Wearable Robotics

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by

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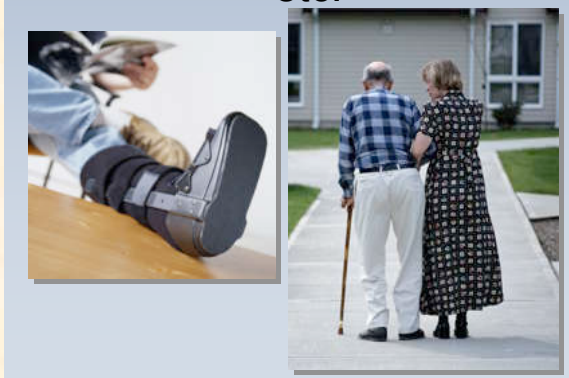
Wearable robotics - A class of human-enhancers

- Enhancers of human abilities have been around since…. the first tools
- Three major types of wearable enhancers:

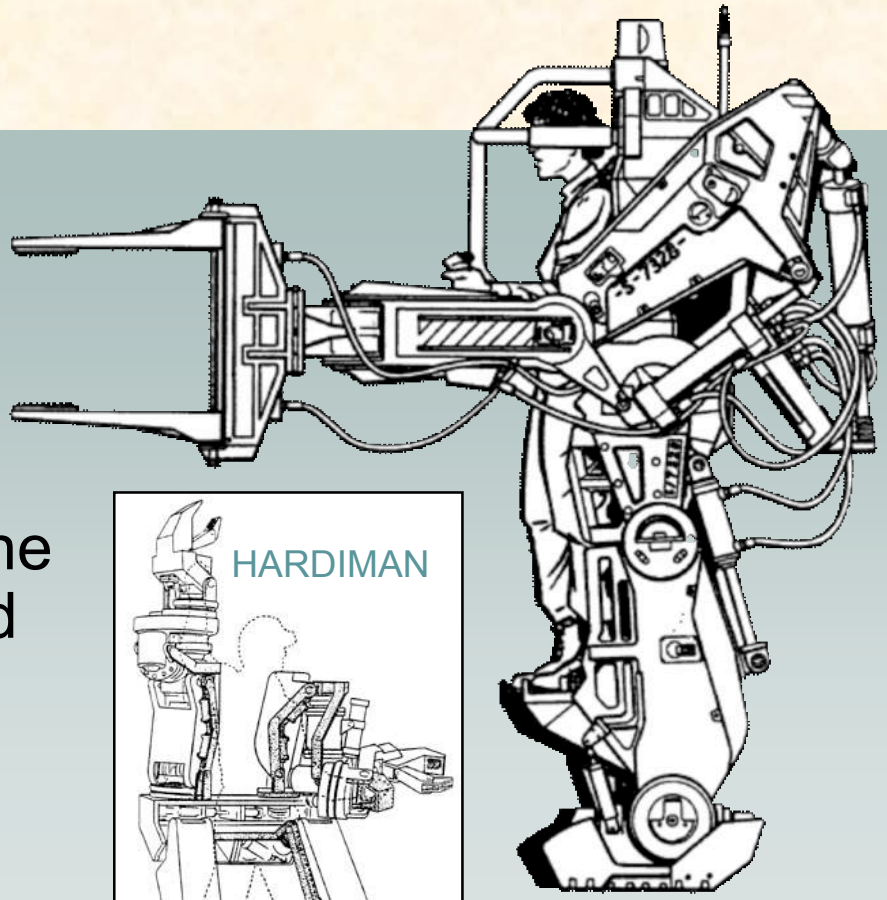
Perceptive enhancers	Cognitive enhancers	Physical enhancers
glasses, hearing aids, night-vision goggles, etc.	shopping lists, recorders, calculators, portable computers, etc.	canes, shoes, braces, prosthetics, etc.

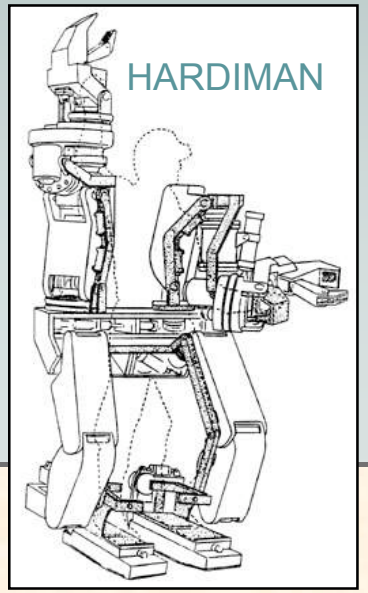


. . . . (and soon) wearable robotics: ***active, powered***, enhancers of human strength, reach, endurance, precision, etc.

Wearable robotics - Hardly a new idea

- Many fiction concepts (Superman, Alien 2, etc.)
- 1960's and 1970's attempts at "Exoskeletons" (Hardiman, Hydroman, etc.) pointed out the significant challenges involved
  - Non-linearities, bandwidth, haptic sensing, force feedback, controls, etc.





Potential payoffs

Productivity • Injury Prevention • Public Health • National Security

Application Fields

Military operations

Materials handling, loading, unloading, or transfer

Assembly line operations

Construction industries

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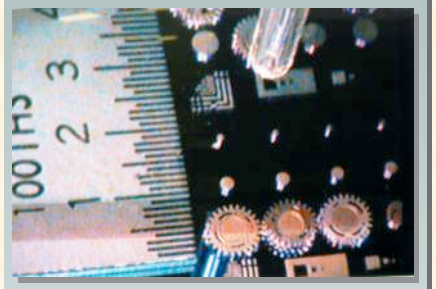
Productivity • Injury Prevention • Public Health • National Security

Application Fields

Rescue operations (rubble removal, casualty evacuation, etc.)

