Uncommon actuators in Robotic

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Why uncommon actuators?

Common actuators
- Rigid
- Bulky (gearboxes)
- Problematic interaction
- Expensive
- Heavy

Uncommon actuators
- Compliant
- Direct drive
- Ideal for interactions
- Cheap
- Lightweight
- Difficult to control
SMA - Principle of function

- **Austenite - Martensite transformation.** *(derived by steel)*
- **Generated by the changing** $T$ **or** $\sigma$. *(change of crystallography)*
Characteristics of Ni-Ti

- Ability to be electrically heated
- Stable transformation temperature
- More recoverable motion $>10^6$ cycles
- High biocompatibility
- Distributed in basic shapes
Advantages and Disadvantages of SMA

Advant.  
- Good ratio power/weight  
- Price availability  
- Silent run

Disadvant.  
- Impossible to use classical contacting methods  
- Slow thermal response  
- Complicated modeling
Types of valves

- **Standard** – electromagnetic or piezo actuated
- **Special** – SMA actuated, EAP actuated etc.
Pneumatic SMA actuated valve

SMA actuated valve with fittings.

Designed endcap of pneumatic muscle with installed SMA actuated pneumatic valves
Responses of SMA actuated valve
Stepping robot with SMA actuators

- Six-legged with two degrees of freedom for each leg
- Actuated by the NiTinol (Flexinol)
- Driven by control unit with microprocessor (PWM)
General usage of SMA

- Health care
  (blood vessel wall, surgical equipment)
- Building industry
  (fixtures of houses)
- Aircraft industry
  (couplings of pipes)
- Robotics
  (actuators)
Pneumatic Muscles
Motivation for hybrid actuator

Pneumatic muscles were first developed in the 1950s for use in artificial limbs. It is cheap, powerfull, but they are still not commonly used!
Pneumatic Muscles

- Working principle.

\[ F = 300 \text{ N/cm}^2 \]

\[ p_0 = 10 \text{ kPa} \quad p_1 = 500 \text{ kPa} \]
Mc Kibben Pneumatic Muscle - working principle

Basic static force equation:

$$F = \frac{pb^2 (3 \cos^2 \alpha - 1)}{4\pi n^2} \quad (1)$$
Mc Kibben Pneumatic Muscle - properties

- High power to weight ratio
- Can be made in any diameter and length
- Comparable with animal muscles (shape and performance)
- Maximal contraction 25 – 30 %,
- Maximal force 300 N/cm²
- Clean and safe
- Many design modifications
Mc Kibben Pneumatic Muscle - problems to solve

- Compensation of deformations
- Compensation of rubber wall elasticity
- Compensation of thread elasticity
- Thermodynamical modelling
- Air transport delay.
- Complex inner friction.
Pneumatic Muscle – test bed
Pneumatic Muscle – test bed output

Force [N]

Legth [mm]
**ICPF – Ionic Conduction Polymer Gel Film**

- Soft gel material – manipulation of soft object.
- Distributed actuation device – amount of EFD elements – applying of sinusoidal voltages with a phase difference results in an elliptical motion in the top point A.
- It moves in water or in wet conditions.
- The driving voltage is low (1.5 V).
- It responds to high frequency input (> 100 Hz).
- It is a soft material E = 2.2*10^8
- Durability > 10^5 bending cycles.

\[
V_a = V_0 \sin \omega t \\
V_b = V_0 \sin \omega t + \Phi
\]

**EFD Element.**
**Electrorheological Fluid**

- ERFs are electroactive fluids that experience dramatic changes in rheological properties, in the presence of an electric field. (e.g. viscosity, yield stress, and other properties).
- The fluids are made from suspensions of an insulating base fluid and particles 0.1-100 µm in size. In the presence of electric field the particles will form chains along the field lines, ERF changes consistency from a liquid to a gel with a response on the order of milliseconds.
- ERFs are used in “electrically controlled stiffness elements” (ECS).
- Operational voltage ~ 2kV.

**ECS Element and Its Piston.**
Electrorheological Fluid

- Characteristic using of ECS element is in haptic interfaces.
- MEMICA - haptic interface shown in figure.
  - Equipped with a series of ECS elements.
  - Each finger needs one or more these elements to maximize the level of stiffness/force feedback.
  - ECS element are responsible for mirroring the level of mechanical resistance.

