Universität Bremen

Institute for Artificial Intelligence
Faculty 03
Mathematics &
Computer Science

Robot Programming with ROS

6. Navigation

Arthur Niedźwiecki
21th May. 2025

Artificial Intelligence

Outline

Autonomous Driving (2005)

https://youtu.be/7a6GrKq0xeU

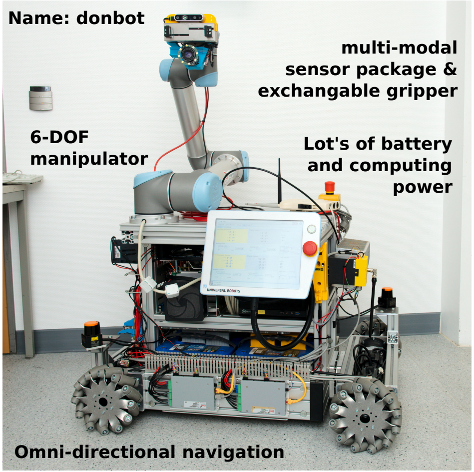
https://youtu.be/7a6GrKq0xeU

Mobile Manipulation (2012)


3x
0:44 / 2:58
3D

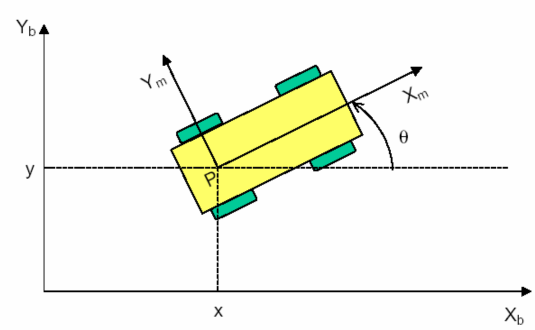
Outline

Robot Capabilities



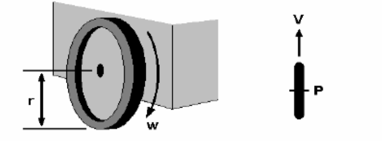
Robot Locomotion - Wheeled Locomotion

Goal: Bring the robot to a desired pose (x, y, θ):
$\Rightarrow$ 3 DOF (typically, with **non-holonomic constraints**)

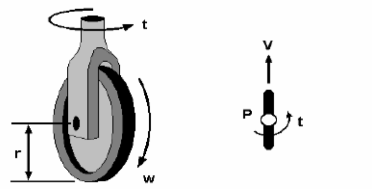


Robot Locomotion - Wheel Types

Fixed wheel

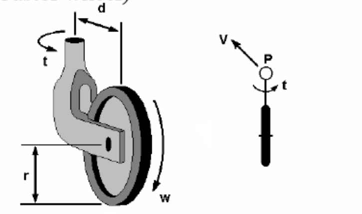


Centered orientable wheel

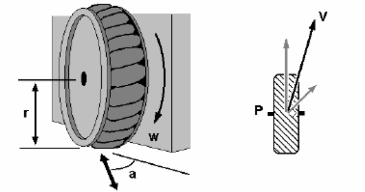


Off-centered orientable wheel

(Castor wheel)

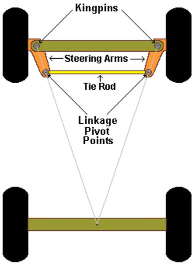


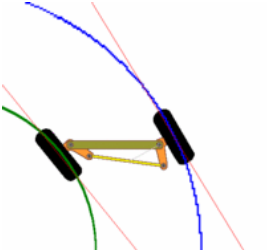
Swedish wheel:omnidirectional property



Robot Locomotion - Ackerman steering

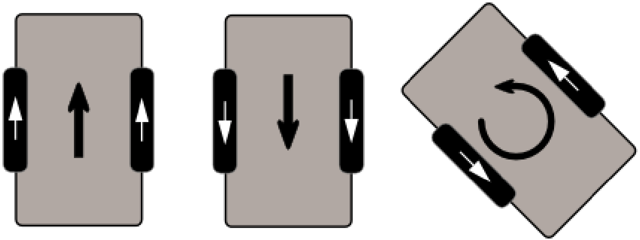
- Car-like steering
- \+ Robust
- \+ Outer wheels moves on a circle of different radius than inner wheel
- – But hard to control (parking!)