Smart prosthetics for post-injury rehabilitation, elderly, or aid to physically handicapped

Micro-assembly and micro-manipulation



Medical and surgical operations (e.g., tremor-removal)

"Extenders" and "strength-amplifiers" are a significant step forward

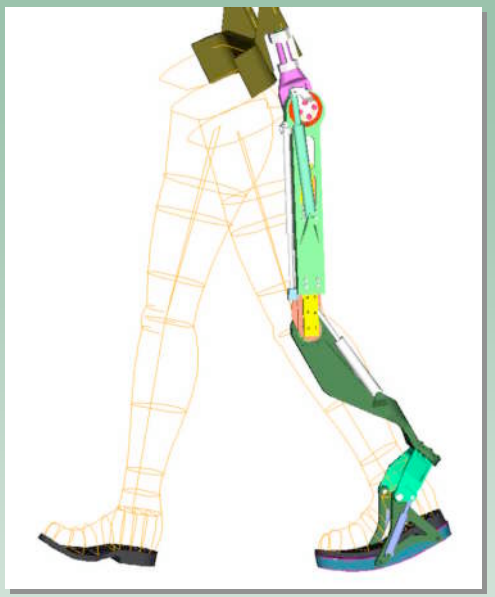
1980's and 1990's high-payload extenders (ORNL, UCB, etc.) addressed some of the significant issues:

- Strength-amplification with implicit and selectable feedback of force phenomena (essential for tasks involving contact with objects)
- High-precision and high-payload capability (two requirements that typically "work against each other")
- Shared controls (human-assist functions)

. . .and opened the field for many near-term applications

Moving toward exoskeletons

- Key technologies
  - Energy supply
  - Power = actuators
  - Haptic interfaces
  - Controls
- Major Issues
  - Safety
  - Compactness: weight, volume, long operational durations
  - Transparency



Energy: fuel + power plant

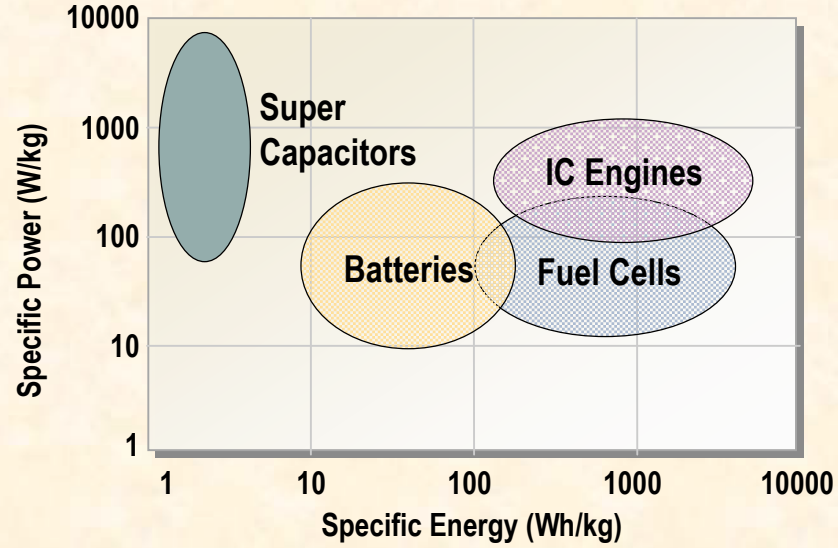
Safety

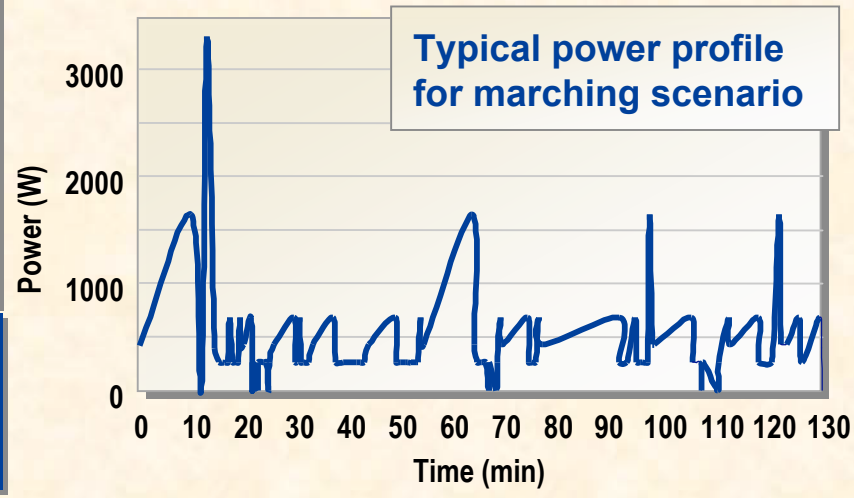
- No toxic, explosive, volatile, pressurized or hazardous materials transported
- In addition, for most applications: low temperature, no hazardous emissions, inert by-products, silent, easy "refueling"

Compactness

- Energy-dense and power-dense (fuel and overall plant)
- Suitable for handling large demand transients and "duty cycles" without "idling costs"
- Able to power computers, controls, and accessory systems
- Scalable

