DTU

Introduction to

Unmanned Autonomous Systems - 31390

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Outline

- About 31390
    - Structure of the course
    - Lecture/Exercise ballance
    - Topics
    - Platforms
    - Facilities

- A bit about Drones
- The exercise of today
- Possibilities for MSc and BSc thesis

About 31390: Lecture/Exercise ballance

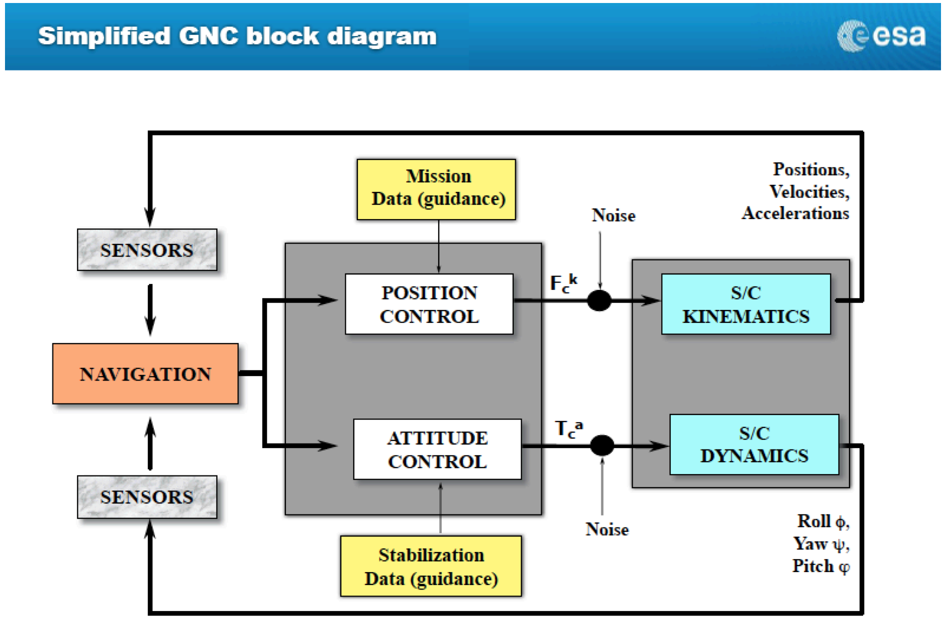
Week 1	
Lecture 1: Introduction to the course and control theory	Introduction to the system + prctice
Practice	Practice
Lecture 2: more on control theory	Practice
Practice	Practice
Practice	Demonstration and intermediate evaluation

Week 2	
Lecture 1: Introduction to navigation	Introduction to the system + practice
Practice	Practice
Lecture 2: more on navigation	Practice
Practice	Practice
Practice	Demonstration and intermediate evaluation

Week 3	
Lecture 1: Introduction to guidance	Introduction to the system + practice
Practice	Practice
Lecture 2: more on guidance	Practice
Practice	Practice
Practice	Demonstration and intermediate evaluation

About 31390: Topics for 2020

- Control
  - how does an autopilot works?
  - how can we reach a position in 3D space?
- Navigation
  - Which sensors can we use to estimate our state?
- Guidance
  - How can we go from point A to point B?
  - How do we define the path between e.g. way-points?



About 31390: Platforms

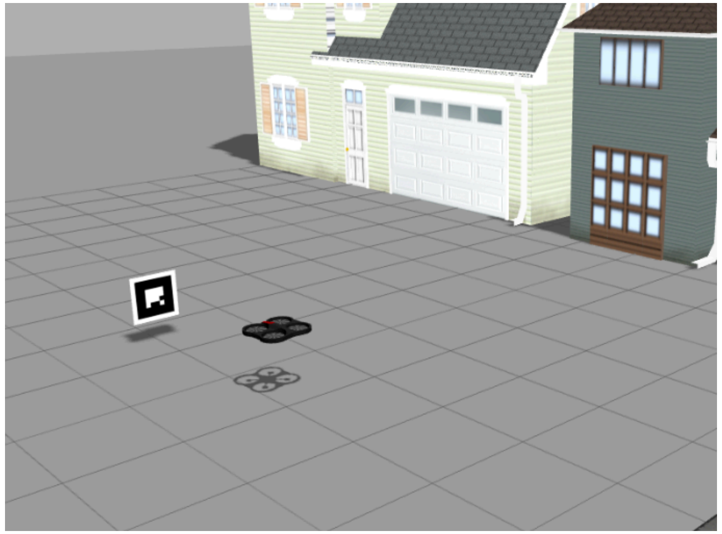
combine MATLAB code and Simulink models together.

ROS

bitcraze

Crazyflie 2.1

GAZEBO



About 31390: Facilities

- Building 326 - Automation and Control Group, DTU Elektro
- Autonomous Systems Test Arena (ASTA)

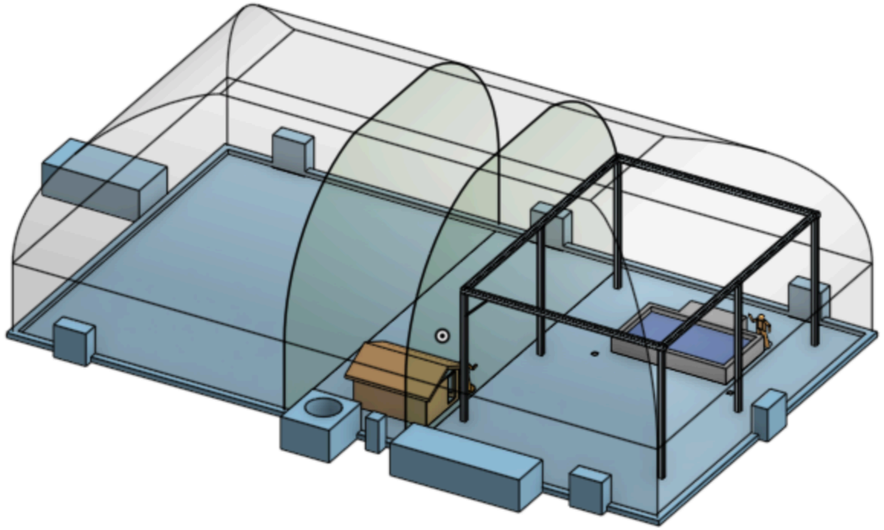
Status

1) Dome
2) Pool
3) Camera localization and truss
4) Drone net
5) Mobile lift (permanent)
6) Office, shelter for equipment

330D ASTA

About 31390: Facilities

Autonomous Systems Test Arena (ASTA)



Pool: 6.5 x 3.5 x 3 m, with current generator

3D tracking arena: 16 x 12 x 8m

Wide volume for testing autonomous systems (ground, aerial)

