CHAPTER 1 Sensor Systems

- A conditioning stage is an electronic device that adapts the signal coming from the sensor to the requirements (voltage, impedance, etc.) of the following stages of the measuring chain.
- Usually the signal output level of the sensor is very low, therefore, the most common operation made by the conditioner is to amplify the signal. But, many other cases has other functions, such as: demodulation, linearization, electric isolation, filtering, etc.
- The conditioner also provides the needed external electrical energy to the sensor, if the case.

SENSORING: Monitoring and Control Systems must interact with their environment. To do this they use **transducers**. Transducer:

- A device that converts a primary form of energy into a corresponding signal with a different energy form (Primary Energy Forms: mechanical, thermal, electromagnetic, optical, chemical, etc.)
- Take form of **sensors** and **actuators**.

According to the *American National Standards Institute* (ANSI): A sensor is a device which provides a usable output in response to a specified physical magnitude and converts it into a signal suitable for processing (usually an electrical signal), whereas an actuator does just the opposite, that is, provides a physical actuation from an electrical signal. **Sensor:**

- A device that detects/measures a physical magnitude
- Acquires data from the "real world". Examples: thermometer, accelerometer, photometer,

Actuator :

- A device that generates some kind of energy from a signal. Examples: automatic valves, electronic switchers,…

Among the sensors, the widely used sensor is the electric sensor **(**A sensor that converts desired parameter into an electrically measurable signal.) Usually an electric sensor has the following structure: primary transducer (changes "real world" parameter into other intermediate parameter) and secondary transducer (converts intermediate parameter into a electrical signal.)

- To transform the main magnitude in an electrical signal, sensors are based on physical principles, such as: electromagnetism, piezoelectricity, photoelectricity, thermoelectricity, etc.
- The way used by a sensor to do this "transduction" is called Transduction Mechanism.
- In some cases this transduction is done directly, that is, from de physical magnitude to an electrical signal. However, in others cases the main magnitude is transformed firstly into an intermediate magnitude that is after transformed in an electrical signal.
- In this cases, actually the sensor has two sensors inside: a primary sensor, that converts the main magnitude into an intermediate magnitude (for example pressure into a displacement), and a secondary sensor that converts this intermediate magnitude in an electrical signal (in our example, displacement into the electrical signal).
- Almost any physical property of a material that changes in response to some excitation can be used to produce a sensor. Widely used sensors include those that are: resistive, inductive, capacitive, piezoelectric, photoresistive, Elastic and thermal.

Range: maximum and minimum values that can be measured

Resolution or discrimination: smallest discernible change in the measured value

Error: difference between the measured and actual values (random errors and systematic errors)

Accuracy, inaccuracy, uncertainty: Inaccuracy is a measure of the maximum expected error. Accuracy is just the opposite, but commonly is given in terms of inaccuracy or uncertainty.

Precision a measure of the lack of random errors (scatter)

Linearity maximum deviation from a ‘straight-line’ response, normally expressed as a percentage of the full-scale value

Sensitivity a measure of the change produced at the output for a given change in the quantity being measured

Resistive thermometers typical devices use platinum wire (such a device is called a platinum resistance thermometers or PRT): *linear* but has poor *sensitivity*

Thermistors use materials with a high thermal coefficient of resistance: *sensitive* but highly *non-linear*

pn junctions a semiconductor device with the properties of a diode

- *inexpensive*, *linear* and *easy to use*
- *limited temperature range* (perhaps -50°C to 150 °C) due to nature of semiconductor material

Photovoltaic light falling on a *pn*-junction can be used to generate electricity from light energy (as in a solar cell)

- small devices used as sensors are called photodiodes
- fast acting, but the voltage produced is *not* linearly related to light intensity

Photoconductive such devices do not produce electricity, but simply change their resistance

- photodiode can be used in this way to produce a linear device
- phototransistors act like photodiodes but with greater sensitivity
- light-dependent resistors (LDRs) are slow, but respond like the human eye

Strain gauge stretching in one direction increases the resistance of the device, while stretching in the other direction has little effect

- can be bonded to a surface to measure strain
- used within load cells and pressure sensors

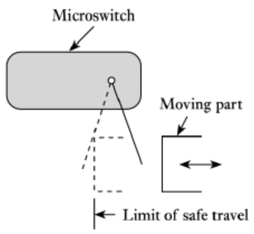
Potentiometers resistive potentiometers are one of the most widely used forms of position sensor

- can be angular or linear
- consists of a length of resistive material with a sliding contact onto the resistive track
- when used as a position transducer a potential is placed across the two end terminals, the voltage on the sliding contact is then proportional to its position
- an inexpensive and easy to use sensor

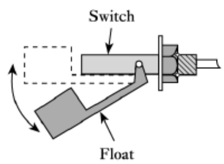
Inductive proximity sensors

- Coil inductance is greatly affected by the presence of ferromagnetic materials.
- Here the proximity of a ferromagnetic plate is determined by measuring the inductance of a coil.

Switches simplest form of *digital* displacement sensor (many forms: lever or push-rod operated microswitches; float switches; pressure switches; etc.)

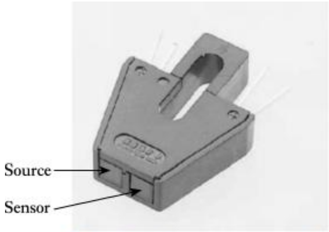


A limit switch

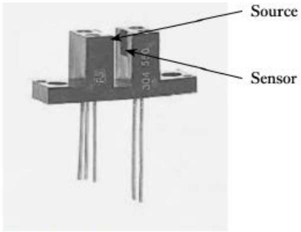


A float switch

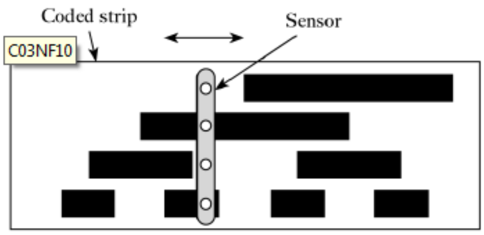
Opto-switches consist of a light source and a light sensor within a single unit (2 common forms are the reflective and slotted types)



A reflective opto-switch



A slotted opto-switch

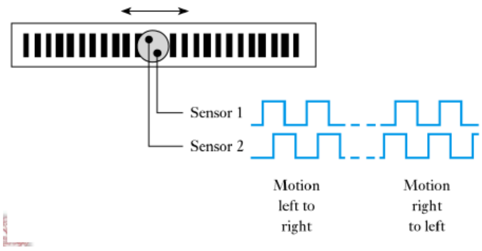


Absolute position encoders a pattern of light and dark strips is printed on to a strip and is detected by a sensor that moves along it

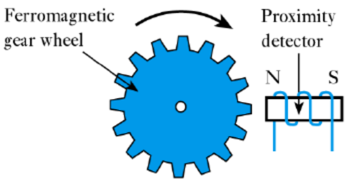
- the pattern takes the form of a series of lines as shown below
- it is arranged so that the combination is unique at each point
- sensor is an array of photodiodes

Incremental position encoder uses a single line that alternates black/white

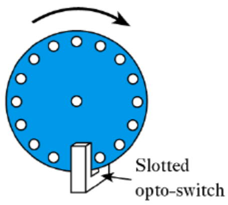
- two slightly offset sensors produce outputs as shown below
- detects motion in either direction, pulses are counted to determine absolute position (which must be initially reset)



Other counting techniques: several methods use counting to determine position



Inductive sensor



Opto-switch sensor

Motion sensors measure quantities such as velocity and acceleration

- can be obtained by differentiating displacement
- differentiation tends to amplify high-frequency noise

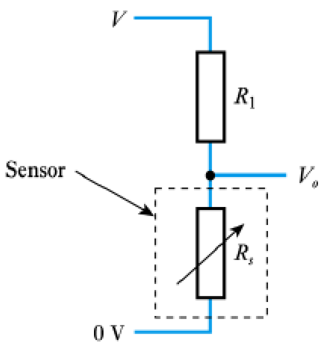
Alternatively can be measured directly

- some sensors give velocity directly e.g. measuring *frequency* of pulses in the counting techniques described earlier gives speed rather than position
- some sensors give acceleration directly e.g. accelerometers usually measure the force on a mass

Microphones a number of forms are available e.g. carbon (resistive), capacitive, piezoelectric and moving-coil microphones

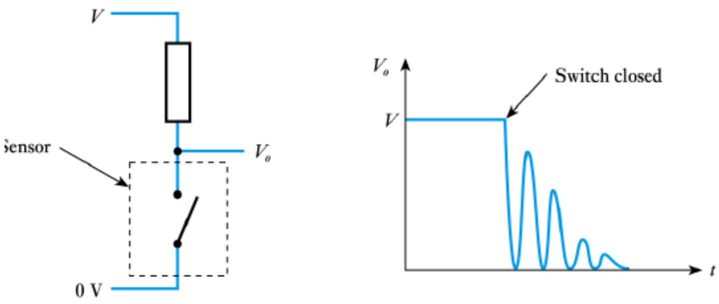
- moving-coil devices use a magnet and a coil attached to a diaphragm

Resistive devices can be very simple e.g. in a potentiometer, with a fixed voltage across the outer terminals, the voltage on the third is directly related to position



- where the resistance of the device changes with the quantity being measured, this change can be converted into a voltage signal using a potential divider – as shown
- the output of this arrangement is *not* linearly related to the change in resistance

Switches switch interfacing is also simple
- can use a single resistor as below to produce a voltage output
- all mechanical switches suffer from **switch bounce**

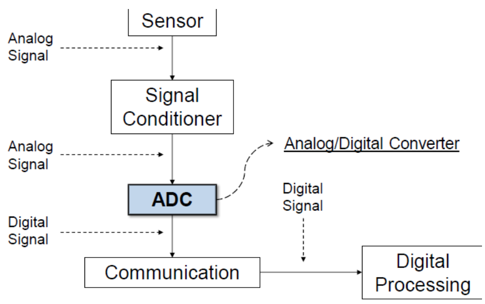


Capacitive and inductive sensors: sensors that change their capacitance or inductance in response to external influences normally require the use of alternating current (AC) circuitry
- such circuits need not be complicated

- ➢ A very wide range of sensors is available.
- ➢ Some sensors produce energy when measuring, therefore, they don't need supply power, because they are generators. They are called: PASSIVE SENSORS
- ➢ In every other case the sensors simply change some of their physical properties, therefore external supply power is needed. They are called: ACTIVE SENSORS
- ➢ Some sensors produce an output that is linearly related to the quantity being measured, others do not.
- ➢ Conditioning may be usually required to produce signals in the correct form.

CHAPTER 2 Basics on Signal Acquisition

Analog signals:
- Continuous, expressed in decimal system
- No limitation on the maximum/minimum value (only technical specif.)
- Any value is possible between the maximum and the minimum
- Can not be processed by digital computer



Digital signals: binary number system
- All numbers are expressed by a combination of states 1&0
- The maximum value is limited by number of bits available
- Only a set of values are possible
- Can be processed by digital computer

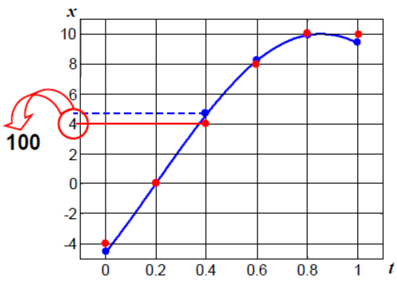
Sensors give usually a very weak signal, not valid to be sent directly to the ADC. Conditioner modifies the analog signal to match the performance of the ADC
- Pre-filtering: remove undesirable high frequency components
- Amplification: amplify the signal to match the dynamic range of the ADC

Convert analog signals into digital signals

$$y(t)=f(t) \rightarrow y_k=f(t_k)$$

Conversion A/D has three different operations:

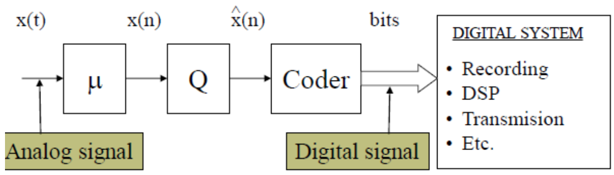
1. Sampling: making time discrete x(t) => x(n)
2. Quantization: Making amplitude discrete x(n) => X(n)
3. Coding :Coding the value X(n) --> 01101...



Signal Acquisition

Sampling: There is no lose of information if *Sampling Theorem* (Nyquist) is satisfied.

Quantization: There's always some lose of information.



Transformation of a continuous analog input in to a set of discrete output state

- Number of possible states: $N=2^n$, n is number of bits
- Quantization resolution: Q=(Vmax-Vmin)/N
- Quantization Error: $|f(t_k)-f_k|$

Coding: the assignment of a digital code word or number to each output states

FEATURES

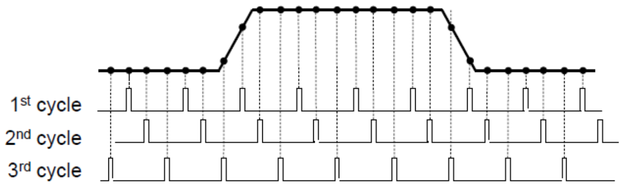
- A/D resolution (Number of bits used)
- Maximum sampling rate
- Number of simultaneous channels
- Total throughput (Vmax–Vmin, amplitude range)
- Aperture time (duration of the time window that the analog is sampled)

Sampling: Evaluate numerically the signal at discrete distance in time , $y_k=y(k\Delta t)$
Digitized Signal: a sequence of numbers that is an approximation to ananalog signal
Sampling time/Period: time duration between two consecutive samples, Δt
Sampling rate (Hz): $1/\Delta t$
Nyquist Frequency: 2*fmax
Sampling theorem: fs >Nyquist Frequency

Shannon-Nyquist sampling theorem (the maximum frequency component in a sampled data system can a accurately handle is its Niquist limit (i.e. Niquist frequency)

Depending on the signal characteristics, there are two main ways to sample:

- **Real Time Sampling** (also called Uniform Sampling). In this case, all the samples of the signal are taken sequentially in real time. The sampling rate is limited by the frequency of the clock of the system, that imposes the bandwidth. This is the only possible method to acquire random signals, for instance, most of the biomedical signals or transient phenomena.
- **Equivalent TimeSampling**. By means of equivalent-time sampling, we can acquire a signal beyond to its analog bandwidth, regardless of its sample rate. This is possible because the DAS gathers the necessary number of samples to rebuild the signal along successive cycles of that signal. Necessarily, the input signal must be repetitive to generate the multiple triggers needed to reconstruct it. Therefore, Equivalent Time Sampling is only applicable to acquire periodic signals. Obviously, this way, a slower, lower cost digitizer provides the same accuracy on repetitive wave forms as a higher cost system with a faster sampler.



One way of avoiding the problem of aliasing is to apply an anti -aliasing filter to the signal, prior to the sampling stage, to remove any frequency components above the "folding" or Nyquist frequency (half the sampling frequency). An anti-aliasing filter is a low-pass filter.

