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MidSem-Exam ME 639

Q1) a) for point A(0.45,0.075,0.1)

```
Enter End-effector position 0.45 0.075 0.1
The Joint Angle q1 for PUMA Style is:  0.16514867741462683
The Joint Angle q3 for PUMA Style is:  0.5642311597275823
The Joint Angle q2 for PUMA Style is:  -0.5997787728460517
The end-effector coordinates of PUMA style are:  0.4562071897723664 0.07603453162872773 0.1
The Joint Angle q1 for Stanford Style is:  9.462322208025617
The Joint Angle q2 for Stanford Style is:  -18.20076026453332
The Joint length q3 for Stanford Style is:  0.23023431780746367
The end-effector coordinates for Stanford type are:  0.45620718977236646 0.07603453162872773 0.1
The Joint Angle q2 for SCARA Style is:  0.8433025087934816
The Joint Angle q1 for SCARA Style is:  -0.256502576982114
The Joint length q3 for SCARA Style is:  -0.15
The end-effector coordinates for SCARA type are:  0.45 0.075 0.1
```

For point B(0.45,-0.075,0.1)

```
Enter End-effector position 0.45 -0.075 0.1
The Joint Angle q1 for PUMA Style is:  -0.16514867741462683
The Joint Angle q3 for PUMA Style is:  0.5642311597275823
The Joint Angle q2 for PUMA Style is:  -0.5997787728460517
The end-effector coordinates of PUMA style are:  0.4562071897723664 -0.07603453162872773 0.1
The Joint Angle q1 for Stanford Style is:  -9.462322208025617
The Joint Angle q2 for Stanford Style is:  -18.20076026453332
The Joint length q3 for Stanford Style is:  0.23023431780746367
The end-effector coordinates for Stanford type are:  0.45620718977236646 -0.07603453162872773 0.1
The Joint Angle q2 for SCARA Style is:  0.8433025087934816
The Joint Angle q1 for SCARA Style is:  -0.5867999318113676
The Joint length q3 for SCARA Style is:  -0.15
The end-effector coordinates for SCARA type are:  0.45 -0.075 0.1
```

For point C(0.25,0.075,0.1)

```
Enter End-effector position 0.25 0.075 0.1
The Joint Angle q1 for PUMA Style is:  0.2914567944778671
The Joint Angle q3 for PUMA Style is:  1.8493860291865472
The Joint Angle q2 for PUMA Style is:  -1.4462986282824137
The end-effector coordinates of PUMA style are:  0.26100766272276377 0.07830229881682912 0.10000000000000003
The Joint Angle q1 for Stanford Style is:  16.69924423399362
The Joint Angle q2 for Stanford Style is:  -29.885800234718975
The Joint length q3 for Stanford Style is:  0.051039864469807406
The end-effector coordinates for Stanford type are:  0.26100766272276377 0.07830229881682912 0.1
The Joint Angle q2 for SCARA Style is:  2.0431685409237517
The Joint Angle q1 for SCARA Style is:  -0.7301274759840087
The Joint length q3 for SCARA Style is:  -0.15
The end-effector coordinates for SCARA type are:  0.24999999999999994 0.07500000000000001 0.1
```

For point D(0.25,-0.075,0.1)

```
Enter End-effector position 0.25 -0.075 0.1
The Joint Angle q1 for PUMA Style is:  -0.2914567944778671
The Joint Angle q3 for PUMA Style is:  1.8493860291865472
The Joint Angle q2 for PUMA Style is:  -1.4462986282824137
The end-effector coordinates of PUMA style are:  0.26100766272276377 -0.07830229881682912 0.10000000000000003
The Joint Angle q1 for Stanford Style is:  -16.69924423399362
The Joint Angle q2 for Stanford Style is:  -29.885800234718975
The Joint length q3 for Stanford Style is:  0.051039864469807406
The end-effector coordinates for Stanford type are:  0.26100766272276377 -0.07830229881682912 0.1
The Joint Angle q2 for SCARA Style is:  2.0431685409237517
The Joint Angle q1 for SCARA Style is:  -1.313041064939743
The Joint length q3 for SCARA Style is:  -0.15
The end-effector coordinates for SCARA type are:  0.24999999999999994 -0.07500000000000004 0.1
```

