Centro Inderdipartimentale di Ricerca “E. Piaggio”, Università di Pisa

Variable Stiffness Actuators:
muscles for the next generation of robots

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Evolution of robotic actuation

Traditional electric motor

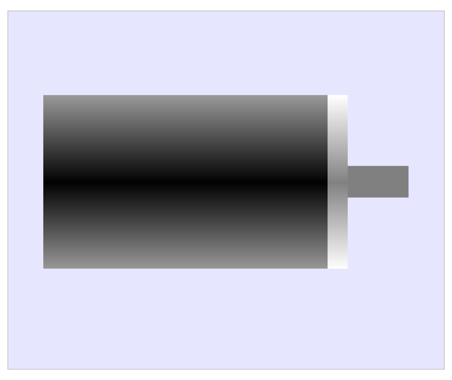

Fig. 1: Schematic drawing of an electric motor used for industrial applications.

- Needs gearbox
- Needs control
- Poor dynamics (acts as torque source)

Traditional Servomotor

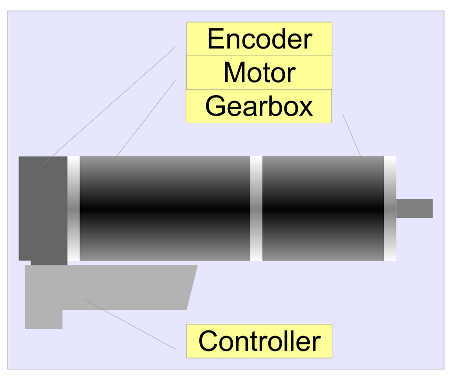

Fig. 2: Schematic drawing of a typical servomotor used for industrial applications.

- Embeds gearbox sensor and control
- Very rigid & inertial structure
- High precision
- Poor dynamics (position source)

Series Elastic Actuation

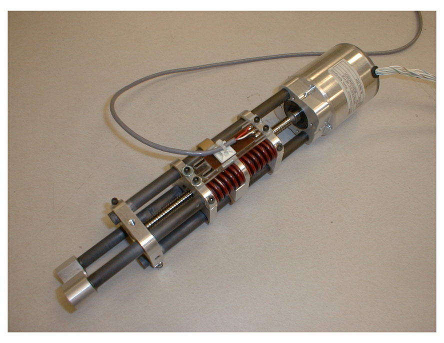

Fig. 3: A SEA (Series Elastic Actuator) used as a robotic leg, realized from the Yobotics! company. Picture from: http://yobotics.com/actuators/actuators.htm

- Compliant structure
- Less precision & bandwidth
- Embedded dynamics

Mechanical Impedance Adjuster

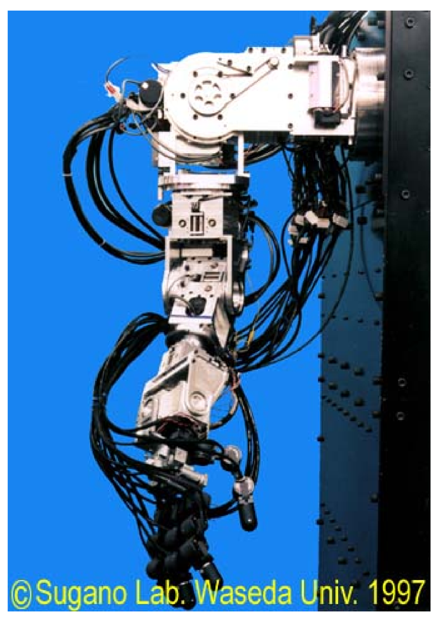

Fig. 4: A MIAs (Mechanical Impedance Actuators) powered arm, realized at Sugano Labs, Waseda University, in 1997. Picture from: http://www.sugano.mech.waseda.ac.jp/wendy/arm/mia1-e.html

- Programmable compliance
- More dynamics are possible

Variable Stiffness Actuation

Fig. 5: A Variable Stiffness arm, realized by the Interdepartmental Research center “E. Piaggio”, in University of Pisa.

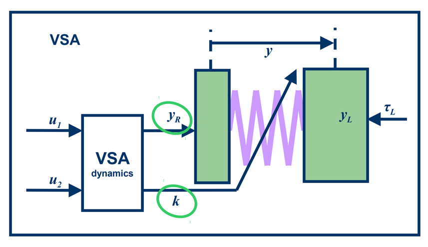

Fig. 6: Working concept of a Variable Stiffness Actuator (VSA).

- Real-time variable compliance
- Variable embedded dynamics
- Advantages
  - Safety / Performance trade-off optimization
  - Actuator Robustness
  - Adaptability to environment
  - Energy optimization
- Applications
  - Human Robot Interaction
  - Rehabilitation
  - Gait locomotion
  - …more to come!

