RehaBot: The Paraplegic Rehabilitation Robot

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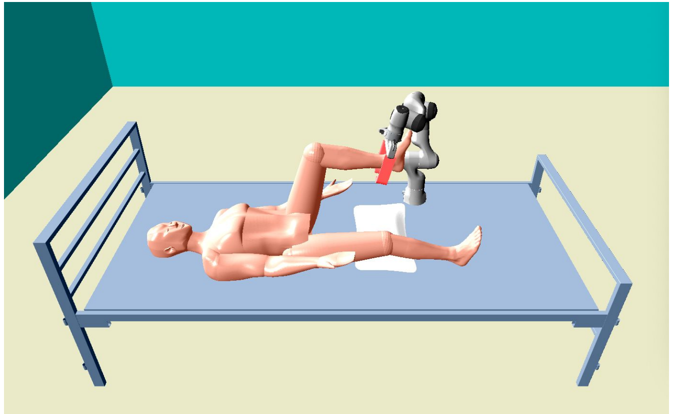


Stanford University

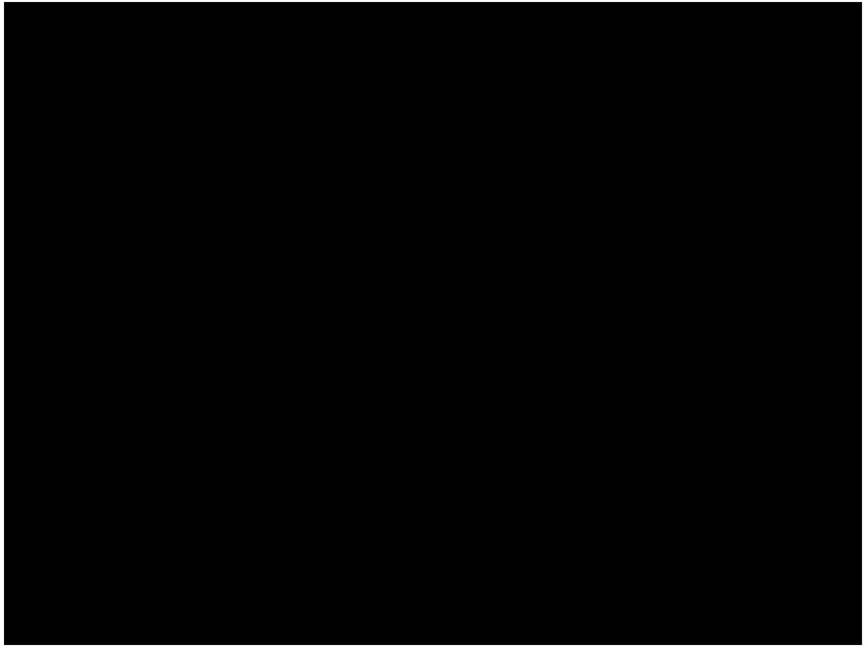
Introduction

Background

Background: The most important goal for paraplegic rehabilitation is to increase strength and prevent the atrophy of the muscles in the lower limbs.

Exercises

1. Knee to Chest
2. Straight Leg Raises



https://www.youtube.com/watch?v=DB9Ifjgfozw

Goal

Goal: Have a robot perform some of the repetitive physical therapy exercises on a patient in replacement of a caretaker or physical therapist

Benefits: Reduce strain on caregivers, make physical therapy accessible from home.

Implementation

State Machine

1) **Pre-approach Controller:**
   From initial position to desired orientation above the grabbing point

