Exam for DD2410 - Introduction to robotics 2020-10-23

With Answer Key

Permitted aids: Paper, pencil, eraser

Notes:

Answer on the separate answer sheet. Write legibly, ambiguous answers will be given 0 points.

Each question can be awarded a maximum of 4 pts. If a question can be awarded partial credit, this will be explicitly described in the question.

Maximum possible score on the exam is 100 pts. Any bonus points will be added to the exam score.

A passing grade requires a sum of exam score and bonus points of at least 80 pts.

A sum of exam score and bonus points of at least 70 pts will be graded as Fx, which means that the student is given the opportunity of completing the grade to a passing grade after passing an oral exam.

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Question 1:

Assuming that we know the DH parametrization for a 6 DoF manipulator with no singularities in its workspace, which of the following can we be sure to be able to calculate? Mark each answer with **true** or **false**.
(0.5 pt. for each correctly marked answer)

a) The closed form forward kinematics.

b) An arbitrarily precise numerical approximation of the forward kinematics.

c) The closed form inverse kinematics.

d) An arbitrarily precise numerical approximation of the inverse kinematics.

e) The differential kinematics.

f) The inverse differential kinematics.

g) The forward dynamics.

h) The inverse dynamics.

Question 2:
Given a 7 DoF manipulator (e.g. Kuka LBR iiwa, see image below) in a non-singular configuration, in how many degrees of freedom can the translational velocity of the end effector be controlled?
(4p for correct answer.)

Question 3:
Mark the generally **true** or **false** statements regarding homogeneous coordinates and transforms.

Assume:

p_i: point p in frame i

$\dot{p}_i$: time derivative of point p in frame i

${}^aT_b$: coordinate transform (homogeneous transformation) between frames a and b

(1p per correctly classified statement.)

a) $p_a = {}^aT_b\, p_b$

b) $p_b = ({}^aT_b)^T\, p_a$

c) $\dot{p}_a = {}^aT_b\, \dot{p}_b$

d) $p_a = {}^aT_x\, {}^xT_b\, p_b$

Question 4:

For each of the following scenarios, suggest the most appropriate actuator type. Note that the same type may be used in multiple answers. Choose from:

1) Pneumatic cylinders **2) Hydraulic cylinders**
3) Brushless electric motors **4) Electric stepper motors**
(1 pt for each correct answer)

a) An animatronic robot that children can touch at a museum
b) A cheap sketch robot that uses a pen to draw pixel graphic images from jpg files
c) A rescue robot for clearing out debris from collapsed buildings
d) A high performance industrial robot that picks car parts from a bin in a factory.

Question 5:

Mark all statements regarding the inverse kinematics of robotic manipulators as either True or False.

(1p per correctly classified statement.)

a) There can exist multiple valid joint configurations that solve the inverse kinematic problem for a given pose in cartesian space.
b) Solutions to the inverse kinematics problem can include configurations that make up a kinematic singularity.
c) Assuming a 6 DoF serial manipulator, and no singularities within a bounded spheroid around the target pose, the closed form inverse kinematics can always be found by inverting the forward kinematics.
d) Given a manipulator with at least 6 DoF, there exists inverse kinematics solutions for all poses in Cartesian space.

Question 6:

What is the minimum number of joints required for a robot to potentially have kinematic singularities in its workspace? State your answer as a number, or answer 'impossible' if it is never possible, regardless of the number of joints.

(The correct answer gives 4 p)

Question 7:

What is the minimum number of contact points necessary to achieve a force closure on a sphere? (Correct answer gives 4 p)

Answer with a number.

Question 8:

Assume that we have a DH description of the 7 DoF KUKA robot pictured in question 2. Assume that we also have recorded accurate, high-frequency measurements of joint angles, joint velocities, and joint torques. Assume that the robot has been moving randomly through a large portion of its workspace, at times close to its dynamical limits, but never touching anything. Which of the following quantities should we be able to calculate from the recorded values?
(Each correctly marked alternative gives 1 p)

Answer with **true/false.**

a) The total distance traveled by the end effector.
b) The inertial properties of all the moving links.
c) The total amount of energy consumed by the robot.
d) The total mass of the robot.

Question 9:

Which of the following statements regarding kinematic singularities for a robot are true? Mark each answer with true/false.
(2p per correctly classified statement.)

a) When a manipulator is in a singular configuration the maximum possible velocity is zero, so it is inherently safe to interact with.
b) One of the benefits of redundant manipulators (like the robot in Question 2) is that they can always use the redundant degree(s) of freedom to avoid any kinematic singularities.

