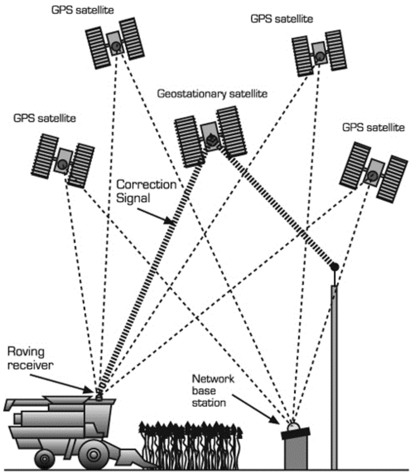
GPS and beacon based navigation



- Global positioning system (GPS) – chapter 4.1.5.1

Ground-Based Active and Passive Beacons

- Elegant way to solve the localization problem in mobile robotics
- Beacons are signaling guiding devices with a precisely known position
- Beacon base navigation is used since the humans started to travel
  - Natural beacons (landmarks) like stars, mountains or the sun
  - Artificial beacons like lighthouses
- The recently introduced Global Positioning System (GPS) revolutionized modern navigation technology
  - Already one of the key sensors for outdoor mobile robotics
  - For indoor robots GPS is not applicable,
- Major drawback with the use of beacons in indoor:
  - Beacons require changes in the environment -> costly.
  - Limit flexibility and adaptability to changing environments.

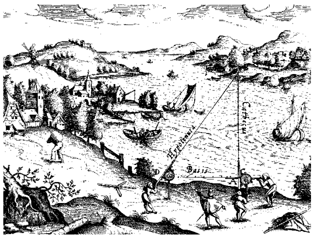
Triangulation

$$l = \frac{d}{\tan\alpha} + \frac{d}{\tan\beta}$$

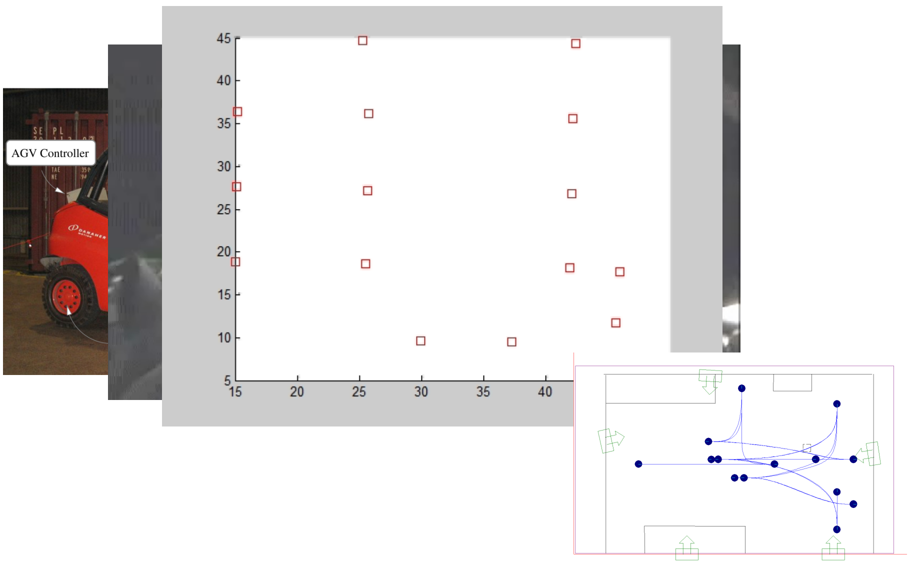
$$d = \frac{l}{\frac{1}{\tan\alpha} + \frac{1}{\tan\beta}}$$

or

$$d = \frac{l \sin\alpha \sin\beta}{\sin(\alpha+\beta)}$$



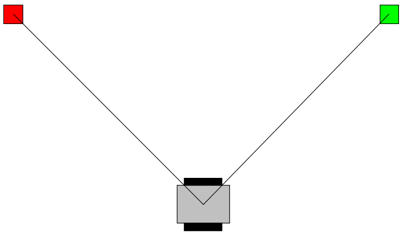
Triangulation – robot navigation

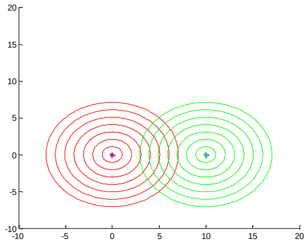


Triangulation

- Homing beacons
  - Position by
    - Measuring angles, i.e. intersection of lines.
  - Lighthouse
- Synchronized beacons
  - Position by
    - Signal time difference (phase)
    - Signal arrive time (require accurate clock)
  - GPS

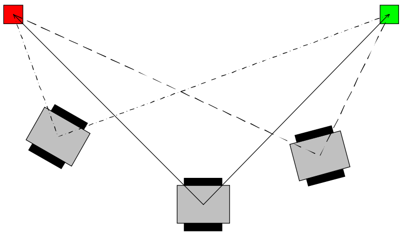
Position of beacons are known!





