KIT-Department of Informatics
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Exam Question Sheet

Robotics III - Sensors and Perception in Robotics

Febuary 15, 2022, 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)

1. Explain the two sensor characteristics *bandwidth* and *response time*. 1 p.
2. Single-track encoders are a type of optical encoder presented in the lecture.
   (a) Explain the working principle of a single-track optical encoder. 1 p.
   (b) How can a single-track encoder be expanded to measure the direction of rotation? 1 p.
3. The piezo-resistive effect is the basis of many sensors.
   (a) What is the piezo-resistive effect? 1 p.
   (b) How is it used in sensors based on piezo-resistive strain gauges? 1 p.
   (c) How can the piezo-resistive effect be used to design a microelectromechanical system (MEMS) accelerometer? 1 p.
4. Describe the measurement principle of an accelerometer. What is the most common technical realization. 1 p.
5. In the lecture, a complementary filter was described for the fusion of accelerometer and angular rate gyroscope data. Explain how the filter works and why it is used. 2 p.
6. Why is a 3-axis magnetometer needed to precisely estimate the yaw angle in an IMU? 1 p.

Exercise 2 *External Sensors* (9 points)

1. Name three measurement principles used in proximity sensors. 1 p.
2. Explain the main difference between a proximity sensor and a distance sensor. 1 p.
3. Which type of proximity sensor allows detection of transparent objects? 1 p.
4. Figure 1 shows the emitted and received signal frequency of a LiDAR sensor with a moving obstacle. Explain the reason for the delta in the peak frequency Δf_D. How is the distance from the obstacle to the sensor calculated? 2 p.

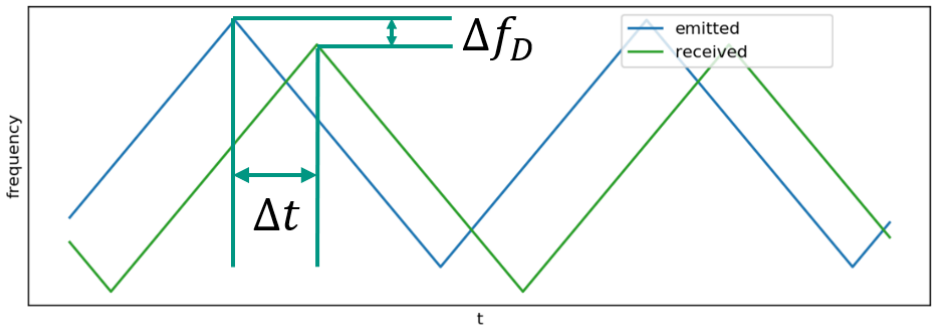

Figure 1: Emitted and received frequencies of a LiDAR Sensor

5. As the measurement principle of LiDAR sensors is based on the reflection of single rays of light, only point-wise depth measurements of a scene can be performed at a time. How can distance and velocity maps be obtained from a LiDAR sensor nevertheless? 1 p.
6. Explain how to obtain a depth image from structured light. 2 p.
7. In which situations or scenes do structured light cameras provide more accurate depth information compared to a stereo camera system? 1 p.

Exercise 3 *Tactile Sensing* (8 points)

1. Explain both terms *Tactile Perception* and *Proprioception*. How does the term *Haptic Perception* relate to these two? 2 p.

2. Explain the working principle of the *Weiss Robotics Tactile Sensor.* 1 p.

3. Explain how normal and shear force is detected in both the *FingerVision* and *GelSight* sensors. 2 p.

4. Fill the table on the answer sheet with the corresponding rationales for the inclusion of the different sensor modalities in the H2T sensorized robotic fingers described in 2 p.

   > *Weiner, P., Neef, C., Shibata, Y., Nakamura, Y. and Asfour, T., "An Embedded, Multi-Modal Sensor System for Scalable Robotic and Prosthetic Hand Fingers." Sensors, 2019.*

5. The paper 1 p.

   > *Kaul, L., Ottenhaus, S., Weiner, P. and Asfour, T., The Sense of Surface Orientation - A New Sensor Modality for Humanoid Robots, IEEE/RAS International Conference on Humanoid Robots (Humanoids), 2016*

   describes a *Surface Normal Sensing* approach. How is the contact with a surface determined in this approach?

Exercise 4 *Scene Understanding* (10 points)

1. Name four levels of scene understanding related to visual perception based on images and objects and sort them increasingly with respect to their degree of semantic understanding. 2 p.

2. You are given a model $M(i) = p$ which can classify the person p in an image i (including a “no person” class). Your task is to localize and classify multiple known persons in an image. Name and explain two methods that allow you to apply M to the given task. 2 p.

3. Why is it challenging to apply neural networks for segmentation of 3D point clouds collected from multiple view points? 1 p.

4. Explain the difference between instance segmentation and pixel-wise segmentation. 1 p.

5. Given an acyclic support graph $G = (O, E)$ with nodes O and edges

$$E = \{e_j\}_{j=1}^{m} = \{(A_j, B_j)\}_{j=1}^{m} \subseteq O \times O.$$

   (a) How can a robot derive an order in which to safely remove one object at a time? 2 p.

   (b) What changes if the support graph can contain cycles? 1 p.

6. What is the difference between static and dynamic spatial relations? 1 p.

Exercise 5 *Robot Vision* (8 points)

1. Humans have foveal and peripheral vision due to the anatomy of the human eye. How would you mimic the human eye for a robotic head? 1 p.
2. Name three descriptors for feature matching. 1.5 p.
3. Describe the basic concept behind Maximally Stable Extremal Regions (MSER). 2 p.
4. What is the complexity class of the general visual search problem? 1 p.
5. Complete the reafference diagram on the answer sheet by filling in the five missing keywords. 2.5 p.