Positioning system for UWB platform

Department of Industrial Engineering
University of Trento

Daniele Fontanelli
Dept. of Industrial Engineering - DII
University of Trento, Italy
daniele.fontanelli@unitn.it

Luca Santoro
Dept. of Industrial Engineering - DII
University of Trento, Italy
luca.santoro@unitn.it

UNIVERSITÀ DI TRENTO | Dipartimento di Ingegneria Industriale

Approaches

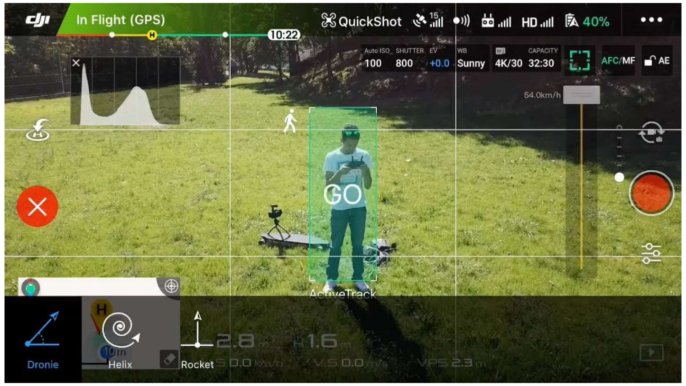
Three main categories:

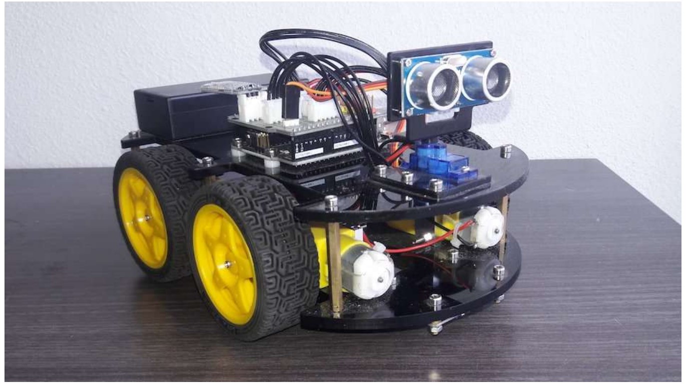
1. Vision based
2. Infrared and/or Lidar
3. Radio Frequency based

Vision based, like Visual Inertial Navigation suffers low visibility conditions and presence of dust or fog