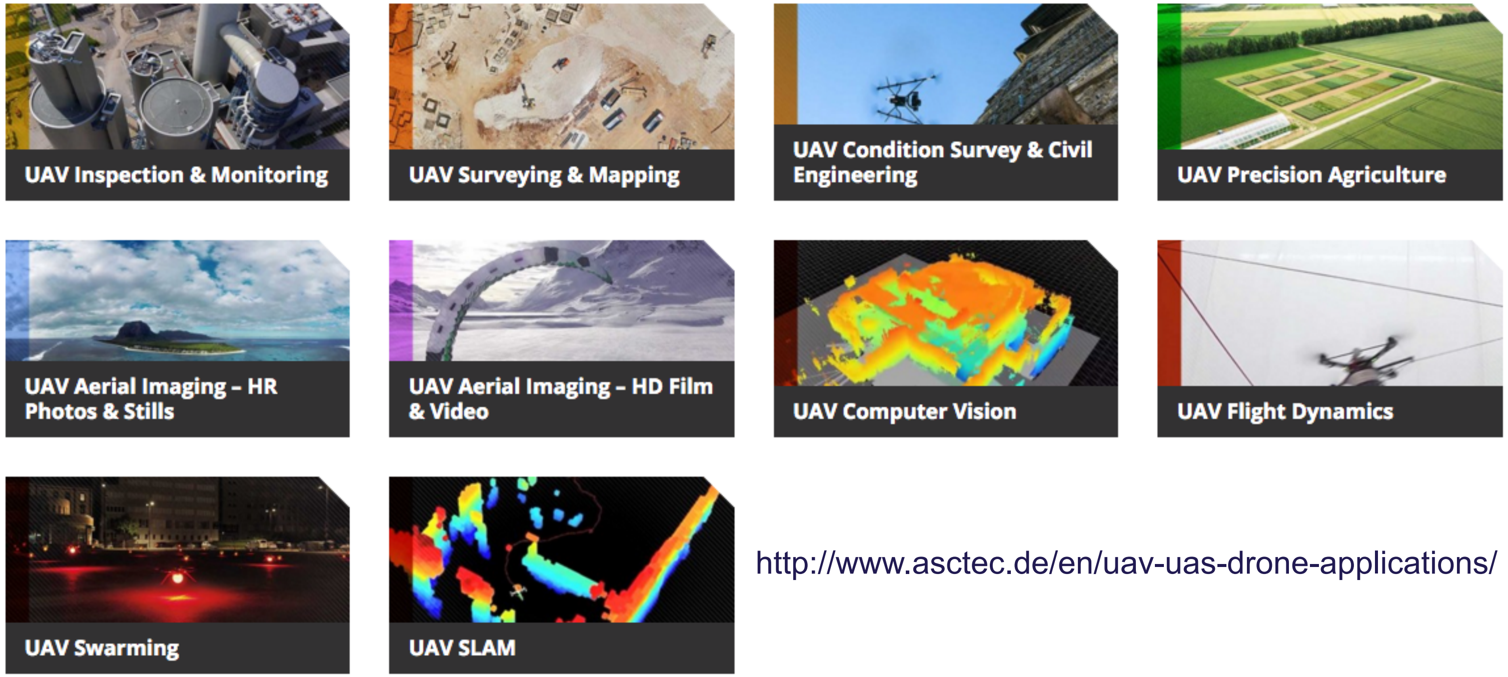
GPS coverage

Ready for use in February 2020!!!

A Bit about Drones

Applications

- Possible application of UAVs

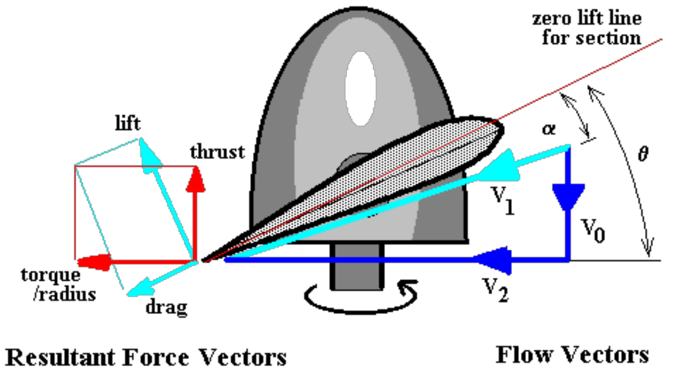


http://www.asctec.de/en/uav-uas-drone-applications/

Flying principle of a quad rotor UAV

What is the physics behind a flying vehicle (multicopter)?

- A rotating propeller generates a lift force and a drag torque

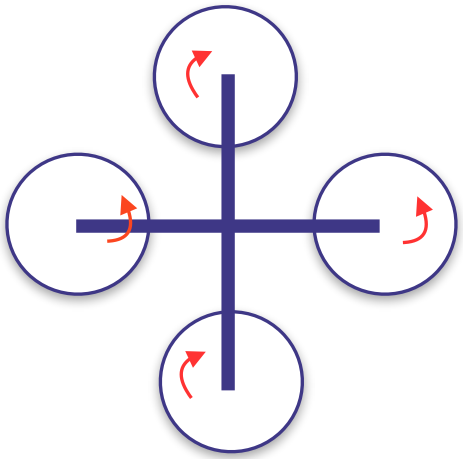


The force and torque are proportional to the second power of the rotational speed of the propeller.
These forces result into a thrust force and a torque that resists to the rotation

Flying principle of a quad rotor UAV

What is the physics behind a flying vehicle?

How can we keep the position to a predefined target? (position and orientation)

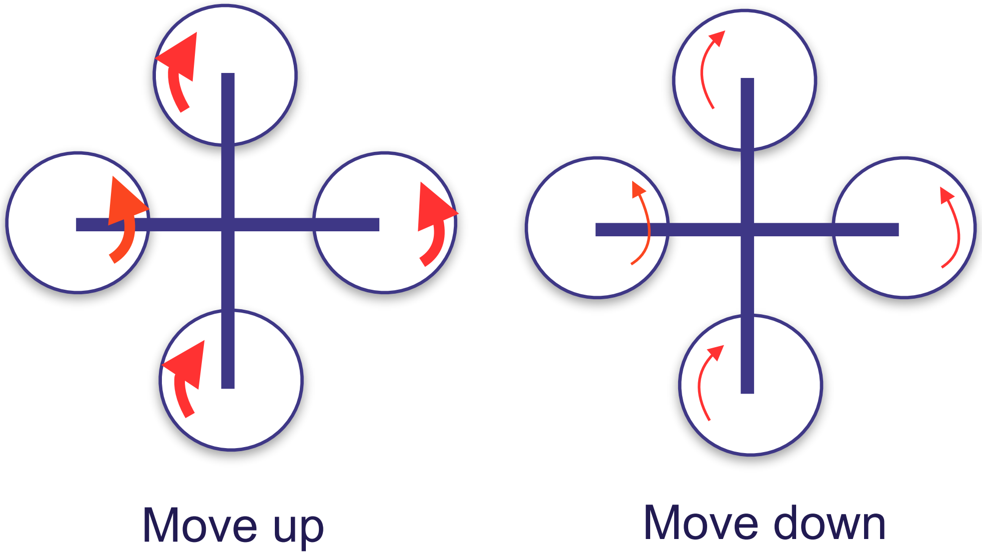


- gravity compensation
- torque on the body is zero

Flying principle of a quad rotor UAV

What is the physics behind a flying vehicle?

How can we go up or down?

