KIT-Department of Informatics
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Exam Question Sheet

Robotics III - Sensors and Perception in Robotics

October 2, 2020, 08:00 – 09:00

- Please fill in your name and matriculation number clearly legible in the header of each answer sheet and the cover sheet.
- Exercise sheets will not be handed in. Therefore, enter your answers only in the areas of the answer sheets provided for each question. Answers on sheets submitted separately will not be graded.
- Apart from writing utensils, no other aids are permitted during the exam. Please use a permanent pen with black or blue ink. Answers written either with a pencil, with red or with green ink will not be graded. Attempts to deceive by using inadmissible resources will lead to exclusion from the exam and result in the grade „failed“.
- Unless otherwise stated in the question, please enter only the final results in the answer sheets. You can use the back sides of the question sheets as concept paper. Additional concept paper can also be provided on request during the exam.
- Please keep answers or explanations brief. The space provided on the answer sheets for a question does not correlate with the length of a correct answer.
- **Answers can be given either in English or German.** You are allowed to switch the language between answers, but not within an answer.
- The total score is 45 points.

Good luck!

Exercise 1 *Internal Sensors* (10 points)

Your task is to develop an internal sensor system for different body parts of a new humanoid robot.

1. For the robot arms, an integrated sensor-actuator unit with comprehensive sensor system should be designed. The sensor system should fulfill the follwoing requirements: 4 p.

   - The robot arm should allow for high precision closed-loop position and velocity control.
   - The robot arm should be ready to use immediately after the power is turned on.
   - A human should be able to teach the robot arm new motions by kinesthetic teaching.
   - The sensor-actuator unit should be as small as possible to realize a humanoid arm with human-like dimension.

   Explicitly name the different sensor types and their respective measurement principle, justify your choices with respect to the requirements.

2. The robot will have to drive over ramps to move between different rooms. Thus, it is important to measure the angle of inclination. You have an accelerometer, an angular rate gyroscope and a magnetometer with three measurement axes each, but installation space in the robot is limited.

   (a) Assume you only have space for one of these sensors and want to have the best possible measurement of inclination, which one would you choose? Justify your answer. 1 p.

   (b) Through careful rearrangement of components you make it possible to allow integrating two of the above sensors into the robot. Which one of the remaining two sensors would you add to the first one to improve the quality of the measurement. Justify your decision and explain how the additional sensor improves the measurement. 2 p.

3. The robot is powered by a battery with a maximum voltage U_{bat} of 60 V. To continuously monitor the battery charge level, you intend to use an analogue-digital converter (ADC) with a maximum input voltage U_{ADC} of 5 V to measure U_{bat}. Hence you need to divide the voltage so that you measure a value proportional to U_{bat} but with a maximum voltage of 5 V. Give and describe a schematic diagram of the ADC and additional components that scales down the battery voltage U_{bat} to the ADC voltage U_{ADC}. Explain the working principle of your design and provide specific values regarding the different components. 3 p.

Exercise 2 *External Sensors* (9 points)

The robot should be equipped with a stereo vision camera system. Both cameras have a focal length $f = 6\,\text{mm}$ and a resolution of 1000×1000 pixels. The baseline of the camera system is $b = 15\,\text{cm}$.

1. Complete the provided sketch of the stereo camera model on the answer sheet by adding the four labels. 1 p.

2. Calculate the disparity d for a point p of an object at distance $z_p = 1.5\,\text{m}$ from the baseline. Write down the equation used. 2 p.

3. Both cameras have a frame rate of 60 frames/s and an RGB24 color format. Which bandwidth is required for the stereo camera system? Is it possible to use one USB 2.0 bus[1] as interface for one or both cameras? 2 p.

4. The robot is also equipped with an additional depth camera. Describe a case where perception is problematic when using 2 p.

   - stereo vision only
   - the depth camera only

5. For navigation of the robot, a LIDAR system based on the *Frequency Modulation Method* is used in the wheel-based mobile base of the robot. In Figure 1, the frequencies of the emitted and received signals are shown. Give the formula to calculate the object distance d based on time of flight Δt. What is the meaning of the physical constant required to describe the relation? 1 p.

