Hard Work for Robot(ic)s from Soft Actuators

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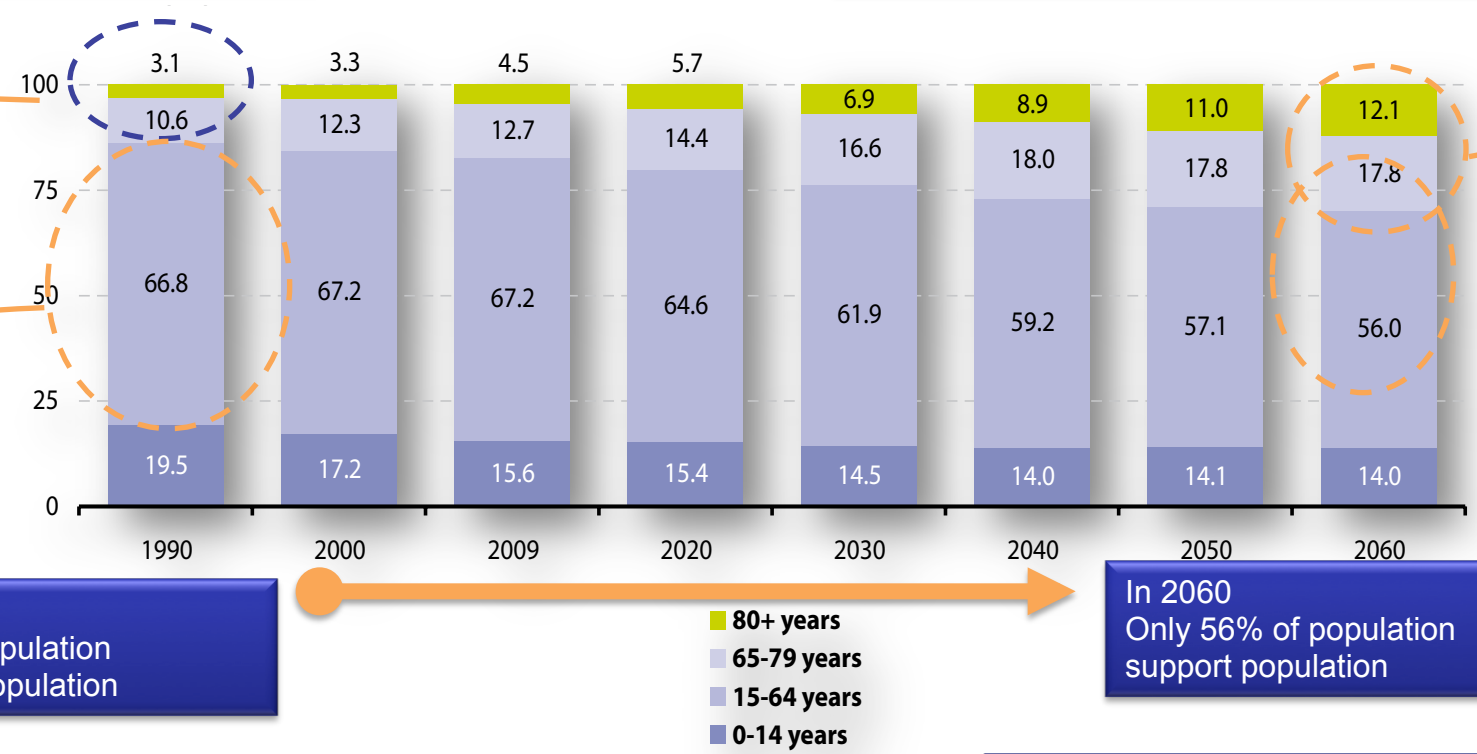
Ageing population

In 1990
Persons 65+ → 13,7 %
Persons 85+ → 3,1 %

In 2060
Persons 65+ → 30% → increase with 250% ↗
Persons 85+ → 12% → increase with 400% ↗



In 1990
67% of population
support population

In 2060
Only 56% of population
support population

Working population shall
- Work harder
- Work more
To realize the same
Today 40 hout/week
→ In 2060: 50 hour/week

(1) Excluding French overseas departments; 2020 to 2060 data are EUROPOP2008 convergence scena

Source: Eurostat (demo_pjanind and proj_08c2150p)

