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

Exam Question Sheet

Robotics II: Humanoid Robotics

on September 24, 2020, 09:00 – 10:00

- 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 exercise. Answers on sheets submitted separately will not be counted.
- Apart from writing utensils, no other aids are permitted during the exam. Please use a permanent pen with black or blue ink. Answers written with a pencil, red or green ink will not be counted. 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 exercise, please enter only the final results in the answer sheets. You can use the back sides of the exercise 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 an exercise 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 *Building Humanoid Robots* (7 Points)

1. Name four humanoid robots from different research institutes or companies that were presented in the lecture. 2 p.
2. Why is it important to build robots with a human appearance and human-like behavior? Name two advantages and two disadvantages of humanoid robots. 2 p.
3. To design humanoid robots, models of the human body are useful. In the lecture, we introduced the Master Motor Map (MMM). Which models of the human body are represented by the MMM? 3 p.

Exercise 2 *Grasping Synergies and Eigengrasps* (8 Points)

You have the task to develop a two-fingered robot hand (gripper) with two active rotational joints in each finger. For the hand control, you want to use the concept of *postural synergies*. Therefore, you derive eigengrasps for your hand as described in the paper

> *M. Ciocarlie, C. Goldfeder and P. Allen, Dimensionality reduction for hand-independent dexterous robotic grasping, IEEE/RSJ International Conference on Intelligent Robots and Systems (IROS), 2007.*

For your hand, you obtain the following two eigengrasps $\mathbf{e}_1$ and $\mathbf{e}_2$:

$$\mathbf{e}_1 = \begin{bmatrix}0.5 & 1.0 & 0.75 & 0.5\end{bmatrix}^T, \quad \mathbf{e}_2 = \begin{bmatrix}0.6 & 0.7 & 0.6 & 0.5\end{bmatrix}^T.$$

The rotational joints of your hand are actuated by tendons. The eigengrasps shall be implemented by an underactuated mechanism as described in the paper

> *C. Y. Brown and H. Asada, Inter-Finger Coordination and Postural Synergies in Robot Hands via Mechanical Implementation of Principal Components Analysis, IEEE/RSJ International Conference on Intelligent Robots and Systems (IROS), 2007.*

1. Draw a mechanism that allows you to actuate all four joints by one motor according to the first eigengrasp $\mathbf{e}_1$. Label the motor M and the tendons for the four joints t_1 to t_4. Also indicate the direction the tendons are pulled when the hand is closed according to the first eigengrasp. 2 p.
2. Another tendon mechanism for the implementation of eigengrasps is shown in Figure 1. Explain its functionality using the annotations in the figure and provide the mathematical formula describing the correlation between $y_{i,1,j}$, $y_{i,2,j}$ and $z_{i,j}$. 1 p.

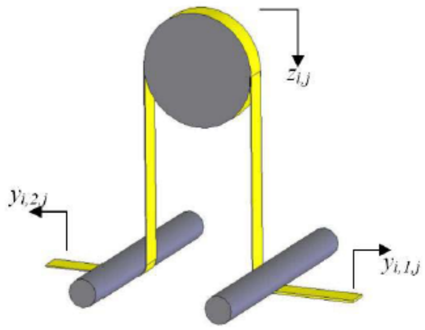

Figure 1: Tendon mechanism for the mechanical implementation of eigengrasps

3. By using both eigengrasps you want to close the hand to the hand configuration **3 p.**

$$\mathbf{p} = \begin{bmatrix} 0.75 & 1.25 & 0.975 & 0.7 \end{bmatrix}^T$$

   Determine the amplitude vector **a** that realizes the desired hand configuration. Please provide a detailed calculation of your solution.

4. When actuating your hand according to the two eigengrasps, you want to apply the concept of *Soft Synergies*. Shortly explain this concept and describe which actuation problem you will solve by using it. **2 p.**

Exercise 3 *Grasping* (10 Points)

The humanoid robot ARMAR-6 should clean a table with several objects of different shape, color and texture placed on it. Most of the objects are unknown to the robot. The robot is equipped with a RGB-D camera.

1. In the given scenario, the robot does *not only* encounter *unknown objects*. In the lecture, we discussed *two other* object classes.

   (a) Name the two other object classes. **1 p.**

   (b) What knowledge does the robot have about the objects for each of the other two classes? **1 p.**

   (c) For grasping objects of the other two object classes, you have access to an object database containing possible grasps. Describe your approach to grasp objects when such information is available. **2 p.**

2. The majority of objects in the given scenario are unknown to the robot. In the lecture, we discussed different approaches to address the problem of grasping unknown objects. In one of the approaches, shape approximation is used to generate grasp hypotheses. Given the segmented point cloud, which steps are necessary to grasp unknown objects using shape approximation? **2 p.**

3. You want to apply machine learning methods (e. g. neural networks) to grasp unknown objects based on low-level features extracted from an RGB-D point cloud.