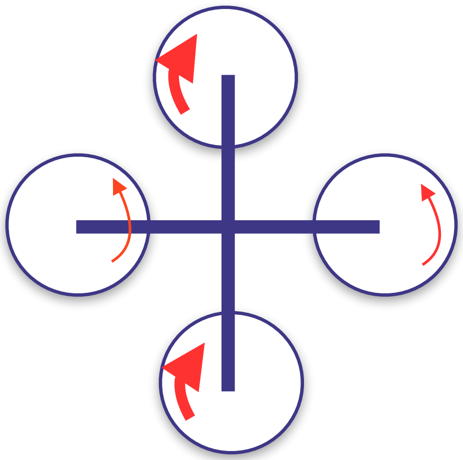


- increase propeller speed equally in modulus, the UAV goes up
- decrease the propeller speed equally in modulus, the UAV goes down

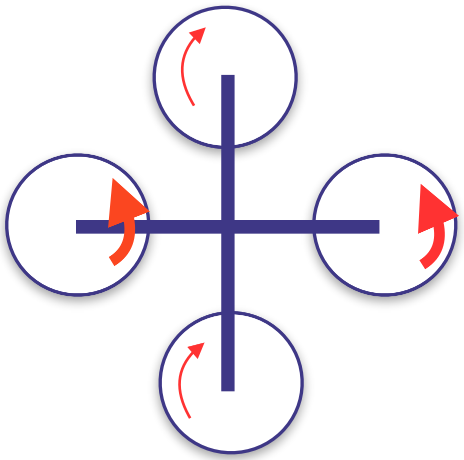
Flying principle of a quad rotor UAV

What is the physics behind a flying vehicle?

How can we head left and right?



head left



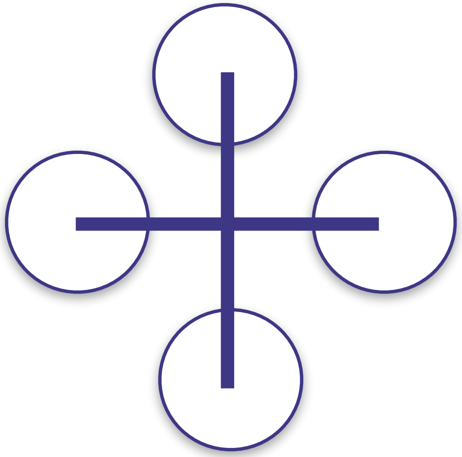
head right

- increasing CCW rotating propellers' speed, and decreasing CW rotating propellers' speed, makes the UAV head left
- increasing CW rotating propellers' speed, and decreasing CCW rotating propellers' speed, makes the UAV head right

Flying principle of a quad rotor UAV

What is the physics behind a flying vehicle?

How can we move forward, backwards, left and right?



Flying principle of a quad rotor UAV

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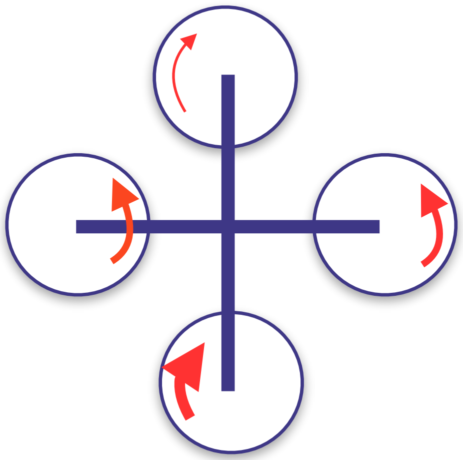

Flying principle of a quad rotor UAV

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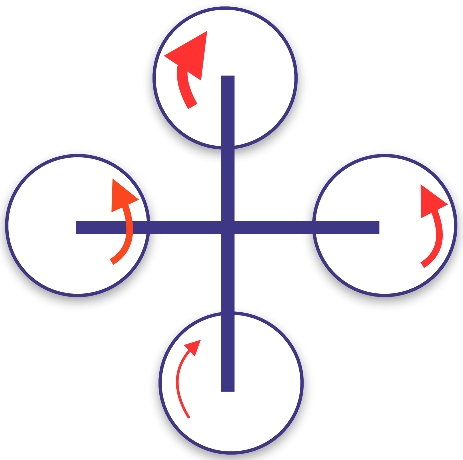

Flying principle of a quad rotor UAV

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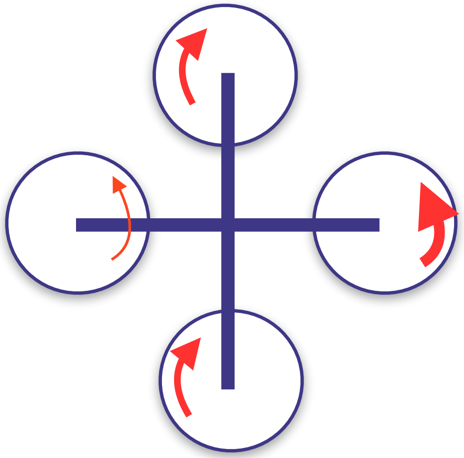

Flying principle of a quad rotor UAV

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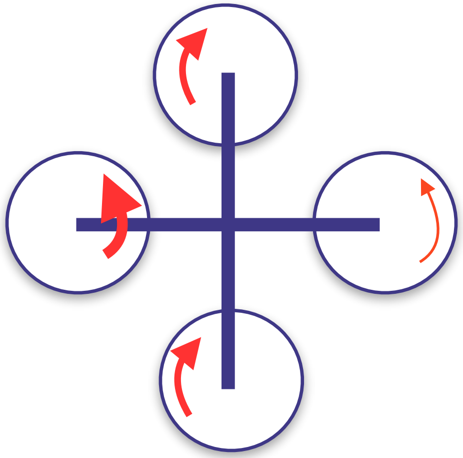
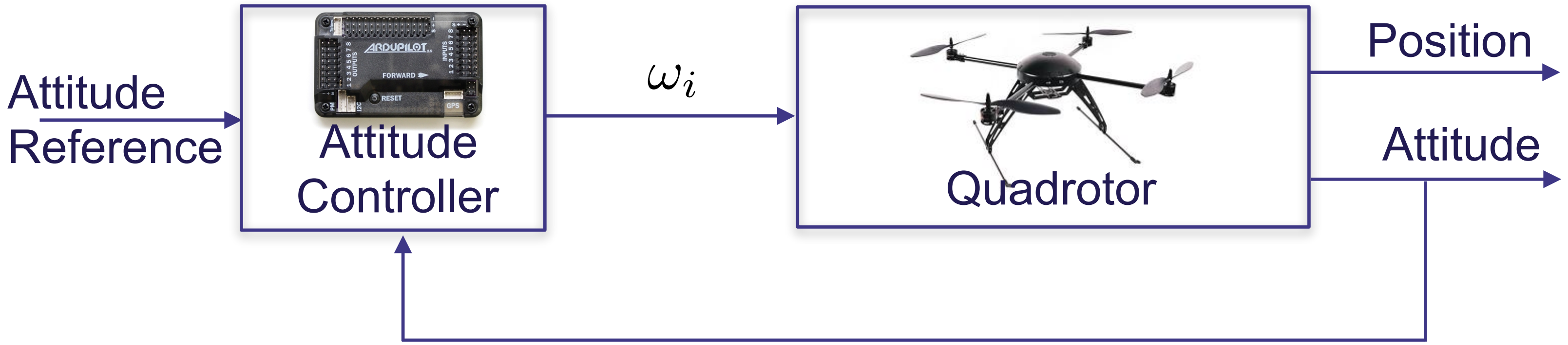