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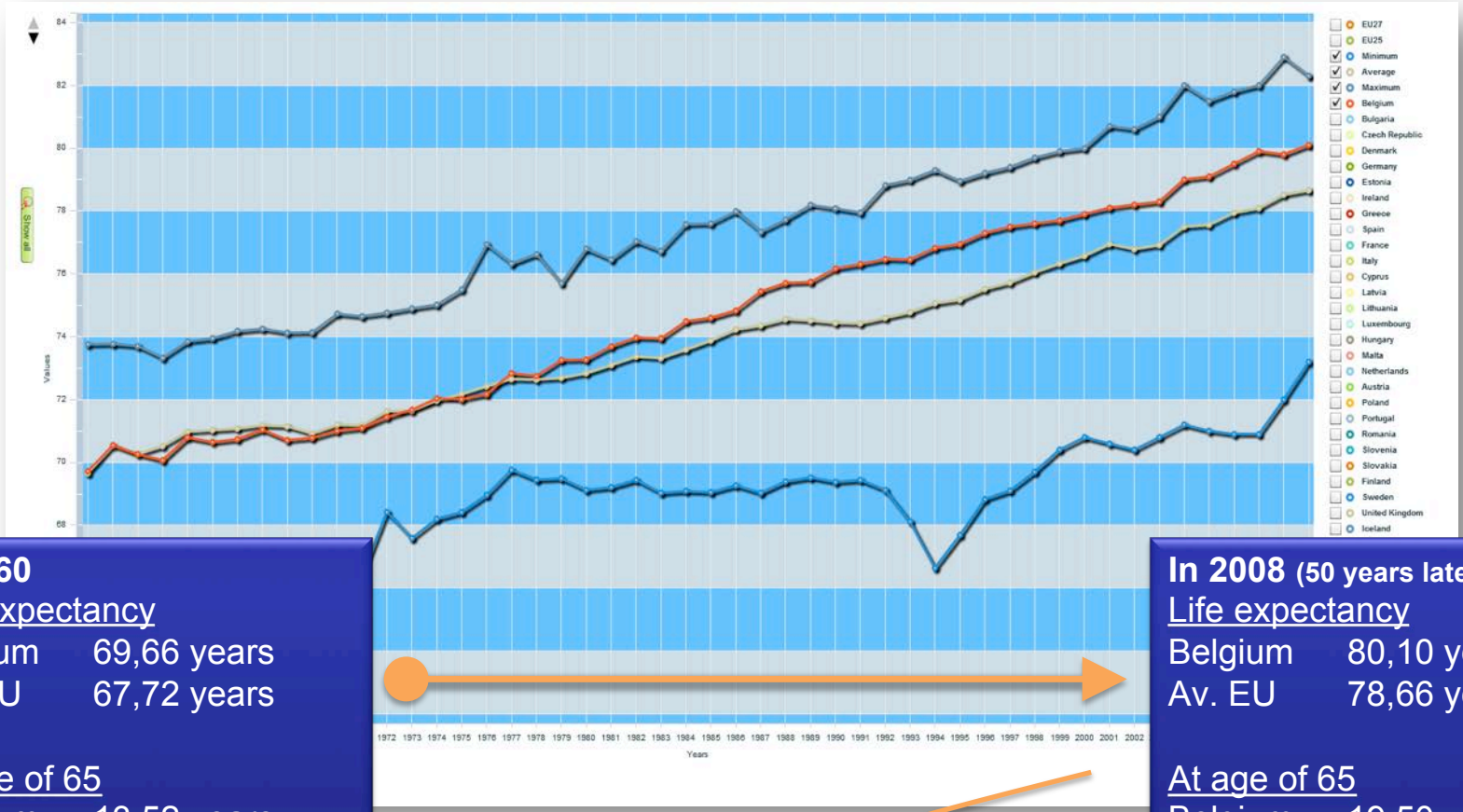
Increasing life expectancy



In 1960

Life expectancy

Belgium	69,66 years
Av. EU	67,72 years

At age of 65

Belgium	13,52 years
Av. EU	13,99 years

In 2008 (50 years later)

