Indoor Positioning by the Fusion of Wireless Metrics and Sensors

Asst. Prof. Dr. Özgür TAMER

Dokuz Eylül University

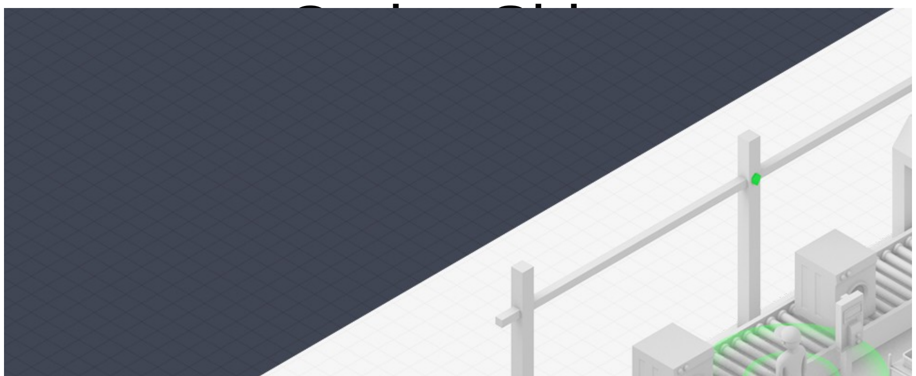
Electrical and Electronics Eng. Dept

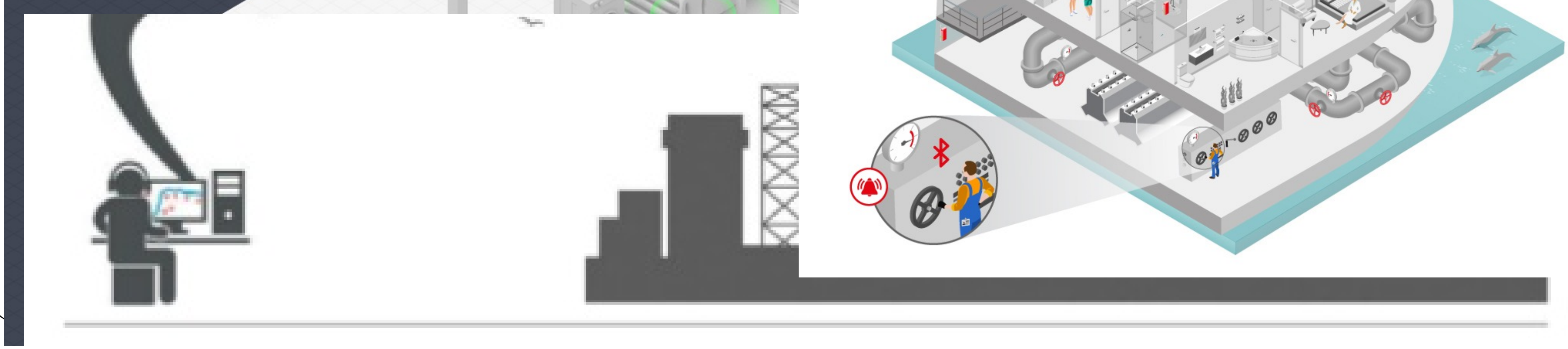
Indoor Positioning

- Indoor positioning systems (IPS) is like a GPS for indoor environments.
- IPS can be used to locate people or objects inside buildings.
- Several sensors, Bluetooth, RFID, Wi Fi, 4G and optical technologies are employed in positioning indoor people or objects.

Indoor Positioning

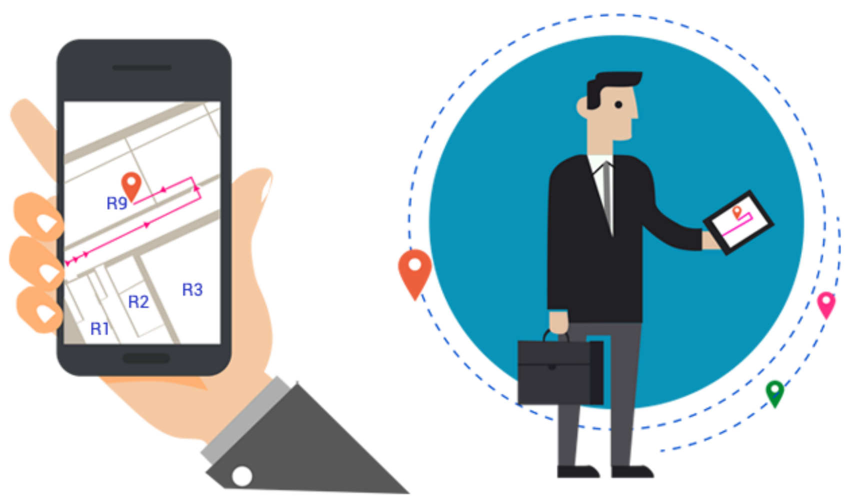
- Application Areas
  - Shopping Malls
  - Factories (Industry 4
  - Mines





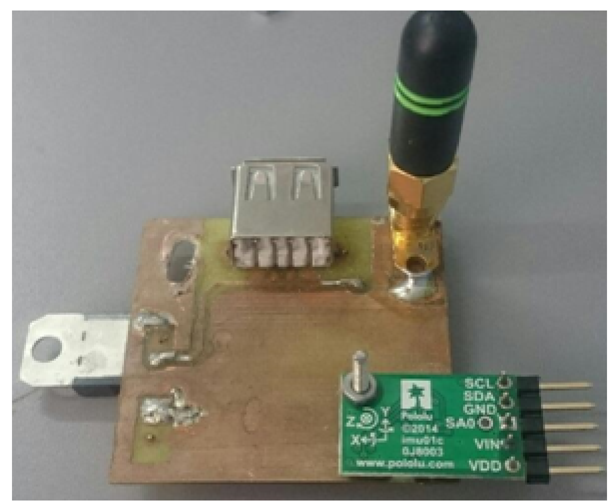
Indoor Positioning

- An Indoor Positioning System employs observation data collected by a set of sensing devices or sensors to estimate the target object location.



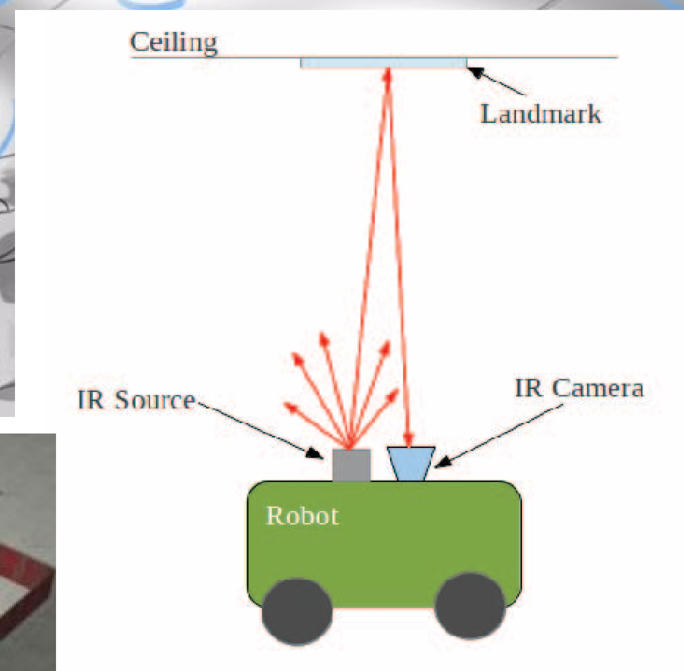
Indoor Positioning Technologies

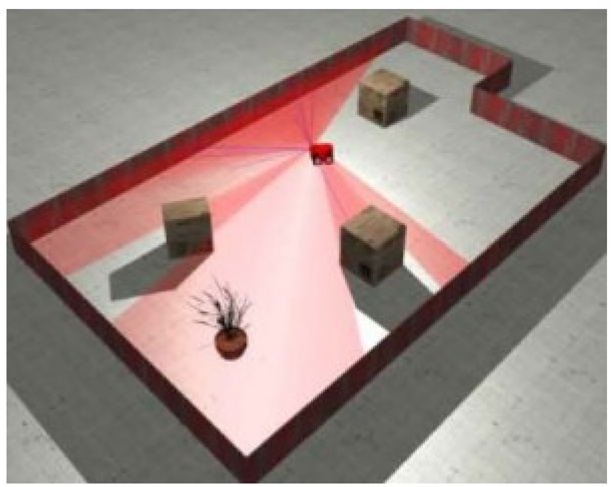
- Radio Frequency Signals (RF)
  - Standard (Wi-Fi and Bluetooth)
    - Communication metrics are used
    - RSSI, ToA, TDoA
    - Too many interferers
    - Easily implemented by software
  - Application specific (ISM bands)
    - Parameters are evaluated by specific measurements
    - Less noisy environments
    - Requires RF harware design and implementation



Indoor Positioning Technologies

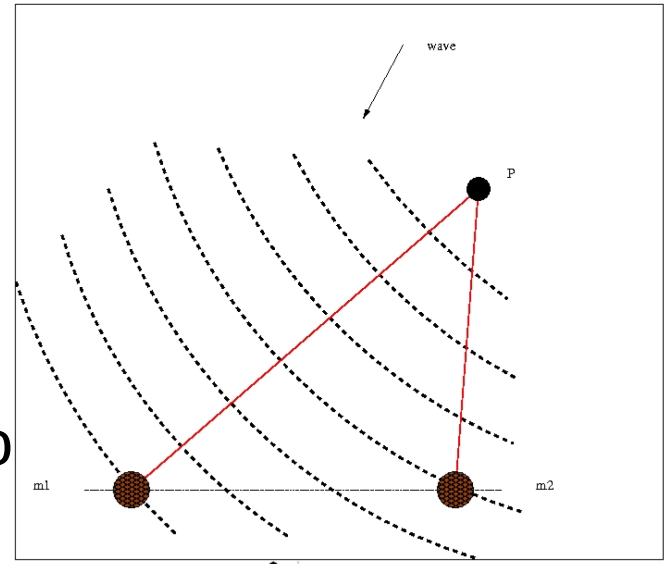
- Light
  - Visible light
  - Infrared Light
  - Laser or LIDAR
    - Time of Flight, Signa
    - Not trustable at close
    - Noise cancellation is

