinates can be transformed correctly. The disadvantage is that many software packages do not support implementation variant 1 for the horizontal component.

Implementation variant 2 includes the datum transformation in the correction grid and uses a different quasi-geoid grid for the height transformation. Implementation variant 2 for the horizontal component is supported by more software but can only be used within the bounds of the correction grid (Figure 1.1.1). The difference in the resulting coordinates between the two variants is well below 0.0010 m within the bounds of the RDNAPTRANS™2018 grids.

Transformation from ETRS89 to RD and NAP: Steps

1. Datum transformation

   1.1 Conversion to geocentric Cartesian coordinates. Variant 1, The ellipsoidal geographic ETRS89 coordinates of a point of interest must be converted to geocentric Cartesian ETRS89 coordinates to be able to apply a 3D similarity transformation. Variant 2, the datum transformation is included in the correction grid.

   1.2 3D similarity transformation

   1.3 Conversion from geocentric Cartesian coordinates back to ellipsoidal geographic Bessel coordinates (Formula 2.2.3).

2. RD correction

   2.1 Bilinear correction grid interpolation to obtain real Bessel coordinates.

   2.2 To transform the point of interest, Determine nearest grid points

   2.3 Iterative correction of the point of interest from pseudo Bessel coordinates to real Bessel coordinates,

   2.4 Datum transformation in the correction grid

3. Map projection

   3.1 Projection from ellipsoid to sphere (Gauss conformal projection from the ellipsoid to a sphere)

   3.2 Projection from sphere to plane

4. Height transformation

   4.1 Bilinear quasi-geoid grid interpolation

   4.2 Transformation to NAP

Transformation from RD and NAP to ETRS89: Steps

1. Inverse map projection

    1.1 Projection from plane to sphere

    1.2 Projection from sphere to ellipsoid

2. RD correction

    2.1 Direct correction

    2.2 Datum transformation in the correction grid

3. Datum transformation

    3.1 Variant 1, transformation from ellipsoidal geographic Bessel coordinates of a point of interest to ellipsoidal geographic ETRS89 coordinates. Variant 2 the datum transformation is included in the correction grid

    3.2 the ellipsoidal geographic Bessel coordinates of a point of interest must be converted to geocentric Cartesian Bessel coordinates

    3.3 The 3D similarity transformation must be applied to the geocentric Cartesian Bessel coordinates of the point of interest to obtain geocentric Cartesian ETRS89 coordinates.

    3.4 The geocentric Cartesian ETRS89 coordinates of the point of interest must be converted back to ellipsoidal geographic ETRS89 coordinates. The latitude is computed iteratively.

4. Conversion of radians or decimal degrees to decimal degrees

5. Height transformation: the physical NAP height of a point of interest to the purely geometrical ellipsoidal ETRS89 height, based on the quasi-geoid model NL-GEO2018. The NAP height of the point of interest must be transformed to ellipsoidal ETRS89 height (Formula 3.5) using the interpolated quasi-geoid height of the point of interest.

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

Performance Metrics

Position

Location

Yield

Consistency

Overhead

Latency

Power Consumption