Life expectancy

Belgium	80,10 years
Av. EU	78,66 years

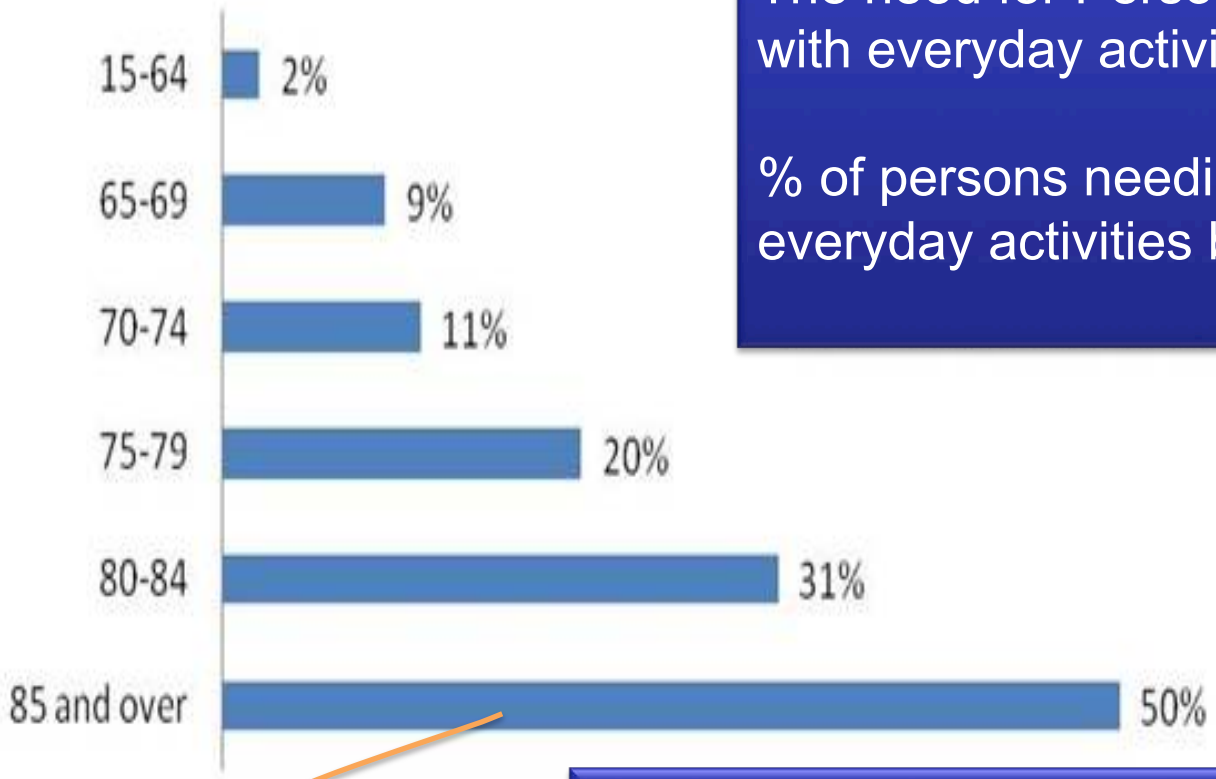
At age of 65

Belgium	19,50 years
Av. EU	18,46 years

Source: HEIDI data tool EU-Commission

For Belgium this is an increase of 18,2% over 50 years !
1/5 longer life!!!

Increased need for assistance



The need for Personal Assistance with everyday activities increases with age.

% of persons needing assistance with everyday activities by age

Not only functional weakness, but mobility also affected by lower motor skills due to stroke or neurological misfunction