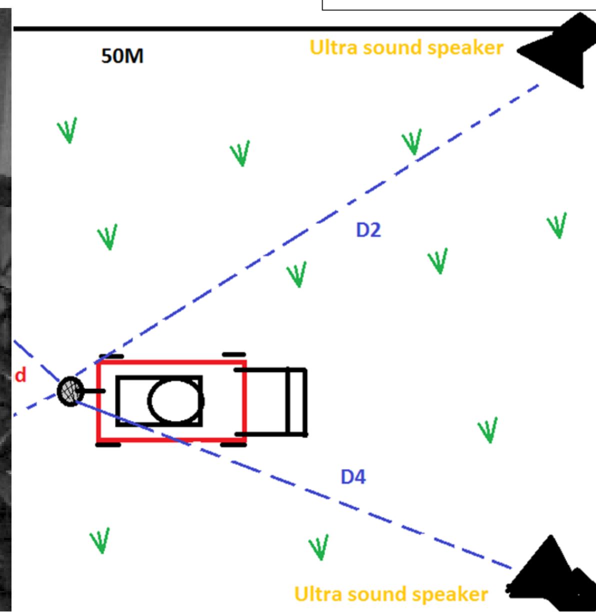




Indoor Positioning Technologies

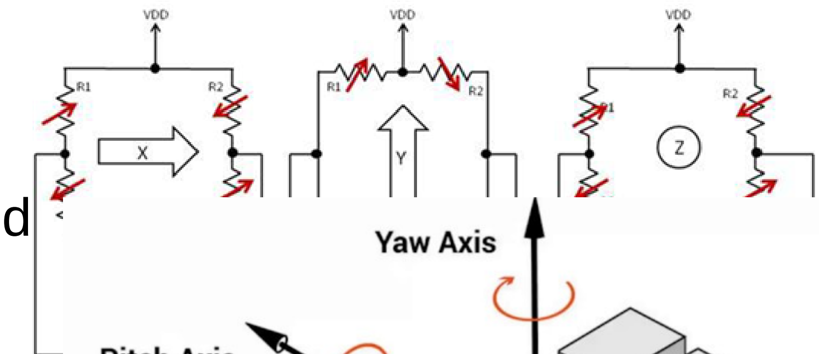
- Sound
  - Audible
  - Ultrasound
- Computer Vision
  - Image processing techniques fo tracking objects

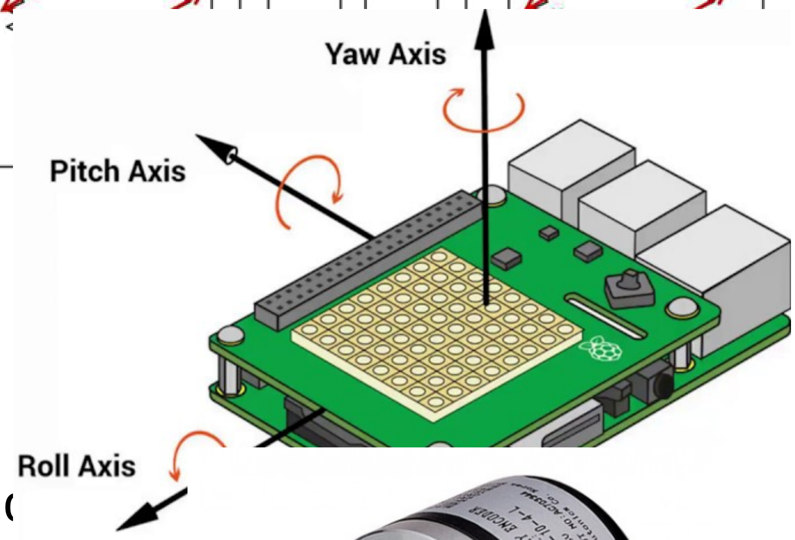


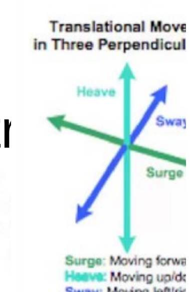


Indoor Positioning Technologies

- Sensors
  - Magnetic Field Sensors
    - Natural Earth's magnetic field
    - Magnetic Strips
  - Inertia Sensors
    - Accelerometer
    - Gyroscope
  - Encoders
    - For displacement of rotational (
  - Proximity sensors
    - Inductive, Capacitive, IR or Ultı

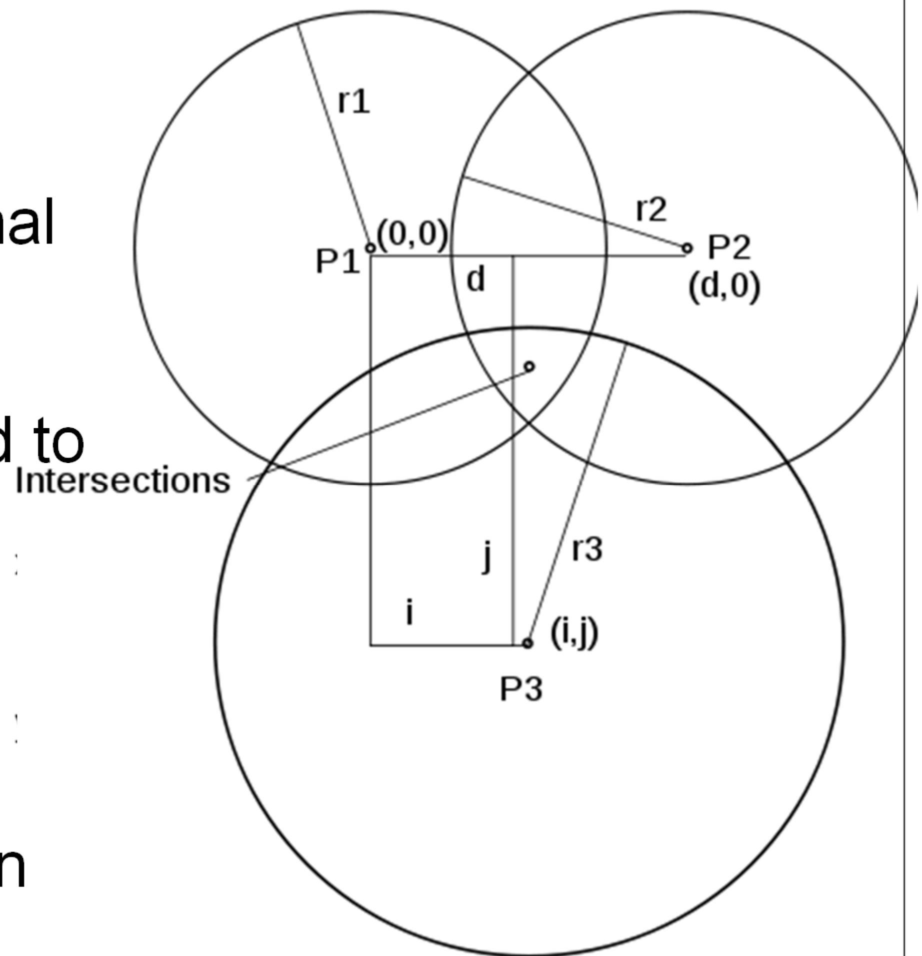






Indoor Positioning

- Location Estimation
  - Measurement: Characteristics of a signal are measured
  - Distance Estimation: Measurements are used to estimate the distance to/from the object
  - Combination: Distance estimates are combined in order to estimate the absolute/relative position of the object



Signal Parameters

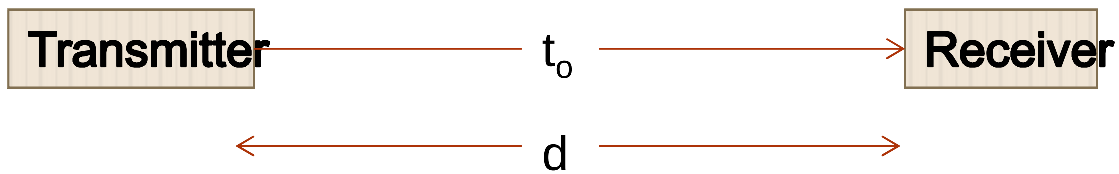
- Signal parameters used to estimate location:
  - Time of Arrival (ToA)
  - Time Difference of Arrival (TDoA)
  - Angle of Arrival (AoA)
  - Received Signal Strength (RSS)

Signal Parameters

- Time of Arrival (Time of Flight)
  - The time taken by the signal to go from the transmitter to the receiver.
  - The distance is estimated by using the speed of light $c=3x10^8$ m/s as;

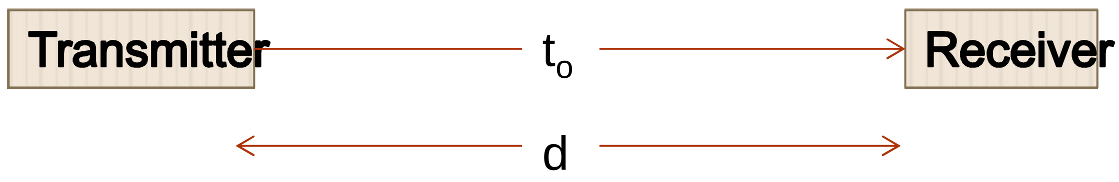
$$d=c \times t_o$$

  - Where t_o is the flight time of the signal



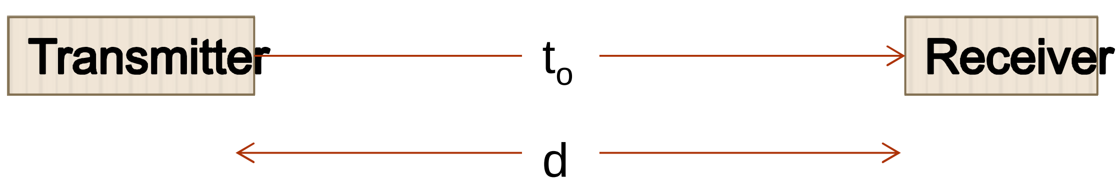
Signal Parameters

- Time of Arrival (ToA)
  - It is generally a metric provided by the communication system and the receiver hardware.
  - Not supported by all hardware.
  - Needs a precise timestamp by the transmitter.
  - Devices need to be synchorinized for accurate distance estimation