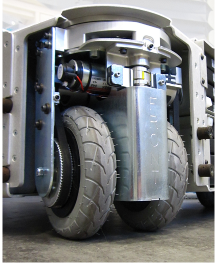
Robot Locomotion - Differential-Drive

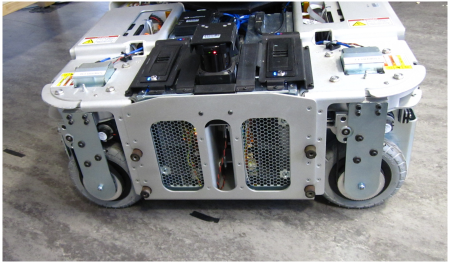
- \+ Turns on spot
- \+ Good choice for round robots
- \+ Parking is easier
- – Cannot move sidewards



Robot Locomotion - Turnable wheels

+ Omnidirectional (can drive forwards, sideways and turn)
– On change of direction, requires ’reconfiguration’ of its wheels.
→ Controllers should not oscillate

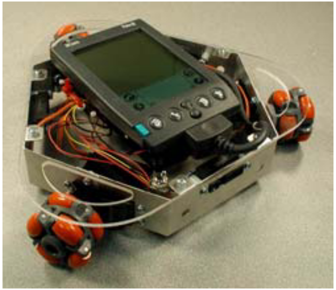


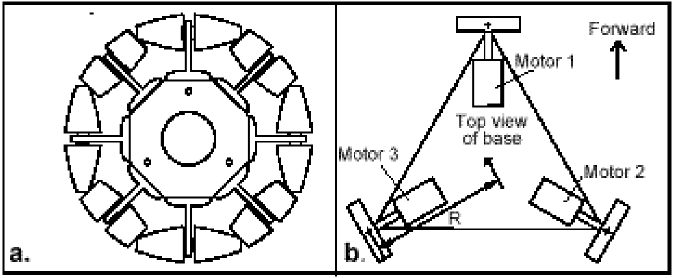


PR2: Double wheel construction to reduce friction while turning the wheel

Robot Locomotion - Omniwheels

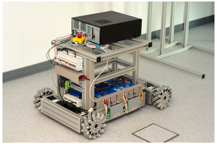
- + Omnidirectional (can drive forwards, sideways and turn)
- • Wheels have free rollers at **90**^{o}
- + Three wheels are enough
- – Hard to make them run smooth

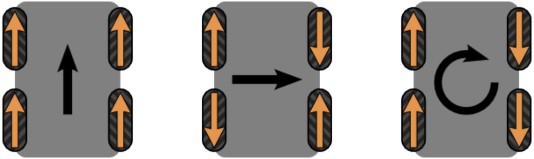




Robot Locomotion - Mecanum-Wheels

+ Omnidirectional (can drive forwards, sideways and turn)
- Wheels have free rollers at **45**^{o}
+ No reconfiguration is involved
– Depending on wheels, requires flat ground





Linearity $\Rightarrow$
A (linear) combination of cartesian movements can be achieved with the linear combination of the respective wheel velocities.

Robot Locomotion - Issue: Dead Reckoning

Dead Reckoning

"In navigation, dead reckoning is the process of calculating one's current position by using a previously determined position, or fix, and advancing that position based upon known or estimated speeds over elapsed time and course."
https://en.wikipedia.org/wiki/Dead_reckoning

Robot Locomotion - Issue: Dead Reckoning

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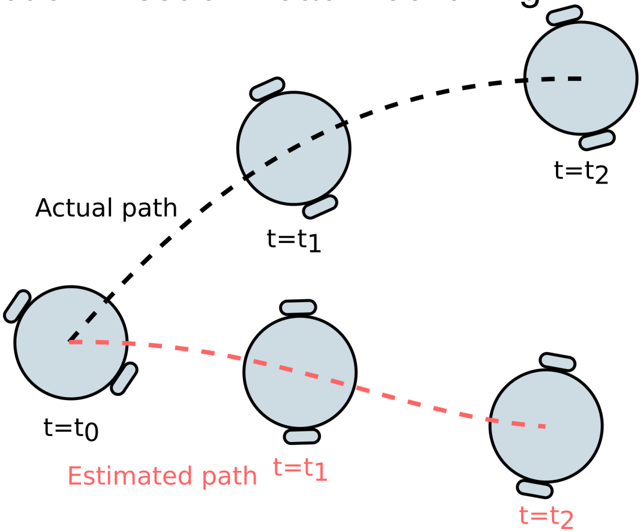
tl;dr: calculating position based on estimating direction and distance traveled (instead of using landmarks)

