ÓBUDAI EGYETEM
ÓBUDA UNIVERSITY

Signals – sensors 5.

Dr. Gyányi Sándor

Navigation and Motion Sensing Technology

- Global Navigation Satellite Systems (GNSS).
- Gyroscopes.
- Accelerometers.
- Inertial Measurement Units (IMUs).

ÓBUDAI EGYETEM
ÓBUDA UNIVERSITY

GNSS

- Global Navigation Satellite Systems are using satellite constellations that provide autonomous geo-spatial positioning with global coverage.
- They have 3 key components:
  - **Space Segment**: Satellites in certain orbit that transmit precise timing and positioning signals.
  - **Control**: Ground stations that monitor, control, and synchronize the satellites.
  - **User equipment**: GNSS receivers that process signals from the satellites and calculates the current position.
- GNSS is very important today (car navigation systems, location-based services).

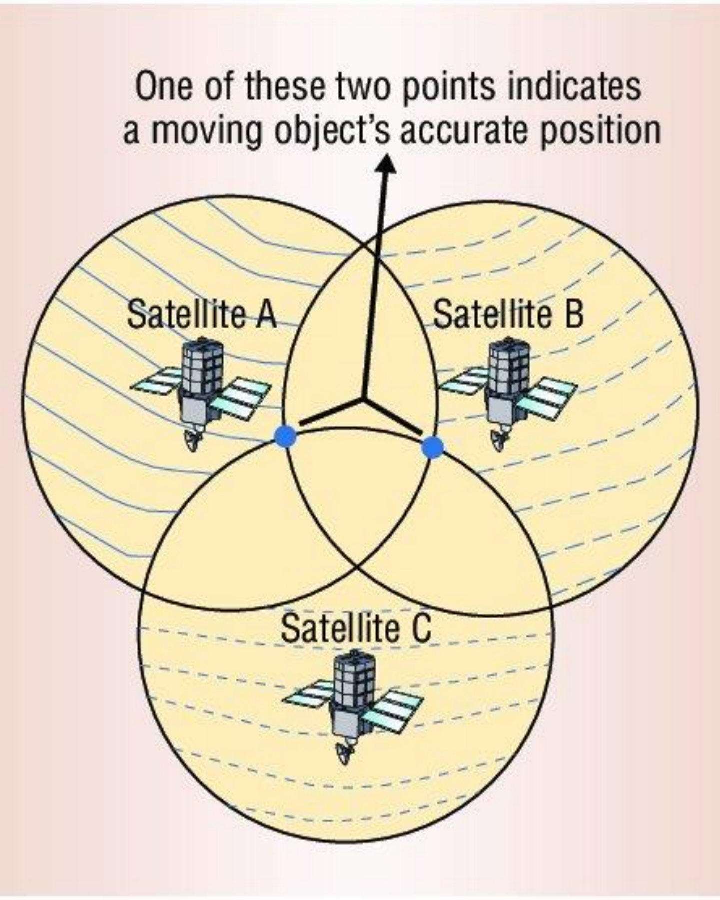
ÓBUDAI EGYETEM
ÓBUDA UNIVERSITY

Currently operating GNS Systems

- There are four global GNSS today:
  - **GPS (Global Positioning System or Navstar)**: Operated by the United States, GPS was the first fully operational GNSS. It needs at least 24 operational satellites, U.S. is committed to replace the broken ones.
  - **GLONASS (Globalnaya Navigazionnaya Sputnikovaya Sistema)**: Operated by Russia.
  - **Galileo**: Developed by the European Union, Galileo offers high precision positioning. It consists 26 satellites (as of 2021).
  - **BeiDou**: Operated by China, BeiDou provides regional and global services. Currently it operates 35 satellites.

