Outdoor Positioning

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Outdoor Positioning

Today:

1. History of Positioning
2. Positioning Fundamentals
3. GPS – Global Positioning System
   – System architecture
   – Positioning via GPS
4. Galileo
   – System architecture
   – Enhancements and new services
5. Other Global Navigation Satellite Systems (GNSS)
1. History of Positioning I

- **Magnetic Compass** (<5th Century in China, then 13th Century in Europe)
- **Octant**, then **Sextant** (18th Century): measurement of height of objects (sun, stars) above horizon, maximum height gives **latitude**
- **Chronometer** (maritime clock) with +/- 1s stability per day (Harrison, 1761), important for **longitude** determination
  - 1 second error means a 450 m longitude error at the equator (caused by the rotation of the earth)
- With **Sextant/Octant** best position accuracy is 1 NM
1. History of Positioning II

- In 1714, following many maritime accidents (including more than 1500 vanished sailors with the loss of the fleet of admiral Clowdisley Shovell in 1707), the British government settled the **longitude act** to offer a 20,000 pounds reward (more than today’s 10 millions €) for a method to determine the longitude.

- **Expected accuracy (drift):**
  - Maximum error: **0,5 degrees**
  - 0,5 degrees = **30 nautical miles** at the equator
    = motion during 2 minutes of earth rotation
    = 3 seconds per day during 40 days
  (40 days = a 6 week journey from England to the West Indies)
1. History of Positioning III

- John Harrison (1693 – 1776)
- Drift on H4 clock: 39.2 seconds after 47 days (4 times better than what was requested)
2. Positioning Fundamentals – Components

- Positioning is determined by
  - one or several parameters observed by measurement methods
  - a positioning method for position calculation
  - a descriptive or spatial reference system
  - an infrastructure
  - protocols and messages for coordinating positioning

<table>
<thead>
<tr>
<th>Positioning method</th>
<th>Observable</th>
<th>Measured by</th>
</tr>
</thead>
<tbody>
<tr>
<td>Proximity sensing</td>
<td>Cell-ID, coordinates, RSS</td>
<td>Sensing for pilot signals</td>
</tr>
<tr>
<td>Lateration</td>
<td>Range or</td>
<td>Traveling time of pilot signals</td>
</tr>
<tr>
<td></td>
<td>Range difference</td>
<td>Path loss of pilot signals</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Traveling time difference of pilot signals</td>
</tr>
<tr>
<td>Angulation</td>
<td>Angle</td>
<td>Antenna arrays</td>
</tr>
<tr>
<td>Dead reckoning</td>
<td>Position and Direction of motion and Velocity and Distance</td>
<td>Any other positioning method and sensors: Gyroscope Accelerometer Odometer</td>
</tr>
<tr>
<td>Pattern matching or learning algorithms</td>
<td>Visual images or fingerprints</td>
<td>e.g., via Camera or Received signal strength</td>
</tr>
</tbody>
</table>
Proximity Sensing

- Proximity is sensed by a station using (short) range pilot signals:
Lateration

- Position is computed by a number of *range measurements* to *known fix-points*:
Angulation

- Position is derived by the measured of the *angle of an arriving signal* by multiple stations at known fix-points:
Dead Reckoning

- From a **fixed starting position**, the movement of a mobile device is estimated (e.g., using velocity and direction of movement)
- Position becomes more inaccurate with each estimation
- Recalibration may be necessary
Fingerprinting

- Position is derived by the comparison of location dependent online measurements with previously recorded data:

- Indoor Navigation / Fingerprinting via RSS measurements
2.1 Positioning Fundamentals – Reference Systems

• Goal of positioning: **derive the geographic position** of a target with respect to a **spatial reference model**

• Spatial reference model
  – Coordinate system (Ellipsoidal/Cartesian)
  – Geodetic datum, e.g., WGS-84
  – Projection (if location is to be represented on a map), e.g., Mercator projection
2.2 Positioning Fundamentals - Infrastructures

- Satellite networks
  - Satellites
  - Databases & Directories
  - Control units

- Cellular networks
  - Base stations

- Indoor networks
  - Access Points
  - Readers

- Terminals
  - Mobiles
  - Vehicles
  - PDAs
  - Notebooks
  - Badges
  - Contactless smart cards
  - RFID tags

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3. Global Satellite Positioning Systems in the past