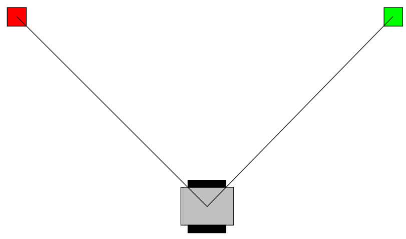
Triangulation – homing beacons

- Case A
  - Multiple possible locations with two beacons
  - Distance not measured
  - Possible locations are on an arc
  - Local coordinates



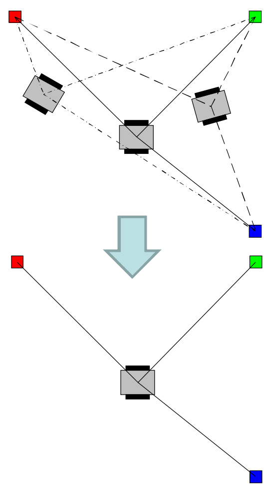
Triangulation – homing beacons

- Case B
  - Unique position if *orientation (global)* is known
  - Orientation known if:
    - Sensor used
      - Compass (absolute)
      - Odometry (relative, drift)
    - If possible to measure distance (not in this example)



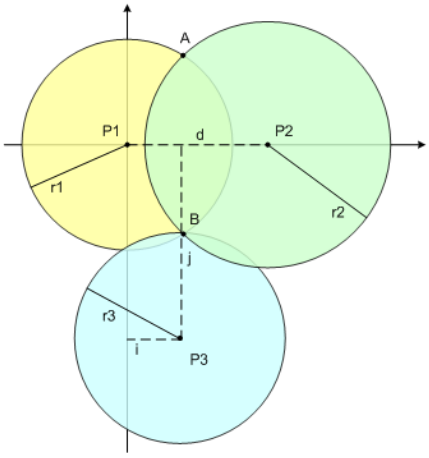
Triangulation – homing beacons

- Case C
  - Unique with three beacons, i.e. different angles

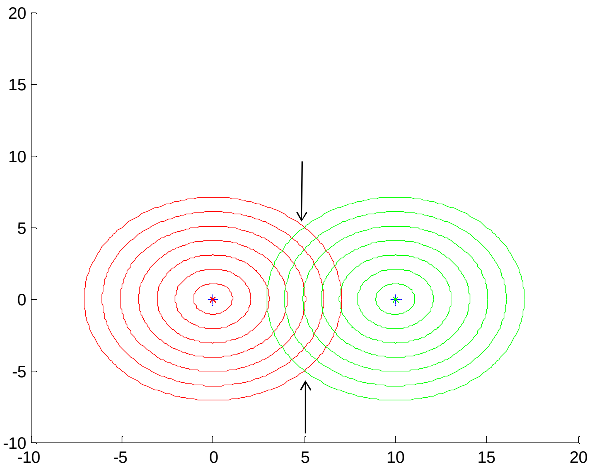


Trilateration - Synchronized beacons

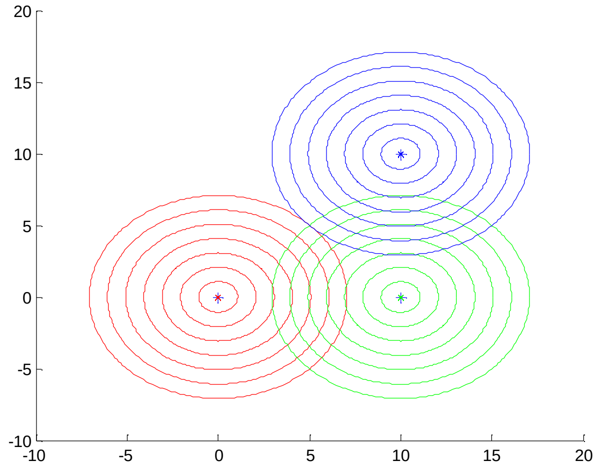
- A method for determine the intersections of three sphere surfaces given centers and radii of the spares
- Used by GPS
  - Synchronized beacons!
  - Radii = time of flight = distance