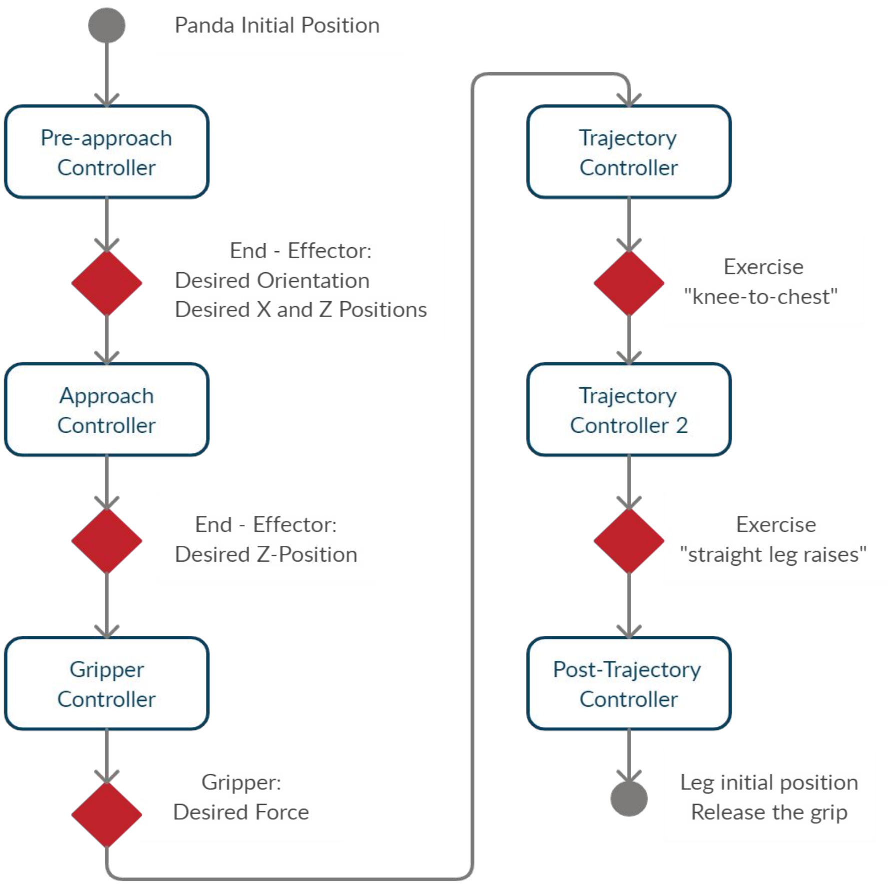
2) **Approach Controller:**
   Move toward the leg until the gripper surrounds the grabbing point

3) **Gripper Controller:**
   Use control force to close the gripper

4) **Trajectory Controller:**
   Execute the “knee-to-chest” exercise

5) **Trajectory Controller 2:**
   Execute the “straight leg raises” exercise

6) **Post-trajectory controller:**
   Return leg to starting position and release the gripper



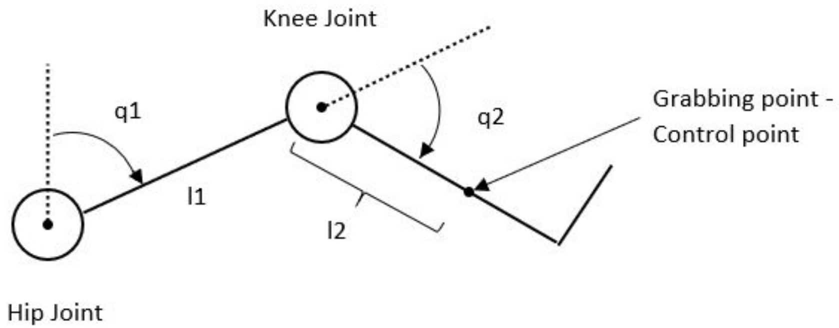
Trajectory Control

- “Knee-to-chest” exercise:

$$q_1 \in [-60^\circ, -10^\circ]$$
$$q_2 \in [-60^\circ, -90^\circ]$$

- “Straight leg raises” exercise:

$$q_1 \in [-80^\circ, -50^\circ]$$
$$q_2 = -10^\circ$$



Leg modeling

Transforming from Leg to World Frame

$$X_{leg} = \begin{bmatrix} -l_1 sin(q_1) - l_2 sin(q_1 + q_2) \\ 0.0 \\ l_1 cos(q_1) + l_2 cos(q_1 + q_2) \end{bmatrix} \rightarrow$$

$$X = X_{leg} - T_{world-leg}$$
$$X = R^{-1}_{world-leg} X$$
$$X = X + T_{world-robot}$$
$$X = R_{world-robot} X$$

Then we use the final desired X to control the end effector position.