Working Principles of GNSS

- GNSS systems function based on the principle of **trilateration**:
  - Satellites transmit signals containing their position and the exact time of transmission.
  - A GNSS receiver captures signals from different satellites positioned in different places in orbit.
  - The receiver calculates the distance to each satellite based on the travel time of the signals.
  - Using these distances, the receiver computes its position.



ÓBUDAI EGYETEM
ÓBUDA UNIVERSITY

Orbit

- **GNSS satellites** (Global Navigation Satellite System satellites) operate in a specific type of orbit known as a **Medium Earth Orbit (MEO)**.
  - **GPS:** Orbit altitude is approximately 20,200 km (11 hours 58 minutes).
  - **GLONASS:** Orbit altitude is approximately 19,100 km (11 hours 15 minutes).
  - **Galileo:** Orbit altitude is approximately 23,222 km (14 hours).
  - **BeiDou:** Orbit altitude is approximately 21,528 km (12 hours) plus it has some GEO orbit satellites for Asia coverage.
- MEO is ideal for GNSS satellites because it offers a good compromise between coverage, power requirements, and signal delay.

ÓBUDAI EGYETEM
ÓBUDA UNIVERSITY

Signal Structure

- GNSS satellites continuously transmit navigation signals in two or more frequencies in L band. The main signal components:
  - Carrier: Radio frequency sinusoidal signal at a given frequency (depending on the system type).
  - Ranging code: Pseudo random codes of 0s and 1s, which allow the receiver to determine the travel time of radio signal from satellite to receiver.
  - Navigation data: A binary-coded message providing information on the satellite ephemeris (Keplerian elements or satellite position and velocity), clock bias parameters, almanac (with a reduced accuracy ephemeris data set), satellite health status, and other complementary information. https://gssc.esa.int/navipedia/index.php/GNSS_signal

ÓBUDAI EGYETEM
ÓBUDA UNIVERSITY

Multiple Access techniques

- The problem: a user devices can receive signals from multiple satellites.
- The origin and content of each signal must be determined.
- Common techniques:
  - CDMA (Code Division Multiplex) used by GPS, Galileo, Beidou.
  - FDMA (Frequency Division Multiplex) used by Glonass.

CDMA 1.

- CDMA techniques use the same carrier frequency.
- Transmitters use different codes to spread the data using much larger spectrum.
- Receivers must know the spread code to decode the data.
- In GPS, for example, receivers know all the operating satellites' code.
  - Satellites use the **L1 (1575.42 MHz)** or **L2 (1227.60 MHz)** frequency.
  - At the receiver, the incoming signal is „despread" by correlating it with the PRN code that corresponds to each satellite.

CDMA 2.

- The received signal R(t) is the sum of multiple signals from different satellites.
- Each signal is modulated by a PRN code Ci(t), where i represents the satellite number.
- Most commonly used modulation methods are: BPSK (Binary Phase Shift Keying) or QPSK (Quadrature Phase Shift Keying).
- The receiver multiplies the incoming signal R(t) by the PRN code Ci(t) for a specific satellite.
- If the correct code is applied, the result is the original data signal, along with some noise.

GPS signals

ÓBUDAI EGYETEM
ÓBUDA UNIVERSITY

- Each GPS satellite continuously transmits signals that include:
  - **Precise Time**: The exact time the signal was sent, based on the satellite's highly accurate atomic clock.
  - **Satellite Position (Ephemeris)**: The satellite's location in space at the time of transmission.
  - **Pseudorandom Code**: A unique sequence that identifies which satellite sent the signal.
  - **Almanac data**: General data about the satellite constellation and system health.
- **Ephemeris data** contains detailed information about the satellite's orbit, including its position (latitude, longitude, altitude), velocity, and orbital corrections.

Calculating position

- The distance between the satellite and the receiver can be determined using this formula: Distance=Travel Time * Speed of Light
- **Single satellite**: Provides only the distance to that satellite. The receiver could be anywhere on a sphere centered on the satellite.
- **Two satellites**: Narrows the possible locations to a circle where the two spheres (from each satellite) intersect.
- **Three satellites**: Narrows the location to two possible points where all three spheres intersect.
- To determine the altitude, four satellites are needed.

