RehaBot: The Paraplegic Rehabilitation Robot

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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=DB9lfjgfozw
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:
  \[ q_1 \in [-80^\circ, -50^\circ] \]
  \[ q_2 = -10^\circ \]
Transforming from Leg to World Frame

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

\[ X = X_{\text{leg}} - T_{\text{world-leg}} \]
\[ X = R^{-1}_{\text{world-leg}} X \]
\[ X = X + T_{\text{world-robot}} \]
\[ X = R_{\text{world-robot}} X \]

Then we use the final desired \( X \) to control the end effector position.
Independent Gripper Control

We set:

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

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
- Adapted to the leg collision mesh
- 4 contact points
- 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

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

\[ \Gamma_{\text{leg}} = -k_{\text{knee}}(\theta_{\text{knee}} - \theta_{\text{eq}}) \]

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.
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**
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Questions?