МИНИСТЕРСТВО НАУКИ И ВЫСШЕГО ОБРАЗОВАНИЯ

РОССИЙСКОЙ ФЕДЕРАЦИИ

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Физики наноструктур

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по дисциплине:

Simulation of Robotic Systems

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1. INPUT DATA OVERVIEW

The objective is to model the passive mechanisms of **Variant 1**, a tendon connected 2R planar mechanism.

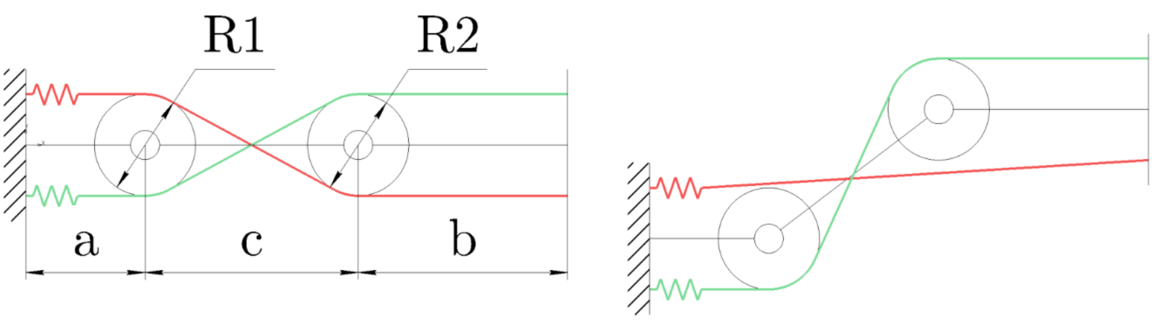

Figure 1: Variant 1 - Tendon connected 2R planar mechanism

1.1 Parameters

Parameter	Symbol	Value	Unit
Diameter R1	$R1$	0.0019	m
Diameter R2	$R2$	0.0012	m
Linkage 1 length	a	0.052	m
Linkage 3 Length	b	0.052	m
Linkage 2 length	c	0.044	m

Table 1: System Parameters

2. MUJOCO MODEL (XML)

2.1 Mechanism Structure (Bodies & Joints)

- **Links:** The mechanism consists of three main links.
  - **link_1**: The initial fixed link.
  - **link_2**: The second link, connected to link_1 via a **hinge joint** named **rotate_1**.
  - **link_3**: The third link, connected to link_2 via a **hinge joint** named **rotate_2**.
- **Degrees of Freedom (DOF):** The two joints, A and B, are hinge joints rotating about the Y-axis (axis="0 1 0"), providing 2 rotational degrees of freedom in the XZ plane (the working plane).

2.2 Pulley and Anchor System (Pulleys & Sites)

- Two cylinder geometries, **pulley_r1** and **pulley_r2**, are placed at joints A and B, representing the pulleys.
- Anchor points (sites) are set up to define the tendon path:
  - **Fixed Anchors: start_green** and **start_red** on the wall body (at the origin).
  - **Intermediate Anchors: mid_green** and **mid_red** are created to ensure the tendon follows the correct path between the two pulleys.
  - **End Anchors: end_green** and **end_red** on link_3.

2.3 Tendon System

- Two tendons, **tendon_green** and **tendon_red**, of the **spatial** type are used to model the winding of the cable around the pulleys.
- **Crossed Path:** The sidesite attributes (**side_r1_green/side_r1_red** and **side_r2_green/side_r2_red**) are used to force the tendons to wrap around the opposite sides of the pulleys, creating the antagonistic mechanism: when one tendon pulls, the other is either released or subjected to a different resistance.

2.4 Actuators and Constraints (Actuators & Equality)

- **Actuators:** Two **velocity** actuators (**motor_green** and **motor_red**) are applied directly to the tendon lengths. This allows controlling the retraction/release speed of each tendon.

- **Constraints (Equality):**
    - A **weld** constraint is used to fix the end position of link_3 to an independent body.
    - **connect** constraints are used to ensure the intermediate and end anchors move synchronously with the pulley centers, ensuring the tendon system functions as intended.