Flying principle of a quad rotor UAV

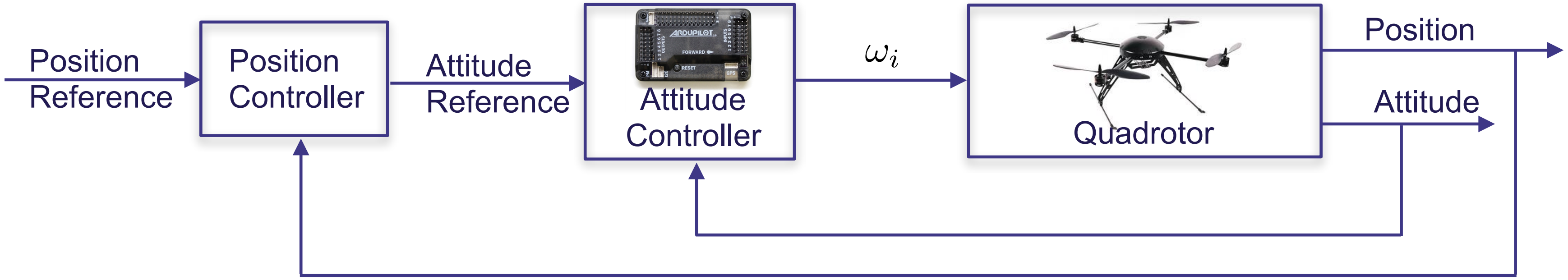
If we can measure the orientation (attitude) of the quadrotor, then we can control it on a reference.

The control system that reads the attitude sensor to generate the propeller velocity is called “attitude controller”



Flying principle of a quad rotor UAV

If we can measure the position of the quadrotor, then we can control it on a reference position.



Note that the quad rotor is **underactuated!!!**
We cannot move laterally, unless we tilt. This means that in order to control the position of the quadrotor, we first have to control its attitude

Flying principle of a quad rotor UAV

NOTE: all this **implies** that:
- we know how to control a Multi-Input-Multi-Output (MIMO) non linear system!!!
- we can measure directly the orientation of a quadrotor

If we can measure the position of the quadrotor, and we can set direction commands that allow us moving it, then we can control its position!

NOTE: now we are also **assuming** that we know the position of the quad rotor

Let's assume that we can do all of this…then what could we achieve?

Flying principle of a quad rotor UAV

Let's assume in first instance that we know how to control the position of a quadrotor by using position measurements (at very high rate), and we somehow have a very good estimate of its orientation.

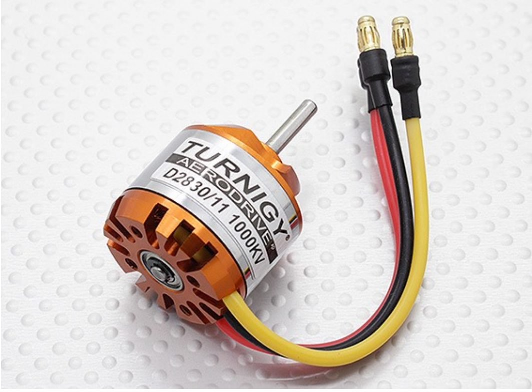
Hardware of a Quadrotor

A quadrotor consists of a set of **actuators**, **sensors**, driving electronics, and control logic and remote communication devices

Hardware of a Quadrotor

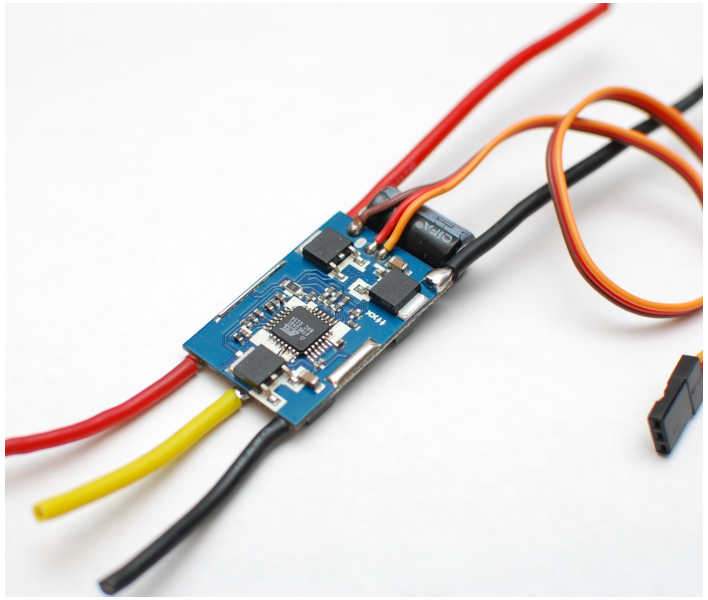
Actuators

Typically electric motors:
- DC brushed motors
- Brushless motors



Hardware of a Quadrotor

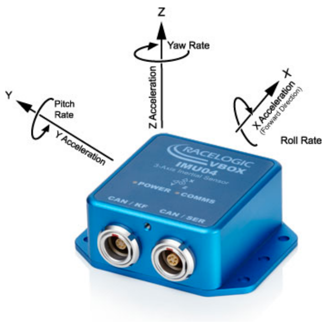
ESC

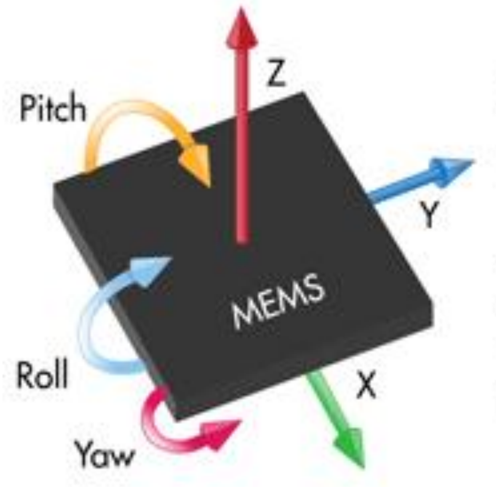


- Typically driven using an ESC (Electronic Speed Controller).
- 6 transistors are used to command the voltage applied to the windings.
- The commutation happens when the rotor reaches a certain position (it requires sensors).
- It is also possible to know the position of the rotor by monitoring the voltage on the phase that is not activated at a certain moment (this does not require position sensors)