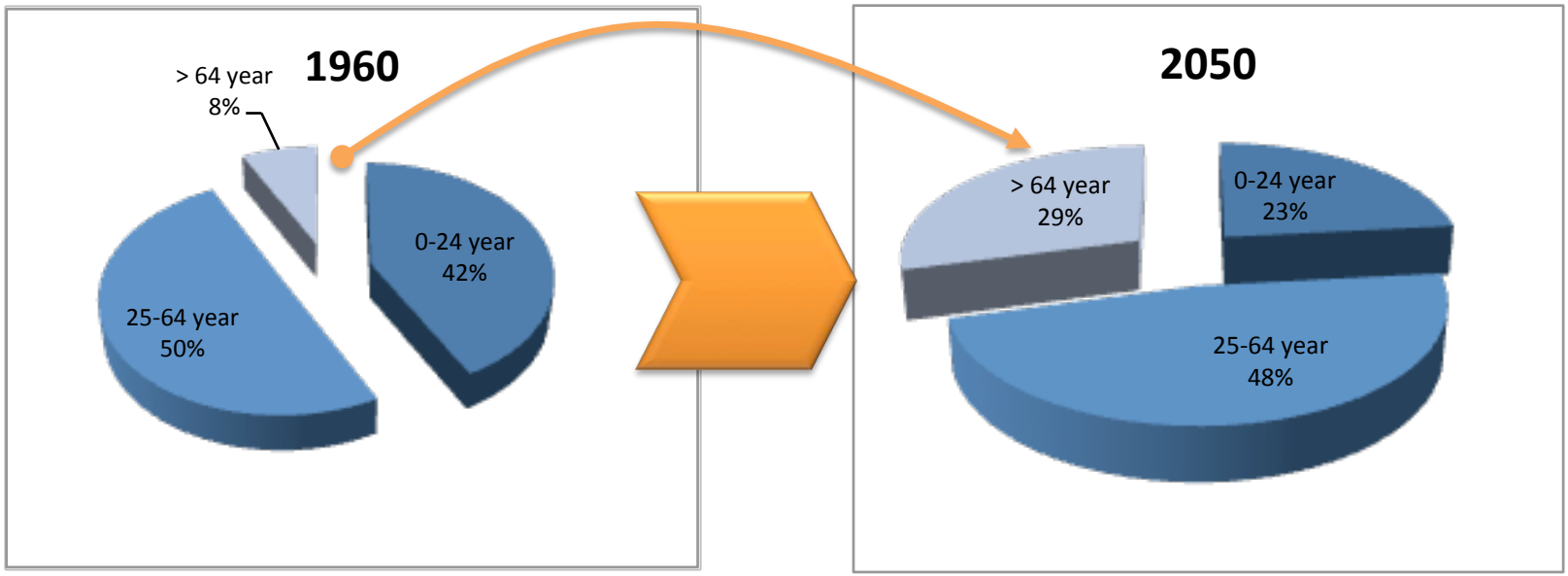
Longer and more working

Ageing population

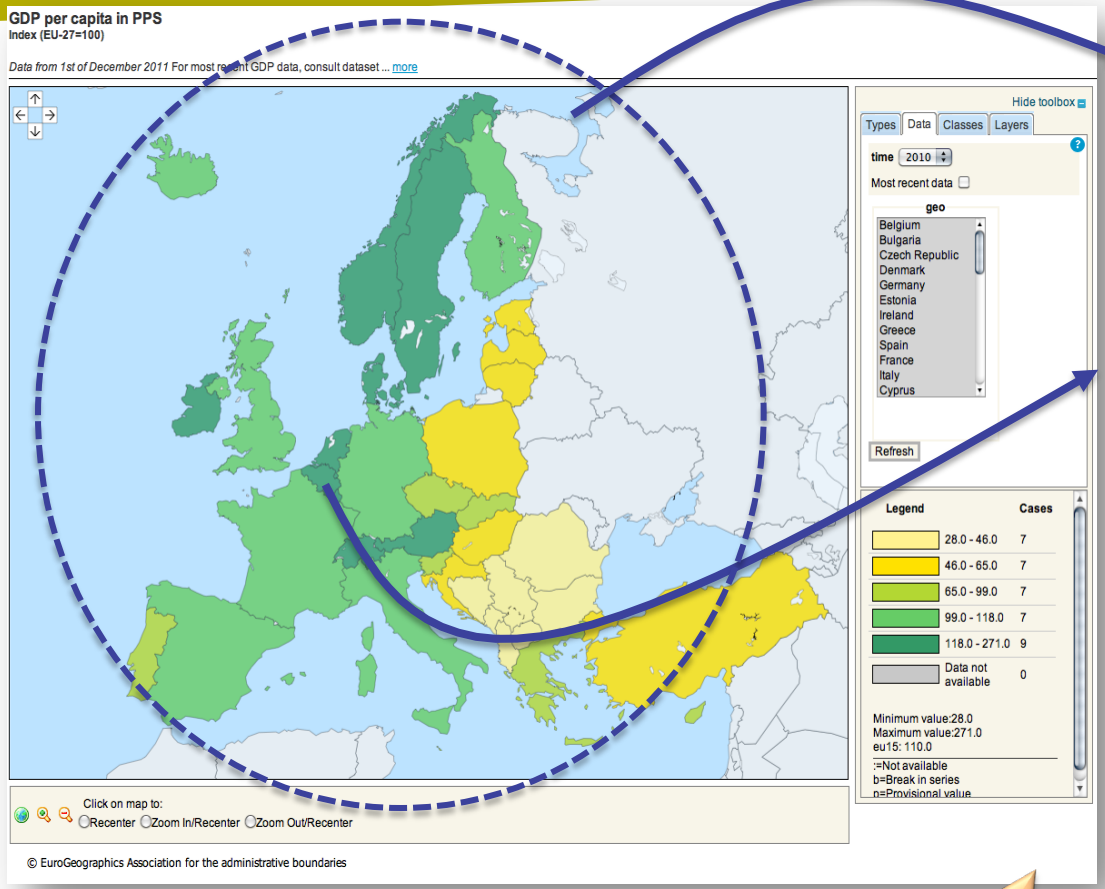
→ Increasing demand for caregivers

→ Decreasing active population

→ With less persons taking care of more persons



