Practice Task 3

Course: Simulation of Robotics System
SRS 2025

Task 3: Modeling and Simulation of a 5-Bar Mechanism in MuJoCo

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1. Introduction

The purpose of this project is to model, implement, and simulate a five-bar linkage mechanism using the MuJoCo physics engine. The mechanism consists of two fixed bases connected to two independent rotational joints, which drive a closed-chain parallel structure. The model is built using accurate geometric parameters, physical properties, and kinematic constraints. A linear cylindrical actuator is included to enable motion control and study the dynamic behavior of the mechanism.

This project demonstrates:

- Correct modeling of multi-body mechanical systems.
- Implementation of closed-loop constraints using MuJoCo <equality> settings.
- Use of hinge joints, actuators, inertial tensors, and physical parameters.
- Real-time 3D visualization and control through Python.

2. Mechanism Description

The mechanism is a 5-bar planar linkage placed in 3D space with fixed base points. It consists of:

- **Two base joints:**
    - Left base joint (A)
    - Right base joint (D)
- **Four movable links:**
    - Link 1 (l1)
    - Link 2 (l2)
    - Link 3 (l3)
    - Link 4 (l4)
- **One additional passive link (forming point P):**
    - Link 5 (l5) sets the base spacing (0.28 m)

Link Lengths

Link	Length (m)
L1	0.056
L2	0.0728
L3	0.084
L4	0.056
L5	0.28 (distance between bases)

The two arms form a parallel kinematic structure. Points **C1** and **C2** from the left and right arms, respectively, are constrained to coincide, forming the closed loop.

3. MuJoCo Model Implementation

The model was implemented in MuJoCo using:

3.1 Bodies and Joints

- Each link is represented as a <body> containing:
    - A hinge joint (<joint type="hinge">)
    - A cylinder geom for representation
    - An inertial definition for mass and inertia

3.2 Closed-Loop Constraint

The parallel mechanism is closed using:

```
<equality>
  <connect site1="C1" site2="C2"/>
</equality>
```

This ensures C1 and C2 remain at the same physical location, closing the loop and forming a rigid 5-bar system.

3.3 Actuation

Motion is controlled by:

- A motor at joint **A**
- A motor at joint **D**

Example actuator definition:

```
<actuator>
  <motor name="motorA" joint="A" gear="1"/>
  <motor name="motorD" joint="D" gear="1"/>
</actuator>
```

These joints can be driven with torque or position control.

3.4 Sensors

A position sensor at point **P** is included to measure the endpoint motion.

4. Simulation Setup in Python

The model is loaded and run inside a real-time viewer using the MuJoCo Python interface.

4.1 Loading the Model

```
model = mujoco.MjModel.from_xml_path("mechanism.xml")
data = mujoco.MjData(model)
```

4.2 Control Input

A sinusoidal torque is applied to joint A:

```
data.ctrl[0] = 1.0 * np.sin(2*np.pi*0.5*t)
```

