Global Navigation Satellite System

Lecture 21

- Principles of EM Waves based Navigation
- GNSS Systems
- GNSS RTK

Basic Principle of Radio Navigation

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- Given a radio beacon (radio transmitter) on a fixed location,
- And a radio antenna receiver on a mobile unit,
- If the antenna is within the range of the beacon then it can detect the direction from itself and to the beacon (via maximum gain principle).
- If signal timing is introduced, then the antenna can also determine the distance (radius) to the beacon. For signal timing, we need also synchronized clocks on the beacon transmitter and the receiver antenna.

Basic Principle of Radio Navigation
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- Consider we have the signal travel time t_i from beacon tower T_i with known location (x_i, y_i, z_i) to antenna A with unknown location (x_0, y_0, z_0).
- The speed of electromagnetic waves is c, thus the distance from A to T_i is $d_i = c t_i$.
- We know this: $(x_i - x_0)^2 + (y_i - y_0)^2 + (z_i - z_0)^2 = d_i^2$
- Furthermore, we need to consider the synchronization error δt between the antenna clock and the towers T_i (considered ideally synchronized among themselves). Thus: $(x_i - x_0)^2 + (y_i - y_0)^2 + (z_i - z_0)^2 = \left(c(t_i + \delta t)\right)^2$;
- With 4 towers we can get the location of the antenna A (we can also get the location with only 3 towers if we ignore the clock variable δt, but the resulting error will be bigger).

Basic Principle of Radio Navigation

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To better grasp the time/distance relationship, it is notes that 1 ns represents approximately 30 cm while 3.3 ns represents approximately 1 m.

GNSS Systems

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- A GNSS system's towers are satellites in medium orbit around earth (around 20000 km). They are constantly moving but their position and in general time-parameterized orbit are precisely known (they broadcast it).
- A GNSS system's signals are more advanced than just a becon pulse signal. They consist of a carrier frequency, and include digital information.
- The receiver antennas have both analog and digital signal processing capabilities, as well as software for performing the localization algorithms.

GNSS Systems

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- GPS system
- GLONASS system
- Galileo
- BeiDou system
- local coverage systems, and local augmentation systems

A GNSS receiver can take advantage of all available satellites, cross-constellations. Line-of-sight is the only physical constraint (and therefore no GNSS in building, underground, underwater).

The GNSS Signal

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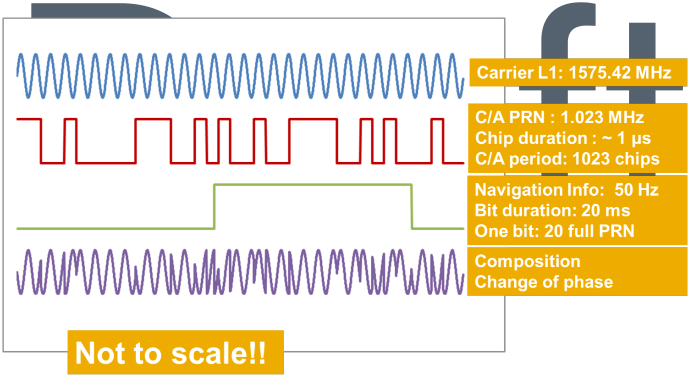

Source https://gssc.esa.int/navipedia/index.php/GNSS_signal.

The GPS Signal

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- Ontop of the carrier frequency, the Ranging -or- PRN -or- C/A (coarse-acquisition) code is modulated (not Amplitude and not Frequency, but BPSK - phase modulation). The PRN code is a sequences of 0s and 1s (zeroes and ones), which allow the receiver to determine the travel time of radio signal from satellite to receiver (but aligning and finding the beginning of the PRN sequence).
- The navigation message is modulated onto the ranging code, and contains:
  - The date and time and the satellite's status;
  - The ephemeris, precise orbital information for the transmitting satellite;
  - The almanac, status and low-resolution orbital information for every satellite in the constellation

Pseudorange Measurement

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The range measurement contains other errors besides the δt clock-synchronization. A more complete description is:

$$\tilde{d}_i = d_i + c(\delta t_{\text{rec}} - \delta t_{\text{sat}}) + T + I + K_{\text{rec}} - K_{\text{sat}} + M + \epsilon;$$

- $\delta t_{\text{rec}}, \delta t_{\text{sat}}$ are the clock synchronization errors (both of the receiver and of the satellite wrt to the GNSS reference clock);
- T and I are the troposphere and ionospheric respectively delays (caused by variation of the speed of light in the earth's atmosphere compared with vacuum);
- K_{rec} and K_{sat} are instrumental delays from the receiver and satellite respectively electronic equipment;
- is the multipath error due to the signal being received not on a direct line-of-sight, but on a path including reflections on various surfaces, usually in the immediate vicinity of the receiver;
- ϵ is the receiver noise.

GNSS Systems

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- In free/commercial configuration the GNSS accuracy of localization is average of meters (one of the reasons is S/A code limitation because of low frequency, military ranging codes of higher frequency offer more accuracy);
- Different techniques can be used to obtain centimeter accuracy ontop of the commerical signals, for example PPP (precise point precision) and RTK (real time kinematics).

GNSS RTK

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- RTK is short for real time kinematics.
- A GPS receiver capable of RTK takes in the normal signals from the GNSS along with a correction stream to achieve centimeter positional accuracy. Output of accurate positions at [illegible]0 Hz is standard.
- The correction data comes from an internet connection (via NTRIP - Networked Transport of RTCM via Internet Protocol) or a long distance radio capable of approximately 500 bytes per second. Usually is a paid service.
- Ideally, with RTK, the receiver can get centimeter accuracy with sub-milimeter precision.

Principle of RTK
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- RTK uses a fixed base stations, whose positions are accurately determined (at centimeter level).
- The base station has itself a GNSS receiver, receives GNSS signals and data, and approximates errors in this GNSS data based on its known, accurate location.
- An RTK service then disseminates these errors/corrections, which are relevant for all other receivers in its vicinity of the a base states (say up to 10, 20 km).
- This allows the “on-the-field”/mobile receivers to calculate their base-station relative position to within millimeters, although their absolute position is accurate only to the same accuracy as the computed position of the base station.

NMEA
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NMEA is a widely used format for the output of a GNSS receiver. This is an output example. Let's read it.

```
$GPGGA,181908.00,3404.7041778,N,07044.3966270,W,4,13,1.00,495.144,M,29.200,M,0.10,0000*40
```

https://www.gpsworld.com/what-exactly-is-gps-nmea-data

NMEA
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The broadcast communication from an RTK base station is structured in RTCM3 messages:

https://www.use-snip.com/kb/knowledge-base/rtcm-3-message-list/

Well done so far!