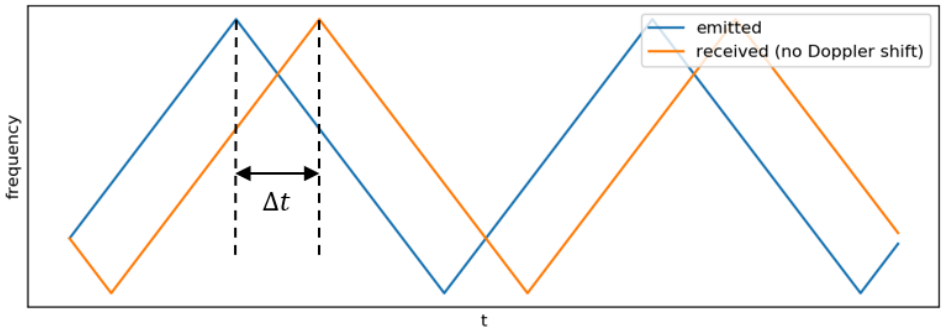

Figure 1: Emitted and received signals of the LIDAR sensor

6. Name two different types of time-of-flight sensors in addition to LIDAR. 1 p.

[1] USB 2.0 datarate: 480 Mbit/s (430 Mbit/s payload)

Exercise 3 *Feature Extraction* (8 points)

1. The robot has to recognize known objects in a kitchen environment based on visual information.

   (a) Name two feature detectors that can be used to find points of interest in an image. 1 p.

   (b) Why do you need an additional descriptor for each point of interest for object identification? Name an approach for textured objects. 2 p.

2. Once the features have been extracted, the robot needs to identify objects in an image and estimate their 6D pose in the world.

   (a) How can feature descriptors be used to identify known objects in a scene? 1 p.

   (b) Select a camera system that you should use for the task of 6D pose estimation. Explain what is necessary to estimate a pose of the object based on the detected features with this camera system. 2 p.

3. What methods are available to estimate the 6D pose of an object using only point cloud information and a 3D object model? Which challenges have to be overcome when using neural networks for this task? 2 p.

Exercise 4 *Scene Understanding* (10 points)

The robot's task is preparing scrambled eggs for breakfast.

1. The robot must understand which objects are in the scene and which relations between these objects exist. As a first step, the robot should estimate the centroid (i. e. center point) of each object on the single-colored table in the kitchen using its RGB-D camera. Assume that objects are spatially separated.

   (a) How would you retrieve a point cloud that only contains the objects without the table. 1.5 p.

   (b) How would you determine the number of objects and the centroid of each object. 1.5 p.

2. The robot needs to fetch an egg carton from the fridge. All objects in the fridge are known and have been localized. Some of the objects are stacked. 2 p.

   How can you generate a sequence of manipulation actions to safely retrieve the eggs from the fridge while preventing objects from falling down? Name the method and describe a strategy to achieve the task.

3. You want the robot to setup the dining table as shown in Figure 2.

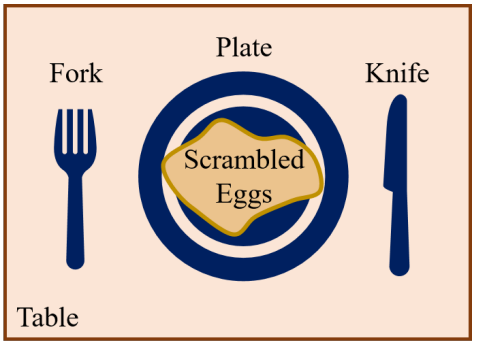

Figure 2: Top view of the desired layout of the dining table.

   (a) Name six spatial relations between different pairs of objects (including the table) defining the desired layout. 2 p.

   (b) What is the difference between a discriminative and generative model of spatial relations? What would be the input and output of each model type? 3 p.

Exercise 5 *Active Vision and Gaze Stabilization* (8 points)

1. In the lecture, Yarbus' experiment on eye movements of a human while perceiving Ilya Repin's picture "'An Unexpected Visitor"' was discussed. 2 p.

   What are the two key observations concerning the human eye movements in this experiment?

2. Describe the *Reafference Principle*. How are the terms *afference*, *exafference*, and *reafference* defined? How do they relate to each other? Give an example in humans. 3 p.

3. Provide a comparison between three gaze stabilization methods covered by the lecture. What are their advantages and limitations? Can one method be used in general for all situations and/or scenarios? 3 p.