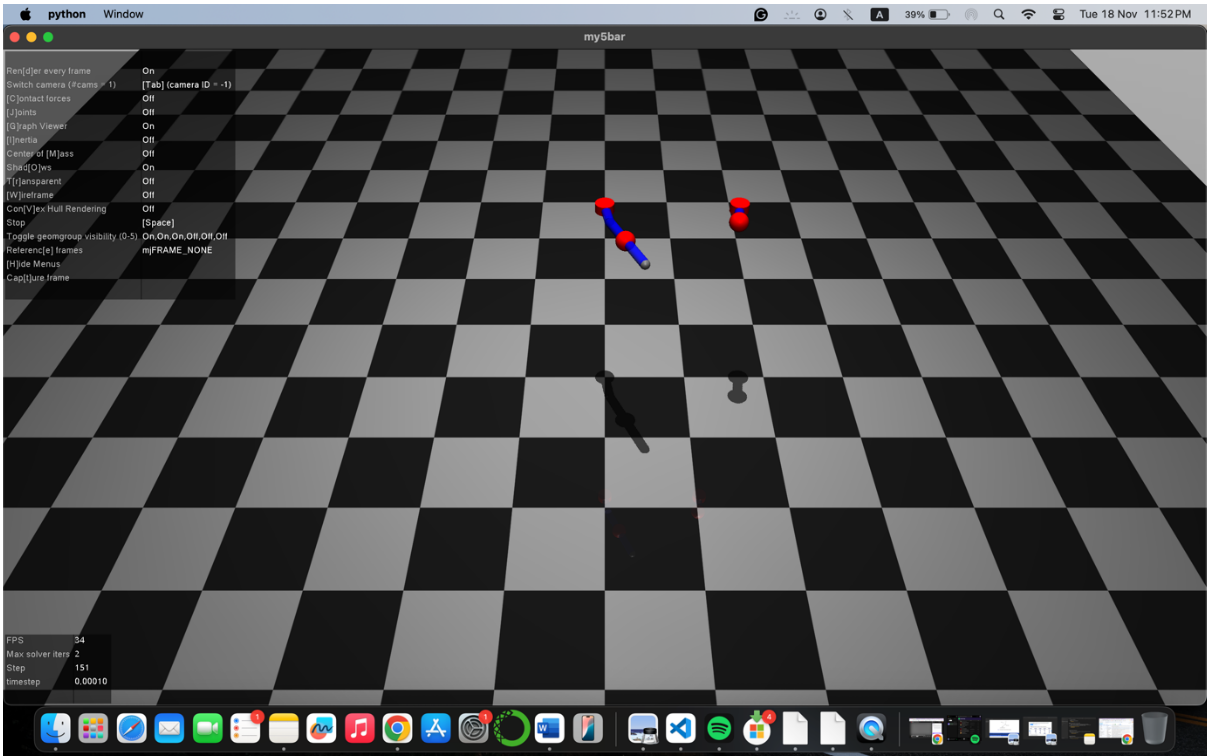
This produces cyclic motion of the mechanism.

