KIT-Department of Informatics
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Exam Question Sheet

Robotics III - Sensors and Perception in Robotics

September 2, 2021, 11:00 – 12:00

- 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/External Sensors* (10 points)

1. Describe the main differences between *internal* (proprioceptive) and *external* (exteroceptive) sensors. Additionally, name an example for each sensor category. 1 p.

2. Given the voltage divider in Figure 1 and the values $R_1 = 50\,\Omega$, $U_1 = 2\,\mathrm{V}$, $U_2 = 4\,\mathrm{V}$. Give the formula for computing R_2 and its value explicitly. 2 p.

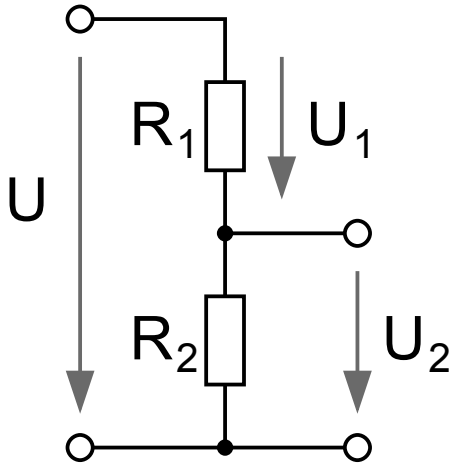

Figure 1: The voltage divider scheme

3. Name an advantage for measuring change in voltage with a Wheatstone bridge compared to a voltage divider. 1 p.

4. Given is an optical absolute encoder disk with three rings and Gray code.

   (a) What is the angular resolution in degrees [°] of the encoder? 1 p.

   (b) Name the main difference between binary and Gray code. Which problem is circumvented with Gray code? 1 p.

5. Inertial measurement units

   (a) Explain why an angular rate gyroscope is unsuited to infer the orientation over time. 1 p.

   (b) The measurements of an accelerometer and angular rate gyroscope are often fused together using a complimentary filter to obtain an orientation measurement. Explain the filter principle. Which filter is applied to the accelerometer data and which to the gyroscope data? 2 p.

   (c) Why is a magnetometer needed in addition to an accelerometer and angular rate gyroscope to obtain orientations in all three degrees of freedom? 1 p.

Exercise 2 *Tactile and Visual Sensing* (9 points)

1. Name *four* measurement principles used for the realization of tactile sensors. 2 p.

2. Describe structural design, components and measurement principle of the *GelSight* sensor. 2 p.

3. A robot is equipped with a stereo vision camera system. Both cameras have a focal length $f = 4\,\text{mm}$. The baseline of the camera system is $b = 15\,\text{cm}$.

   (a) Calculate the disparity d for a point p of an object at distance $z_p = 0.75\,\text{m}$. Write down the equation used. 1 p.

   (b) Name one advantage and one disadvantage of a stereo camera system with a larger baseline. 2 p.

4. Why does an RGB-D camera system need two cameras? What is the difference between these two cameras? What other component is essential for the system? 2 p.

Exercise 3 *Feature Extraction* (8 points)

1. Why is it beneficial to *normalize* correlation functions? Name two applications in robot vision where correlation methods are used. 2 p.

2. The *Harris Corner Detector* was developed to improve upon the Moravec Operator.

   (a) How is the image function $I(u + s, v + t)$ approximated in the Harris Corner Detector? 1 p.

   (b) The eigenvalues of the image structure $M(u, v) \in \mathbb{R}^{2\times2}$ can be used to indicate different regions in an image. Since the eigenvalue decomposition is computationally expensive, an alternate approach was proposed. Describe the approach and justify why this approach is more efficient? 1 p.

3. What is the difference between a *Feature Detector* and a *Feature Descriptor*? 1 p.

4. Name two applications in robot vision for the *SIFT* algorithm. 1 p.

5. Pose estimation algorithms are strongly dependent on the camera system used.

   (a) How is the computation of the homography between 2D image coordinates and 3D world coordinates called? 1 p.

   (b) Name an advantage and a disadvantage of stereo-based pose estimation. 1 p.

Exercise 4 *Scene Understanding* (10 points)

1. Scene Representations

   (a) What is the difference between object classification and segmentation when applied to images? 1 p.

   (b) Name two approaches for using a single-object classifier to detect multiple instances of the same object class in one image. 1 p.

   (c) Why is it difficult to use a neural network architecture for image classification to segment point clouds? 1 p.

   (d) What is the difference between static and dynamic spatial object relations? Give one example for each type. 1 p.

2. A Graph Network (GN) Block is defined by its *update* and *aggregation* functions.

   (a) Which of the two function types is usually learned from data? What is the purpose of this function type in a GN Block? 1 p.

   (b) What are the required properties of an *aggregation* function? Why are these properties necessary? 2 p.

   (c) For each *update* function of a full Graph Network (GN) Block, give its name or mathematical symbol as well as its inputs using the symbols for these terms: 3 p.

Node attributes:	$\mathbf{v}_i$	$\mathbf{v}'_i$	$\mathbf{v}_{s_k}$	$\mathbf{v}_{r_k}$	$\bar{\mathbf{v}}$	$\bar{\mathbf{v}}'$
Edge attributes:	$\mathbf{e}_k$	$\mathbf{e}'_k$	$\bar{\mathbf{e}}_i$	$\bar{\mathbf{e}}'_i$	$\bar{\mathbf{e}}$	$\bar{\mathbf{e}}'$
Global attribute:	$\mathbf{u}$					

   where $\mathbf{x}'$ denotes an updated attribute and $\bar{\mathbf{x}}$ denotes aggregated attributes.

Exercise 5 *Active Vision* (8 points)

1. Yarbus studied human eye movements in an experiment where participants perceived Ilya Repin's picture "An Unexpected Visitor". 1 p.

   What are the two key observations of this experiment as discussed in the lecture?

2. Complete the active perception diagram on the answer sheet by filling in the five missing keywords. 2 p.

3. Gaze stabilization methods compute compensatory eye movements to counteract disturbances and thus stabilize visual perception.

   (a) What is the goal of the *Vestibulo Ocular Reflex (VOR)*? Which sensors are needed for its implementation? Provide the control law used for its implementation in the ARMAR-III robot and explain all the terms you use. 2 p.

   (b) What is the difference between the *Vestibulo Ocular Reflex (VOR)* and the *Opto-Kinetic Reflex (OKR)* ? 1 p.

4. We discussed a gaze stabilization method based on the *Reafference Principle* in the lecture. 2 p.

   Explain the terms *afference*, *exafference*, and *reafference*? How do they relate to each other? Give an example for the exafference in robotics.