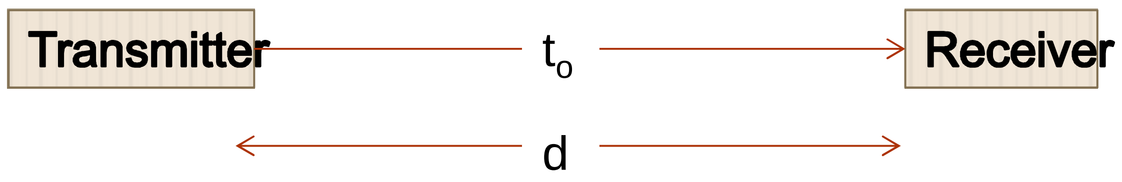
Signal Parameters

- Time of Arrival (ToA)
  - The precision of the timestamp effects the resolution and minimum distance of the estimation
  - Time of flight value for 3 m. range is 10 ns.
  - A 1 ns resolution timestamp can give results with 0.3 m resolution at best.
  - Error rate decreases with distance.



Signal Parameters

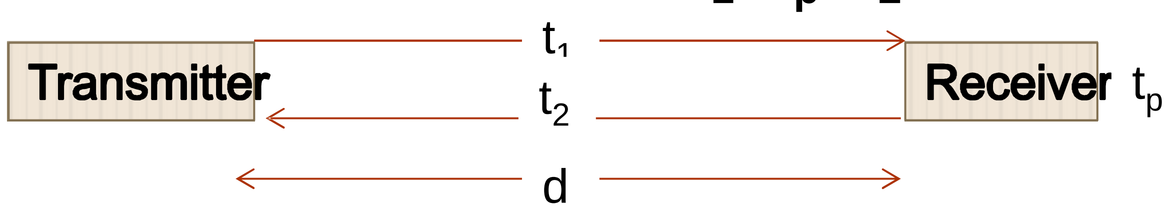
- ToA measurement errors
  - Small errors
    - Noise
    - Measurement precision
    - Synchronization
  - Large errors
    - Reflections
    - Multipath
    - Scattering



Signal Parameters

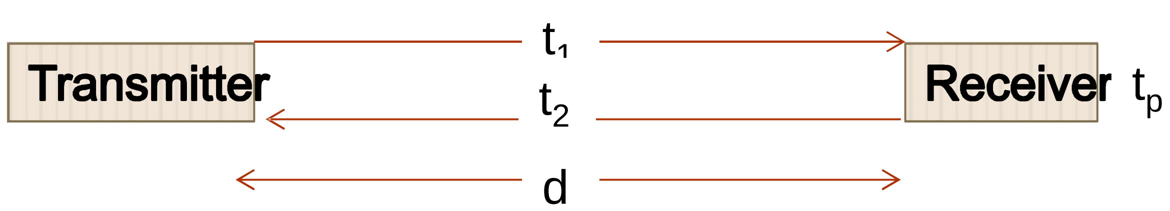
- Time Difference of Arrival (TDoA):
  - TDoA is similar to ToA but the signal is first transmitted by the transmitter and the receiver retransmits a specific code so that the transmitter can calculate the time of flight according to the difference of time between its data and the received data.
  - Synchronization is less important.

$$\mathbf{TDoA=t_1+t_p+t_2}$$



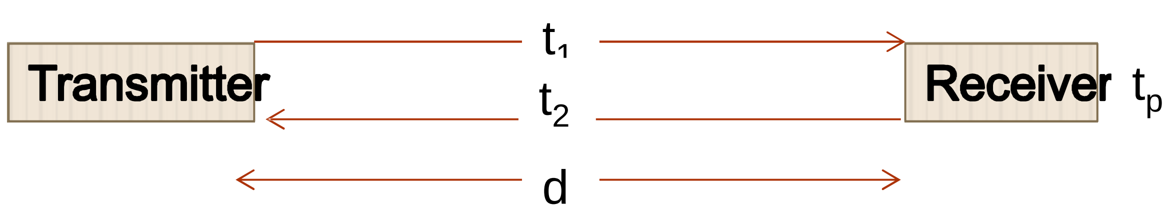
Signal Parameters

- Time Difference of Arrival (TDoA):
  - TDoA is a metric provided by specific wireless IC providers.
  - The processing time is also added to the time which must be precisely calculated according to the chip and must be known by both sides.
  - The receiver and the transmitter must be calibrated for a precise result



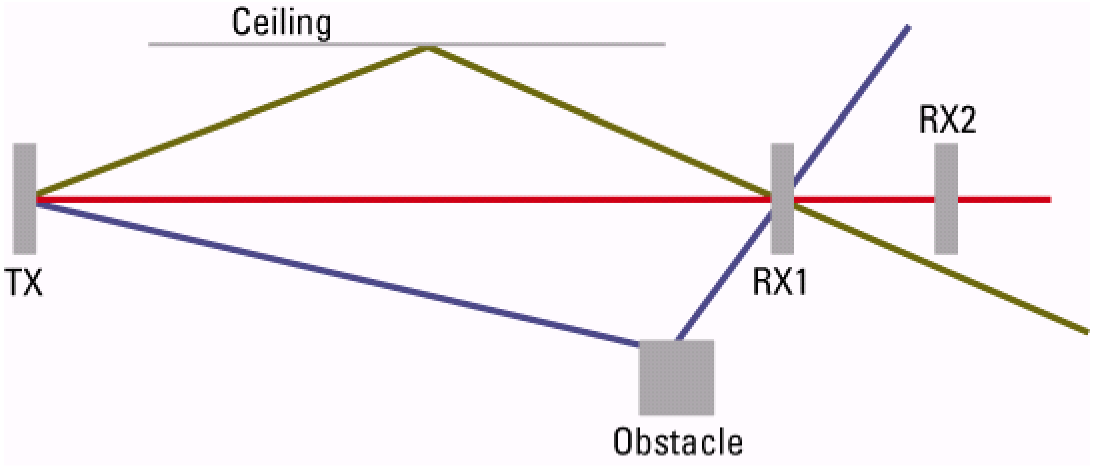
Signal Parameters

- Time Difference of Arrival (TDoA):
  - Time of flight value for 3 m. range is 20 ns. (plus processing time)
  - A 1 ns resolution timestamp can give results less than 0.15 m. resolution at best.
  - Error rate also decreases with distance.



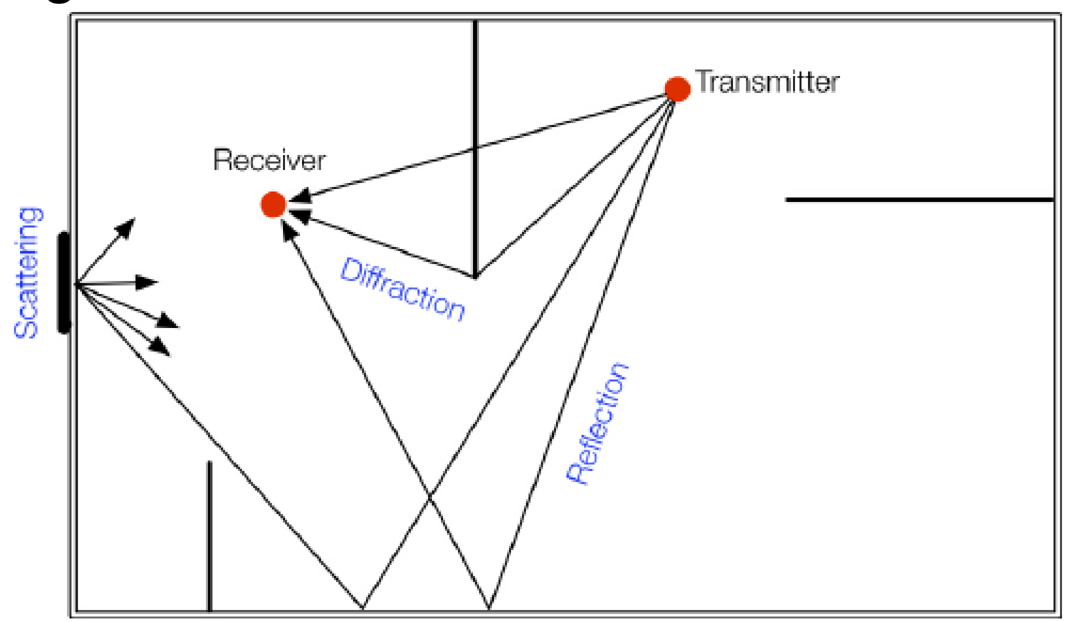
Signal Parameters

- Received Signal Strength (RSS)
  - Received field intensity of a signal at the receiver.
  - Highly depends on the environment.
  - Gives reliable results at closer distances.
  - Automatic gain control can cause faults