Lesson 3.- Global Navigation satellite System, GNSS

A GNSS sensor provides position, velocity and time (PVT). Today there is two operative systems, both military system

- GPS: Global Positioning System →USA>
- GLONASS: Global Navigation Satellite System →Russia

And two in development phase:

- GALILEO. A civil GNSS from Europe
- COMPASS: Chinese system.

Navigation: To know the position every time, that is, to be able to plot the vehicle trajectory, x(t),y(t),z(t)] over a map.

Pilotage: essentially relies on recognizing landmarks to know where you are and how you are oriented. It is older than humankind.
Dead reckoning: relies on knowing where you started from plus some form of heading information and some estimate of speed
Celestial navigation: using time and the angles between local vertical and known celestial objects (e.g. sun, moon, planets, stars) to estimate orientation, latitude and longitude
Radio navigation: relies on radiofrequency sources with known locations (including global navigation satellite systems satellites)
Inertial navigation: relies on knowing your initial position, velocity and attitude and thereafter measuring your attitude rates and accelerations. It is the only form of navigation that does not rely on external references.

- GPS
  - The Global Positioning System (GPS) is part of a satellite-based navigation developed by the U.S. Department of Defense under its NAVSTAR satellite program.
- GLONASS
  - Global Orbiting Navigation Satellite System, placed in orbit by the former Soviet Union, and now maintained by the Russian Republic
- GALLILEO
  - The Galileo system is the third satellite-based navigation system currently under development. Its frequency structure and signal design is being developed by the European Commission’s Gallileo Signal Task Force (STF), which was established by the European Commission (EC) in March 2001. The STF consists of experts nominated by the European Union member states, official representatives of the national frequency authorities and experts from the European Space Agency (ESA).
- Beidou/Compass System
  - China fielded a demonstration regional satellite-based navigation system known as Beidou (Chinese for the “ Big dipper” asterism) following a program of research and development that began in 1980. The initial constellation of three geostationary Earth orbit (GEO) satellites was completed in 2003. A fourth GEO satellite was launched in 2007. The initial regional Beidou system (Beidou-1) is being expanded, in stages, into a global system known as Beidou-2 or Compass. It will include five GEO satellites.

27 medium Earth orbit (MEO) satellites and five inclined geosynchronous orbit (IGSO) satellites. The system will cover the Asia-Pacific region by 2012 with the global system expected to be fully completed by 2020.

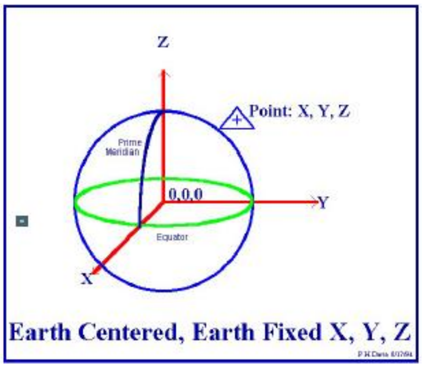
- DGPS: Differential GPS
  - Local coverage
  - Regional coverage
    - Both in real time or post-process.
    - High accuracy and precision. •
- Satellite-Based Augmentation Systems, SBAS
  - Continental coverage.
  - Real time system
    - WAAS: Wide Area Augmentation System. (USA)
    - EGNOS: European Geo Stationary Navigation Overlay System (Europe)
    - GAGAN : GPS Aided Geo Augmented Navigation (India)
    - MSAS : Multi-functional Satellite Augmentation System. (Japan)
    - QZSS: Quasi-Zenith Satellite System. (Japan)

GNSS

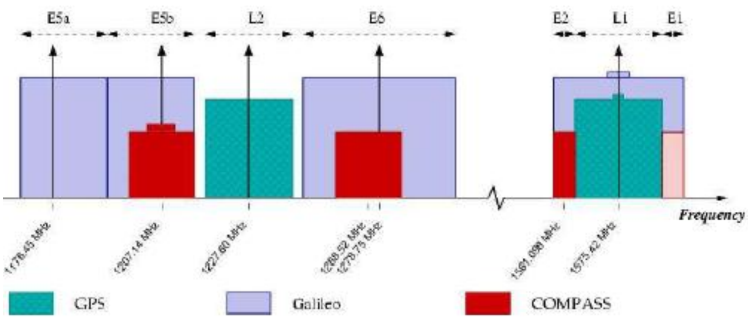
- GNSS are satellite communication system
- GNSS employ a Medium Earth orbit (MEO) constellation
- SBAC is based on use of GEO sats.
- Each Space Vehicle broadcast signal with information such as navigation, ranging ,… in L band carriers
  - GNSS employ different RF carrier in L band (1-2 GHz), L1, L2, E5,..
- Each user compute his absolute position (3D or 2D) in a coordinate system by triangulation
- GNSS allow a global coverage, but restricted to outdoor sceneries
- There are some accuracy/precision degrees

GNSS: Coordinate systems

- Geographic (LLU): Latitude, Longitude, height
- Plane, local (UTM): ENU/END: East, North, height
- Cartesian: ECEF, ECI



frequency bands GLONASS: L1=1602+0.5625k (MHz)
L2= 1246+0.4375k (MHz)



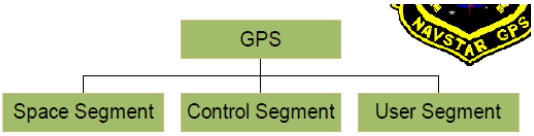
Reference Ellipsoid

Reference ellipsoid are defined by some parameters...

- Semi major axis (equatorial radius)
- Semi minor axis (polar radius)
- Flattening (ratio between polar radius and equatorial radius)
- First eccentricity squared
- Others parameters….

GPS

- Global Positioning System
- NAVSTAR GPS (Navigation Satellite Timing and Ranging Global Positioning System)
- Telecommunication system. Unidirectional, L Band (1GHz -2GHz)
- The GPS consists of a constellation of satellites in obits of medium attitude , MEO, that continuously transmit coded information, to make it possible to calculate the position, velocity and time (PVT) of any user at any site on the surface of the Earth.
- The system use the concept “one-way” Time of arrival “TOA”



Space segment:

- 24 satellites “Space vehicles (SVs)”.
    - Earth orbiting with period of approximately 12hrs.
    - 6 orbital planes inclined at 55 degrees with respect to the plane of Ecuador
    - This constellation ensures that at any place on Earth are simultaneously between 5 and 8 satellites
- Transmission of SVs are synchronizes with high stability clocks (atomic) installed on board each satellite. All SVs are use a unique time pattern (“GPS time base”)
- Each SV broadcast “ranging codes” and navigation data over two carrier (L1 and L2). The modulation technique employed is BPSK and also use Code Division Multiple Access CDMA.

Signal transmitted by each GPS sat

- Carrier L1: frequency of 1575,42 Mhz) carries C/A code and navigation message
- Carrier L2: frequency of 1227,60 Mhz) carries P(Y) code and navigation message
- These 3 binary codes modulate (BPSK) two carriers L1 y L2:
    - C/A code “Coarse Acquisition”. Length 1,023 chips, Rb=1 Mchip/seg
    - P(Y) code. Length 15,345,000 chips. Rb=10,23 Mchips/s
    - Navigation message consist in a binary frame of 50 bps that carries necessary information: orbit description, clock correction and other system parameter

C/A code generator

Each, Space Vehicle has an ID: His PRN code Pseudo Random Number

Control Segment

- The control segment is compose by de 1 Master Control monitor stations that: Station and 5 monitor stations that:
    - Maintain the satellites in due orbit through small maneuvers.
    - Introduce corrections and adjustments to satellite clocks and payload
    - Tracking the GPS satellites and uploading navigation data to each satellite of the constellation
    - Provide through commands major relocations in case of satellite failure.

User Segment

- This segment consists of the user receivers.
- A GPS receiver catch the signal of at least 4 satellites in order to be able to compute his 3D position (Latitude, Longitude and height).
- Each receiver (sensor) does the following task:
    - Capture and demodulate the signal (SIS) from the constellation of GPS satellites
    - Decode the frame with navigation data

- Estimate a Pseudo range from the distance measurements to each view satellite. Typical elapsed time by C/A code is about 70 msec.
- Compute his position by the employ of an iterative algorithm.
- Synchronize the receiver clock with GPS time.

How to compute the position?

- The receiver does the distance measure to, at least, • 4 satellites
- Each distance has some error, then we call it as pseudorange : p1, p2 , …
- Then, an iterative algorithm compute the user position: (x_u,y_u,z_u) because the receiver known the precise position of each satellite in ECEF coordinates (x_i,y_i,z_i) and the error due to the time delay between GPS clock and Receiver clock, C_b meters

$$\rho_1 = \sqrt{(x_1 - x_u)^2 + (y_1 - y_u)^2 + (z_1 - z_u)^2} + C_b$$
$$\rho_2 = \sqrt{(x_2 - x_u)^2 + (y_2 - y_u)^2 + (z_2 - z_u)^2} + C_b$$
$$\rho_3 = \sqrt{(x_3 - x_u)^2 + (y_3 - y_u)^2 + (z_3 - z_u)^2} + C_b$$
$$\rho_4 = \sqrt{(x_4 - x_u)^2 + (y_4 - y_u)^2 + (z_4 - z_u)^2} + C_b$$

There are two services: SPS y PPS

- SPS (Standard Positioning Service) provides GPS single-receiver (standalone) positioning service to any user on a continuous, worldwide basis. SPS is intended to provide access only to the C/A code and L1 carrier
  - The receiver compute the correlation of the C/A code received from a specific satellite with a local C/A generated in the receiver
- Precise Positioning Service Formal, proprietary service Precise Positioning Service, is the full-accuracy, single receiver GPS positioning service provided to the United States and its allied military organizations and other selected agencies. This service includes access to the unencrypted P-code and the removal of any SA effects.

GPS receivers

- A wide range •
- A lot of manufacturers (more than 50)
- Different performances (Precision, accuracy, DGPS functionality)
- Different format (Card OEM, sensor)
- Different applications
  - Topography
  - Marine navigation, terrestrial navigation, air.
  - Military applications
- A wide range of cost, from 100€ to more than 20.000€

Parameters for static characterization

- Accuracy: If the estimated position is very close to the true position, the accuracy is good.
- Precision: If all the fixes are very close, that is, the std is low.
- Availability: Is the percentage of the time that the system is able to estimate a good position.
- Integrity: Is the ability to provide timely warnings to the user whenever any navigation parameters estimated using the system are outside tolerance limits

Accuracy parameters for static Position

- Measures in position domain
- Definitions
  - Horizontal Position Error HPE
  - Vertical Position Error VPE
- Statistical analysis
  - CEP circular equal probability
  - 1 sigma, 68 % in a Gaussian distribution
  - HPE95% , percentile 95%
  - Mean

$$HPE = \sqrt{(E_m - E_{ref})^2 + (N_m - N_{ref})^2}$$

$$VPE = H_m - H_{ref}$$

    - RMS…

Availability

- Availability of a estimated position with same rate
- Typical (1fix/seg)
- Plot with the number of satellites used (SV) in the solution versus time
- Plot the parameters PDOP, HDOP, VDOP…
    - If the number of SV used is >4 then there is available a solution.

Error sources in GNSS

- Selective availability, SA
    - When is ON typically is about 30m, 1 sigma
    - SA was suspended, midnight GMT (8 p.m. EDT), May 1 , 2000
- Ionospheric propagation delays
    - Ionospheric signal propagation group delay can be as much as 20-30m during the day to 3-6m at night. Receivers that can utilize both the L1 and L2 frequencies can largely remove these errors by applying the inverse square law dependence of delay on frequency
- Tropospheric delays
    - There delays which occur in the lower atmosphere , are usually smaller and more predictable than ionospheric errors, and typically are in 1-3 m range but can be significantly larger at low satellite elevation angles
- Ephemeris errors
    - Are the difference between the actual satellite location and the location predicted by satellite orbital data, are typically less than 3m and will undoubtedly become smaller as satellite tracking technology improves
- Satellite clock errors
    - Are the difference between the actual satellite clock time and predicted by the satellite data
- Geometric Distribution of satellites used in the position GDOP
    - Position calculations involve range differences and where the ranges are nearly equal , small relative errors are greatly magnified in the difference. This effect, brought about as a result of satellite geometry, is known as dilution of precision (DOP). This means that range errors occur from other causes such as clock errors are also magnified by the geometric effect
- Multipath propagation
    - Objects in the vicinity of a receiver antenna (notably the ground) can easily reflect GPS signals, resulting in one or more secondary propagation paths. There secondary-path signals, which are superimposed on the desired direct-path signal, always have a longer propagation time and can significantly distort the amplitude and phase of the direct-path signal

GDOP error

- Poor GDOP
    - Al SV used are near.
- Good GDOP
    - All SV are spaced.
- GDOP parameters:
    - PDOP
        - HDOP
        - VDOP
    - TDOP

Communications in GPS receivers

- Most GPS employ one o more serial port, RS-232 but the new ones add USB ports and/or Bluetooth.
- To get data and send configuration parameters each manufacturer use specific protocol or standard protocol such as NMEA

NMEA messages

- Standard that use a set of sentences to connect GPS receiver with a plotter, PC, GUI, MCU, etc.
- There are sentences to configure, query and response. Examples:
  - GGA: provide data about the solution
  - GSA: quality of the solution (DOP) and active satellites
  - GSV: Satellite viewed
  - RMC: course, position, speed, etc.
- I/P messages
  - IBIT Built In test command
  - ILOG log control
  - INIT Initialization
  - IPRO Proprietary protocol

NMEA messages

- $GPBOD - Bearing, origin to destination
- $GPBWC - Bearing and distance to waypoint, great circle
- $GPGGA - Global Positioning System Fix Data
- $GPGLL - Geographic position, latitude / longitude
- $GPGSA - GPS DOP and active satellites
- $GPGSV - GPS Satellites in view
- $GPHDT - Heading, True
- $GPR00 - List of waypoints in currently active route
- $GPRMA - Recommended minimum specific Loran-C data
- $GPRMB - Recommended minimum navigation info
- $GPRMC - Recommended minimum specific GPS/Transit data
- $GPRTE – Routes
- $GPTRF - Transit Fix Data
- $GPSTN - Multiple Data ID
- $GPVBW - Dual Ground / Water Speed
- $GPVTG - Track made good and ground speed
- $GPWPL - Waypoint location
- $GPXTE - Cross-track error, Measured
- $GPZDA - Date & Time

Differential GPS (DGPS)

- Differential GPS (DGPS) is a technique for reducing the error in GPS-derived positions by using additional data from a reference GPS receiver at a known position. The most common form of DGPS involves determining the combined effects of navigation message ephemeris, ionospheric and satellite clock errors (including the effect of SA) at a reference station and transmitting pseudo range corrections, in a real time, to a user's receiver, which applies the corrections in the process of determining its position
- Local Area Differential GPS: LAGPS is a form of DGPS in which the user's GPS receiver also receives real-time pseudo range and possibly carrier phase corrections from a local reference receiver generally located within the line of sight. The corrections account for the combined effects of navigation message ephemeris and satellite clock errors (including the effect of SA) and usually propagation delay errors at the reference station. With the

assumption that these errors are also common to the measurements made by user's receiver , the application of the corrections will result in more accurate coordinates.

