Control of Mobile Robots

Introduction

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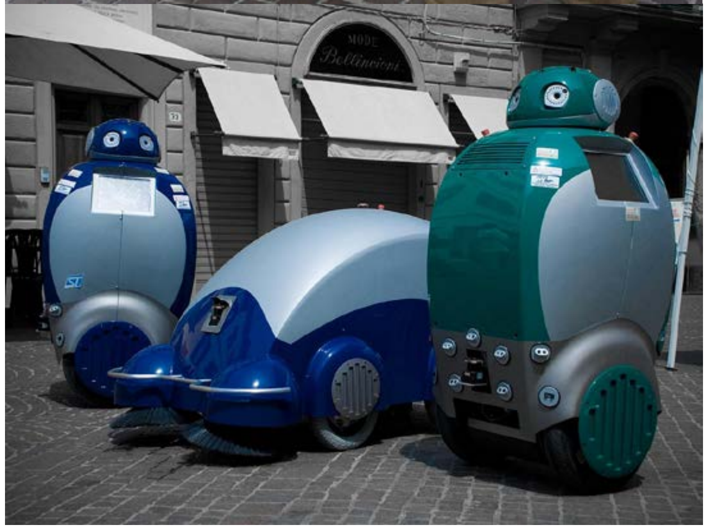
Applications of mobile autonomous robots
Logistic robotics





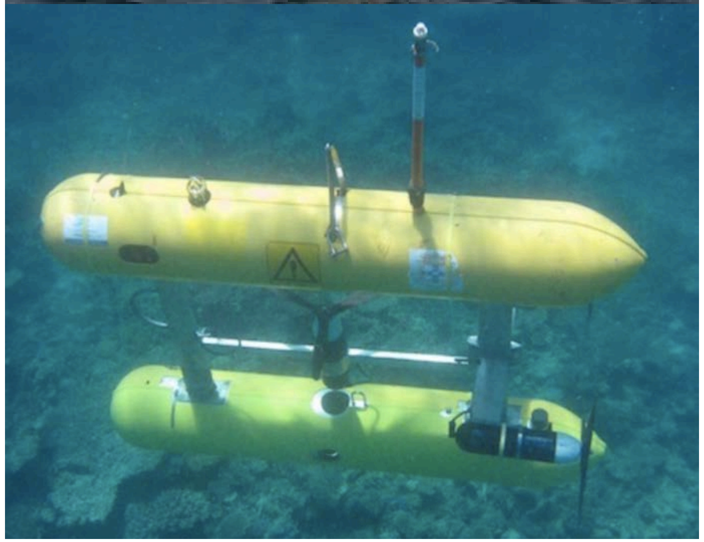
Applications of mobile autonomous robots
Agricultural robotics

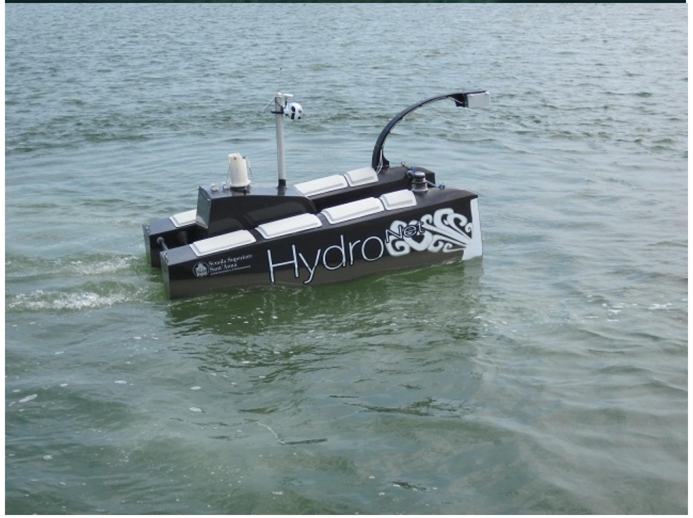
Applications of mobile autonomous robots
Construction robotics