...towards Variable Impedance

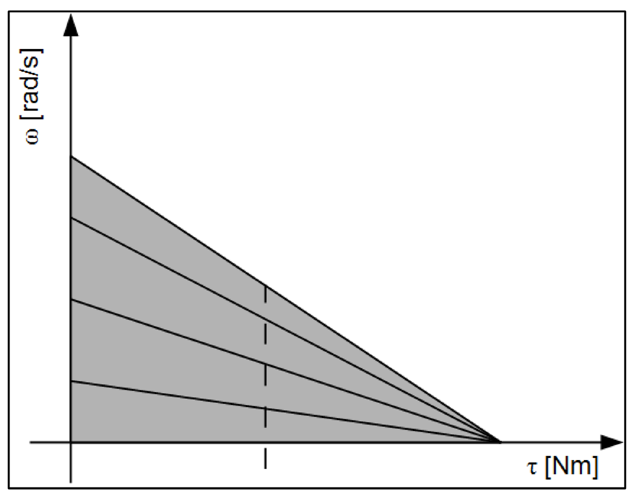

Fig. 7: typical workspace of a DC motor

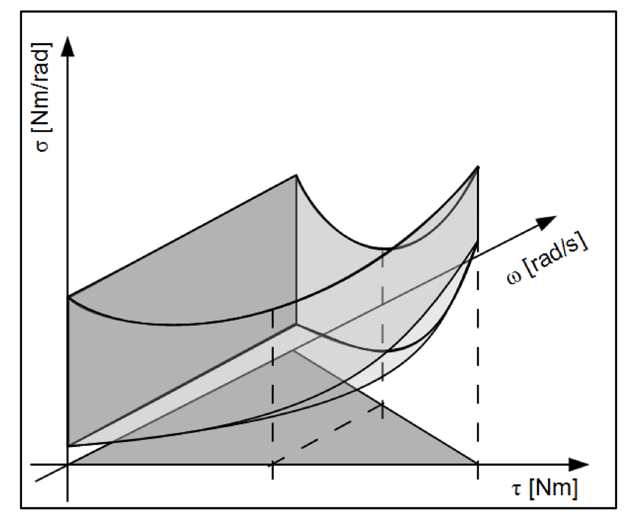

Fig. 8: Example workspace of a VSA.

VSA adds one degree of freedom to the possibilities of robotic actuation!

hardware

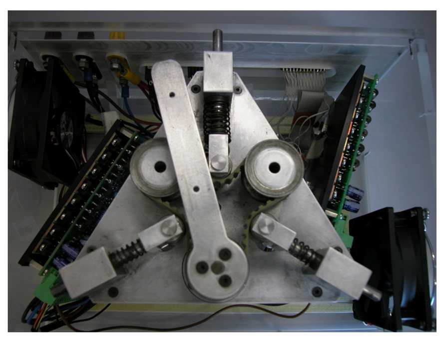

Fig. 9: VSA I, the first electric variable stiffness actuator, developed within the Interdept. center “E. Piaggio”, of University of Pisa.

Proof of concept

Fig. 10: VSA II, the second variable stiffness actuator developed within the Interdept. center “E. Piaggio”, of University of Pisa, uses bidirectional non-linear springs.

Miniaturization

Fig. 11: VSA HD, the third VSA developed within the Interdept. center “E. Piaggio”, optimizes and integrates the whole actuation system trough the clever usage of harmonic drive gearboxes

Optimization

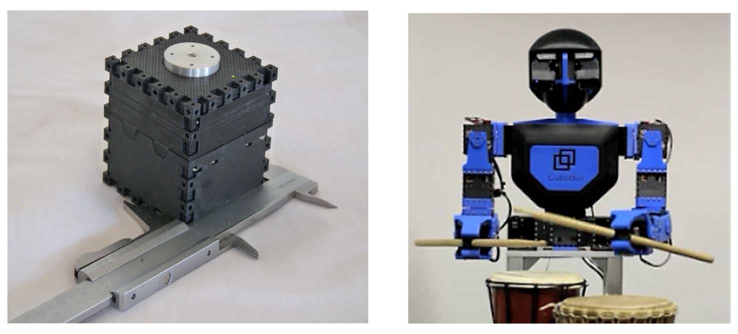

Fig. 12: the Qbot is the ultimate version of VSA developed within the Interdept. center “E. Piaggio”. Completely integrates prime movers, gearboxes, sensors and low level control logic and power drivers inside a modular structure to offer an easy variable stiffness robotic development platform. The Qboid on the right is just one example of the many multi-dof robot that can be realized combining more Qbots.

