KIT-Department of Informatics
Prof. Dr.-Ing. Tamim Asfour

Exam Question Sheet

Robotics III - Sensors and Perception in Robotics

October 7, 2022, 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 Sensors* (8 points)

1. Our robots utilize digital magnetic off-axis absolute encoders for joint angle measurements. The sensors output a 20 Bit number over a full revolution corresponding to the angular position. The lowest two bits are highly noisy and hence they are not taken into account in the calculation of the position. 2 p.

   What is the *measurement range/span* and *accuracy* of the sensor? Provide numbers including units.

2. Figure 1 shows a circuit commonly used for the readout of analog sensors in robotics. R_1 is a resistive strain gauge with a resistance range of $3\,\mathrm{k\Omega}$ to $9\,\mathrm{k\Omega}$ depending on the amount of mechanical strain. The *Analog to Digital Converter* (ADC) is measuring voltage from + to the other terminal −.

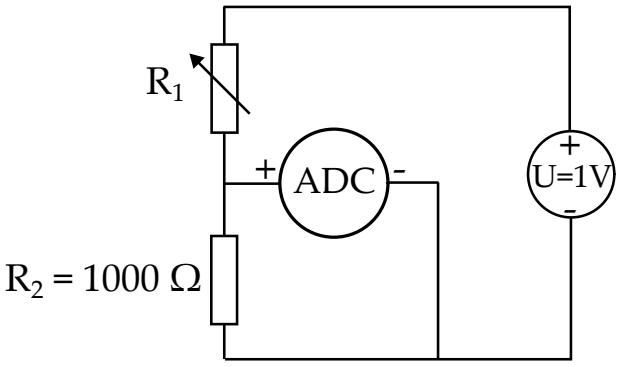

Figure 1: Analoge sensor readout circuit.

   (a) What is the name of the circuit? 1 p.

   (b) Explain the disadvantage of measuring a strain gauge with this type of circuit in contrast to using a Wheatstone bridge. 2 p.

   (c) Calculate the minimum and maximum voltage that the ADC will measure depending on the load on the strain gauge. Provide calculations. 2 p.

3. Explain one common realization method for *Microelectromechanical System* (MEMS) accelerometers. 1 p.

Exercise 2 *External Sensors* (9 points)

1. An acoustic proximity sensor uses ultrasound to detect an object.
   (a) Name a possible frequency for the emitted ultrasound signal. 1 p.
   (b) Which measurement principle is used to calculate the distance? 1 p.
2. In Figure 2 the emitted and received signal frequency of a *Frequency Modulation* (FM) *Light Detection and Ranging* (LiDAR) sensor is depicted. An object O_1 is placed in front of the sensor, the object is not moving.

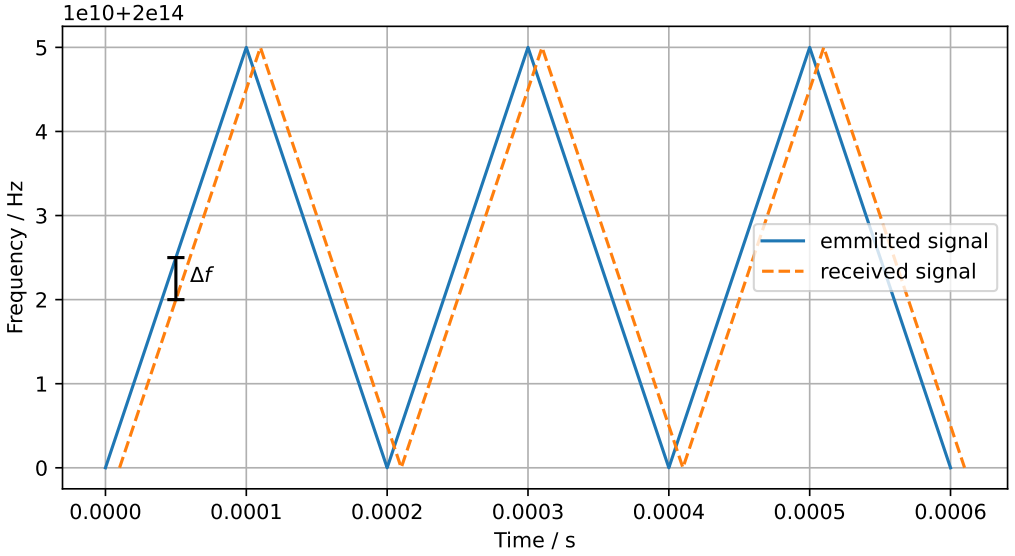

Figure 2: Emitted and receives LiDAR signal.