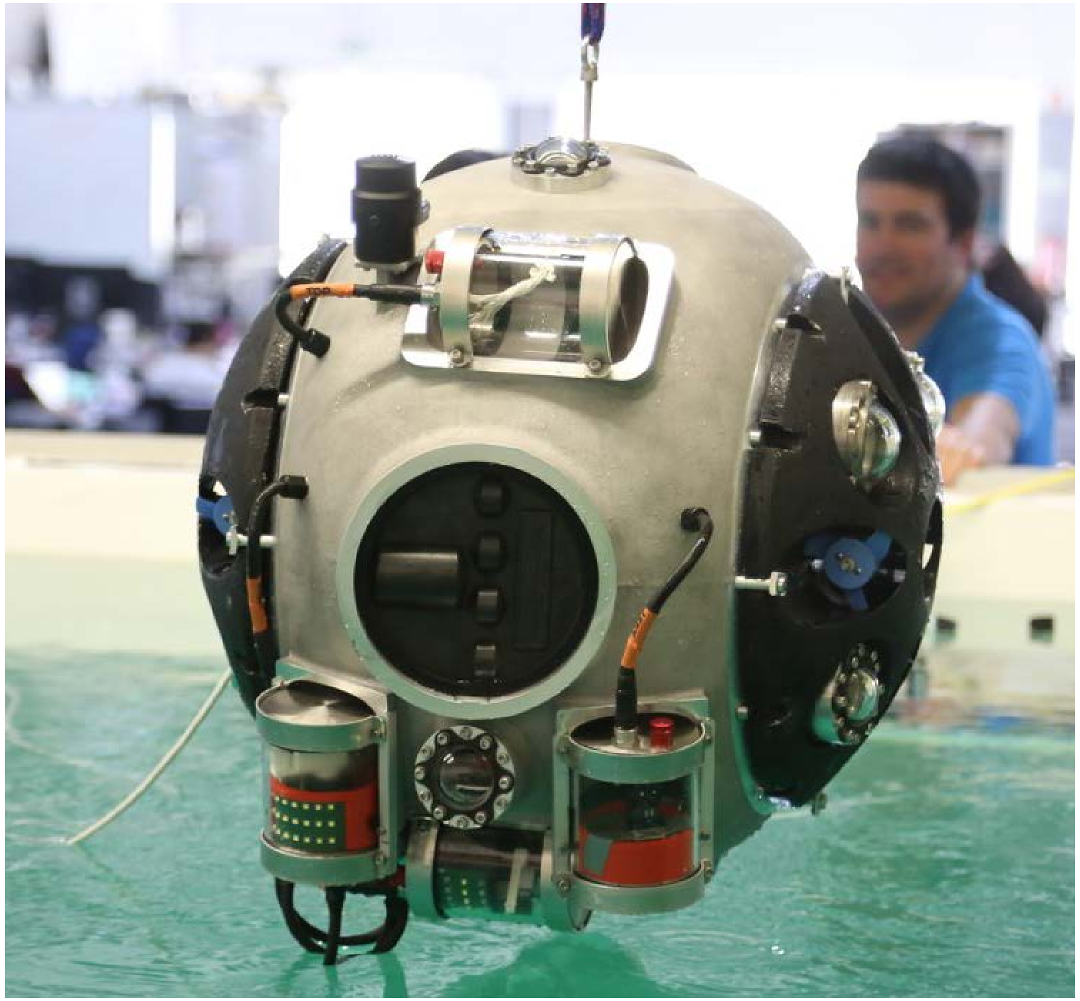
Military robotics

Applications of mobile autonomous robots
Transportation robotics

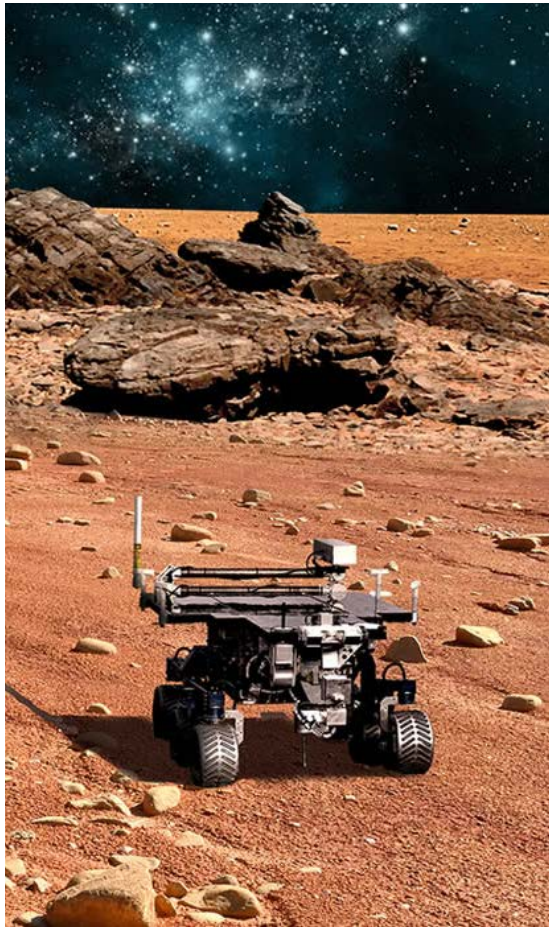
Applications of mobile autonomous robots
Marine robotics

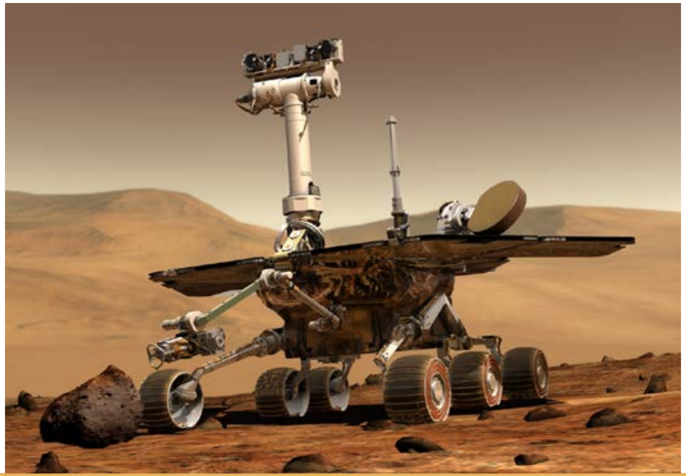




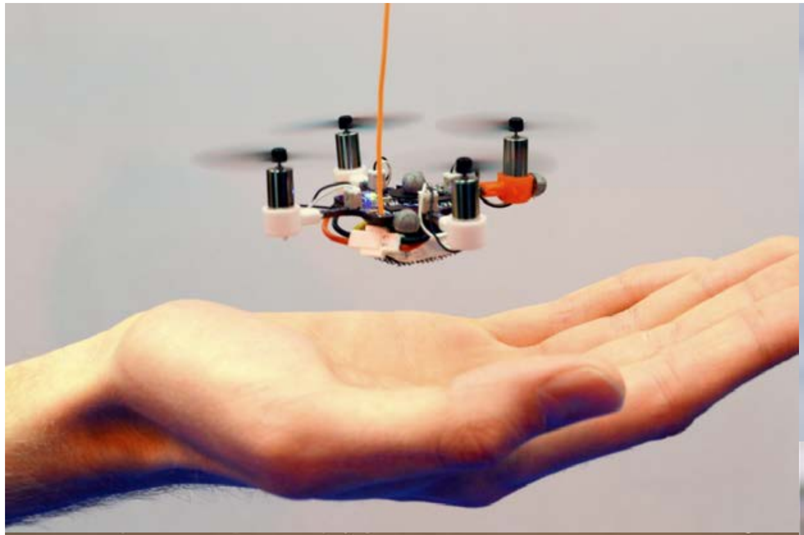


Applications of mobile autonomous robots
Space robotics



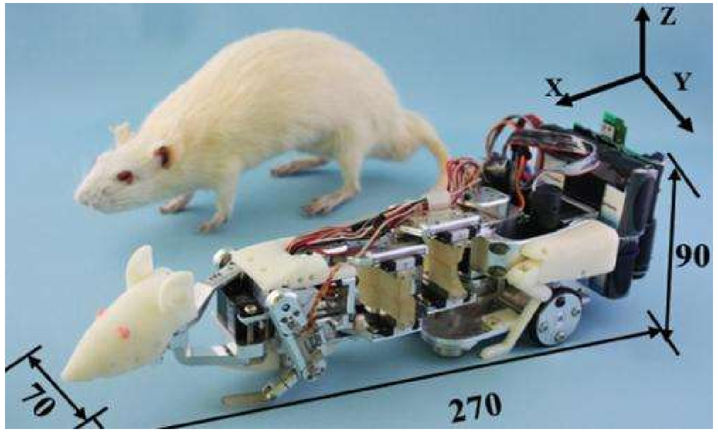


Applications of mobile autonomous robots
Aerial robotics





Applications of mobile autonomous robots
…and many more



Though there are many different application fields, we will focused on:

- ground robotics
- mobile manipulation

In the context of ground robotics we will concentrate on *wheel-based mobile robots*.

We start introducing:

- wheeled locomotion and kinematic structures
- main components of an autonomous mobile robot
- hardware, software and control architectures

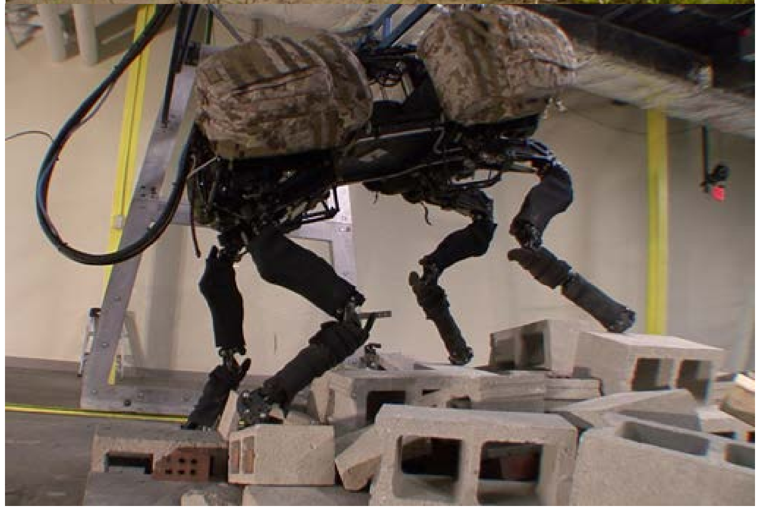
A mobile robot consists of

- one or more rigid bodies (base or chassis)
- a locomotion system

Considering only ground mobile robots, we can classify them in

- *<u>wheeled mobile robots</u>*
- *<u>legged mobile robots</u>*

We will concentrate on wheeled mobile robots.



Let’s start considering wheels, the most important mechanical element of a wheeled robot.