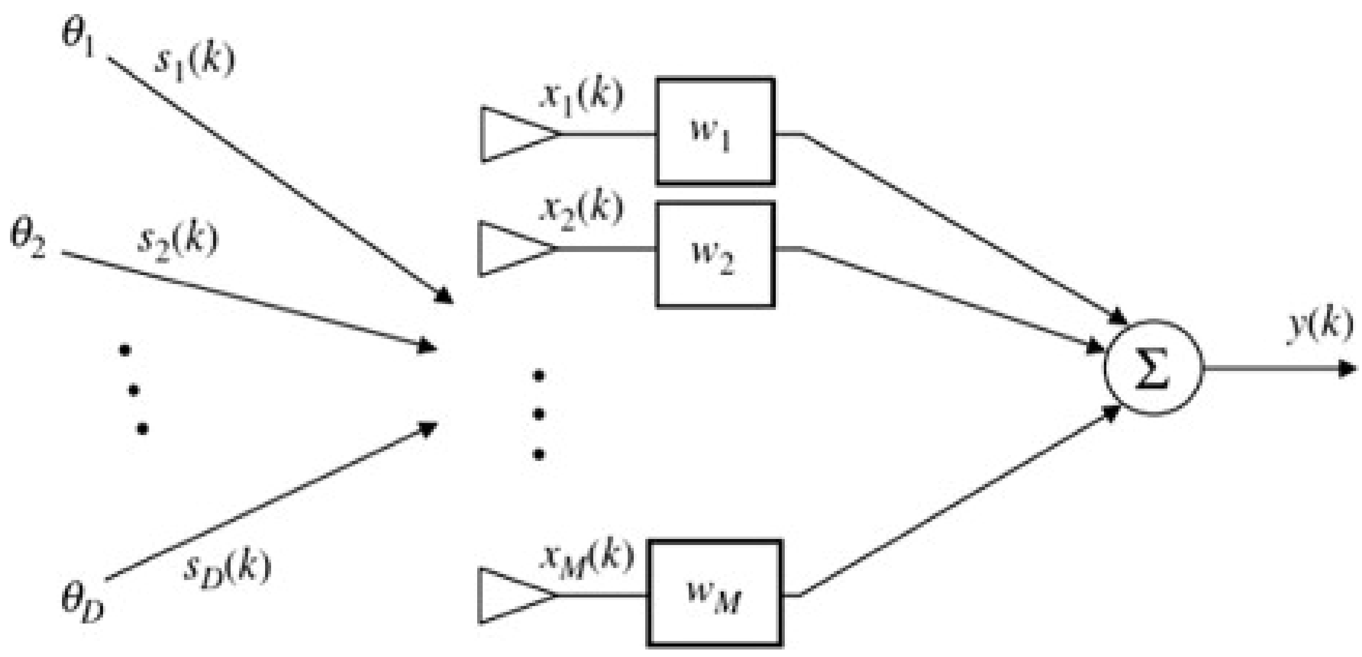
Signal Parameters

- Received Signal Strength
  - When distance increases reflecting signals from surrounding objects interfere and corrupt the main signal.
  - In NLoS case estimated distance is the strongest reflected signal.



Signal Parameters

- Angle (Direction) of Arrival (AoA - DoA)
  - Arrival angle of the signal can be estimated by an antenna array.

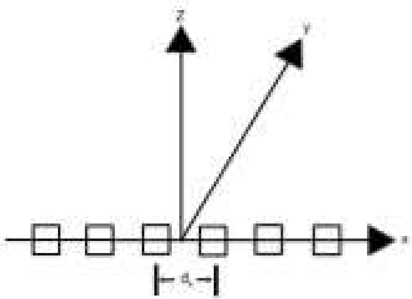


Signal Parameters

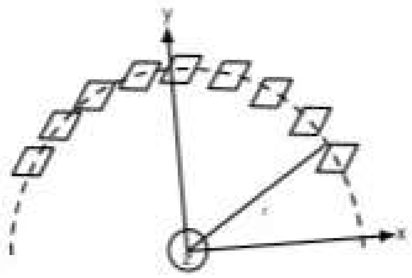
- Angle (Direction) of Arrival (AoA - DoA)
  - Array processing algorithms are used to estimate the angle of arrival
  - At least N+1 antennas are required for estimating N signals
  - Increasing the number of antennas increases the resolution of the estimation
  - Can be used to select the correct crossing points in trilateration

Signal Parameters

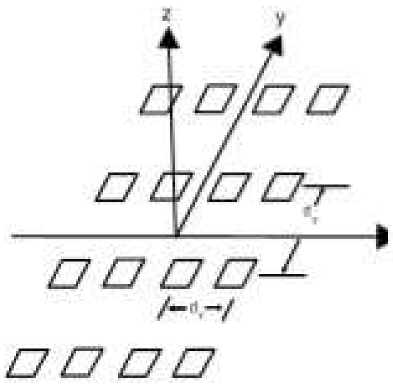
- Array Geometry is Highly effective on the performance



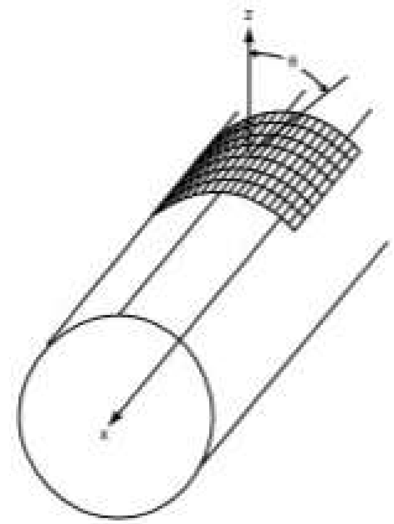
Linear Array



Circular Array



Planar Array



Conformal Array

Range Estimation

- Time Based Range Estimation
  - Used in RF, ultrasound and light based systems.
  - Reliable for large distances.
  - Based on the simple formula

$$D = V \times t$$

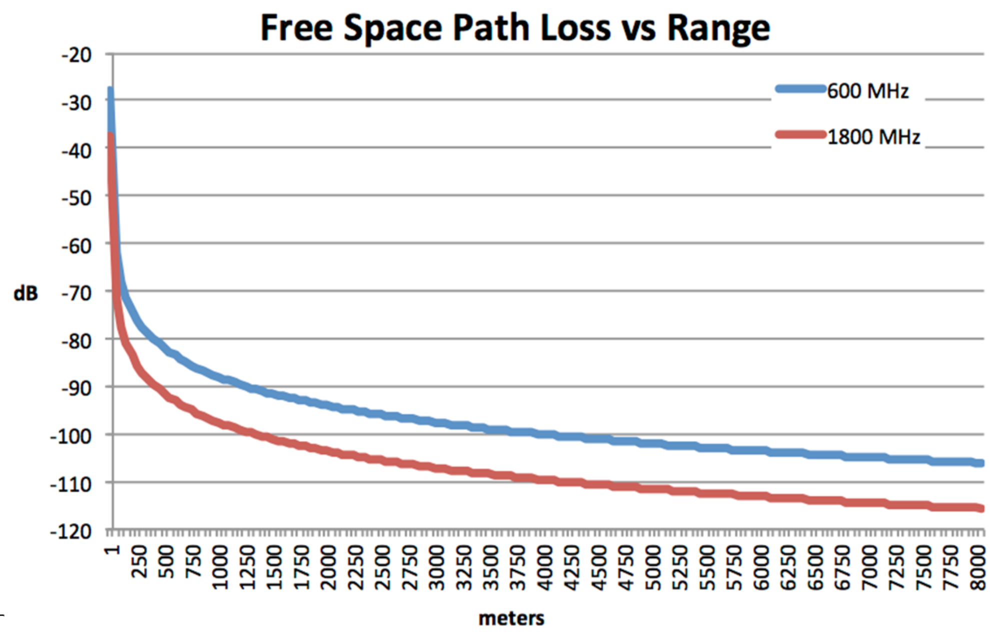
  - Here D is the range to be estimated where V is the speed of the propagating wave and t is the time of flight from the source to the receiver
  - Time of flight is estimated using ToA or TDoA metric

Range Estimation

- Time Based Range Estimation
  - If the source propagates an RF signal or light, the speed is the speed of light
  - If it is ultrasound, it is the speed of voice.
  - Resolution of time information gives the resolution of distance estimation.
  - Timestamps as low as 0.1 ns are available, therefore distance resolution is approximately 0.3 m at best.