   (a) Name two ways for generating training data to learn a model for grasping unknown objects. 1 p.

   (b) Draw a complete block diagram of your approach to grasp unknown objects and describe how grasp hypotheses are generated. 3 p.

Exercise 4 *Active Perception* (8 Points)

1. Discuss the difference between *classic Computer Vision, Active Vision* and *Interactive Perception.* 2 p.

2. In lecture, we discussed the paper: 3 p.

   Schiebener, D., Ude, A. and Asfour, T., Physical Interaction for Segmentation of Unknown Textured and Non-textured Rigid Objects, IEEE International Conference on Robotics and Automation (ICRA), 2014

   In this work, three different heuristics are used to generate initial object hypotheses based on the camera images in a cluttered scene. Name these three heuristics.

3. Haptic exploration is a promising way to complete knowledge about object shape. In the lecture, we discussed the paper: 3 p.

   Ottenhaus, S., Weiner, P., Kaul, L., Tulbure, A., Asfour, T., Exploration and Reconstruction of Unknown Objects using a Novel Normal and Contact Sensor, IEEE/RSJ International Conference on Intelligent Robots and Systems (IROS), 2018

   The paper introduces an Information Gain Estimation Function ψ defined as

   $$\psi = \psi_1 \cdot \psi_2 \cdot \psi_{3,pos} \cdot \psi_{3,rot}$$

   with the following cost functions:

   $$\psi_1 = \min_{c \in C} \left(1 - \exp\left(-\frac{||x-c||^2}{\sigma^2}\right)\right) \qquad \psi_2 = \exp\left(-\frac{(||x-c|| - \mu)^2}{\sigma^2}\right)$$

   $$\psi_{3,pos} = \frac{1}{\mathrm{Path}(r,x)} \qquad \psi_{3,rot} = \exp\left(-\frac{\sin^2\left(\frac{\arccos(r_n \cdot x_n)}{2}\right)}{\sigma^2}\right)$$

   Explain the purpose of the different costs functions $\psi_1, \psi_2, \psi_{3,pos}, \psi_{3,rot}$. What would be the result of the exploration if only ψ_1 was used?

Exercise 5 *Imitation Learning* (12 Points)

1. What are *mirror neurons* and which role do they play in imitation learning? 1 p.
2. A schematic overview of the *Imitation Learning Cycle* is shown in Figure 2. 2 p.

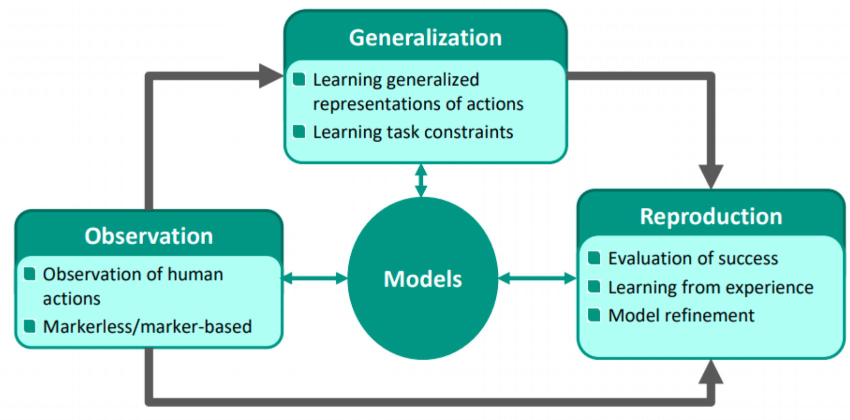

Figure 2: Imitation Learning Cycle

   Name and explain in details two challenges associated with different blocks of the cycle for building such an imitation learning system.

3. Which information should be extracted from human demonstration to build semantic representations of the demonstrated task? 1 p.
4. In the lecture, we discussed task constraints as important information for task understanding. Name two types of task constraints and discuss how you would represent these constraints. 2 p.
5. For segmentation of human demonstrations, we introduced a two-level hierarchical method in the lecture. Which criteria and segmentation methods can be used on the different levels? 2 p.
6. Dynamic Movement Primitives (DMP) provide an efficient way to represent robot actions. How is a DMP defined? Give the mathematical formula of the transformation and canonical system and describe the different terms. 3 p.
7. Can DMPs be learned from multiple demonstrations? Provide an explanation of your answer. 1 p.