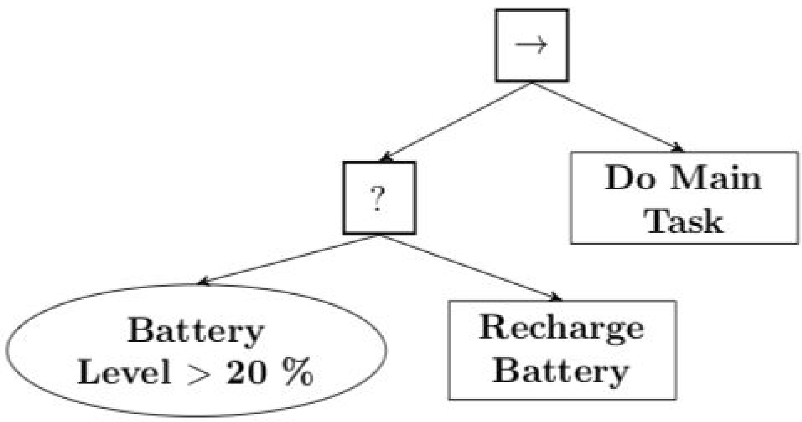
Question 10:

Sort the following numerical computations in order of **increasing** computational cost for the general case. Assume that we only have a DH description of the robots.
(Complete list in correct order gives 4 p)

a) Computing the **forward kinematics** of an RRRRRR (6 DoF) serial link manipulator.
b) Computing the **inverse kinematics** of a PPP cartesian gantry robot.
c) Computing the **inverse kinematics** of an RRRRRR (6 DoF) serial link manipulator.
d) Computing the **inverse differential kinematics** for an RRRRRR (6 DoF) serial link manipulator.

Question 11:

Mark the following statements regarding the behavior tree below as either true or false: (2p per correctly classified statement.)



a) If we add "... AND not re-charging" to the condition, fast switching is less likely.

b) The battery is only recharged if the condition is False

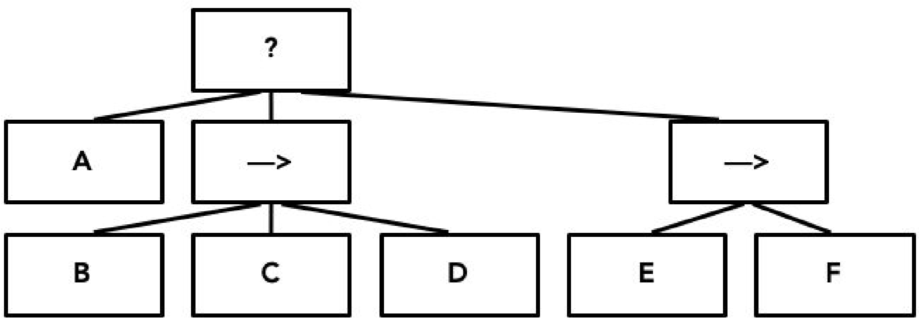
Question 12:

Mark the following statements regarding behavior trees as either **true** or **false**: (1p per correctly classified statement.)

a) If all conditions in a behavior tree return Failure, then the top node must also return Failure
b) A condition has fewer possible return statuses then an action.
c) A condition cannot return Failure
d) If the 2nd child of a Sequence returns running, the 1st child must have returned Success.

Questions 13:

Consider the backward chained Behavior Tree below. The overall objective is to get the object to the goal area. Write the numbers 1 - 6 for the components below at the corresponding letter so that the design makes sense. (4p for a correct answer)



1. Object in Gripper (condition)
2. Object on the Floor (condition)
3. Object in Goal Area (condition)
4. Robot in Goal Area (condition)
5. Drop Object (action)
6. Push Object (action)

Question 14:

Given the planning problem defined by X and U below. Each correct answer gives 2p.

This will be expressed using Formulation 2.1. Let X be the set of all integer pairs of the form (i, j), in which $i, j \in \mathbb{Z}$ ($\mathbb{Z}$ denotes the set of all integers). Let $U = \{(0,1), (0,-1), (1,0), (-1,0)\}$. Let $U(x) = U$ for all $x \in X$. The state

a) What is the min number of transitions needed to get from (0,0) to (2,3)?

b) If, instead *U = {(x,y) x,y in Z such that x=0 or y=0}*, with Z the same as in a above, what would be the minimum number of transitions needed to get from (0,0) to (2,3)?

