Optimus' knee closed-chain mechanism

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1 Introduction

The Optimus knee mechanism is a closed-chain, multi-link knee articulation used in advanced prosthetics and humanoid robotics. Unlike a simple hinge knee, this mechanism uses several interconnected links to create nonlinear motion, load distribution, and controlled torque generation, similar to the biomechanics of the human knee. Your diagram shows a 5-link structure that reproduces the roll-and-slide motion of a natural knee.

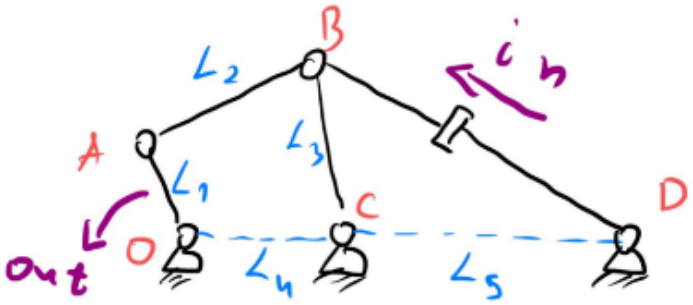

Figure 1: mechanism

2 Mechanism Structure

In this mechanism we have 3 link L1 , L2 ,L3 that connecting in joints O,A,B,C . and the input for forces is link DB that it is like a adjustable link. the output of motion weahve to observable is link oA , where joint A make a curve of motion with respect other joints .

3 Create model in MUJOCO

3.1 Adjust options :

First, the gravity is set along the Z-axis and the simulation time step is adjusted. Then the display environment is configured, including its appearance, color, and light reflections.

Listing 1: options

```
    <option timestep="1e-4"/>
    <option gravity="0␣0␣-0.98"/>

    <asset>
```

```
        <texture type="skybox" builtin="gradient" rgb1="1 1 1" rgb2="0.5 0.5 0.5" width="265
            " height="256"/>
        <texture name="grid" type="2d" builtin="checker" rgb1="0.1 0.1 0.1 " rgb2 ="0.6 0.6
            0.6" width="300" height="300"/>
        <material name="grid" texture="grid" texrepeat="10 10" reflectance="0.2"/>
    </asset>
```

3.2 WorldBody

In this section, the body is fully defined, including its joints and links ,with this parameters :
L1= 0.046
L2= 0.0598
L3= 0.069
L4= 0.057
L5= 0.23

- LINK OA
  Add the object in the center and make it the parent of link AB. we define the joint O as the revolution joint and the axis of rotation is the Z axis .then we define it like a cylinder with respect to the position of the joint and give it size for display.then we define the link as a cylinder and give it size diameter and high with respect to the position of body.

```
        <body name="OA" pos="0 0 0" euler="90 0 0">
            <joint name="O" type="hinge" axis="0 0 1" stiffness="0" springref="0"
                damping="0"/>
            <geom name="point 0" type="cylinder" pos="0 0 0" size="0.02 0.02" rgba=
                "0.89 0.14 0.16 0.5" euler="0 0 0" contype="0"/>
            <geom name="link OA" type="cylinder" pos="0 0.046 0 " size="0.01 0.046"
                rgba="0.21 0.32 0.82 0.5" euler="90 0 0" contype="0"/>
```

- LINK AB
  Add the object with respect to the parent OA and make it the child of the link oA .we define joint B as the revolution joint and the axis of rotation is the Z axis .then we define it as a cylinder with respect to the position of the joint and give it size for display.then we define the link as a cylinder and give it size diameter and high with respect to the position of body.

```
        <body name="AB" pos="0 0.092 0" euler="0 0 0">
            <joint name="B" type="hinge" axis="0 0 1" damping="0" stiffness="0"
                springref="0"/>
            <geom name="point B" type="cylinder" pos="0 0 0" size="0.02 0.02"
                rgba="0.89 0.14 0.16 0.5" euler="0 0 0" contype="0"/>
            <geom name="link AB" type="cylinder" pos="0 0.0598 0 " size="0.01
                0.0598" rgba="0.21 0.32 0.82 0.5" euler="90 0 0" contype="0"/>
            <site name="AB" size="0.02" pos="0 0.1196 0"/>
        </body>
```