Hardware of a Quadrotor

IMU: Inertial Measurement Unit



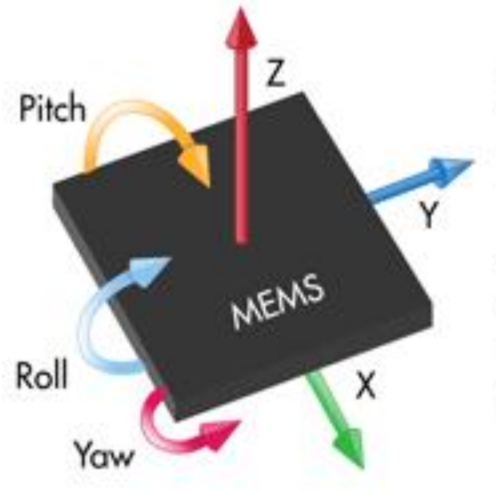


Gyroscope (r-p-y): radiand/s

Gyroscopes measure rotational velocity in 3 axes. Gyroscope measurements provide orientation and, if combined with an accelerometer in three dimensions, they can beused to track the robot position. NOTE: these methods are subject to drift, unless kinematic models and complex algorithms are used (e.g. tracking human arm position)

Hardware of a Quadrotor

IMU: Inertial Measurement Unit

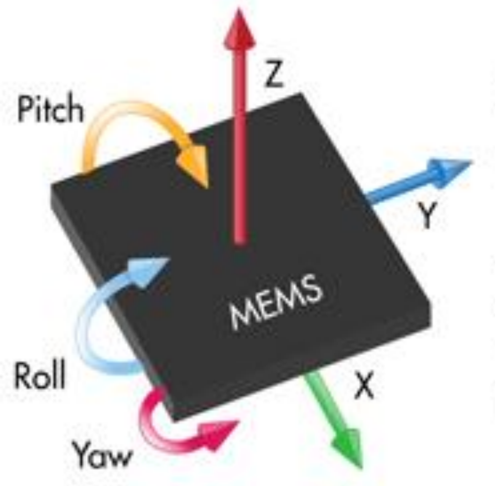


Accelerometer (x-y-z): m/s^2

measure acceleration based on user movement. Generally, a three-axis accelerometer measures the change in user velocity

Hardware of a Quadrotor

IMU: Inertial Measurement Unit

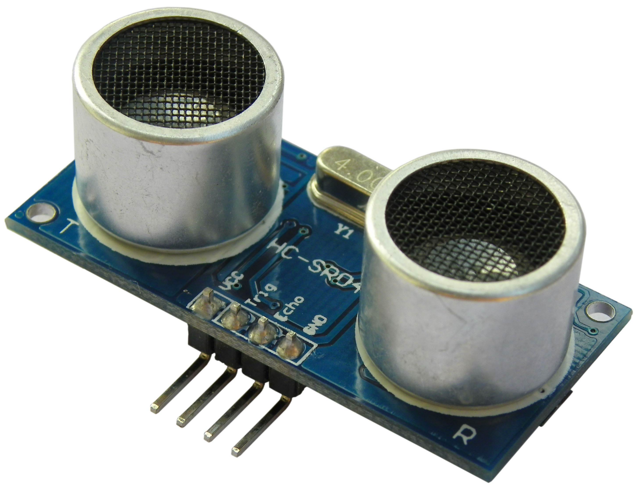


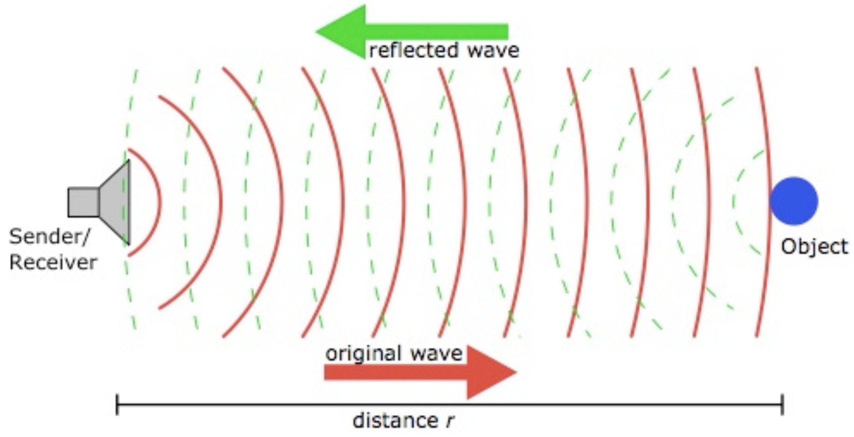
Magnetometer: magnetic flux density (microTesla)

Measure the earth's magnetic field as well as any ambient magnetic influences.

Hardware of a Quadrotor

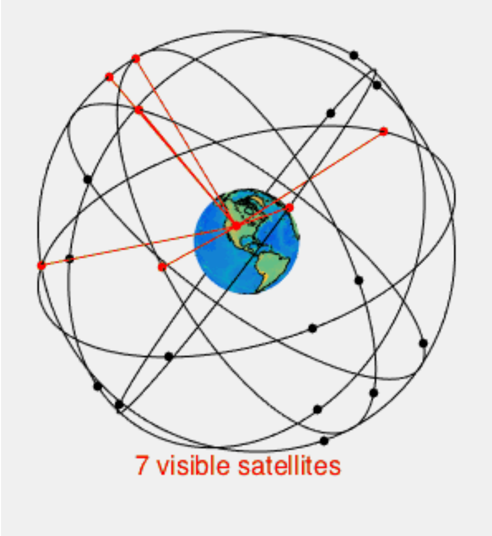
Ultrasound sensors: measure the properties of acoustic waves with frequencies above the human audible range,(>40 kHz). They generate a high-frequency pulse of sound, and then receive and evaluate the properties of the echo pulse.





Hardware of a Quadrotor

Global Positioning System (GPS):
provides location and time information where there is an unobstructed line of sight to four or more GPS satellites.

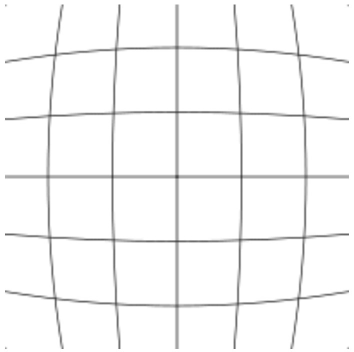


Hardware of a Quadrotor

Camera

RGB camera detect all light that falls in the visible light region of the electromagnetic spectrum.

Optics influence the distortion of the resulting image

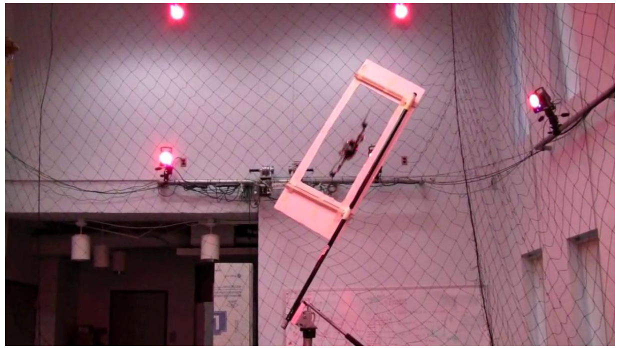


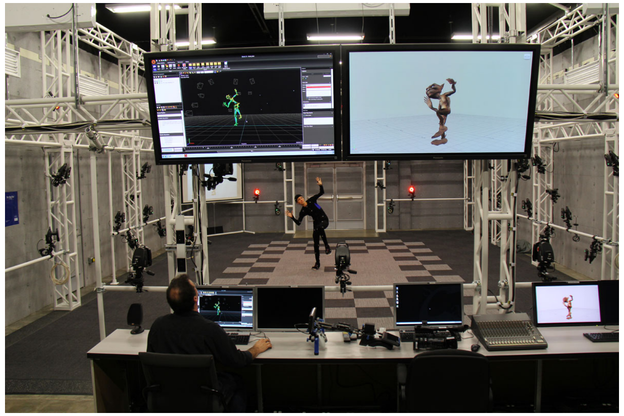
Distortion can be corrected by calibrating the camera (not part of this course)