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Q1 b) For user-defined inputs of A,B,C and D.

```
Enter End-effector position A: 0.3 0.045 0.1
Enter End-effector position B: 0.3 -0.015 0.1
Enter End-effector position C: 0.26 -0.015 0.1
Enter End-effector position D: 0.26 0.045 0.1
The end-effector joint parameters for PUMA style are:  0.14888994760949725 -1.2865597242309434 1.6546947181180154
The end-effector coordinates of PUMA style are:  0.30335622624235026 0.04550343393635254 0.10000000000000003
The end-effector joint parameters for PUMA style are:  -0.04995839572194276 -1.2977258416963964 1.6691548433334658
The end-effector coordinates of PUMA style are:  0.3003747659175118 -0.015018738295875588 0.1
The end-effector joint parameters for PUMA style are:  -0.05762842747747396 -1.4485010481524019 1.8518831682182606
The end-effector coordinates of PUMA style are:  0.26043233286210084 -0.015024942280506251 0.09999999999999999
The end-effector joint parameters for PUMA style are:  0.17137912638950764 -1.4353773988734875 1.83692668414771
The end-effector coordinates of PUMA style are:  0.2638654960391752 0.04566902816062648 0.09999999999999998
The end-effector joint parameters for Stanfrd type are:  0.14888994760949725 -0.4592123651719358 0.08841542518035433
The end-effector coordinates for Stanford type are:  0.30335622624235026 0.04550343393635254 0.1
The end-effector joint parameters for Stanfrd type are:  -0.04995839572194276 -0.4631484200296635 0.08574543928399087
The end-effector coordinates for Stanford type are:  0.3003747659175118 -0.015018738295875588 0.1
The end-effector joint parameters for Stanfrd type are:  -0.05762842747747396 -0.5225594640432716 0.05054117854297441
The end-effector coordinates for Stanford type are:  0.26043233286210084 -0.015024942280506251 0.1
The end-effector joint parameters for Stanfrd type are:  0.17137912638950764 -0.5169140567996323 0.053521004215523804
The end-effector coordinates for Stanford type are:  0.26386549603917525 0.045669028160626485 0.1
The end-effector joint parameters for SCARA type are:  -0.7699880368676325 1.8377559689542595 -0.15
The end-effector coordinates for SCARA type are:  0.3 0.044999999999999984 0.1
The end-effector joint parameters for SCARA type are:  -0.9763163693824748 1.8527159473210641 -0.15
The end-effector coordinates for SCARA type are:  0.2999999999999993 -0.014999999999999986 0.1
The end-effector joint parameters for SCARA type are:  -1.0805611992300455 2.045865543505143 -0.15
The end-effector coordinates for SCARA type are:  0.26 -0.014999999999999986 0.1
The end-effector joint parameters for SCARA type are:  -0.8434901289576102 2.029738510694236 -0.15
The end-effector coordinates for SCARA type are:  0.26 0.04500000000000001 0.1
```

Q1 c) to trace out rectangle of 5cm with points A=(0.40,0.06,0.1), B=(0.40,0.01,0.1), C=(0.35,0.01,0.1), andD=(0.35,0.06,0.1)

```
Enter End-effector position A: 0.4 0.06 0.1
Enter End-effector position B: 0.4 0.01 0.1
Enter End-effector position C: 0.35 0.01 0.1
Enter End-effector position D: 0.35 0.06 0.1
The end-effector joint parameters for PUMA style are:  0.14888994760949723 -0.8851696682987094 1.0600826270863721
The end-effector coordinates of PUMA style are:  0.40447496832313373 0.06067124524847005 0.10000000000000003
The end-effector joint parameters for PUMA style are:  0.02499479361892016 -0.9046179420290408 1.091899934609392
The end-effector coordinates of PUMA style are:  0.40012498047485123 0.010003124511871282 0.09999999999999998
The end-effector joint parameters for PUMA style are:  0.028563657838759998 -1.1093916739127891 1.4092951796178457
The end-effector coordinates of PUMA style are:  0.3501428280002319 0.010004080800006625 0.10000000000000002
The end-effector joint parameters for PUMA style are:  0.16977827396833844 -1.0901026085347887 1.3808563007082255
The end-effector coordinates of PUMA style are:  0.35510561809129404 0.06087524881565041 0.09999999999999996
The end-effector joint parameters for Stanfrd type are:  0.14888994760949723 -0.3551283547555233 0.18139309220245986
The end-effector coordinates for Stanford type are:  0.40447496832313373 0.06067124524847005 0.1
The end-effector joint parameters for Stanfrd type are:  0.02499479361892016 -0.3586679747243447 0.17731721238442993
The end-effector coordinates for Stanford type are:  0.40012498047485 11 0.010003124511871278 0.10000000000000003
The end-effector joint parameters for Stanfrd type are:  0.028563657838759998 -0.4047440841038663 0.13091993909481814
The end-effector coordinates for Stanford type are:  0.3501428280002319 0.010004080800006625 0.10000000000000003
The end-effector joint parameters for Stanfrd type are:  0.16977827396833844 -0.3996744581806758 0.13548670534792762
The end-effector coordinates for Stanford type are:  0.355105618091294 0.0608752488156504 0.1
The end-effector joint parameters for SCARA type are:  -0.4795426595751927 1.25686521436938 -0.15
The end-effector coordinates for SCARA type are:  0.4 0.06 0.1
The end-effector joint parameters for SCARA type are:  -0.6180895978105604 1.2861687828589612 -0.15
The end-effector coordinates for SCARA type are:  0.4 0.010000000000000009 0.1
The end-effector joint parameters for SCARA type are:  -0.7664350954805546 1.5899975066386292 -0.15
The end-effector coordinates for SCARA type are:  0.35 0.010000000000000009 0.1
The end-effector joint parameters for SCARA type are:  -0.6112198326377974 1.5619962132122718 -0.15
The end-effector coordinates for SCARA type are:  0.35 0.06 0.1
```

