Robot Intelligence **Name:** ____________
Fall 2022
Midterm Exam
8/31/2022
Take Home Exam - Due Before Class on Canvas 10/28/2022

This exam contains 12 pages (including this cover page) and 10 questions. The total number of points is 200. Graduate students must answer some additional questions. Undergraduates answering graduate questions will be given additional points and a feeling of satisfaction from attempting difficult things (probably).

Any programming/code artifacts associated with this exam should be submitted along with the final PDF to canvas. Please put your entire submission in a single .zip file.

This exam will cover topics in motion, planning, sensor processing, and ethics.

Grade Table (Quick view to see the breakdown)

Question	Points	Score
1	20	
2	20	
3	20	
4	20	
5	20	
6	20	
7	20	
8	20	
9	20	
10	20	
Total:	200	

1. (20 points) Moving in a car

   I would like you to use a skid steer model of a robot that is $75cm$ long and $55cm$ wide and run a few simple experiments with it. Please upload your resulting figures and python (or other) code:

   (a) (5 points) Make a list of commands (at t=0.1) that will allow this robot to traverse along the edge of a $5m$ diameter circle. The robot starts off in the center of the circle (0,0), and you cannot leave the circle's border. Plot both the resulting path (x, y) and trajectory (x, y, and angular velocities). Assume a constant velocity of $8m/s$

   (b) (5 points) Do the same as the above for a traditional car (Ackermann steering).

   (c) (10 points) If the car is traveling for $10s$, what is my position error using the discretized equations of motion if I define my time steps at $\Delta t = 1, 0.1, 0.01$? Plot the errors and computing time for the Ackermann vehicle in these cases. Use the forward Euler approach and compute a total error based on the distance difference from the analytical circle to the discrete-time equations.

   (d) (10 points) **Graduate Student Question** Compute part c again where road frictions are much lower (due to rain or ice). Slip causes your tires to respond very differently. Assume that your theta is $\theta_{actual} = \theta(1 - 0.08)$ and velocity is $v_{actual} = v(1 - 0.04)$.

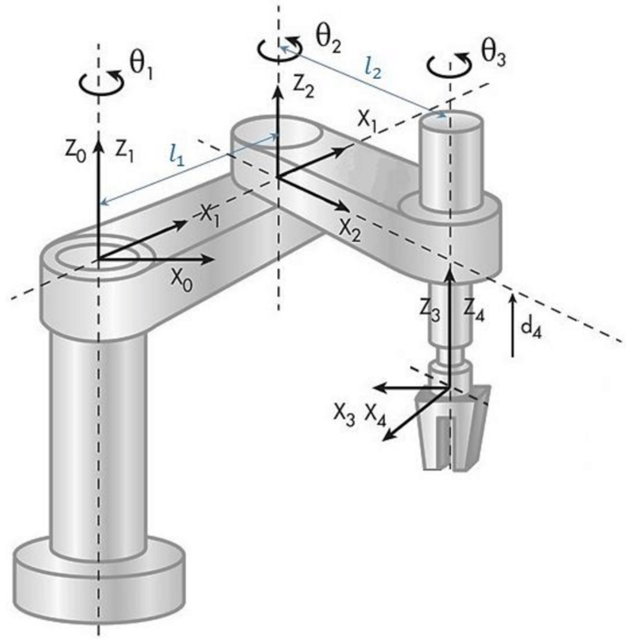


Figure 1: SCARA type manipulator.

2. (20 points) Inverse Kinematics, numerical approaches

   The following SCARA-type manipulator has physical characteristics as follows: $l_1 = 60cm$, $l_2 = 40cm$, and an arbitrary height (ie: assume that $(0, 0)$ is at the first motor).