We can classify a conventional wheel as:

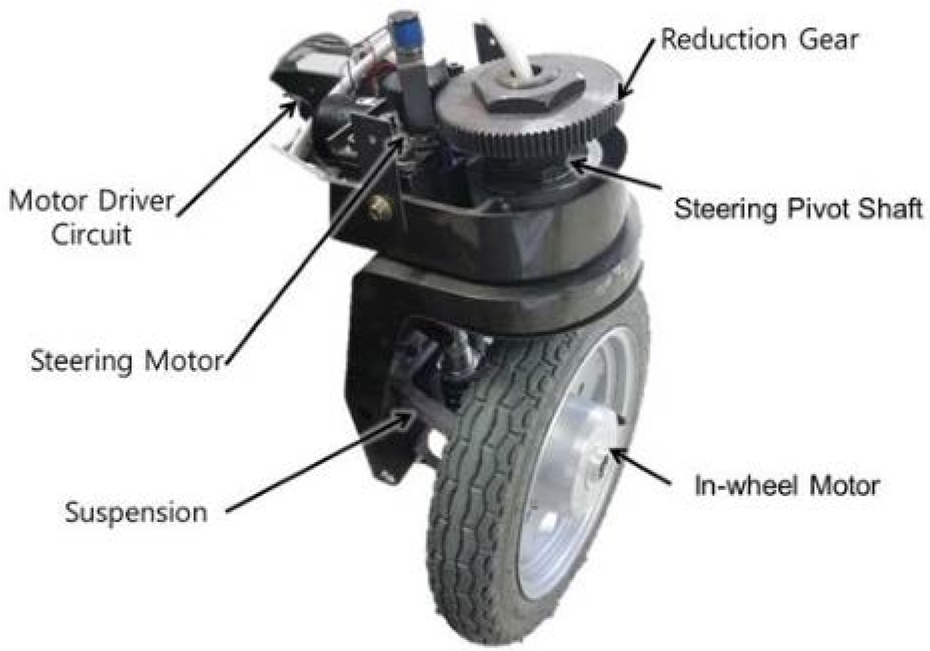
- *fixed wheel*, can rotate about an axis going through its center and orthogonal to the wheel plane.
  The wheel is rigidly attached to the chassis
  (its orientation with respect to the chassis is constant)

Conventional wheels

Let's start considering wheels, the most important mechanical element of a wheeled robot.

We can classify a conventional wheel as:

- *fixed wheel*
- *steerable wheel*, can rotate about an axis going through its center and orthogonal to the wheel plane, and about a second vertical axis going through its center (the wheel can change its orientation with respect to the chassis)



Conventional wheels

Let's start considering wheels, the most important mechanical element of a wheeled robot.

We can classify a conventional wheel as:

- *fixed wheel*
- *steerable wheel*
- *caster wheel*, has two axes of rotation, but the vertical axis is displaced by a constant offset with respect to the center of the wheel

Special wheels

Other special types of wheels also exist, the most important one being the *Mecanum or Swedish wheel*.

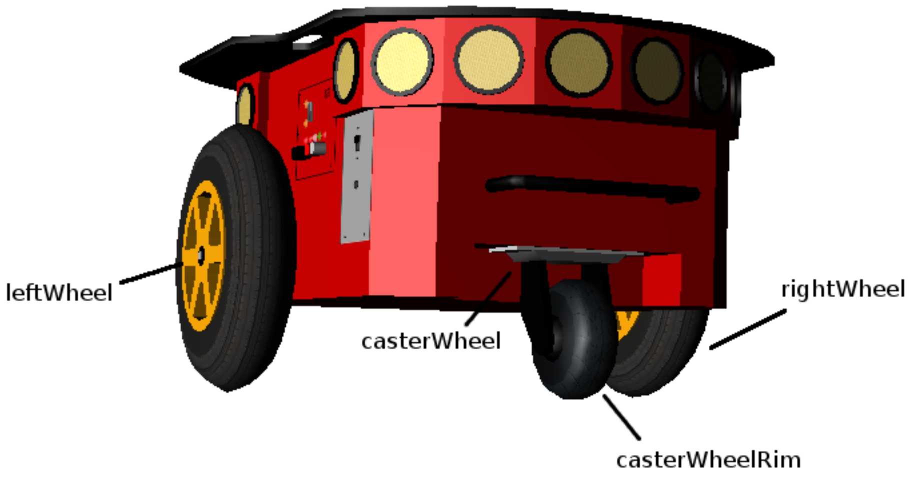
A mecanum wheel is a fixed wheel with passive rollers placed along the external rim. The axis of rotation of each roller is typically inclined by 45° with respect to the plane of the wheel.

Mecanum wheels allows to set up omnidirectional vehicles.

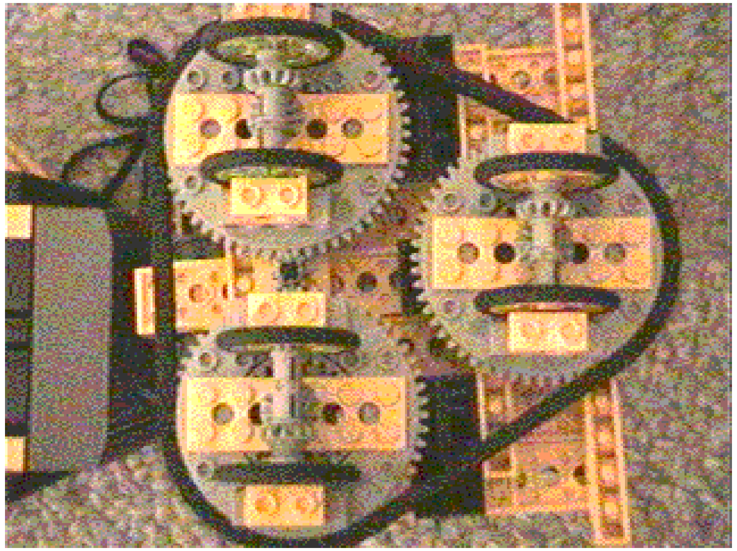
Kinematic structures

The main kinematic structures we can obtain by combining the three conventional wheels are:

- *differential-drive vehicle*, a vehicle with two fixed wheels with a common axis of rotation, and one or more caster wheels.
  The fixed wheels are separately controlled, each one by a different motor.
  The caster wheel is passive and is only used to keep the robot statically balanced.
  The main characteristic of this robot is that it can rotate on the spot.



- *synchro-drive vehicle*, a vehicle with three aligned steerable wheels, synchronously driven by two motors through a mechanical coupling.
  One motor controls the rotation of the wheels around the horizontal axis (traction), the second motor control the rotation of the wheels around the vertical axis (steering).
  The main characteristic of this robot is that the heading of the chassis does not change during motion, unless a third motor is added.

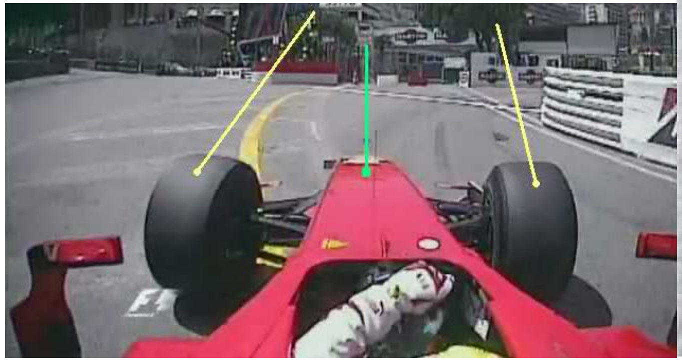


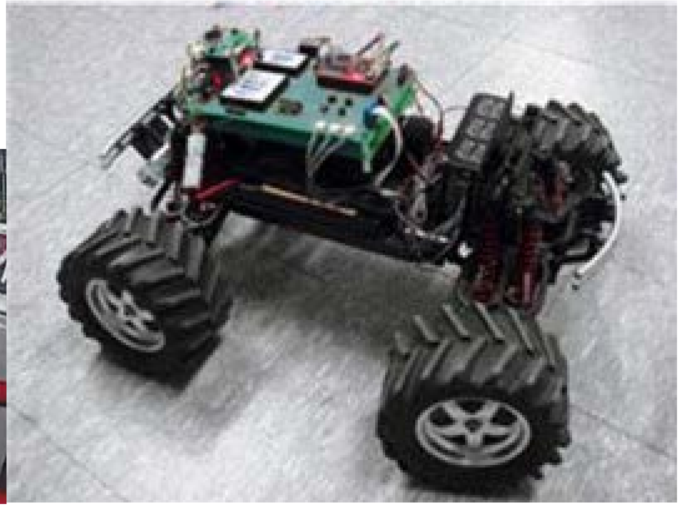
Kinematic structures

- *tricycle vehicle*, a vehicle with two fixed rear wheels and a steerable front wheel.
  The steering wheel is actuated by a steering motor.
  The rear fixed wheels are usually driven by a single motor, whose torque is distributed to the wheels by a mechanical differential.