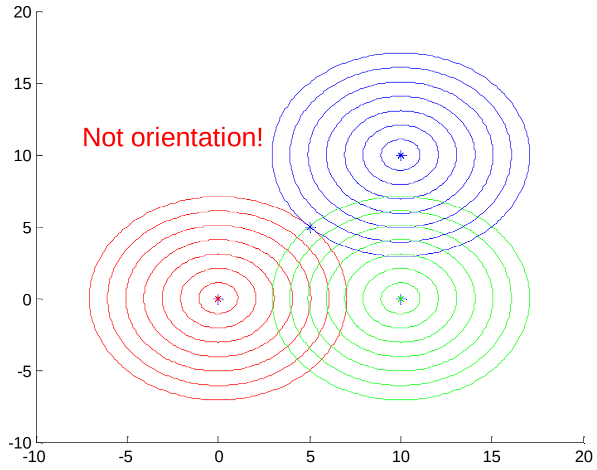
Trilateration - Example



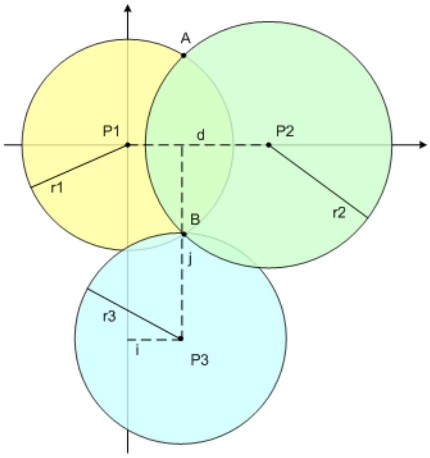
Trilateration - Example



Trilateration - Example



Trilateration - Example



$$x = \frac{r_1^2 - r_2^2 + d^2}{2d}$$

$$y = \frac{r_1^2 - r_3^2 + i^2 + j^2}{2j} - \frac{i}{j}x$$

$$P_1 = (0,0)$$

$$P_2 = (10,0)$$

$$P_3 = (10,10)$$

$$r_1 = r_2 = r_3 = \sqrt{50}$$

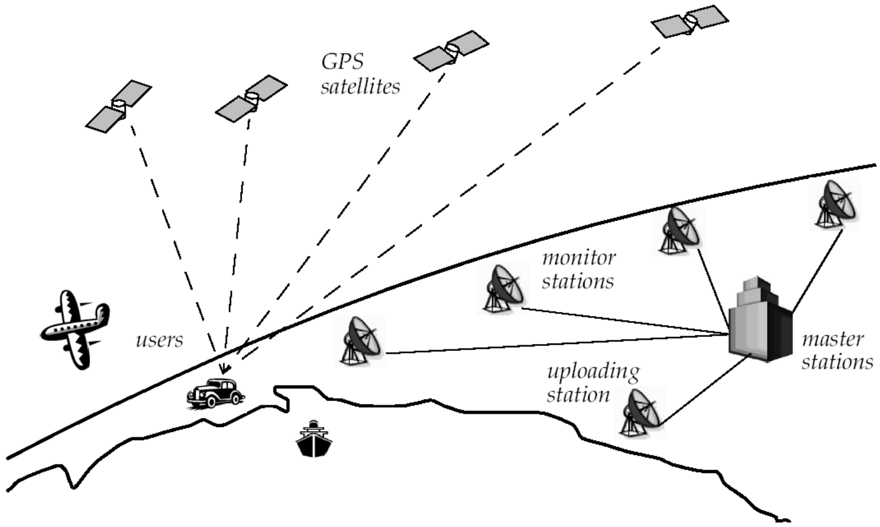
$$\Rightarrow B = (5,5)$$

Global Positioning System (GPS) (1)

- Developed for military use
- Recently it became accessible for commercial applications
- 24 satellites (including three spares) orbiting the earth every 12 hours at a height of 20.190 km.
- Four satellites are located in each of six planes inclined 55 degrees with respect to the plane of the earth's equators
- Location of any GPS receiver is determined through a time of flight measurement

- Technical challenges:
  - Time synchronization between the individual satellites and the GPS receiver
  - Real time update of the exact location of the satellites
  - Precise measurement of the time of flight
  - Interferences with other signals