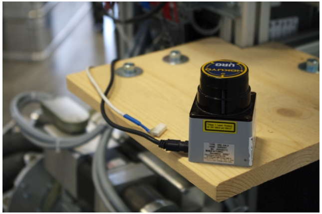
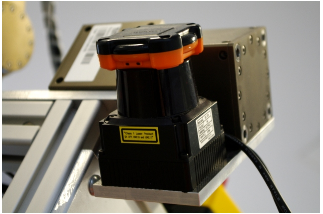
Robot Locomotion - Issue: Dead Reckoning



Robot Sensing - Time-of-Flight Sensors

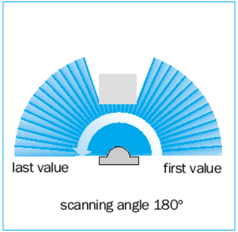
- Measurement principle: send out wave pulses, wait for the echo, and compute distance by *time of flight*
- *Same principle used by bats, dolphins, RADAR and the police...*

Robot Sensing - Laser scanners

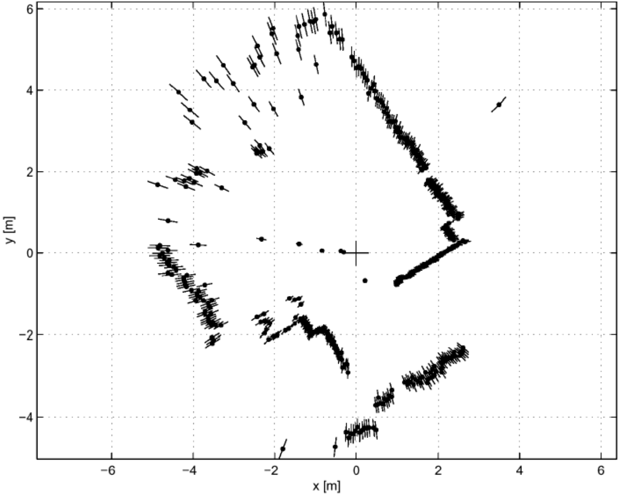
- Principle: send beam of light, beam hits target, measure time between beam transmission and reception of backscatter
- Rotating mirror deflects beam $\rightarrow$ 2D Scanner
- If the round trip time is t, the distance is $d = (c \cdot t)/2$.
- Time t is very short $\rightarrow$ use phase difference instead

Robot Sensing - Typical Laser Range Scanner



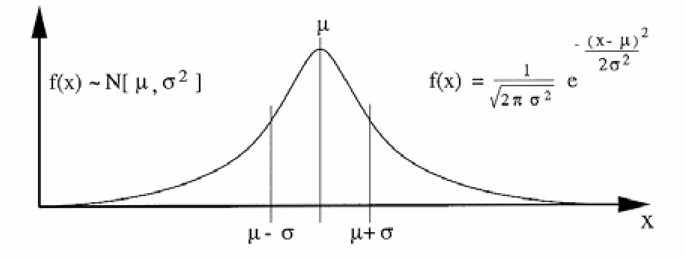
- Scanning angle: 180 degrees
- Resolution: 0.25deg, 0.5deg, or 1deg.
- Typical detection range: 30m (max. 80m)
- Data Received: Angle + Distance
- Normally used for:
  - Making maps of the environment
  - Localization of the robot
  - Tracking of objects or people
- In some circles, it is known as LIDAR (LIght Detection And Ranging)

Robot Sensing



Robot Sensing - Issue: Sensor Noise

- Anything that obscures a signal.
- External noise
  - Part of the environment, e.g. temperature, electromagnetic interference, sun light, gravitational flux, or ...
- Internal noise
  - White noise (uniform), e.g. thermal noise
- Often estimated with a Normal distribution