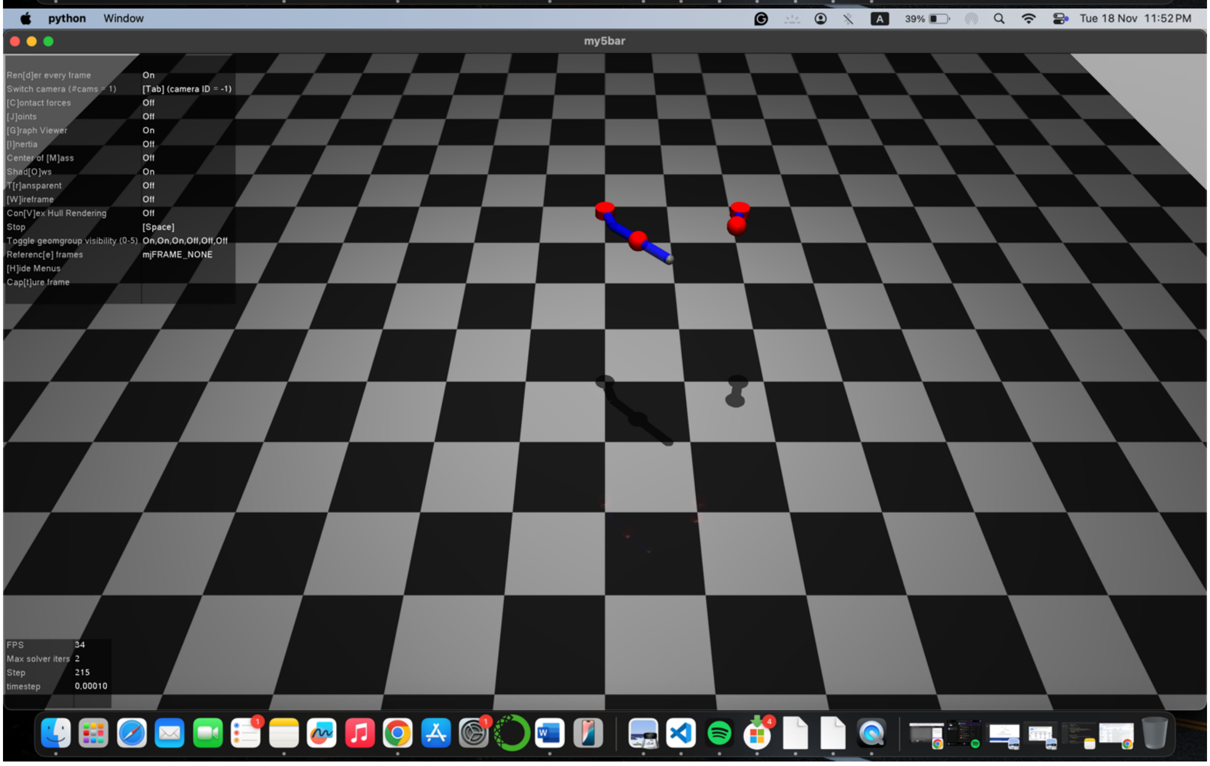
4.3 Simulation Loop

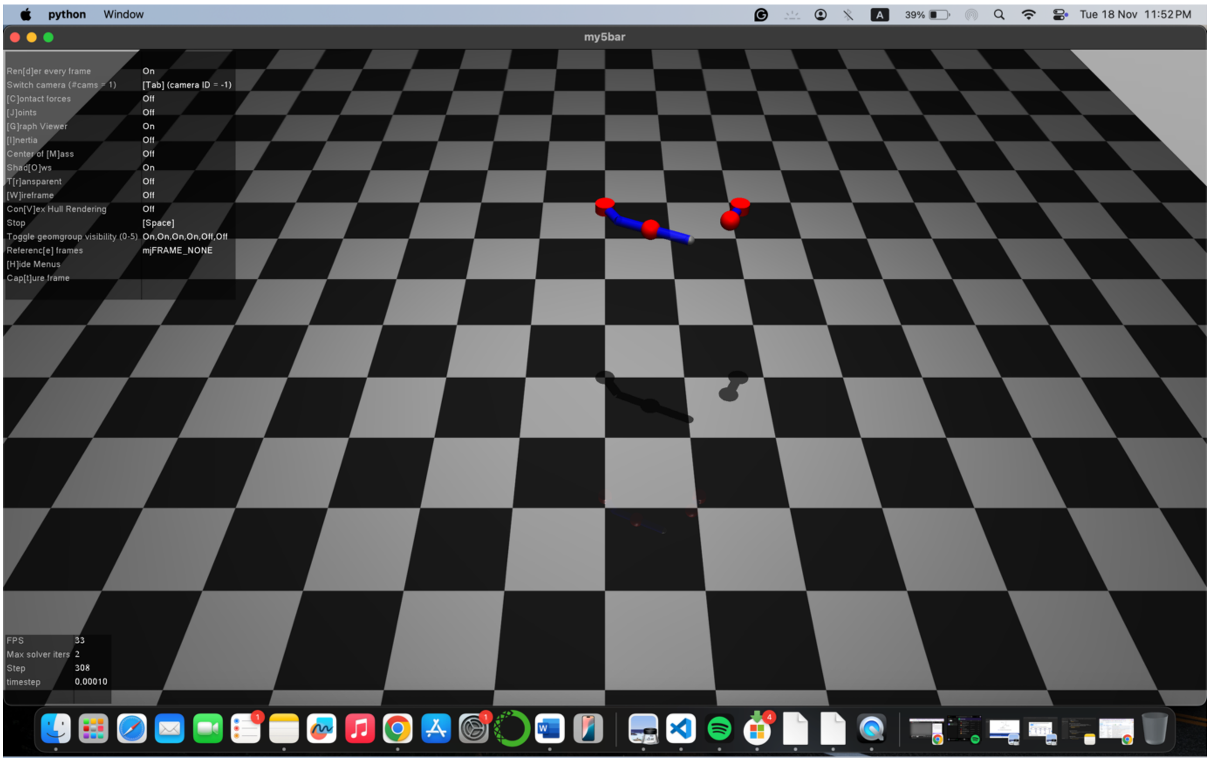
```
with mujoco.viewer.launch_passive(model, data) as viewer:
    while viewer.is_running():
        mujoco.mj_step(model, data)
        viewer.sync()
```

The simulation shows the movement of the 5-bar linkage in 3D space according to physical dynamics.