- Wide Area Differential GPS: WADGPS is a form of DGPS in which the user's receiver receives corrections determined from a network of reference stations distributed over a wide geographic area. Separate corrections are usually determined for a specific error sources- such as satellite clock, ionospheric propagation, delay and ephemeris. The corrections are applied in the user's receiver or attached computer in computing receiver's coordinates. The corrections are typically supplied in real time by way of a geostationary communications satellite or through a network of ground-based transmitters. Corrections may also be provided at a later date for post processing collected data.

Reference station

- Basically, a reference station can be seen as a conventional GPS receiver (although it should be equipped with much more sophisticated and accurate receiver technology) but differs from it in that it is stationary and its position has been very accurately determined by surveying.
- The reference station make a frame with correction information that need to transmit to the users. If the system work in real time typically employ a Transmitter/receiver to connect in real time reference station and user receiver
    - Usually in VHF or UHF band
- GPS receivers need to be able to decode the frame with information about the necessary corrections
    - Serial format
    - RTCA DO-229A/B
    - RTCM-104 (Radio technical commission for Maritime Services Special Committee No. 104)
- There are some private services such as OmniStar and Skyfix who allow the subscribed users the access to the corrections performed by a network of reference stations around the Earth.

Satellite Based Augmentation System (SBAS) → WAAS, EGNOS, MSAS y GAGAN
GPS/GLONASS + Satélites Geoestacionarios = EGNOS

SBAS improvements

- Integrity: Is the better performance of SBAS. With a network of monitoring station around a continent, the system monitors all GNSS segments and send to the users necessary data to compute integrity parameters in real time
- Accuracy: The system provide real time correction for all the receivers around a continent
- Availability: Provide new satellites , GEP with a PRN ID. This increase the number of SV in the GPS constellation.

GALILEO

- The Galileo system is the third satellite-based navigation system currently under development.
- Its frequency structure and signal design is being developed by the European Commission's Galileo Signal Task Force (STF), which was established by the European Commission (EC) in March 2001.
- The STF consists of experts nominated by the European Union (EU) member states, official representatives of the national frequency authorities, and experts from the European Space Agency (ESA).

Galileo Navigation Services

- Open Service (OS) provides signals for positioning and timing free of direct user charge, and is accessible to any user equipped with a suitable receiver with no authorization required. In this respect it is similar to the current GPS L1 C/A-code signal. However, the OS will be of higher quality, consisting of six different navigation signals on three carrier frequencies. OS applications will include the use of a combination of Galileo and GPS signals, thereby improving performance in service environments such as urban, canyons, and heavy vegetation.

- Safety of life Service SOL is intended to increase public safety by providing certified positioning performance, including the use of certified navigation receivers. Typical users of SOL will be airlines and transoceanic maritime companies
- Commercial Service CS is intended for applications requiring performance higher than that offered by the OS. Users of this service pay a fee for the added value. CS is implemented by adding two additional signals to the OS signal suite
- Public Regulated Service (PRS) The PRS is an access-controlled service for government-authorized applications. It will be used by groups such as police, coast guards and customs. The signals will be encrypted and access by region or user group will follow the security policy rules applicable in Europe. The PRS will be operational at all times and in all circumstances, including periods of crisis. A major feature of PRS is the robustness of its signal which prospects it against jamming and spoofing.
- Search and Rescue SAR is Europe's contribution to the international cooperative effort on humanitarian search and rescue. It will feature near real-time reception of distress messages from anywhere on Earth, precise location of alerts (within a few meters), multiple satellite detection to overcome terrain blockage and augmentation by the four low earth orbit (LEO) satellites and the three geostationary satellites in the current COSPAS-SARSAT system.

Galileo Signal Characteristics

- E_{5a}-E_{5b} band: (1260MHz -two carrier: 1300 MHz) There are two carrier:
  - 1176.45 MHz
  - 1207.140 MHz
  - Both are available to the Open Service (OS), CS, and SQL services
- E_6 Band: (1260-1300 MHz). The carrier is 1278.75 MHz
- E_2-L_1-E_1 Band: span the frequency range from 1559 to 1591 MHz. Used by the PRS service, OS, CS and SQL services

GNSS Internet Information

- The Aerospace Corporation's GPS Primer Civil GPS Service Interface Committee
- European Commission — Enterprise and Industry (Galileo)
- Educational Observatory Institute
- Federal Aviation Administration Navigation Services
- Federal Geographic Data Committee
- European Satellite Services Provider (EGNOS)
- European Space Agency
- GPS, Geodesy, and Application Program
- How GPS Receivers Work
- The Institute of Navigation
- International GNSS Service
- Japanese Quasi-Zenith Satellite System (QZSS)
- NASA's GPS Applications Exchange
- National Air and Space Museum, GPS — A New Constellation
- NOAA's National Geodetic Survey
- National Institute of Standards and Technology (NIST), Time and Frequency Division
- USAF Global Positioning Systems Directorate
- WAAS Test Team

Terrestrial Radio Navigation systems.

• T4.- Loran-C, VOR

• T5.- RADAR and SONAR

LORAN-C

- LOng RAnge Navigation (LORAN) uses signal phase information from three or more long-range navigation signal sources positioned at fixed, known locations.
- The LORAN-C system relies upon a plurality of ground-based signal towers, spaced 100-300 km apart. Antenna towers transmit distinguishable electromagnetic signals that are received and processed by a LORAN signal antenna and LORAN signal receiver/processor that are analogous to GPS antenna and receiver/processor.
- Loran-C allow the user compute his absolute 2D position (Latitude, Longitude) like GPS
- Class II navigation.
- Hyperbolic system. As GPS, it allow the user to compute his absolute position, but only in 2D.
  - Triangulation.
  - 2D
  - Low accuracy, about 200 m for CEP.
- Carrier in Low Frequency band, LF.
  - 100 KHz.
- Propagation by surface wave.
- High coverage but not global.
- It was developed for nautical transoceanic navigation
- Continuity is discussed in the coming years and also its possible improvement to use it as a backup for GNSS.

LORAN-C Termination Information USA

- The Coast Guard published a Federal Register notice on Jan. 7, 2010, regarding its intention to terminate transmission of the LORAN-C signal Feb. 8, 2010.
- A LORAN Programmatic Environmental Impact Statement Record of Decision stating that the environmentally preferred alternative is to decommission the LORAN-C Program and terminate the North American LORAN-C signal was published in the Federal Register on Jan. 7, 2010.
- TERMINATION OF RUSSIAN AMERICAN LORAN-CHAYKA SIGNALS:
  - The U.S. Coast Guard transmission of the Russian American signal was terminated on 01 Aug 2010.
- TERMINATION OF CANADIAN COAST LORAN-C SIGNALS:
  - The U.S. Coast Guard transmission of Canadian LORAN-C signals was terminated on 03 Aug 2010.

Loran-C status in Europe

- Availability: The system is design to reach 99,9% of availability. Users can be warned of chain or station problem using blink
- Application: Maritime, terrestrial or air-plane positionning. Loran C is also used for time transfert by laboratories and observatories.
- Frequency: 100 Khz.
- Range: 1000 nautical miles from transmitting stations.
- Coverage: Variable depending on navigation area. The coverage is good in Europe but null in Africa and America. (The US and Canadian Loran-C chains were stopped in 2010)
- Precision: Varying from several 10th meters to several 100th meters. Precision depends on several parameters: season, position compare to transmitters, receivers quality, accuracy of chain synchronisation..

  Future? →Enhanced Loran (eLoran)
- As a back up system?
- Technological improvements in transmitter performance, system control, and end-user signal processing equipment and antennas offer improved system accuracy, availability, and integrity.

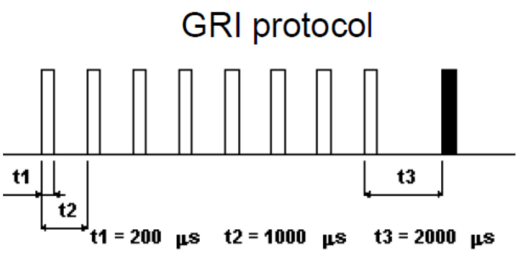
- The Enhanced Loran (eLoran) Definition Document was developed in 2006 at the United States Coast Guard Navigation Center by an international team of authors and was published by the ILA in 2007.
- eLoran is a high power, low-frequency, accurate radionavigation system that delivers a 2-dimensional position, velocity, precise timing information and additional data to its users. The system operates at 100 kHz in a band reserved for radio navigation. For minimal navigation operation, a user needs to receive at least three stations, typically located hundreds of miles apart, that transmit pulses at precisely timed intervals. The excellent stability of the system yields repeatable accuracies of 20-50 meters and timing information accurate to within 50 ns from UTC.

- Numerous reports and studies assessed the vulnerabilities associated with short- or long-term outages of GNSS.
- Recommendations to minimize safety, environmental, or economic impacts include the retention or provision of alternate services that provide position, velocity, and time.
- Loran is, for the largest user communities, the only viable alternative system. It is:
  - Characterized by dissimilar failure modes to GNSS
  - Difficult to jam due to high power levels
  - Provision of an area navigation capability (RNAV)
  - Precise time and frequency service
  - Capable of meeting harbor/harbor minimums
  - Most cost effective per square kilometer

Long-Range Navigation, LORAN-C. : LORAN-C is a low-frequency ground-based Radio navigation and time reference system that uses stable 100 kHz transmissions to provide an accurate regional positioning service.

- LORAN-C is an independent, standalone system that does not provide corrections to GPS signals, but instead uses time difference of arrival (TDOA) to establish position.
- LORAN-C transmitters are organized into chains of 3–5 stations.
- Within a chain one station is designated as the master (M) and the other secondary stations (slaves) are identified by the letters W, X, Y, and Z.
- The sequence of signal transmissions consists of a pulse group from the master station followed at precise time intervals by pulse groups from the secondary stations.
- All LORAN-C stations operate on the same frequency of 100 kHz, and all stations within a given chain use the same group repetition interval (GRI) to uniquely identify the chain.
- Within a chain, each of the slave stations transmits its pulse group with a different delay relative to the master station in such a way that the sequence of the pulse groups from the slaves is always received in the same order, independent of the location of the user. This permits identification of the individual slave station transmissions

Each Loran-C pulse has an approximate duration of 200 μs. The interval between pulses within a pulse group is 1000 μs, except for the last two pulses at the Master which have a 2000 μs interval.



LORAN-C principles

- The basic measurements made by LORAN-C receivers are TDOA between the master station signal pulses and the signal pulses from each of the secondary stations in a chain
  - Each time delay is measured to a precision of about 0. 1 μ s or better.
- LORAN-C stations maintain integrity by constantly monitoring their transmissions to detect signal abnormalities that would render the system unusable for Navigation
  - If a signal abnormality is detected, the transmitted pulse groups "blink" on and off to notify the user that the transmitted signal does not comply with the system specifications.

LORAN-C Accuracy

- LORAN-C, with an accuracy approaching approximately 30 m in regions with good geometry, is not as precise as GPS.
    - However, it has good repeatability, and positioning errors tend to be stable over time.
- A major advantage of using LORAN-C as an augmentation to GPS is that it provides a backup system completely independent of GPS.
    - A failure of GPS that would render LAAS inoperable does not affect positioning using LORAN-C.
- On the other hand, LORAN-C is only a regional and not a truly global navigation system, covering significant portions, but not all, of North America, Canada, and Europe, as well as some other areas

Avionics Radio-Navigation systems VOR

• By 1946, VHF Omnidirectional Range, VOR, had become the US standard and later was adopted by International Civil Aviation Organization (ICAO) as an international Standard

VHF Omnidirectional Range, VOR

• The VHF Omnidirectional Range navigation system, VOR, was probably the most significant aviation invention other than the jet engine.
• With it, a pilot can simply, accurately, and without ambiguity navigate from Point A to Point B.
• The widespread introduction of VORs began in the early 1950s and 60 years later it remains the primary navigation system in the overwhelming majority of aircraft.

VOR principle

• The basic principle of operation of the VOR is very simple:
– the VOR facility transmits two signals at the same time. One signal is constant in all directions, while the other is rotated about the station. The airborne equipment receives both signals, looks (electronically) at the difference between the two signals, and interprets the result as a radial from the station.
– it is entirely based on radials away from the station.

VOR display

• It has 4 elements:
– Rotating Course Card, calibrated from 0 to 360°, which indicates the VOR bearing chosen as the reference to fly TO or FROM. Here, the 345° radial has been set into the display. This VOR gauge also digitally displays the VOR bearing, which simplifies setting the desired navigation track.
– The Omni Bearing Selector, or OBS knob, used to manually rotate the course card.
– The CDI, or Course Deviation Indicator. This needle swings left or right indicating the direction to turn to return to course. When the needle is to the left, turn left and when the needle is to the right, turn right, When centered, the aircraft is on course. Each dot in the arc under the needle represents a 2° deviation from the desired course. This needle is more-frequently called the left-right needle, with the CDI term quickly forgotten after taking the FAA written exams. Here, the pilot is doing well, and is dead-on course—or maybe lazy and with the autopilot activated in the "NAV" mode.
– The TO-FROM indicator. This arrow will point up, or towards the nose of the aircraft, when flying TO the VOR station. The arrow reverses direction, points downward, when flying away FROM the VOR station. A red flag replaces these TO-FROM arrows when the VOR is beyond reception range, has not been properly tuned in, or the VOR receiver is turned off. Similarly, the flag appears if the VOR station itself is inoperative, or down for maintenance. Here, the aircraft is flying TO the station

RADAR RAdio Detection And Ranging

- Device which employs the transmission properties of electromagnetic waves for measuring the following parameters of a given target:
    - Distance
    - Relative Position (Azimuth, elevation, height)
    - Velocity

- Notice that the Radar don’t provide absolute position.

RADAR principle

- RADAR systems use modulated waveforms and directive antennas to transmit electromagnetic energy into a specific volume in space to search for targets. Objects (targets) within a search volume will reflect portions of this energy (radar returns or echoes) back to the radar. These echoes are then processed by the radar receiver to extract target information such as range, velocity, angular position, and other target identifying characteristics.
- Typically, the frequency band used span from 2 GHz- 18 Ghz.