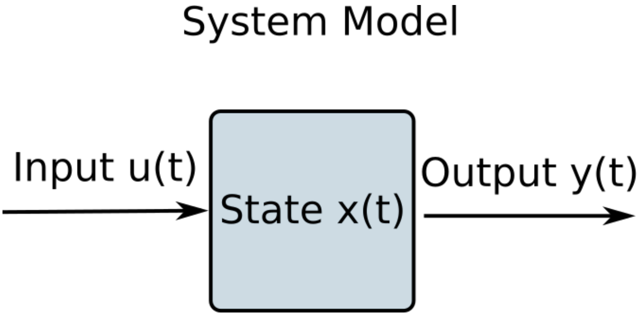


Outline

Concepts

State Estimation	Localization
Mapping	SLAM
Path Planning	Navigation

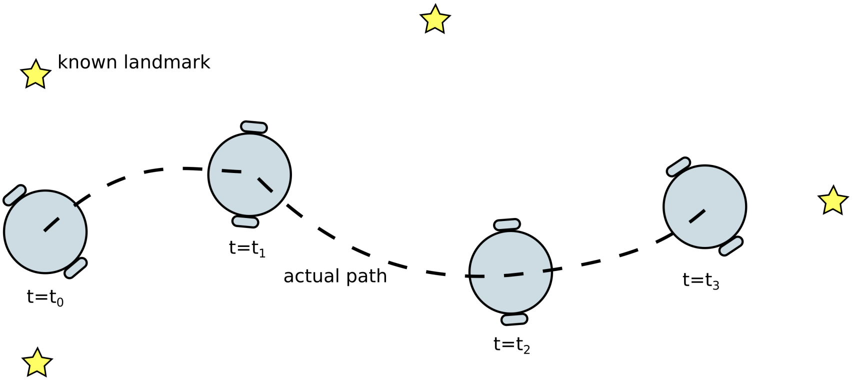
Concepts - State Estimation



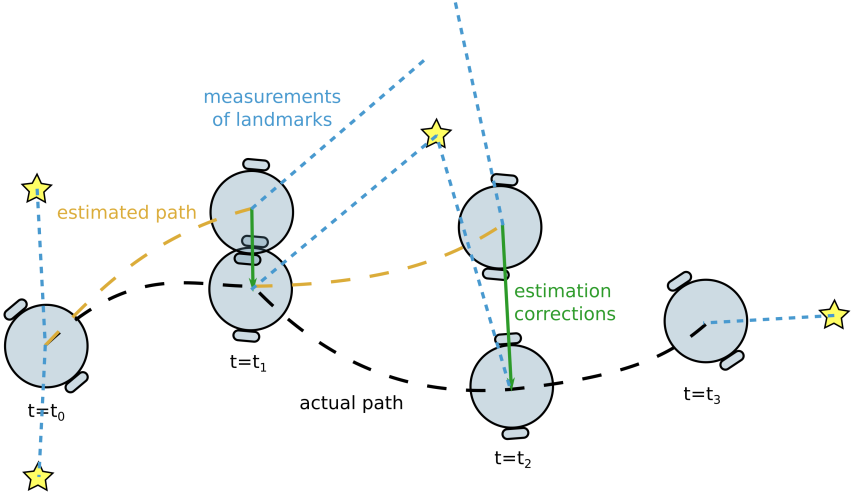
State Estimation

Computation of an estimate $\hat{x}(t)$ of the internal state $x(t)$ of a system from observations of the system's inputs $u(t)$ and outputs $y(t)$.