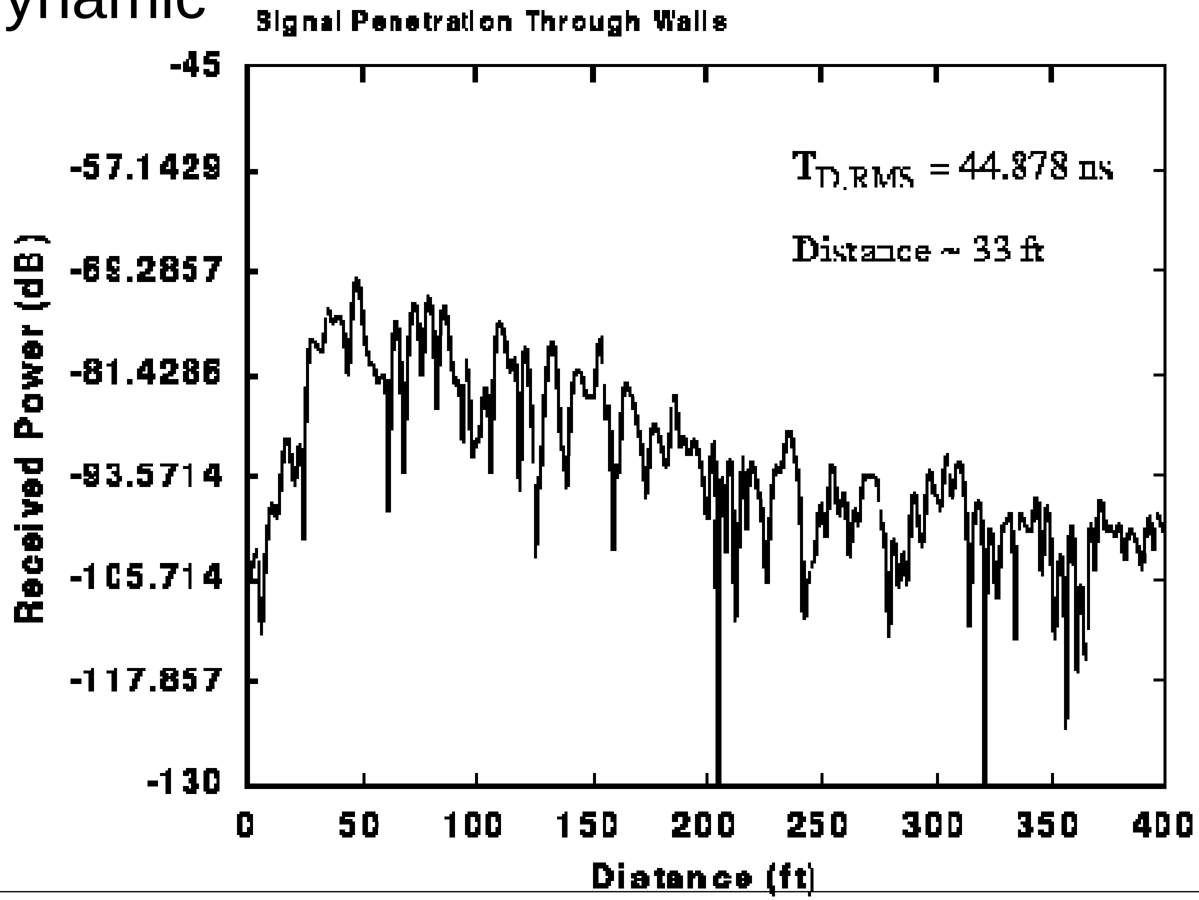
Range Estimation

- Amplitude Based Range Estimation
  - Attenunation of an RF signal depends on the distance between transmitter and receiver
  - If the power at the receiver part is known, and the received signal strength is acquired the distance is estimated according to the difference.



Range Estimation

- Amplitude Based Range Estimation
  - Indoor propagation loss is highly variable and dynamic



Range Estimation

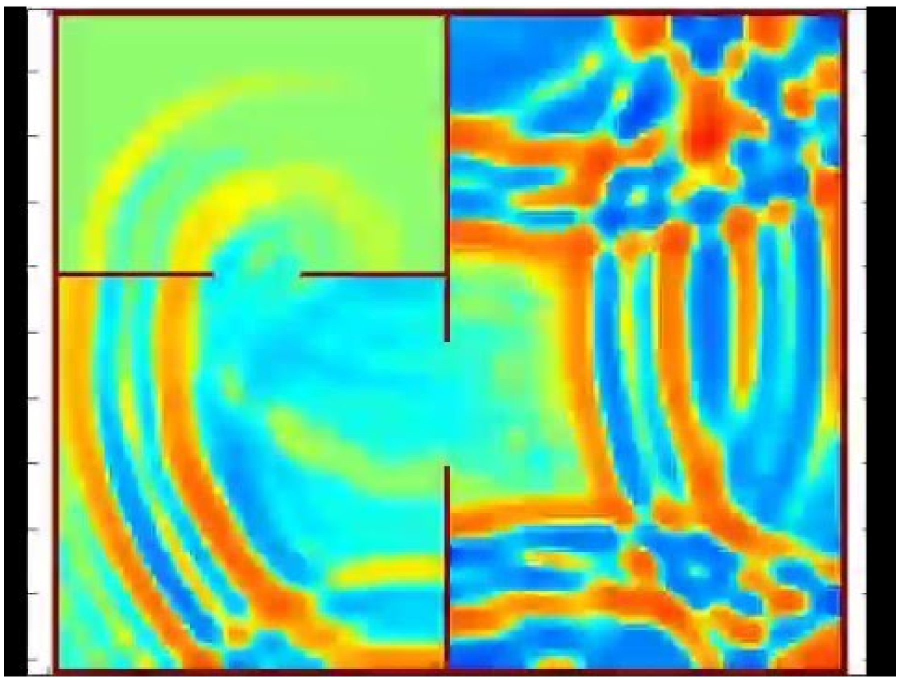
- Amplitude Based Range Estimation
- Distance can be estimated by using the below formula [And 94]

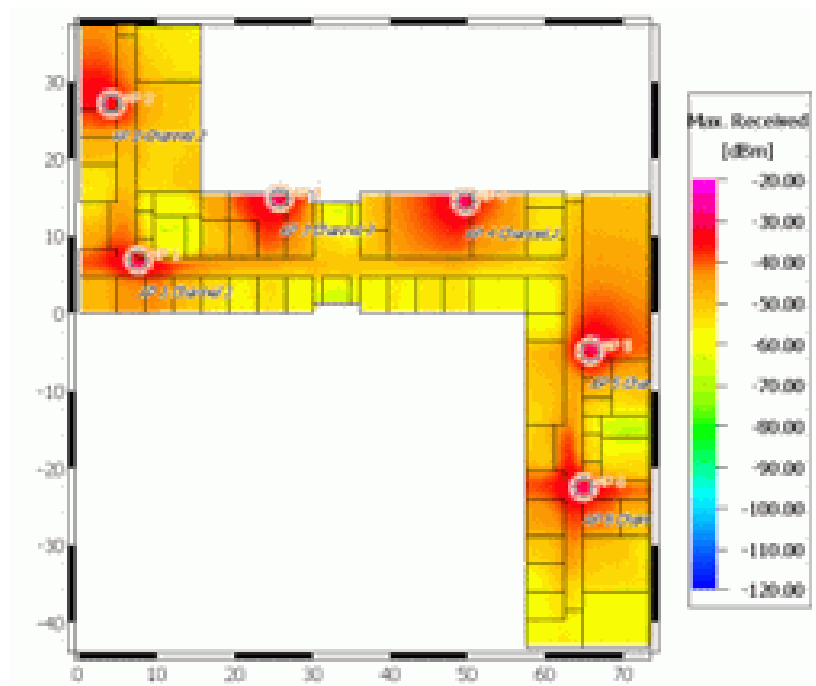
$$PL(d) = PL(d_0) + 10n\log(d/d_0) + X_\sigma$$

Building	Frequency (MHz)	*n*	σ (dB)
Retail Stores	914	2.2	8.7
Grocery Store	914	1.8	5.2
Office, hard partition	1500	3.0	7.0
Office, soft partition	900	2.4	9.6
Office, soft partition	1900	2.6	14.1
Factory LOS			
Textile/Chemical	1300	2.0	3.0
Textile/Chemical	4000	2.1	7.0
Paper/Cereals	1300	1.8	6.0
Metalworking	1300	1.6	5.8

Range Estimation

- Amplitude Based Range Estimation
  - Attenuation is highly dependent on the medium



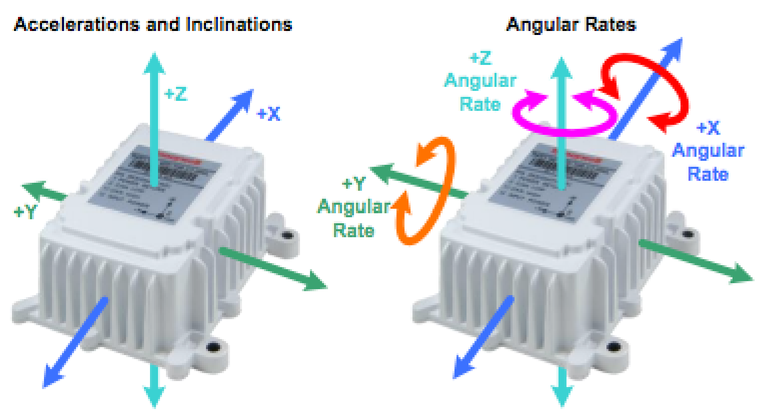


Range Estimation

- Displacement Estimation
  - Sensors are used to estimate the displacement of an object with respect to an initial position
  - Encoders
  - Inertial Sensors

Range Estimation

- Inertia Based displacement estimation:
  - Acceleration in 3 dimensions is evaluated using an IMU sensor



Range Estimation

- Inertia Based displacement estimation:
  - Once the acceleration vector is evaluated, speed and displacement can be calculated as:
  - The velocity is the indefinite integral of the acceleratior

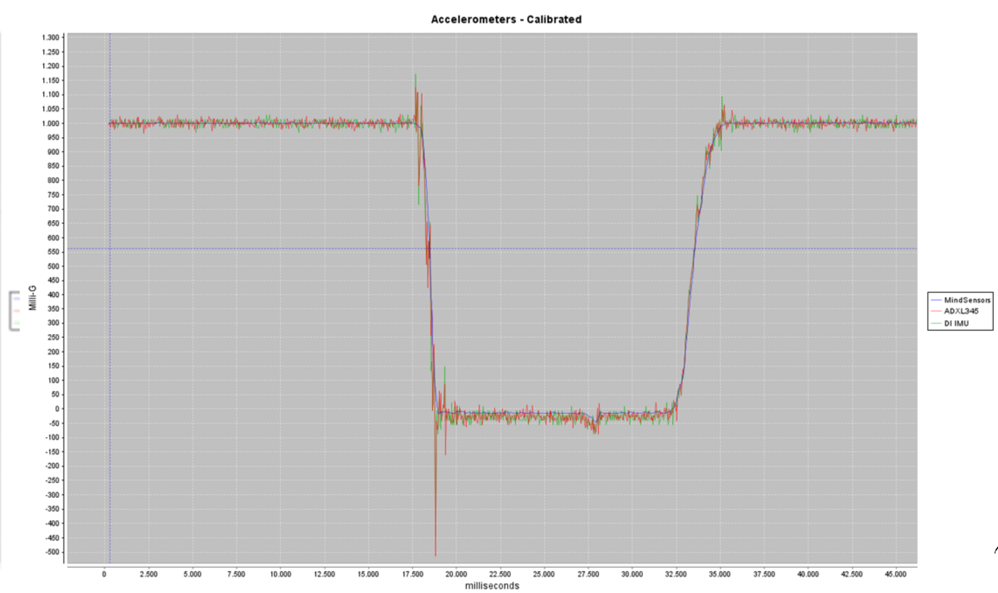
$$v(t) = v_0 + \int_{t_0}^{t} a(t')\mathrm{d}t'$$