Kinematic structures

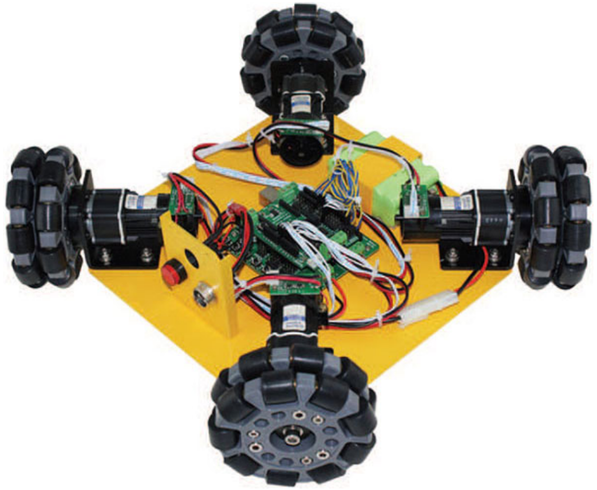
- *car-like vehicle*, a vehicle with two fixed wheels mounted on a rear axle and two steerable wheels mounted on a front axle.
  The steering wheels are actuated by a steering motor.
  Another motor provides traction acting on the front or rear wheels.
  In order to avoid slippage, the front wheels must have a slightly different orientation. When the vehicle moves along a curve the internal wheel is slightly more steered with respect to the external one.
  This behavior is guaranteed by a mechanical device called *Ackermann steering*.

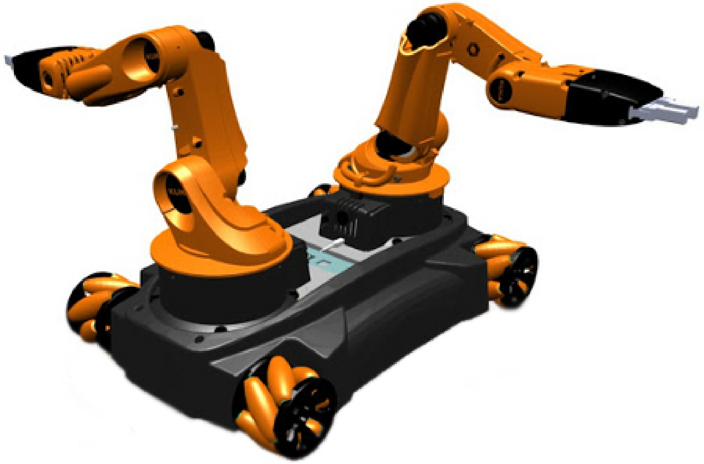


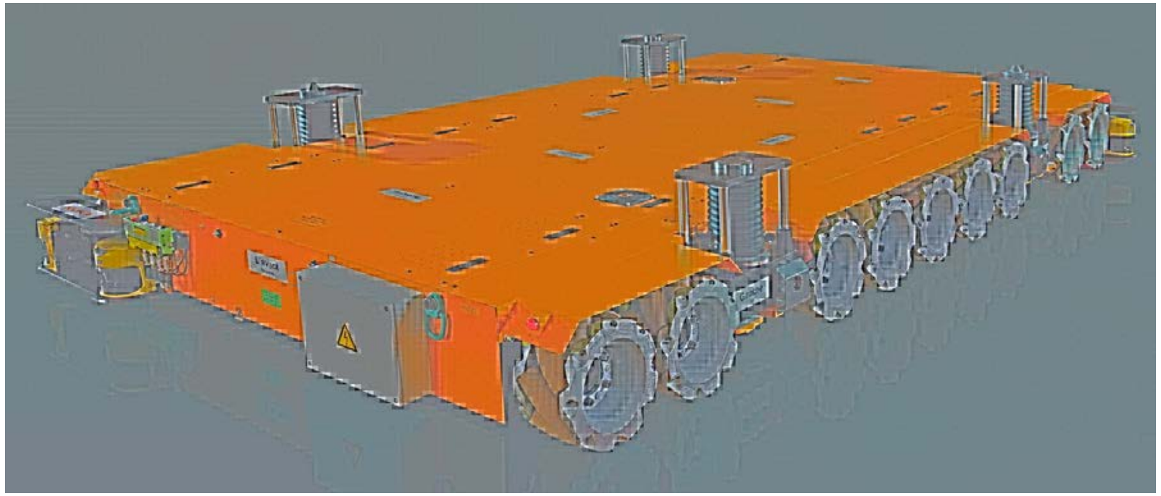


Kinematic structures

- *omnidirectional vehicle*, a vehicle typically equipped with four mecanum wheels that can move instantaneously in any Cartesian direction, as well as reorient itself on the spot.







Kinematic structures

- *mobile manipulator*, as we have already seen in many examples, a mobile robot can be combined with a manipulator to obtain a mobile manipulator.
  Adding a mobile base to a manipulator decreases its accuracy, but can definitely increase its workspace.

Let's consider the following example of personal mobility.

We would like to design an autonomous personal mobility device using a commercial electric wheelchair.

Consider the following indoor use case:

- a user selects a room from the building map
- the wheelchair has to autonomously move from its current location to the desired room
- avoiding static and moving obstacles

What are the most important functionalities we need to design in order to develop this device?

Control of Mobile robots: an example

Using a commercial electric wheelchair, we must design:

- the *navigation system*
- the hardware/software interface between the navigation system and the wheelchair commercial control system

Let's start analyzing the commercial wheelchair:

- it is a differential-drive robot, characterized by two rear independently driven fixed wheels and two front caster wheels
- a user can operate the wheelchair commanding its linear and rotational velocities using a joystick

- its internal control system is equipped with
  - two motor drives (current and velocity loops)
  - an algorithm to synchronize the two motors to guarantee the desired linear/angular speed

To let the wheelchair autonomously move in the environment we have to substitute the user manual control with an automatic control system (navigation system).

The control variables of this system are the wheelchair linear and angular velocity. We need to design an hardware/software interface between the navigation system and the wheelchair internal control system.

Control of Mobile robots: an example

What is a navigation system?

… a combination of algorithms that aims at allowing the autonomous motion of the robot in the environment, avoiding obstacles and accomplishing its task (moving from the current position to a desired position).

What are the most important functionalities of a navigation system?