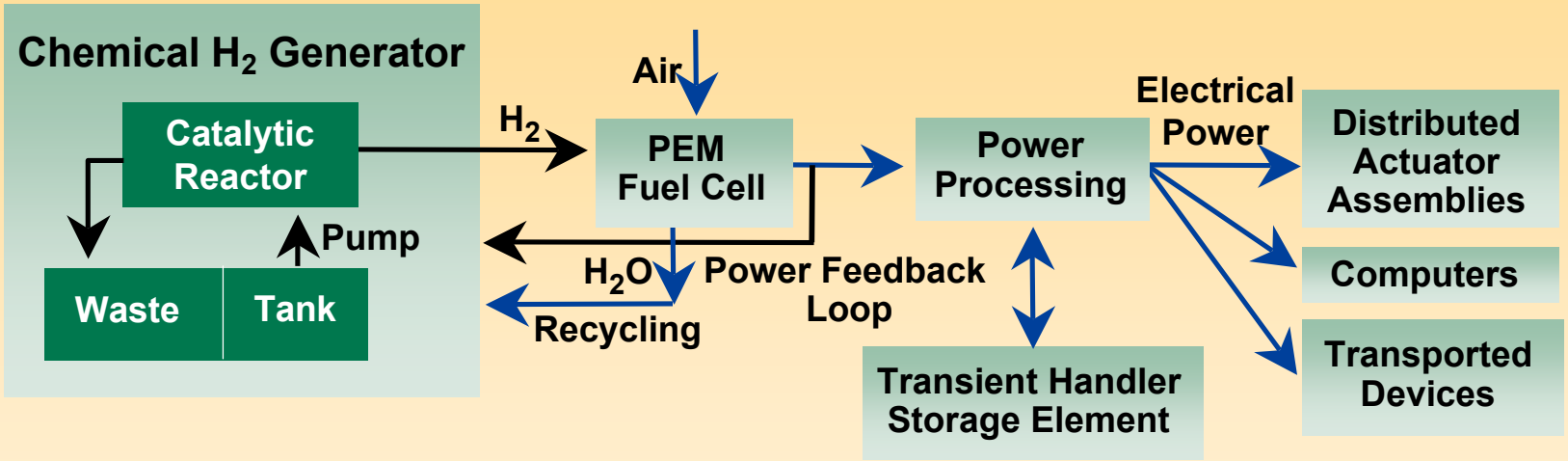
Each of the major candidates (IC engines, batteries, fuel cells) offers only some of the desired characteristics. "No silver bullet yet"





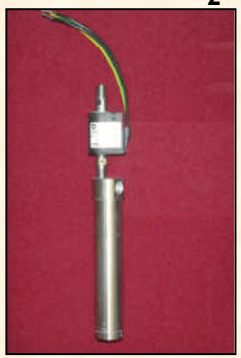
An example of an hybrid approach

Fuel transformer → Fuel cell → Transient handler → Actuation



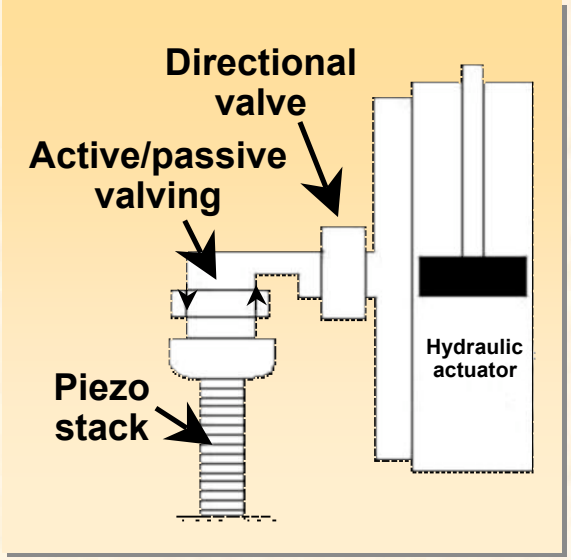
Energetic fuel (H_2) generated only on demand and in a controlled manner from Sodium Borohydride (transported fuel) through catalytic reaction

ORNL H_2 Generators



Actuators

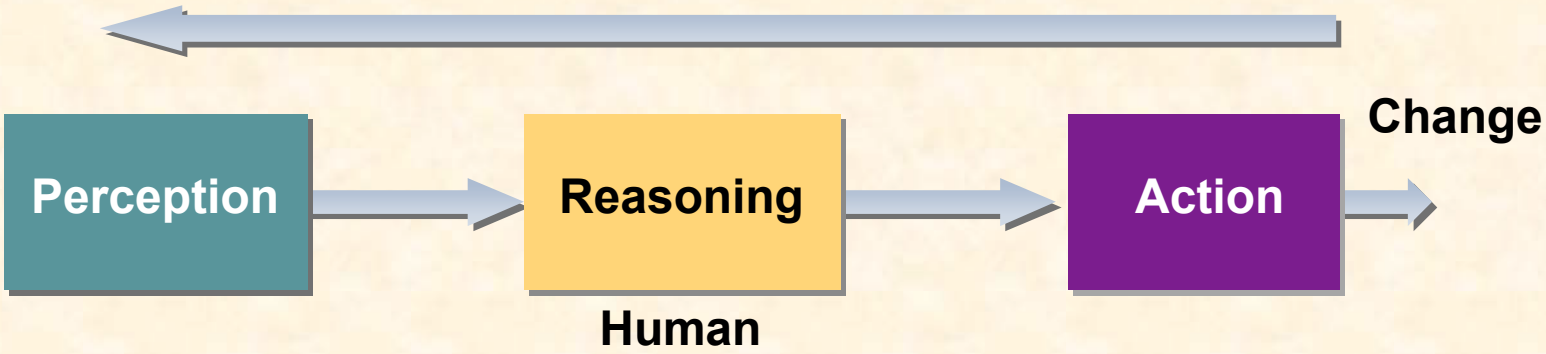
- Transform energy from the supply into mechanical motion and power at the joints
- Major issues: safety, compactness (power density), responsiveness
- For high-power applications, fluidic actuators are superior to electric motors (power density greater by a factor of about 5). However, electric motors are suitable for some low-power applications



An example of a novel electrically powered hydraulic actuator: piezo-electric driven fluidic pump.

