Design of Robust and Force Sensitive Hydraulic Actuator for Humanoid Robot Systems

Hiroshi Kaminaga,
The University of Tokyo
Motivation

Some functionalities required for robots to become practical

- Produce Sufficient Force for Meaningful Tasks
- Safely Interact with Environment

High-Power Electronics and cooling

SHCAFT

- High-Power Output
- Robustness
- Force Sensitivity

Atlas, Petman, Bigdog, HyQ, CB

Torque Sensing

Hydraulics

Hydrostatic Actuation

DLR Biped

COMAN

DLR Hand-Arm

Elasticity

Backdrivability

Pressure Control

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Pressure Control
Force Controller

Force sensitive robots = robots that can react to force with high sensitivity
Are they equivalent?

Rigid body equation of motion with feedback

\[ M(q) \ddot{q} + c(q, \dot{q}) + g(q) = \tau + J^T f \]
\[ \tau = k(\dot{q}, q, q^{\text{ref}}) \]

Real robot

Controller

\[ \tau = k(\dot{q}, q) \]

Joint wise high-gain feedback

Reject disturbance, model error and dynamics of the robot mechatronics
Examples of difficult force control

Negative Work

Impact

Force measurement based admittance control
Force Controller

Force sensitive robots = robots that can react to force with high sensitivity
Force sensitivity, force measurement, and backdrivability

- Force sensitivity
  - Passive character
  - Active character
- SEA
  - [Pratt et al. 1995]
- EHA
  - [Humanoids2007]
- backdrivability
- Torque sensing
Backdrivability

Actuator can be driven from output axis
Electro-Hydrostatic Actuator

- Displacement control type hydraulics
- Hydraulics as gears

- Low friction in speed reduction
- No valve friction
- Force estimation with pressure sensors
- Whole actuator become backdrivable
Model of EHAs

\[
\begin{align*}
J_1 \ddot{\theta}_1 &= -k_{13} (k_{11} \dot{\theta}_1 - k_{12} \dot{\theta}_2) - \tau_{1f} + \tau_1 \\
J_2 \ddot{\theta}_2 &= -k_{23} (k_{21} \dot{\theta}_2 - k_{22} \dot{\theta}_1) - \tau_{2f} + \tau_2
\end{align*}
\]

Subscript 1: pump side
Subscript 2: output side

[ICRA 2009]
Abstract Model of Backdrivable Actuators

- Series Elastic Actuator

- Electro-Hydrostatic Actuators [ICRA2010]

Series damping actuator [Chew et al. 2004]
How EHAs work

Trochoid pump

Double vane motor
Previous Studies on EHA

[Humanoids2007] [Humanoids2009]
[ICRA2009] [IROS2011] [IROS2013]

Backdrivability
Scalability
System Integration
Recent Design of Rotary EHA

[Odanaka 2012]
Force-sensitive Joint Mechanism Impedance control
Nakamura Takano Lab.

Compliance: off
Friction compensation: on
Inertia scaling: 5:1
Singular perturbation method: on
Recent Design of Rotary EHA

[Odanaka 2012]
Linear EHA

To be presented Nov. 20

Related work: S. Alfayad et al. 2011

<table>
<thead>
<tr>
<th>Item</th>
<th>Value</th>
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<tbody>
<tr>
<td>Max. Force</td>
<td>1500N</td>
</tr>
<tr>
<td>Max. Speed</td>
<td>0.27m/s</td>
</tr>
<tr>
<td>Pos. Control BW</td>
<td>&gt;2Hz</td>
</tr>
<tr>
<td>Stroke</td>
<td>50mm</td>
</tr>
<tr>
<td>Weight (Pump+Cyl.)</td>
<td>0.35+0.44kg</td>
</tr>
</tbody>
</table>
Cluster of small EHAs

Kang et al. To be presented Nov. 19
Linear EHA Frequency Response Test

Development of High-Power and Backdrivable Linear Electro-Hydrostatic Actuator

H. Kaminaga, S. Otsuki, and Y. Nakamura
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2014 IEEE-RAS International Conference on Humanoid Robots
Cluset EHA Frequency Response Test
A Robot Hand Driven by Hydraulic Cluster Actuators

Treratanakulwong et al., 2014

Wire Driven Underactuated Hand

Treratanakulwong et al. (ICRA2014)

11 Dof Tendon Driven Hand with 12 active tendons
Coupling mechanism for fingertip pinching
Carpal tunnel mechanism with no sliding contact between the tendons and structure

Treratanakulwong et al., 2014
Hand in Action

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Friction Compensation

No Friction Compensation
Force Control of EHA

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Prof. Y. Nakamura

Hiroshi Kaminaga, Assistant Prof.
The University of Tokyo
kaminaga@ynl.t.u-tokyo.ac.jp