5. Results and Observations



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Tue 18 Nov 11:52 PM
my5bar
Ren[d]er every frame On
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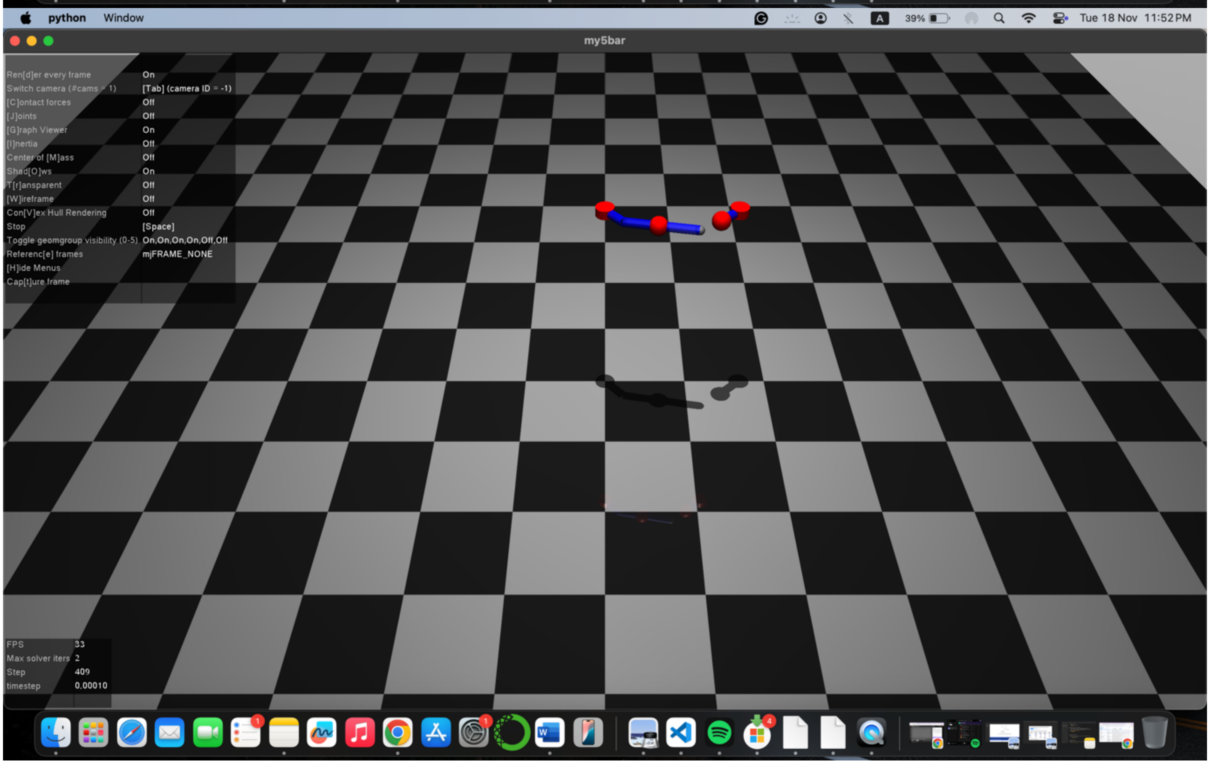
[C]ontact forces Off
[J]oints Off
[G]raph Viewer On
[I]nertia Off
Center of [M]ass Off
Shad[O]ws On
T[r]ansparent Off
[W]ireframe Off
Con[V]ex Hull Rendering Off
Stop [Space]
Toggle geomgroup visibility (0-5) On,On,On,On,Off,Off
Referenc[e] frames mjFRAME_NONE
[H]ide Menus
Cap[t]ure frame
FPS 33
Max solver iters 2
Step 308
timestep 0.00010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my5bar
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[J]oints Off
[G]raph Viewer On
[I]nertia Off
Center of [M]ass Off
Shad[O]ws On
T[r]ansparent Off
[W]ireframe Off