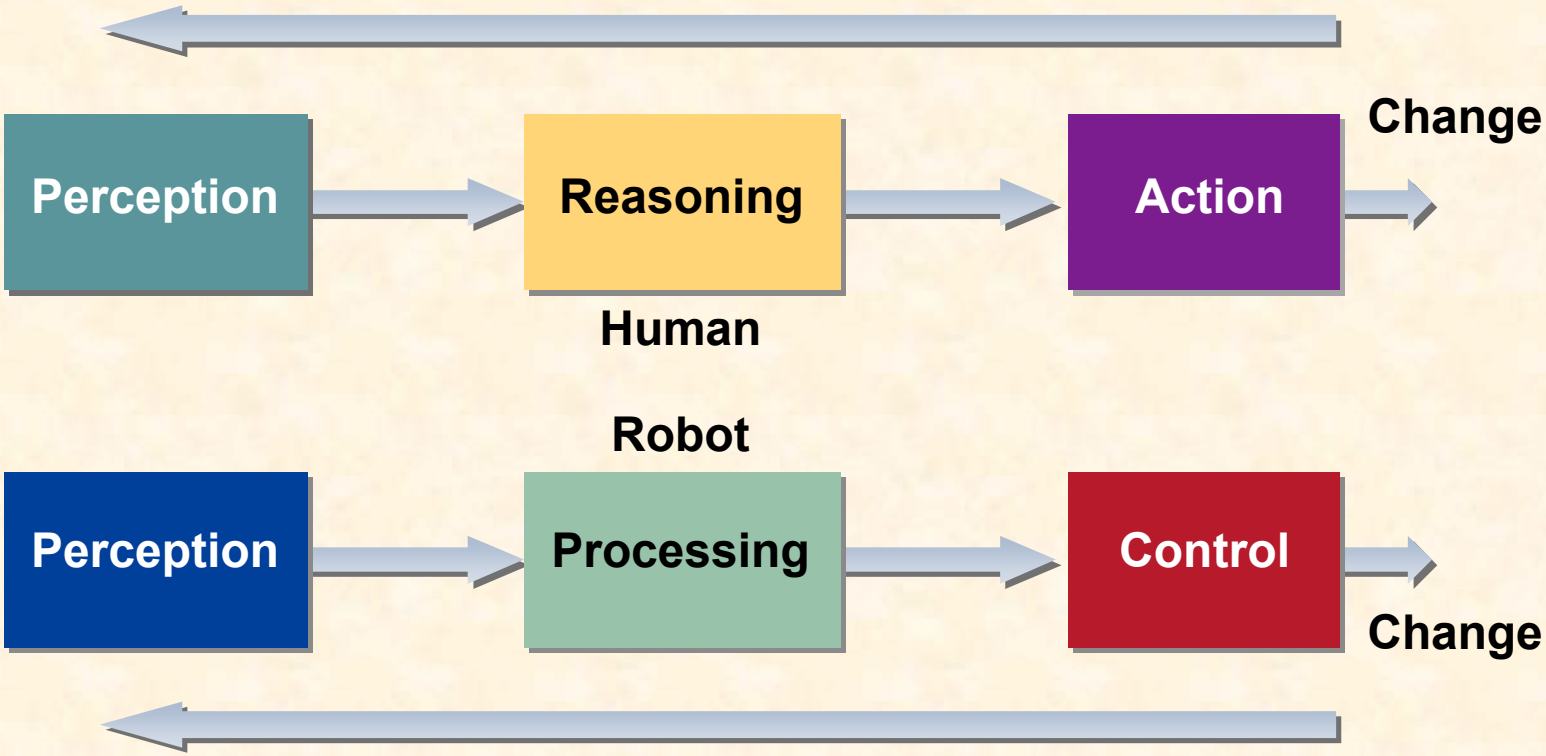
ORNL 2nd generation piezo pump: power /\ , power densities /\ , but still at least an order of magnitude away.

Why is wearable robotics such a challenge?