3. APPENDIX

Below is the code implemented in python to model the mechanism:

```
import mujoco
import mujoco.viewer
import time
import sys

# Define constant speeds for the tendon actuators
PULLEY_SPEED_1 = 0.06
PULLEY_SPEED_2 = -0.01
# Define geometric constants for the 2R mechanism and pulleys
# R1, R2: Diameter of the two pulleys
# a, b, c: Lengths of the linkage segments
R1, R2, a, b, c = 0.019, 0.012, 0.052, 0.044, 0.052

def generate_model_xml(R1: float, R2: float, a: float, b: float, c:
float):
    return f"""
        <mujoco model="2R_tendon_planar">

        <asset>
            <texture type="skybox" builtin="gradient" rgb1="1 1 1" rgb2="0.5
0.5 0.5" width="265" height="256"/>
        </asset>

        <option timestep="1e-4" integrator="RK4" gravity="0 0 -9.81"/>

        <worldbody>
            <body name="wall" pos="0 0 0" euler="0 90 0">
                <geom type="box" size="0.05 0.05 0.005" pos="0 0 0" rgba="0.5
0.5 0.5 1"/>
                <site name="start_green" pos="{R1 / 2} 0 0" type="sphere"
size="0.001" rgba="1 0 0 0.5" />
                <site name="start_red" pos="{-R1 / 2} 0 0" type="sphere"
size="0.001" rgba="0 1 0 0.5" />
            </body>

            <body name="green_mid" pos="{a + c / 2} 0 0">
                <site name="mid_green" pos="0 0 0" type="sphere"
size="0.001"/>
                <joint name="mid_joint_x_green" type="slide" axis="1 0 0"/>
                <joint name="mid_joint_y_green" type="slide" axis="0 0 1"/>
                <geom type="sphere" size="0.001" mass="0.0001" rgba="0 1 0
0.5" contype="0"/>
            </body>

            <body name="red_mid" pos="{a + c / 2} 0 0">
```

```
                <site name="mid_red" pos="0 0 0" type="sphere" size="0.001"/>
                <joint name="mid_joint_x_red" type="slide" axis="1 0 0"/>
                <joint name="mid_joint_y_red" type="slide" axis="0 0 1"/>
                <geom type="sphere" size="0.001" mass="0.0001" rgba="1 0 0
0.5" contype="0"/>
            </body>

            <body name="link_end" pos="{a + b + c} 0 0">
                <site name="end_link" pos="0 0 0" type="sphere" size="0.001"/>
                <joint name="end_x" type="slide" axis="1 0 0"/>
                <joint name="end_y" type="slide" axis="0 0 1"/>
                <geom type="box" size="0.002 0.002 {R2 / 2}" rgba="1 1 0 0.5"
mass="0.001" contype="0"/>
            </body>

            <body name="link_1" pos="0 0 0">
                <geom type="cylinder" pos="{a / 2} 0 0" size="0.0002 {a / 2}"
euler="0 90 0" rgba="0 1 1 0.5" contype="0"/>

                <body name="link_2" pos="{a} 0 0">
                    <joint name="rotate_1" type="hinge" axis="0 1 0"
stiffness="0" springref="0" damping="0"/>
                    <geom type="cylinder" pos="{c / 2} 0 0" size="0.0002 {c /
2}" euler="0 90 0" rgba="0 1 1 0.5" contype="0"/>

                    <geom name="pulley_r1" type="cylinder" size="{R1 / 2}
0.01" pos="0 0 0" euler="90 0 0" rgba="1 0 0 0.5" contype="0"/>
                    <site name="side_r1_green" pos="0 0 {-R1 / 2 - 0.0001}"
type="sphere" size="0.001"/>
                    <site name="side_r1_red" pos="0 0 {R1 / 2 + 0.0001}"
type="sphere" size="0.001"/>
                    <site name="pulley_r1_center" pos="0 0 0" type="sphere"
size="0.001"/>

                    <body name="link_3" pos="{c} 0 0">
                        <joint name="rotate_2" type="hinge" axis="0 1 0"
stiffness="0" springref="0" damping="0"/>