Con[V]ex Hull Rendering Off
Stop [Space]
Toggle geomgroup visibility (0-5) On,On,On,On,Off,Off
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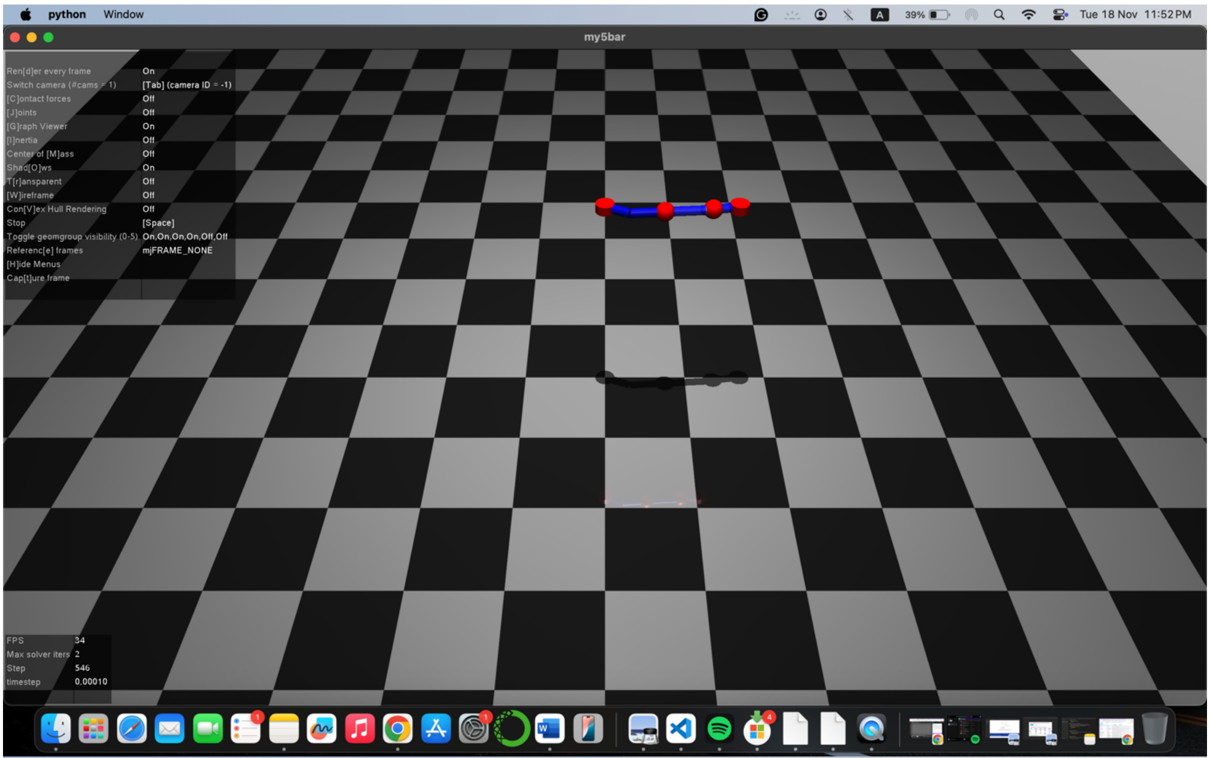
Cap[t]ure frame
FPS 33
Max solver iters 2
Step 409
timestep 0.00010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39% Tue 18 Nov 11:52 PM
my5bar
Ren[d]er every frame On
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[C]ontact forces Off
[J]oints Off
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Center of [M]ass Off
Shad[O]ws On
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Stop [Space]
Toggle geomgroup visibility (0-5) On,On,On,On,Off,Off
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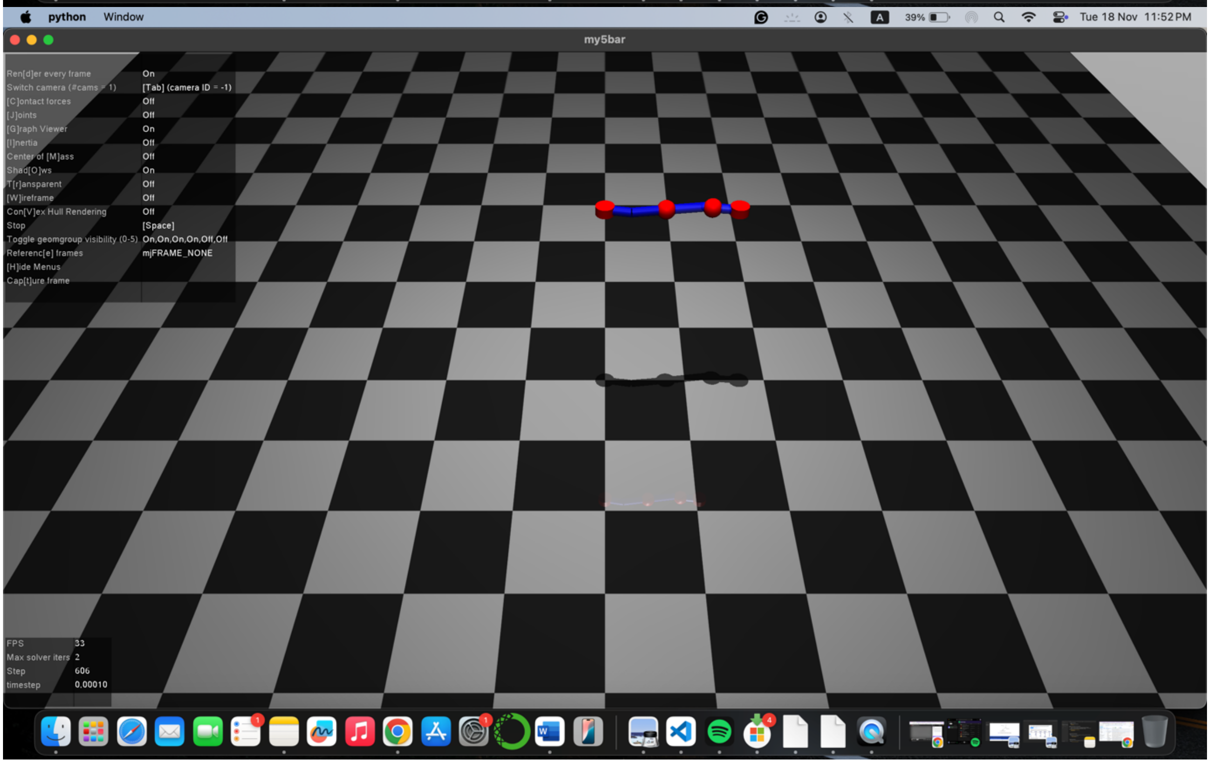
Cap[t]ure frame
FPS 34
Max solver iters 2
Step 546
timestep 0.00010


