Task 2

I think two options might be considered for the purpose of the pill-picking robot:

1. A traditional gripper: This would satisfy the requirements. However, it might damage the pill. Extreme care would have to be taken so that the pill is not crushed.
2. A soft robotic gripper: This would solve the problem of accidental pill damage. Compliant mechanisms can be used for gripping, or even a solution where the gripper is made using rubber materials and is actuated using pressurization would work (like in this video: https://www.youtube.com/watch?v=X0XGure7mak&ab_channel=TechCrunch). Control and design of such a gripper would be difficult. Nonetheless, this would be the best possible solution for this type of robot.

Thus, a soft robotic gripper would be the superior solution for this purpose but also harder to achieve.

1. Flexible Mechanisms: Flexible mechanisms are mechanisms which derive atleast some of its motion from the deflection of flexible components instead of movable joints only.

   Flexible manipulators have the following advantages:
   a. Part Count: They usually require lesser parts as compared to traditional mechanisms.
   b. Production processes: They can be manufactured using various different, simple processes.
   c. Price: They are often quite inexpensive
   d. Precise motion
   e. Performance: Since there are no joints, no lubrication is required and friction is reduced.
   f. Proportions: Miniature compliant mechanisms can also be designed
   g. Portability: Using compliant mechanisms reduces the weight, which is often desirable.
   h. Predictability

   However, the following challenges are also raised for flexible mechanisms:

   a. Analysing and designing compliant mechanisms is quite difficult and the biggest roadblock for compliant mechanisms.
   b. Non-linear equations arise for large deflections, as the linearized beam equations are no longer valid. These are very difficult to solve.
   c. Energy storage: In compliant mechanisms, not all of the energy is transferred; some gets stored in the mechanism.
   d. Fatigue: Sufficient fatigue life is required for compliant mechanisms
   e. Limited motion

Considering all of these factors, I conclude that compliant mechanisms might be suitable for pill-picking robots, but they would be quite hard to design and analyse. The same tasks can be done with relative ease by rigid grippers too.

https://www.compliantmechanisms.byu.edu/about-compliant-mechanisms
https://www.youtube.com/watch?v=97t7Xj_iBv0&ab_channel=Veritasium

2. Soft Robotic Grippers:

   Soft robotic grippers are beneficial because they often don't need information about the object they have to grasp. They can be classified into three types: actuation, controlled stiffness, controlled adhesion. This gripper would be useful for picking up pills in different orientations without damaging the pill itself. Compared to traditional grippers, soft grippers can usually grasp and manipulate a larger variety of objects. They can be made out of rubber materials. They have no rigid joints. Due to material softness and mechanical compliance, control complexity is also often reduced. However, speed, integration of sensing, robustness and control raise problems for soft robotic grippers.

   Such grippers would be useful for this application since they can pick pills without damaging them. Challenges would arise due to the complexity of designing such robots. Thus, a soft robotic gripper might be used for pill-picking.

   https://www.researchgate.net/publication/325016962_Soft_Robotic_Grippers
   https://www.youtube.com/watch?v=X0XGure7mak&ab_channel=TechCrunch

3. Universal Grippers:

   Universal Grippers use a vacuum to grip the objects. The end-effector is spherical. It goes up to the object to be gripped and conforms according to its shape, then grips it using a vacuum. It is useful in situations where the high adaptability of a human hand is needed or where minimal information about the object is known.

   This gripper is not suitable for this application for two reasons:

   1. It would pick up multiple pills at once.
   2. The company does not desire a vacuum-based solution.

   https://www.youtube.com/watch?v=0d4f8fEysf8&ab_channel=TheUniversityofChicago
   https://www.pnas.org/content/107/44/18809

4. Paper Grippers:

   Kirigami is a concept in which paper is cut and stuck together. It is an ancient Japanese technique. It is adopted for robotic grippers as shown in the video. A sheet of a flexible material is cut into specific shapes, which when folded in certain directions folds in 3D, which can then be used for gripping. Since the material is flexible, it can also grip delicate objects. It can also pick up extremely small objects. Hence, this paper gripper might be suitable for this application. However, it is highly difficult to design such a gripper.