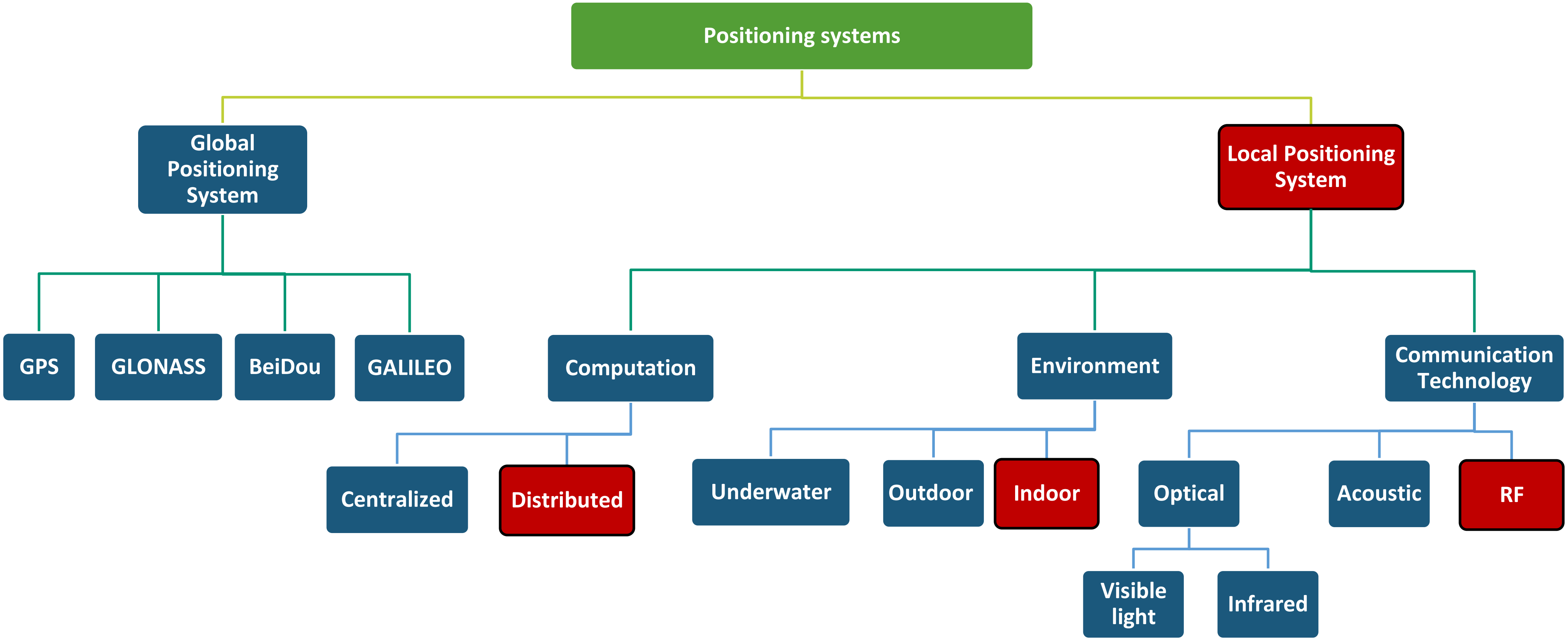
Radio-Frequency solutions advantages

- Robust to lights changes, dust and fog
- Low computational cost



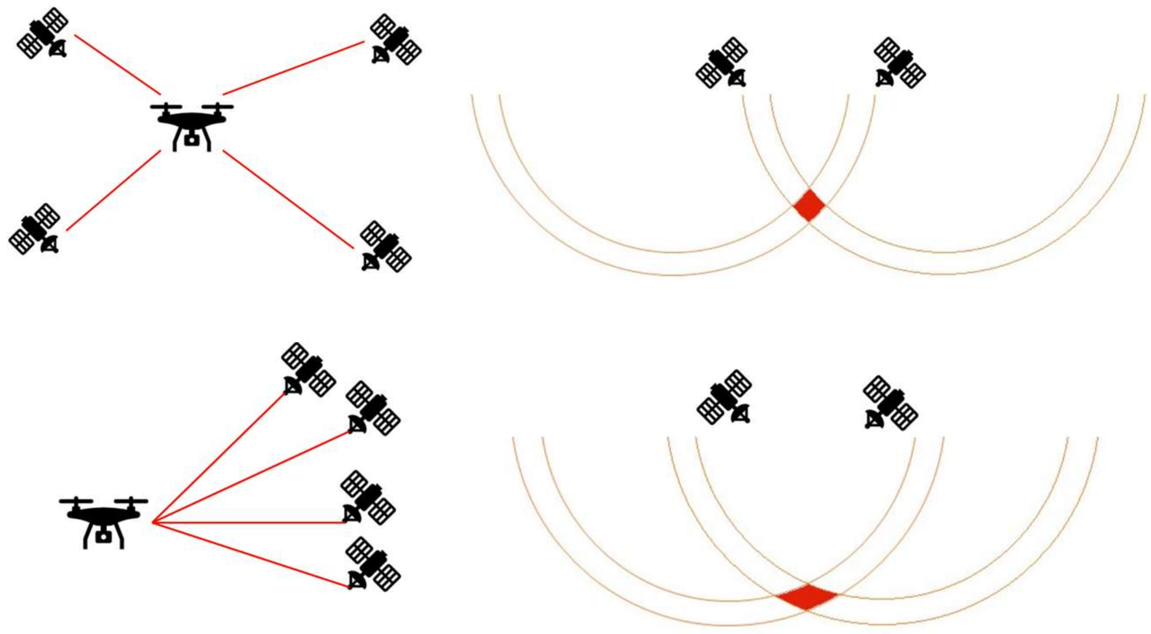


Overview of the Positioning System



Precision Dilution of Precision

PDoP is a metric adopted to quantify the precision and accuracy of the data received from GPS satellites, which is now being adopted to the wider set of generic positioning system. This metric indicates how well the satellites are geometrically organized. The lower the value, the better is the position accuracy.