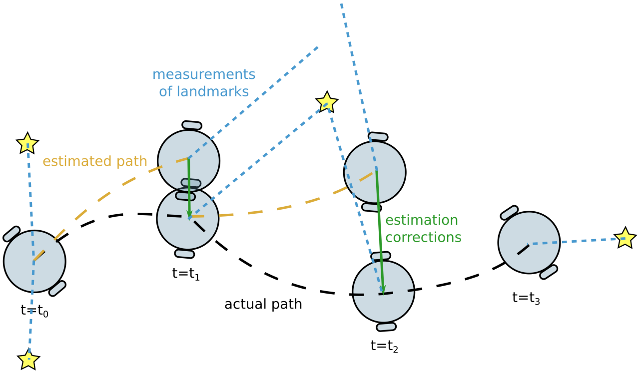
Concepts - Localization



Concepts - Localization



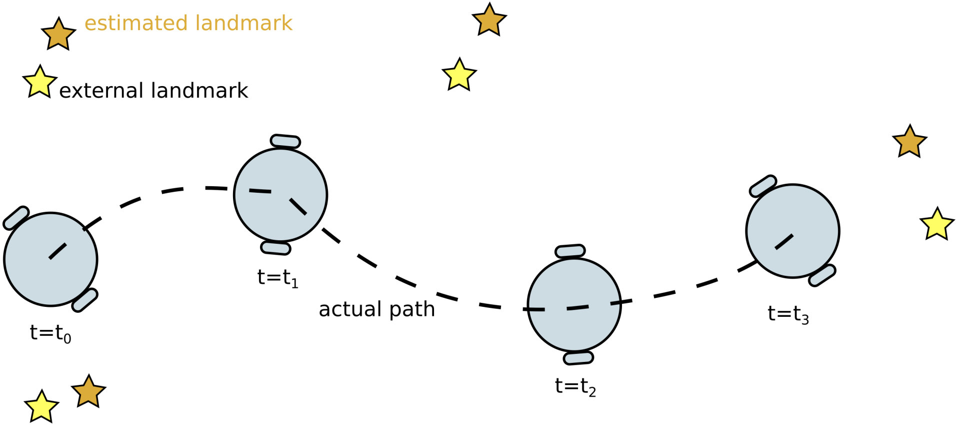
Concepts - Localization



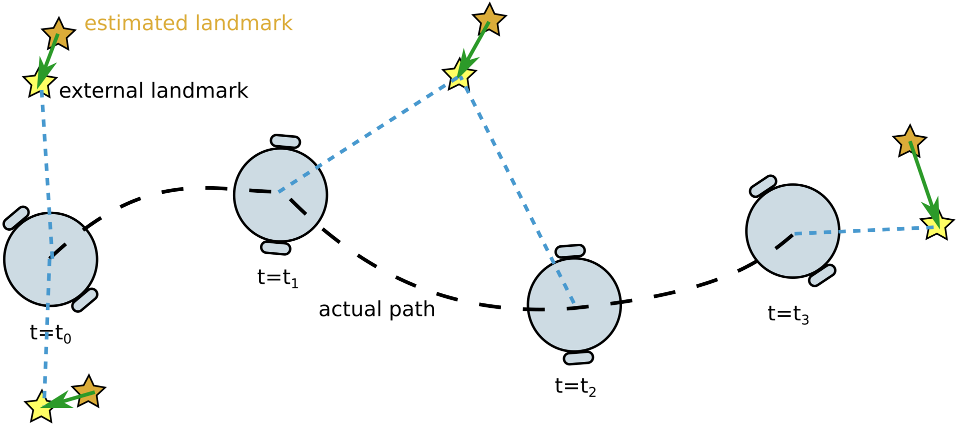
Localization

Estimation of the robot's location in the world, given some known external landmarks.

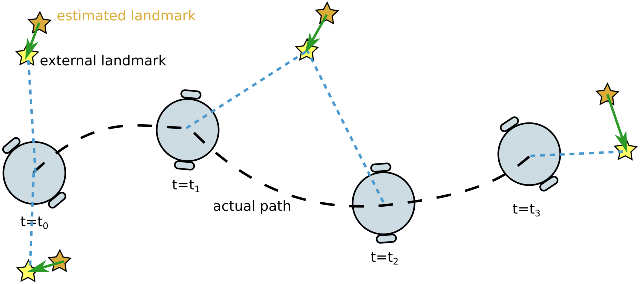
Concepts - Mapping



Concepts - Mapping



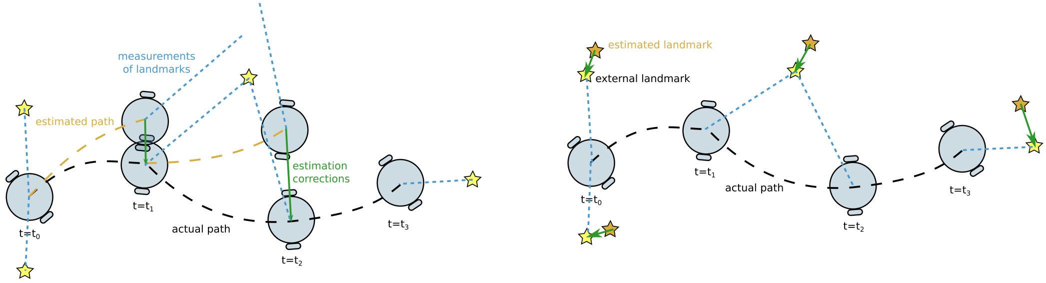
Concepts - Mapping



Mapping

Estimation of external landmarks in the world, given the robot's location is known.

