MID-SEMESTER EXAMINATION

classmate

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⇒ Level 0 attempt.

5) Yes. In DH convention we take z-axis to be the axis of revolution of a revolute joint & the axis of translation for a prismatic joint. Due to this fixed convention, we are able to simplify the homogenous matrix using 4 parameters instead of 6.

6) No. Many times the origins of coordinate frames in DH convention lie outside the joint centre. They lie on the common normal of the z-axes connecting two consecutive coordinate frames.

~~(Depends how we percieve the statement)~~

7) No. A homogenous transformation can consist of only a rotation, only a translation or both. This primarily depends upon our choice of coordinate frames. A homogenous matrix primarily connects two ~~consecutive~~ coordinate frames according to their orientation. (If we consider no rotation to be a 0° or 360° rotation or no translation as 0 unit translation, then statement is true)

8) Yes. The product of individual rotations, keeping in mind the exact sequence of rotations, can be multiplied together in the sequence order to form an overall rotation matrix. In this case, we are considering rotation matrices in the SO(3) category & are ignoring special cases such as improper rotations etc.

9) Yes. Considering all individual rotation matrices are of SO(3) type and no special cases such as improper rotations etc are considered, the composite rotation matrix will be an orthogonal matrix with determinant equal to 1. A short proof for two

matrices that can be scaled to n matrices is as follows:-
Let rotation matrices be Q_1 & Q_2.
$\therefore$ Composite matrix = $Q_1 Q_2$.
$\therefore (Q_1 Q_2)^T (Q_1 Q_2) = Q_2^T (Q_1^T Q_1) Q_2 = I$ ... Orthogonality.
$\det(Q_1 Q_2) = \det(Q_1) \times \det(Q_2) = 1$ ... Improper rotations are ignored.
$\therefore$ This proof is scalable for 'n' matrices.
$\therefore$ Proved

⇒ Level 1 attempts

2)
a) The pill picking robot by Timetooth technology is supposed to pick up a single pill lying in any orientation from a cup containing multiple pills of the same type. The following are some important considerations for solving this problem:-
① Only one pill is to be picked from the cup. Hence a vacuum based approach wont work since multiple pills may get picked & we wont have proper control over the no. of pills to be picked.
② The pills will be lying in different orientations, hence, the gripper will exert different magnitudes of force on the pills while picking them up. depending on orientation.
③ The gripper should not exert compressive forces on the pill or damage the pill while picking up the pill.
Taking the above considerations into account, I think a compliant / soft gripper will be more suitable for the task.
Reasons:-
① A hard gripper is more likely to damage the pill due to exertion of forces.
② It has been observed that the dynamic reaction force

exerted upwards during grasping is reduced for soft grippers, but it wont create much difference since the weight of the pills is very less. We will have functionality similar to a hard gripper.

③ The geometry of soft grippers varies slightly according to the objects it grasps such that the forces on the object are minimised. This will ensure that the pill doesn't get damaged during the gripping operation.

④ In case of a power-cut, a soft gripper will still hold on to the pill due to slight flexibility in its geometry.

⑤ The weight of soft grippers ~~wa~~ is mostly lesser than hard grippers. This will reduce the robot weight & will also reduce the errors in actuation due to weight, ultimately making control easier.

Due to these reasons, I feel that a soft/compliant robotic gripper will be more suitable for the task.

3)

a) Selecting reasonable link lengths by measuring length, we have:

Link 1 = Hip to knee distance = 50 cm = 0.5 m

Link 2 = Knee to ankle distance = 43 cm = 0.43 m

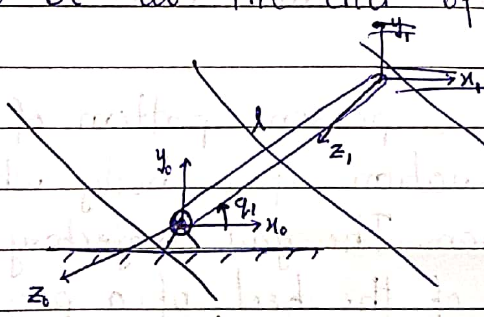
Gait trajectory: The gait is a persons pattern of walking. The balance & muscle coordination of a body while walking affects the gait of a human. The gait trajectory of a human refers to the locus of the heel of a persons leg while walking. This is mapped for a single step of a person. A typical gait trajectory is divided into three main phases: toe-off phase, swing phase, heel strike phase. When we consider the leg to be a 2R manipulator, the locus of the end effector gives us the gait trajectory. The images attached below will explain the gait trajectory.