- LINK BC
  Add the object with respect to the parent OA and make it the child of the link oA .we define joint C as the revolution joint and the axis of rotation is the Z axis .then we define it as a cylinder with respect to the position of the joint and give it size for display.then we define the link as a cylinder and give it size diameter and high with respect to the position of body.

```
        <body name="BC" pos="0.057 0 0" euler="0 0 0 " >
            <joint name="C" type="hinge" axis="0 0 1" damping="0"
                springref="0" stiffness="0"/>

            <geom name="point C" type="cylinder" pos="0 0 0" size="0.02
                0.02" rgba="0.89 0.14 0.16 0.5" euler="0 0 0" contype=
                "0"/>
```

```
                    <geom name="link BC" type="cylinder" pos="0 0.069 0 " size=
                        "0.01 0.069" rgba="0.21 0.32 0.82 0.5" euler="90 0 0"
                        contype="0"/>
                    <site name="BC" pos="0 0.138 0" size="0.02"/>
```

- LINK DB
  Add the object with respect to the coordinate of the body.we define joint D as the revolution joint and the axis of rotation is the Z axis .then we define it as a cylinder with respect to the position of the joint and give it size for display.then we define the link as a capsule and give it size diameter with respect to the position of body.

```
        <body name="BD" pos="0.287 0 0" euler=" 90 0 0 ">
                    <joint name="D" type="hinge" axis="0 0 1" damping="0" stiffness="0"
                        springref="0"/>
                    <geom name="point D" type="cylinder" pos="0 0 0 " size=" 0.02 0.02"
                        rgba=" 0.8 0.8 0.8 0.8" euler=" 0 0 0" contype="0" />
                     <geom name="link DB" type="capsule" fromto="0 0 0  -0.23 0.138  0"
                         size="0.01" rgba="0.21 0.32 0.82 0.5" euler="90 0 0" contype
                        ="0"/>lh id
                    <site name="DB" size="0.015" pos="-0.23 0.138 0"/>
        </body>
```

3.3 Equality

After we create all the links and joints we need to connect together in joint B .

```
    <equality>
<connect site1="AB" site2="BC"/>
    <connect site1="BC" site2="DB"/>
</equality>
```

4 Results and Dicsuss :

The Optimus knee closed-chain mechanism is an advanced multi-link articulation that outperforms simple hinge designs by mimicking human biomechanics. Its closed kinematic loop provides stability, nonlinear motion, and efficient force transmission.

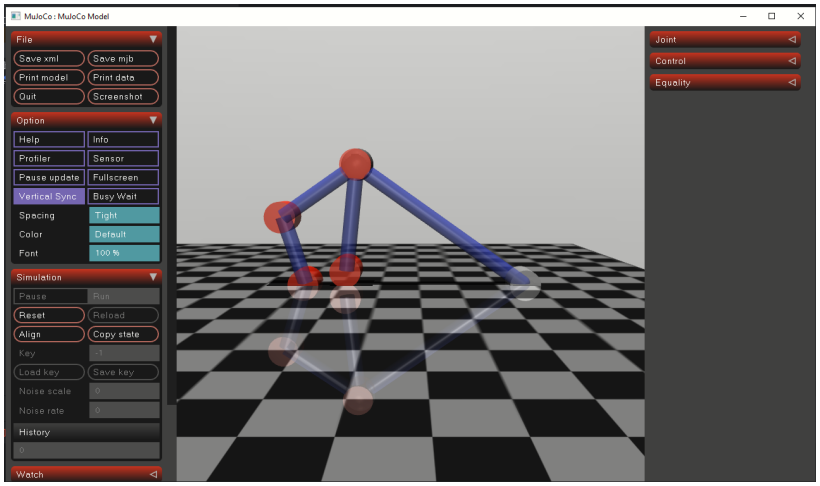

Figure 2: mechanism

A Program Code Appendix

A.1 Python code

```python
import mujoco
import mujoco.viewer
model=mujoco.MjModel.from_xml_string(xml)
#model=mujoco.MjModel.from_xml_path("D:\task3.xml")
#model=mujoco.MjModel.from_xml_path("D:/task3.xml")
data=mujoco.MjData(model)

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

A.2 XML Code