RADAR classification

- Radars can be classified as ground based, airborne, space borne, or ship based radar systems.
- Also can be classified into numerous categories based on the specific radar characteristics, such as the frequency band, antenna type, and waveforms utilized.
- Another classification is concerned with the mission and/or the functionality of the radar:
  - Weather
  - acquisition and search
  - Tracking
  - track-while-scan
  - fire control
  - early warning, over the horizon, terrain following, and terrain avoidance radars.
- Radars are most often classified by the types of waveforms they use, or by their operating frequency.
- Considering the waveforms, radars can be:
  - Pulsed Radars (PR).
  - Continuous Wave (CW)

CW radars

- CW radars are those that continuously emit electromagnetic energy, and use separate transmit and receive antennas.
- Unmodulated CW radars can accurately measure target radial velocity (Doppler shift) and angular position

RADAR DOPPLER

- Radars use Doppler frequency to extract target radial velocity (range rate), as well as to distinguish between moving and stationary targets or objects such as clutter.
- The Doppler phenomenon describes the shift in the center frequency of an incident waveform due to the target motion with respect to the source of radiation. Depending on the direction of the target’s motion, this frequency shift may be positive or negative.
  - A waveform incident on a target has equiphase wavefronts separated by , the wavelength. A closing target will cause the reflected equiphase wavefronts to get closer to each other (smaller wavelength). Alternatively, an opening or receding target (moving away from the radar) will cause the reflected equiphase wavefronts to expand (larger wavelength).
- Notice that with a CW doppler Radar we only compute the velocity, not de range.

$$f_d = 2v/c \quad f_0 = 2v/lambda$$

SONAR Applications

• As Communication system

• As Ultrasonic Sensor: Underwater or in the air

Ultrasonic sensors (In the air)

- Ultrasonic waves are used to enable stable detection of transparent objects, such as transparent films, glass bottles, plastic bottles, and plate glass, using Through-beam or Reflective Sensors
- Terms

Speed of sound: The speed of sound "C" in air is $C \approx 331.5 + 0.61\ \theta$ (m/s), where θ is the air temperature (°C). The speed of sound changes as the air temperature changes, and this results in temperature-based distance measurement error.

– Reflection and transmission: Ultrasound waves move straight forward in a uniform medium, and are reflected and transmitted at the boundary between differing media. This phenomenon is affected by the type and shape of the media. A human body in air causes considerable reflection and can be easily detected.

– Multi-reflection: This occurs when ultrasound waves that have already reflected from the detection object once reflect from the sensor head surface, nearby walls, or the ceiling back to the detection object, and then back to the sensor.

- For example, in the case of double reflection, the same ultrasound waves are received as a single reflection but at twice the distance.

– Limit zone (reflective models): Not only the maximum detection distance but also the minimum detection distance can be adjusted, in connection with or independently of the maximum distance. This detection range is called the limit zone (zone limit).

– Non-sensitive zone and uncertainty zone (reflective models): The non-sensitive zone is the interval between the surface of the sensor head and the minimum detection distance resulting from detection distance adjustment. The uncertainty zone is the area close to the sensor where detection is not possible due to the sensor head configuration and reverberations.

– Detection may occur in the uncertainty zone due to multi-reflection between the sensor and the object.

- Directional characteristics: The ratio of the sound output (needed to transmit the specified sound energy to the target object) of the nondirectivity transmitter to the sound output of the directivity transmitter is called the directivity gain.
  - As the frequency and vibration area increase, the directivity grows sharper and sound waves are emitted with greater efficiency.
  - The directivity of a sensor unit used as an ultrasound switch is 8° to 30° (sound pressure half-angle).
  - The directivity is also strongly affected by the shape of the sensor horn and the vibration mode of the transducer, and thus the sensor unit shape, operation frequency, and transducer type are selected to provide the desired operation range

Assisted GPS, GNSS and SBAS

A-GPS

- A-GPS is an enhanced position location method based on the satellite-based global positioning system (GPS). It ensures fast position location information for mobile devices by obtaining precise positioning data from base stations that are constantly monitoring GPS satellites. This positioning data, called Assistance Data, allows the mobile to determine its exact location information to the network within seconds, rather than taking up to several minutes using unassisted GPS techniques.
- Assisted GPS (A-GPS) improves on standard GPS performance by providing information, through an **alternative communication channel**, that the GPS receiver would ordinarily have received from the satellites themselves.
- The A-GPS receiver still makes measurements from the satellites, but it can do so more quickly, and with weaker signals, than an unassisted receiver.
- GPS is now expected to work almost anywhere, even, sometimes, indoors
  - **Push-to-fix applications** have emerged where a single position is expected almost instantly.
  - All of this must be delivered in a way that adds little or no cost, size, or power consumption to the host device
  - These requirements are what drove the development of A-GPS

- A-GPS works by providing the information that allow the GPS receiver to know what satellites to expect before it even tries, and then the assistance data provides the satellite ephemerides for use in the GPS position computation.
- The total time to first fix is reduced from an order of 1 min to the order of 1 second
- Typical architecture of the A-GPS receiver is designed in order to increase the sensitivity of the receiver and allows it to acquire signals at much lower signal strengths.
- Cellular Networks are the best option to provide data from a-GNSS server to the users.
- The assistance may be:
    - Acquisition assist
    - Almanac
    - Ephemeris
    - Frequency
    - Time
    - Position approx.

DSRC by ETSI

- Dedicated Short-Range Communications (DSRC) provide communications between a vehicle and the roadside in specific locations, for example toll plazas. They may then be used to support specific Intelligent Transport System applications such as Electronic Fee Collection.
- DSRC are for data-only systems and operate on radio frequencies in the 5,725 MHz to 5,875 MHz Industrial, Scientific and Medical (ISM) band. DSRC systems consist of Road Side Units (RSUs) and the On Board Units (OBUs) with transceivers and transponders. The DSRC standards specify the operational frequencies and system bandwidths, but also allow for optional frequencies which are covered (within Europe) by national regulations.
- DSRC systems are used in the majority of European Union countries, but these systems are currently not totally compatible. Therefore, standardization is essential in order to ensure pan-European interoperability, particularly for applications such as electronic fee collection, for which the European imposes a need for interoperability of systems.
- Standardization will also assist with the provision and promotion of additional services using DSRC, and help ensure compatibility and interoperability within a multi-vendor environment.

Dedicated Short-Range Communication, DSRC

- DSRC is a localized, bidirectional, high-datarate channel that is established between a fixed roadside system and a mobile device installed within a vehicle.
- The most widely used frequency bands for DSRC are:
    - 902 to 928 MHz (mainly North America).
    - 5.8 GHz or 5.9 GHz, depending on locally applicable standards
    - Infrared frequencies (mainly selected countries in Southeast Asia).

Potential DSRC Transportation Applications for Public Safety and Traffic Management

- Blind spot warnings
- Forward collision warnings
- Sudden braking ahead warnings
- Do not pass warnings
- Intersection collision avoidance and movement assistance
- Approaching emergency vehicle warning
- Vehicle safety inspection
- Transit or emergency vehicle signal priority
- Electronic parking and toll payments
- Commercial vehicle clearance and safety inspections
- In-vehicle signing
- Rollover warning
- Traffic and travel condition data to improve traveler information and maintenance Services

DSRC was developed with a primary goal of enabling technologies that support safety applications and communication between vehicle-based devices and infrastructure to reduce collisions. DSRC is the only short range wireless alternative today that provides:

- Designated licensed bandwidth: For secure, reliable communications to take place. It is primarily allocated for vehicle safety applications by FCC Report and Order FCC 03-324.
- Fast Network Acquisition: Active safety applications require the immediate establishment of communication and frequent updates.
- Low Latency: Active safety applications must recognize each other and transmit messages to each other in milliseconds without delay.
- High Reliability when Required: Active safety applications require a high level of link reliability. DSRC works in high vehicle speed mobility conditions and delivers performance immune to extreme weather conditions (e.g. rain, fog, snow, etc.).
- Priority for Safety Applications: Safety applications on DSRC are given priority over non-safety applications.
- Interoperability: DSRC ensures interoperability, which is the key to successful deployment of active safety applications, using widely accepted standards. It supports both V2V and V2I communications.
- Security and Privacy: DSRC provides safety message authentication and privacy.

•DSRC enables the most reliable, high speed vehicle-based technology for crash prevention safety applications
•DSRC provides for a broad cross-section of dedicated connectivity options for surface transportation safety.
•DSRC based communications serves as the basis for connected vehicle safety and mobility application integration

European Commission. Mobility and Transport. Road Safety

Intelligent Speed Assistance (ISA)

- is an in-vehicle system that uses information on the position of the vehicle in a network in relation to the speed limit in force at that particular location.
- ISA is meant to support drivers and help them to comply with the speed limits everywhere in the network. In that way ISA aims to prevent speeding violations (see also the ERSO text on Speeding).
- If large scale voluntary adoption of ISA will reduce the bulk of speed violations, this not only supports speed enforcement but may shift the emphasis of enforcement from general deterrence to specific deterrence.
- Instead of keeping speeds of the general driving public down - a task then taken over by generally accepted technology - the police can focus more on detecting extreme or repeated speed offenders.
- Rule 10: To the extent that new technologies facilitate voluntary speed control, police speed enforcement can direct itself more at detecting extreme or repeated speed offenders

Electronic Vehicle Identification (EVI)

- is a system that uniquely identifies a vehicle electronically. More specifically it can be defined as an electronic device that allows the unique, remote and reliable communication of identifying parameters of a vehicle. It would typically comprise a secure invehicle data storage element, suitable and secure interfaces and a vehicle-to-infrastructure data communication element.
- EVI can be used for many application such as crime prevention (prevention vehicle theft), vehicle tolling, access control (e.g. overview of cross border traffic). It can also be used for enforcement purpose, not only of speeding, but also of red light running and tail gaiting.

EVI project

- Electronic vehicle identification (EVI) was defined by the ERTICO-hosted EVI

- Project Consortium as " . . . a system that uniquely identifies a vehicle electronically and, as an electronic device that allows the unique, remote and reliable communication of one or more identifying parameters of a vehicle" .
- In its 2-year study concluding in 2004, the Project Consortium identified several application areas that would benefit from EVI, including crime prevention, access control, electronic road user charging, vehicle registration ownership identification, and enforcement of traffic regulations. The Consortium suggests that ". . . it should be possible to replace the existing systems for classification and identification . . . by storing a minimum set of vehicle-related data in the invehicle EVI components"

Vehicle Identification

ANPR Automatic Number Plate Recognition.

- Systems that process the video images taken by a camera in a lane, at the roadside, or on a gantry, to locate the license plate in the image and convert this into the appropriate alphanumeric characters, without any human intervention
- The significant advantage of such an approach is that it removes the need for any in-vehicle equipment to be installed.
- ANPR is a variation on the automatic account identification system, which relies on the vehicle's license plate as its unique identifier.
- Using video cameras for vehicle identification in tolling is a mature technology. Automatic Number Plate Recognition (ANPR) has been used in urban congestion charging schemes, such as London, Stockholm and Milan, although other examples exist outside city centres, such as the ETR407 toll highway in Toronto. ANPR is generally implemented for charging and enforcement purposes. Some countries such as Australia, Chile and South Africa are considering it as an alternative to the DSRC schemes (Kapsch, 2013).
- The increasing use of video cameras for road traffic monitoring has been an incentive to improve camera technology and optical processing, which is necessary to provide better contrast clearer images, even when the license plate is in a dark shadow, in the glare of low angles of sunlight, or surrounded by bright headlights in direct alignment with the camera.
- To improve accuracy and performance, the technical challenges facing ANPR technology vendors also include:
  - License plates of many and different shapes and sizes due to lack of regional standardization;
  - Non reflective license plates
  - Dirt and poor weather, including rain and snow
  - Non standardized fonts
  - Similarities between some letters and numbers (e.g., O and D, B and 8);
  - Insufficient control of ambient light at camera positions.
- This system works through cameras (mounted on poles or gantries at the roadside) taking a picture of the licence plate as the vehicle drives through the detection point. Optical Character Recognition (OCR) software reads the licence plate and the system then checks it against a list of registrations to identify the vehicle and apply a charge to the owner or driver. The user is charged without the need to install any OBU, either through a pre- registered account or individual payments per use.
- The OCR process can be deployed either in the field (integrated camera and ANPR) or at a central site. In the first case, the entire process can be performed at the roadside in real time. Data can be stored in the camera or roadside cabinet for later retrieval or is sent to a back office for additional processing. In the latter case images from the cameras are transmitted to a central computer which subsequently carries out the OCR process. The back office process may also require an additional manual check, in order to improve the accuracy of number plate interpretation.

Applications

- Intelligent Transportation Systems

- Road transportation
    - Electronic Toll Collection
    - Fleet Management
- Rail Transport
    - Train control

Rail signalling

- High speed signalling systems in EUROPE
- The ERTMS: European Rail Traffic Management System
    - ERTMS benefits related to the system (Why ERTMS?)
    - Main features of ERTMS (Which ERTMS?)

Why ERTMS ?

- Interoperability: European Commission supports the development of operational and technical interoperability with unified signalling equipment in order to open railway markets to all train operators;
- Safety: ERTMS equipments are designed and produced in compliance with CENELEC standards;
- Performance: high speed can be reached using the lowest amount of time distance between the trains (in Italy only 2’30’’ between two trains running at 300 Km/h);
- Availability/Reliability: due to the particular ERTMS architecture, there are less equipments along the lines, reducing fault probability and improving system reliability.

ERTMS levels

- ERTMS Level 1:
    - Overlay using Eurobalises and track side signals;
- ERTMS Level 2:
    - Fixed Block Authority is communicated directly from the Radio Block Center (RBC) to the train using GSM-R. Wayside track signals are optionally required;
- ERTMS Level 3:
    - Introduction of “moving block”. Wayside track signals are not required.

ERTMS level 1

- Discontinuous system working on an underlying and already existing signaling system; provides a continuous speed supervision;
- Movement authorities and track description data are generated by electronic Lineside Equipment Unit (LEU), located by side of the tracks, on the basis of information received from external signalling systems and track circuits;
- Movement authorities are transmitted to the train via wayside equipments called balises;
- The on-board sub-system calculates a dynamic speed profile taking into account the train braking characteristics and commands the brake application if necessary;
- Lineside signals are required. Loop (cable or radio) could be used in order to immediately refresh information related to the clear signal aspect (infill function).

ERTMS level 2

- Radio based Automatic Train Control (ATC) system (working on optional signalling system), which provides a continuous speed supervision toward fixed points of the line (end of block sections, speed restrictions, etc.);
- Movement Authorities, track description data, temporary speed restrictions and emergency messages are generated by Radio Block Centre (RBC) on the basis of information received from train itself, external interlocking system and track circuit. A RBC usually manages about 62 miles of double track section line.
- Messages are transmitted/received to/from the train via GSMR system;

- Balisesare used mainly for spot transmission of train location reference, to manage hand-over between RBCs and other particular situations;
- The on-board sub-system calculates a dynamic speed profile taking into account the train braking characteristics and commands the brake application if necessary;
- Linesidesignals are optional.
- GSM-R System: Coverage redundancy
  - High level of signal coverage
  - In case of Fault or Outage of one BTS the adjacent BTS provide ERTMS Radio Coverage and GSM-R Traffic Channel.