Q1 d) not done

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Q1 e)

```
Enter End-effector position A: 0.4 0.06 0.1
Enter End-effector position B: 0.4 0.01 0.1
Enter End-effector position C: 0.35 0.01 0.1
Enter End-effector position D: 0.35 0.06 0.1
The end-effector joint parameters for PUMA style are:  0.14888994760949723 -0.8851696682987094 1.0600826270863721
The end-effector coordinates of PUMA style are:  0.40447496832313373 0.06067124524847005 0.10000000000000003
The end-effector joint parameters for PUMA style are:  0.02499479361892016 -0.9046179420290408 1.091899934609392
The end-effector coordinates of PUMA style are:  0.40012498047485123 0.010003124511871282 0.09999999999999998
The end-effector joint parameters for PUMA style are:  0.028563657838759998 -1.1093916739127891 1.4092951796178457
The end-effector coordinates of PUMA style are:  0.3501428280002319 0.010004080800006625 0.10000000000000002
The end-effector joint parameters for PUMA style are:  0.16977827396833844 -1.0901026085347887 1.3808563007082255
The end-effector coordinates of PUMA style are:  0.35510561809129404 0.06087524881565041 0.09999999999999996
The end-effector joint parameters for Stanford type are:  0.14888994760949723 0.7133207550585834 0.2848831648126533
The end-effector coordinates for Stanford type are:  0.4044749683231338 0.060671245248470056 0.09999999999999998
The end-effector joint parameters for Stanford type are:  0.02499479361892016 0.7186751839533975 0.2816013544000805
The end-effector coordinates for Stanford type are:  0.40012498047485123 0.010003124511871128 0.09999999999999998
The end-effector joint parameters for Stanford type are:  0.028563657838759998 0.7851941650237756 0.2450757517794625
The end-effector coordinates for Stanford type are:  0.3501428280002319 0.010004080800006625 0.09999999999999998
The end-effector joint parameters for Stanford type are:  0.16977827396833844 0.7781573632503707 0.2485980344927164
The end-effector coordinates for Stanford type are:  0.3551056180912941 0.060875248815650415 0.09999999999999998
The end-effector joint parameters for SCARA type are:  -0.4795426595751927 1.2568652143693 8 0.35
The end-effector coordinates for SCARA type are:  0.4 0.06 0.09999999999999998
The end-effector joint parameters for SCARA type are:  -0.6180895978105604 1.2861687828589612 0.35
The end-effector coordinates for SCARA type are:  0.4 0.010000000000000009 0.09999999999999998
The end-effector joint parameters for SCARA type are:  -0.7664350954805546 1.5899975066386292 0.35
The end-effector coordinates for SCARA type are:  0.35 0.010000000000000009 0.09999999999999998
The end-effector joint parameters for SCARA type are:  -0.6112198326377974 1.5619962132122718 0.35
The end-effector coordinates for SCARA type are:  0.35 0.06 0.09999999999999998
```