Concepts - SLAM



Simultaneous Localization and Mapping

Estimation of the locations of the robot and the external landmarks, at the same time.

Arthur Niedźwiecki

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Mathematics &
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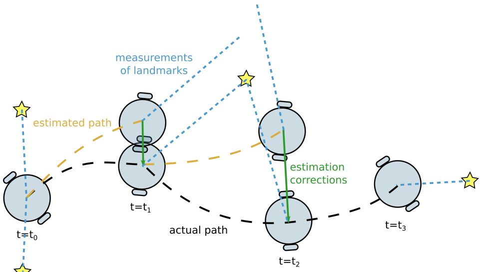
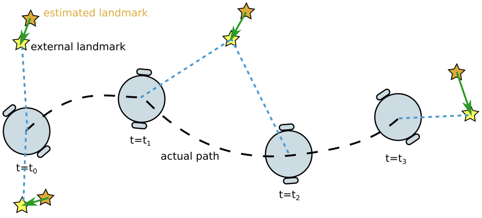
Concepts - SLAM





SLAM is a **chicken-or-egg** problem

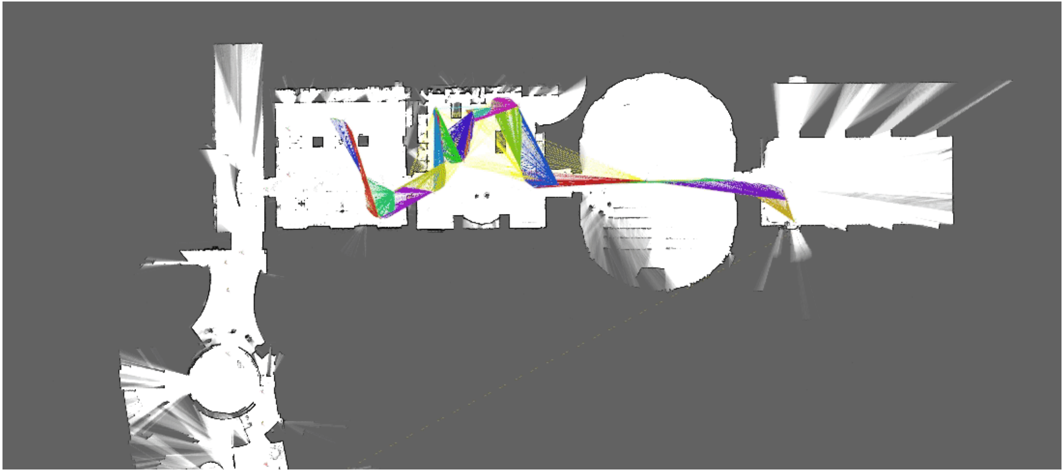
- Known landmarks are needed for localization
- Known robot is needed for mapping

Concepts - SLAM

Problem Definition of SLAM

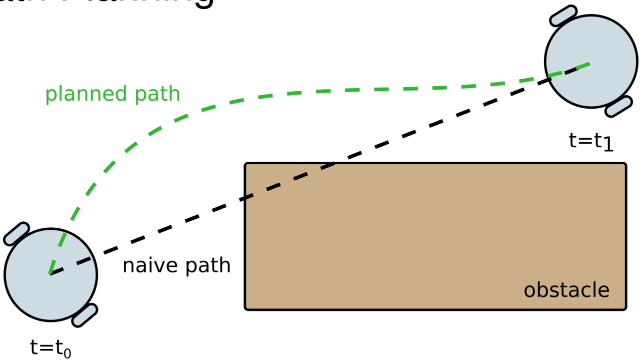
- Given:
  - The robot's control inputs: $u_{1:T} = \{u(1), u(2), \ldots, u(T)\}$
  - The robot's measurements: $y_{1:T} = \{y(1), y(2), \ldots, y(T)\}$
- Wanted:
  - Environment map m
  - The robot's path $x_{1:T} = \{x(1), x(2), \ldots, x(T)\}$