  - And the displacement is the integral of velocity in the same time

$$x(t) = \int v(t)\,\mathrm{d}t$$

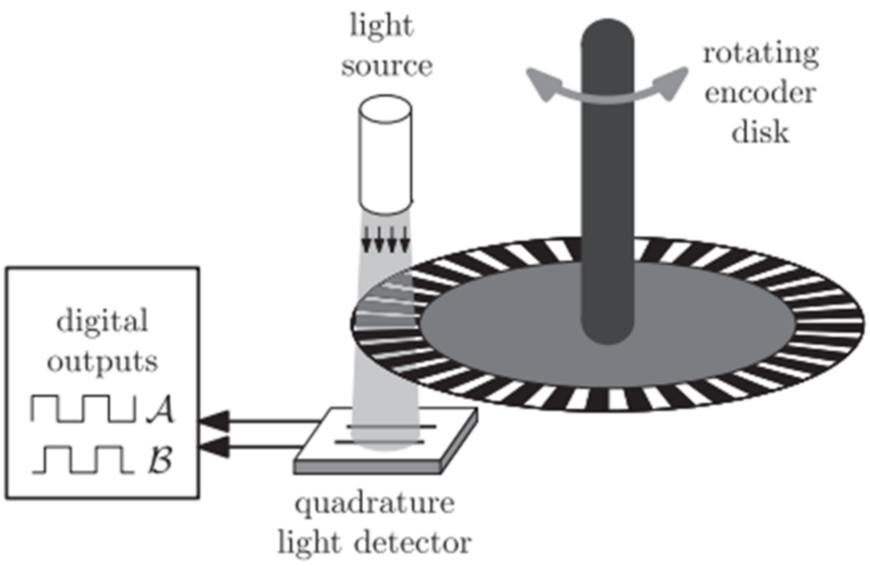
Range Estimation

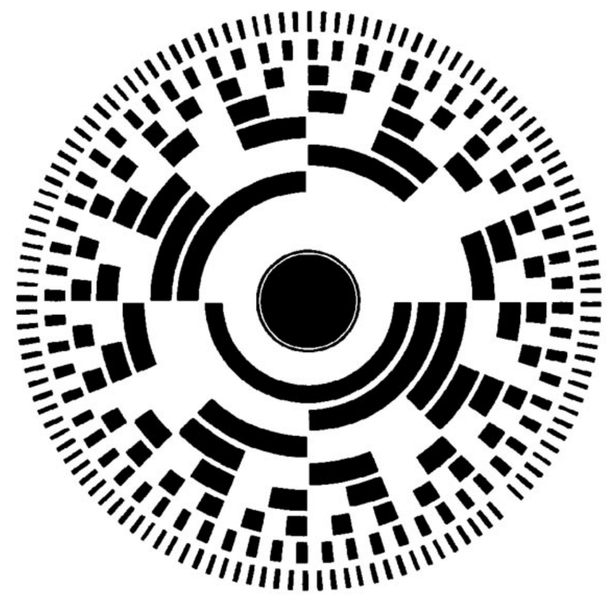
- Inertia Based displacement estimation:
  - Inertial sensor outputs are highly noisy
  - They need to be properly filtered for accurate results



Range Estimation

- Encoder Based displacement estimation:
  - Rotation of a wheel is measured with a mechanical, optical or magnetic sensor



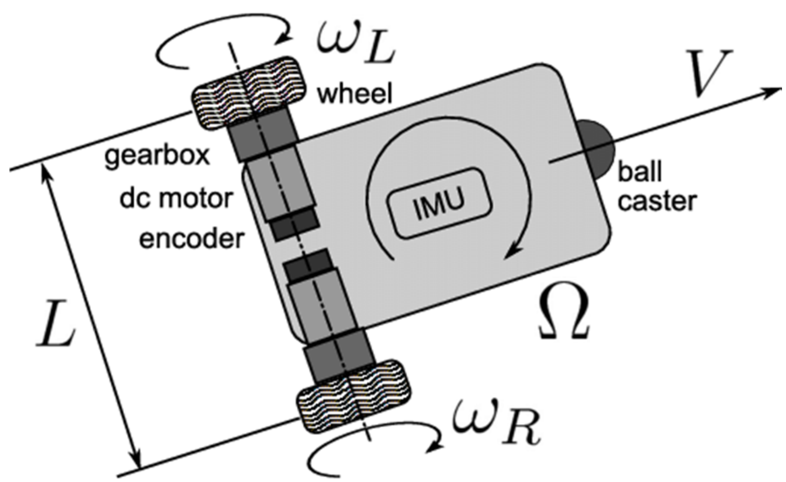


Range Estimation

- Encoder Based displacement estimation:
  - Number of rotations at a certain time is measured and multiplied with the circumference of the wheel
  - Number of rotations is not an integer number, each turn is divided into several angles

Range Estimation

- Encoder Based displacement estimation:
  - Rotation of the object can be sensed by different number of turns of the wheels on two sides.

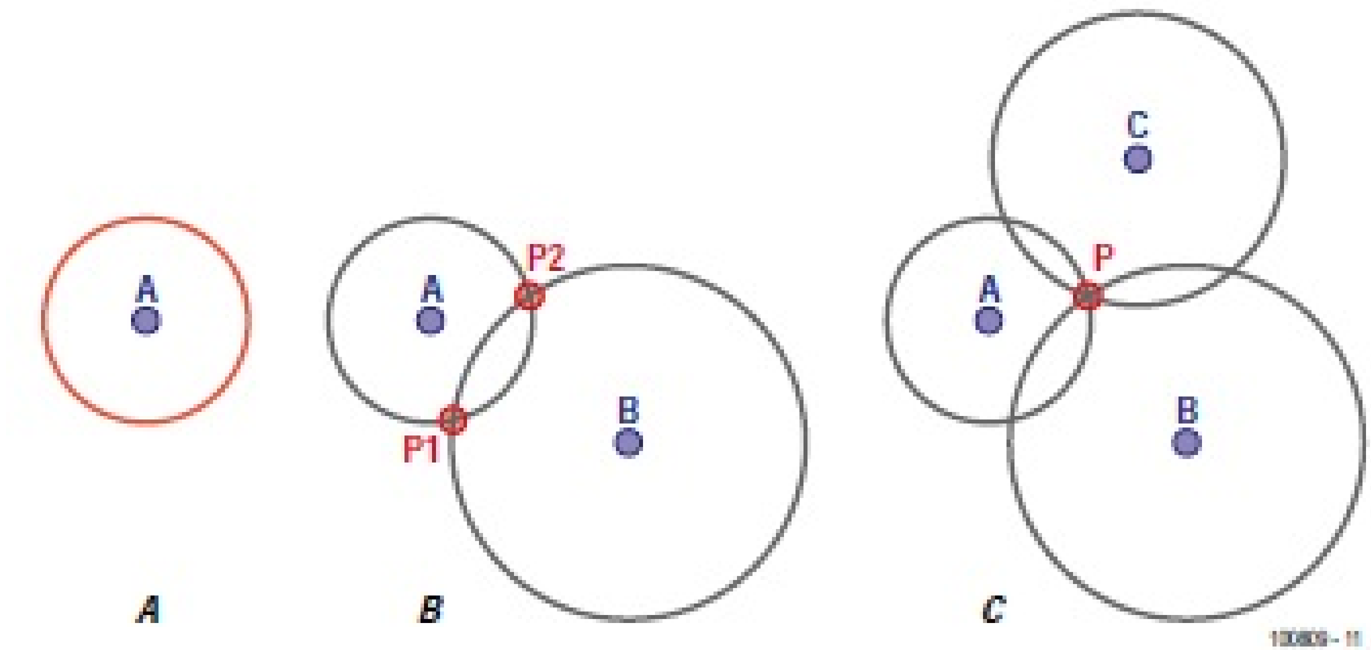


Position Estimation

- Position of an object can be estimated by;
  - Using the distances of the object to other objects or reference points.
  - Displacement of the object with respect to a reference point

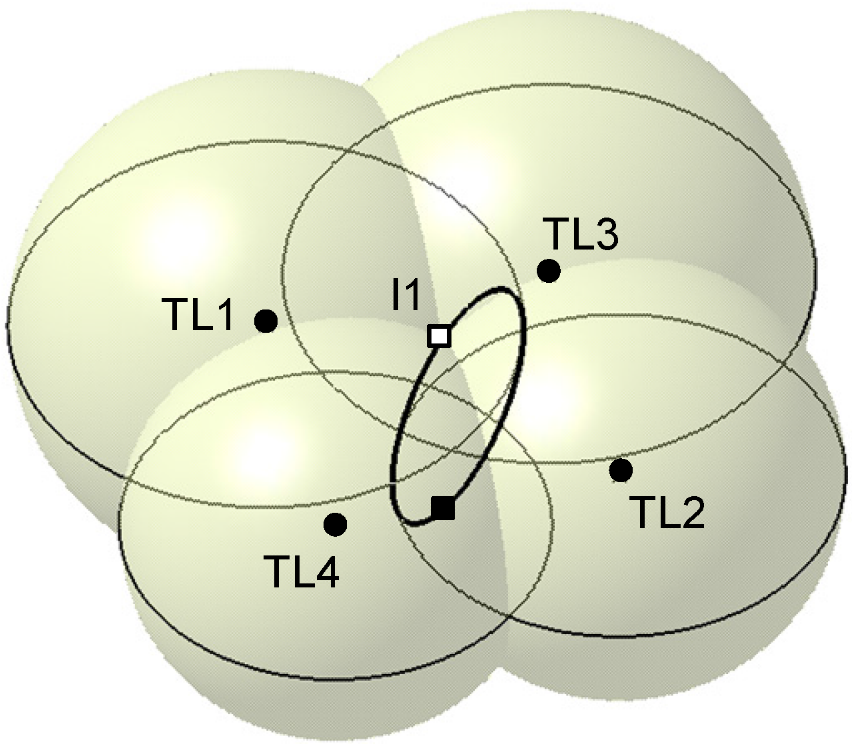
Position Estimation

- Trilateration
  - Used to locate an object using the range estimates from different reference devices