Independent Gripper Control

We set:

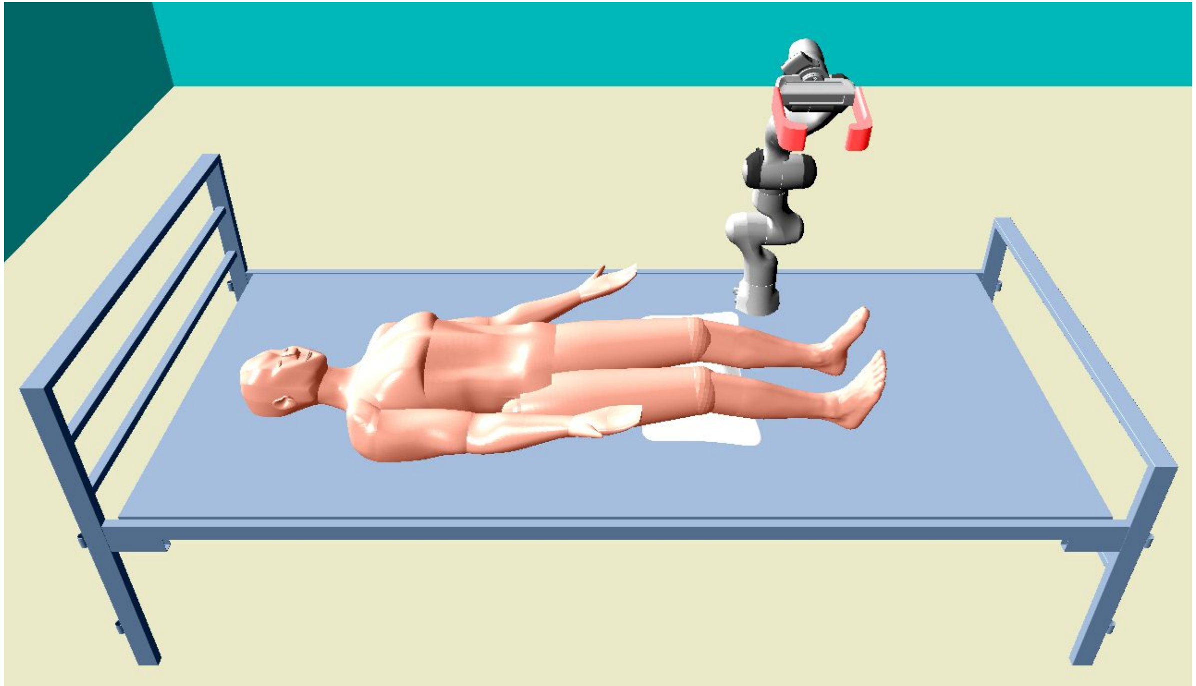
$$\Gamma_{gripper} = -k_p(x - x_{des}) - k_v v$$

when the gripper is open to control its position.

We use force control to close the gripper. When the force felt by both fingers exceeds a fixed constant, we move to the next state.

Design

Environment



Static Objects:

- Bed
- Torso/head of the patient

Dynamic Objects (Non-actuated):

- Human legs

Actuated:

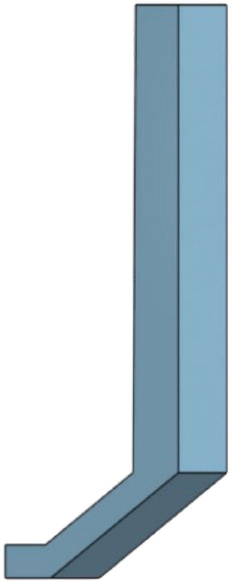
- Panda robot

End Effector

New End-Effector Design:

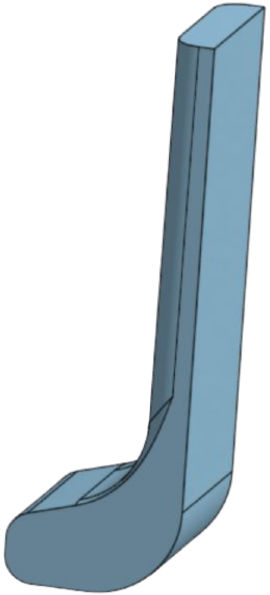
- 2 symmetric fingers
- Prismatic joints