- Russian satellite **Sputnik** launched in 1957
  - Proof of the ability to track artificial objects in space via short wave radio signals
  - **Worldwide triangulation program** (BC-4): simultaneously photographing reflective satellites by several sites separated by some 4000 km
  - **Doppler shift** in the signal broadcast by a satellite could be used to determine exact time of closest approach. Together with the ephemerides this leads to precise positioning anywhere in the world.
- Navy Navigation Satellite System (NNSS), also called **TRANSIT**
  - Predecessor of GPS
  - Six satellites / 1100km altitude
  - Primarily for vessel and aircraft positioning
  - **1m accuracy** if point was occupied for several days
  - A satellite passed overhead only every 90 minutes
3. GPS – Mission Goals

• Defined by the US Department of Defense (DoD), developed to replace the TRANSIT system and to deliver **not only position**, but also **accurate time and speed**.

• Initial goals
  – User receiver cost < 10.000 $ and „5 bombs in the same hole“
  – Positioning anywhere, continuously & in all weather conditions

• Services
  – **Standard positioning service** (SPS) open to civil users, but single-frequency with **L1 coarse/acquisition signal** 1575.42 MHz, i.e. no ionosphere effect correction, **selective availability**
  – **Precise positioning service** (PPS), dual-frequency, using P(Y) signals in **L1 and L2** (1227.60 MHz) bands, with military control access (key for pseudo-code)
## 3.1 GPS - History

<table>
<thead>
<tr>
<th>Year</th>
<th>Event</th>
</tr>
</thead>
<tbody>
<tr>
<td>1973</td>
<td>Decision to develop satellite navigation system</td>
</tr>
<tr>
<td>1978-1985</td>
<td>11 Block-I satellites launched</td>
</tr>
<tr>
<td>1989</td>
<td>First Block-II satellite launched</td>
</tr>
<tr>
<td>Dec 1993</td>
<td>Initial Operational Capability (IOC)</td>
</tr>
<tr>
<td>Mar 1994</td>
<td>Last Block-II satellite</td>
</tr>
<tr>
<td>July 1995</td>
<td>Full Operational Capability (FOC)</td>
</tr>
<tr>
<td>May 2000</td>
<td><strong>Deactivation of Selective Availability</strong></td>
</tr>
<tr>
<td>Sep 2005</td>
<td>First IIR-M GPS satellite</td>
</tr>
</tbody>
</table>
3.2 GPS - Satellites

**Geostationary orbit** (ca. 36,000 km) communication, TV, and meteorology

**MEO**: Medium Earth Orbit  
e.g., **GPS satellites** (ca. 20,200 km)

**LEO**: Low Earth Orbit  
e.g., **ISS** (ca. 700 km)
3.2 GPS - Satellites

- **Block-I**
  - Weight: 845 kg; Lifespan: **4.5 years**;
  - Energy: Solar panels (400W); Nickel-Cadmium batteries
  - Out-of-order since 1996
- **Block-II/-IIA**
  - Weight: 1500kg; Lifespan: **7.5 years**; Wingspan: 5.1m
  - **Four atomic clocks** (2 rubidium, 2 cesium)
- **Block-IIR**
  - Weight: 2000kg; Costs: 75 million USD
  - **Three atomic clocks** (all rubidium clocks)
  - **Second civil signal** (L2C)
  - **New military signal with new code**
- **Block-IIF**
  - **Third frequency for civil use** (L5)
3.3 GPS – Components

- **Space segment**
  - 24 satellites circulating the Earth every 12 sidereal hours on six orbits
  - Each satellite is equipped with onboard atomic clocks
  - Orbits are equally spaced 60° apart from each other with an inclination angle of 55° to the equator
  - Orbit altitude: approx. 20,180 km

- **Control segment**
  - Initially: Five ground stations for monitoring and controlling the satellites
  - In 2005: Six additional monitoring stations
  - Adjust or synchronize satellites

- **User Segment**
  - GPS receiver
  - Applications: land, sea, and air navigation, as well as military purposes and location-based services
### 3.4 GPS – Circular Lateration

- **Known:**
  - Position $p_i = (x_i, y_i, z_i)$ for satellites $i \in \{1, 2, 3, 4\}$ at time $t_i$
  - Inaccurate reception time $t_{ri}$
  - Speed of light $c$
- **Unknown:**
  - Position $p$  
- **Calculation:**
  - $r_i = (t_{ri} - t_i) \cdot c$ for $i = 1, 2, 3$
  - Estimate position $p_{est}$: intersection of spheres (centered on satellite $i$ with radius $r_i$)
  - $p_{est}$ contains the coordinates $(x, y, z)$ and is determined on basis of the signals 1, 2, and 3
  - $p_{est}$ is **not accurate** due to different clock times at the satellites and the receiver
  - Signal 4 is now used to determine the corrected reception time $t$
3.5 GPS - Possible Errors