ERTMS level 3

- Main features similar to ERTMS level2, except for:
  - Functional difference: the target is the end of the preceding train (moving block);
  - Technical differences:
    - On-board equipment to check the train integrity is required (RBC needs this information to calculate movement authority);
    - Track Circuit for train detection are not required.
- Performances:
  - Increase line capacity (relevant for lines with intense traffic at low speed as subway)

ETCS lineside equipment (Siemens)

- Trainguard Eurobalise S21

The Trainguard Eurobalise S21 is used to transmit data to the vehicle intermittently. It consists of a compact module mounted in the center of the track. The Trainguard Eurobalise S21 transmits data in the form of telegrams. When the vehicle passes over the Trainguard Eurobalise S21, it feeds power to it by induction. The Trainguard Eurobalise S21 uses this energy to transfer its information to the EVC via the on-board balise/loop antenna. Trainguard Eurobalises S21 are used as transparent data balises and as fixed-data balises.

- Trainguard Euroloop S21 F

Trainguard Euroloop S21 F is a continuous option complementing the Trainguard Eurobalise S21, making it possible to transfer data continuously from the fixed system to the vehicle (infill function). It consists of a coaxial spaced conductor up to 1,000 m in length that is placed in the base of the rail between the distant signal and the main signal. The Euroloop modem modulates and amplifies the telegram data of the Trainguard LEU S21 onto the HF carrier.

- Trainguard LEU S21 lineside electronic unit

The Trainguard LEU S21 lineside electronic unit links the transparent data balise or the Euroloop modem with the signals on the line. It is either installed in a signal switchbox or in a separate housing on the signal to pick up the signal aspect via the signal cable. If it is not possible to mount a switchbox on the signal mast, installation close to the signal is also possible. The Trainguard LEU S21 has a telegram store in which the customized telegrams are stored. Each telegram contains a description of the track relating to the associated signal aspect. Depending on the signal aspect, the appropriate telegram is selected and sent to the transparent data balise

- Trainguard MiniLEU S11 mini lineside electronic unit

The MiniLEU can be used to replace old train protection systems by a cost-optimized ETCS L1LS solution. The Trainguard MiniLEU S11 links the Trainguard Eurobalise S11 to the lineside signals. The indicated signal aspect is read in by the MiniLEU and converted into an ETCS data telegram. The interface between the balise and the MiniLEU is activated by magnetic coupling when traversed by a tractive unit. This ensures minimum energy consumption which is completely covered by solar generated electricity.

- Trainguard 200 RBC

The radio block center generates the driving instructions from the track information from an electronic interlocking and ETCS-specific data and transmits them to the vehicle via GSM-R, in accordance with the Euroradio specification. The Trainguard 200 RBC also enables telegrams to be output to the vehicle via balises as an extended Level 1 solution.

- Trainguard FUTUR 1300 ERTMS Level 1

Trainguard FUTUR 1300 is the complete Siemens Level 1 solution which provides class leading performance for operation and maintenance for railway administrations throughout the world. Trainguard FUTUR 1300 complies with the latest versions of the Technical Specifications for Interoperability(TSI), Functionality Requirement Specifications (FRS), System Requirement Specifications (SRS) and all UNISIG related specifications.

- Trainguard FUTUR 2500 ERTMS Level 2

Trainguard FUTUR 2500 is Siemens' comprehensive Level 2 system which provides great performance for operation and enhanced maintenance features for railway administrations throughout Europe. The system employs already proven techniques in order to increase process speed. Its components comply with the highest level of reliability. Contains:

- Central ERMTS Control (CEC)
- Local ERTMS Control (LEC)
- Juridical Recorder Unit (JRU)
- Maintenance Assistance System (MAS)
- Communicating through an Interface Control Equipment (ICE)

ETCS on-board equipment

- On-board computer on a state-of-the-art platform (TCC)
- Display solution with a driver-machine interface (DMI) or an indicator lamp block
- Data recorder with a bus interface
- GSM-R system

GSM-R is based on the proven GSM standard, but also offers numerous railway-specific functions in addition to the continuous transmission of driving instructions; for example, forwarding of text messages and emergency calls. The digital radio system completely replaces the existing communications equipment and therefore contributes to interoperability.

Autonomous Systems: Inertial Systems

Inertial sensors are the most important mechanical microsensors

- Micro-accelerometers (linear acceleration)
- Micro-gyroscopes (angular rate)

Only micro-accelerometers (without gyroscopes) held the 2nd place in sensors sales record of the world, with a 609 M$ market in 2005. Automobile applications stood for a 90% of the market : Airbag, suspension…

Growth in MEMs-based semiconductor (sensors and actuators) market due to the introduction of accelerometers and gyro sensors into smartphone handsets for intelligent control and motion-sensing applications for navigation and a range of new uses, such as activity tracking, health monitoring, and hand-gesture interfaces.

Accelerometers: measurement of acceleration. Speed and travelled distance estimates
Gyroscopes: measurement of angular rate: heading estimate

Consumer Applications:

- Virtual reality devices
- 3D mice
- HITECH Sport equipment
- Photo cameras
- Videocameras (stabilization)
- Games
- cellphones

Biomedical applications:
- Activity monitoring
- Person movement tracking

Industrial applications:
- Robotics
- Space

Monitoring and control of impacts and vibrations
- During transportation(fragile goods)
- During manufactury

Depending on the application we must choose accelerometers taking into consideration the measurement range:
- < 1g: ABS
- < 2g: Vertical motion
- 50g: frontal airbag, wheel motion

Other parameters: frequency, temperature range, linearity, etc.

Accelerometers:
- VTI Technologies (35% of the market)
- Denso, Delphi-Delco, Analog Devices, Bosch…

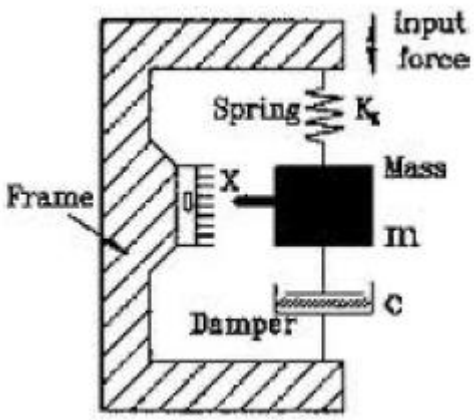
Gyros:
- BAE, Bosch, Delphi-Delco, Samsung…

¿what does an accelerometer do?
- It measures tilt and motion, In static, tilt is measured
- In motion, It measures vibrations and impacts (acceleration), Speed estimate (from the acceleration) and Position estimate (from the speed)

¿How?
An accelerometer normally contains:
a) A proof mass
b) A spring
c) A sensing element (to measure acceleration)

Proof mass moves as a consequence of an acceleration (or deceleration). The spring holds the mass and returns it to its original position

Sensing method transforms the motion into an electrical impulse



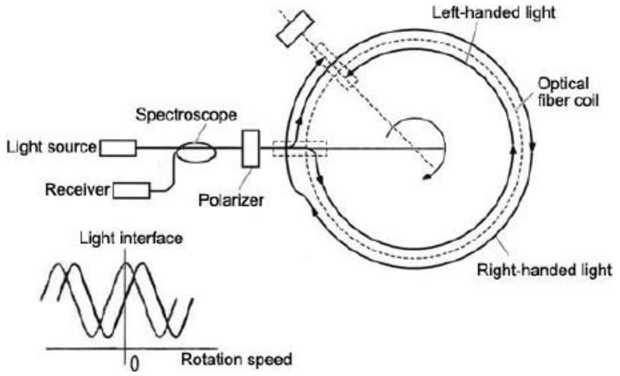
How come an accelerometer can measure the tilt?
If the sensor is on the horizontal plane, the measurement along the two other coordinated Cartesian axis must be null, being 9.81 m/s2the one along the sensitivity axis of the sensor

Parameters
- Sensitivity
- Maximum operation range
- Frequency
- Scale-factor
- Resolution

- Non-linearity
- Bias (zero offset)
- Impact survival (sharp changes in a)
- Cross-axis sensitivity

What does a gyro do?
It measures orientation changesIn static, it measures the orientation. In motion,

- Turn rate (angular velocity)
- Angles (from turn rate)



¿How?
Principle of angular momentum conservation (traditional gyro) → Laser Fiber optic gyro, by means of interference of light (more accurate)

Parameters

- Resolution
- Random walk
- Scale-factor
- Zero rate output (output with null turn rate)
- Bandwidth
- Maximum range

With a gyro we can measure turn rates, but to find out the final angle we need an initial estimate of the orientation. ¿How could we do that with the same gyro?

The gyro trends to point to a fixed point in the space (not of the Earth). Since the Earth completes a turn every 24h, if we align the gyro axis with the one of the Earth a value of 7.27 x 10^{-5}rad/s will be obtained. With a set of 3 gyros in 3 axes, the other two axes should be null, and a value of 7.27 x 10^{-5}rad/s in the axis aligned with the astronomic north (Polaris).

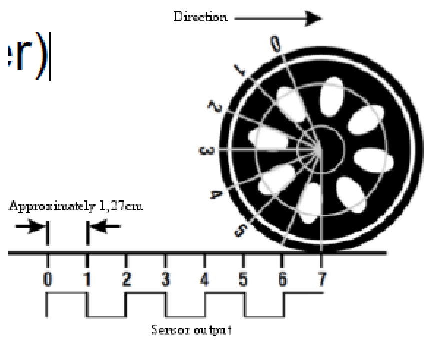
Pros when compared to magnetic compass:

- Astronomic North (real), no magnetic, if precession and nutation are not considered (slow motions)
- Not jammed by magnetic fields, metals moving iron parts, bridges, buildings, etc.
- Easier installing
- Applicable in outer space, where there is no GPS!

INS Inertial Navigation Systems

- Exploitation of inertial sensors to calculate the position and orientation of a moving object
- Principle: *if an object experiences no net forces, then the object stays at rest or with constant velocity. In the case of having a net force acting on the body, this will cause an acceleration that can be measured and integrated to estimate velocity and position*

Odometry:
It is not really inertial navigation. It is based on the count of wheels' (partial) turns and the wheels' perimeter (odometer y speedometer)



Odometry, flaws:

- slippages
- glides
- Nominal value of the wheel diameter

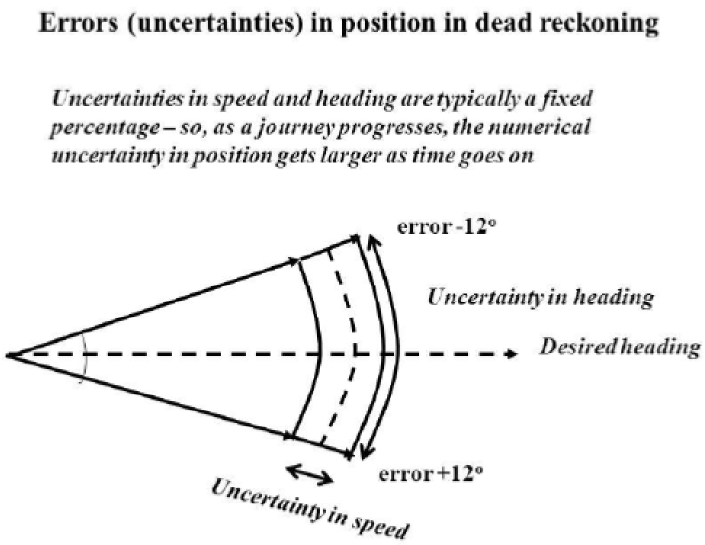
Main disadvantage of the inertial navigation: integration drift
(Accumulation of Mean Squared Error due to the integration proces)

In road vehicle navigation we can ignore the Earth turn but not gravity

- In aerial navigation we must take into account the Earth turn, but not precession and nutation
- Commercial aircrafts use INS for flying, using GPS for INS calibration

Dead-reckoning (DR) is the process of calculating the current pose (position and heading) based on previous ones by integrating velocity, acceleration and turn-rate.

- Usual dead-reckoning sensors are encoders, accelerometers and gyroscopes, providing travelled distance, acceleration and turn rate, respectively.
- Its use in vehicle navigation is very common because measurements can be easily retrieved from the CANBUS of vehicles and from the inertial sensors installed onboard modern cars.
- The fact that these sensors provide measurements of the first or second order derivative of the pose implies that the position and heading estimates are subject to cumulative errors.
- The magnitude of these errors depends on the sensors accuracy (noise and bias), but also on the techniques employed for the pose calculation, including the modelling of the sensor errors and the vehicle models.



Hybrid GNSS/DR

- In the case of hybridized dead-reckoning-assisted GNSS-based positioning systems, the fusion architecture and the fusion algorithm have a relevant impact, as well.
- The use of a GNSS-based multi-sensor positioning brings different benefits.
- For a usual configuration with encoders and inertial sensors, the most relevant features may be enumerated as follows (next page).

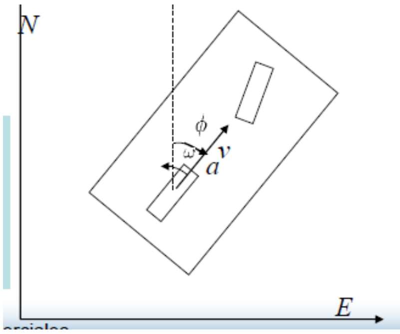
Advantages

- Immunity to usual GNSS problems, such as signal blockage, jamming, weather conditions, etc. thanks to the nature of inertial navigation. IMPROVES AVAILABILITY AND CONTINUITY
- Provision of PVT at a higher rate, as inertial sensors usually work 1 or 2 orders or magnitude faster than GNSS receivers.
- Complementary information, such as acceleration and attitude (roll, pitch, yaw).   2&3: TRACK VEHICLE DYNAMICS

- Redundant positioning estimates coming from different sources. REDUNDANCY: ACCURACY AND INTEGRITY

Vehicle models provide the mean to integrate the DR sensors. A common assumption when slippage can be neglected is that the vehicle motion is non-holonomic, so that the heading equals the track angle.

- A good choice of the vehicle model for a dead-reckoning system leads to important reduction of the positioning error.



Vehicle models become of special interest in the case of a system with low-cost sensors, as the worse the sensor performance, the more convenient to constraint the positioning problem to avoid the rapid accumulation of the positioning error.

A simple model that suits the sensor set a+g+GPS: Velocity and acceleration are assumed to be aligned

Fusion

- The purpose of data fusion is the combination of all the navigation information into a single hybridized output that benefits from the complementary nature of the different sources, such as GNSS and dead-reckoning (GNSS/DR).
- The most common algorithm for GNSS/DR data fusion is the Extended Kalman Filter (EFK). With an EKF, the filtering problem is linearized around the current estimates. EKF gives the optimal (with Minimum Mean Square Error) solution to the linearized problem, when the error sources are uncorrelated and zero-mean.

Extended Kalman Filter. Cycle

i. **Prediction** of the **state vector** by applying the state transition model.
ii. **Prediction**of the **covariance** of the error of the state vector taking into consideration the system modelling error and the sensor noise characteristics.
iii. Calculation of the **innovation** of the observation and its **covariance**, taking into consideration the error characteristics of the measurements.\
iv. Calculation of the **Kalmangain**. The gain will be in favor of, either the prediction, or the observation, depending on how much confidence can be laid on each of them.
v. **Update of the state estimate and its covariance** by using the gain calculated in iv.
vi. Return to step i.

