Analysis, Design and Control of a new Generation of Compliant Actuators for Safe HRI

Matteo Laffranchi, Nikos Tsagarakis
and Darwin Caldwell

Istituto Italiano di Tecnologia (IIT)
Dept. of Advanced Robotics (AR)
Introduction

Compliance

- Safety
  - "Soft" collisions
  - Decouple link from the actuator

- Performance/Energy efficiency
  - Energy exchange/conversion
  - Potential energy exploitation
  - Stiffness variation
Introduction

Compliance

• **PROS**
  • Safety
  • Performance
  • Energy efficiency

• **CONS**
  • Precision
  • Bandwidth
  • Complexity, volume, weight
  • Oscillations

*(TO BE DAMPED)*

Analysis, Design and Control of a new Generation of Compliant Actuators for safe HRI

ICRA 2010, Anchorage, AK, May 3rd - 8th
State of the art

**COMPLIANCE**

- SEAs
  - Fixed (passive)
  - Variable (control)
- VSAs
  - Variable (passive)

**DAMPING**

- VPDA
  - Variable (passive)

---

*Tsagarakis, Laffranchi, et al, '09*

*Pratt, Williamson, '95*

*Wisse et al, 2007*

*Verrelst et al, '05*

*Schiavi, Bicchi, 2008*

*Wolf et al, 2008*

*Van Ham et al, 2007*

*Laffranchi, Tsagarakis, Caldwell, ICRA '10*

*A Variable Physical Damping Actuator (VPDA) for Compliant Robotic Joints, TuF2.3*
Development phases

1. Preliminary analysis
   Define a suitable configuration
   • task
   • stiffness range
   • dimension/weight
   • ...

2. Mechatronic Design and Development of the Actuator
   Mechanics
   • Introduce compliance
   • Introduce damping
   Electronics
   • Power
   • Control

3. Control
   Regulate impedance (how?)
   • Stiffness (?)
   • Damping

SPECS

COMPLEXITY:
VSA: 2X
VSA+damping : 3X
Development phases

1. Analysis between antagonistic and series actuation
   - Energy consumption

2. Design and control of the Compliant actuation unit
   - SEA
   - Fixed passive compliance
   - Variable active compliance

3. Design and control of the VPDA
   - introduces variable physical damping
   - to be used in compliant joints

Laffranchi, Tsagarakis, Cannella, Caldwell, IROS’09
Tsagarakis, Laffranchi, Vanderborght, Caldwell, ICRA’09
Laffranchi, Tsagarakis, Caldwell, ICRA ‘10
Antagonistic VS SEA - Models

• **ANTAGONISTIC**
  - Inverse Kinematics/Dynamics
    \[ q_1, q_2(k_{\text{tors}}, \theta, \dot{\theta}, \ddot{\theta}) \]

• **SEA**
  - Inspired by antagonistic
  - Inverse Kinematics/Dynamics
    \[ \theta_{\text{in}}, x(k_{\text{tors}}, \theta_{\text{out}}, \dot{\theta}_{\text{out}}, \ddot{\theta}_{\text{out}}) \]
Antagonistic VS SEA - Simulation

ANTAGONISTIC SIMULATOR

SERIAL SIMULATOR

• required work difference
• energy is retained in the springs
• SEA is more efficient (in this case!)

Analysis, Design and Control of a new Generation of Compliant Actuators for safe HRI
ICRA 2010, Anchorage, AK, May 3rd - 8th
Compliant Actuation Unit

Features

- Modular
- Small size
- Introduces “real” passive compliance
- Adjustable active compliance
- Provide full joint state measurement
  - Gearbox position
  - Outer link position
  - Joint torque
Compliant Actuation Unit

**Input pulley:** rigidly linked with the gear’s outer shaft

**Output three spoke part:** rigidly linked with the link

---

**Analysis, Design and Control of a new Generation of Compliant Actuators for safe HRI**

ICRA 2010, Anchorage, AK, May 3rd - 8th
Control Issues – effect of physical damping

Link position/Voltage TF

- Compliance → 2 mechanical poles: 180° phase lag
- 270° phase lag after mechanical poles: difficult to control
- Phase lag is more smooth with physical damping
  → Easier to control
VPDA

Motivation
• Facilitate control
  – Damp vibrations
  – Inherently passive
  – Damping action is not limited by the mechanical bandwidth of the joint actuator
• Manage energy of the spring

Principle & Features
• Semi-Active Solution
• Introduces “real” physical damping
• Piezoelectric actuation
VPDA - Mechanism

Ground

Torsion Spring

Outer Link

Contact Surfaces

Piezo Stacks

Ground

43x5x5 mm

9g
VPDA - Control

- Inner Force loop
- Outer Damping loop
  - Damping ratio
  - Viscous damping coefficient
- FFWD Block
  - Desired damping level
  - Link velocity

Laffranchi, Tsagarakis, Caldwell, ICRA ’10

A Variable Physical Damping Actuator (VPDA) for Compliant Robotic Joints, TuF2.3
Conclusions

1. Preliminary analysis phase
   • Actuator’s design should depend on:
     • task
     • objective criteria (energy exp., performances, safety..)
     • ...

2. Design
   • Introduction of
     • Compliance
     • (Damping)

3. Control
   • Regulate stiffness (active or passive)
   • Regulate damping (active or passive)
   • Satisfy Objective criteria

AFFECT FINAL PERFORMANCE

DEPENDS ON MECHANICAL CONSTRAINS

EXPLOIT THE VARIABILITY OF IMPEDANCE
Future work

• Implement VPDA in the Compliant Actuation Unit

• Design a Multi DOF damped compliant system

• Control integrated system
Acknowledgements

Work supported by
The European Commission project
Viactors

http://www.viactors.eu/
Special Issue on **Advances on Humanoid Robot Body-ware Design and Development**

**Editors:**
Nikos G. Tsagarakis  
Gordon Cheng  
Fethi Ben Ouezdou

**Manuscript due:**  
July 1, 2010
Thank you for your attention

Matteo Laffranchi
Advanced Robotics

Via Morego, 30 16163 Genova
tel: +39 010 71781481
e-mail: matteo.laffranchi@iit.it