Question 15:

A common approach in path planning is to stop once you find a feasible solution. For which of these algorithms does it make sense to keep running the algorithm after a feasible solution is found? (several options might be correct, 4p for a completely correct answer)

a) RRT
b) RRT*
c) Dijkstra’s algorithm
d) A*

Question 16:

For each alternative below, mark if it is true or false, regarding a differential drive robot. (2p per correctly classified statement.)

a) Unless you have encoders on both wheels you cannot estimate the dead reckoning motion in any way.
b) If you have wide wheels (think rear wheel of a Formula 1 car), odometry is, in general, more accurate than if you have thin wheels (think bicycle wheel).

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Question 17:

Mark each statement about multi-rotor aerial vehicles as true or false. (2p per correctly classified statement.)

a) The can glide without motor power well
b) They are can hold still in air quite well

Question 18:

Mark each of the following statements as **true** or **false** regarding a walking robot. (2p per correctly classified statement.)

a) The gait describes the walking pattern, i.e., the order in which legs are lifted and moved.
b) Compared to using wheels, the main advantage of legs are, in general, lower mechanical complexity and lower energy consumption.

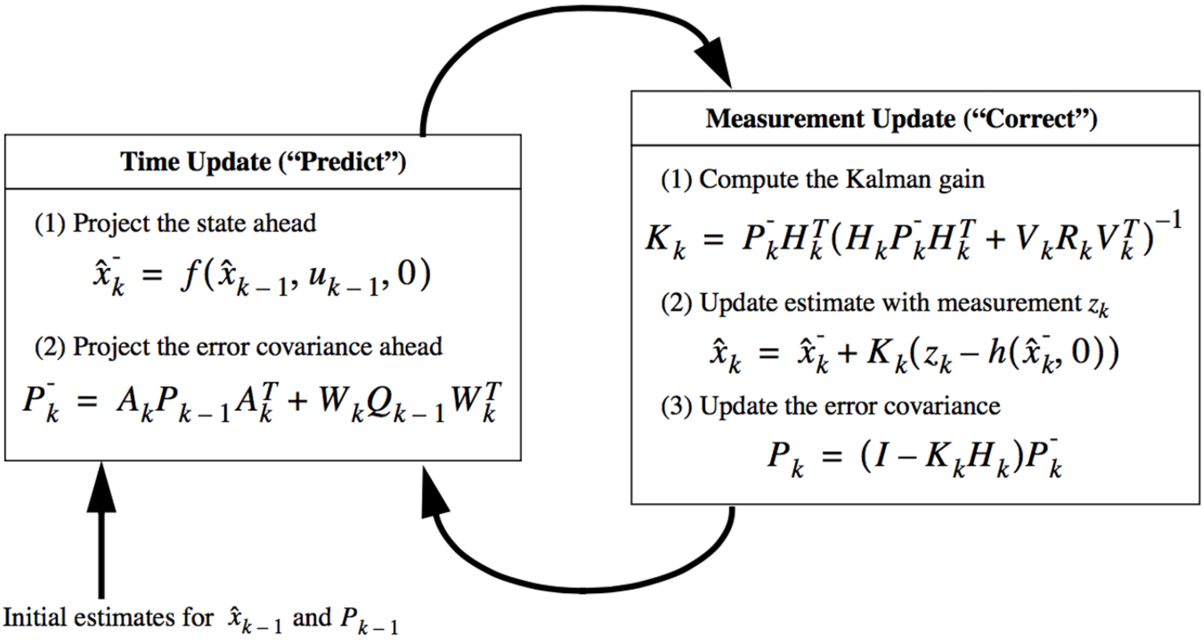
Question 19:

Which of the following sensors allows us to measure distance traveled, either directly or by comparing two consecutive sensor readings. Mark each alternative as true or false. (2p per correct answer.)

a) LIDAR
b) Gyro

Question 20:

Use the Kalman filter equations to answer the questions below.



Consider a scalar case where A=1, W=1, H=1, V=1 and the motion model is

$x_{k+1}=x_k + vel_k*dT + w_{k+1}$

and the measurement model is

$z_k=x_k + v_k$,

where z_k is also a scalar. The noise processes are distributed as

$w_k \sim N(0,Q_k)$ and $v_k \sim N(0,R_k)$.

In this context, mark each statement as **true** or **false**. (2p per correctly classified statement.)

a) A very accurate sensor would be modelled as Q_k being large.
b) If the state covariance matrix P is very large and the sensor noise is low, the Kalman gain K would be close to 1.