Hardware of a Quadrotor

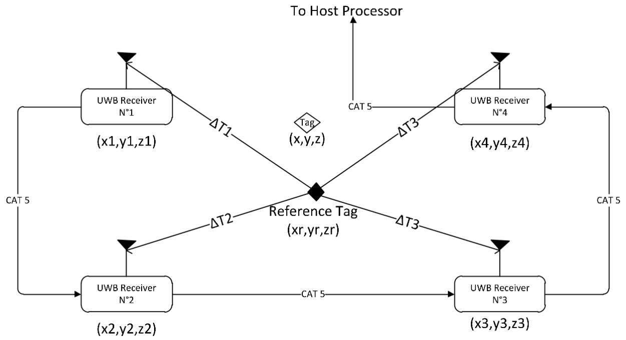
External trackers

Vicon system





UWB Localization



Hardware of a Quadrotor

General Hardware in practical implementation

Autonomous
flight

Challenges of Aerial Robotics (and possible course topics)

What are the challenges that make the use of this technology difficult?

Which research fields are related to aerial robots?

What makes aerial robot a WIP technology?

We have already seen the difficulties in CONTROL
Now we will address some challenges in:
- LOCALIZATION
- MAPPING
- NAVIGATION

Challenges of Aerial Robotics

Localization

Aerial robots suffer from the fact that measurements are quite often not global and raw data have to be interpreted

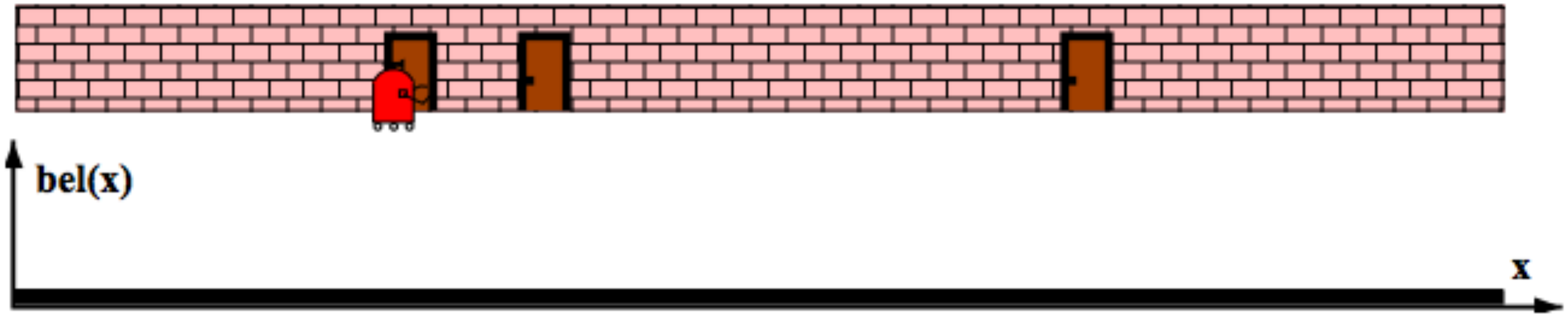
There exist algorithms that make use of multiple sensor data and combine the different measurements to provide the best estimate of the system state

These algorithms are typically based on probabilistic approaches

Challenges of Aerial Robotics

Example: robot navigation in known map

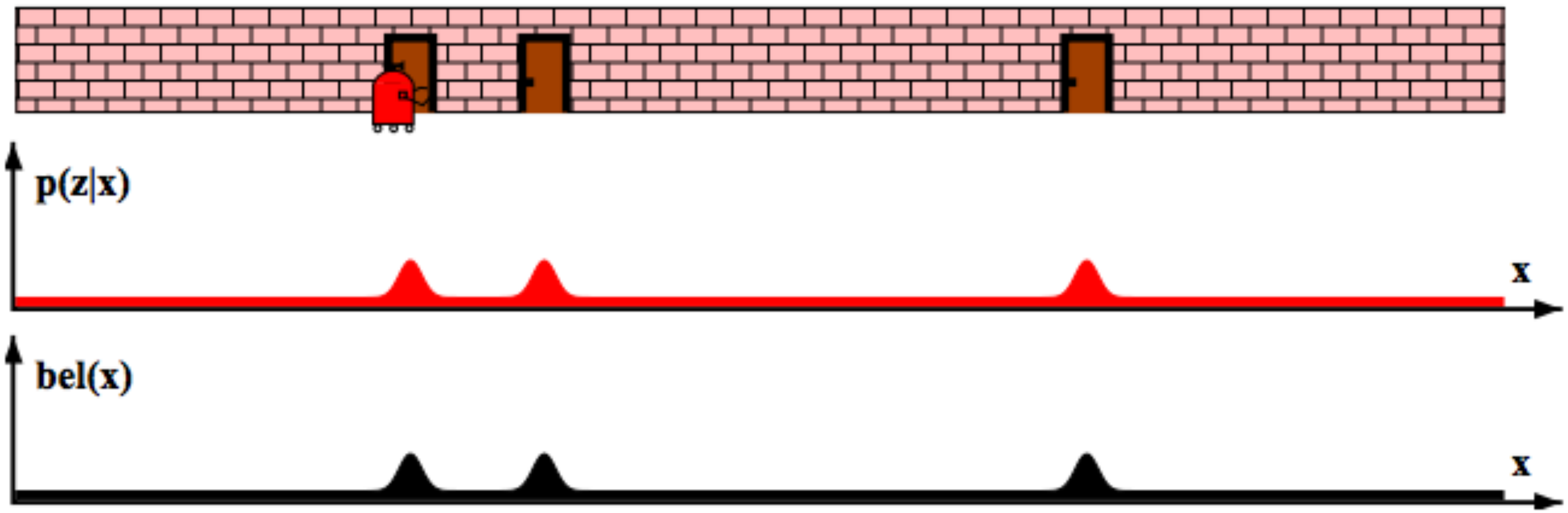
Our initial belief is constant, as we have no clue yet where we are