GNSS Error Sources

- **Ionospheric and Tropospheric Delays**: Signal distortion as it passes through the Earth's atmosphere.
- **Satellite Clock and Orbit Errors**: Inaccuracies in the satellite's internal clock or position (every GNSS satellite contains atomic clocks).
- **Multipath Effects**: Interference caused by signal reflection from surfaces.
- Noise or jamming signals: noise can degrade performance. Jamming can overshadow or compromise the satellite signals.

GNSS accuracy

- The accuracy of GNSS depends on the system type, satellite geometry, and corrections applied.
  - **GPS**: 5 to 10 meters without augmentation, less than 1 meter with augmentation (ground- or satellite-based correctional signals).
  - Glonass: 5 to 10 meters.
  - Beidou: 2.6 – 3.5 meters.
  - Galileo: less than 1 meter.

GNSS frequencies

ÓBUDAI EGYETEM
ÓBUDA UNIVERSITY

- **L1 (~1575.42 MHz)**: Used by most GNSS systems (GPS, Galileo, BeiDou) for civilian signals. It is one of the primary frequencies for standard positioning services.
- **L2 (~1227.60 MHz)**: Commonly used for military and high-precision applications.
- **L5 (~1176.45 MHz)**: Used for safety-critical and high-precision applications (aviation, surveying). It’s available in GPS, Galileo, BeiDou.
- **L3 and L4 (1207–1278 MHz)**: Used by some systems (GLONASS, Galileo, BeiDou) for advanced services.

ÓBUDAI EGYETEM
ÓBUDA UNIVERSITY

GNSS devices

- Many types are available.
- They have an on-board microprocessor.
- UART, I2C or other digital communication interfaces.
- Modern GNSS chips can receive signals from different types of satellites (GPS, Glonass, Galileo).

Gyroscopes

- The working principle of a gyroscope is based on the concept of **conservation of angular momentum**.
- Angular momentum is the property of a spinning object that makes it resist changes to its axis of rotation.
- This resistance allows gyroscopes to maintain their orientation.
- Components of a Basic Mechanical Gyroscope:
  - **Rotor (Flywheel)**: A spinning disc or wheel that stores angular momentum,
  - **Gimbal**: A set of rings that allow the rotor to pivot freely in multiple axes.
  - **Frame**: The outer structure that holds the gimbals and rotor.

Mechanical gyroscope

https://www.ion.org/museum/

ÓBUDAI EGYETEM
ÓBUDA UNIVERSITY

Applications of Gyroscopes

- Inertial Navigation Systems (INS). They use gyroscopes and accelerometers to track the position, orientation, and velocity.
- Smartphones and Consumer Electronics. They use gyroscopes to determine the orientation of the device.
- Automotive Systems: gyroscopes are used for electronic stability control (ESC) and rollover detection.
- Drones and UAVs: gyroscopes help maintain the stable flight by determining the current position changes.
- Aerospace and Space Exploration: it can help to determine of the position of the aircraft or spacecraft.

Types of gyroscopes

- **Mechanical Gyroscope: t**he traditional type of gyroscope.
- **Optical Gyroscope:** highly accurate and have no moving parts. They work based on the **Sagnac effect**, which measures the difference in the phase of light traveling in opposite directions around a loop.
- **MEMS Gyroscope:** measure the Coriolis force produced by the vibrating element when the system experiences rotation. This is used to compute the angular velocity.

Accelerometers

- There will be a different class for accelerometers…

Inertial Measurement Units (IMUs)

- They have gyroscope, magnetometer and accelerometer to determine position, rotation, speed.
- These measured values can be synthesized to make a more precise measurement.
- https://www.movella.com/products/sensor-modules/xsens-mti-2-vru