Control of Mobile robots: an example

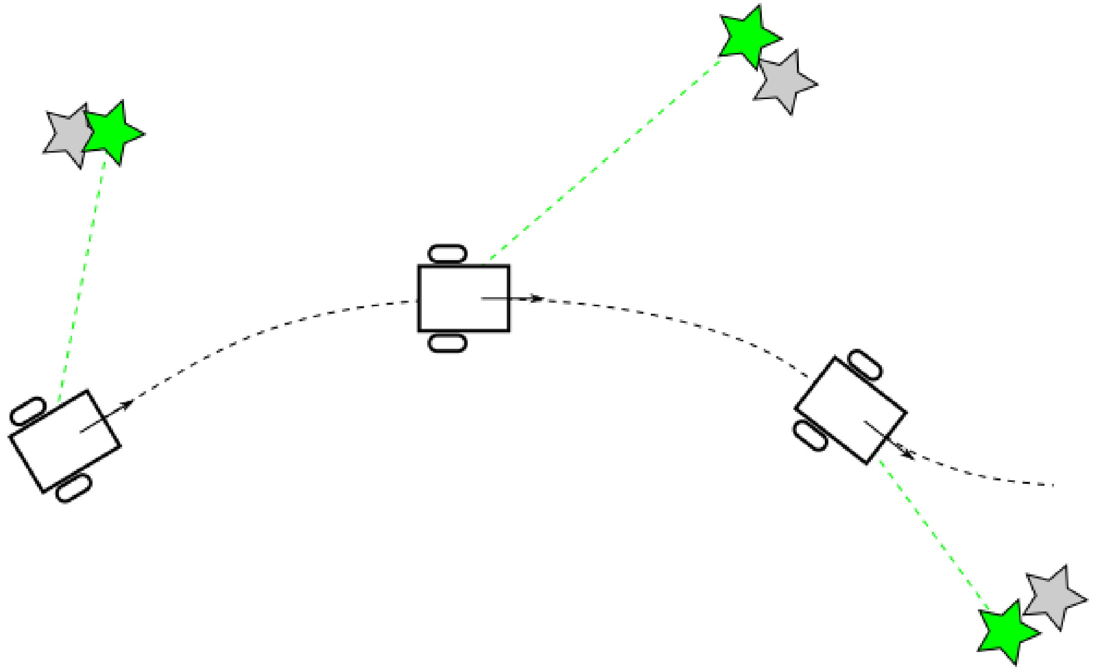
A navigation system is composed of the following main functionalities:

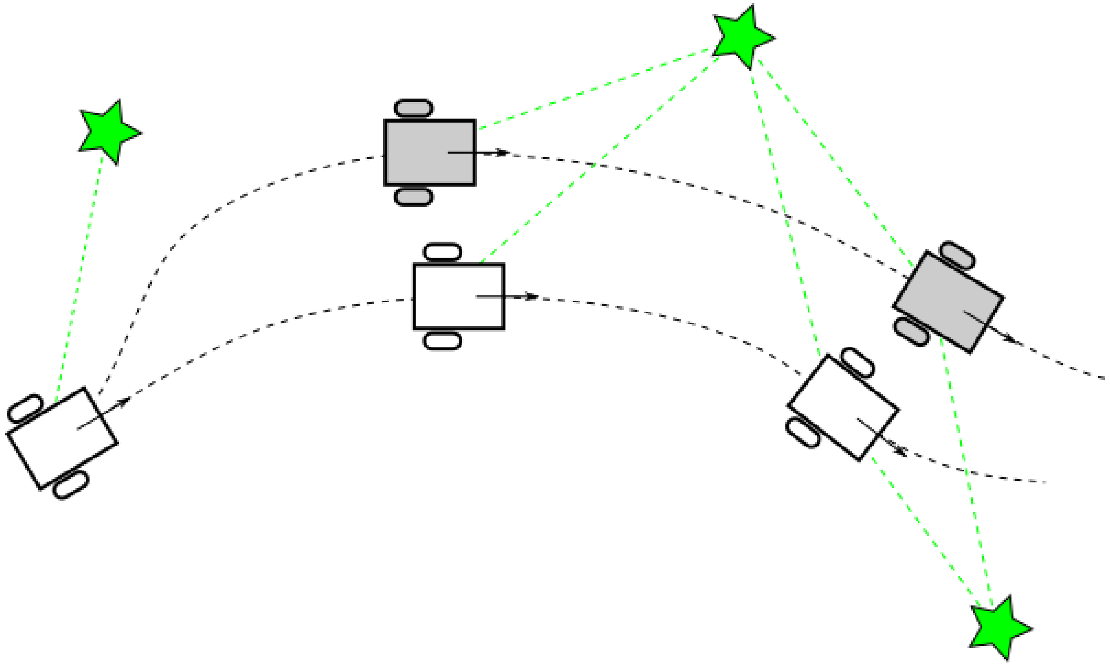
- mapping
- localization
- environment perception
- path planning
- path following

The wheelchair has to autonomously move from its current location to the user selected room, avoiding obstacles

Mapping and localization

Mapping is the task of modelling the environment





Localization is the task of estimating the robot pose with respect to the environment

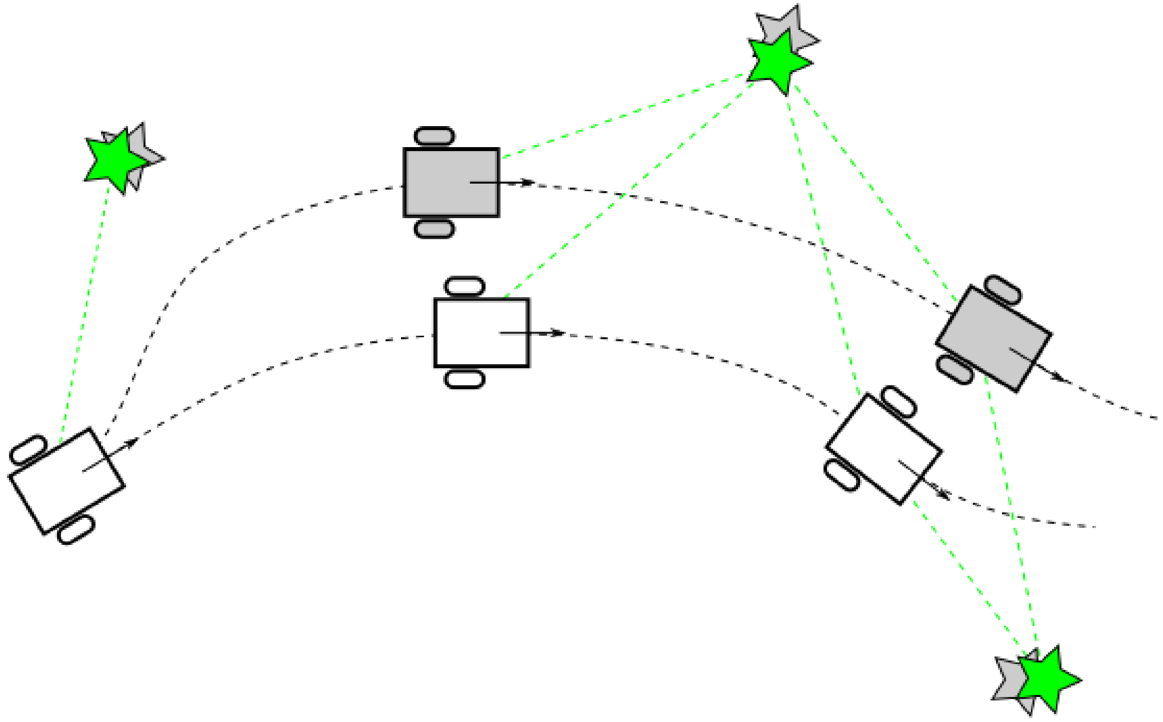
Simultaneous localization and mapping

If robot poses and map of the environment are computed at the same time we have a *SLAM* problem.

SLAM is a complex problem

- a map is need for localization, and…
- a pose estimate is needed for mapping

but it is fundamental for autonomous navigation.