Challenges of Aerial Robotics

Example: robot navigation in known map

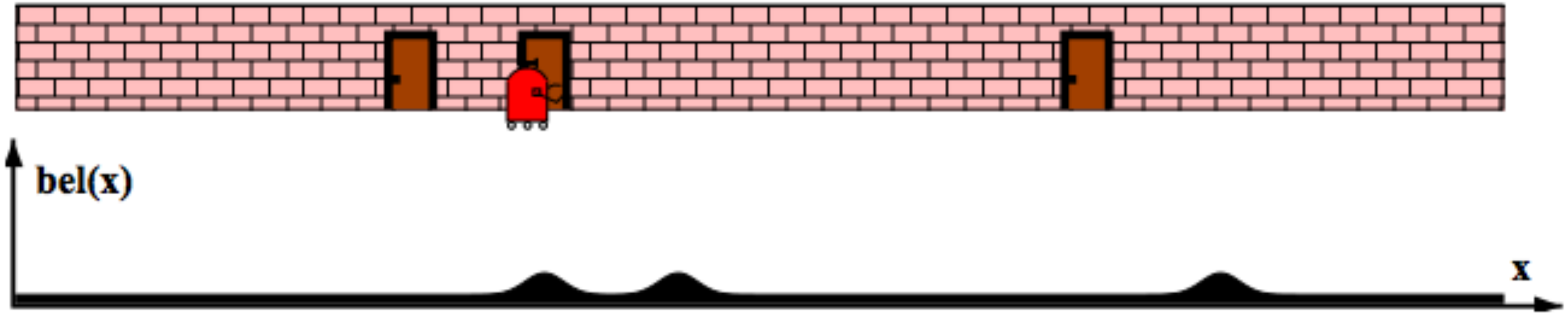
Once we encounter a door, we update our belief. We could be in front of any of the doors



Challenges of Aerial Robotics

Example: robot navigation in known map

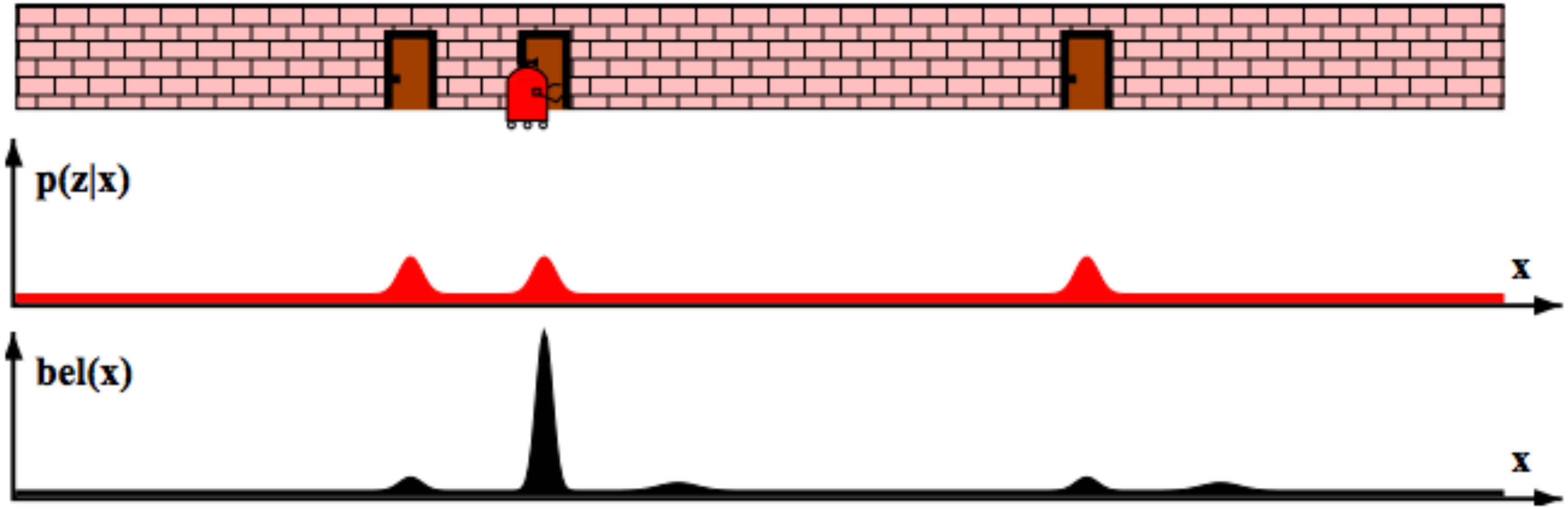
We move again and our belief attenuates, as we have no reference (the uncertainty increases over time)



Challenges of Aerial Robotics

Example: robot navigation in known map

We encounter another door and we combine the previous belief, with the probability that we are in front of any of the three doors



Challenges of Aerial Robotics

Example: robot navigation in known map

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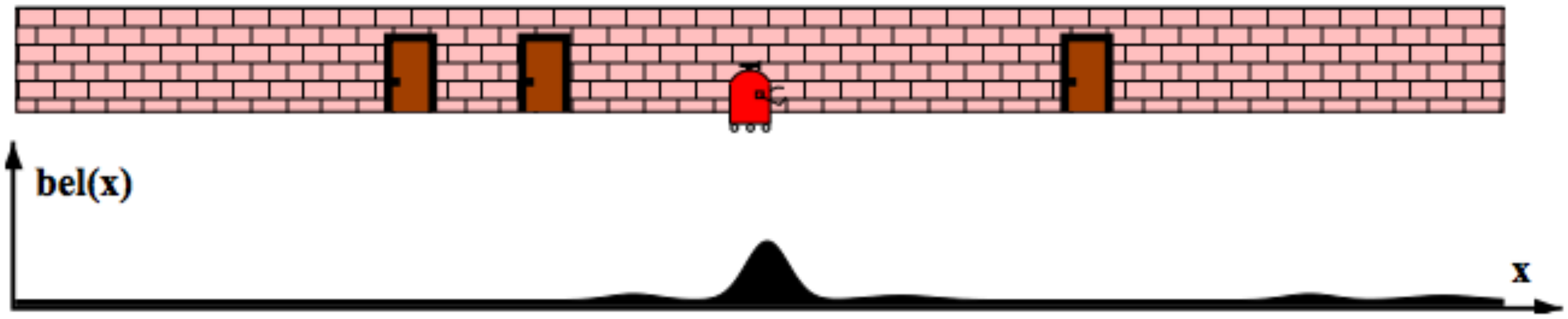
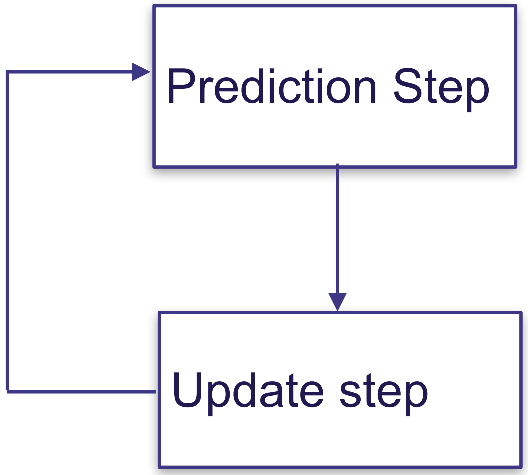


Challenges of Aerial Robotics

Example of such algorithm:
EKF (Extended Kalman Filter) uses the non-linear model of the system as well as sensor measurements to minimise the uncertainty originating by the fact that both the sensors and the process are noisy



We make a prediction based on our system model, and we update our estimation as soon as we have a measurement

Challenges of Aerial Robotics

This approaches can be used for robot localization using e.g. visual odometry

Sometimes, we have multiple sensors that we could use. The sensors may provide different information:
- acceleration
- velocity
- position

And the measurement arrive at different time, and they are subject to different delays

Algorithms that address these issues perform MULTI-SENSOR FUSION

Challenges of Aerial Robotics

Mapping

Sometimes, we don't know the map a priori

We need to use our sensors to build a map. In order to build a map, we need to know our own pose

Challenges of Aerial Robotics

The sensors that are most commonly used to build maps are:
- Camera
- Lidar (laser scanner)
- Range finder based on US
- tactile sensors
- compass
- GPS

All these sensors are subject to noise!!!