   (a) (5 points) What is the workspace volume for this robot?. (Draw a picture of it as well)

   (b) (5 points) Write the DH parameters

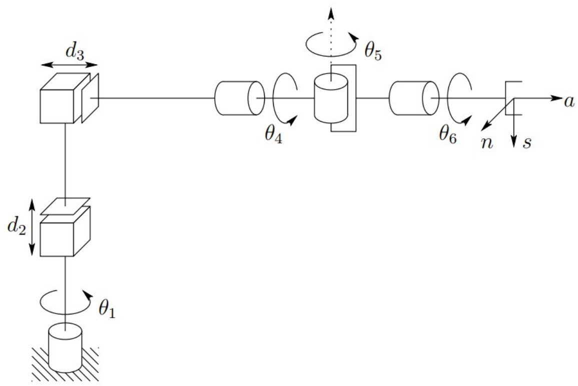
   (c) (10 points) Compute the forward kinematics to find the position of the end effector if $\theta_1 = 30deg$, $\theta_2 = 45deg$, $\theta_3 = 90deg$, and $d = 14cm$

3. (20 points) Inverse Kinematics with numerical approaches (Use the manipulator on the following page). Note that d_6 refers to the length of the arm on the top and d_1 is the length of the system from the base to the first motor.)

   (a) (10 points) Compute the joint angles and extension distances that will get this robot to pick up an object at x=1.2, y=0.8, z=0.5 if the robot started at if the robot started with the end effector at $\theta_1 = -90deg$, $d_2 = 0.5m$, $d_3 = 1.0m$, $\theta_4 = -90deg$, $\theta_5 = 90deg$, $\theta_6 = 40deg$, $d_6 = 0.2m$.

   (b) (10 points) What would be the joint angles and extension distances to get to the same goal coordinates if the robot started with the end effector at $\theta_1 = -90deg$, $d_2 = 0.5m$, $d_3 = 1.0m$, $\theta_4 = -90deg$, $\theta_5 = 90deg$, $\theta_6 = 40deg$, $d_6 = 0.2m$ and we wished to minimize the total distance traveled for each actuating part?

   (c) (10 points) **Graduate Question:** Using the same system, start configuration, and goal coordinates, compute the energy-efficient joint angles and extension distances. For your energy model, assume that actuating θ_1 costs 3x the energy of $\theta_{4,5,6}$, and $d_{2,3}$ costs 2x the energy.



$$
\begin{aligned}
T_6^0 &= \begin{bmatrix} c_1 & 0 & -s_1 & -s_1 d_1 \\ s_1 & 0 & c_1 & c_1 d_3 \\ 0 & -1 & 0 & d_1 + d_2 \\ 0 & 0 & 0 & 1 \end{bmatrix} \begin{bmatrix} c_4c_5c_6 - s_4s_6 & -c_4c_5s_6 - s_4c_6 & c_4s_5 & c_4s_5d_6 \\ s_4c_5c_6 + c_4s_6 & -s_4c_5s_6 + c_4c_6 & s_4s_5 & s_4s_5d_6 \\ -s_5c_6 & s_5c_6 & c_5 & c_5d_6 \\ 0 & 0 & 0 & 1 \end{bmatrix} \quad (3.34) \\
&= \begin{bmatrix} r_{11} & r_{12} & r_{13} & d_x \\ r_{21} & r_{22} & r_{23} & d_y \\ r_{31} & r_{32} & r_{33} & d_z \\ 0 & 0 & 0 & 1 \end{bmatrix}
\end{aligned}
$$

$$
\begin{aligned}
r_{11} &= c_1c_4c_5c_6 - c_1s_4s_6 + s_1s_5c_6 \\
r_{21} &= s_1c_4c_5c_6 - s_1s_4s_6 - c_1s_5c_6 \\
r_{31} &= -s_4c_5c_6 - c_4s_6 \\
r_{12} &= -c_1c_4c_5s_6 - c_1s_4c_6 - s_1s_5c_6 \\
r_{22} &= -s_1c_4c_5s_6 - s_1s_4s_6 + c_1s_5c_6 \\
r_{32} &= s_4c_5c_6 - c_4c_6 \\
r_{13} &= c_1c_4s_5 - s_1c_5 \\
r_{23} &= s_1c_4s_5 + c_1c_5 \\
r_{33} &= -s_4s_5 \\
d_x &= c_1c_4s_5d_6 - s_1c_5d_6 - s_1d_3 \\
d_y &= s_1c_4s_5d_6 + c_1c_5d_6 + c_1d_3 \\
d_z &= -s_4s_5d_6 + d_1 + d_2.
\end{aligned}
$$

Figure 2: Cylindrical/Prismatic manipulator. Use for problem 6.