Question 21:

Mark each statement about a feature based representation as **true** or **false**. (2p per correctly classified statement.)

a) Can be used with both images and LiDAR data as input.

b) Matching the features over time, so called data association, is one of the main challenges.

Question 22:

Mark each statement as **true** or **false** regarding occupancy grids. (2p per correctly classified statement.)

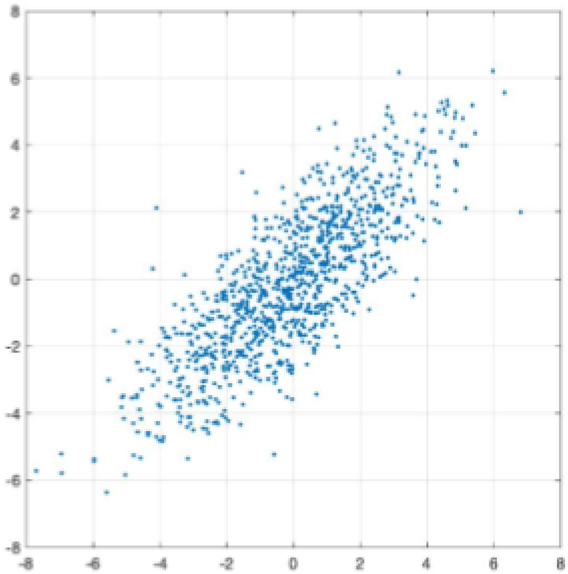
a) Occupied space is represented explicitly, allowing you to query the representation directly for what parts of space that are occupied (given on a specific threshold).

b) Using an adaptive cell size allows us to save memory.

Question 23:

Consider the following two sampled probability distributions a) and b). For each distribution, give the best matching covariance matrix. (2p for each correct match)

a)



b)

1) $\mathrm{Cov} = \begin{bmatrix} 5 & 4 \\ 4 & 5 \end{bmatrix}$

2) $\mathrm{Cov} = \begin{bmatrix} 1 & 0 \\ 0 & 1 \end{bmatrix}$

3) $\mathrm{Cov} = \begin{bmatrix} 50 & 40 \\ 40 & 50 \end{bmatrix}$

4) $\mathrm{Cov} = \begin{bmatrix} 10 & 0 \\ 0 & 10 \end{bmatrix}$

5) $\mathrm{Cov} = \begin{bmatrix} 3 & 0 \\ 0 & 1 \end{bmatrix}$

6) $\mathrm{Cov} = \begin{bmatrix} 1 & 0 \\ 0 & 3 \end{bmatrix}$

Question 24:

Mark each statement regarding SLAM as either **true** or **false**. (2p per correctly classified statement.)

a) Having moving objects in the field of view of the sensor typically makes solving SLAM easier.

b) All other things being equal, if you travel in a straight line and thus never revisit previously seen areas the error you get at the end would typically be much larger than if you instead move the same distance several laps around a building.

Question 25:

Your phone is often equipped with both an accelerometer and a gyro. Let us say that you put the phone flat on the table and spin it around. Which of the two sensors would best help you estimate the number of rotations it makes before it stops? (4p for correct answer)

a) Gyro

b) Accelerometer.

Answer sheet

Q1: a)___T_ b)___T_ c)__F__ d)__T__

e)__T__ f)__T__ g)_F___ h)__F__

Q2: _____3_______

Q3: a)__T__ b)__F__ c)__F__ d)__T__

Q4: a)__1___ b)__4___ c)_2____ d)__3___

Q5: a)_T____ b)__T___ c)__F___ d)__F___

Q6: _2__________

Q7: __3_________

Q8: a)__T___ b)_T____ c)__F___ d)__F___

Q9: a)__F___ b)_F____

Q10: __b__ __a__ __d__ __c__

Q11: a)__T___ b)___T__

Q12: a)_F____ b)__T___ c)_F____ d)__T___

Q13: a)__3_ b)_1___ c)_4__ d)_5___ e)_2___ f)_6___

(a)__3_ b)_ 4_ c)_ 1_ d)_5___ e)_2___ f)_6___ is also OK)

Q14: a)_5___ b)_2___

Q15: a)_F___ b)_T____ c)__F___ d)_F____

Q16: a)__F___ b)__F___

Q17: a)__F___ b)_T___

Q18: a)_T___ b)__F___

Q19: a)__T___ b)___F__

Q20: a)__F___ b)___T__

Q21: a)_T____ b)___T__

Q22: a)__T___ b)__T___

Q23: a)__2___ b)__1___

Q24: a)__F___ b)__T___

Q25: __a_________

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