Depending on the measurements used in the fusion algorithm, the fusion architecture can be either loosely or tightly coupled.

- In loosely coupled fusion architectures, the GNSS fix is merged with the position estimate of the system. Considering the positioning loop described before, the simplest state vector is the vehicle position and heading, and the observation vector can be the GNSS fix in the same navigational frame. In this case, the state covariance matrix represents the confidence on the state estimate.
- In tightly coupled architectures, the fusion is not carried out with positioning variables, but with GNSS pseudoranges and Doppler measurements.

At the expense of a higher complexity of the architecture, the tightly coupled approach allows three remarkable benefits:

a) The GNSS pseudorange measurements errors are, a priori, less correlated than the errors of the calculated positioning variables, what matches better the assumptions of Kalman filtering.

b) It provides a mean to benefit from the GNSS measurements even when the GNSS fix cannot be calculated (when there are less than 4 satellites in view).

c) It makes it possible to exploit dead-reckoning measurements for detecting faulty satellite measurements, enhancing the integrity of the position.

Flaws of EKF

When applied to the GNSS-based positioning problem, the EKF strategy presented before has several drawbacks

1. The optimal solution stands for a linearized problem, and not for the original problem. The more non-linear the problem, the worse the EKF.
2. The assumption of zero-mean and uncorrelated noises is very rough for standalone GNSS receivers, especially in urban areas subject to multipath and diffraction errors.

Alternatives to EKF

Due to these two problems, the literature of the field presents many alternatives. Mostly, these can be categorized in two groups:

1. Fusion algorithms that exploit more refined a priori statistical information about the noises and errors.
2. Intelligent Fusion techniques that do not use an explicit model of the system and demand often a learning phase (e.g; neural networks, fuzzy logic).

Among those of category 1, it is worth to mention the Particle Filter (PF) which is capable of dealing with non-Gaussian errors, at the expense of increasing the computational complexity.

Digital Maps: GIS

GISGeographic Information System: A database that is structured geographically

Normally, a GIS is assumed to include the database plus all the HW and SW necessary for handling, editying, analizying, etc.

GIS is a set of intelligent maps that show features and their geographical relations. These maps accept queries and analysis

GIS are organized in layers described by digital maps.

- Each layer describes a different feature or detail level. e.g. major roads, streets, bus-lines, etc.
- There are two main formats for digital maps:
    - Raster
    - Vectorial

Formats

Raster codified image arranged in a cell array. Each cell contains position coordinates and an attribute value. Adjacent cells with same value share the same attribute.

Raster image of codified array of cells. Resolution: cell size

Vectorial geometrical elements such as lines, points and polygons

Points: e.g. Hydrant points

Lines: streets

Polygons: parcels, buildings.

Pros

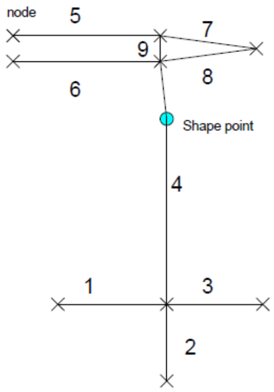
- Vectorial: more convenient for the description of lines (streets) or elements with a certain given geometry. It demans less memory, no resolution-loss.
- Raster : more convenient for the description of features that can be measured at each point, such as elevation or when feature bounds are blurred. The process of superposition (relation between layers) is straightforward.

Cons

- Vectorial: information to be stored is limited by the vectorial model (incomplete maps). Superposition is more complex. More difficult updates.
- Raster: resolution limited to the cell size. More memory use to describe all the cells.

Within a GIS both map formats can be included. Both formats can be complementary

Digital road maps



- Geometry location of elements: nodes and shape points (latitude, longitude)
- Topology atributes of the geometric elements (segments) and its relations: connectivity
- Segments 4 and 6 are connected (a vehicle can drive from 6 to 4)
- Segments 4 and 5 are not connected (only through 9)

Most road digital maps define their topology at the nodes

- A vehicle can drive from one segment to another through the nodes
- Segments are defined as carriageways, not lanes
- Carriageway object includes number of lanes and direction.
- In highways and major roads opposite driving directions are represented by different segments
- In sideways and minor roads, there is a center line for the road that can be either one way or two ways

Digital road maps manufacturers

- Navteq (USA) (Nokia) Mercedes, Yahoo! Maps, Bing maps…
- Teleatlas (Netherlands) (tomtom) Used to provide Google Maps Data
- Google maps
- Openstreetmaps (free maps, GPS traces)
- Emaps (Enhanced maps)

Commercial digital maps. Based on:

- Polylines (straight)
- Nodes
- Shape points
- Simplified. In some cases and for certain applications they lack precision, accuracy or integrity

Enhanced maps: Emaps

- More complete: a line per lane (clothoid)
- More accurate: decimetric errors
- Higher costs (at large scale)

How to make an Emap:

- From GPS traces GPS + inertial sensors (with one or several loops)
- From aerial images (at the computer)

Lane-level services →CVIS Project

Successful demonstration onboard real tests with prototypes in Nantes, Berlin, Stockholm, Amsterdam…

Commercial digital maps

First road digital maps were scanned versions of paper road maps. How are maps made by TeleAtlas?

Map-matching

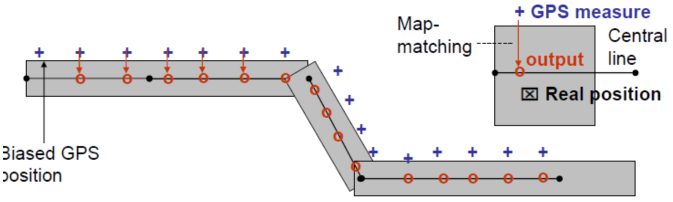
You are exactly here!

You are on the X Street, 40 m far from the crossroad with Y Avenue.

Latitude and longitude data are normally not very practical per se at the user end. A map reference is usually demanded.

Projection of positions obtained by the sensors on a reference map.

Final position of the vehicle is normally assumed to be on the road, and not where the GPS tells if the latter means that is off the road.



Map-matching techniques

- Point to point
- Point to segment (curve)
- Multi-dimensional (point to segment + direction, orientation, speed limit…)
- Topological: topology contraints, curve to curve

Radio-frequency Identification (RFID)

Currently, The most deployed technology for object identification: BARCODE

- Disadvantages of bar code system: Stores few quantity of information
- Can not be reprogrammed.
- Due to this deficiencies, appears the Radio-frequency Identification technology (RFID)

Alternative: QR code Quick response code is the trademark for a type of matrix barcode (or two-dimensional barcode) first designed for the automotive industry in Japan.

- Became popular outside the automotive industry due to its fast readability and greater storage capacity compared to standard UPC barcodes.
- Applications include product tracking, item identification, time tracking, document management, and general marketing.
- Inherits most of the disadvantages of UPC barcodes.

Summary of RFID technology:

- RFID is a labelling system where are used transponders or tags set in the different objects to be identified. Each transponder carries out an identifier.
- Transponders have a non-volatile memory, that can be read by an external element called scanner or RFID reader through a radio link.
- An RFID reader can detect a nearby tag and extract the stored information.

Actually RFID technology is very old.

- It is considered the beginning of the RFID technology in the Second War World, where the IFF system (Identify Friendor Foe) was used to indentify friend airplanes.
- During the last decade has been the “big bang” of this technology, mainly due to reduction of prices.
- We can find a milestone of this technology in 2003, when the WalMart supermarket company ordered 500.000.000 RFID tags, and forced to its suppliers to include RFID technology in their products.

- In the following years this technology had a big deployment in the mass-market.

Deployment of RFID technology
- Between 1950 and 2000 were sold 1500 millions of RFID tags.
- In 2004 were sold 1000 millions.
- The predictions are about one bilion of RFID tags in 2015.
- In few years, RFID tags will be as popular as barcodes.

RFID architecture
An RFID system consist of three components: tags, readers and a controller to run the middleware

Tags or transponders
- They have the data that identify the objects. They use the Electronic Product Code (EPC), that identify each object without doubt (unique identification number).
- There are a great variety, depending on its size, memory storage, operating distances, range of temperatures, etc.
- Most of tags are embedded in plastics or other materials, for withstanding impacts, chemical products, humidity, dust, etc.
- Operating distances can change due to metals and electromagnetic radiations

RFID readers
- They establish a wireless communication channel with tags by means of a radio link.
- There are different readers, depending on the antenna size, frequency and power.

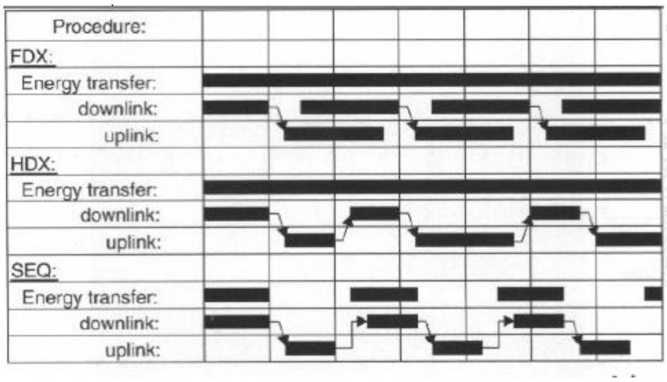
Controllers and software application
- At least they include a database with the EPCs of the tags (objects).
- The application runs the tag reading/writing steps

The basic system operation of RFID technology(passivetags)
1. The reader generates through its antenna a radio frequency wave that produces an electromagnetic field in its neighbourhood.
2. If a passive tag goes into this generated field, it is induced in the tag a current proportional to the power of this field, that is able to supply power to the tag chip.
3. The tag embedded in a object, consists of a electrical wire for reflecting RF energy (antenna) and a chip.
4. The tag sends an answer that contains its EPC and its data memory, that is received by the RF module of the reader (through its antenna) and can be read and decoded

Classification of RDIF systems
Some of the most important classification criteria in RFID systems are the following:
- According to transmission mode: Full-Duplex, Half-Duplex or Sequential systems.
- According to quantity of transmitted information: with or without microchip.
- According to tag activation mode: electromagnetic backscatter coupling and inductive coupling.
- According to tag access mode: read-only and writable tags
- According to power supply: active and passive tags.
- According to working frequency: LF, HF, UHF and Microwave.

According to transmission mode
- Full-Duplex systems: The data transfer between tag-reader and reader-tag, both take place at the same time.
- Hall-Duplex systems: The data transfer between tag and reader alternates.

- Sequential systems: The electromagnetic field is generated only to send data from reader to tag



According to quantity of transmitted information

- Tags with microchip have non-volatile memory (from few bytes up to Kbytes).
- Tags without microchip, transmit 1 bit, and they are widely used in shops as anti-theft system

According to tag activation mode

- With electromagnetic backscatter coupling, the reader's antenna transmits electromagnetic waves. The tag's antenna backscatter the energy returned to the reader's antenna. This kind of activation is used in UHF and Microwaves tags.
- Inductive coupling system is based on Lenz law. The reader's antenna generate a electromagnetic alternating field. When a tag goes through this field, the magnetic flux generates a voltage in the tag's antenna coil by inductance. This voltage is rectified and serves as the power supply for the microchip. This mode is used in LF and HF systems.

According to tag access mode:

- Read-only tags (RO): it works like bar codes, a serial number in ROM memory identifies the object.
- Writable tags (W): it allows to modify the information stored (most usual are EEPROM memories).
- Write-once-read-many tags (WORM): they are RO tags that can be programmed only once. One of its applications is to store the manufacture date.

According to power supply:

- Active tags: they have battery. The range distances is much better, but the cost is high and the life cycle is linked to the battery.
- Passive tags. (without battery) described in previous slides.
- Hybrid tags: they include a battery, but also use the electromagnetic field of the readers to send the signal. In this way, they get longer distances that passive tags and maintain a higher life cycle of the battery (e.g.in tracing of goods).

According to working frequency:

- Low Frequency (LF): range 125-134Khz. They have the shortes tdistance for readings, and are the cheapest ones. They are used in access control, animal identification, etc.
- High Frequency (HF): working frequency 13,56Mhz. Cost and distance a little bit higher. They are used in smart cards (contactless) and tracing.
- Ultra High Frequency (UHF): range 866-960Mhz. This technology has a long distance range (several meters), and a bit rate moderately high. It is used for object and products in motion.

- Microwaves: above2,4Ghz. The distance range is about tens of meters in the line of sight view, and the bit rate and price are the highest. They are used in toll-collect and port managements.

The working frequency of the tags have important implications
- The LF s ystem save very short distances of working, but the radio signals are not disturbed by water. With low frequencies, the waves get to transmit through the human body.
- The UHF systems (supermarkets), longer distance and bit rate, but the signals are easily disturbed by water, and are not able to go through metal layers of many cans and bottles. A bottle of water in the trolley can avoid a correct identification of all the products.

RFID tags
A RFID tag consists of an antenna and a chip embedded in any place into the substrate.

Functional classification according to EPCglobal:
- Class0. Read-only passive tags. ID programmed by manufacturer.
- Class1.WORM passive tags. ID programmed by user and blocked to avoid other writings.
- Class1(Gen2). Writable passive tags. It is an update that supports higher security and have optional user memory.
- Class 2: Writable passive tags that improves Gen2 class. They have user memory that allow updating and higher security.
- Class 3: Writable with battery power to enhance range, with user memory.
- Class 4: Writable active tags.
- Class 5: Readers.

RFID Readers
The reader is the most representative element of the system and it is in charge of transmitting the tag information that is processed by the controller It is in charge of:
- Read the data stored in the tags.
- Write data in the tags.
- Send information to the controller.
- Supply energy to passive tags.
- Implement a collision detection system to communicate with several tags simultaneously.

A reader consists of three elements**: antennas, RF module and communication module**. In any cases, reader can have also computational resources (smart readers).
- The main functionalities that can offer the smart readers are the authentication and encryption of the communication channel with the tags.

The antennas can be embedded in the reader (LF and HF) or can be external (UHF and microwaves).
- Two of the key factors with the antennas are its polarization (linear or circular) and its type (dipole, omnidirectional, directional).
- These factors define the reading field and the ability to read tags in different orientations.

Anti-collision system
- There are several protocols to solve this problem: Space Division Multiple Access (SDMA), Frequency Division MultipleAccess (FDMA), and Time Division Multiple Access(TDMA).
- Once the reader has established connection link with a tag, it will use any method to avoid a new connection with the same tag, e.g. keeping the tag in standby for a few seconds.
- Security
    - It is necessary to assure communications (e.g. for payments) to avoid frauds.
    - As a consequence, tags have to be ready for the authentication and encryption processes.

RFID controlers

- Controller is in charge of gathering readers' data and processing that information.
- Middleware is in charge of:
    - Readers management. It manages its operation
    - Data collection. It extracts, mixes and filters the received data.
    - Data routing. It routes processed data to different systems.
    - Process management. Run services as a response to received data.

Other RFID elements

- RFID printers. It Makes easier the encoding of new tags.
- Hand readers. They can be used in ranges non-covered by fixed readers or for looking for a specific tag.

