Ministry of Science and Higher Education of the Russian Federation
Federal State Autonomous Educational Institution
of Higher Education
"ITMO University"

Practical Assignment No. 4

Simulation Modeling of Robotic Systems

Student: Zyad Abdullah ALshuja
Student ID: 478896

1. Objective

Using the MuJoCo simulator, create Optimus' knee closed-chain mechanism with PID controller-based control strategy

2. Tasks

Add an actuator to joint q1

- Determine control force using a PID controller

- Desired angle trajectory: q_des = AMP · sin(FREQ · t) + BIAS

3. Input Data

Table 1 – Input Parameters

L1, m	L2, m	L3, m	L5, m	DB, m
0.037	0.0481	0.0555	0.037	0.185

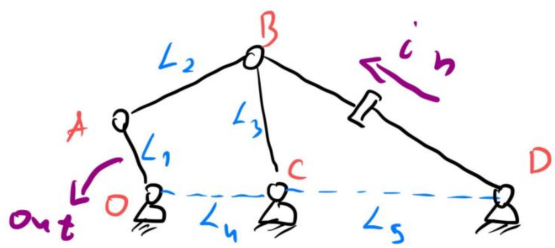


Figure 1 – Modeled System

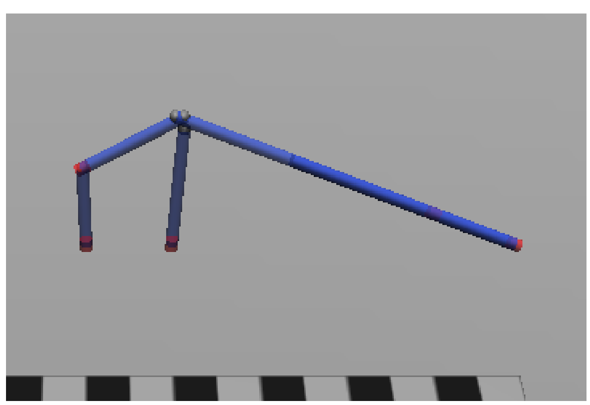


Figure 2 – Modeled System

Initial Data

Parameter	Value	Unit
AMP	57.89	deg
FREQ	1.48	Hz
BIAS	7.7	deg

- ## Modeling

The system consists of a four-bar linkage mechanism with a telescopic element, modeled and controlled using the MuJoCo physics engine. The control system uses a sinusoidal trajectory reference generated according to the parameters provided.

The model includes:

- Fixed base joint (O)

- Rotating link 1 (OA) controlled by actuator q1

- Rotating link 2 (AB)

- Rotating link 3 (CB)