Global Positioning System (GPS) (2)



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Global Positioning System (GPS) (3)

- Time synchronization:
  - atomic clocks on each satellite
  - monitoring them from different ground stations.
- Ultra-precision time synchronization is extremely important
  - electromagnetic radiation propagates at light speed,
- Roughly 0.3 m per nanosecond.
  - position accuracy proportional to precision of time measurement.
- Real time update of the exact location of the satellites:
  - monitoring the satellites from a number of widely distributed ground stations
  - master station analyses all the measurements and transmits the actual position to each of the satellites
- Exact measurement of the time of flight
  - the receiver correlates a pseudocode with the same code coming from the satellite
  - The delay time for best correlation represents the time of flight.
  - quartz clock on the GPS receivers are not very precise
  - the range measurement with four satellite
  - allows to identify the three values (x, y, z) for the position and the clock correction ΔT
- Recent commercial GPS receiver devices allows position accuracies down to a couple meters. RTK-GPS -> centimeters

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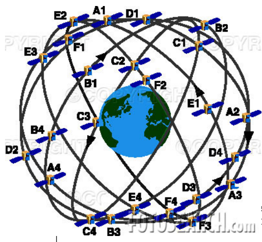
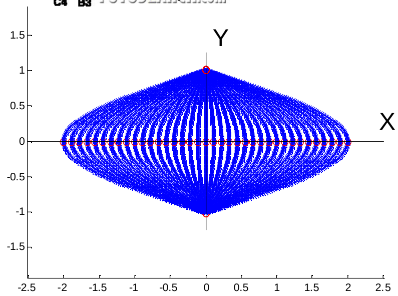
GPS – (Lon, Lat) <=> (X, Y)

- Assumes flat world, i.e. approximate to calculate position in x and y. All positions lies on the same height above ground, i.e. z is constant in the area.
- Origin = Greenwich and the Equator
- Use conversion tables or calculate exact values for a defined height above ground





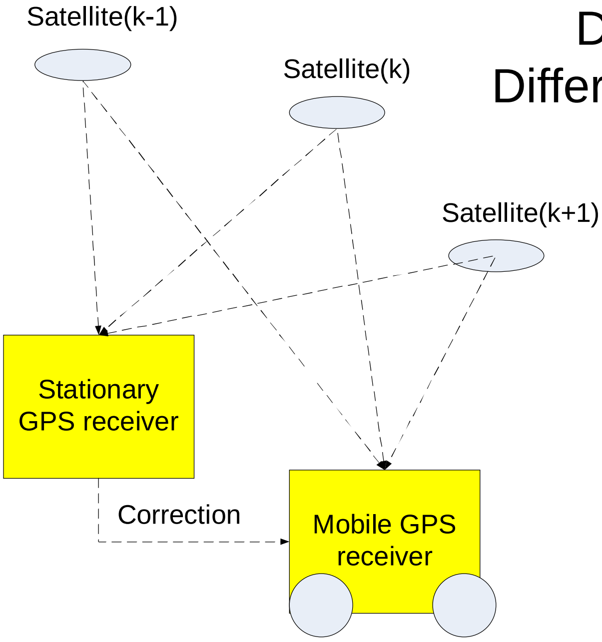
GPS - Applications

- Human navigation – ”treasure hunt”

- Navigation: ship, car, airplanes

Images from http://www.fotosearch.com

DGPS – Differential GPS

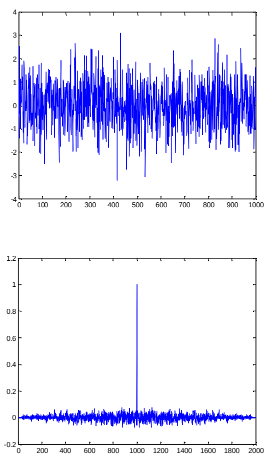


Exercise 1 - GPS

- GPS accuracy
- Errors correlated in time
- How this effect estimation of:
  - Velocity
  - Position

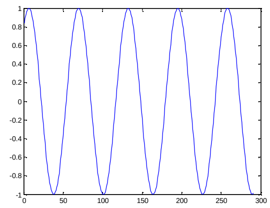
Matlab

```
x = randn(1,1000);
plot(x);
plot(xcorr(x,'coeff'));
```

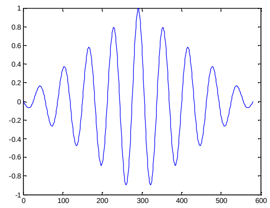


Exercise 1 - GPS

matlab
y = sin(1:0.1:30);
plot(y);