Haptic Interface with ECFs.
Piezoelectric Stack Actuators

- Material: lead-citronate-titane (PZT).
- Accurate positioning and/or force controlling.
- Stack structure of actuators.
Rotational Actuators

- They transform elastic wave into rotation motion. Elastic wave arise from two summed sinusoidal signal with phase difference.

Structure of Piezo Motor.

Deformation under Influence of Connected Voltage.
ICPF – Ionic Conduction Polymer Gel Film

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- **Distributed actuation device** – amount of EFD elements – applying of sinusoidal voltages with a phase difference results in an elliptical motion in the top point A.
- **It moves in water or in wet conditions.**
- **The driving voltage is low** (1,5 V).
- **It responds to high frequency input** (> 100 Hz).
- **It is a soft material** $E = 2,2 \times 10^8$
- **Durability** $> 10^5$ bending cycles.
Actuator comparison

Figure 3.22 Haptic feedback actuator comparison based on mechanical bandwidth.
Figure 3.21  Haptic feedback actuator comparison based on power-to-weight ratio.
Figure 3.8  Shape memory metal (SMM) power density vs. other actuators. Adapted from Hirose et al. [1989] and Hollerbach et al. [1992]. Reprinted by permission of the MIT Press.
Haptic Glove with Pneumatic Muscles

- Position sensing

- Force sensing / Force feedback
Haptic Interface – Data Glove (Input/feedback Glove Interface)

- Haptic feedback – forces and movement sensing/tracking (sensors), and feedback actuation (actuators).

  - **Sensors**
    - Resistance force and bending sensors.
    - Charging force and bending sensors (piezo, poly-piezo).
    - Magnetometers and accelerometers.

  - **Actuators**
    - Standard solution – DC motors with gears and tendons, pneumatic pistons – heavy-handed.
    - Uncommon actuators: pneumatic muscles or pockets, piezoelectric tactile elements, ICPF, electrically controlled stiffness elements (ECS).
    - Extending actuators (affecting to other senses) – e.g. Peltier heat pump.
Human Psychophysics for Teleaction System Design

- How to display tactile senses to a remote operator?

- Tactile sensors – array of piezo or resistance pressure sensors (surface strain).
- Tactile display – array of piezoelectric-driven pins, pneumatics, nitinol, solenoids, etc.
- Progress in tactile display has been slow, due to demanding mechanical requirements: 50 N/cm² peak pressure, 4 mm stroke, 50 Hz bandwidth.
- Viscoelastic finger model.
Design Specifications of the Glove Interface

- We plan developing and implementation in:
  - Appropriate placing of bend and pressure sensors into the data glove.
  - Tactile display - pneumatics, nitinol, ICPF. Teamwork with Faculty of Mechanical Engineering.

- Developing, testing and optimization of ECF elements (Electrorheological fluid). Teamwork with Faculty of Chemical Science.

- Developing and testing of other uncommon actuators.

Block Diagram of Data Glove with Force, Haptic and Thermal Feedback [N. Tsagarakis].
Haptic Interface – Data Glove (Input/feedback Glove Interface)

Data Glove CyberGlove and Force Feedback CyberGrasp.
Motivation for hybrid actuator

Traditional AC servo motor is commonly used, it has low power to weight ratio, but is easy to control.
Kinematic design

AC servo – precise position control
PMA - high power, low precision
Control Scheme of Hybrid System
\[ F = p \frac{(3L^2 - b^2)}{4\pi n^2} \approx 1.5 \text{ kN} \]
Torque on arm angle

arm angle [°]
torque [Nm]
Power supply

- Pressurized tank with liquid CO₂
- Pressurized tank with air
- Pressurized tank with air; ability of long term self-refuelling by small low power compressor
- Chemical reaction (e.g. hydrogen peroxide (catalyser) -> water, oxygen)
Conclusion

Use in extreme situations, where traditional actuators are useless and high force actuation is needed.

Especially suited for mobile robots due to lightweight and space-saving design.