KIT-Department of Informatics
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Exercise sheets for the exam

Robotics II: Humanoid Robotics

on January 25, 2019, 18:00 – 19:00

- 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 *Grasping* (10 Points)

1. Complete the missing category labels (1) to (6) of the *Cutkosky Grasp Taxonomy* depicted in the solution sheets. 3 P.

The lecture discussed the paper *„I. M. Bullock, R. R. Ma, A. M. Dollar, A Hand-Centric Classification of Human and Robot Dexterous Manipulation, IEEE Transactions on Haptics, 6(2):129-144, 2013“*. **Questions 2, 3 and 4 refer to this paper.**

2. Explain the difference between a *grasp taxonomy* (as proposed by Cutkosky) and a *manipulation taxonomy* (as proposed by Bullock et al.). 1 P.
3. The Bullock Taxonomy distinguishes between *prehensile* manipulation tasks and *non-prehensile* manipulation tasks. Define the term *prehensile manipulation*. 1 P.
4. Explain the difference between the categories *motion* and *motion at contact*. 1 P.

The lecture discussed the paper *„J. Bohg, A. Morales, T. Asfour and D. Kragic, Data-Driven Grasp Synthesis - A Survey, IEEE Transactions on Robotics, pp. 289-309, vol. 30, no. 2, 2014“*. **Questions 5 and 6 refer to this paper.**

5. Many approaches to robotic grasp synthesis maintain a *grasp database*. Which information is typically stored in this database? 1 P.
6. Explain if and how a grasp database is used for grasping 3 P.
   (a) known objects,
   (b) familiar objects,
   (c) unknown objects.

Exercise 2 *Grasp Synergies* (7 Points)

The lecture discussed 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"*. **Questions 1, 2 and 3 refer to this paper.**

1. Assume a simple three-fingered gripper with one rotational, individually actuated joint in each finger. Figure 1 shows the mechanical implementation of the first *eigengrasp* for this gripper. Compute the corresponding vector $\mathbf{e}_1 = \begin{bmatrix} y_{11} & y_{21} & y_{31} \end{bmatrix}^T$. 1 P.

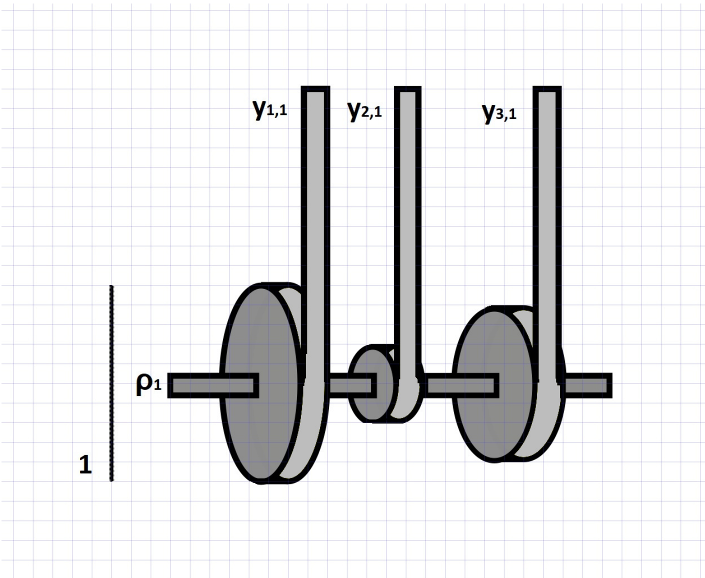

Figure 1: Mechanical implementation of an eigengrasp $\mathbf{e}_1$

2. Draw a mechanism for controlling the first finger joint based on two eigengrasps $\mathbf{e}_1 = \begin{bmatrix} y_{11} & y_{21} & y_{31} \end{bmatrix}^T$ and $\mathbf{e}_2 = \begin{bmatrix} y_{12} & y_{22} & y_{32} \end{bmatrix}^T$. The mechanism should realize: 2 P.

$$z_1 = \frac{1}{2}(y_{11} + y_{12}).$$

3. Assume the same gripper is controlled by the two eigengrasps $\mathbf{e}_{1,new}$ and $\mathbf{e}_{2,new}$: 4 P.

$$\mathbf{e}_{1,new} = \begin{bmatrix} 0.9 & 0.5 & 0.6 \end{bmatrix}^T, \quad \mathbf{e}_{2,new} = \begin{bmatrix} 0.2 & 1.0 & 0.8 \end{bmatrix}^T.$$

