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Exam Solution Sheet

Robotics II: Humanoid Robotics

am January 16, 2020, 17:30 – 18:30

Family name:	Given name:	Matriculation number:
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Exercise 1	7 out of 7 points
Exercise 2	7 out of 7 points
Exercise 3	12 out of 12 points
Exercise 4	8 out of 8 points
Exercise 5	11 out of 11 points

Total:	45 out of 45 points

	Grade: **1.0**

Exercise 1 *Humanoid Robots*

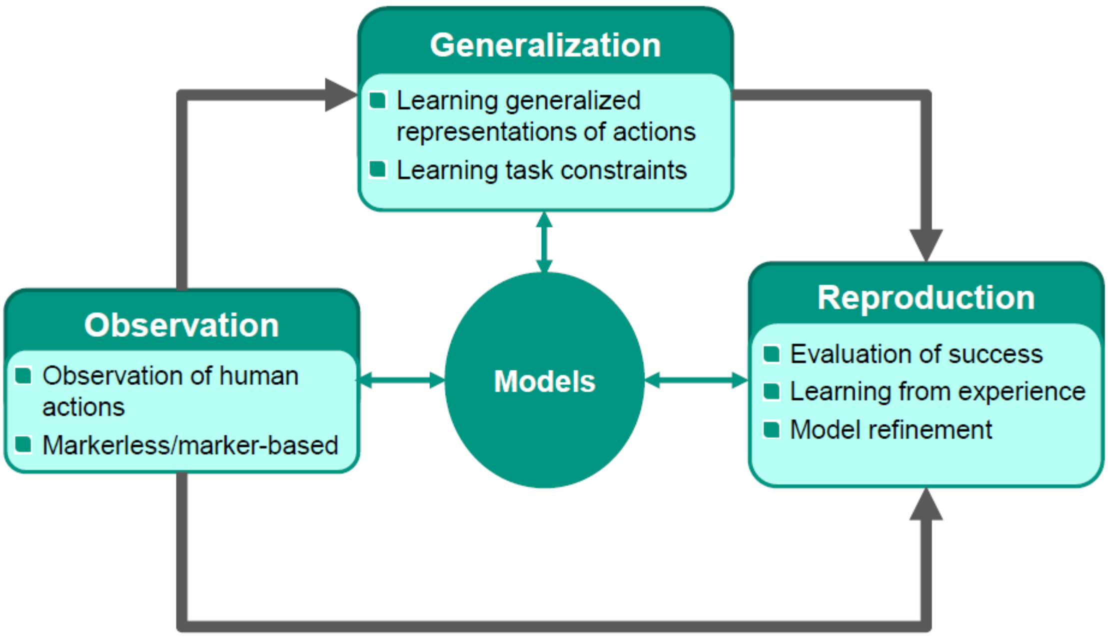
1. Motivation:

   - Versatility: We need robots that can perform a wide variety of tasks, that can (inter-)act in made-for-human environments and can use made-for-human-tools
   - Predictability of robot actions: Motion behavior of robots with human-like morphology, i.e. humanoid robots, allows humans to better predict the robot actions. This leads to intuitive and fluent human-robot interaction.
   - Acceptance: Human-like appearance may support acceptance and intuitive human-robot interaction but the Uncanny Valley tells us something different!

2. "Uncanny Valley":

   - The uncanny valley is the region of negative emotional response towards robots that seem "almost" human. (Movement amplifies the emotional response).
   - The uncanny valley could influence the design of future humanoid robots to the extent that their static appearance as well as their motion generation only resemble or exactly imitate the appearance and movements of humans

3. Diagram:



Exercise 2 *Grasping Synergies and Eigengrasps*

1. Postural Synergies:

    - Postural synergies are the correlation of degrees of freedom in patterns of more frequent use.
    - Human grasp motions were gathered from human subjects grasping 57 imaginary objects.
    - The hand movement was observed and measured by 15 sensors embedded in a glove.
    - Each posture is approximated by a 15 DoF hand model.

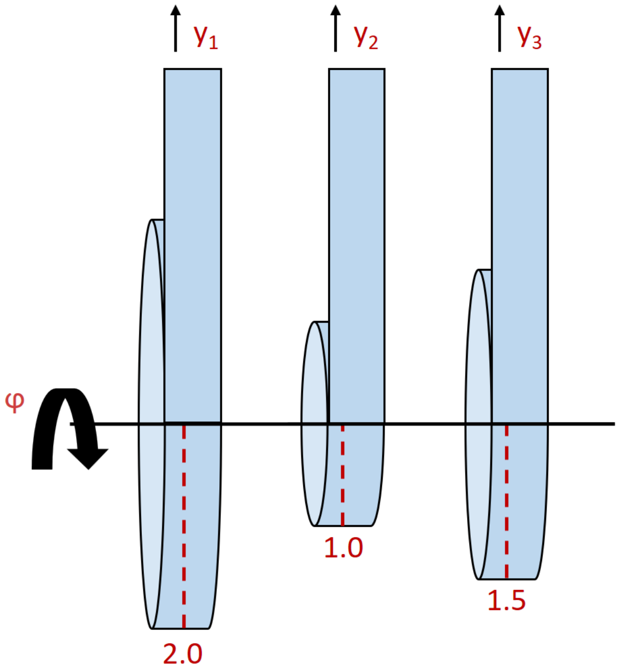
2. Higher Order Components:

    - The experiment shows that higher order components do not simply represent noise and hence it is possible that the hand postures associated with a few of the objects might be best represented by higher components.
    - The higher order components do not seem to contribute substantially to any one particular hand posture.
    - Nevertheless the higher order components contribute substantially to the information transmitted.
    - They control the hand shape on a finer level affecting all joints.
    - Higher order components allow the fine adaptation of grasps on the object shape.

