KIT-Department of Informatics
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Exam Solution Sheet

Robotics III - Sensors and Perception in Robotics

October 7, 2022, 11:00 – 12:00

Family name:	Given name:	Matriculation number:
Bond	James	007

Exercise 1	8 out of 8 points
Exercise 2	9 out of 9 points
Exercise 3	8 out of 8 points
Exercise 4	10 out of 10 points
Exercise 5	10 out of 10 points

Total:	45 out of 45 points

	Grade: **1,0**

Exercise 1 *Internal Sensors* (8 points)

1. Absolute encoders: 2 p.

   - Range/Span: Since it covers a full resolution: $0°$ to $360°$ or $0 - 2\pi\,\mathrm{rad}$
   - Accuracy: Since the two least significant bits represent noise, effective accuracy is only 18 bit: $\frac{360\,°}{2^{18}\,\mathrm{bit}} \approx 0.001\,37\,°\,\mathrm{bit}^{-1}$

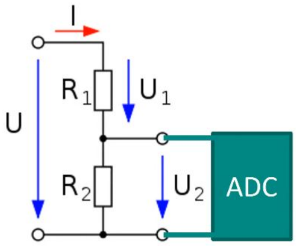
2. Analog sensor measurement:

   (a) Name: Voltage Divider 1 p.

   (b) Disadvantage: The voltage is measured with respect to ground (-) and hence resulting in only small changes in voltage for changes in resistance and therefore ADC output (voltage differences can not be easiliy amplified). 2 p.

   (c) Voltages: Recall the formula for voltage dividers from the lecture: 2 p.

$$R_2 = \frac{U_2}{U}(R_1 + R_2).$$



Rearanging the fomula from the lecture gives

$$U_2 = \frac{R_2}{R_1 + R_2} U.$$

For the voltage divider we need to look at the maximum and minimum resistance of the strain gauge:

$$U_{min} = \frac{1000\,\Omega}{9000\,\Omega + 1000\,\Omega} \times 1\,\mathrm{V} = 0.1\,\mathrm{V} \text{ and}$$

$$U_{max} = \frac{1000\,\Omega}{3000\,\Omega + 1000\,\Omega} \times 1\,\mathrm{V} = 0.25\,\mathrm{V}.$$

So the interval in which the ADC will measure is $[0.1, 0.25]\,\mathrm{V}$.

3. MEMS Accelerometer: 1 p.

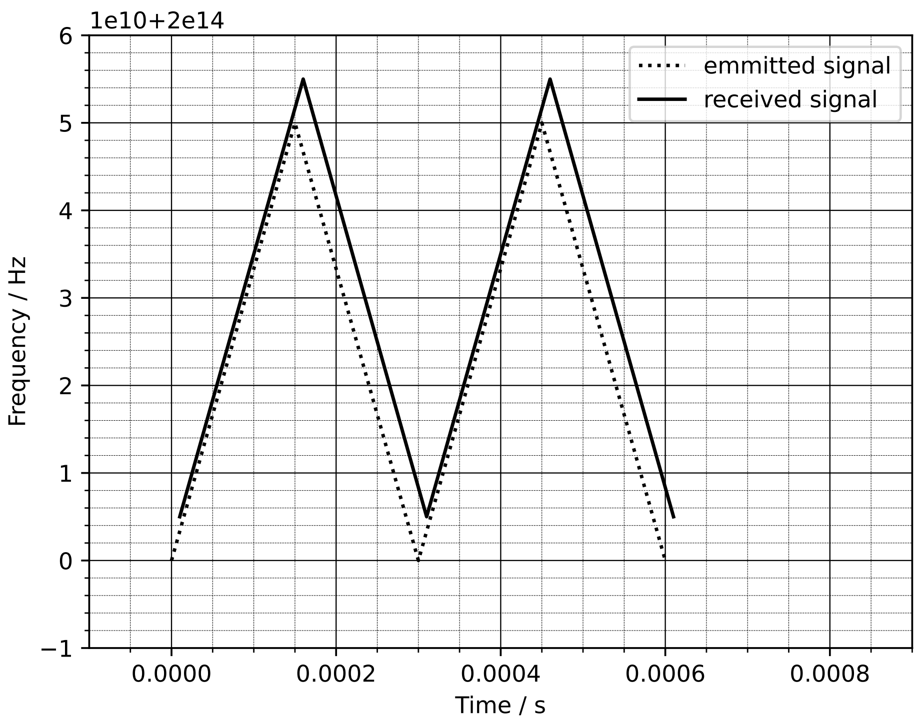
   - Capacitive: comb structures are suspended on elastic arms next to fixed comb structures, forming a capacitor. Accelerations will change the comb position and hence capacitance.
   - Resistive: A proof mass is suspended on elastic arms. Accelerations will move the proof mass and bend the arms, changing their resistance due to the piezoelectric effect. The resistance can then be measured.