Collision Mesh



- Adapted to the leg collision mesh
- 4 contact points

Visual Mesh



- Render the end-effector safer to the patient

Challenges

Gripper Control

Force sensors on both fingers:

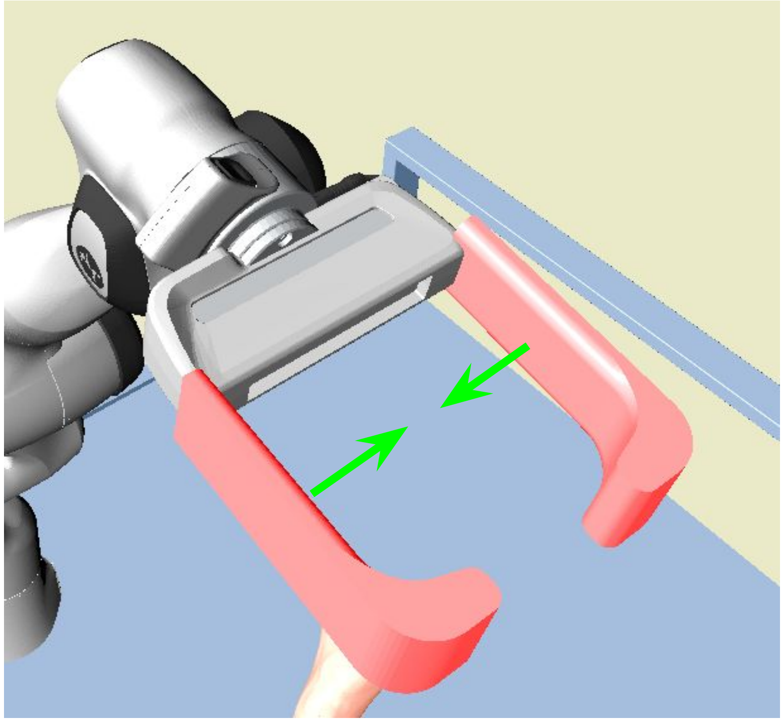
- Close until force is high enough (30 N)

What's a strong enough grip?

- Leg should not fall out
- Patient should not be hurt

In the real world:

- Modulate gripping strength based on patient comfort before starting



Human Leg Dynamics

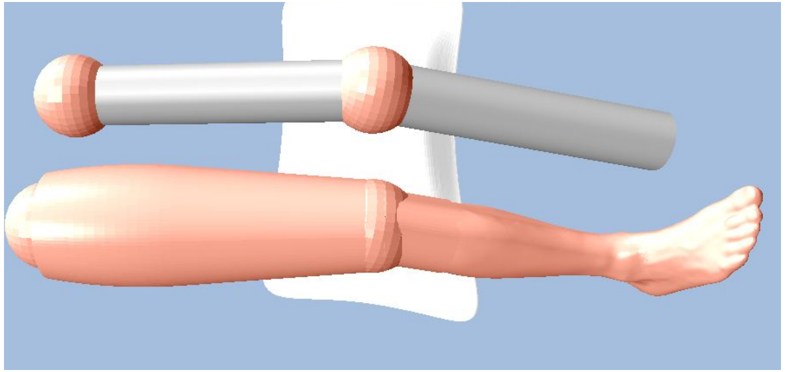


Fig. Collision mesh (top) vs visual mesh (bottom)

Hip joint = revolute in one axis
Knee joint = revolute in one axis

Spring constant at the knee to simulate joint limits.