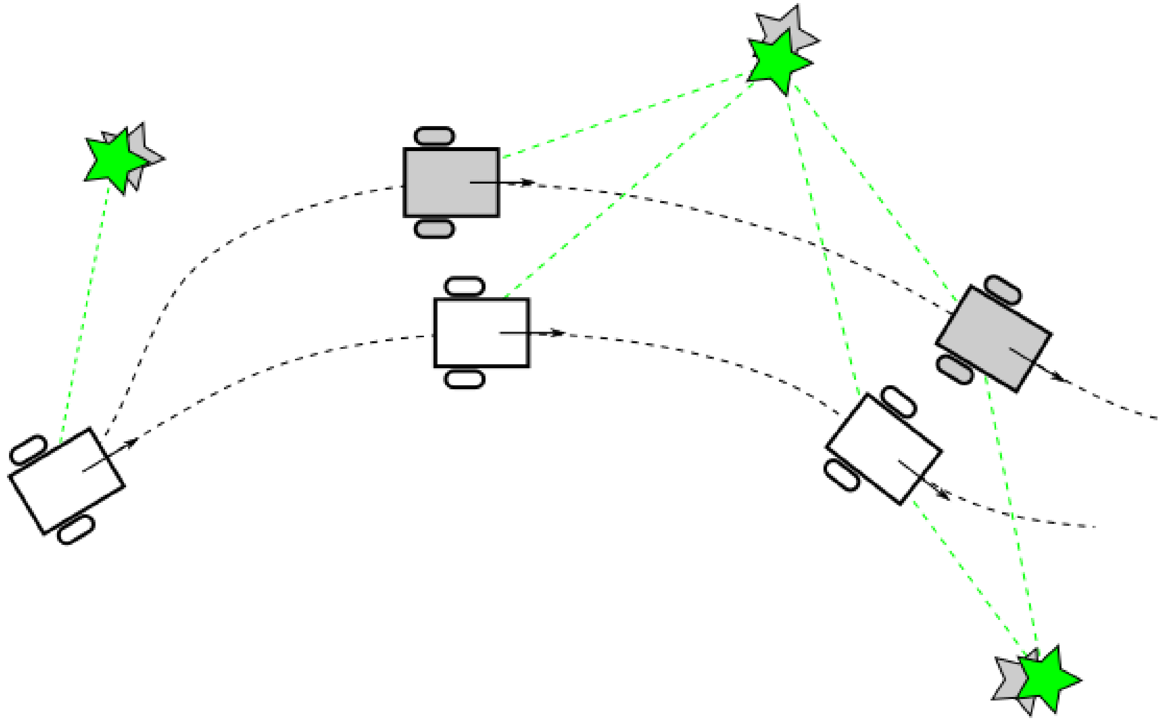
Simultaneous localization and mapping

In SLAM a probabilistic approach is adopted, in order to properly consider

- uncertainty in robot motion
- uncertainty in measurements

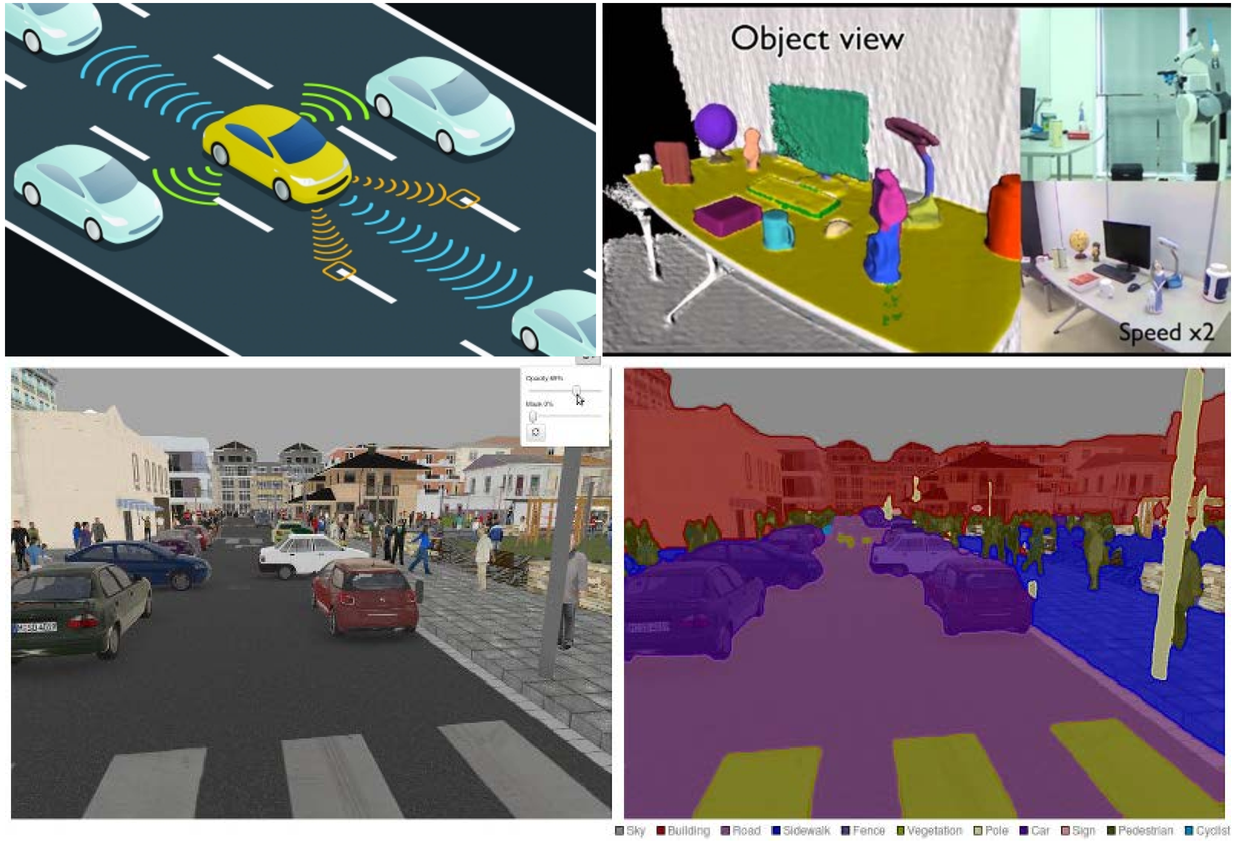
Three main approaches exist:

- Kalman filtering
- particle filtering
- graph-based



What are the roles of perception in robotics:

- localization and mapping (where am I relative to the world?)
- collision avoidance, navigation, and learning (what is around me?)
- manipulation, navigation, and learning (how can I safely interact with environment?)
- inference and learning (how can I solve new problems?)



Environment perception

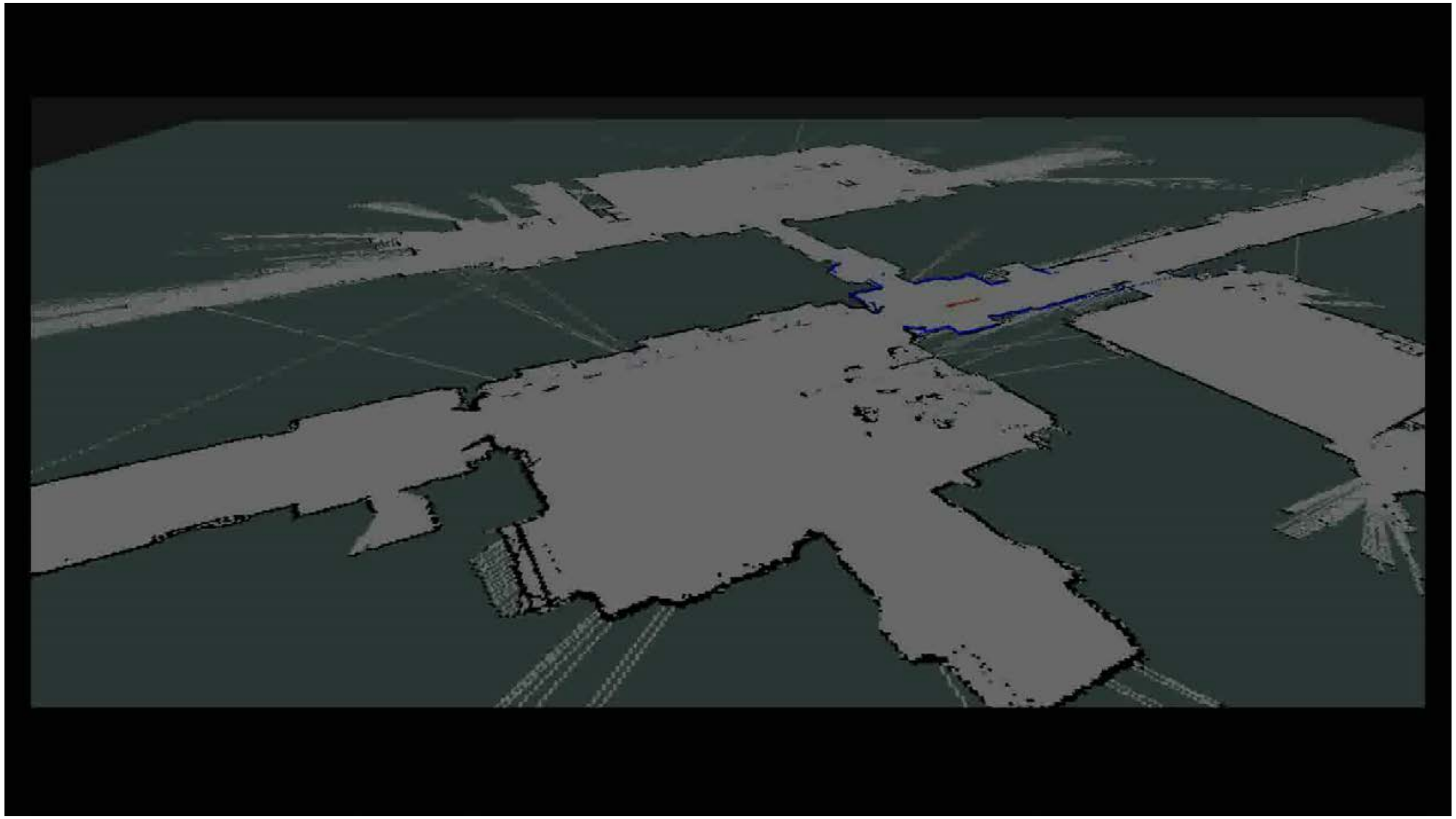
Many different sensors are used:

- position / velocity sensors
- IMU (accelerometer / gyroscope / magnetometer)
- RGB / RGB-D cameras
- 2D / 3D laser scanners
- GPS

Depending on:

- indoor / outdoor environments
- accuracy / reliability / cost constraints
- specific application constraints

Perception, localization and mapping: the wheelchair example



We consider again the wheelchair example to analyze the hardware, software and control architecture of a navigation system.

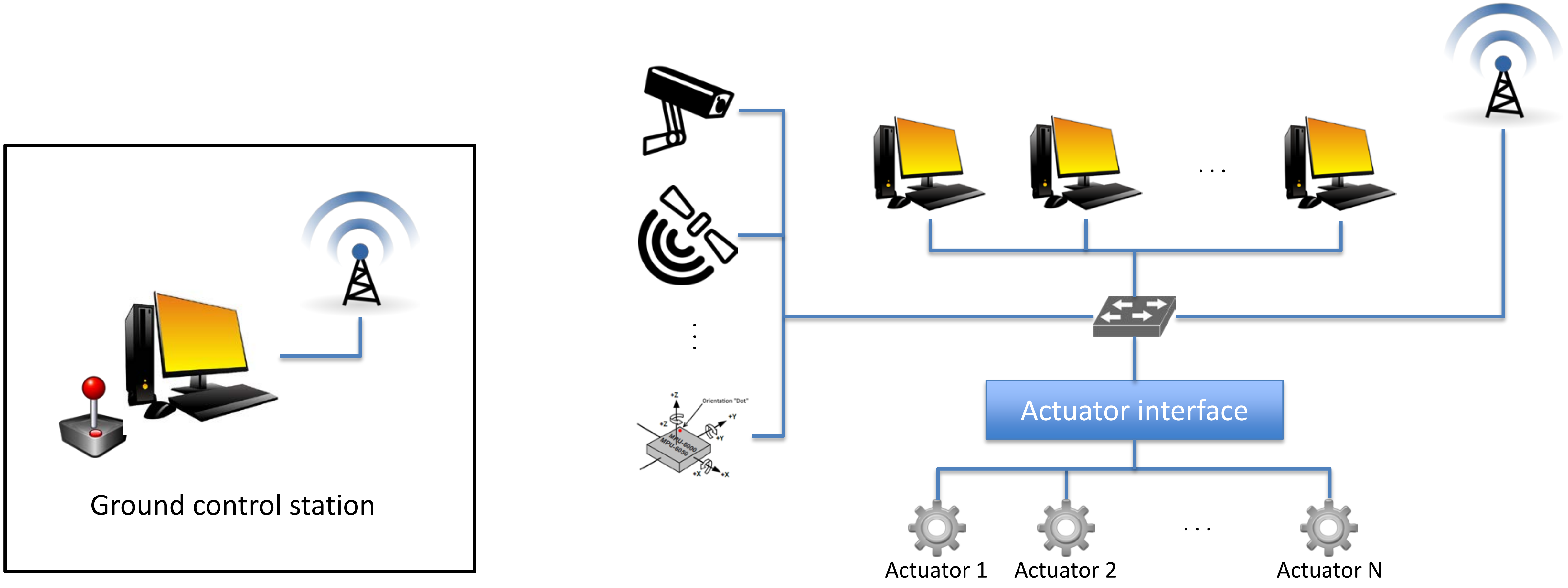
The analysis is based on an example, it is thus not complete (e.g., safety is not considered), but it is useful to emphasize the main components of the three architectures.

The software architecture is based on ROS (Robot Operating System), a set of open source software libraries and tools, from drivers to state-of-the-art algorithms, and powerful developer tools, that help build robot applications.