Exercise 2 *External Sensors* (9 points)

1. Acoustic proximity sensor:
   (a) $f = 20\,\text{kHz}$ to $200\,\text{kHz}$
   (b) Principle: Time-of-Flight (ToF)
2. LiDAR
   (a) Δt:

$$\Delta t = \Delta f \cdot \frac{T}{f_1 - f_0} = 5\,\text{GHz} \cdot \frac{0.1\,\text{ms}}{5 \times 10^{10}\,\text{Hz}} = 1 \times 10^{-5}\,\text{s} = 10\,000\,\text{ns}.$$

   (b) Received signal for moving object:



   (c) $\Delta f(t)$ for moving object: The amplitude of Δf is no longer constant, it alternates when the receiver signal slope direction changes
   (d) AM LiDAR: AM sends a pulsed laser signal. Distance R can be measured using the time elapsed. Or: An alternative measurement principle for AM LiDAR uses the phase shift of the incoming and outgoing light signal
3. Satellite navigation:
   (a) Satellites: 4
   (b) Errors
      i. Atmospheric refraction
      ii. Multipath reflection

Exercise 3 *Tactile Sensing* (8 points)

1. Human Skin: 3 p.

   Mechanoreceptor:
   A **mechanoreceptor** is a sensory receptor that responds to mechanical pressure or distortion.

   Main types:

   - Pacinian corpuscles
   - Meissner's corpuscles
   - Merkel's discs / corpuscles / endings
   - Ruffini endings / corpuscles
   - (Free nerve endings)

2. iCub Skin:

   (a) Measurement Principle: The iCub skin has a modular structure that relies on **capacitive sensing**. When a force is applied to the skin, a soft dielectric is compressed. This changes the capacitance of the dielectric proportional to the compressed distance. 1 p.

   (b) Abilities : 1 p.

   - Collision Detection
   - Self-Calibration
   - Tactile-based Guidance
   - Tactile exploration

3. Hall-Effect for tactile Sensing: To measure the applied force to a surface with Hall-sensors, **small magnets** are embedded in a **soft material** . When a force is applied to the surface, the soft material is **deformed and the magnets move with the material**. The Hall-effect sensors, which are arranged in a matrix, measure the resulting **change in the magnetic field** that is proportional to the force applied. 2 p.

4. Benefit: Supplement external vision with local object information. 1 p.

Exercise 4 *Feature Extraction* (10 points)

1. Moravec Operator

   (a) Interest Point: An interest point is defined as a point where a sliding window filter has strong variations when moved in any direction. 0.5 p.

   (b) Difference $D(u, v, s, t)$ between the original and the moving image window: 1.5 p.

	Feature
Value of D for a translation in any direction is high	(Interest Point)
Value of D along a certain direction R is low, for translation orthogonal to R the value is high	along R
Value of D is for all translations low	(nearly)

   (c) Disadvantages of the Moravec Operator: 2 p.

   - Non-isotropic operator response (operator depends on the shift-direction)
   - Noisy operator response (window is binary and quadratic; corner have the same weight, which may cause error)
   - Strong response to a point on an edge (operator is sensitive to corner points, that have a slight deviation to the predefined shift-directions)
   - not normalized, uses SSD; not invariant to differences in illumination

2. Harris Corner Detector

   (a) Explanation: 1 p.

   - Compute eigenvalues of image structure tensor instead of using four predefined directions in the Moravec Operator

   (b) Image function of the Harris Corner Detector. 2 p.

   - Approximation: (First-order) Taylor series expansion
   - Symbols:
     - s, t: shift of image point (within sliding window)
     - I_x, I_y: directional derivatives

   - How can I_x and I_y be calculated?
     $\rightarrow$ I_x, I_y can be calculated with Prewitt- or Sobel operator.

   (c) • Eigenvalues: Can be computed by solving $det(M - \lambda I) = 0$. 3 p.

$$
\begin{aligned}
\lambda_{\pm} &= \frac{1}{2}[(m_{11} + m_{22}) \pm \sqrt{4m_{12}m_{21} + (m_{11} - m_{22})^2}] \\
&= \frac{1}{2}[(10 + 10) \pm \sqrt{4 \cdot 10 \cdot 10 + (10 - 10)^2}] \\
&= \frac{1}{2}[20 \pm 20] = 10 \pm 10
\end{aligned}
$$

$\rightarrow \lambda_1 = 0, \lambda_2 = 20$

- Image feature: edge as $\lambda_2 \gg \lambda_1$
- Eigenvectors: indicate the direction of the largest / smallest change or: direction of edge

Exercise 5 *Scene Understanding* (10 points)

1. (a) 2 p.
   - Input of YOLO: RGB image
   - Output of YOLO: Bounding boxes of objects
   - Input of Mask R-CNN: RGB image
   - Output of Mask R-CNN: Pixel-wise segmentation (and bounding boxes) of objects

   (b) Mask R-CNN, because you need pixel-wise segmentation to get an accurately segmented point cloud. 1 p.

   (c) 6D pose estimation 1 p.

   (d) Support relations / support graph 1 p.

2. (a) Example: A is left of B if $\max(x_A) < \min(x_B)$, where $\max(x_A)$ and $\min(x_B)$ are the highest and lowest point of A and B along the x-axis, respectively. 1 p.

   Note: A discriminative model *decides* whether the relation between two given objects is present or not.

   (b) Example: A probability distribution / multivariate Gaussian / Gaussian × von Mises / polar distribution over points in the plane where A can be placed so it is left of B / where points roughly left of B have a high likelihood / centered at 180° from the $+x$ direction. 1 p.

   Note: A generative model can *generate* suitable placing locations given the desired relation.

   (c) Potential solutions: 2 p.
   - Discriminative: Sample all possible positions, use the model to decide which are *left of*, and select a feasible one .
   - Generative: Use the model to generate suitable positions, and select a feasible one.
     Note: “Select a feasible one” can comprise checking for collisions, reachability, etc.

3. Advantages of Graph Networks: 1 p.
   - Arbitrary number of entities / objects.
   - Independent of order of entities / objects.