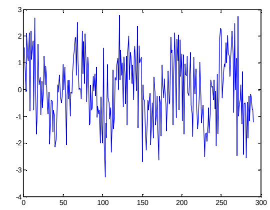


plot(xcorr(y,'coeff'));

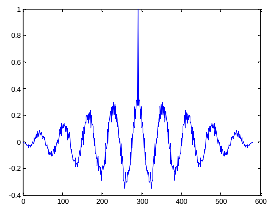


Exercise 1 - GPS

Matlab
y = sin(1:0.1:30);
A = y + randn(1,length(y));
plot(A);

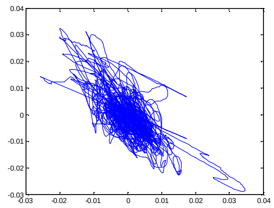


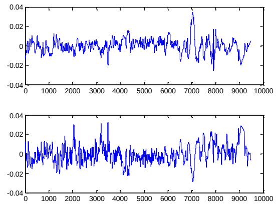
plot(xcorr(A,'coeff'));



Exercise 1 - GPS

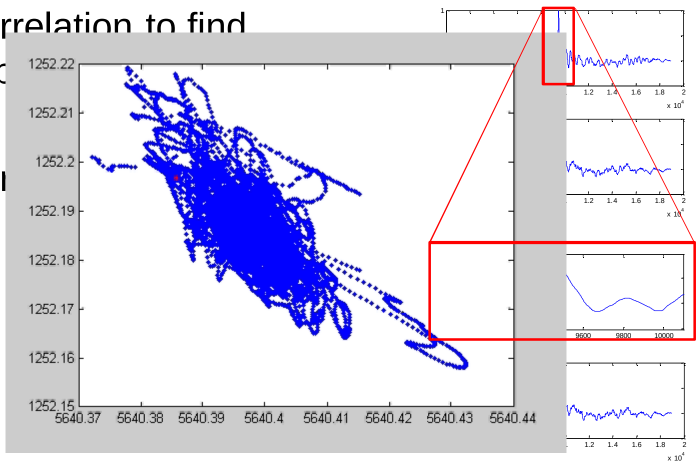
- Exercise data – stationary reciver
  - Error_x = x – mean(x)
  - Error_y = y – mean(y)





Exercise 1 - GPS

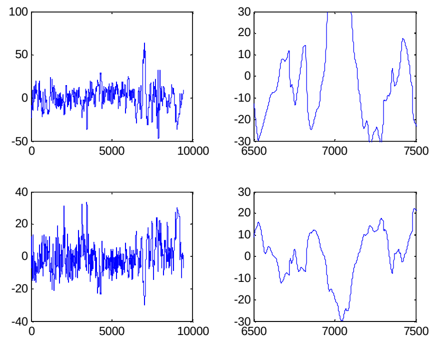
- Correlation to find dep
- Co



Auto-correlation plot

GPS – Errors

- Errors are correlated with time
- How to use this knowledge?
  - Velocity
  - Position



X: Longitude

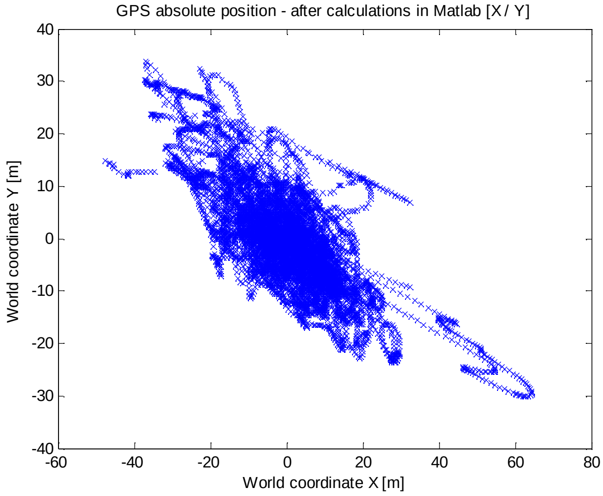
$e_x = x - \bar{x}$

Y: Latitude

$e_y = y - \bar{y}$

Exercise #1

GPS - Errors


GPS absolute position - after calculations in Matlab [X / Y]
World coordinate Y [m]
World coordinate X [m]
40
30
20
10
0
-10
-20
-30
-40
-60
-40
-20
0
20
40
60
80