RFID in cellular phones. NFC

- Near Field Communication (NFC)
    - In 2007, Nokia made the first cellular with an RFID reader.
    - NFC is the application of RFID technology to mobile phones.
    - NFC works in HF band (13,56Mhz) with proximity instead of vicinity to assure read/write operations, and works under request.
    - It complies with ISO14443 standard about proximity cards (contactless), that is, a NFC device can communicate with contactless cards, readers and other NFC devices.

Regulation and standardization with RFID

- ISO 18000
    - Part 1: defines general parameters.
    - Part 2: specifies parameters in LF band.
    - Part 3: specifies parameters in HF band.
    - Part 4: works in microwave band.
    - Part 6: works in UHF band.
    - Part 7: works in 433 MHz (active RFID).
- EPC global: Organization in charge of world wide standardization of EPC technology. Nowadays, the goal of the group is to do a world standard In RFID and the use of Internet to share data via the EPC global network.
- Other ISO regulations: ISO 14443, 15693, 14223, etc.

RFID data

- High quantity of data
    - It is necessary to reduce the quantity of generated and processed data.
    - It is not easy to identify repeated data (there is not context).
- Non contextual data
    - Lack of context in the data generated by the reader.
- Spurious readings
    - Due to lack of signal, signal reflexions or an antenna bad placed.
- Short life
    - Data generated use to have a short life. What to do with old data?

Privacy

- Impact of RFID technology: big information systems connected to Internet.
    - The information obtained from the tags can be used to feed databases that give information about objects, and people (a controversial matter).
    - Another problem with RFID: User not always knows when the communication with tag is carried out.

    - After the technology has been deployed, users realize that their private life can be harmed E.g. Tracking of customers that visit again the shop, speed control in tolling, etc.
    - However, this technology can be widely used in a lot of applications without malice E.g. a washing-machine that adapts the washing program to the information about the textiles.

Applocations with RFID technology

- Tracing and life cycle of a product.
- Truck fleet management.
- Security.
- Smart cards.
- Identification of animals.
- Tolling.
- Applications linked to Wireless Sensor Networks.
- Applications in clinical environments.
- Localization systems. Etc.

Challenges of RFID technology

- We can find some problems with the definitive deployment of RFID technology
    - Price. Still the technology is more expensive than bar code. As far as the deployment was bigger, prices will be lower.
    - New designs. New design of antennas that allow readings in all the conditions, readings methods, etc.
    - Acceptance. Avoid the privacy problems with RFID.
    - Multiple standards.

Internet of things

- Name of a Workshop in 2007 under the FP7 frame in the RFID field.
- Idea: The physical objects in the real world have their corresponding virtual models in an information network (Internet of things).
- Conclusion of the workshop
    - This kind of networks should be self-configuring networks. Its size and capacity do unviable to be managed by humans.
    - The link between RFID technology and sensorsis very important to provide to this network information about the real world.
    - It is necessary a generic programming platformthat allows to shut yourself off from the physical layers, and to provide services over this network of objects
- A wide range of IoT technologies have appeared in the last years
- RFID technology plays an important role in the IoT world.

SmartHome Technologies

- Data networks
    - USB, FIREWIRE, ETHERNET, HomePlug, HomePNA, HomeRF, Bluetooth, Zigbee, WLAN, IR
- Control networks
    - X-10, KNX, EIB, BatiBUS, EHS, CEBus, LonWorks
- Multimedia networks
    - HAVi
- Software architectures
    - UPnP, Jini

Data networks

Previously, Data networks in Home Automation Networks were strictly centralized (all peripheral connected to one computer or embedded system). Nowadays it is possible different configurations:

–LAN(*Local Area Network*): e.g. Ethernet.

–WLAN(*Wireless Local Area Network*): e.g. Wi-Fi.

–PAN(*Personal Area Network*): e.g. USB.

–WPAN(*Wireless Personal Area Network*): e.g. Bluetooth, Zigbee or 6lowPAN.

- Performance
  - Attending the distance, LAN networks reach more distances, continuing with WLAN
  - Attending the bandwidth, PAN networks are better.

Data networks wired or wireless technology?

Taking into account if it is necessary to install new wires or not, home networks can be:

- with new wires
  - It is mandatory to install a new wired network infrastructure
  - E.g. Ethernet
  - High cost infrastructure and low flexibility
  - Less investment in equipment and interfaces
- without new wires
  - Using the existing in-home infrastructure
  - HomePNA. It uses the wires of the phone infrastructure. It provide a data connection in each phone socket.
  - HomePlug. It uses the AC Electrical wiring of the house to provide a data point in each socket.
  - Radio frequency and wireless networks
  - Bluetooth, home RF and the standards based on IEEE 802.11 (WiFi)
  - IEEE 802.11 provides mobility, with a bandwidth proportional to the cost of the infraestruture installed. Widely used in buildings, offices, hotels, airports, etc.
  - Home RF is focused on the voice and data wireless transmission in homes. In general, it provides a great availability in any place of the house, but with bigger infrastructure, and with less bandwidth than Ethernet, USB, etc.
  - In Personal Area Networks (PAN), Bluetooth and IrDA are well-know and balanced solutions on price and features (headset, remote controls, Smartphone-PC interface, Hi-Fi control, etc.).

USB (Universal Serial Bus)

- External expansion bus. It allows to install peripherals directly connecting devices to the bus, without opening the computer equipment.
- Hot-plug, without resuming the system.
- The standard allows to connect up to 127 devices in the same USB port. The bit rate of this standard is 12 Mbps (version 1.0), 480 Mbps (version 2.0) and 4.8Gbps (version 3.0)

USB -advantages

- Easysetup.
  - It is difficult to find any error in the setup and connection
- PlugandPlay
- It is not necessary switch off/on the computer. The OS recognizes the device and install the appropriate drivers
- Hot-plug (connection/disconnection)
- High performance
  - High transmission rate compared with the previous technology
- Multi-platform suport (PC, Mac...)

- Multiple devices connected at the same time
- Power supply in the same wire

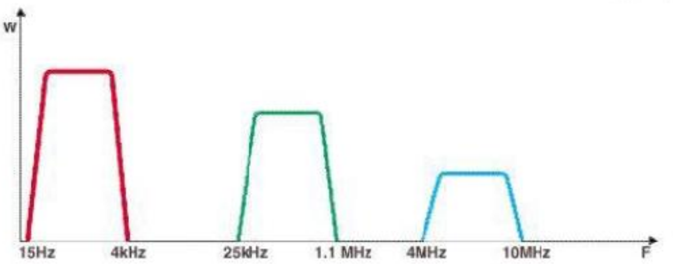
FireWire (IEEE 1394)
- Is one of the faster peripheral interfaces developed (very useful in multimedia applications)
- Can connect a maximum of 63 devices
- Bit rates of 100, 200, 400, 800 Mbps, 1.6Gbps and 3.2Gbps.
    - New releases allows to reach up to 6.4Gbps.

Ethernet
- Is the most deployed technology for implementing residential (houses) and business (buildings) networks.
- Based on Fast Ethernet: 100Mbps/1Gb.
- Wired with UTP (Unshielded Twisted Pair) cable, that is cheap
    - Ethernet sockets deployed in each room of the house.
    - Bit rate of 10/100/1000 Mbps with a reasonable price and safer than wireless technologies

Home Plug
- This technology allows to implement local networks using the AC electrical wiring of the house, avoiding to install new cables
- Data rate: 14Mbps (ver1).
- It allows an Internet connection from any socket in the house.
- Its direct rivalis Wi-Fi, with similar (or better) performance, that can be considered cheaper due to the complexity of the PLC (Power Line Carrier) chips that have to be installed to avoid electrical noise.
- The company Intellon Corporation developed the INT5130 chip, which can be embedded in devices as PC, printers, TVs, etc.
- The architecture could be:
    - APLC modem, where it is connected different devices
    - Each device includes its chip, without modem
- The Electricity suppliers uses this technology to provide Internet for the users.
- The backbone can be set in the medium to low voltage transformer, or in the cable to the house (less than 500 meters)
- Compatibility with the existing technologies in a home control network:
    - Full compatibility with X-10.
    - Possible interferences with CEBus and LonWorks.

HomePNA
- The goal with this technology was to provide a LAN without new cables, using the phone line inside the houses and flats.
- In American market this is a successful technology. Each room had usually a phone socket.
- InEurope, it has appeared some compatibility problems with VDSL technology that discourage using Home PNA technology.
    - VDSL (Very High Speed Digital Subscriber Line) will reach up to 52Mbits/s for downloading. Maximum distance to the control centre with maximum performance: 300meters.

In the following graphic you can see
- The different phone signals (analog 15hz-4KHz), xDSL (25KHz-1,1MHz) and HomePNA (above2MHz), in the same wires.
- Power (Watt) of all these signals.



- HomePNA technology is like an Ethernet:

  –Version1.01Mbit/s

  –Version2.010Mbit/s

  –Version3.0128Mbit/s

  –Version3.1320Mbit/s
- The HomePNA standard complies CSMA/CD, IEEE-802.3 and MAC address (like Ethernet).
- The difference with respect to Ethernet is the physical layer.
- The Operative Systems work with the HomePNA adapters in the same way than with Ethernet ones.
- The system works in the following way:
  - The bandwidth signal arrives throuth cable or DSL modem
  - This is connected to a HomePAN router.
  - The output is connected to a phone line in the house, providing bandwidth in each phone socket.
  - Each device connected to Internet will need a PCI or USB adaptor o HomePNA.

HomeRF

- It is a wireless digital transmission technology
- The main advantage respect to other technologies: video and audio distribution In low computational devices, as an Hi-Fiequipment.
- The idea is to use home gate ways or PC as a multimedia centre for downloading films and songs via Internet, and the HomeRF technology to distribute among different players.
- This technology guarantees simultaneous access of eight speakers to a phone central, meanwhile Bluetooth only can guarantee one, and WiFi does not comply the temporal requirements.
- Despite this advantages, nowadays HomeRF technology is obsolete, since others wireless networks have become accessible to home users.
  - This technology uses the specification called SWAP (Shared Wireless Access Protocol), which combines the best of several technologies:
  - Related to data transmission in wireless technology
    - WLAN802.11 –CSMA/CA: it support synchronous data transfer.
  - The standard of voice transmission more deployed in the world, DECT (Digital Enhanced Cordless Telephone).
    - DECT is the most deployed system in wireless phones in offices and houses.
    - TDMA: time division multiple access.
    - Support data transfer for voices (isochronous).
- This technology uses the 2.4GHz band, as Bluetooth and Wi-Fi
- Data rates:

–SWAP1.01.6Mbps

–SWAP2.010Mbps

–SWAP3.020Mbps

Bluetooth

- BT is an standard for wireless technology that exchange data over short distances (up to10metres).
- BT creates a low cost PAN with fixed and mobile devices (laptop, mobilephones, mousses, etc.).
- Initially, the goal was to replace the RS-232 and centronics interfaces, eve the IR interface
  - Avoids using wires.
  - Increasest the data rate.

    - Contributes to the mobility of the devices (up to 10 metres without amplifiers and additional antennas).
- The BT devices are installed and configured in the same way than a Printer with a PC, the communication channel remains open, without user intervention.
- BT and Wi-Fi are not rival each other, they are complementarily. BT devices are smaller, cheaper and they consume less power than Wi-Fi ones, but they have less data rate and range.
- It is possible to transmit data, voice and video with a data rate of 712Kbps
    - Version 2.0 supports 3Mbps and version 3.0 24Mbps.
- The output power is exactly limited to the needed value in order to increase the battery life of the BT devices.
- Security
    - It has been defined a basic level of security in communications, embedded in the same radio frequency chip. In this way, every device with low computational resources can provide a minimum security level

Bluetooth Low Energy v4.0

- New stack of protocols
- Orientated to low power applications. In many cases, The BLE devices will be able to operate more than one year with a non-rechargeable button battery.
- It is able to operate sensors directly.
- Distance range up to 50 m and data rate of 200Kbps.
- A BLE device working in continuous transmission does not consume less than a BT device transmitting the same quantity of data, even It would need more power. That is because the protocol is optimized for small data burst

Zigbee

- It is a specification for a suite of high level communication protocols based on the IEEE802.15.4 standard for WPAN.
- ZigBee is targeted to applications that require a low data rate, long battery life, and secure networking
- The main applications involve home and building automation systems, Smart Energy, Health Care and others applications that need a large deployment of sensors.
- Zigbee takes into account a much bigger number of nodes than BT.
- It has less power consumption and less data rate than BT.

6LoWPAN

- 6LoWPAN is an acronym of IPv6 over Low power Wireless Personal Area Networks
- Idea: “the Internet Protocol could and should be applied even to the smallest devices”. Low power devices with limited processing capabilities should be able to participate in the Internet of Things.
- It defines encapsulation and header compression mechanisms that allow IPv6 packets to be sent to and received from over a IEEE802.15.4 based network
- Target areas: applications that need wireless internet connectivity at lower data rates for devices with very limited resources

WLAN

- AWireless Local Area Network is a very flexible communications sytem that connects several computers instead of the conventional wired Ethernet.
- Modern WLANs is based on the IEEE802.11 standards, marketed under the Wi-Fi brand name.
- Versions:
    - 802.11b 11 Mbps Wi-Fi (band a de 2.4 GHz)
    - 802.11b+22 Mbps (band a de 2.4 GHz)
    - 802.11g54 Mbps (band a de 2.4 GHz)
    - 802.11n300 Mbps (band a de 2.4 GHz)

    - 802.11a54 Mbps (band a de 5 GHz)
- The goal of the WLAN is not to replace the wired LAN but to be an extension of LAN
- However, it exists some advantages:
    - Mobility: Access inside the coverage area
    - Quit installation: without any cable installation
    - Flexibility: it allows to reach difficult point for a LAN.
    - Easy to extend: it is very easy to add new users without any network socket.

Infrared

- Infrared has technical limits and low reliability for data networks, but it is widely used in remote controls for audio, video, air conditioning equipments…
- The infrared communication has no electromagnetic interferences

Control networks

- It is used for control and automation applications in smart buildings. It is independent of the data and multimedia networks.
- It controls sensors with low bandwidth requirements.
- This networks involves the smart appliances too.
- The control network can be centralized. That allows to reduce the complexity of the system but also reduce the reliability of the system.
- The control network can be also distributed.
- Control networks can use different physical communication channels:
    - Twisted pair cables, coaxial cables, optic fiber, infrared, radiofrequency, etc.
- It is important that a protocol can support different physical media in order to be able to adapt to a building topology.
- Nowadays, free and flexible technologies are the most important ones in the global market.
- The technologies design for a specific market have less possibilities to survive
- Most of these protocols support different layers of the OSI model.
    - Physical layer, link layer, network layer and application layer
- These protocols are designed to be embedded with lowest cost:
    - Maximize the data per frame, and minimize the control fields (address, CRC,etc.).
    - Allow to reduce memory and microprocessor speed requirements, and exploit the maximum bandwidth available

X10

- X10 is one of the most deployed and old protocols in home automation applications (since 1978).
- It is designed to transmit data through the AC electrical wiring of the house (PLC).
- It is a open protocol, but it is necessary to use the chip invented by the father (Scottish) of the technology (very low royalty).
- It is the cheapest and simplest to install

X10. Operation

- The X10 transceiver is in charge of looking for the zero crossing point of the AC current wave form, immediately later it inserts a burst with a frequency of 120kHz.
- Each “0” or “1” need two zero-crossing points in the 50Hz signal. The complete frame of a X-10 command needs 11cycles. Each frame is transmitted twice.