Step height: The maximum height reached by the foot from the ground while walking is known as the step height. The step height is averaged over multiple strides. In the gait trajectory, the y-coordinate of the highest point should give the step height for that ~~stride~~ step. The step height affects the step length and the stride length.

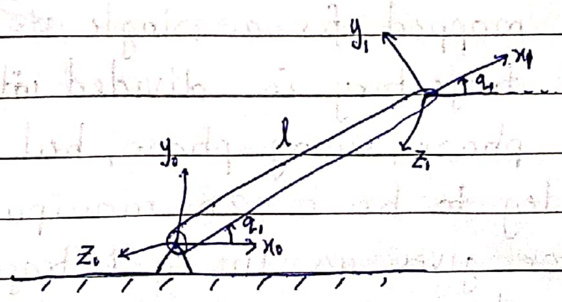
Step length: The distance covered by a human by one leg for a single step gives us the step length. The healthy step length for an average adult is approximately 2.5 feet (30 inches). The stride length is approximately double the step length, 5 feet (60 inches). A humans height, balance & muscle coordination affects the step length. A healthy step length to height ratio for an average adult is considered to be near 0.4.

4)

a) We have a robot with a single revolute joint and single ~~length~~ link of length 'l'. We consider the end effector to be at the end of the link.



~~Link~~	~~θ~~	~~d~~	~~a~~	~~α~~
~~1~~	~~0~~	~~0~~		



DH parameters

Link	θ	d	a	α
1	q_1^*	0	l	0

* = joint variable

The DH parameters vary according to our choice of 2^{nd} axis since the z axes are parallel for both coordinate frames. In this case, we take the x-axis along the ~~link~~ length of the link for better representation.

Q2]
b)
Flexible Gripper: These type of grippers adapt to the shape of the objects they are supposed to hold and accordingly change the way they grip the object. However, in this case they might not be feasible to hold small objects like pills. Although they are capable of holding small objects, there is relatively less control over the amount of forces applied on the object. Hence, a flexible gripper can be used for the pill picking robot, but it would be assigned a low priority.
Flexible Grippers:

1. Robotic Hand for Manufacturing Industries: Main Features - Robotiq
2. https://link.springer.com/chapter/10.1007%2F978-3-319-48923-0_40 .

Soft Robotic Gripper: These type of grippers enable grasping using actuation, controlled stiffness and controlled adhesion. They can be used to grasp a large variety of objects and the force applied on the object can be controlled and is usually very less. Hence, these grippers will be extremely useful for picking up pills lined in different orientations without damaging the pills. However, there is a challenge of increasing the speed of the operation and integrating sensing and control while locating and picking the pills. Hence, this gripper can be used, but a better alternative would be preferred, if present.

Soft Robotic Gripper:

1. Universal Soft Robotic Gripper
2. Soft Robotics' octopus-inspired robots industrial grippers
3. https://www.researchgate.net/publication/325016962_Soft_Robotic_Grippers.

Universal Gripper: These type of grippers lift a large variety of objects based on suction created by air pumps. This approach is not feasible as we will not have control over the number of pills that get picked from the cup. It would have been ideal in cases where the pills are scattered on a horizontal surface or if there is only one pill in the cup. Also, it is specifically mentioned in the problem statement that a vacuum based gripper is not desired. Hence this gripper cannot be used.
Universal Robot Gripper:

1. Universal Robot Gripper
2. Universal Gripper: Grabbing, Drawing, & Pouring
3. https://ieeexplore.ieee.org/abstract/document/6142115

Paper Gripper: I found two types of paper grippers on the internet. The first one is a suction based gripper used for picking paper sheets. This type of gripper is similar in principle with the universal gripper and may give more control over the number of pills picked due to its small size. However, it can not be used since it is vacuum based. The second type is a shape memory based gripper made of paper that is artificially synthesized. This type of gripper can be used for pill picking since it will exert less force on the pill, will pick a single pill and will also do it fast since it retains shape memory. However, this gripper is not easily available and is hard to manufacture.