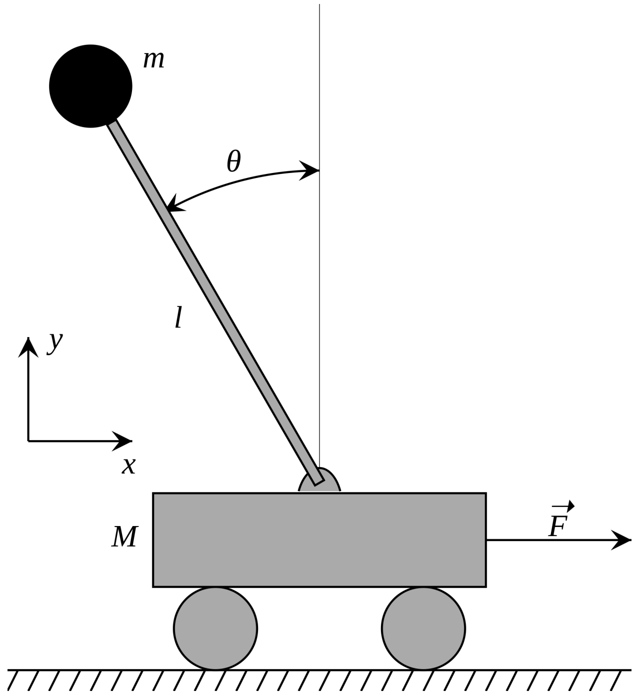


Figure 3: Assume that the mass $m = 0.2kg$, $l = 1.0$, $M = 4.0kg$

4. (20 points) Balancing a Pole

   A cart and pole suddenly appears before you and you feel compelled to answer burning questions you have always held about these systems.

   (a) (5 points) Describe the equations of motion that governs this system

   (b) (10 points) Generate code for a controller that would be able to keep the pole balanced in the air.

   (c) (5 points) What is the maximum angle that my pole can fall to before it cannot recover if max Force $F = 6N$?

5. (20 points) Control and Reinforcement Learning

   (a) (5 points) Explain three merits and three demerits of using reinforcement learning for mechatronic systems.

   (b) (5 points) Draw a diagram for reinforcement learning and controls and contrast the two

   (c) (10 points) Use OpenAI Gym to create a trained reinforcement learning model for the cart and pole problem (CartPole-v1).
   `https://www.gymlibrary.ml/environments/classic_control/cart_pole/`

   This tutorial will help you get started with using the OpenAI gym python library.
   `https://blog.paperspace.com/getting-started-with-openai-gym/`

   (d) (10 points) **Graduate Question:** Implement this example of a 2D running robot (cheetah) and adapt the code to penalize hip motor movements faster than $\pi\frac{rad}{s}$.
   `https://github.com/openai/gym/blob/master/gym/envs/mujoco/half_cheetah.py` A Virtual Machine that was made with VMWare is available on Canvas for you to use for this question if you have trouble installing Mujoco.

6. (20 points) Human Emotions

   (a) (10 points) Using the FER library in python, example in the following link: `https://towardsdatascience.com/the-ultimate-guide-to-emotion-recognition-from-facial-e` build a system that classifies human emotions and validate on video 1 and 2 from this repository: `https://github.com/rjrahul24/ai-with-python-series/tree/main/07.%20Emotion%20Recognition%20using%20Live%20Video` Generate plots of predicted emotions over time for both videos.