3. Synergy Concept:
   Soft Synergy Model

    - It uses a combination of two force fields to control the physical hand.
    - One field is attracting the physical hand towards a virtual hand (which is moving on the synergy manifold).
    - The other field is repelling the hand from penetrating the object.
    - The dynamical equilibrium between those two fields is found depending on the stiffness of the hand actuation and control system.

4. Synergy Mechanism:



Exercise 3 *Grasping*

1. (a) The missing step is **grasp synthesis**.

   (b) Pipeline:

   Data: Depth image

   ↓

   S1: Scene segmentation and feature extraction

   ↓ Data: segmented object [point cloud]

   S2: Grasp synthesis

   ↓ Data: Grasp hypothesis [6D pose]

   S3: Path planning

   ↓ Data: Trajectory

   S4: Grasp execution

(c) Which steps have to be changed in your pipeline?

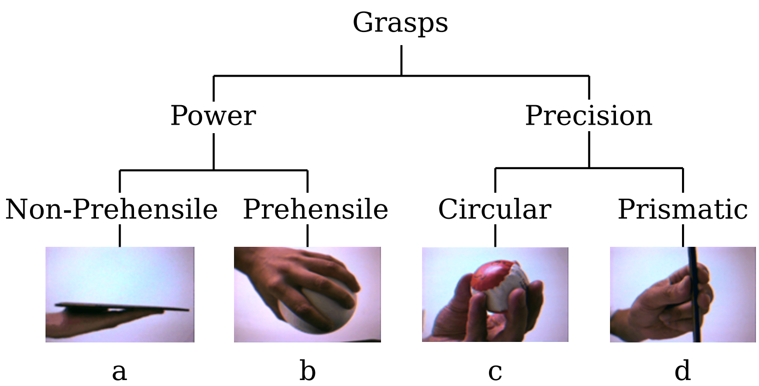
Step 1 and step 2 have to be replaced. New Steps:

- Object detection: Find the known objects in the scene
- Pose estimation: Estimate the 6D pose for all known objects
- Grasp selection: Select one or multiple grasps from a grasp database.

2. Possible sources of training data:

- Learning by demonstration: A human teacher demonstrates the task while the robot observes.
- Training data collection on the target system: The robot tries different policies and updates the policies according to the results.
- Training data generation in simulation: The robot and scene is simulated in a virtual environment. Actions and respective outcomes are stored as training examples.
- Hand-labeled data: Create a dataset by hand labeling a set of inputs with the respective outputs.

3. Example taxonomy solution:



4. Applications for taxonomies:

- Benchmark to test robot hand abilities
- Simplify grasp synthesis
- Inspire hand design
- Optimization of synergies: Formulation of dexterity/functionality as number of achievable grasps for maximization
- Guide autonomous grasp selection

Exercise 4 *Active Perception*

1. Interactive Perception

   (a) **S**: Multi-model sensory input

   A: Executed action(s)

   t: Time

   (b) Benefits:

   - Generation of new sensory input
   - Using the regularity in $S \times A \times t$ to predict, update world state
   - Prior knowledge makes interpretation easier
   - Learn the regularity $S \times A \times t$

2. Segmentation

   (a) Next Step: Re-localization of the object hypotheses (+ Transformation estimation)

   (b) Steps :

   i. Find the closest point correspondences

   ii. Calculate transformation T that minimizes the mean squared distance of the correspondences

   iii. Apply T to all points in the matching set

   Improvement: Use weighted color and cartesian distance in step 1.

3. Haptics

   Proprioception: Perception of position and movement of the limbs

   Tactile: Sensation arising from stimulus to the skin

   Relation: Haptics = Proprioception + Tactile

Exercise 5 *Imitation Learning*

1. Three motivations:

   - PbD is a powerful mechanism for **reducing the complexity of search spaces for learning**. When observing either good or bad examples, one can reduce the search for a possible solution, by either starting the search from the observed good solution, or conversely, by eliminating the bad ones from the search space.
   - PbD offers an **implicit means of training a robot**, such that **explicit and tedious programming by a human user can be minimized or eliminated**
   - Studying and modeling the **coupling of perception and action**, which is at the core of imitation learning, helps us to understand the mechanisms by which the self-organization of perception and action could arise during development.

2. Diagram:

   1. Spatial information
   2. Object recognition
   3. 3D movement (Teacher + Object)
   4. Movement recognition
   5. Learning system
   6. Movement primitive 1
   7. Movement primitive 2
   8. Movement primitive 3
   9. Movement primitive n-1
   10. Movement primitive n
   11. Movement generation
   12. Inverse kinematic
   13. Motor command generation

3. Segmentation principles and their approaches:

   - Fod et al.:
     ZVC (Zero-Velocity-crossings): 1. Label all ZVC, 2. Segment if the movement is significant and at least two joints have a ZVC within T sec
   - Barbic et al.:
     PCA (Principal-component-analysis): Use sliding window and PCA to identify dimensionality r. Calculate derivative $d_i = e_i - e_{i-l}$ and segment if d_i is more than three standard deviations from average
   - Lin et al.:
     ML (Machine Learning): Train a classifier (e.g. k-Nearest Neighbors, RBF, SVM, ANN, ...). Segment if binary classification result says so.

- Wächter et al.:
  Object Relations and Motion characteristics: Two levels of segmentation (Hierarchical segmentation): Trajectory level segments the motion recursively into most distinctive parts based on motion characteristic (e.g. acceleration profile). Object relations level segments the motion based on contact/non-contact rules.

4. Common key points:

   S_1, S_4 and S_5 are common key points (shared on every observation)