Paper Gripper:

1. Paper-Gripper Automatism
2. https://link.springer.com/article/10.1007/s12541-019-00199-6

Origami Gripper/Robot: These type of robots function by folding. They are made of many dynamic folds that together actuate the machine. An origami robot gripper functions similarly to a soft robot gripper, the only difference being that the actuation is done by origami folds. An origami gripper can be useful if the end that grabs the pill can be modified to fit the shape of the pill. Else, it will be similar to a soft gripper. It will exert less force on the pill while lifting, but we may face problems in controlling the number of pills that are lifted. Also, some variants that are vacuum based cant be used.

Origami Gripper:

1. Origami Robot Gripper
2. https://iopscience.iop.org/article/10.1088/1361-665X/aa67fd/meta
3. https://ieeexplore.ieee.org/abstract/document/9442354

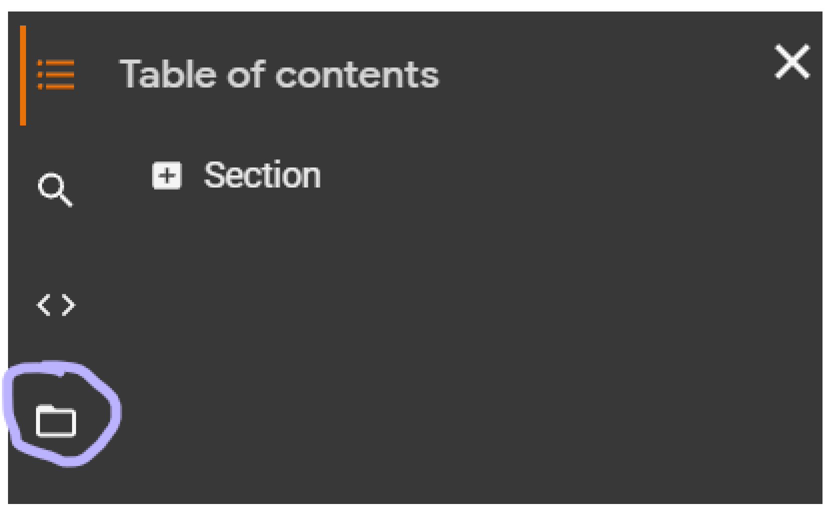
So, based on the overall research, I feel that a soft robotic gripper whose shape could be modified such that it lifts only one pill could be used ideally for the picking pill robot project. If we are able to make a modified soft, flexible robot gripper, we could also use it to pick different types of pills with high accuracy and a relatively good speed.

Q3]

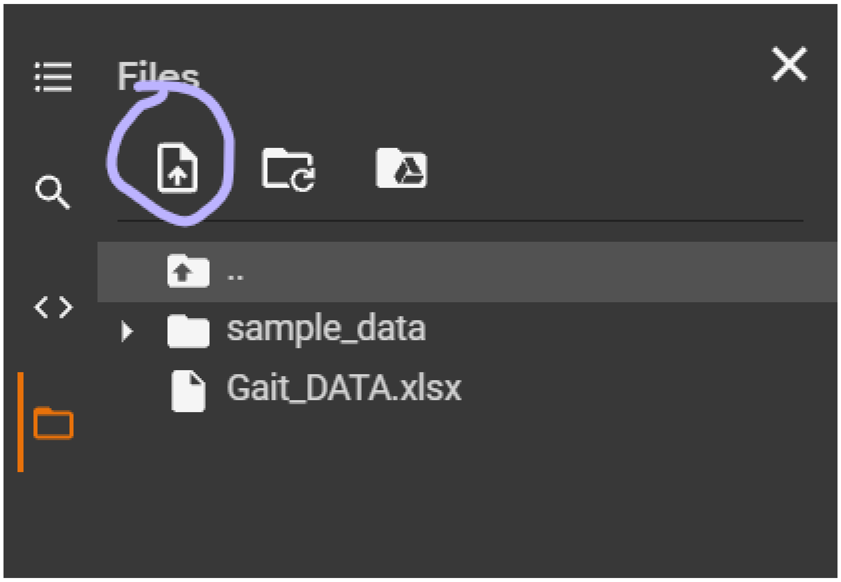
b)

Instructions:

1. Open code in Google Collaboratory.
2. Click on the folder icon to the left

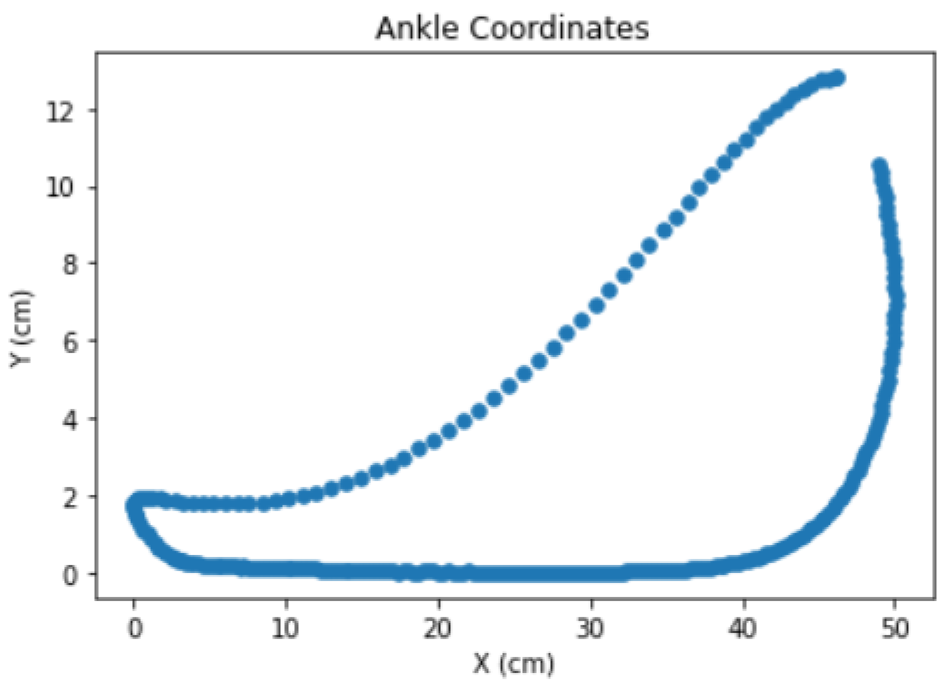


3. Click on the upload file icon



4. Upload the “Gait_DATA.xlsx” file to the Colab Runtime
5. Run the code.

Plot obtained:



The above graph demonstrates the gait trajectory of a person walking to the left along the direction of the page plane. As expected, the process of putting the foot down is relatively slower and moving forward is faster relative to that.

a)
Attached below are the images referred in the handwritten explanations above

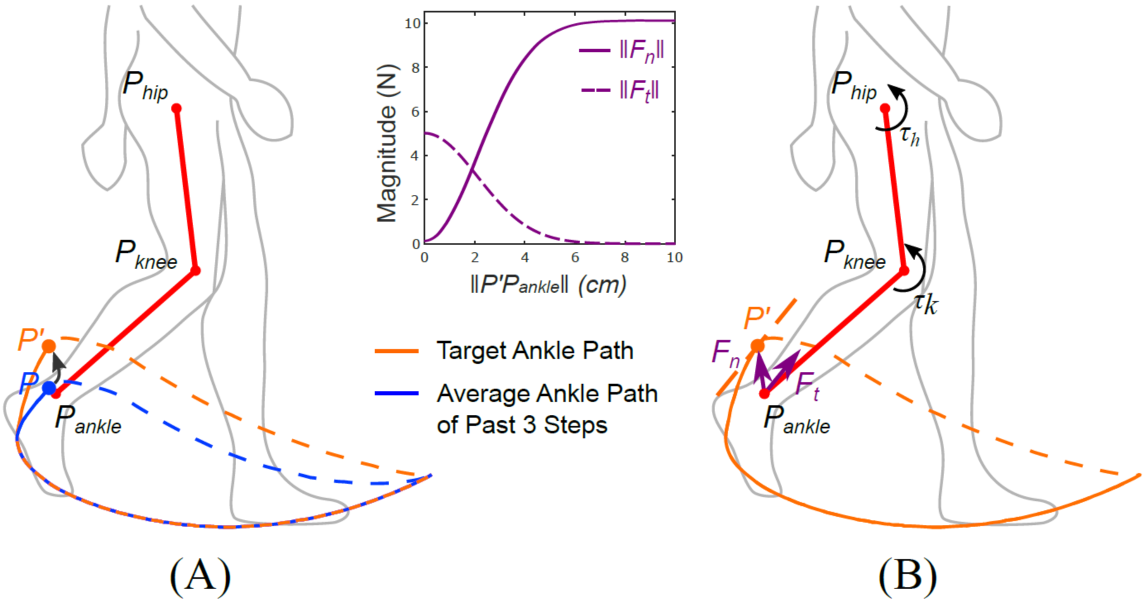


Image source:
https://roar.me.columbia.edu/news/retraining-human-gait-are-lightweight-cable-driven-leg-exoskeleton-designs-effective

The gait trajectory is the locus of the end effector when the leg is considered as a 2R manipulator.

