1. Identify the revolute and prismatic joints in this picture of a manipulator.

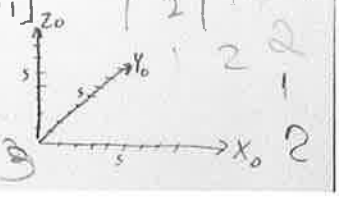
2. Draw a kinematic diagram of the joints in this manipulator

3. Tell me what type of manipulator this is

4. Draw coordinate frames, joint variables, and link lengths on your kinematic diagram.

5. Find the homogeneous transformation matrices A_1, A_2, and A_3 from your diagram.

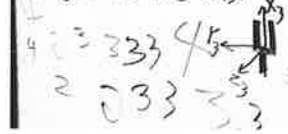
6. Suppose that the homogeneous transformation matrix is $H_3^0 = \begin{bmatrix} 0 & 1 & 0 & 2 \\ 0 & 0 & 1 & 4 \\ -1 & 0 & 0 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix}$. Draw a dot showing the location of the end-effector



7. For the H_3^0 and 0 frame in question 6, draw frame 3 here in the correct orientation.

8. Suppose that an object held by the robot gripper is located at $X_3 = 5$ cm, $Y_3 = 2$ cm, $Z_3 = 1$ cm in the end-effector (3) frame. Where is the gripper relative to the ground?

9. Suppose that after the robot moves, the end-effector is now located at $X_0 = 4$ cm, $Y_0 = 10$ cm, $Z_0 = 2$ cm and is oriented like this: What is the homogeneous transformation matrix?



10. What do each of these terms mean: manipulator, end-effector, degrees of freedom, kinematically-redundant?

11. How many degrees of freedom does the manipulator in question 2 have?

12. Why is it either good or bad for a manipulator to be kinematically-redundant?

1. Suppose that you have a motor with a motor constant of $0.004 \frac{V}{rpm}$. What voltage will set a speed of 250 rpm?

4. Suppose that you have set the 'period' value of the PWM to 100 ticks. For question 3, what number should you set for the 'compare' value of the PWM?

2. Suppose that you are using a 5V microcontroller PWM pin to both power the motor and control the speed. What duty cycle (in %) should you set?

5. Suppose that the clock used for the PWM 'ticks' at a rate of 10 MHz. How much time (in seconds, ms, or μs) will pass during the PWM period, and how much time will pass during the compare?

3. Now, suppose that you are using an external 10V power supply to power the motor, and are using the 5V pin of the microcontroller to turn the 10V on and off through a motor controller chip. Now, what should be the duty cycle (in %)?

6. Using the information in questions 3-5, draw the PWM pulse string, labeling all key voltages and times.

7. Explain the difference between open-loop and feedback position control. Discuss: accuracy, hardware required, and disturbance rejection.

10. Shown here is some 'pseudocode' (code written in human language) for proportional control. Fill in the blanks.

set the _____
start loop
check the _____
error = _____
duty cycle = _____
apply duty cycle (send to motors)
end loop

8. Draw a block diagram for feedback control. Label all blocks and lines/arrows connecting the blocks.

11. State the meaning of each of the letters P, I, and D, give a description of how each works, and fill in this table:

Effects of Increasing Gains

	rise time	overshoot	steady-state error
P			
I			
D			

9. Explain how on/off control works, and how it is different from PID control. Compare the two in terms of speed, accuracy, and stability.

12. Shown here is a 'time response' of a robot joint moving to a target position with PID control. Label the rise time, overshoot, and steady-state error, and suggest one change to the gains to improve the response.