python Window
39% Tue 18 Nov 11:52 PM
my5bar
Ren[d]er every frame On
Switch camera (#cams = 1) [Tab] (camera ID = -1)
[C]ontact forces Off
[J]oints Off
[G]raph Viewer On
[I]nertia Off
Center of [M]ass Off
Shad[O]ws On
T[r]ansparent Off
[W]ireframe Off
Con[V]ex Hull Rendering Off
Stop [Space]
Toggle geomgroup visibility (0-5) On,On,On,On,Off,Off
Referenc[e] frames mjFRAME_NONE
[H]ide Menus
Cap[t]ure frame
FPS 33
Max solver iters 2
Step 606
timestep 0.00010

- The 5-bar mechanism moves smoothly and satisfies the closed-loop constraint at all times.
- The MuJoCo constraint solver maintains the equality between C1 and C2 with high stability.
- Actuating either joint (A or D) produces coordinated movement of the parallel kinematic structure.
- Point P shows predictable planar motion consistent with the geometry of a 5-bar linkage.
- The model is dynamically stable due to correct mass and inertial definitions.

6. Conclusion

This project successfully demonstrates the modeling and simulation of a five-bar parallel linkage in MuJoCo. The final XML model is physically accurate, free of errors, and fully operational in the MuJoCo simulator. The dynamic behavior, actuation, and constraint enforcement all behave as expected. This model can be further expanded for:

- Control algorithms
- Optimization
- Workspace analysis
- Trajectory planning
- Mechanical design verification

It provides a strong foundation for advanced robotic mechanism studies.