ROBOT DESIGN LAB WiSe 2022/2023

Exam Handout

This is a list of the important topics covered in the lecture. You can use this list to prepare for the oral exam or group interview with Prof. Frank Kirchner.

Disclaimer: This list is meant for your exam preparation. The questions asked in the exam will be related to the topics covered in this list. However, the phrasing of the questions need not be exactly the same as in this list.

Lecture 01: Introduction to Robotics

- What is a robot? Give some possible definitions.
- Beginnings of robotics: Which is the first AI-enabled mobile robot?
- Birefly explain the developements to which the Shakey robot contributed (e.g. A* search algorithm, STRIPS planner, Hough transform).
- Name possible applications domains of robotics.
- Explain the role of robotics for achieving the UN Sustainable Development Goals (SDGs).
- What is robot autonomy?
- What are the levels of autonomy according to Sheridan and Verplank (1978)?
- What are the main components of the autonomous robot navigation stack?

Lecture 02: Robot Programming

- Introduction to Operating System
  - What is an operating system? Give examples.
  - Explain some of the functions of an operating system.
  - Give an overview of the hardware-software structure of a mobile robot.
- Robot Operating System (ROS)
  - What is ROS?
  - Is ROS an operating system?
  - What are the advantages of using ROS?
  - ROS concepts: node, topic, service, launch file.
  - Main differences between ROS1 and ROS2.
  - Communication between a publisher and a subscriber node.
- Battery Handling
  - What type of battery does a TurtleBot use?
  - What are the dangers of manipulating a LiPo/LiFe battery?
  - How should we properly charge batteries?
  - How do we safely handle and use batteries?
  - What has to be done in case of battery fire?

Lecture 03: Sensors

- What is a sensor?
- Role of perception in robotics.
- Challenges in robot perception.
- Parallel between robot and human sensing.
- Sensor classification:
  - Active vs passive.
  - Digital vs analogue.
  - Interoceptive vs proprioceptive vs exteroceptive sensors.
- Sensor characteristics: range, sampling rate, resolution, accuracy, quantization error.
- Working principle of proprioceptive sensors: wheel encoder, IMU, resistive sensors.
- Working principle of exteroceptive sensors: laser scanner, sonar, infrared sensor, photocell.
- Challenges in robot sensing.
- Name methods for sensor fusion.
- How can we ensure long term autonomy from sensing point of view?

Lecture 04: Odometry

- What is odometry?
- Give examples of wheeled robot models (e.g. unicycle model, bicycle model, …).
- Explain the unicycle model.
- Explain the differential drive model.
- Sensors needed for odometry (e.g. wheel encoder working principle).
- Odometry drift: causes and solutions.

Lecture 05: Mapping

- What is mapping?
- What is SLAM (Simultaneous Localization and Mapping)?
- Role of mapping in mobile robotics.
- Types of maps in robotics and their properties (e.g. grid maps, feature maps).
- Types of sensors that can be used for mapping.
- What is the scan matching algorithm?
- What is the problem of loop closure in localization and mapping?
- What is the principle of mapping with known poses?
- Which assumptions do we make when performing mapping with known poses?
- Why do we use a probabilistic approach for occupancy grid mapping?
- What is the laser scanner inverse sensor model for mapping?
- Which mapping libraries do you know in ROS? Which of them did you use with the TurtleBot?
- Challenges in robot mapping.
- How does the resolution of the occupancy grid map influence mapping?
- ~~LEFT OUT: Bayes theorem.~~

Lecture 06: Localization

- What is robot localization?
- What is the robot pose in a 2D plane composed of (e.g. for TurtlebBot)?
- Role of localization in mobile robotics.
- Sensors used for localization (pros and cons).
- What is Monte Carlo localization and what inputs does it expect?
- What are the steps of a particle filter-based localization?
- What is the sensor model used in Monte Carlo localization?
- What is an Adaptive Monte Carlo localization (AMCL)?
- What is the main difference between position tracking and global localization?
- What is the kidnapped robot problem and how can we cope with it?
- Main challenges in robot localization.

Lecture 07: Path Planning and Obstacle Avoidance

- What is a path in the navigation context? What is a waypoint?
- Define path planning.
- What information do we need for path planning? (pre-requisites for path planning)
- Explain point robot simplification.
- Name three algorithms for path planning. What are their advantages and disadvantages?
- What is the difference between informed and uninformed search? Give an example for each.
- When does A* algorithm return a least-cost path?
- Give two examples of an admissible heuristic that can be used by A* algorithm.
- How does breadth-first search work?
- Why is breadth-first search optimal?
- What is a variable resolution grid map? Why do we need it?
- Why do we need obstacle avoidance?
- Explain the basic idea of local obstacle avoidance approaches.
- How does the dynamic window approach for obstacle avoidance work?
    - How are candidate velocities determined?
    - Describe three criteria for scoring candidate velocities or trajectories.
- Compare global path planning with local obstacle avoidance.
- Give examples of path planning and obstacle avoidance parameter configuration for your robot.