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Q1 f)

```
Enter End-effector position A: 0.4 0.06 0.1
Enter End-effector position B: 0.4 0.01 0.1
Enter End-effector position C: 0.35 0.01 0.1
Enter End-effector position D: 0.35 0.06 0.1
The wrist angles for PUMA style are:  0 3.141592653589793 0.3238029063971602
Final Rotation matrix is:  [[-1.00000000e+00  0.00000000e+00  1.16100471e-16]
 [ 0.00000000e+00  1.00000000e+00  3.89650931e-17]
 [-1.16100471e-16  3.89650931e-17 -1.00000000e+00]]
The end-effector coordinates of PUMA style are:  0.40447496832313373 0.06067124524847005 0.10000000000000003
The wrist angles for PUMA style are:  0 3.141592653589793 0.21227678619927148
Final Rotation matrix is:  [[-1.00000000e+00 -2.77555756e-17  1.19715809e-16]
 [-2.77555756e-17  1.00000000e+00  2.58016088e-17]
 [-1.19715809e-16  2.58016088e-17 -1.00000000e+00]]
The end-effector coordinates of PUMA style are:  0.40012498047485123 0.010003124511871282 0.09999999999999998
The wrist angles for PUMA style are:  0 3.141592653589793 0.3284671635438165
Final Rotation matrix is:  [[-1.00000000e+00  0.00000000e+00  1.15917465e-16]
 [ 0.00000000e+00  1.00000000e+00  3.95061897e-17]
 [-1.15917465e-16  3.95061897e-17 -1.00000000e+00]]
The end-effector coordinates of PUMA style are:  0.3501428280002319 0.010004080800006625 0.10000000000000002
The wrist angles for PUMA style are:  0 3.141592653589793 0.4605319661417752
Final Rotation matrix is:  [[-1.00000000e+00  5.55111512e-17  1.09705845e-16]
 [ 5.55111512e-17  1.00000000e+00  5.44263303e-17]
 [-1.09705845e-16  5.44263303e-17 -1.00000000e+00]]
The end-effector coordinates of PUMA style are:  0.35510561809129404 0.06087524881565041 0.09999999999999996
The wrist angles for Stanford type are:  -3.141592653589793 2.2841170818534797 0.14888994760949725
Final Rotation matrix is:  [[ 9.55990220e-01 -2.93398533e-01 -3.65873686e-17]
 [ 2.93398533e-01  9.55990220e-01  8.42891123e-17]
 [-3.65873686e-17 -7.79536949e-17  1.00000000e+00]]
The end-effector coordinates for Stanford type are:  0.4044749683231338 0.060671245248470056 0.09999999999999998
The wrist angles for Stanford type are:  3.141592653589793 2.289471510748294 0.024994793618920163
Final Rotation matrix is:  [[ 9.98750781e-01 -4.99687695e-02  5.47362916e-17]
 [ 4.99687695e-02  9.98750781e-01 -7.86486802e-17]
 [ 5.47362916e-17  7.99850940e-17  1.00000000e+00]]
The end-effector coordinates for Stanford type are:  0.4001249804748512 0.01000312451187128 0.09999999999999998
The wrist angles for Stanford type are:  3.141592653589793 2.3559904918186723 0.02856365783876
Final Rotation matrix is:  [[ 9.98368679e-01 -5.70962480e-02  8.88664404e-18]
 [ 5.70962480e-02  9.98368679e-01 -8.68716865e-17]
 [ 8.88664404e-18  8.35296571e-17  1.00000000e+00]]
The end-effector coordinates for Stanford type are:  0.3501428280002319 0.010004080800006625 0.09999999999999998
The wrist angles for Stanford type are:  -3.141592653589793 2.348953690045267 0.16977827396833847
Final Rotation matrix is:  [[ 9.42902458e-01 -3.33068993e-01  5.37707098e-18]
 [ 3.33068993e-01  9.42902458e-01  8.89046170e-17]
 [ 5.37707098e-18 -8.91777694e-17  1.00000000e+00]]
The end-effector coordinates for Stanford type are:  0.3551056180912941 0.060875248815650415 0.09999999999999998
The wrist angles for SCARA type are:  0 0 -2.364270098795606
```

```
Final Rotation matrix is:  [[-1.00000000e+00  2.77555756e-16  0.00000000e+00]
 [ 2.77555756e-16  1.00000000e+00  0.00000000e+00]
 [ 0.00000000e+00  0.00000000e+00 -1.00000000e+00]]
The end-effector coordinates for SCARA type are:  0.4 0.06 0.09999999999999998
The wrist angles for SCARA type are:  0 0 -2.4735134685413924
Final Rotation matrix is:  [[-1.  0.  0.]
 [ 0.  1.  0.]
 [ 0.  0. -1.]]
The end-effector coordinates for SCARA type are:  0.4 0.010000000000000009 0.09999999999999998
The wrist angles for SCARA type are:  0 0 -2.3180302424317185
Final Rotation matrix is:  [[-1.00000000e+00  5.55111512e-17  0.00000000e+00]
 [ 5.55111512e-17  1.00000000e+00  0.00000000e+00]
 [ 0.00000000e+00  0.00000000e+00 -1.00000000e+00]]
The end-effector coordinates for SCARA type are:  0.35 0.010000000000000009 0.09999999999999998
The wrist angles for SCARA type are:  0 0 -2.190816273015319
Final Rotation matrix is:  [[-1.00000000e+00 -1.66533454e-16  0.00000000e+00]
 [-1.66533454e-16  1.00000000e+00  0.00000000e+00]
 [ 0.00000000e+00  0.00000000e+00 -1.00000000e+00]]
The end-effector coordinates for SCARA type are:  0.35 0.06 0.09999999999999998
```