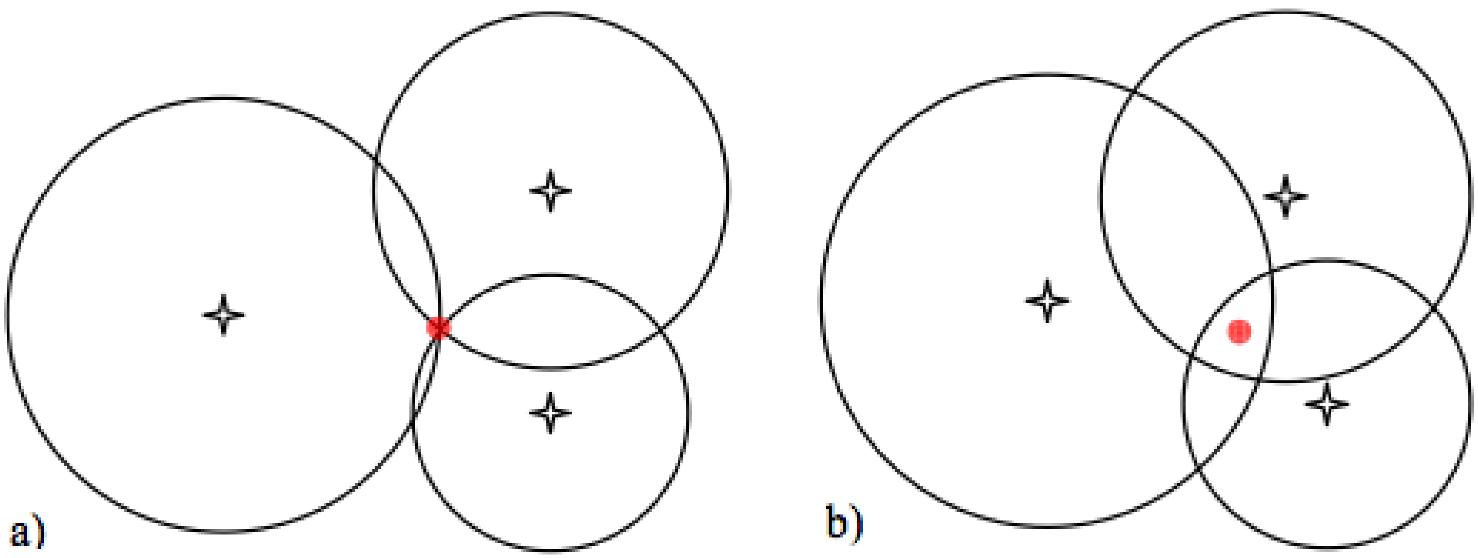
Indoor Positioning

- Multilateration
  - More than three distance estimates are used for 3D positioning or to enhance the position estimate



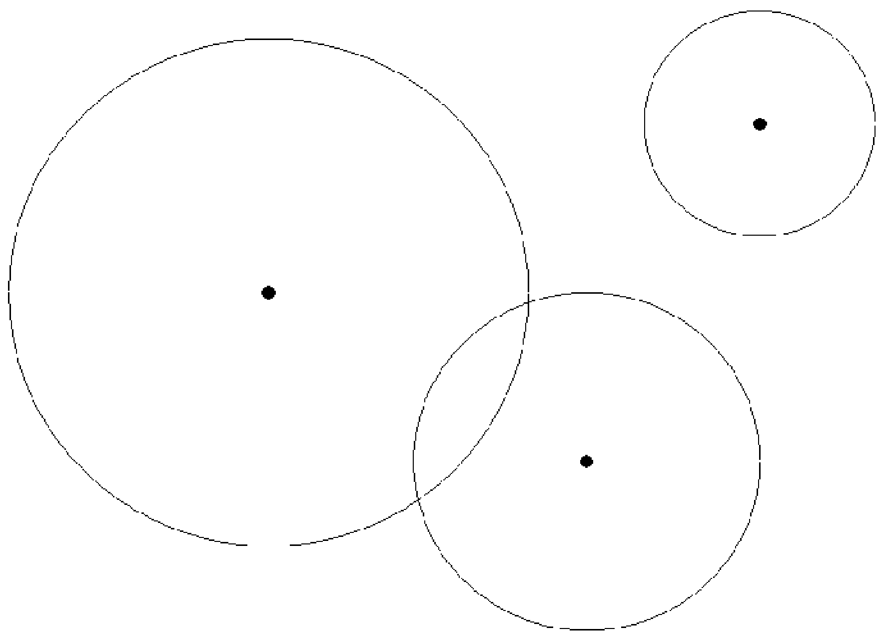
Indoor Positioning

- Trilateration Error
  - Intersections do not always show a single location, they rather show an area



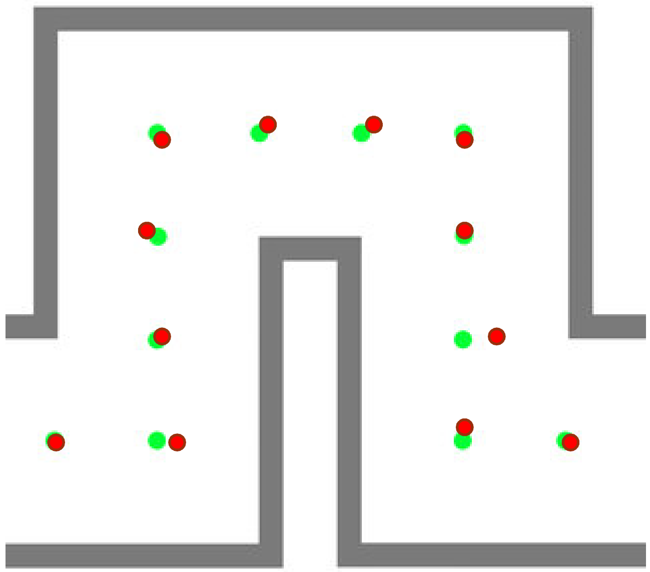
Indoor Positioning

- Trilateration Error
  - No intersection between circles



Position Estimation

- Displacement based position estimation
  - Requires displacement information based on a sensor measurement.
  - Displacement in all dimensions is evaluated using mathematical calculations.
  - After the movement of the object for a certain time new location is calculated.



Coordinate System

- Absolute Coordinate System
  - Solid reference(s) are defined
  - Locations of all objects are defined according to the solid reference(s)
  - Positions could be given in a number of different coordinate systems

Coordinate System

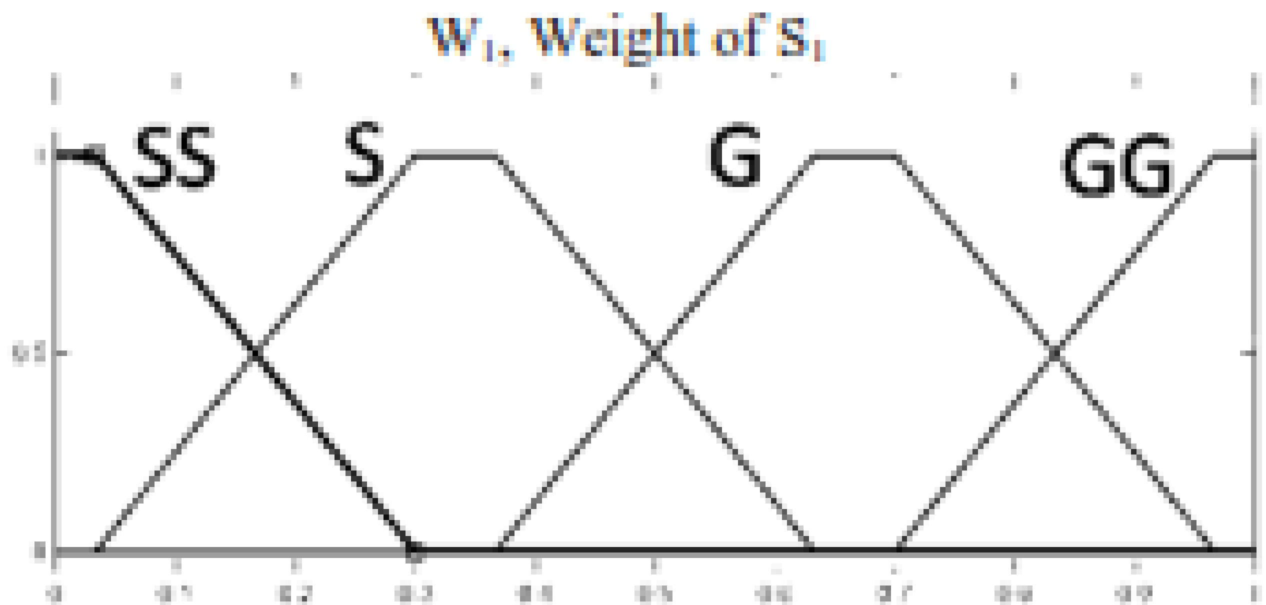
- Relative Coordinate System
  - Position is defined with respect to reference mobile unit(s)
  - Coordinate system moves with the reference mobile unit(s).
  - In some cases reference unit might also change