- **Satellite clocks** (although four highly accurate atomic clocks) can cause **time error** of 10ns
- **Satellite position** is only known up to approx. 1-5m
- **Receiver** has only limited accuracy
- **Multipath propagation**
- **Satellite geometry** (Dilution Of Precision, DOP)
- Signal (speed of light) **slow down** when crossing **ionosphere** and **troposphere**
3.6 Differential GPS (DGPS)

- **Reference station (RS)** located at a **known and accurately surveyed point**
- RS determines its GPS position using four or more satellites
- Deviation of the measured position to the actual position can be calculated
- Variations are valid for all the GPS receivers around the RS
- Runtime corrections are transmitted by radio
3.7 Satellite-based Augmentation Systems

![Diagram of satellite-based augmentation systems with ionosphere].

ionosphere
4. Galileo

- European GNSS
- Publicly available since December 2016
- Independence of other systems
- **More services**: Open, Commercial, Safety of Life, Public Regulated, Search and Rescue
- Advantages
  - **Precision**: Combination of GPS and Galileo in dual receivers is about to lead to higher precision
  - **Availability**: Higher number of satellites to improve the availability.
  - **Coverage**: Galileo aims to provide a better coverage at high latitudes due to the location and inclination of the satellites.
4.1 Galileo – Services

- **Open Service**
  - basic signal provided free-of-charge

- **Safety-of-Life Service**
  - Enhanced signal including an **integrity function** that will **warn** the user within a few seconds in case of a **malfuction**. This service will be offered to the safety-critical transport community, aviation, etc.

- **Commercial Service**
  - combination of two encrypted signals for higher data throughput rate and higher accuracy authenticated data;

- **Public Regulated Service**
  - two encrypted signals with controlled access for specific users like governmental bodies; security against manipulation, availability garantis

- **Search And Rescue Service**
  - Galileo will contribute to the international COSPAS-SARSAT cooperative system for humanitarian search and rescue activities. Each satellite will be equipped with a transponder transferring the distress signal from the user to the Rescue Coordination Centre and informing him that his situation has been detected.

4.2 Galileo – Operation

- Galileo programme structured in two phases
  - In-Orbit Validation (IOV) phase
    - Qualifying and validating the systems through in-orbit tests
    - Two experimental satellites: Dec 2005, Apr 2008
    - Four operational satellites: Q3/4 2011, Q1/2 2012
  - Full Operational Capability (FOC) phase
    - Deployment of remaining ground and space infrastructure
    - Intermediate initial operational capability: 18 satellites in operation
    - Full system: 30 satellites, control centers located in Europe and a network of sensor stations and uplink stations installed around the globe
4.3 Galileo – Architecture

- 30 satellites in MEO: Each satellite will contain
  - a navigation payload
  - search and rescue transponder
- 30-40 sensor stations
- 3 control centers
- 9 Mission Uplink stations
- 5 TT&C stations.

5. Other GNSS

- Global Navigation Satellite System (GLONASS)
  - Program started in 1982
  - System currently operated by the Russian Defense Ministry
  - 24 planned satellites
  - 3 orbital levels
  - Orbital altitude of 19,100 km
  - Full operation since 1996

- Compass Navigation Satellite System (CNSS)
  - China’s second-generation satellite navigation system (also known as BeiDou 2)
  - Long-term goal: Development of a system similar to the GPS and GLONASS
  - 25~35 satellites: 4 GEO satellites and MEO satellites
  - Two levels of positioning service: Open and restricted (military)
  - Coverage: Initially only neighboring countries, later on extension to global navigation satellite system.
  - Launches: 1 MEO (Apr 07) and 3 GEO (Apr 09 – June 10)
Hands-on

- Create location-based applications with Android location services
  - Android Developer tutorials
    https://developer.android.com/guide/topics/location/strategies
  - Get familiar with typical challenges:
    - Multitude of location sources
    - User Movement
    - Varying accuracy
  - Applying an application process chain satisfying your application’s individual needs (e.g., demands for accuracy or update-rate):

Source: https://developer.android.com/guide/topics/location/strategies