Lecture 08: Task Planning

- What is meant by task planning?
- Why do we need a formal representation for task planning?
- What are the pre-requisites for task planning? (planning domain, planning problem)
- What does a planning domain consist of?
- What does the statement of a planning problem consist of?
- How is an operator defined in the classical representation?
- What is the difference between an operator and an action?
- What is a state and how is it represented in classical representation?
- When can we say that an action is applicable to a state? (positive and negative preconditions)

- How do we determine the new state after applying an action to the current state? (positive and negative effects)
- What is a plan?
- What is meant by the statement "a plan is executable in a state"?
- When can we say that a plan is a solution to a given planning problem?
- Describe any five assumptions of classical task planning.
- How does forward search work in state space planning?
- What happens if a plan fails during execution?
- What is a behaviour tree?
- Name three types of nodes in a behaviour tree.
- What is the difference between a selector node and a sequence node?
- Describe two advantages of behaviour trees (reactivity, modularity).
- How can you represent an action in the form of a behaviour tree?

Lecture 09: Perception 1

- What is the visible spectrum of light?
- What is the function of rod and cone cells in human retina?
- What are color spaces? Give an example.
- What is chromaticity diagram?
- Explain pinhole camera model.
- Explain the Bayer sensor arrangement in cameras.
- Two examples of image transformations.
- Four examples of computer vision tasks.

Lecture 10: Perception 2

- What is a rotation matrix used for?
- What is meant by translation? How is a translation performed?
- What is the purpose of a camera calibration matrix?
- Describe the intrinsic and extrinsic camera parameters.
- What are the two main steps in camera calibration?
- Name a commonly used camera calibration pattern.
- Which computer vision tasks require camera calibration (name any two)?
- Give examples of Haar features.
- What are Haar features used for (e.g. face detection)?
- Name a circle detection algorithm.
- Why is perception a hard task? Give any two reasons that you can think of.
- ~~LEFT OUT: Eigen faces and PCA for object detection~~

Lecture 11: Mechanical Design

- What is meant by mechanical design?
- Explain the three steps involved in mechanical design.
- Give examples of machine elements.
- What is the modulus of elasticity of a spring?
- Explain the stress-strain diagram of a spring.
- What is the difference between qualitative and quantitative design?
- What is CAD and what is it used for?

- What are the differences between additive and subtractive manufacturing processes?
  - How do they compare in terms of speed and robustness?
- How does a photoactive 3D printer work?
- Name two subtractive manufacturing methods.
- What is biomimetics?
- How can robotics design benefit from biomimetics?
- What are the two principles for biomimetic design (top-down, bottom-up)?
- Give two examples of biomimetic design in robotics.
- Can you think of a few challenges involved in mechanical design?

Lecture 12: Actuators

- Comparison between different types of motors: DC motor, stepper motor, servo motor.
- What is the difference between brushed and brushless motors?
- What is the difference between inner and outer rotor motor?
- What is a motor characteristic curve?
- Pneumatic vs. hydraulic actuation (working principle, advantages / disadvantages).
- What is a series elastic actuator (SEA)?
- Examples of bio-inspired actuator design (e.g. McKibben artificial muscles – spider robot, fluidic microactuator – elephant trunk).

Lecture 13: Electronics

- Explain the construction and hardware architecture of TurtleBot III Burger robot (mechanical structure, hardware components like sensors, actuators, microcontrollers, etc.)
- Name some of the main electronic components (e.g. resistors, capacitors, inductors diodes, transistors, etc.) and describe their operation.
- What is a bypass capacitor used for?
- Which electronic component is used to generate the clock signal? What is its principle of operation?
- What is the difference between a BJT and a MOSFET?
- Why do we need voltage regulators? Name two types of voltage regulators.
- What are the pros and cons of analog and digital signals?
- How is analog-to-digital conversion done?
- Define the duty cycle and frequency of a pulse width modulated signal.
- What does 50% duty cycle mean?
- Give a few applications of pulse-width modulation.
- Explain the truth table of tristate diodes.
- What is a low-voltage differential signal?
- What are serial and parallel interfaces? Give examples of each.
- What are the differences between SPI, I2C and UART?
- What are integrated circuits?
- What is the difference between microprocessors and microcontrollers?
- Name some of the interfaces available on Raspberry Pi 4 and the OpenCR board of TurtleBot3 Burger robot.
- Explain the working principle and applications of the H-bridge.

Lecture 14: Robotics and AI

- What is the robotics problem (perception, action, reward)?
- What are intelligent machines (Alan Turing's definition)?
- What is long-term autonomy? Why is it needed?
- What are the challenges / problems associated with long-term autonomy?
- How can AI help in achieving long-term autonomy?
- What do you understand by embodied localization and mapping?
- What are the key elements of localization and mapping?
- Give examples of current and future goals of robotics

Note to students attending group interview:
Please revise the feedback that we provided to your submissions.

General Note: Think about different application scenarios (e.g. underwater, rehabilitation, logistics, etc.) and reflect on:

1. The tasks that a robot has to perform in these scenarios;
2. The sensors a robot would need for doing these tasks;
3. The types of maps that would be suitable in these scenarios;
4. The mechanical design considerations that would be important;
5. The challenges the robot might have to face in these scenarios.