Legged Robotics

Final Exam

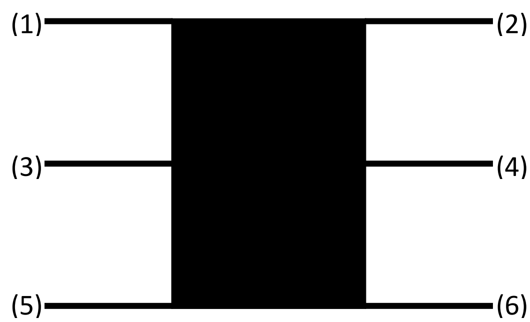
This exam includes three problems. According to the syllabus, your exam has 15 points total (and you will be graded out of 15) but you can get up to 18 points in this exam. In other words, the exam includes 3 Extra Credit points.

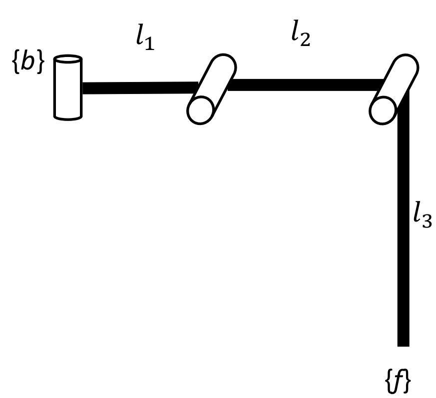
For submission, you need to submit a PDF of your solution for grading plus any original files such as MATLAB scripts.

Problem 1 – 11.5 pts.

This problem is continuation of your HW6. In HW6, you did the first 5 questions of this problem. For this problem, you will continue by doing Questions 6 through 10. If you had any mistakes in HW6, please use the HW6 solution to correct your answers before moving to the new questions in this problem.

Consider a rectangular hexapod robot with six identical 3-DOF legs with the configuration shown below in its home position.





If we want the robot to walk with an average constant velocity of $0.01\ m/s$ with a duty factor of $\beta = \frac{4}{6}$, stride length of $= 0.03\ m$, and we know that $l_1 = 0\ mm$, $l_2 = 50\ mm$, and $l_3 = 100\ mm$,

1. Write down the average velocity of swing (transferring) legs with respect to the **body**. (0 point)
2. Write down the average velocity of swing (transferring) legs with respect to the **ground**. (0 points)
3. Draw the kinematic phase diagram. How many legs are in contact with ground (support phase) when walking? (0 point)
4. Write down the relative kinematic phase of each leg. (0 point)
5. How long is one cycle time in seconds? (0 point)
6. Calculate the transfer time (swing period). Then, for a single leg, consider identical time intervals with time steps of $[t_1 \quad t_2 \quad t_3 \quad t_4 \quad t_5 \quad t_6]$ within the transfer time, where t_1 is the lift-up and t_6 is the touchdown time. Then draw horizontal and vertical position and velocity of foot tip with respect to the time in **ground** coordinate system. Show all **numbers** on the axes of the graphs. (3 pts.)
7. Calculate **positions** of all 18 joints at all intervals. (2.5 pts.)
8. Calculate **velocities** of all 18 joints at all intervals. (2.5 pts.)
9. According to the results of Questions 7 and 8, show a simulation (video) of the robot walking. ***Hint: Synchronize the motion of swing and supporting legs during the cycle.*** (2.5 pts.)
10. If the only information that we have is that legs 1, 2, and 5 are on the ground, would the robot be statically and dynamically stable? Explain your answer clearly? (1 points)

Problem 2 – 4.5 pts.

1. Draw a kinematic phase diagram for your own walking. An approximation would suffice. (0.75 points)
2. What is the duty factor of each of your legs when walking? How many legs are in contact with the ground when walking? (0.75 points)
3. From top view, show an approximation of the trajectory of your center of mass (COM) together with ZMP when walking. Show this for at least two complete steps. (0.75 points)
4. Draw a kinematic phase diagram for your own running. (0.75 points)
5. What is the duty factor of each of your legs when running? How many legs are in contact with the ground when running? (0.75 points)
6. From top view, show an approximation of the trajectory of your center of mass (COM) together with ZMP when running. Show this for at least two complete steps. (0.75 points)

Problem 3 – 2 pts.

Assume that a humanoid robot, with two rectangular flat feet, is standing on both feet on a level ground and in its maximum stability condition. Assume that the ZMP for each of the left and right feet are in the middle of the corresponding feet and the ZMP for the whole robot is in the middle of the support polygon and between the two feet. Now assume that the robot is being pushed from its left side by an increasing force until it tips over from its right side. In this case, the tip-over axis would be the right side of the right foot. Assume that the pushing force is applied to the COM of the robot. Consider $t = 0$ to be the instant at which the force starts applying. Figure below shows the robot at $t = 0$. Consider $t = 1$ to be the instant at which the robot starts tipping over. When $t > 1$, the robot will be in falling phase (tipping over) until $t = t_g$ when the whole body hits the ground (fall is complete).

Consider a 2D coordinate frame $(t - x)$ whose horizontal axis is time (t) and its vertical axis is the x component of ZMP (x_{ZMP}). To clarify, the vertical axis of this coordinate frame will be the same as the x axis shown in the figure below. I would like you to plot three trajectories on this $t - x$ coordinate frame (all in one graph) representing:

1. x_{ZMP} of the left foot from $t = 0$ to $t = t_g$
2. x_{ZMP} of the right foot from $t = 0$ to $t = t_g$
3. x_{ZMP} of the whole robot from $t = 0$ to $t = t_g$

Please note that I am not asking for any mathematical calculations. I just need to see how you think the ZMP will move as a result of the increasing lateral force until the robot falls and hits the ground.

Also, make sure to properly label your axes with corresponding values and add a legend for trajectories. Your plot should be very clear to read.

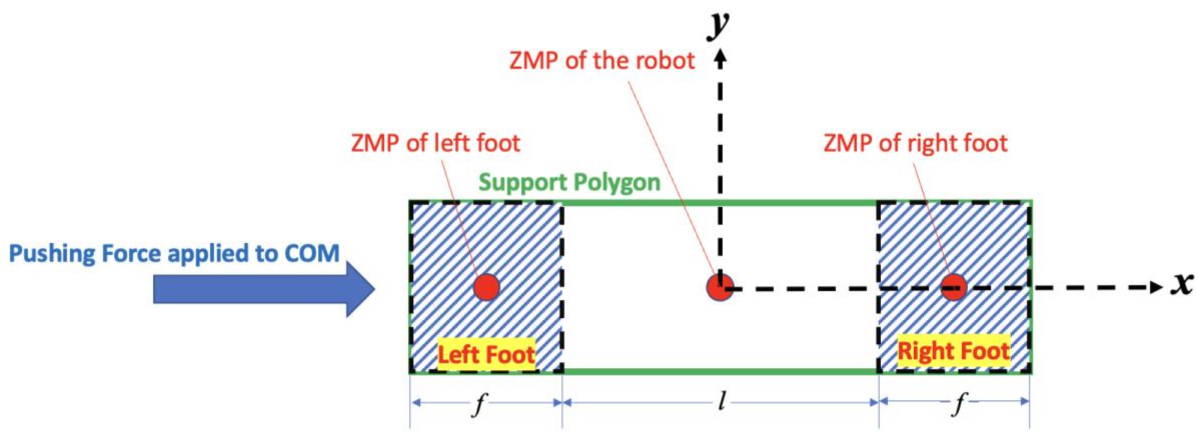


Figure for Problem 3: The support polygon and ZMP locations at $t = 0$.

Good Luck!