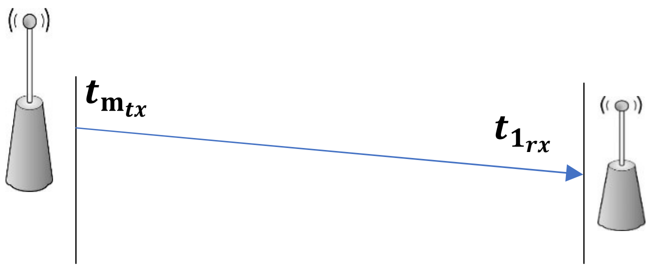
Good PDoP

Bad PDoP

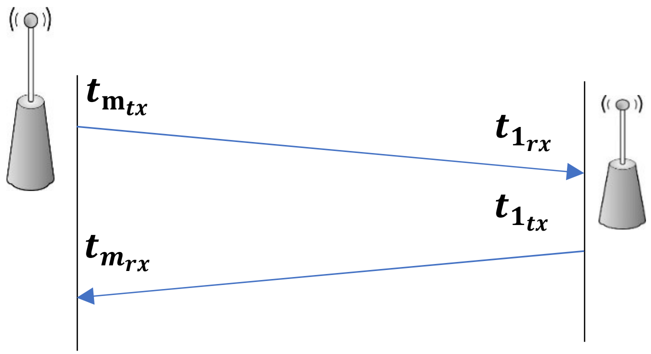
How to estimate distance

Parameter	Synchronization	Accuracy	Extra HW	Scalability (Update rate)	Communication Type
RSS	×	Low	×	Medium	Single cast
TOA	✓	High	×	Low	Single cast
RTT	×	High	×	Low	Single cast
AOA	×	High	✓	Low	Multi cast
TDOA	✓	High	✓	High	Multi cast