Increased health cost



Source: EU White Paper "Together for Health: A Strategic Approach for the EU 20[illegible]2013".

For EU by 2050:

healthcare spending increase with 25%

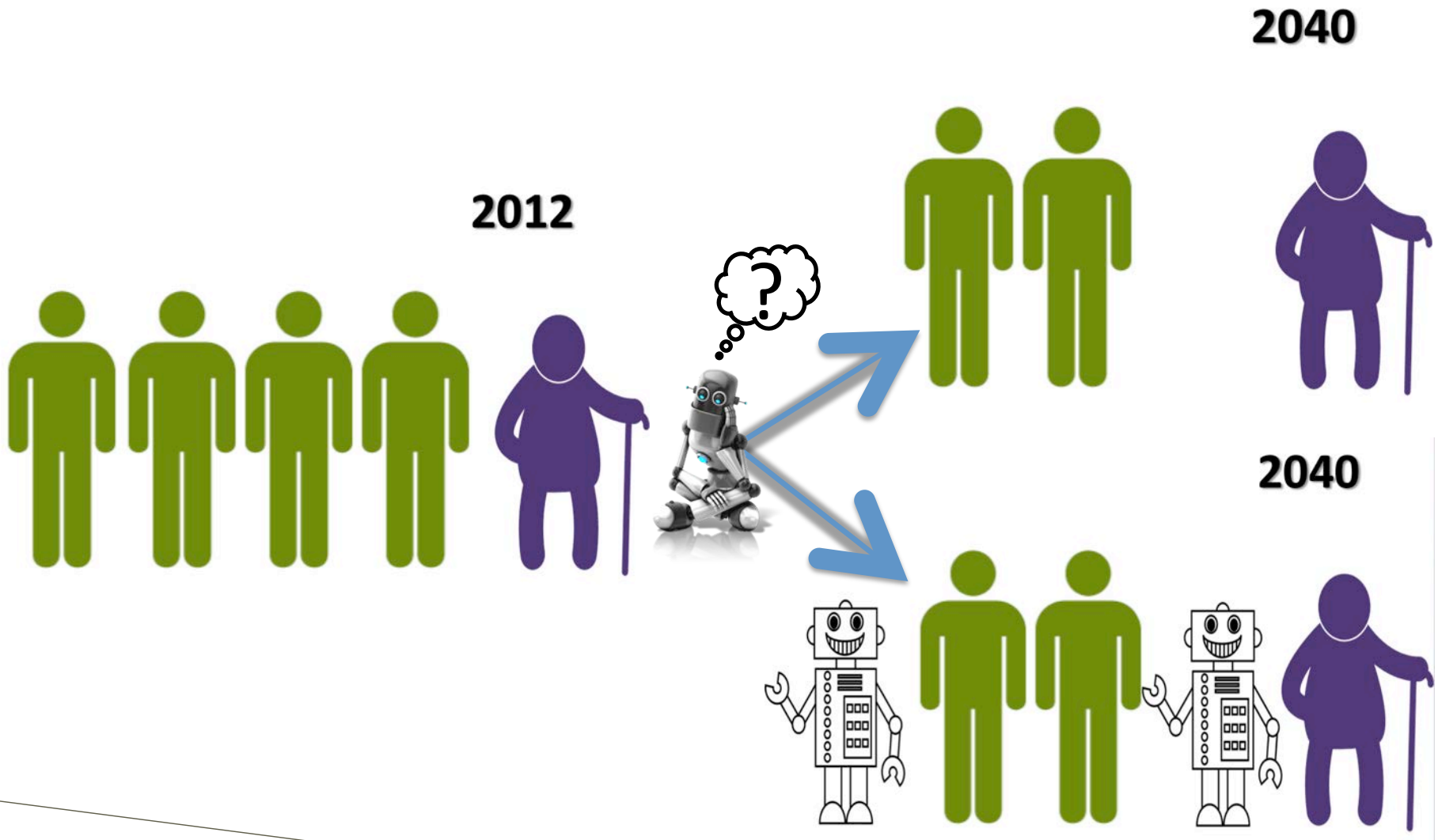
For Flanders by 2050 :