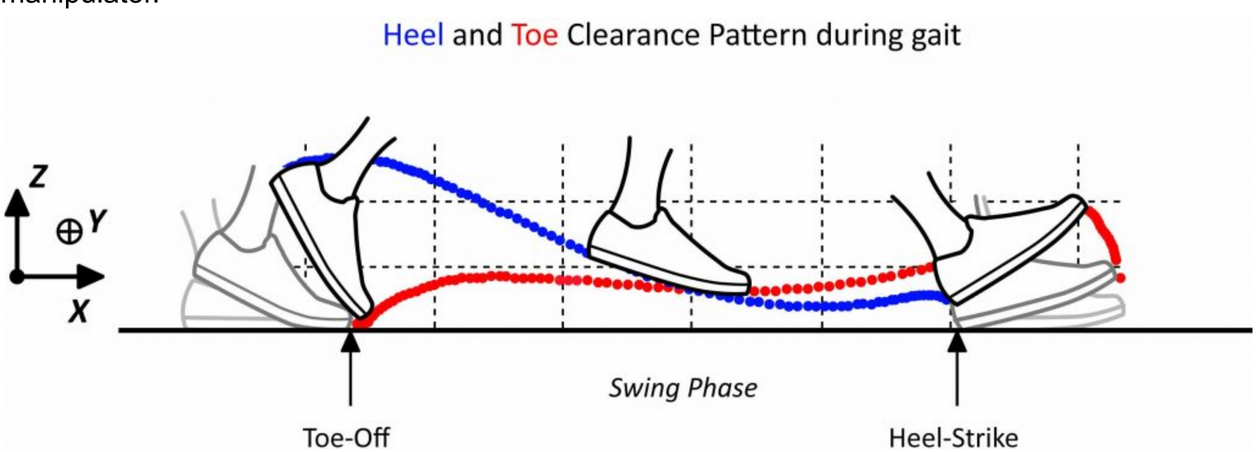
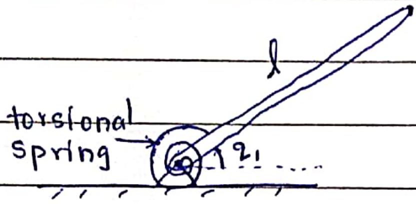


Image Source:
https://www.epfl.ch/labs/lmam/page-125471-en-html/page-125544-en-html/page-125556-en-html/page-73893-en-html/

⇒ Level 2 attempts.

4)

b) We have the following joint diagram:



∴ When the link moves, the torsional spring will apply a linear force that corresponds to the angular displacement.

Since we are neglecting gravity, the only force to be considered will be that of the torsional spring.
∴ The motor at the joint should provide torque in such a manner that the link moves as if connected to a torsional spring.
∴ We have, for a linear torsional spring,

$$\tau = -k\theta \quad \ldots \quad \theta = \text{angular displacement}$$

In this case,

$$\tau = -kq$$

$$\therefore \quad I\ddot{q} = -kq \quad \ldots \quad I = \text{moment of inertia}$$

$$I\ddot{q} + kq = 0$$

∴ The above equation represents a mass-spring equation.
∴ The desired torque to be provided by the motor will be $\tau = kq_1$, where q_1 will be the angular displacement.
This torque will added to the torque to resist gravity.
∴ Neglecting gravity, we get;

$$m.l^2\ddot{q}_1 = \tau = kq_1$$

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1)

d) We have,

$$v = J_v \dot{q}$$ ... J_v is the first 3 rows of Jacobian matrix.

$\therefore$ J_v will be invertible for each robot as every robot has 3 links hence J_v will be 3x3 matrix. (Here, we have not attached wrist yet)

$\therefore$ We get:

$$\dot{q} = (J_v)^{-1} v$$

$\therefore$ The tool moves at intervals of 0.01. Hence we have

along x-axis : $v = \begin{bmatrix} 0.01 \\ 0 \\ 0 \end{bmatrix}$

along y-axis : $v = \begin{bmatrix} 0 \\ 0.01 \\ 0 \end{bmatrix}$

$\therefore$ We already have computed J_v from the code. We use a for loop to calculate velocities at ~~for~~ the given length intervals & print the output.