ToA scheme

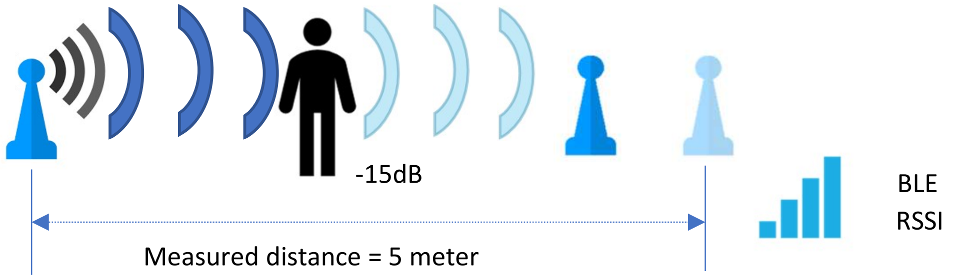


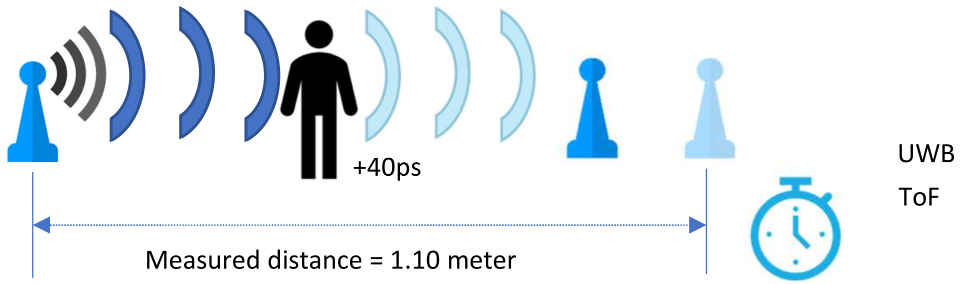
RTT scheme



Indoor localisation technology: BLE vs UWB

True distance is 1 meter, the presence of obstacle cause an error on measurement

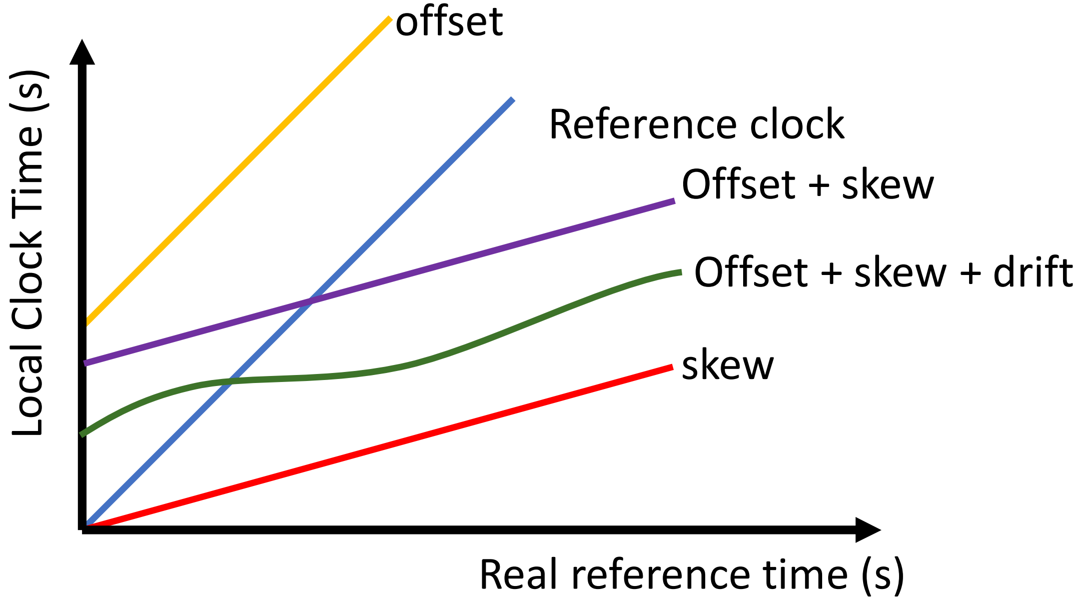




Features	BLE	UWB
Technique	RSSI	ToF
Typical accuracy	200 cm	10 cm
Accuracy with IMU fusion	Under 1000 mm	Under 10 mm
Typical power consumption	40 mAh	150 mAh
Data rate	Over 2 Mbps	Over 20 Mbps
Multipath resistance	Low	High
Discovery functionalities	Available API	Not available API

The combination of the two technologies offers a new way to develop a tracking system