                        <geom type="cylinder" pos="{b / 2} 0 0" size="0.0002
{b / 2}" euler="0 90 0" rgba="0 1 1 0.5" contype="0"/>

                        <site name="end_green" pos="{b} 0 {R2 / 2}"
type="sphere" size="0.001"/>
                        <site name="end_red" pos="{b} 0 {-R2 / 2}"
type="sphere" size="0.001"/>
                        <geom name="pulley_r2" type="cylinder" size="{R2 / 2}
0.01" pos="0 0 0" euler="90 0 0" rgba="0 1 0 0.5" contype="0"/>
                        <site name="side_r2_green" pos="0 0 {R2 / 2 + 0.0001}"
type="sphere" size="0.001"/>
```

```
                        <site name="side_r2_red" pos="0 0 {-R2 / 2 - 0.0001}"
type="sphere" size="0.001"/>
                        <site name="pulley_r2_center" pos="0 0 0"
type="sphere" size="0.001"/>

                        <site name="end" pos="{b} 0 0" type="sphere"
size="0.001"/>
                    </body>
                </body>
            </body>
        </worldbody>

        <tendon>
            <spatial name="tendon_green" width="0.001" rgba="1 0 0 0.5"
stiffness="1" damping="10" springlength="0.005">
                <site site="start_green"/>
                <geom geom="pulley_r1" sidesite="side_r1_green"/>
                <site site="mid_green"/>
                <geom geom="pulley_r2" sidesite="side_r2_green"/>
                <site site="end_green"/>
            </spatial>

            <spatial name="tendon_red" width="0.001" rgba="0 1 0 0.5"
stiffness="1" damping="10" springlength="0.005">
                <site site="start_red"/>
                <geom geom="pulley_r1" sidesite="side_r1_red"/>
                <site site="mid_red"/>
                <geom geom="pulley_r2" sidesite="side_r2_red"/>
                <site site="end_red"/>
            </spatial>
        </tendon>

        <equality>
            <weld site1="end" site2="end_link" torquescale="100"/>
            <connect site1="mid_green" site2="pulley_r1_center"/>
            <connect site1="mid_green" site2="pulley_r2_center"/>
            <connect site1="mid_red" site2="pulley_r1_center"/>
            <connect site1="mid_red" site2="pulley_r2_center"/>
        </equality>

        <actuator>
            <velocity name="motor_green" tendon="tendon_green" gear="1"
ctrlrange="-1 1"/>
            <velocity name="motor_red" tendon="tendon_red" gear="1"
ctrlrange="-1 1"/>
        </actuator>
    </mujoco>
    """
```

```python
def main():
    # Generate the XML model
    xml = generate_model_xml(R1, R2, a, b, c)
    # Load the model and create the data structure
    model = mujoco.MjModel.from_xml_string(xml.encode("utf-8"))
    data = mujoco.MjData(model)
    # Set the test control signals for the actuators
    data.ctrl[0] = PULLEY_SPEED_1
    data.ctrl[1] = PULLEY_SPEED_2

    try:
        with mujoco.viewer.launch_passive(model, data) as viewer:

            while viewer.is_running():
                # Simulation step loop
                simstart = data.time
                while data.time - simstart < 1.0/60.0:
                    mujoco.mj_step(model, data)
                # Update the viewer's scene
                viewer.sync()
                # Sleep to maintain the real-time simulation rate
                time.sleep(model.opt.timestep - data.time % 
model.opt.timestep)

    except Exception as e:
        # Handle potential errors in the simulation process
        print(f"Error during simulation: {e}")
        sys.exit(1)

if __name__ == "__main__":
    main()
```