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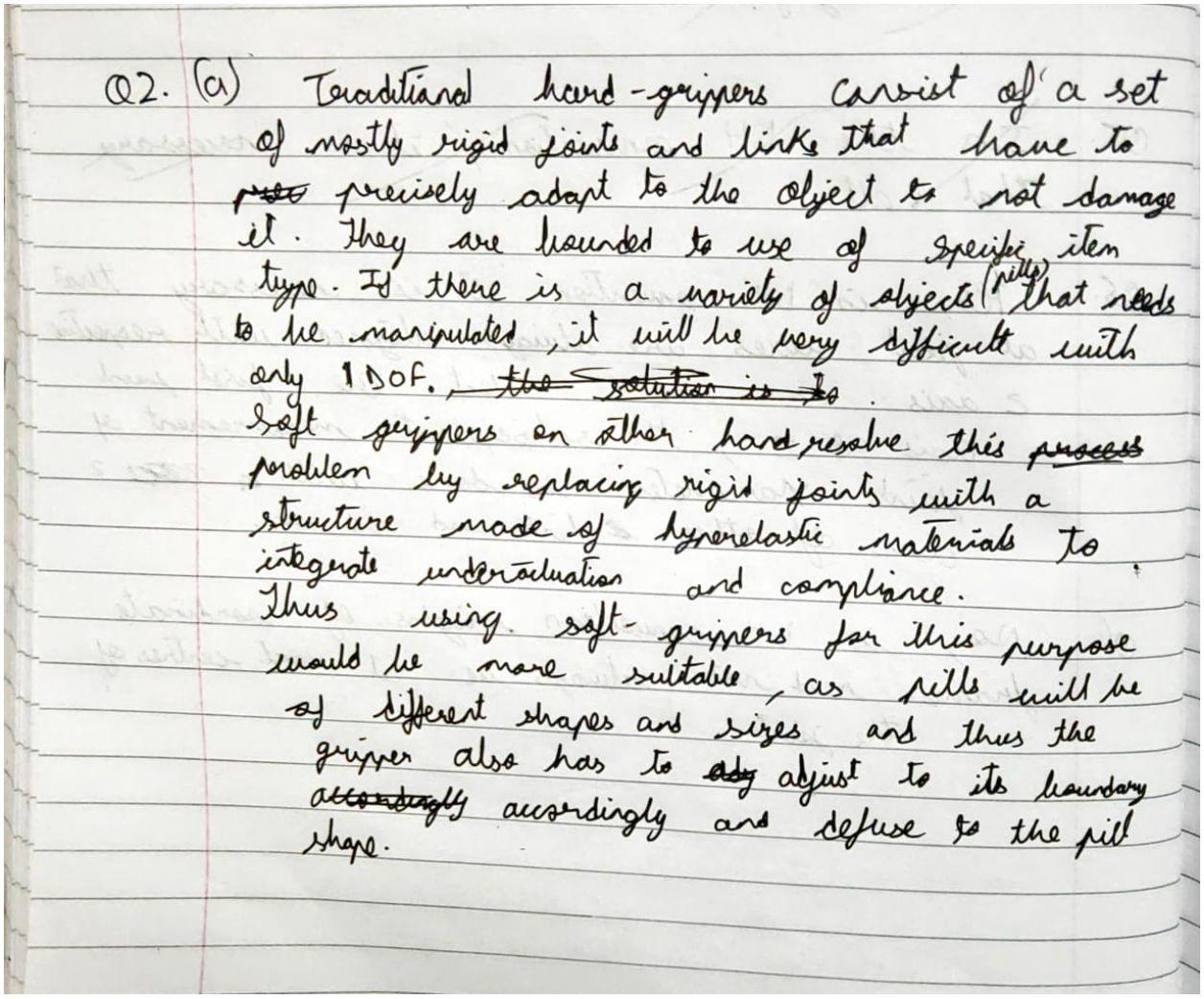
Q2 a)