Costs down-cut, control integration toward mass production

VSA Development within UNIPI

control

Optimal control

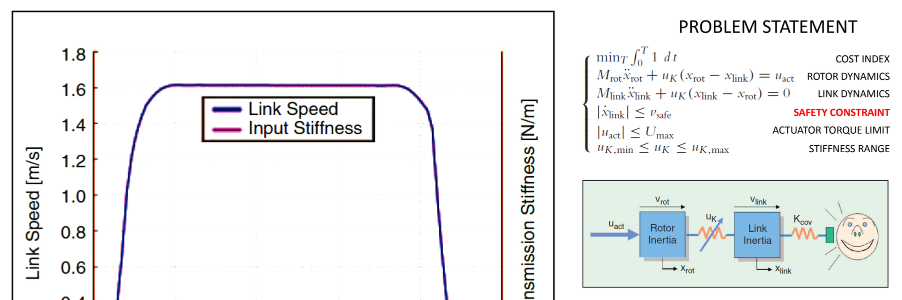

Fig. 13: Performance of VSAs can be optimized to achieve very different goals, achieving profound insights which can help to understand also biomechanical behavior of human and animals. In the picture an example of the optimal control pattern designed to move a VSA arm in the shortest time while remaining within safety constraints determined by injury risk in case of accidental impact with a human operator.

FAST AND SOFT, SLOW AND STIFF

- Safe Brachistochrone

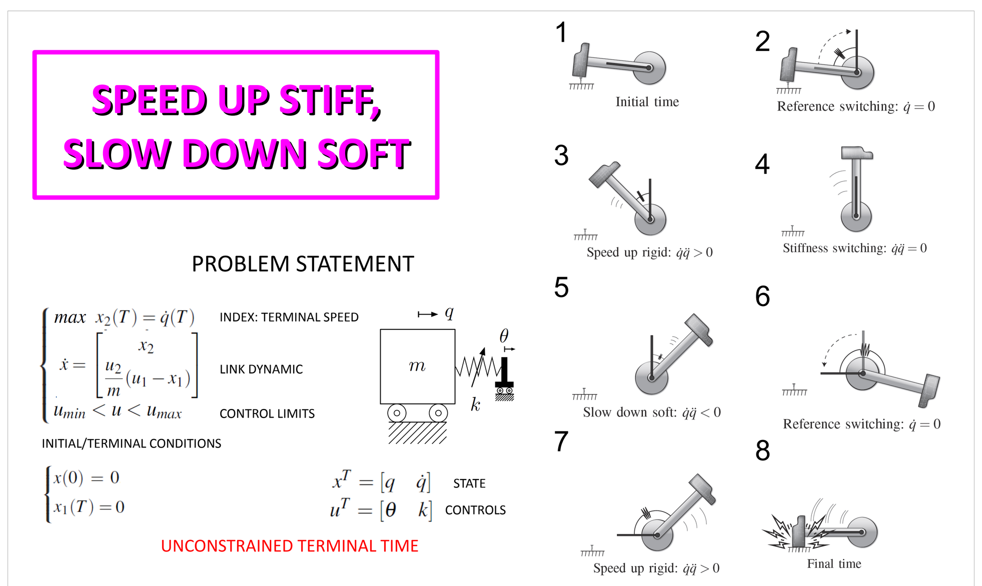

Fig. 14: Performance of VSAs can be optimized to achieve very different goals, achieving profound insights which can help to understand also biomechanical behavior of human and animals. In the picture an example of the optimal control pattern designed to drive a nail with the fewest hits of a VSA-hammer .

- Energy Transfer Optimization

Identification

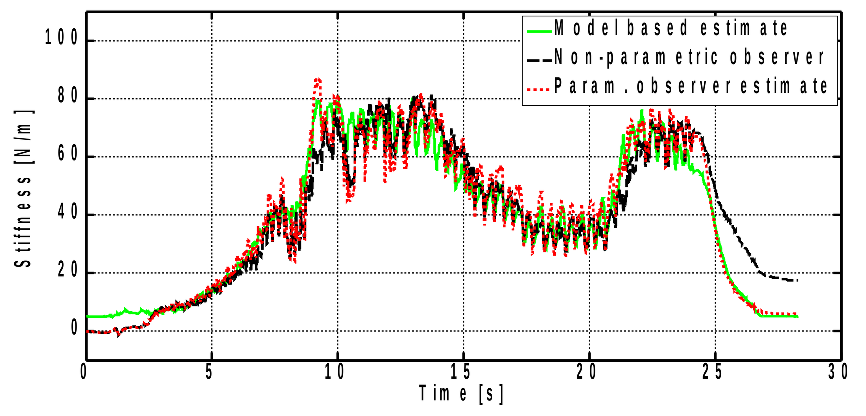

Fig. 15: Performance of two different types of stiffness observers, developed within University of Pisa, tracking the stiffness of a VSA. Due to the absence of stiffness sensors, stiffness must be identified either offline, trough accurate calibrations, or online with a non-linear observer.

- Impedance Observers

EU projects

PHRIENDS — Physical Human-Robot Interaction: DepENDability and Safety
2006 -2009

VIACTORS — Variable Impedance ACTuation systems embodying advanced interaction behaviORS
2009 - 2012

SAPHARI — Safe and Autonomous Physical Human-Aware Robot Interaction
Upcoming: 2011 - 2015