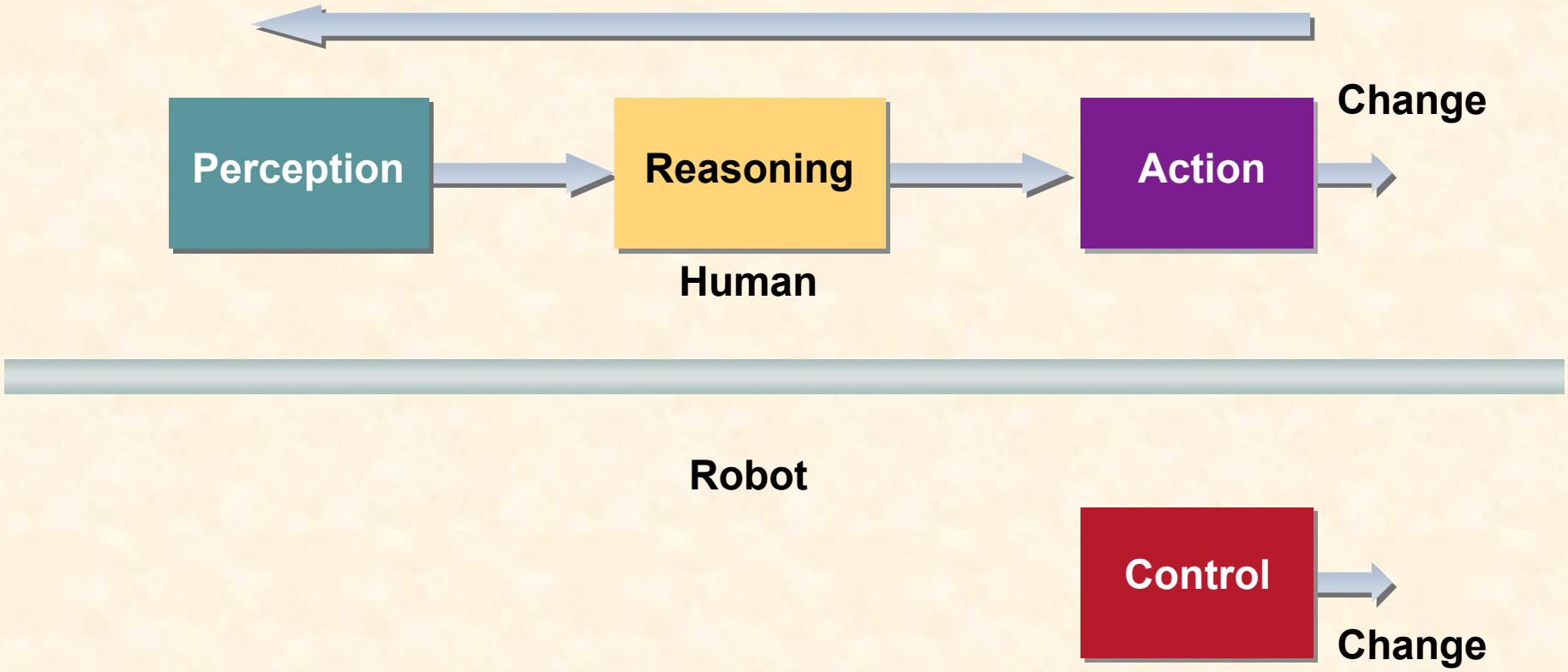
Typical Human Perception-Reasoning-Action Loop

Why is wearable robotics such a challenge?