Q2. (a) Traditional hard-grippers consist of a set of mostly rigid joints and links that have to ~~pose~~ precisely adapt to the object to not damage it. They are bounded to use of specific item type. If there is a variety of objects (pills) that needs to be manipulated, it will be very difficult with only 1 DOF. ~~the solution is to~~.
Soft grippers on other hand resolve this ~~process~~ problem by replacing rigid joints with a structure made of hyperelastic materials to integrate underactuation and compliance.
Thus using soft-grippers for this purpose would be more suitable, as pills will be of different shapes and sizes and thus the gripper also has to ~~adj~~ adjust to its boundary ~~accordingly~~ accordingly and deform to the pill shape.

Q2 b) Flexible Mechanisms: It is a compliance mechanism that achieves force and motion transmission through elastic body deformation. Traditionally machines are thought to be rigid and tough, and it's considered bad to have flexibility in your machines, thus flexible mechanisms is depicting how flexibility can be used in traditional machine tasks. Instead of relying solely on movable joints, this system derives at least some of its mobility from the deflection of flexible elements.
https://www.youtube.com/watch?v=058hRtaCWC0
https://www.youtube.com/watch?v=97t7Xj_iBv0
https://www.compliantmechanisms.byu.edu/about-compliant-mechanisms
https://en.wikipedia.org/wiki/Compliant_mechanism

Soft robotic Grippers: Soft robotic grippers, like underactuated, compliant hands, are adept at responding to changes in object size and shape. Soft robotic systems are also well-suited to gripping and manipulating fragile objects and complex shapes due to their ability to mold to the curvature of the object and distribute grabbing forces.

https://www.liebertpub.com/doi/full/10.1089/soro.2015.0019
https://www.youtube.com/watch?v=X0XGure7mak
https://www.youtube.com/watch?v=gI0tzsO8xwc

Universal Gripper: A universal gripper confirms all arbitrary shapes and is passive in that all shape adaptation is performed autonomously by the contacting material and without sensory feedback.
https://www.youtube.com/watch?v=0d4f8fEysf8
https://www.youtube.com/watch?v=oa_JfBXwnkk
https://www.wevolver.com/wevolver.staff/universal.robotic.gripper

Paper Grippers: The paper used in this type of gripper is optimized to hold the object using evolutionary techniques.
https://www.youtube.com/watch?v=UerxNyu147g
https://www.youtube.com/watch?v=0oqqXxeGVDg

Origami Grippers: It is an origami-inspired designed gripper that allows it to grasp a variety of objects, it is a soft-robot gripper that is both strong and flexible.
https://www.youtube.com/watch?v=byqGFH6AZuk
https://www.designboom.com/technology/origami-robot-gripper-mit-csail-03-14-2019/#:~:text=a%20team%20of%20technologists%20at,encased%20by%20an%20airtight%20skin.

Based on reviewing all the different types of grippers, I feel that a soft robotic gripper would be more suitable for the pill picking task, as it has high flexibility and can easily mold around the object boundary. In particular, I'll use the electromagnetic gripper it generates magnetic absorption force to pick up, hold, transfer the object and place it to another position, all this being done automatically by the robot.

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Q3 a)
L1(Hip-to-knee length): 45cm
L2(Knee-to-ankle length): 40cm
Gait Trajectory: Gait is the trajectory of the endpoint of the leg(ankle), while a person is moving. It includes the phase angle and the length optimization of L1 and L2.
Step Height: The step height in the gait cycle is defined as the height of the heel during the backward phase.
Step length: Step length is the distance between the point of initial contact of one foot and the point of initial contact of the opposite foot.