- will be confronted much stronger
- its demographic pattern counts more elderly people
- And Healthcare costs are higher in comparison with other EU countries

- Today = 11,1% of GDP
  = 36,8 billion EUR

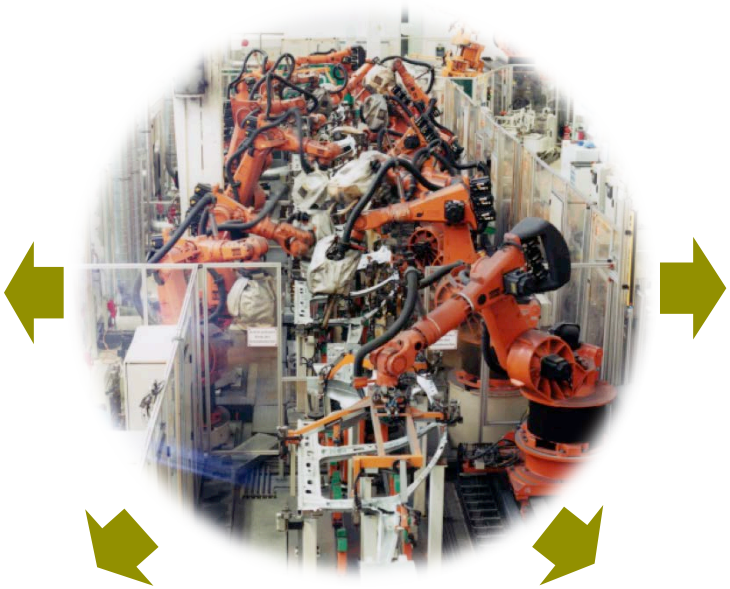
- Increase of 25%
  = 9,2 billion EUR/year

Health is the greatest wealth!


2040
2012
?
2040

Robots are about to enter our daily life

Aibo



Lopes

Claudia Mitchell

Roomba

Disruptive technologies: Advances that will transform life, business, and the global economy