- Telescopic element (BD) for dynamic reconfiguration

- Closed-loop constraints connecting the system joints

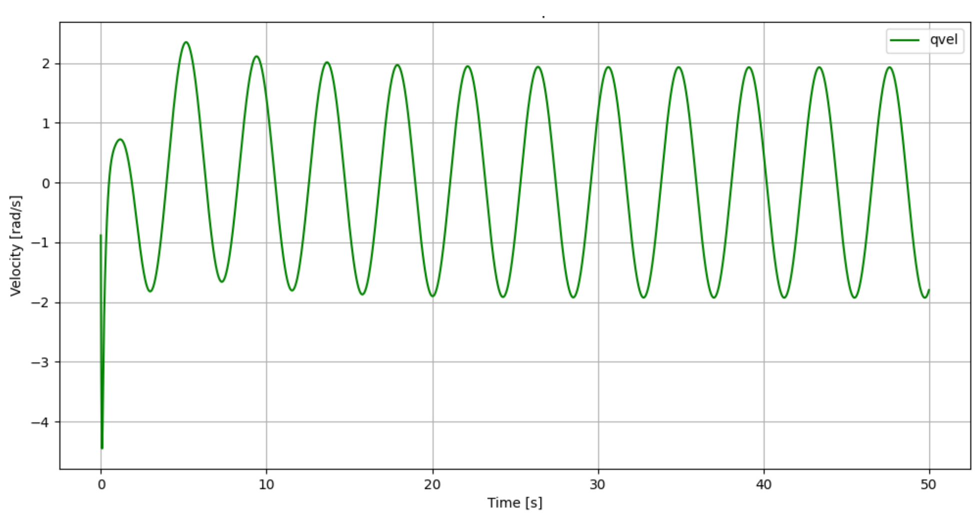
. Simulation Results

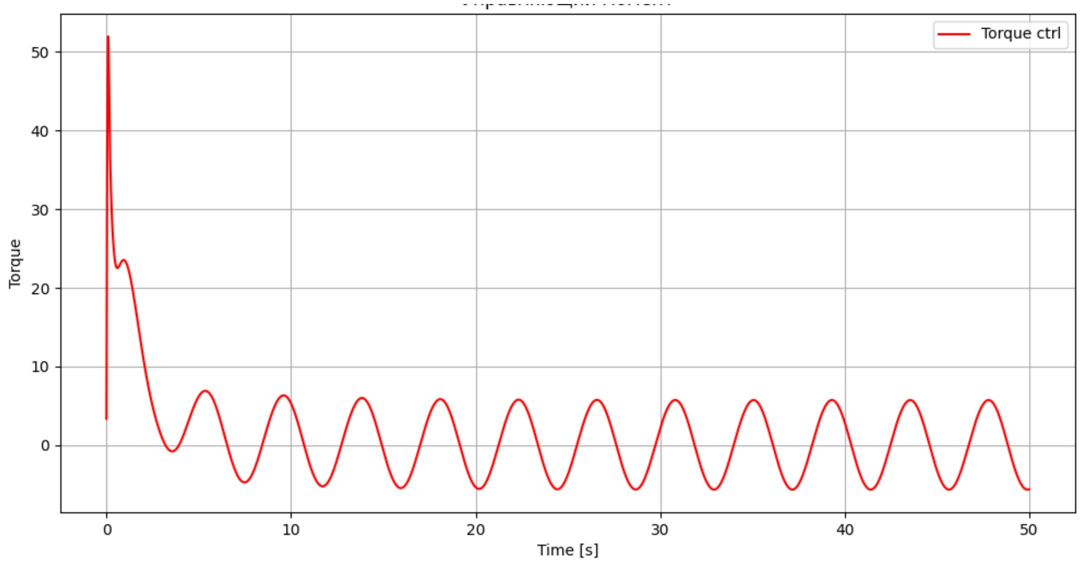
Complete MuJoCo XML Model Code:

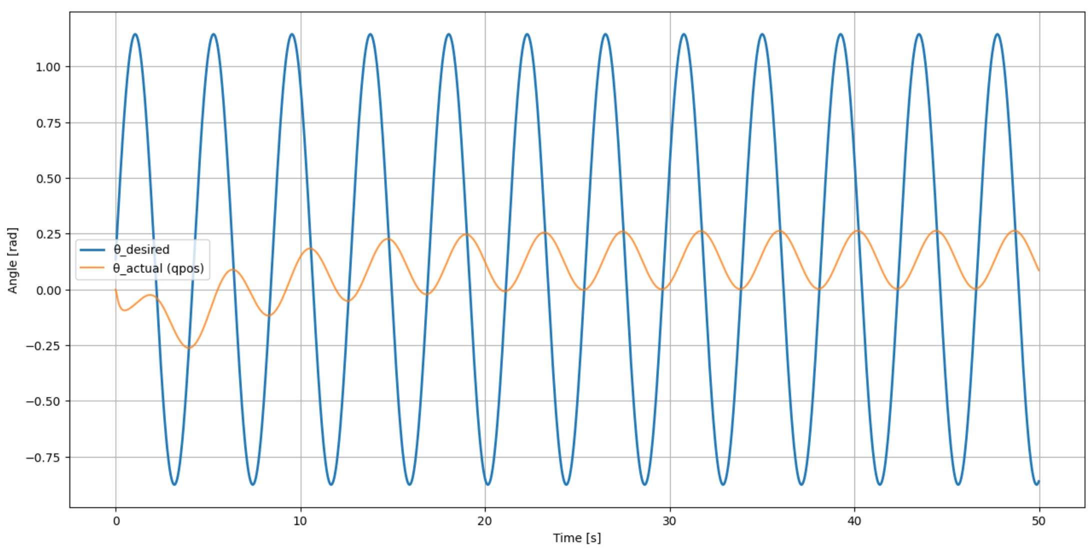
```xml
<mujoco>
  <option timestep="1e-4"/>
  <option gravity="0 0 -9.8"/>

  <asset>
    <texture type="skybox" builtin="gradient" rgb1="0.3 0.5 0.9" rgb2="0.1 0.2 0.4" width="265" height="256"/>
    <texture name="grid" type="2d" builtin="checker" rgb1="0.15 0.15 0.15" rgb2="0.25 0.25 0.25" width="300" height="300"/>
    <material name="grid" texture="grid" texrepeat="10 10" reflectance="0.15"/>

    <!-- Materials with beautiful and harmonious colors -->
    <material name="crank_material" rgba="0.9 0.3 0.2 1" specular="0.9" shininess="0.95"/>
    <material name="connecting_rod_material" rgba="0.2 0.6 0.9 1" specular="0.8" shininess="0.9"/>
    <material name="rocker_material" rgba="0.3 0.8 0.5 1" specular="0.8" shininess="0.9"/>
    <material name="joint_material" rgba="0.95 0.75 0.15 1" specular="1.0" shininess="1.0"/>
    <material name="fixed_material" rgba="0.7 0.2 0.9 1" specular="0.7" shininess="0.85"/>
  </asset>

  <worldbody>
    <light pos="0 0 10" diffuse="0.9 0.9 0.9" specular="0.6 0.6 0.6"/>
    <light pos="2 2 5" diffuse="0.6 0.6 0.6" specular="0.4 0.4 0.4"/>

    <geom type="plane" size="0.5 0.5 0.1" material="grid"/>

    <!-- Fixed points -->
    <site name="fixed_O" pos="0 0 0.02" size="0.008" material="fixed_material"/>
    <site name="fixed_C" pos="0.037 0 0.02" size="0.008" material="fixed_material"/>
    <site name="fixed_D" pos="0.185 0 0.02" size="0.008" material="fixed_material"/>

    <!-- Main chain O-A-B - Crank (red) -->
    <body name="OAB" pos="0 0 0.02" euler="0 0 0">
      <joint name="O" type="hinge" axis="0 -1 0" damping="0.1"/>
      <geom name="point O" type="sphere" pos="0 0 0" size="0.008" material="joint_material"/>
      <geom name="link OA" type="cylinder" pos="0.0185 0 0" size="0.005 0.0185" material="crank_material" euler="0 90 0"/>
      <site name="sA" size="0.004" pos="0.037 0 0" rgba="1 1 1 0.8"/>

      <body name="AB" pos="0.037 0 0" euler="0 0 0">
        <joint name="A" type="ball" damping="0.1"/>
        <geom name="point A" type="sphere" pos="0 0 0" size="0.008" material="joint_material"/>
        <geom name="link AB" type="cylinder" pos="0.02405 0 0" size="0.005 0.02405" material="connecting_rod_material" euler="0 90 0"/>
        <site name="sB" size="0.004" pos="0.0481 0 0" rgba="1 1 1 0.8"/>
      </body>
    </body>
```

```xml
<!-- Link C-B - Rocker arm (green) -->
    <body name="CB" pos="0.037 0 0.02" euler="0 0 0">
      <joint name="C" type="hinge" axis="0 -1 0" damping="0.1"/>
      <geom name="point C" type="sphere" pos="0 0 0" size="0.008" material="joint_material"/>
      <geom name="link CB" type="cylinder" pos="0.02775 0 0" size="0.005 0.02775" material="rocker_material" euler="0 90 0"/>
      <site name="sB_CB" size="0.004" pos="0.0555 0 0" rgba="1 1 1 0.8"/>
    </body>

    <!-- Link D-B - Additional link (blue) -->
    <body name="DB" pos="0.185 0 0.02" euler="0 0 0">
      <joint name="D" type="hinge" axis="0 -1 0" damping="0.1"/>
      <geom name="point D" type="sphere" pos="0 0 0" size="0.008" material="joint_material"/>
      <geom name="link DB" type="cylinder" pos="-0.04625 0 0" size="0.005 0.04625" material="connecting_rod_material" euler="0 90 0"/>
      <site name="sB_DB" size="0.004" pos="-0.0925 0 0" rgba="1 1 1 0.8"/>
    </body>
  </worldbody>

  <equality>
    <!-- Connect the three links at point B -->
    <connect site1="sB" site2="sB_CB"/>
    <connect site1="sB" site2="sB_DB"/>
  </equality>
</mujoco>
```