Sensor Fusion

- All methods for location estimation have superiorities to each other depending on the environmental and application conditions.
- At a far distance time based methods are superior to amplitude based methods, but at close distances the inverse is valid.
- IMU is superior to encoder for rotational movements but the inverse is valid for straight movements

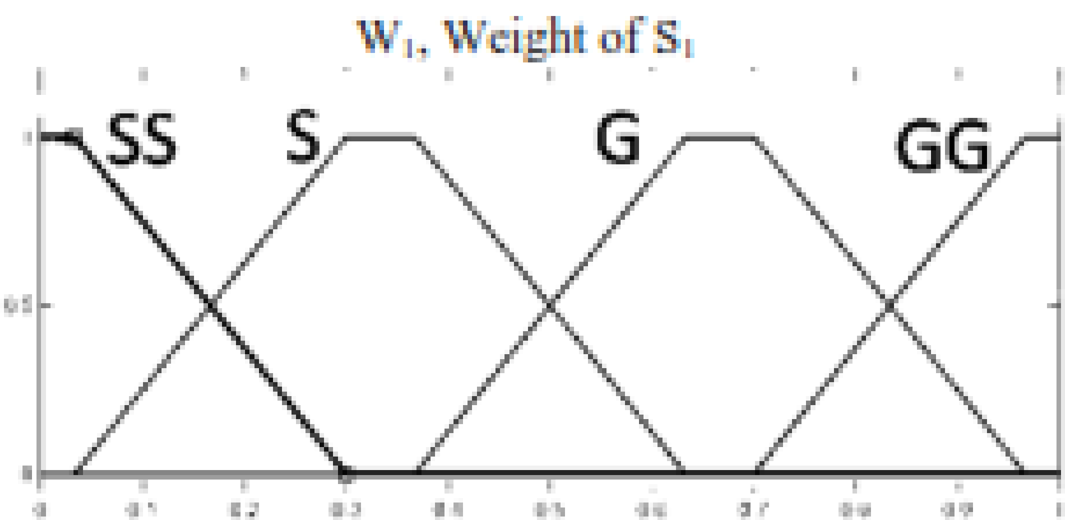
Sensor Fusion

- Sensor fusion is the weighted sum of the outputs of sensors giving the same type of output (displacement, range etc…)



Sensor Fusion

- There must be a rule table for determining the weights
- The rule table is based on external conditions



If *abs* $(S_1 - S_2)$ is *small* and *abs* (dS_2/dt) is *small*,
Then: W_1 should be *small*.

If *abs* $(S_1 - S_2)$ is *small* and *abs* (dS_2/dt) is *large*,
Then: W_1 should be *large*.

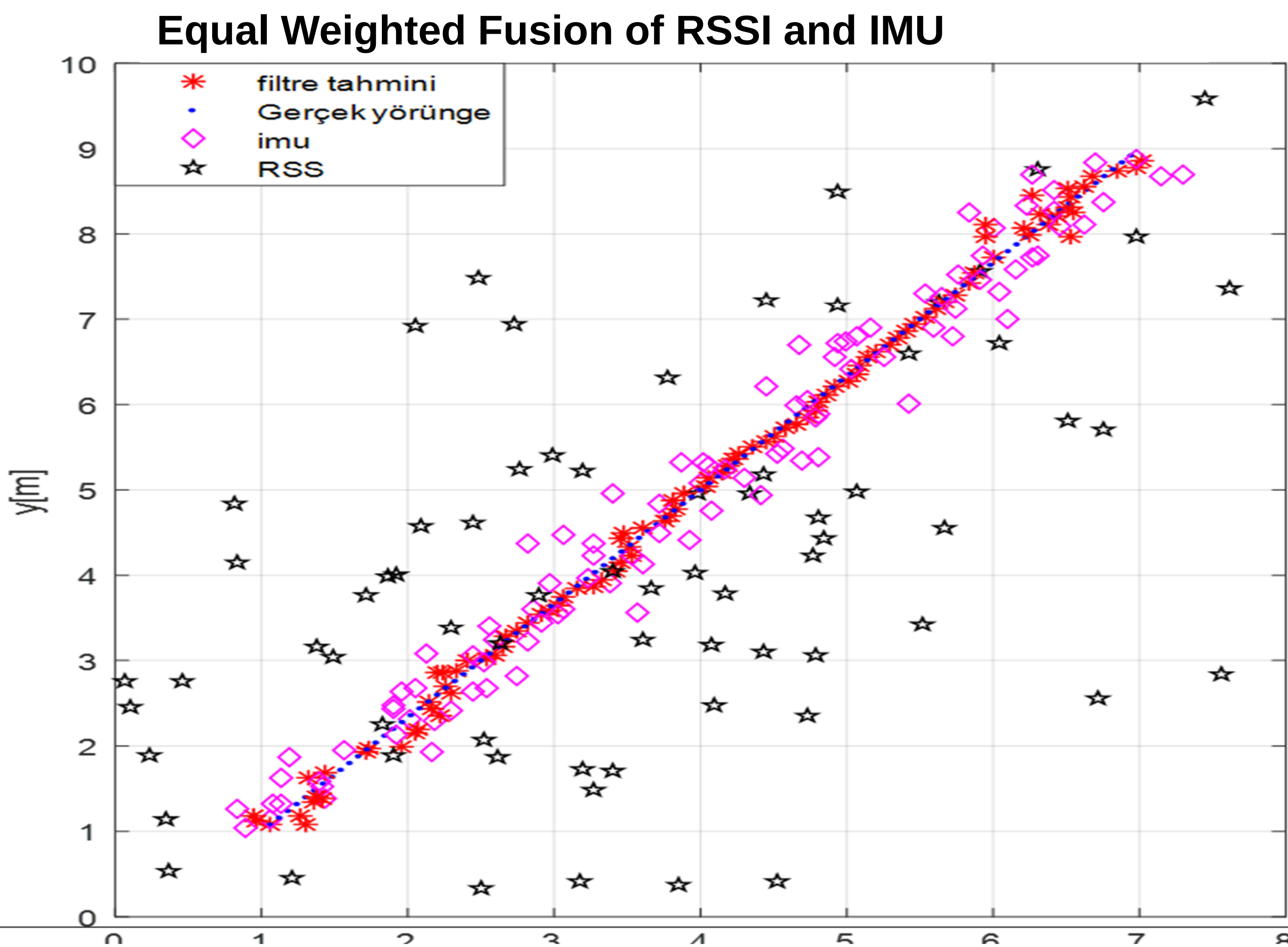
If *abs* $(S_1 - S_2)$ is *large* and *abs* (dS_2/dt) is *small*,
Then: W_1 should be *very small*.

If *abs* $(S_1 - S_2)$ is *large* and *abs* (dS_2/dt) is *large*,
Then: W_1 should be *very large*.

Sensor Fusion

- Fusion processes are often categorized in a three-level model distinguishing low, intermediate, and high level fusion
  - Low-level fusion: combines several sources of raw data to produce new data that is expected to be more informative than the inputs
  - Intermediate-level fusion: Combines various features processed from raw data to be used for further processing
  - High-level fusion: Combines decisions from several methods
- High Level Fusion is preferred during our work.

Results


Equal Weighted Fusion of RSSI and IMU
filtre tahmini
Gerçek yörünge
imu
RSS
y[m]
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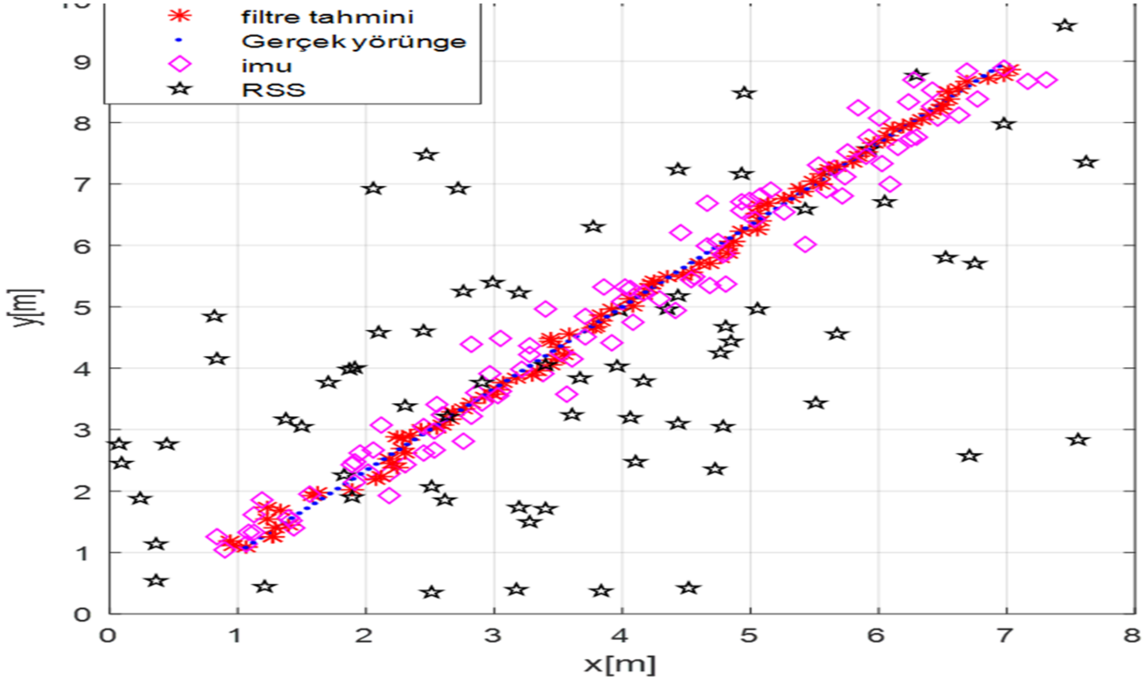
8

Results

Adaptive Weighted Fusion of RSSI and IMU



Adaptive weights