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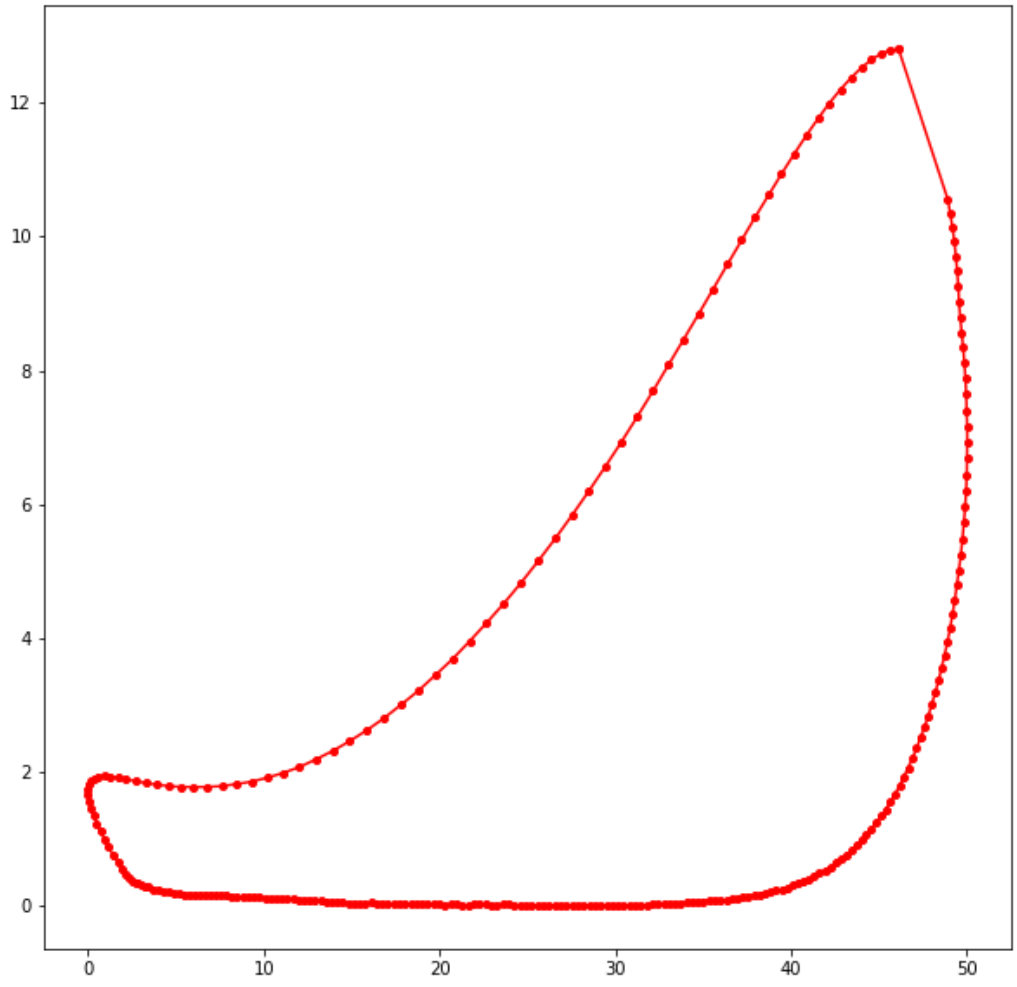
Q3 b)



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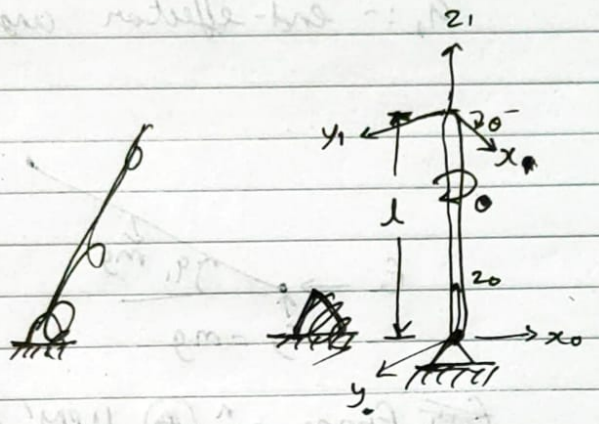
Q4 a)

Q4. (a)



For this link, the D-H parameters are defined as

D-H parameters:

	θ	a	α	d
link 1	θ^*	0	0	l

We have $T_1^0 = A_1 =$

$$\begin{bmatrix} C\theta^* & -S\theta^* & 0 & 0 \\ S\theta^* & C\theta^* & 0 & 0 \\ 0 & 0 & 1 & l \\ & 0 & 0 & 1 \end{bmatrix}$$

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Q4 b)

(b) For the joint to behave like a virtual torsional stiffness with linear characteristics