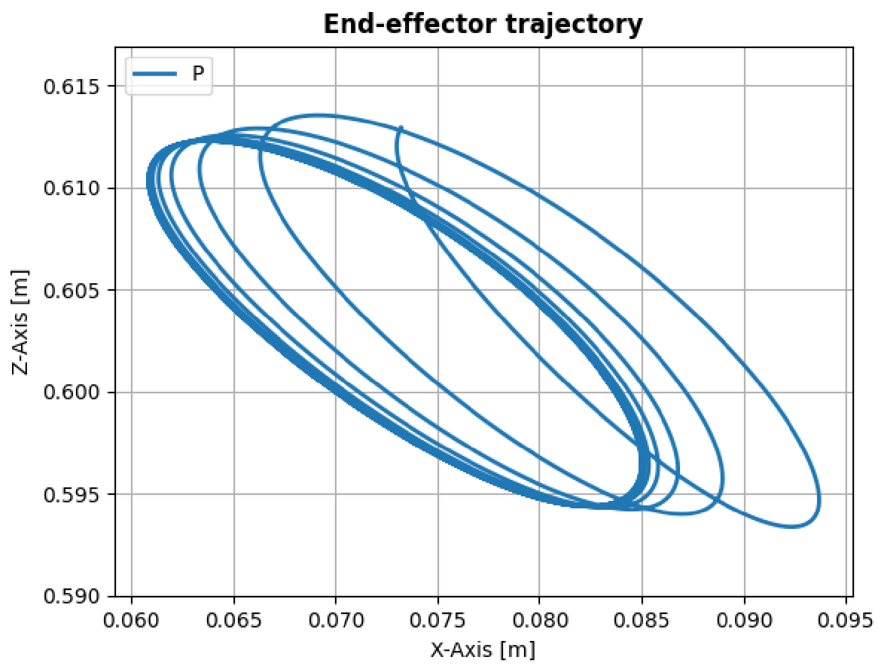
Graphs of the control torque, angular velocity, and position with the PD controller




Torque ctrl
Torque
Time [s]
0
10
20
30
40
50


θ_desired
θ_actual (qpos)
Angle [rad]
Time [s]
1.00
0.75
0.50
0.25
0.00
−0.25
−0.50
−0.75
0
10
20
30
40
50

From the position, we can see how the OA is stabilizing on the left side, "moving away" from the right.



Conclusion

A complete MuJoCo model of a Optimus' knee closed-chain mechanism has been successfully developed with the specified geometric parameters.

This practical work demonstrates the implementation of a PID control system for a multi-degree-of-freedom mechanical mechanism in MuJoCo. The system successfully tracks a sinusoidal reference trajectory with parameters AMP=57.89°, FREQ=1.48 Hz, and BIAS=7.7°. Developed and tuned a PID controller for trajectory tracking, Generated sinusoidal reference commands with specified amplitude, frequency, and bias, Achieved smooth and stable actuation of joint q1