https://www.youtube.com/watch?v=UerxNyu147g&ab_channel=BostonUniversity

5. Origami Robots:

   Origami grippers are also vacuum-based. They harness the characteristics of origami: the form and function of the grippers can be changed using the direction of their folds. The kinematic behaviour of the gripper can be changed by the way the creases are folded. It can hold delicate objects as well as heavy objects. However, it faces the same problems as the universal gripper: it might pick up multiple pills and it is vacuum-based which is not desirable.

   https://www.youtube.com/watch?v=byqGFH6AZuk&ab_channel=MITCSAIL
   https://ieeexplore.ieee.org/abstract/document/9442354

Task 3

The link lengths were measured by measuring the distances on my legs.

Hip-to-knee distance (l1) = 51 cm

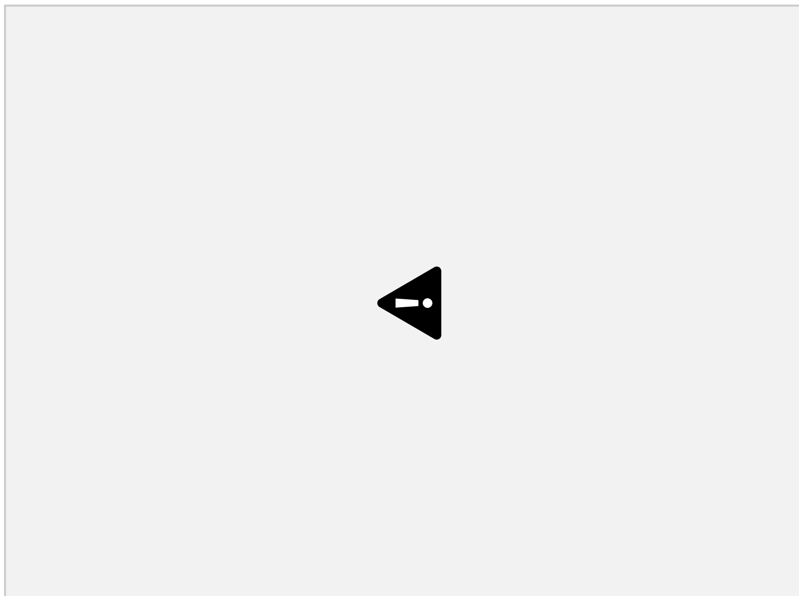
Knee-to-ankle distance (l2) = 41 cm

1. Gait Trajectory: Gait can be defined as the manner or style of walking. Gait trajectory is the locus of the heel of the leg while the person is walking. It is mapped for a single step of the person who is walking. Gait trajectories can be divided into 8 parts:
   a. Initial Contact (heel strike)
   b. Loading response (foot flat, body absorbs impact)
   c. Midstance
   d. Terminal stance (heel off)
   e. Pre swing (toe off)
   f. Initial swing
   g. Mid swing
   h. Late swing
2. Step height: The step height of a gait trajectory is the maximum height reached by the foot from the ground while a person is walking. The y-coordinate of the highest point in a gait trajectory gives the step height. The step length is also affected by the step height.

3. Step length: The distance that a person covers in one single step while walking is known as the step length. If one leg is at x1 and the other leg reaches x2 after taking a step, the step length would be given as (x2-x1).