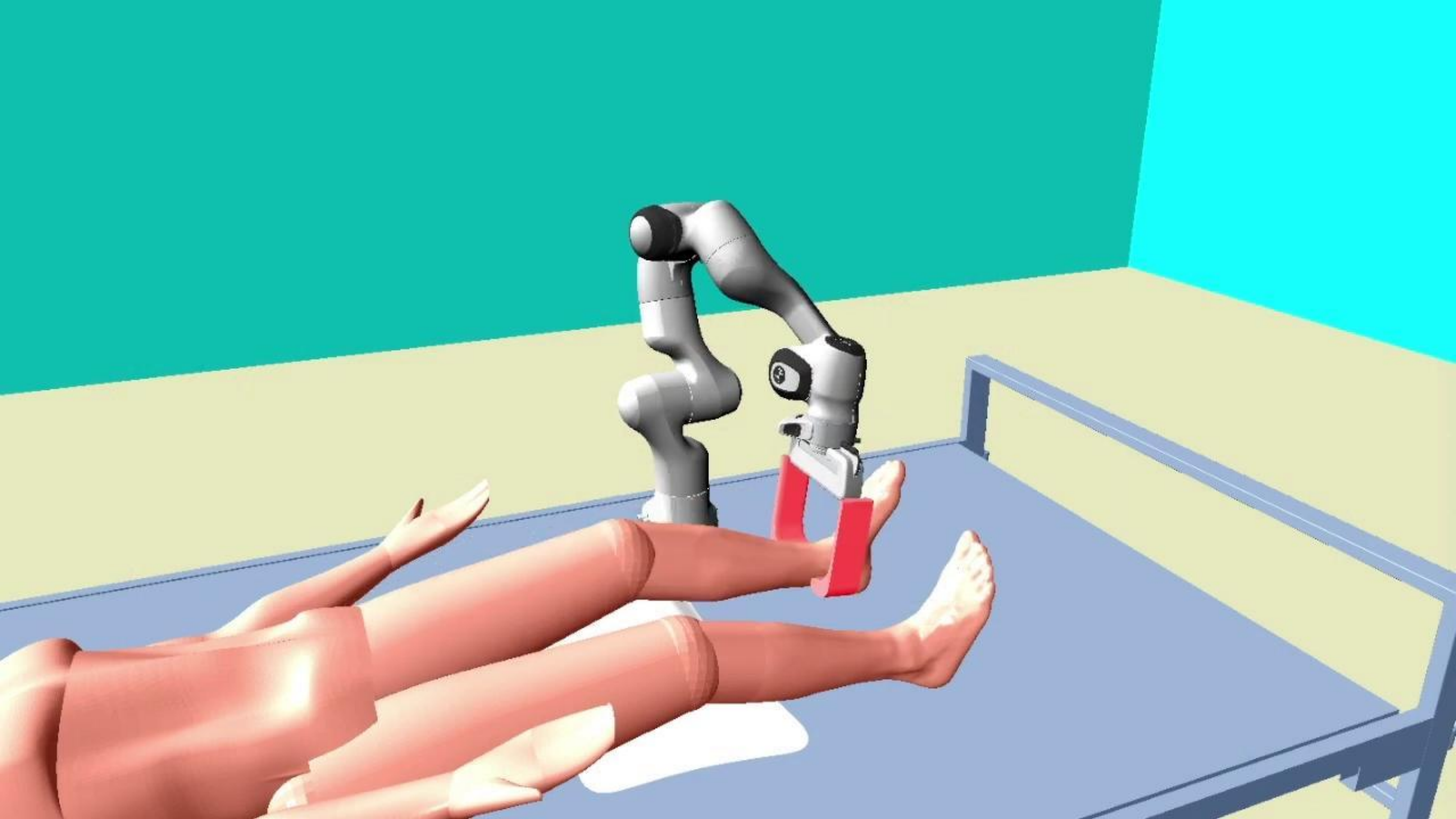
Collision Mesh:

- Two cylinders, 0.07 radius, 0.5 m
- Connected by a sphere at each revolute joint

Visual Mesh:

- Lower leg and upper leg meshes found on grabcad

$$\Gamma_{leg} = -k_{knee}(\theta_{knee} - \theta_{eq})$$



Future Work

Future Directions

- **Manual gripper strength calibration**:
  - patient determines the strength of the grip
- **External exercise switching controls**:
  - patient/caregiver decides when to switch to the next exercise
- **Emergency controls**:
  - stop all motion and safe release
- **Biologically accurate joint simulation**:
  - Hip joints are spherical, not hinge
- **Actuated leg simulation**:
  - Non-paraplegic patients can apply torques against robot EE
- **Add another robot for coordinated exercises:**
  - Bicycling, up/down motions, etc.
- **Exploring other therapy areas**

Thank you to Adrian, William, and Professor Khatib for their help and advice on this project!

Questions?