Using Compliant Actuators in the Mechanical Design of Robots developed at the VUB

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Overview

• Classical approach: the stiffer the better
  → Good for tracking precision

• New generation: introducing compliance
  – Active compliance (using software)
    • No energy storage, limited bandwith
  – Passive compliance
    (containing passive element)
  → For energy efficiency and safety
• Fixed compliance
  \((\text{Series Elastic Actuator})\)
  – Only one motor
  – Natural dynamics of the system cannot be changed

• Adaptable compliance
  – Two motors required
  – Natural dynamics can be changed
Adaptable compliant actuators

- Equilibrium Controlled Stiffness
- Antagonistic Controlled Stiffness
- Structure Controlled Stiffness
- Mechanically Controlled Stiffness
Antagonistic Controlled Stiffness

- Requires non-linear springs
- Dependent position and stiffness setting
- 2 springs required (part energy of springs is transferred between two springs)

Energy efficiency: exploiting natural dynamics

- Choosing optimal stiffness reduces the energy consumption.
- Developed a compliance controller to select the optimal stiffness.

\[
\begin{align*}
\tilde{p}_1 &= p_m + \Delta \tilde{p} \\
\tilde{p}_2 &= p_m - \Delta \tilde{p}
\end{align*}
\]
MACCEPA 1.0:
Mechanically Adjustable Compliance and Controllable Equilibrium Position Actuator

Paper: Van Ham et al. MACCEPA, the mechanically adjustable compliance and controllable equilibrium position actuator: Design and implementation in a biped robot, Robotics and Autonomous Systems 07
• Shape of the profile disk determines torque-angle curve
• Maccepa 2.0 stiffening characteristic for hopping robots
Design torque-ankle curve

- Torque (Nm)
  - \[ y = 0.0174x^2 - 0.0341x \]
  - \( R^2 = 0.9998 \)

- Stiffness (Nm/deg)
  - \[ y = 0.0349x \]
  - \( R^2 = 0.9921 \)
Energy efficiency: energy storing capabilities

Energy is stored during one phase and released during next phase. Less powerful motor is needed.

Paper: Vanderborght et al MACCEPA 2.0: Adjustable Compliant Actuator with Stiffening Characteristic for Energy Efficient Hopping, ICRA 09
Human torque-ankle curve
Switchable MACCEPA

(a) Initial contact (IC) to Foot flat (FF).

(b) Foot flat (FF) to maximum dorsiflexion (10°).

(c) Maximum dorsiflexion (10°) to Toe off (TO, 20°).

(d) Swing phase of the gait cycle.
AMPfoot: an Ankle Mimicking Prosthetic foot
Passive compliance is a double-edged sword with respect to robot safety

- Passive actuators can store energy which is a potential danger if not properly controlled
- Use of proxy based sliding mode controller

<table>
<thead>
<tr>
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<th>Step</th>
<th>switch between trajectories</th>
<th>Tracking error for sinus</th>
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unsafe | safe

Paper: Van Damme et al. Proxy-Based Sliding Mode Control of a Planar Pneumatic Manipulator, IJRR 09
Huggable robot Probo

- Research platform for HRI studies with children
- 20 DOF in head to show emotions
- SEA in all DOF for safety and huggable aspect

http://probo.vub.ac.be
Safe and soft interaction

- Safe compliant actuators
- Soft and flexible materials
- Three layers of protection:
  - Plastic covers
  - Soft layer of foam
  - Removable jacket
Conclusion

• Different designs of adaptable compliant actuators
• Used for energy efficiency (exploit natural dynamics, store and release energy)
• Used for safety (decouples inertias of the links)
• Many open questions.
Thank you