Clock Model

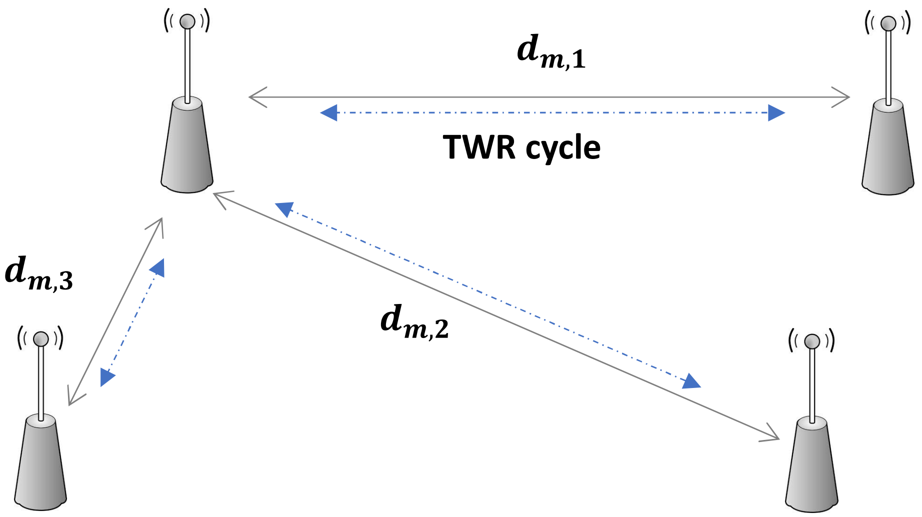


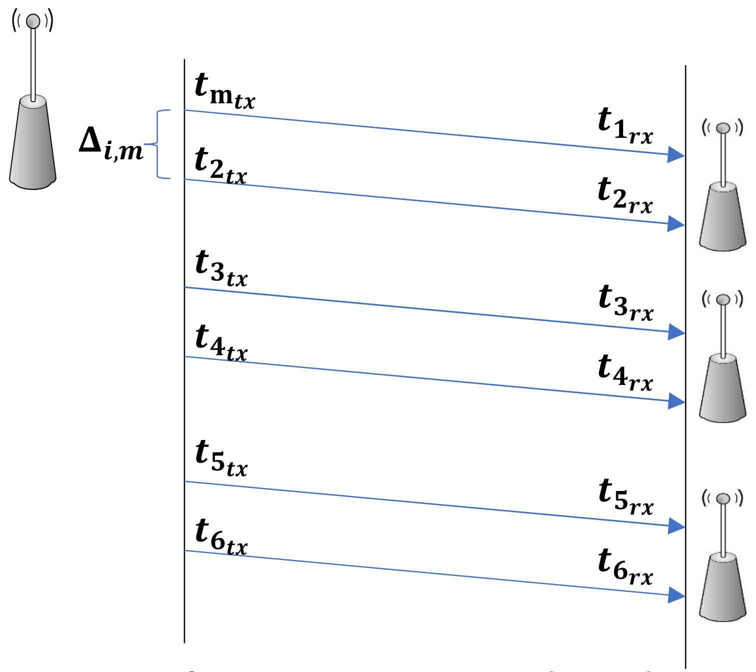
Simplified clock model

$$\tau(t) = o + vt$$

- Offset is a delay of a given clock source or the difference between two clock
- Skew is the difference between the frequencies o fa given clock and the reference clock
- Drift is variations over the skew

Calibration and Synchronization factors on infrastructure side





Calibration factor to estimate the relative offset

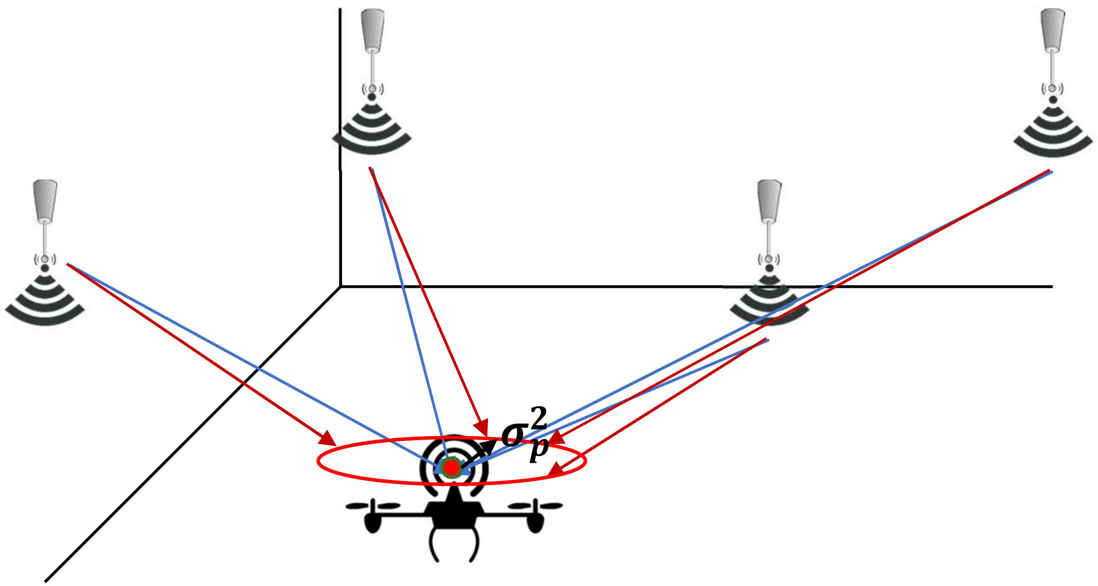
$$o_{i,m} = \overline{tof}_{m,i} - \frac{d_{m,i}}{c}$$