Concepts - SLAM



https://google-cartographer-ros.readthedocs.io/en/latest/_images/demo_2d.gif

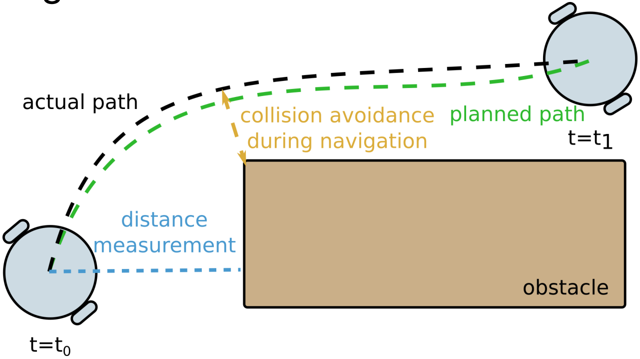
Concepts - Path Planning



Path Planning

Compute a sequence of valid configurations that moves the robot from the source to destination. https://en.wikipedia.org/wiki/Motion_planning

Concepts - Navigation



Navigation

Navigation is a field of study that focuses on the process of monitoring and controlling the movement of a craft or vehicle from one place to another.
https://en.wikipedia.org/wiki/Navigation

Concepts

- State Estimation
- Localization
- Mapping
- SLAM
- Path Planning
- Navigation

Outline

Software in ROS

- SLAM, Mapping, Localization
  - slam toolbox:
    `https://docs.ros.org/en/jazzy/p/slam_toolbox/`
    `https://roboticsbackend.com/ros2-nav2-generate-a-map-with-slam_toolbox/`
- Navigation, Path Planning:
  - nav2: `https://docs.nav2.org/`

Courses and Literature

- Very good course on SLAM from Uni Freiburg: `http://ais.informatik.uni-freiburg.de/teaching/ws13/mapping/`
- Nav2 Online Tutorials:
  `https://docs.nav2.org/tutorials/index.html`
  `https://roboticsbackend.com/ros2-nav2-tutorial/`
  `https://ros2-industrial-workshop.readthedocs.io/en/latest/_source/navigation/ROS2-Navigation.html`
- Mapping with SLAM: `https://roboticsbackend.com/ros2-nav2-generate-a-map-with-slam_toolbox/`

Autonomous Driving right now

- Waymo:
  `https://www.youtube.com/watch?v=hA_-MkU0Nfw`
- Why autonomous driving stalls:
  `https://www.youtube.com/watch?v=4sCK-a33Nkk`
- Pros and cons: `https://www.youtube.com/watch?v=G20U_lzsMdE`

Robot Navigation (2019)

Outline

Schedule

18	19	20 **Deadline 3**	21 **Lecture Navigation**	22 **Group assignment 4**	23	24
25	26	27 **Deadline 4**	28 **Praktikum 1**	29	30	31
1	2	3	4	5	6	7

June 2025

SUNDAY	MONDAY	TUESDAY	WEDNESDAY	THURSDAY	FRIDAY	SATURDAY
1	2	3	4 **Praktikum 2**	5	6	7
8	9	10	11 **Praktikum 3 with deputy**	12	13	14
15	16	17	18 **Praktikum 4 + presentations**	19	20	21
22	23	24	~~25~~	26	27	28
29	30	1	2	3	4	5
6	7	8	9	10	11	12

July 2025

SUNDAY	MONDAY	TUESDAY	WEDNESDAY	THURSDAY	FRIDAY	SATURDAY
29	30	1	2 **Presentation**	3	4	5
6	7	8	9	10	11	12

Assignment and dates

Form groups on StudIP > RPWR Course > Participants > Groups

- **Group** Assignment 4: with 4 people per group
  `https://github.com/artnie/rpwr-assignments`
- Grade: 15 points
- Due in one week: 27.05., 23:59 German time
- Submit with group number and name of participants.

Tutorium here after lunch at 14:15

Praktikum begins next week: 28.05., 12:15

Thanks for your attention!

Special thanks to the IAI team for the content of this lecture!