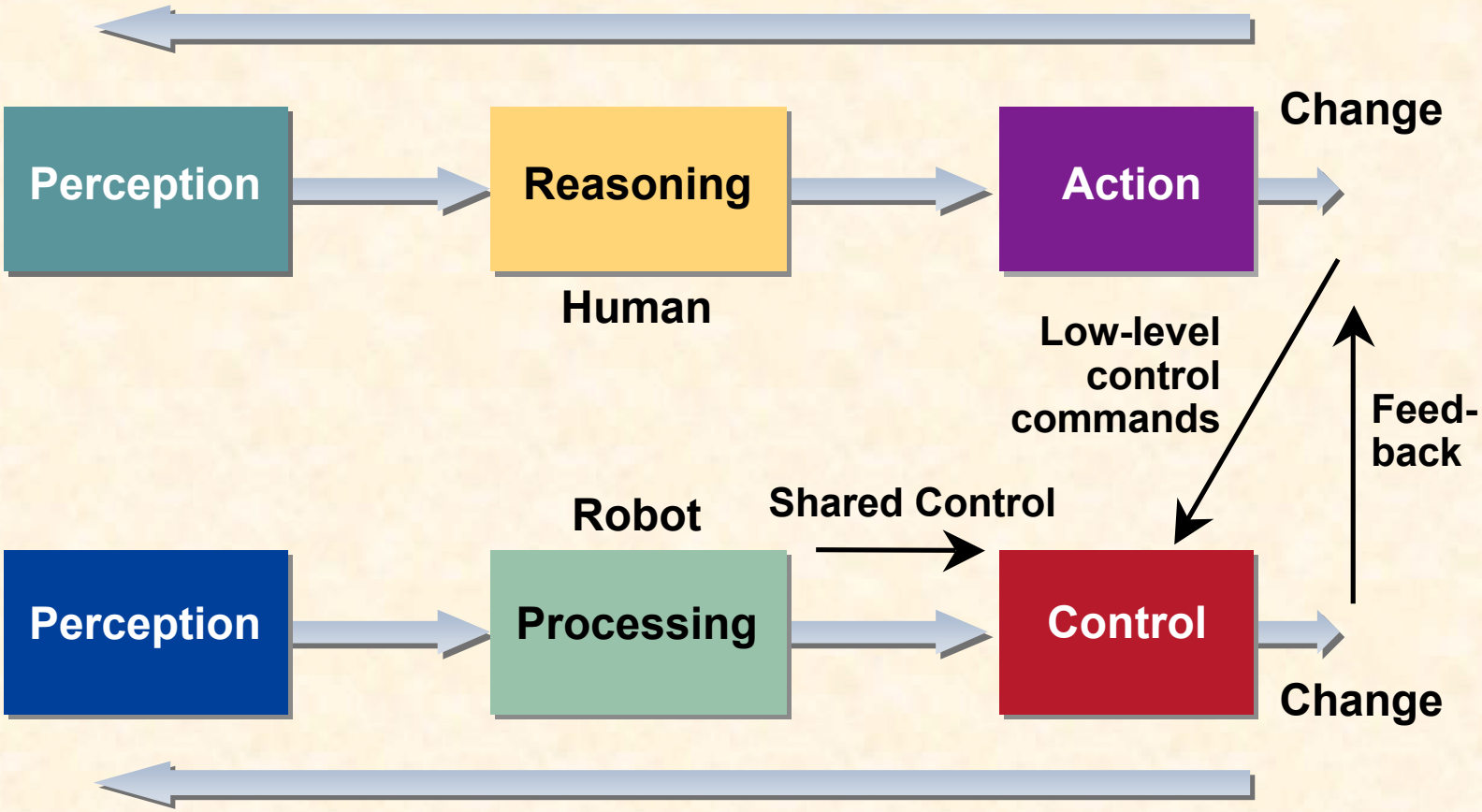


Typical Robot Perception-Processing-Control Loop

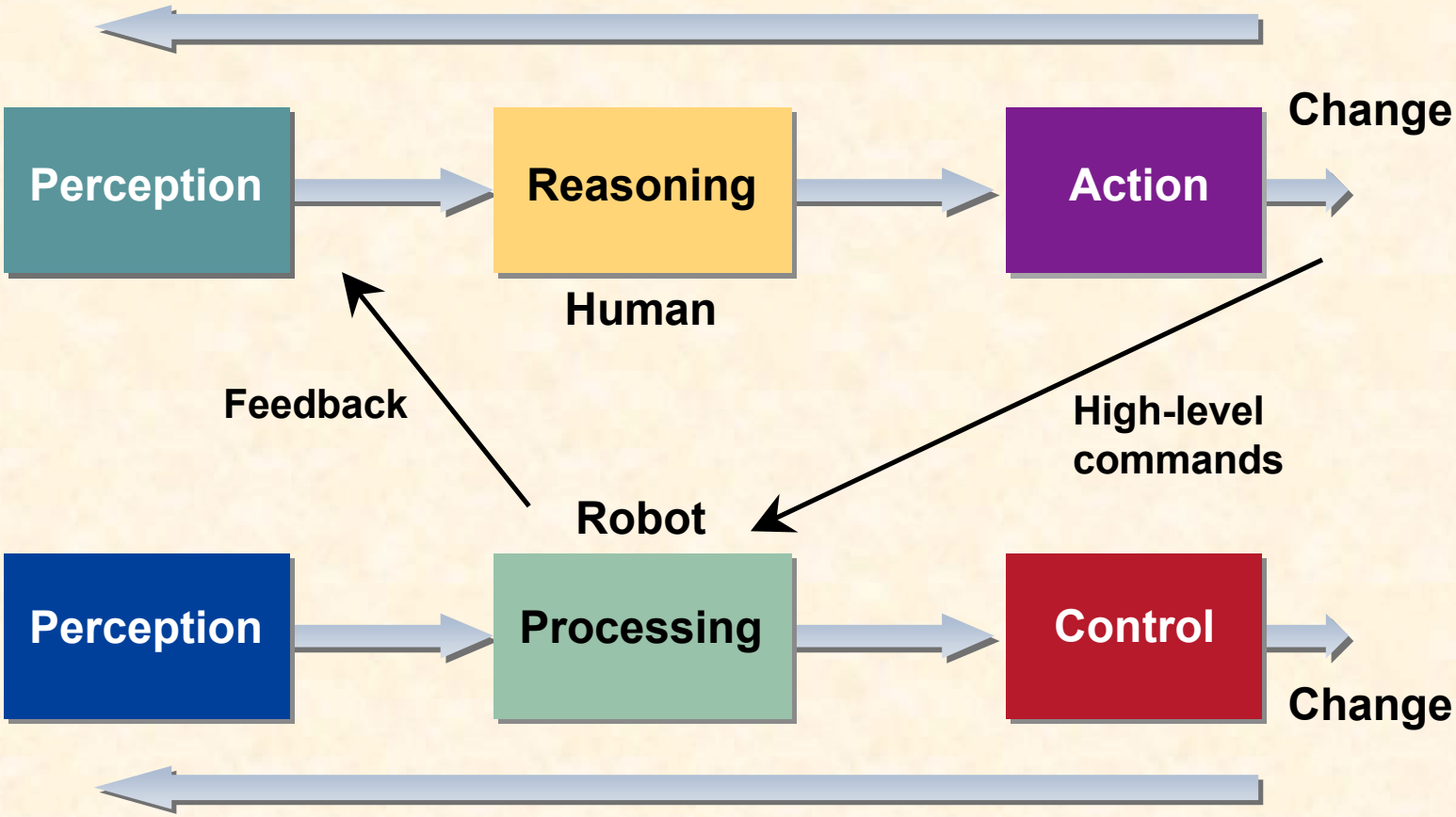
Traditional industrial robotics



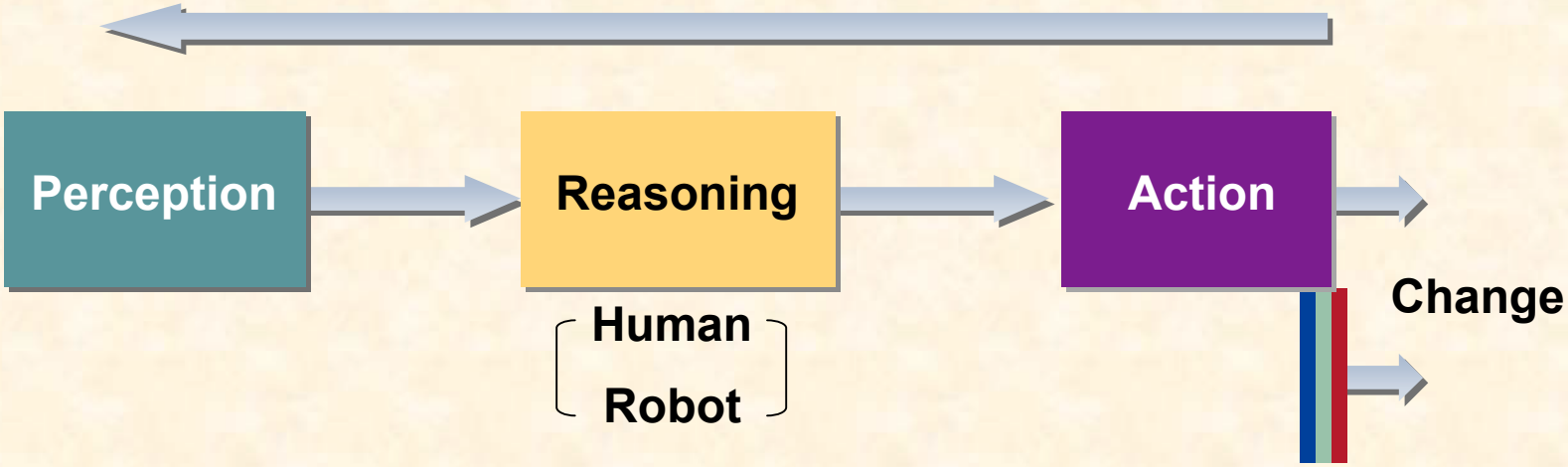
RC, teleoperated robots and telerobotics



Sensor-based robotics (a.k.a. semi-autonomous, supervised autonomy)



Wearable robotics

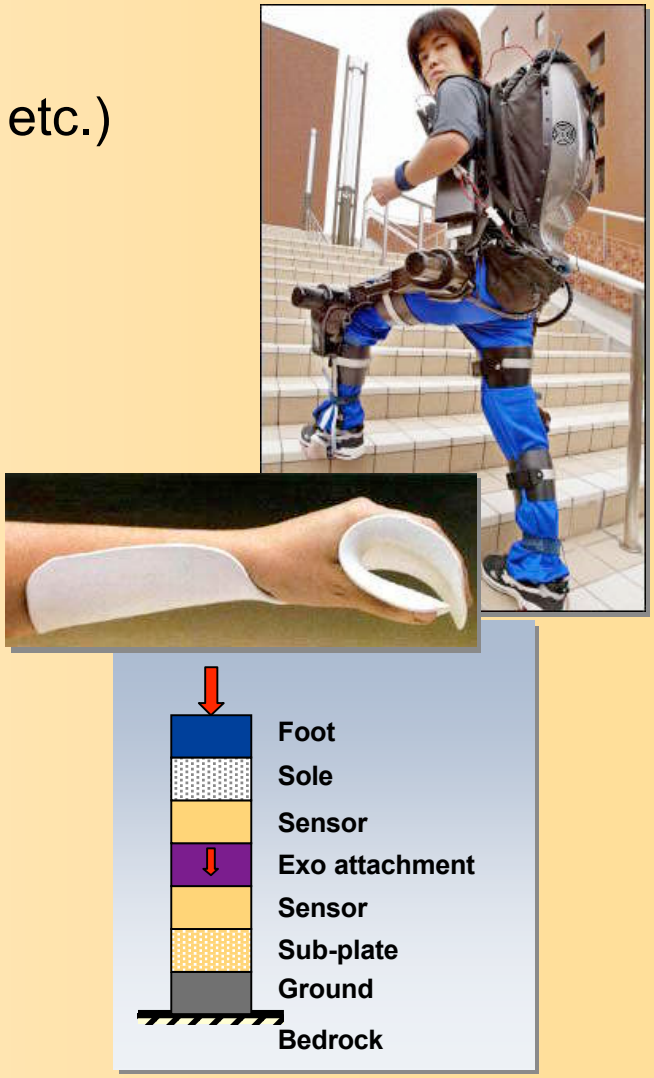


The human and robot are in constant contact and moving together, while exerting scaled forces and feeding back sensing to each other

Ideally, the perception of an action and the action resulting from the perception should be simultaneous with the original action

Haptic interfaces

- Interface points/areas with human soft tissues to sense stimulus signals (motion, forces, ME, etc.) and drive the controls of the machine
- Also points/areas where load transfers occur
- Acceptable tissue loadings
  - Function of load and duration (and person)
  - 100 mmHg (2 psi) for 2 hrs, 35 mmHg for 4 hrs ➔ tissue damage
  - Shear must be kept to a minimum
  - Padding materials matter but leads to:
- Body attachment trade-off
  - Haptic interface with high-bandwidth and high-fidelity sensing vs. comfort
  - Rigid (what we want) vs. comfort ➔ feel, responsiveness, acceptability