Determine the amplitude vector $\mathbf{a}$ that realizes the desired hand configuration $\mathbf{p}$ using $\mathbf{e}_{1,new}$ and $\mathbf{e}_{2,new}$:

$$\mathbf{p} = \begin{bmatrix} 1.4 & 3 & 2.6 \end{bmatrix}^T.$$

Please provide a detailed calculation of your solution. *Hint: Keep in mind that the addition of both eigengrasps is scaled by 0.5 according to Question 2.*

Exercise 3 *Active Perception* (8 Points)

1. Active Visual Search in general is an NP-complete problem. In order to find approximate solutions in a timely manner, the lecture presented an approach which decomposes the problem into two sub-problems: *restriction of the search space* and *validation of object candidates*.

   (a) Which visual inputs are used for each sub-problem? 1 P.

   (b) Explain the method for the restriction of the search space. 1 P.

   (c) Explain the method for the validation of object candidates. 1 P.

2. The lecture presented a method for saccade generation using saliency based on the Bayesian Strategy.

   (a) What is the goal of saccade generation? 1 P.

   (b) How is saliency represented in the aforementioned method? 1 P.

3. The lecture introduced the *transsaccadic memory* as an approach to achieve consistency of scene and memory.

   (a) Name the two layers in the transsaccadic memory and explain the differences between them. 2 P.

   (b) What does consistency of scene and memory mean? 1 P.

Exercise 4 *Haptics* (12 Points)

The lecture discussed the paper *„A. Bierbaum, M. Rambow, T. Asfour and R. Dillmann, Grasp Affordances from Multi-Fingered Tactile Exploration using Dynamic Potential Fields, IEEE/RAS International Conference on Humanoid Robots, 2009“.*
All questions in Exercise 4 refer to this paper.

1. What is the purpose of the potential field? Which regions are assigned to attractive potentials and which regions to repellent potentials? [2 P.]

2. Specify the equation for the total potential field and briefly explain the individual components. [2 P.]

3. Which geometric features are derived from the obtained point cloud? [1 P.]

4. All calculated features are filtered using a geometric pipeline. Name the four criteria that are applied in this pipeline. [2 P.]

5. Specify the equation for the virtual force $F(\mathbf{x})$, resulting from the potential field. [1 P.]

6. Calculate the force $F(\mathbf{x})$ for one repulsive potential $\Phi_r(\mathbf{x})$ at position $\mathbf{p}$, defined as follows: [1 P.]

$$\Phi_r(\mathbf{x}) = \|\mathbf{x} - \mathbf{p}\|^{-2}$$

Hint:

$$\nabla \left(\frac{1}{\|f\|^2} \right) = -\frac{2f}{\|f\|^4}$$

7. In a two-dimensional example ($\mathbf{x} \in \mathbb{R}^2$), assume two repulsive potentials $\Phi_{r,1}$ and $\Phi_{r,2}$ defined as follows: [3 P.]

$$\Phi_{r,1}(\mathbf{x}) = k_1 \left\| \mathbf{x} - \begin{bmatrix} 3 \\ 4 \end{bmatrix} \right\|^{-2}, \qquad \Phi_{r,2}(\mathbf{x}) = k_2 \left\| \mathbf{x} - \begin{bmatrix} -3 \\ 4 \end{bmatrix} \right\|^{-2},$$

with the scaling factors $k_1 = 1$ and $k_2 = 3$. Compute the virtual forces $F_1(\mathbf{x}), F_2(\mathbf{x})$ induced by each repulsive potential and the total force $F(\mathbf{x})$ at position $\mathbf{x} = \mathbf{0}$. Please provide a detailed calculation of your solution.

Hint: $5^4 = 625$

Exercise 5 *Imitation Learning* (8 Points)

1. Explain the *correspondence problem* in imitation learning. 1 P.
2. What are *mirror neurons*? 1 P.
3. Explain passive and active imitation. 2 P.
4. Explain the idea of the *Master Motor Map (MMM).* 1 P.
5. The MMM reference model contains a kinematic and dynamic model of the human body. Which parameters does the kinematic model contain? Which parameters does the dynamic model contain? 3 P.