   (b) (5 points) Do the same as the above with a video feed from your webcam. Set your software up to allow video feed or a pre-recorded video. (In essence, make faces at yourself and make sure that your service works). Submit a short faces-recording along with the script that can read live webcam streams.

   (c) (5 points) What are the logical applications of this tool for an autonomous robot? What are the ethical and legal consequences of fielding a system that makes decisions based on this tool?

   (d) (10 points) **Graduate Question:** Set up a service that allows 2 or more faces to be processed at once.

7. (20 points) Motion Planning

   (a) (20 points) Implement an A* based planner and compare it's results with the Djikstra, A-Star, RRT-Star, Bi-Directional A-Star, and the Breadth First Search Planners from this github. `https://github.com/AtsushiSakai/PythonRobotics/tree/master/PathPlanning`. Create a table comparing the average cost of the path found over 10 iterations along with the time to convergence.

   After you have implemented your planner and compared it answer the below questions.

   - Which planner provided a path with the lowest cost on average?
   - Which one found a path the fastest on average?
   - After comparing your planner to these five other ones is there anything you would change in your planner to help it converge faster or find a path with a better cost?
   - Which planner appears to be the best overall? Which planner would you use for a robot in a complex environment?

   (b) (10 points) **Graduate Question:** Take the RRT planner from `https://github.com/AtsushiSakai/PythonRobotics/tree/master/PathPlanning` and update it to be an RRT-Star algorithm.

8. (20 points) Object Detection (Please put the classified images as part of your submission)

   (a) (5 points) Classify the first 10 pictures in `https://github.com/ravirajsinh45/Crop_and_weed_detection` using any image classification algorithm.

   (b) (5 points) Implement Yolo and do the same, what are the differences.

   (c) (10 points) Using transfer learning, pick an image classification algorithm and retrain it to learn to detect a new object of interest.

   (d) (10 points) **Graduate Question:** Implement Detectron (`https://github.com/facebookresearch/Detectron`) and test the image segmentation of the objects you are interested in. Give metrics on relative segmentation/classification quality comparing: Mask R-CNN, faster R-CNN, and RetinaNet.

9. (20 points) Full Circle - Car planning in a complex environment

   (a) (5 points) A pedestrian suddenly begins to walk in front of the moving vehicle ($11m/s$). The pedestrian is 20 meters in front of the car. What commands will the car need to receive to stop before it hits the pedestrian? Plot the velocity, position, and commanded inputs.

   (b) (5 points) Assume that your vehicle can only decelerate at $4.2m/s^2$ (max). If there is an open lane to your left or right, generate a new stopping trajectory. Plot the velocity, position, and commanded inputs.

   (c) (5 points) A New vehicle pulls out into the road 15 meters ahead of you and speeds up to $11m/s$. Design a trajectory to pass on the left if your vehicle is moving at $13m/s$. Plot the velocity, position, and commanded inputs.

   (d) (5 points) As you are passing the vehicle (where you begin to overlap), it speeds up to $13m/s$. Compute a new passing trajectory if you are willing to accelerate to $14m/s$, how much time will you be in a "Passing" maneuver? Plot the velocity, position, and commanded inputs.

10. (20 points) Ethics of Robotics - Open Ended Questions

    (a) (5 points) Many people (particularly those in the robotics industry) believe that robotics is purely within the purview of technical development and should not have any ethical considerations. What do you feel can be a merit or demerit to this way of thinking?

    (b) (5 points) Isaac Asimov listed 3 laws of robotics, comment on the algorithmic complexity of implementing these into working intelligence. Define a scenario and write Psuedo code to implement these rules.

    (c) (5 points) In the event of an autonomous system causing harm or damages, who is responsible? Read and comment on the following two documents: `https://www.callahan-law.com/articles-and-expert-advice/when-an-autonomous-vehicle-hits-a-pe` and `https://en.wikipedia.org/wiki/Self-driving_car_liability`

    (d) (5 points) What laws may be helpful for regulating or controlling autonomous systems? What drawbacks will this potentially have?