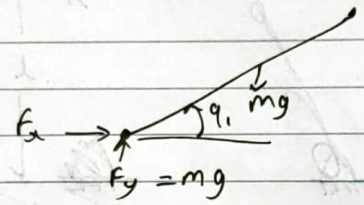
we first need to calculate Torque using Lagrange's equation:

$$\frac{d}{dt}\left(\frac{\partial L}{\partial \dot{q}_i}\right) - \frac{\partial L}{\partial q_i} = Q_i$$

Ignoring gravity,

$$\tau_1 = \frac{1}{3} m_1 l_1^2 \ddot{q}_1$$

$\ddot{q}_1$:- end-effector angular acceleration



~~For~~ From eq^n (4) HPM' Notes,

$$\tau_{1\,\text{PS}} = K(l_1 s q_1) l_1 c q_1$$

thus the motor torque

$$\tau = \tau_1 + \tau_{1s}$$

$$\boxed{\tau = \frac{1}{3} m_1 l_1^2 \ddot{q}_1 + \frac{K l_1^2 \sin 2q_1}{2}}$$

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05. Yes, in DH convention it is necessary that all joint axes are always aligned with respective z axis as we select the first joint axis as z, the subsequent measurement of joint parameter is done with z axis of other link and so on.

06. No, in DH convention origins of coordinate frames need not always be at centres of the joints.

In the case when the points z_i and z_{i-1} coincide, the origin of coordinate frames is not in the centre.

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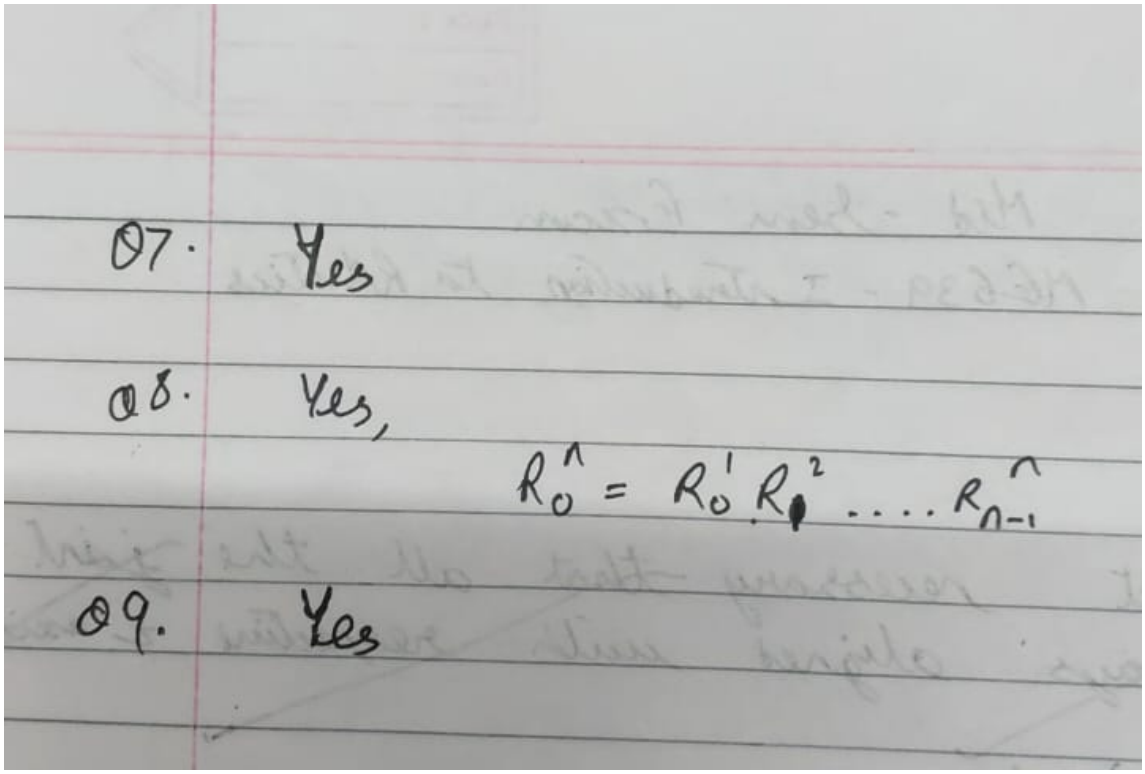

Q7. Yes

Q8. Yes,

$$R_0^{\wedge} = R_0^1 R_0^2 \ldots R_{n-1}^{\wedge}$$

Q9. Yes

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