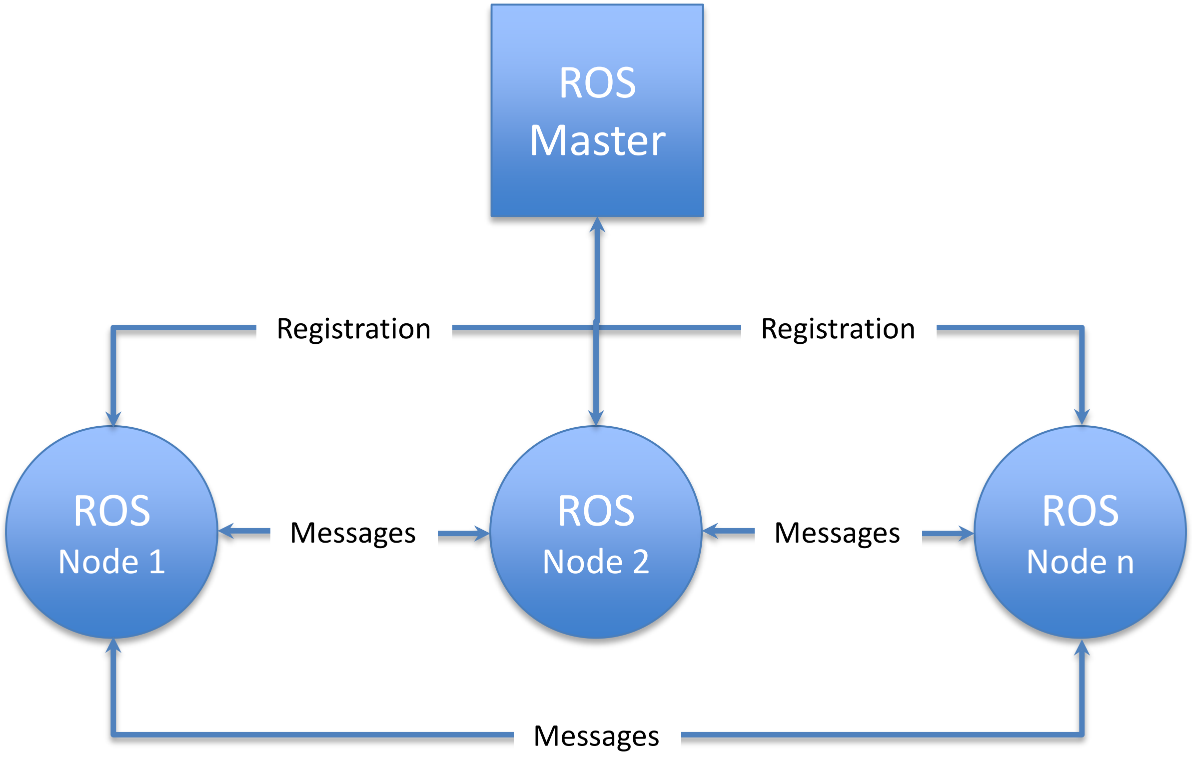
ROS

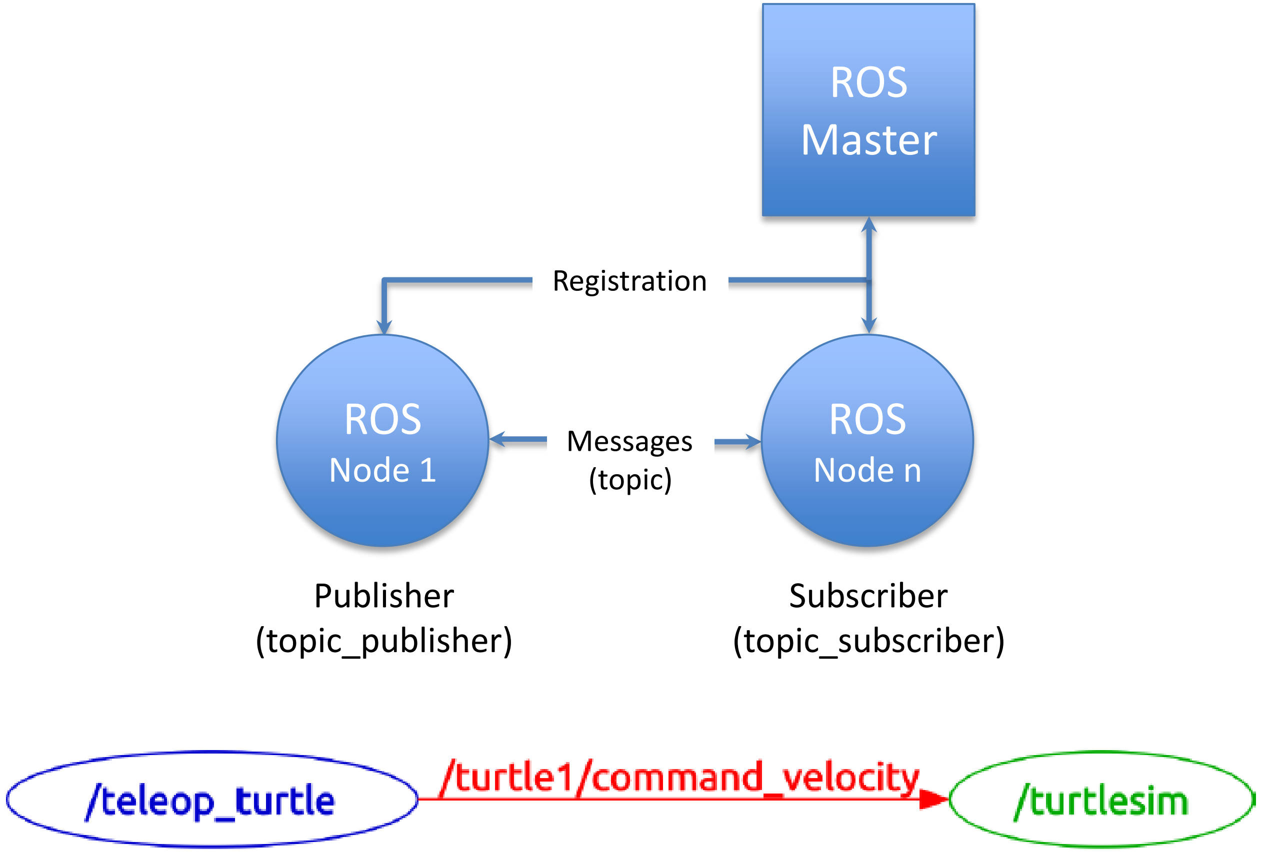
www.ros.org

Hardware architecture

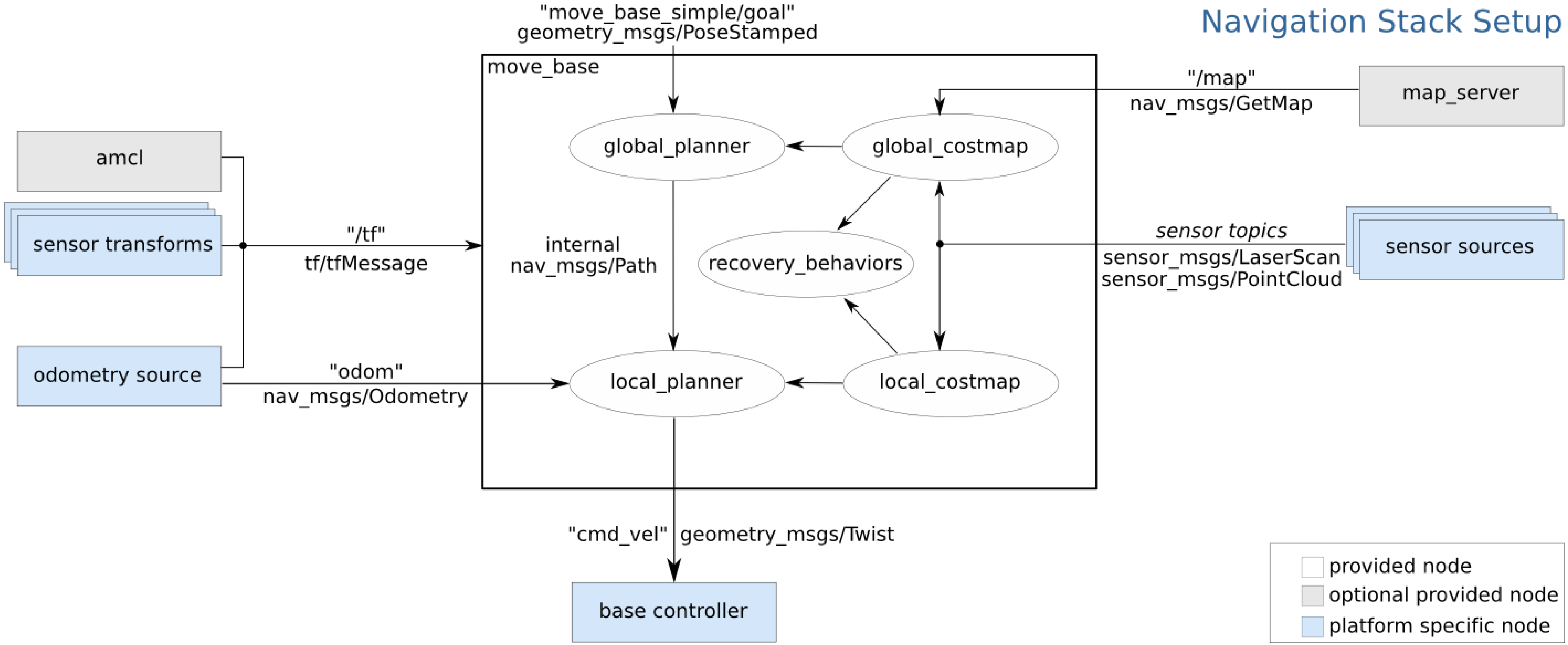


A few words on ROS





Software architecture



Control architecture

Slow, not real-time, should only support online replanning in the sensor range

Approximately the same bandwidth of a human driver, sensor processing is computationally intensive and not real-time, control can be soft real-time

Motor drives, standard PID control, torque / velocity loops, fast loops, hard real-time systems