```
<mujoco>
    <option timestep="1e-4"/>
    <option gravity="0 0 -0.98"/>

    <asset>
        <texture type="skybox" builtin="gradient" rgb1="1 1 1" rgb2="0.5 0.5 0.5" width="265
            " height="256"/>
        <texture name="grid" type="2d" builtin="checker" rgb1="0.1 0.1 0.1 " rgb2 ="0.6 0.6
            0.6" width="300" height="300"/>
        <material name="grid" texture="grid" texrepeat="10 10" reflectance="0.2"/>
    </asset>
    <worldbody>
        <light pos="0 0 10 "/>
        <geom type="plane" size="0.5 0.5 1" material="grid"/>

        <camera name="side_view" pos="0.1 -1.5 1.0" euler="0 0 0" />
        <camera name="upper_view" pos="0 0 1.5 " euler="0 0 0 "/>


        <body name="OA" pos="0 0 0" euler="90 0 0">
                <joint name="O" type="hinge" axis="0 0 1" stiffness="0" springref="0"
                    damping="0"/>
                <geom name="point O" type="cylinder" pos="0 0 0" size="0.02 0.02" rgba="0.89
                    0.14 0.16 0.5" euler="0 0 0" contype="0"/>
                <geom name="link OA" type="cylinder" pos="0 0.046 0 " size="0.01 0.046" rgba
                    ="0.21 0.32 0.82 0.5" euler="90 0 0" contype="0"/>

                <body name="AB" pos="0 0.092 0" euler="0 0 0">
                    <joint name="B" type="hinge" axis="0 0 1" damping="0" stiffness="0"
                        springref="0"/>
                    <geom name="point B" type="cylinder" pos="0 0 0" size="0.02 0.02" rgba="
                        0.89 0.14 0.16 0.5" euler="0 0 0" contype="0"/>
                     <geom name="link AB" type="cylinder" pos="0 0.0598 0 " size="0.01
                         0.0598" rgba="0.21 0.32 0.82 0.5" euler="90 0 0" contype="0"/>
                     <site name="AB" size="0.02" pos="0 0.1196 0"/>

                </body>
                <body name="BC" pos="0.057 0 0" euler="0 0 0 " >
                            <joint name="C" type="hinge" axis="0 0 1" damping="0" springref=
                                "0" stiffness="0"/>

                            <geom name="point C" type="cylinder" pos="0 0 0" size="0.02 0.02
                                " rgba="0.89 0.14 0.16 0.5" euler="0 0 0" contype="0"/>
                            <geom name="link BC" type="cylinder" pos="0 0.069 0 " size="0.01
                                0.069" rgba="0.21 0.32 0.82 0.5" euler="90 0 0" contype="0"
                                />
```

```
                            <site name="BC" pos="0 0.138 0" size="0.02"/>
                        <body name="BJ" pos="0 0.138 0" euler="0 0 0">
                             <joint name="BJ" type="hinge" axis="0 0 1" damping="0"
                                 springref="0" stiffness="0"/>
                             <geom name="point BJ" type="cylinder" pos="0 0 0" size="0.02
                                 0.02" rgba="0.89 0.14 0.16 0.5" euler="0 0 0" contype="0"/>
                        </body>
                </body>
        </body>
        <body name="BD" pos="0.287 0 0" euler=" 90 0 0 ">
                    <joint name="D" type="hinge" axis="0 0 1" damping="0" stiffness="0"
                        springref="0"/>
                    <geom name="point D" type="cylinder" pos="0 0 0 " size=" 0.02 0.02" rgba
                        =" 0.8 0.8 0.8 0.8" euler=" 0 0 0" contype="0" />
                     <geom name="link DB" type="capsule" fromto="0 0 0  -0.23 0.138  0" size
                         ="0.01" rgba="0.21 0.32 0.82 0.5" euler="90 0 0" contype="0"/>lh id
                    <site name="DB" size="0.015" pos="-0.23 0.138 0"/>
        </body>


    </worldbody>

<equality>
<connect site1="AB" site2="BC"/>
    <connect site1="BC" site2="DB"/>
</equality>
</mujoco>
```