   (a) The sensor measures $\Delta f = 5\,\text{GHz}$. The signal emitted from the sender takes the time Δt to travel from the sender to O_1 and back. Give the formula to calculate Δt and calculate the result in nanoseconds (ns). 2 p.
   (b) Now, assume O_1 is moving towards the receiver. Draw an exemplary received signal in the diagram given in the solution sheet where the effect of the moving object is visible. 1 p.
   (c) Explain how $\Delta f(t)$ changes with a moving object. 1 p.
   (d) Explain the measurement principle of an *Amplitude Modulation* (AM) LiDAR. 1 p.
3. Satellite navigation
   (a) How many satellite signals are at least needed for position estimation? 1 p.
   (b) Name two reasons for position errors depending on satellite position and environment conditions. 1 p.

Exercise 3 *Tactile Sensing* (8 points)

Your goal is to design a haptic sensor system for a humanoid robot hand, which is inspired by the human skin.

1. What is a *mechanoreceptor*? Name the *four* main types in human skin. 3 p.
2. A well known example of robot skin is the skin of the iCub robot.
   (a) Name and explain the measurement principle of the iCub skin. 1 p.
   (b) Which robot abilities were made possible by the skin on the iCub robot. 1 p.
3. Explain how the Hall-effect can be used to measure the force applied to a surface. 2 p.
4. Why can it be beneficial for robotic grasping to embed cameras directly into the hand? 1 p.

Exercise 4 *Feature Extraction* (10 points)

1. Moravec Operator
   (a) How is an *Interest Point* defined by the *Moravec Operator*? 0.5 p.
   (b) The difference $D(u, v, s, t)$ – as introduced in the lecture – between the original and the moving image window is now being calculated using the sum of squared differences. Fill the table in the solution sheet with the feature type corresponding to the value of D. 1.5 p.
   (c) Name two disadvantages of the *Moravec Operator*. 2 p.
2. Harris Corner Detector
   (a) Explain briefly how the *Harris Corner Detector* addresses the disadvantages of the *Moravec Operator*. 1 p.
   (b) Given is the approximated image function of the *Harris Corner Detector*: 2 p.

$$I(u+s, v+t) \approx I(u, v) + \begin{pmatrix} I_x(u, v) & I_y(u, v) \end{pmatrix} \begin{pmatrix} s \\ t \end{pmatrix}.$$

   Name the type of approximation that is used in I. What are s, t, I_x and I_y? How can I_x and I_y be calculated?
   (c) Compute the eigenvalues of the image structure tensor 3 p.

$$M(u_1, v_1) = \begin{pmatrix} 10 & 10 \\ 10 & 10 \end{pmatrix}.$$

   Which type of image feature can be found at (u_1, v_1)? What do the eigenvectors represent in this case?

Exercise 5 *Scene Understanding* (10 points)

1. A robot needs to grasp objects from a box. The robot has an RGB-D camera and a grasp planner that generates possible grasps given a segmented point cloud of the object.

   (a) Consider YOLO and Mask R-CNN for this task. What is the input and output in the case of YOLO and Mask R-CNN? [2 p.]

   (b) Which of these methods would you use to acquire the point cloud of an object and why? [1 p.]

   (c) Now, the box can also contain textured objects with known 3D models. What kind of method can you now integrate to allow grasp planning based on 3D object models instead of point clouds? [1 p.]

   (d) As the objects are densely stacked in the box, there is the risk of objects collapsing and falling when grasping out of the box. What kind of scene representation needs to be extracted in order to find a manipulation order that prevents objects from falling? [1 p.]

2. After grasping an object from the box, the robot needs to place it based on given spatial relations to other objects in the scene. Consider the spatial relation *left of* between two objects A and B represented by axis-aligned bounding boxes (AABBs) in the robot's coordinate system, where $+x$ points to the right and $+z$ points up.

   (a) Give an example for a discriminative model of *left of*. [1 p.]

   (b) Give an example for a generative model of *left of*. [1 p.]

   (c) Explain how you would use *either* a discriminative *or* a generative model to find a suitable placing position of an object A to be *left of* another object B. [2 p.]

3. Name two advantages of *Graph Networks* over traditional machine learning methods that make them especially suitable for learning object relations. [1 p.]