We need to compute a POINT-CLOUD, and project it in the space.
NOTE: the point cloud is usually relative w.r.t. the location of the sensor on our robot. This means that, in order to build a map, we need to know where we are in space at every acquisition.

Challenges of Aerial Robotics

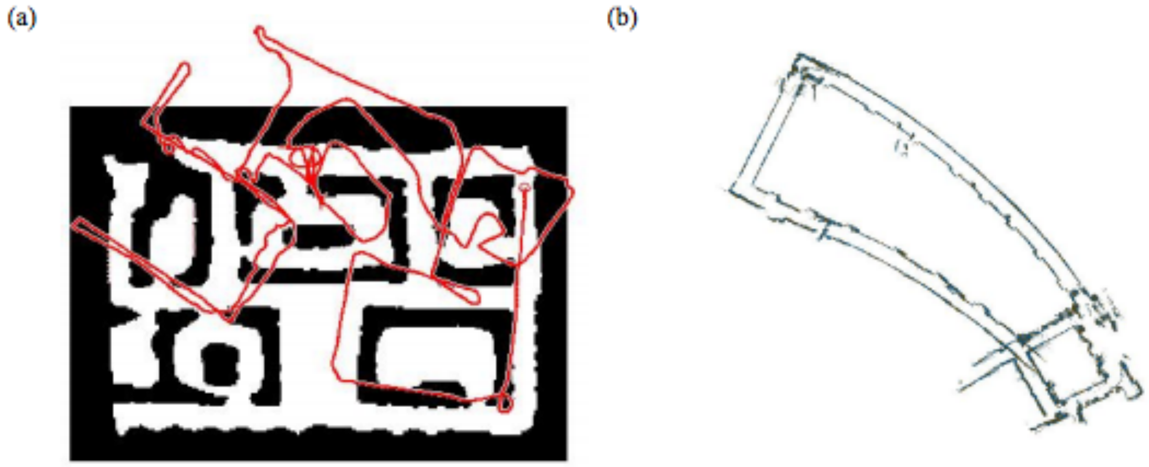


Figure 1: (a) Example of odometry error: Shown here is a robot's path as obtained by its odometry, relative to a given map. Small odometry (or control) errors can have large effects on later position estimates. (b) One of the many faces of the correspondence problem: Shown here is a robot traversing a cyclic environment during which it accrues significant odometry error. For building consistent maps the robot has to establish correspondence between the present and past positions, which is particularly difficult when closing a cycle. Establishing this correspondence is one of the most challenging problems in robotic mapping.

Challenges of Aerial Robotics

Path planning

How to go from point A to boint B
We need to define a path that traverse the free space in our map

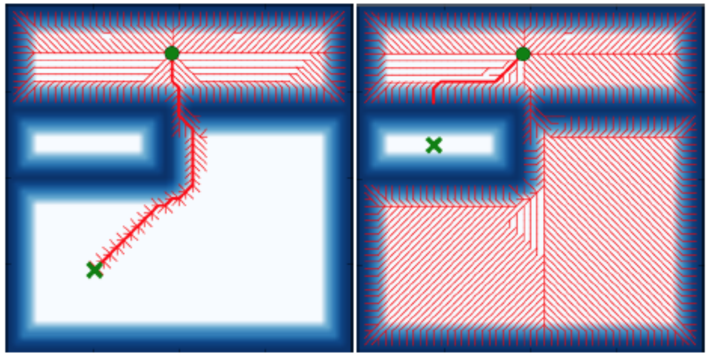


Fig. 4. Left: First the algorithm expands its search for routes with less proximity to obstacles. Then it expands through the opening, finding the target quickly after. Right: This is the worst case situation. The target is unreachable and the algorithm has to search all possible paths. The grid is sized 51×51 points; calculation time is $0.53s$.

A* algorithm: It is an euristic algorithm that finds the best global path based on an euristic function, and evaluates the total cost for traveling from A to B, selecting the path with minimum cost

Challenges of Aerial Robotics

Planning

Typical problems:

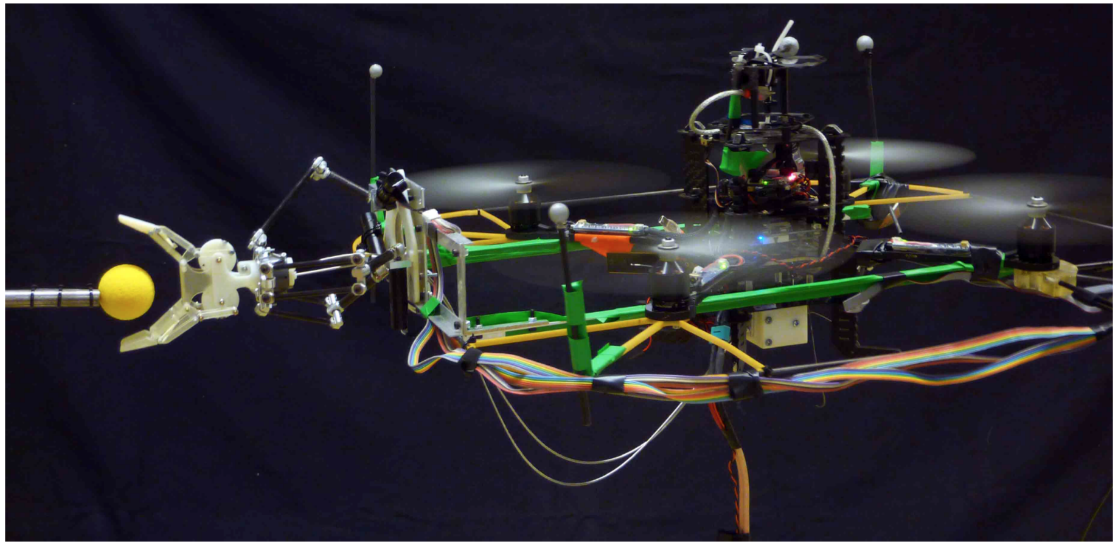
- Dynamic obstacles in the environment
  - need to recompute (local) path
  - need to perceive the dynamic obstacles

- Computational cost
  - fine grid vs coarse grid
  - global vs local planning
  - detection of landmarks

Exercise of today

- Drone simulation in Gazebo
- Create software architecture to move the drone with a keyboard/joypad
- Use Lidar, to detect obstacles

Possibilities for MSc and BSc Thesis on drone technologies and robotics/automation



- Several opportunitis available
  - Design and control of an aerial manipulator for:
    - Inspection
    - Installation of sensors
  - Explore DTU subterranean dungeon
  - Possibilities with companies

  - Contact me: mafum@elektro.dtu.dk
  - Visit me in Building 326, second floor