4. RESULTS

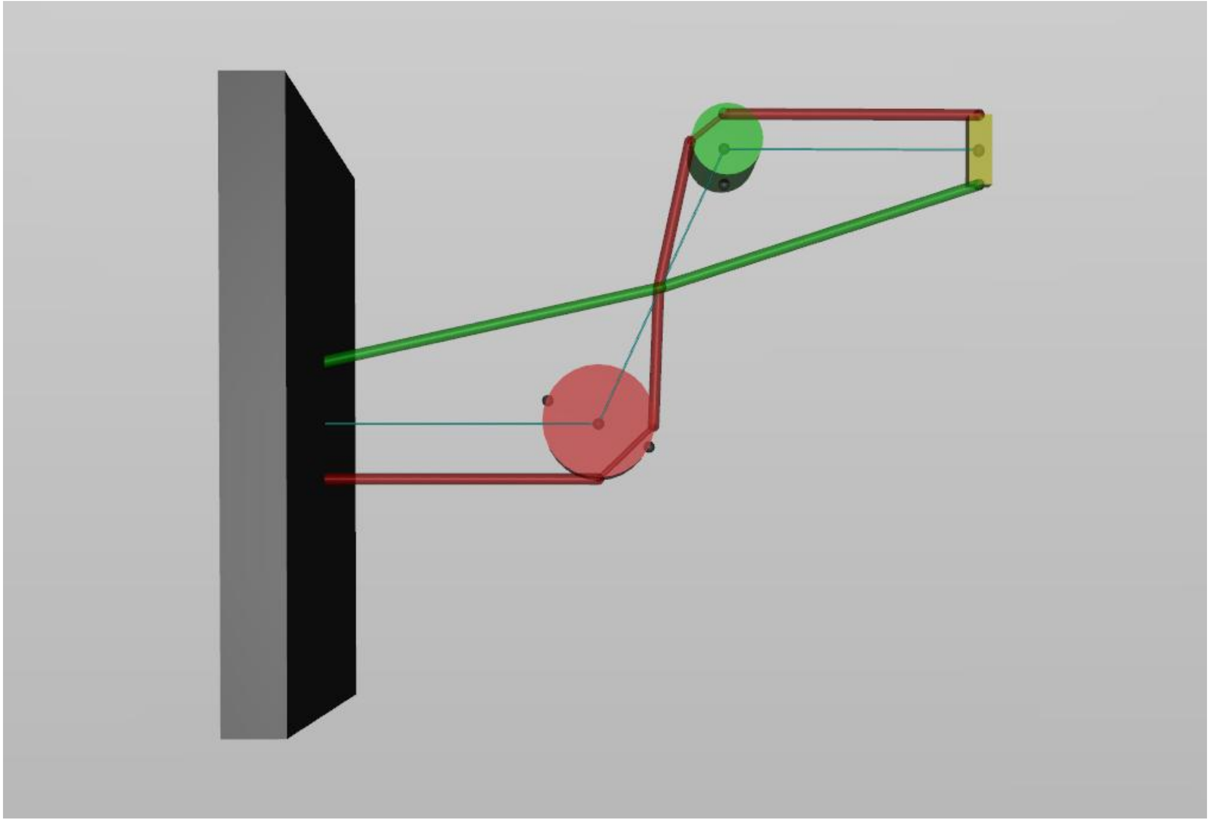

Figure 2: Tendon connected 2R planar mechanism in simulation

5. CONCLUSION

When running the simulation, the 2R mechanism exhibits kinematic motion generated by the tendon tension:

- **Tension Impact:** A positive velocity control signal (**PULLEY_SPEED_1** = 0.06) shortens the **tendon_green**, creating a pulling force. Conversely, a negative signal (**PULLEY_SPEED_2** = -0.01) reduces tension or releases the **tendon_red**.
- **Mechanism Response:** The tension differential between the two crossed tendons generates an **antagonistic torque** at joints **rotate_1** and **rotate_2**, forcing links **link_2** and **link_3** to rotate.
- **Stability:** The use of parameters like **stiffness**="1" and **damping**="10" in the tendon definition helps stabilize the system, preventing excessive physical oscillations.

The model successfully met the assignment requirements, simulating the planar 2R mechanism driven by an antagonistic tendon system.