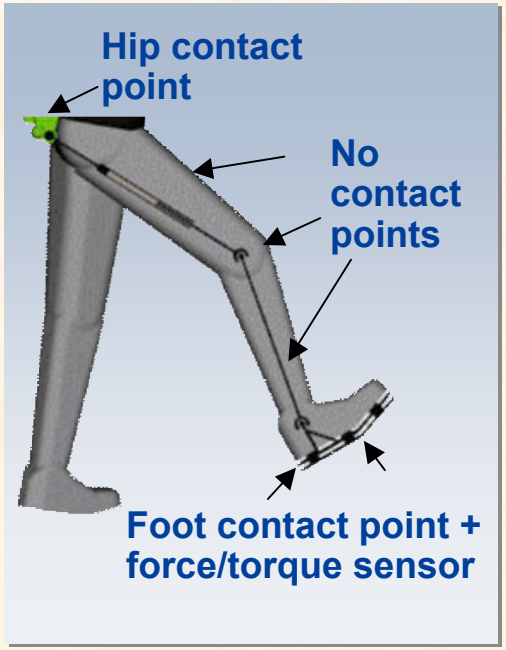
Example of a haptic interface

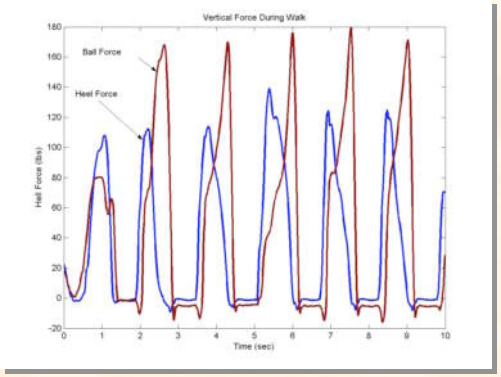
Interface with human soft tissues at "natural" attachment points

- Foot, waist, shoulder strap, wrist
- Improves comfort, endurance, acceptability
- Minimizes contact with soft and deforming tissues

Flexible 4-axis and 7-axis force/torque sensors prototypes

- Permit normal foot flexing
- Measure positive and negative forces, moments and toe force
- 1200 lb rating with 0.2 lb resolution
- High impact force tolerance
- Portable real-time data interface



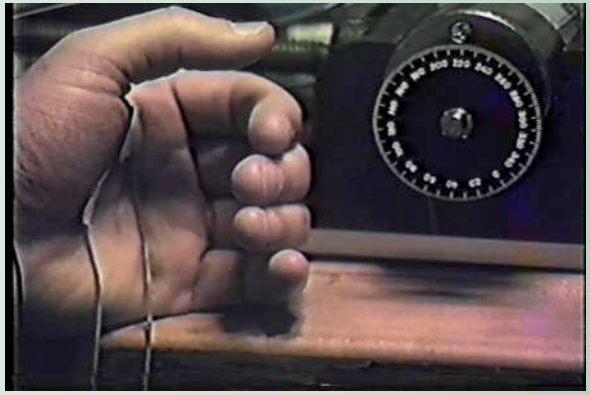


Controls

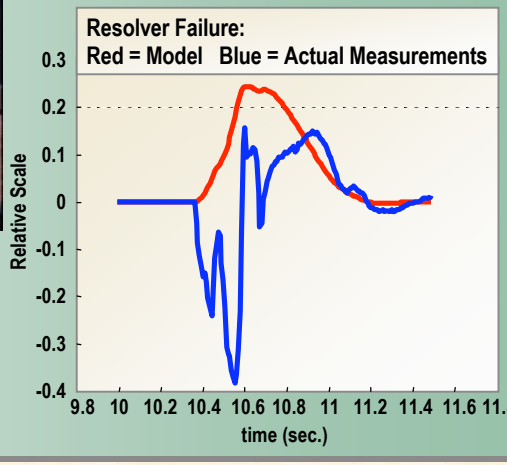
Some major issues

- Responsiveness (for transparency)
  - Very high bandwidth (e.g., stumble recovery, balancing, throw, etc.)
  - "Optimum" lag (well phased)
- Force control
  - Required for tasks in contact and feedback
- Impact stability
  - Intentional contacts (e.g., foot steps)
  - Accidental impact
- Safety
  - Fault detection

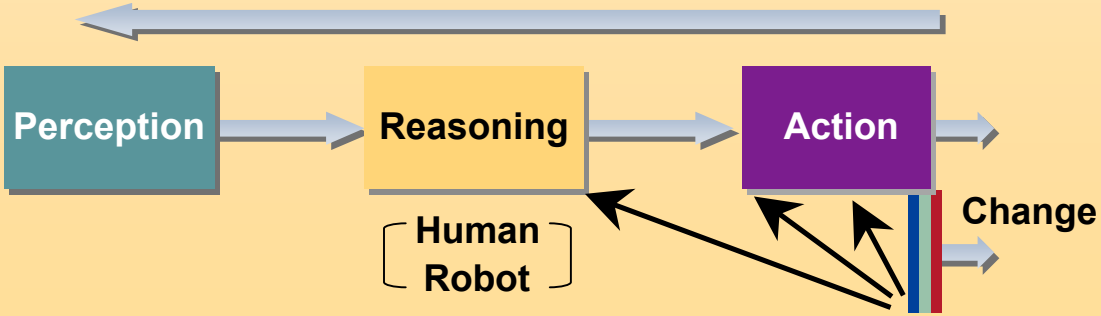
Example: ORNL Cartesian-type controls development test-stand



Myoelectric-based controls



Future of wearable robotics

- Potential for significant impact: economical and improved quality of life
- Some applications are feasible in the very near future (transition from S&T to R&D)
  - Medical areas
  - Material handling areas
  - Time frame dependent mostly on programs availability and priorities (i.e., focus on human-centric improvements)

- A few more breakthroughs still needed for the "Superman Suit"
  - Power and energy ➔ much higher densities
  - Sensing and controls ➔ lots more to be done