X10. Features

- It is a decentralized architecture, each device can send/receive information.
- It allows to command up to 256 devices in the same facilities (16 house code x 16 device code)
- Low bandwidth.
- The field of application is mainly reduced to houses.

- Flexible and easy to extend.
- Easy to install and manage
- Sensible to electrical interferences

KNX

- KNX groups tree European associations (EIBA, BCI and EHSA) with the aim of linking all the experience and acknowledge of the main Europe an standards in only one: common, open and with competitive low-cost devices.
- The idea is a common standard from EIB, BatiBUS and EHS, able to compete with the American systems LonWorks and CEBus
- In 2002 appears the first version1.0
- The KNX standard is based on the EIB technology, and expand its functionality adding new physical communication channels and configuration modes from BatiBUS and EHS.
- The KNX standard provides tree configuration modes:
    - System Mode. It works like the current EIB, that is, different devices or nodes in a new installation are installed and set-up by professional staff with a software application (ETStool).
    - Easy Mode. The devices are programmed in the factory to carry out specific functions. Lately, some details are configured during the installation (with micro-switches).
    - Automatic Mode: Plugand Play philosophy. Neither the installer nor the user have to configure the device. This mode is specially indicated for appliances and entertainment devices

EIB (European Installation Bus)

- Developed to compete against the imported home automations systems from Japan and North America.
- Proposed by the EIBA (EIB Association).
- Open bus protocol.
- It defines the OSI layers: 1, 2, 3, 4 and 7.
- Apart from sensors, exists appliances that are compatible with EIB and they are tele-controlled and programmed remotely through a home gateway.
- It allows to supervise and monitor all the connected devices.
- EIB can be implemented in different media:
    - EIB.TP: Twisted pair.
    - EIB.PL: Power Line Carrier.
    - EIB.net: Ethernet (10Mbps).
    - EIB.RF: radiofrequency.
    - EIB.IR: infrared.

- EIB.TP
    - The data rate among all the devices is 9600bps.
    - The system works with 24Vdc supplied to the devices through the bus wires itself.
    - Each device uses two addresses with 16bits (physical and logical) mutually exclusive.
    - The physical address is used during the installing procedure, to register the device in the system, with the following fields:
        - Zone (4bit)+ line (4bit) +device (8bit)
    - The logical address (16bit) is used in the system operation stage, and it can be repeated in several devices in order to do functional groups (lights,etc.).
    - The topology is like a matrix, that is, the devices can be connected in lines up to 1000 meters (maximum 255 devices per line). The lines can be grouped by mean of line couplers, with a maximum of 16 lines, and that is call “zone”. The different zones can be interconnected (maximum 16 zones) through a network coupler

    - EIB uses a decentralized control architecture. Sensors and devices are conntected to the same bus, and they communicate among them without any contribution of the central control unit.
    - Despite this, to reduce size and cost of sensors, the EIB manufacturers consider a control unit that integrate most of the system intelligence

BatiBUS

- It is an old French protocol (Merlin Gerin Schneider Electric) for control applications in the industrial field.
- Easy to install, low cost and flexible, allowing new control functions.
- Open protocol
- Twisted pair bus with different network topology (star, bus, ring, tree).
- Distance between the central unit and the most far away device up to 2.5Km.
- Bit rate: 4800bps
- 15Vdc power supply in the same bus wire

EHS (European Home System)

- The goal is to satisfy the need for home automation in the most of the European houses whose in habitants can not afford the performance and cost of more expensive home automation systems like LonWorks, EIB or BatiBUS, due to the skilled labour that these systems need.
- Cover the features of CEBus in NorthAmerica, and it has better features than X-10.
- Open protocol.
- First deployments used PLC with bit rate up to 2400bps
- Currently, EHS is implemented in other media:
    - Twisted pair, 4800bps.
    - Coaxial, 9600bps.
    - Infrared, 1200bps.
    - Radio frequency, 1100bps.
- It uses CSMA/CD protocols (like Ethernet).
- Devices associated in segments (maximum 256 nodes per segment).
- Plug&Play. It makes mobility and extension easier.

CEBus

- Developed by the American Electronics Industry Association (EIA).
- Goal: to develop a specific domotic bus for homes
    - Low cost
    - Easy to install and use.
    - It has more functionalities than X-10, and It can be used in remote control, energy management, security and other applications.
- Disadvantages
    - Few and expensive devices.
    - The OSI physical layer in CEBus do not comply the European regulations related to PLC
- With CEBus technology has been developed a lot of Plug&Play devices, inside the called CEBus Home Plug and Play.
- Physical layer: PLC, RF, IR, TP, Coaxial, Fiberopticcable,…
- In PLC medium, CEBus uses spread spectrum frequency modulation.

LonWorks

- Proprietary control technology from Echelon company.
- Robust and reliable technology, widely deployed in industrial field, but too much expensive for home implementations.
- Each LonWorks node should incorporate a specific microcontroller called Neuron Chip.

  - Each Neuron Chip has a unique identifier: Neuron ID.
- The Neuron Chip implements the LonTalk protocol for communicating among the nodes.
- An important advantage with LonWorks is the implementation of all the ISO model layers. For example, automatic retransmission of a lost frame is implemented by Neuron Chip.
- Support different media
  - RS-485, coaxial, twisted pair cable, PLC, fiberoptic, radiofrequency,…
  - Neuron Chip provides a five pin port interface with the suitable line transceiver (it adapts the signals in the Neuron Chip to the level needed in each physical medium)
  - LonWorks presents the following advantages with respect to CEBus
    - Narrow band transmissions. It has more robust communications and complies the European regulations for PLC.
    - It allows the forward error detection and correction (FEC). CEBus can only detect error by means of a CRC, needing there transmission of the frame.
- Sensors have intelligenc eand can interchange information among themselves without central controller.
- It is not necessary a central control unit.
- Minimum quantity of cables, and easy to expand.
  - Every **node** is physically connected to a channel.
  - A **domain** is a set of logical nodes belonging to one or more channels. The communication link is only possible between nodes with the same domain.
  - A **subnet** is a logical set of nodes up to 127, inside a domain. A domain can have up to 255 subnets.
  - A **group** is a set of nodes inside a domain too. But in this case they are grouped without taking into account its logical situation inside the domain.
- Maximum numer of nodes per domain: 32.385.
- To build a LONnetwork is necessary to use routers, bridges and signal amplifiers.
  - Routers: connect two subnets
  - Bridges: connect two domains
  - Amplifiers: for long distances.

BACnet

- The Building Automation and Control Networks (BACnet) is an open communication protocol created by ASHRAE (American Society of Heating, Refrigerating and Air-Conditioning Engineers) and currently is an ISO16484-5 standard.
- Designed to communicate different building control systems such as HVAC, lighting, fire detection systems, access control, etc.
- Deep impact in HVAC systems, initially was implemented in RS485 buses. Currently it is implemented an IP version (using for example Ethernet bus).

EnOcean

- EnOcean GmbH is the originator of the patented energy harvesting wireless technology. EnOcean was founded in 2001 as a spin-off from Siemens AG.
- The basic idea behind the technology stems from a simple observation: where sensors capture measured values, the energy state constantly changes.
  - When a switch is pressed, the temperature alters or the luminance level varies. All these operations generate Enough energy to transmit wireless signals.
- Instead of batteries, EnOcean consequently uses miniaturized energy converters to supply power: kinetic motion converters, solar cells and thermal converters.
- The EnOcean wireless signal uses the 868 MHz, 902 MHz and 928 MHz frequency bands.
- Telegrams are just one millisecond in duration and are transmitted at a rate of 125 kilobits per second.
- To eliminate transmission errors, a telegram is repeated twice in the space of 40 milliseconds.
- Data packets are transmitted at random intervals, so the probability of collision is extremely small.

- The range of EnOcean wireless sensors is about 300 meters in the free field and up to 30 meters inside buildings.
- Each EnOcean module comes with a unique 32-bit identication number to exclude any possibility of overlap with other wireless switches.
- Enhanced data security features include rolling code and 128 AES encryption.

Z-wave

- Z-Wave was originally developed by Danish start-up Zen-Sys and later acquired by Sigma Designs in 2008.
- The Z-Wave protocol is an interoperable, wireless, RF-based communications technology designed specifically for control, monitoring and status reading applications in residential and light commercial environments.
- Low Powered RF communications technology that Supports full mesh networks without the need for a coordinator node
- A Z-Wave automation system can be controlled via the Internet, with a Z-Wave gateway or central control device serving as both the Z-Wave hub controller and portal to the outside.
- Z-Wave is designed to provide reliable, low-latency transmission of small data packets at data rates up to 100kbit/s.
- It operates at 868.42MHz in Europe, at 908.42MHz in the U.S. and Canada

DALI

- Digital Addressable Lighting Interface (DALI) is a trademark for network-based systems that controlling thing in building automation developed by Philips. It is an open standard that replaces the analog 0-10 V lighting control.
- ADALI network, consist of a controller and one or more slave devices that have DALI interfaces.
- With DALI protocol, the controller can monitor and control each device individually or via multicast (simultaneously).
- A basic system can reach 64 DALI devices, and with gateway scan be extended.
- Data is transferred between controller and devices by means of an asynchronous, half-duplex, serial protocol over a two-wire bus, with a fixed data transfer rate of 1200bit/s.

Multimedia networks

- In a multimedia network it is connected the TV, radio, HiFi, cameras and video cameras, alarm clocks, etc…
- These networks are used to distributed information with a strict requirements related to quantity of information, quality and transference delay.
- The audio and video devices need a higher bandwidth that the rest of the home devices.
- Applications supported by this network:
    - Networked video games
    - Pay-per-view TV broadcast
    - Interchange of multimedia files (video, music, photos, etc.) among different devices.
- The devices of the multimedia network have very diverse functionalities and processing capabilities. It has necessary to use protocols that allows the abstraction of details in the user configuration.
- The logical and physical system architecture is totally distributed. All the devices can communicate directly, without routers or intermediate devices.
- Currently, the most relevant architectures are:
    - HAVi
    - UPnP
    - Jini

HAVi

- (Home Audio Video interoperability) is a distributed software architecture that specifies a set of APIs, designed to interconnect directly the audio and video devices from different providers.
- That is , if different devices comply the HAVi specifications, they will be able to interoperate, even if they are from different manufacturers.
- This technology provide a quick and easy way of connection, configuration a installation.
- HAVi uses the IEEE1394 (i.link or Firewire) digital network for data and command interchange.
- IEEE1394 has a bandwidth of 400 Mbps and 800 Mbps, real time communication, that allows audio and video transference with high quality in real time.
- In HAVi does not exist any controller unit. Any device can be the controller or be controlled by another device.
- It is open architecture, in dependent of the platform and programming language.
- HAVi provides the APIs for:
    - The development of inter-operative devices.
    - Writing applications based on Java to operate the devices from Internet
- In HAVI , the APIs are able to detect automatically devices in the network, and also to coordinate the functions among the devices connected to the network.
- HAVi provides bridges with other technologies as Jini (Sun Microsystems) and UPnP (Microsoft).
- HAVi as a non profits association funded in 1998, and is made up by the main manufactures in consumer electronic devices: Grundig, Hitachi, Panasonic, Philips, Sharp, Sony, Thomsonand Toshiba.

Software architectures. UPnP

- Universal Plugand Play (UPnP) was proposed by Microsoft for interconnecting electronic devices. Currently, It is used in PCs and peripheral.
- Is an open and distributed architecture, based on the TCP/IP stack of protocols, that makes easier the control and data transference among devices connected to the network, avoiding that user has to be skilled in network configuration, devices and OS.
- When a UPnP device is linked to the network, automatically and in a transparent way to the user, the device get an IP address, announces its name, reports its functionalities and learns about the presence and functionalities of other devices.
- Very easy installation, expansion and upgrades in the network.
- UPnP is independent of the physical medium, even the OS and the programming language used for the development of control software in the UPnP devices.
- The goal is the same than Jini : to make the communication among devices easier for the users and network managers.
- Example: When a UPnP printer Is connected to a network, it provides the drivers necessary for its correct configuration and communication.

DLNA

- (Digital Living Network Alliance). Founded by consumer electronics companies in 2003 for sharing digital media files among multimedia devices.
- DLNA uses uPNP for management, discovering and multimedia control.
- uPNP defines the types of devices that supports DLNA:
    - Digital Media Server (DMS): store content and make it available to networked digital media players and rederers.
    - Digital Media Players (DMP): find contenton DMS and provide playback and rendering capabilities.
    - Digital Media Renderer (DMR): play content as instructed by a digital media controller (DMC), which will find content from a digital media server (DMS).

  - Digital Media Controller (DMC): find content on digital media servers (DMS) and instruct digital media renderers (DMR) to play the content.
- Can be used by Ethernet or Wi-Fi communication channels.

Jini

- Software architecture developed by Sun Microsystems.
- Goals:
  - To make possible that users can share services and resources In the network.
  - To provide to the users an easy access to this resources from any device in the network, even if they change its location (flexibility).
  - Simplify the implementation, maintenance and management of the system tasks.
  - Jini is a distributed system that conforms a federation of Java Virtual Machines.
- The objects that conform the Jini system offer services that can be used by any user/object connected to this system.
- The services can be actions carried out by devices (hardware), applications (software) or combinations of both.
- The Jini core only has 40 KB of program memory
- Jini supports any physical medium: IEEE 1394, Bluetooth, IrDA, Ethernet, ..., and it is independent of the OS.
- Services are the entity that gives sense to the distributed system: devices, data, storage, filters, computation,... , and any service that can be useful for the user and other services.
- Jini provides different mechanisms to create, find, communicate and use the services in the network or community.
- These services are connected among themselves using a protocol of services, a set of interfaces in Java.

Services

- Lookup: identifies the available services in a Jini community (network). When the service starts, it looks through the network and gets the set of objects that provide the available resources.
- A new service is linked to Lookup service by means of the discovery and join protocols.
- The service, that can be linked to the system, looks for the Lookup service by means of discovery protocol, and later, when the appropriated Lookup service is found, is linked to it with join protocol.
- RMI (Remote Method Invocation): allows to a Java object be invoked by another remote object or class. That enables to share objects in the network.
- Security: Jini provides different levels of security for the services.
- Leasing: it assigns a time slot for using a service (it is negotiated between client/server as part of the protocol). Ones time is up, it can be renewed or not.
- Transactions: They are jini interfaces that provide a protocol to coordinate the transactions between two or more services.
- Events: it supports distributed events. It is able to request to events happened in the system (e.g. a new user connection)