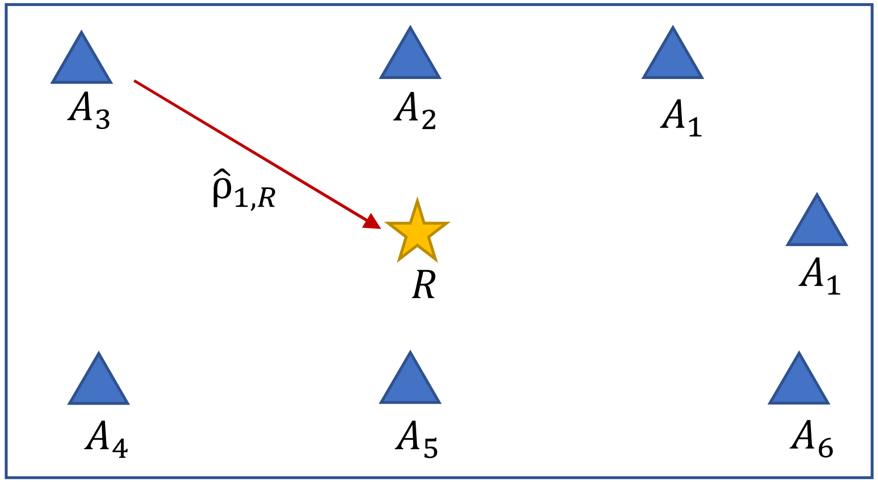
Syntonize factor to estimate the relative skew

$$\bar{\nu}_{i,m} = \frac{\nu_i}{\nu_m} = \frac{\tau^i(\bar{t} + \Delta_{i,m} + \delta_{i,m}) - \tau^i(\bar{t} + \delta_{i,m})}{\tau^m(\bar{t} + \Delta_{i,m}) - \tau^m(\bar{t})}$$

Problem case

Localization in general plays a major role in emergent applications in the field of medical, industrial or consumer application. Such applications aim for use in indoor application where in general Global Navigation Satellite System (GNSS), e.g. GPS, is not available. This is because the GNSS signal is too weak to penetrate concrete walls or is otherwise shadowed or reflected. Therefore other solutions to determine the position within buildings is required.





Ranging equation

$$\hat{\rho}_{1,R} = (x_R - x_i)^2 + (y_R - y_i)^2$$

Problem case

Considering that the distances between anchors and tag are available, solve the localisation problem with Least Squares.

To linearise ranging equation a reference node needs to be chosen. All other equations are subtracted from equation which incorporates the reference anchor. For this derivation the first anchor is chosen as the reference anchor

$$\rho_{1,R}^2 - \rho_{2,R}^2 = [(x_R - x_1)^2 + (y_R - y_1)^2] - [(x_R - x_2)^2 + (y_R - y_2)^2]$$

Now, the squared unknown coordinates r vanish which results in:

$$\rho_{1,R}^2 - \rho_{2,R}^2 = -2x_R x_1 - 2y_R y_1 + 2xx_2 + 2yy_2 + x_1^2 + y_1^2 - x_2^2 - y_2^2$$

Rearrange the equation. Everything which is known e.g. anchor coordinates are grouped together with the measurements distance on the right-hand side. On the left-hand side of the equation the unknown receiver coordinates are grouped.

$$2x_R(x_2 - x_1) - 2y_R(y_2 - y_1) = \rho_{1,R}^2 - \rho_{2,R}^2 - x_1^2 - y_1^2 + x_2^2 + y_2^2$$

Problem case

For *n* anchors, a system of linear equation is found. This system of equations are written in matrix notation:

$$\underbrace{2\begin{bmatrix} x_2 - x_1 & y_2 - y_1 \\ \vdots & \vdots \\ x_n - x_1 & y_n - y_1 \end{bmatrix}}_{A}\begin{bmatrix} x_R \\ y_R \end{bmatrix} = \underbrace{\begin{bmatrix} \rho_{1,R}^2 - \rho_{2,R}^2 - (x_1 + x_2)^2 + (x_2 + y_2)^2 \\ \vdots \\ \rho_{n,R}^2 - \rho_{n,R}^2 - (x_1 + x_2)^2 + (x_n + y_n)^2 \end{bmatrix}}_{b}$$

This is solved using linear algebra:

$$\boxed{\begin{bmatrix} x_R \\ y_R \end{bmatrix} = A^{-1}b = \underbrace{(A^T A)^{-1} A^T}_{\text{Moore–Penrose inverse}} b}$$