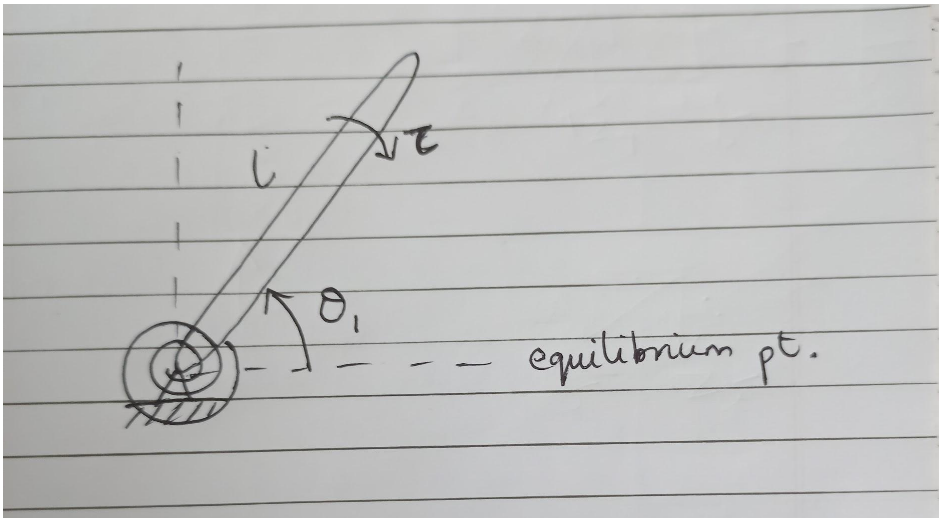
https://www.physio-pedia.com/Gait

Task 4



DH Parameters

Link	θ	d	a	α
1	θ1*	0	l	**0**



We want the joint to behave like a virtual torsional stiffness with linear characteristics. TO understand how much torque would be required for such an effect, we first consider a robot with an actual torsion spring as shown in the figure. Let us assume the torsion spring has a spring constant K. Also, the horizontal line is the equilibrium position. When released from any non-zero angle, the link would oscillate indefinitely about the equilibrium position. The spring applies a torque in the opposite direction of the angular displacement of the link. Thus,

$$\tau = -K\theta_1$$

On providing such a torque to a robot with one revolute joint (neglecting gravity), we would obtain a response like the robot had a virtual torsional spring.

Task 5

Yes. In DH convention, the z-axis is always taken along the joint axis. This is one of the conventions followed by the DH convention in order to standardize and simplify the forward kinematics.

Task 6

No, not necessarily. Often, this is true, but it is not necessary. The origin is located at the intersection of the common normal of z_{i-1} and z_i and z_i. If z_{i-1} and z_i are parallel, the origin can be located at the joint i.

Task 7

Usually, a homogeneous transformation is used to represent both a translation and a rotation simultaneously. Hence, in general, homogeneous transformations consist of both a rotation and a translation. However, it is possible to conduct just rotation of a vector (by setting d=0) or just translation of a vector (by setting R=I) using homogeneous transformations.

Task 8

Yes, the rotation matrices for a sequence of rotations can be multiplied together to get the overall transformation matrix. However, each rotation is affected by the rotations before it, since the rotations are conducted with respect to the axes of the current frame of reference (i.e. frame of reference after rotating by the previous rotations). The order of multiplying the matrices is also important and needs to be taken care of: if I want rotation by R1 first and next, rotation by R2, the correct order is:

$$R_{tot} = R_1 R_2$$

This assumes that only rotation matrices with determinant = 1 are considered, not matrices with determinant = -1.

Task 9

If we consider only rotation matrices with determinant = 1 and not rotation matrices with determinant = -1, then yes, this is true. A composite rotation matrix will always be orthogonal and have determinant equal to 1, no matter how many rotations are used to form that composite rotation matrix. Example:

$$(R_1 R_2)(R_1 R_2)^T = R_1 R_2 R_2^T R_1^T = R_1 I R_1^T = I$$
$$det(R_1 R_2) = det(R_1) det(R_2) = 1$$

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Task 1

d) We know that

$$\cancel{\dot{q} = J_v v}$$

$$V = J_V \dot{q}$$

where J_V is the first 3 rows of the Jacobian matrix, v is the end-effector cartesian velocity and $\dot{q}$ is the joint velocities.

We have 3 links in all the three robots (Stanford (RRP), PUMA (RRR), SCARA (RRP)). Hence, J_V will be 3×3. Thus, J_V will be invertible.

$$\Rightarrow \quad \dot{q} = (J_V)^{-1} V$$

When moving along y-axis, ~~Thus~~ v will be

$$v = \begin{bmatrix} 0 \\ 0.01 \\ 0 \end{bmatrix}$$

When moving along x-axis,

$$v = \begin{bmatrix} 0.01 \\ 0 \\ 0 \end{bmatrix}$$

Jv will keep changing as the robot moves

References:

1. Links attached in the document
2. Codes from the GitHub repository
3. Robot Dynamics and Control, Spong and Vidyasagar