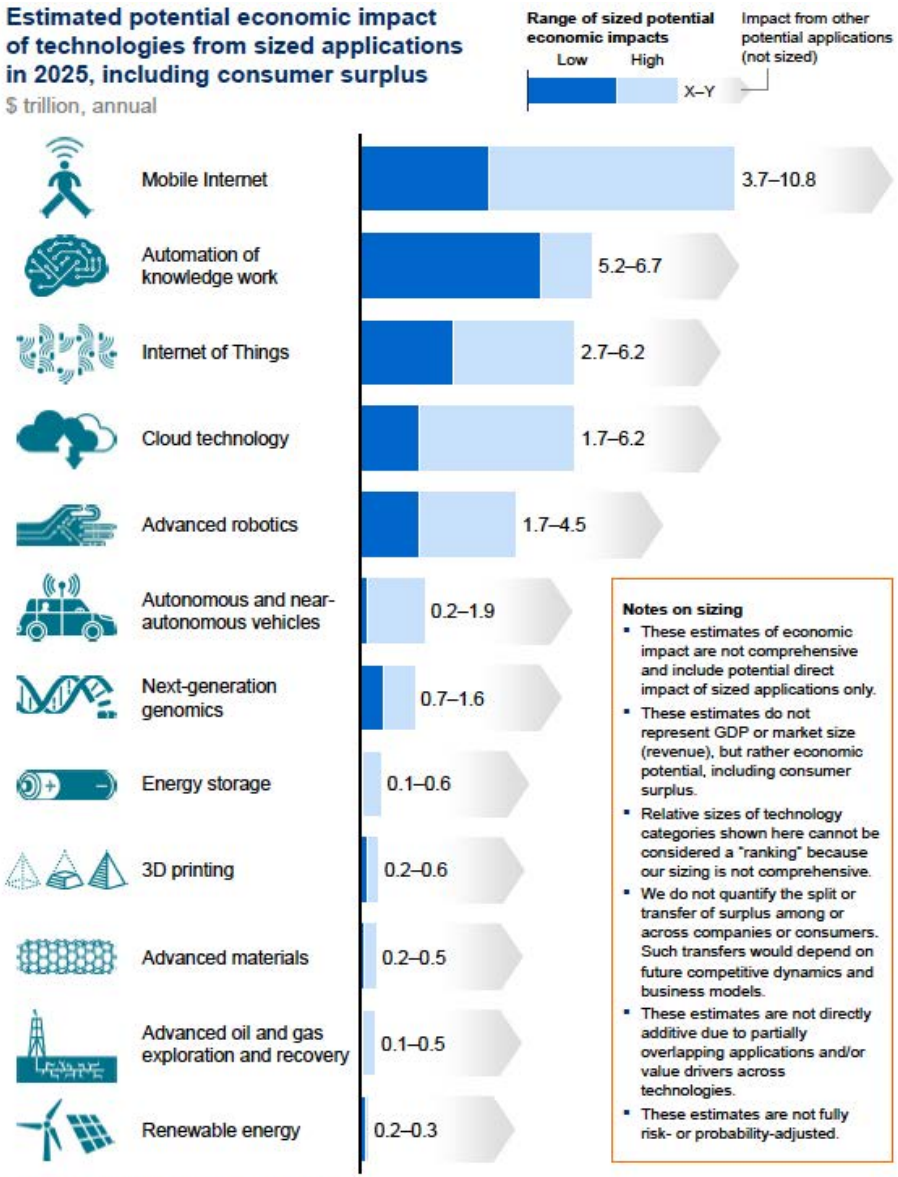
McKinsey Global Institute

May 2013

Policy makers and societies need to prepare for future technology. To do this well, they will need a clear understanding of how technology might shape the global economy and society over the coming decades.

Since the Industrial Revolution, technology has had a unique role in powering growth and transforming economies.

The McKinsey Global Institute set out to identify which of these technologies could have a massive economically disruptive impact between now and 2025.



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Study Gartner

- 2013 Hype Cycle on evolving relationship between human and machine.
- 3 trends:
  - Augmenting humans with technology
  - Machines replacing humans
  - Humans and machines working alongside each other

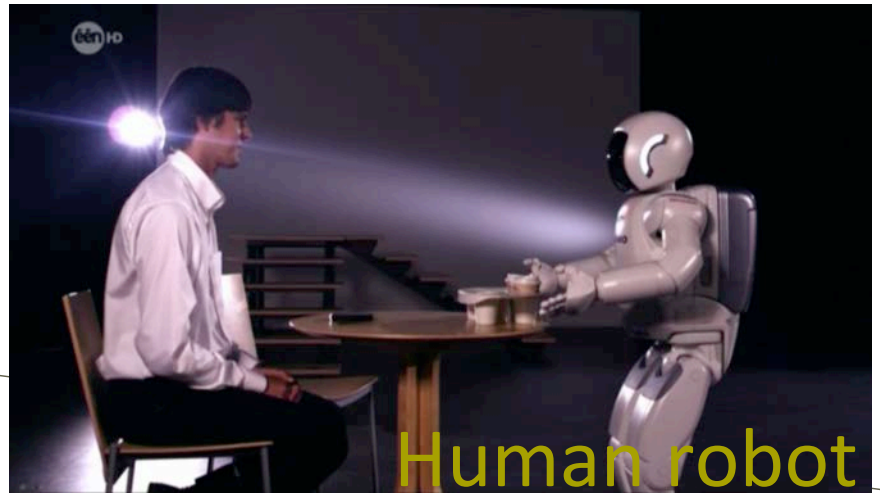
Combine the best of the two worlds

Machines

- precision
- repeatability
- 3D jobs
- …

Humans

- creativity
- problem solving
- dexterity
- …



Human robot interaction

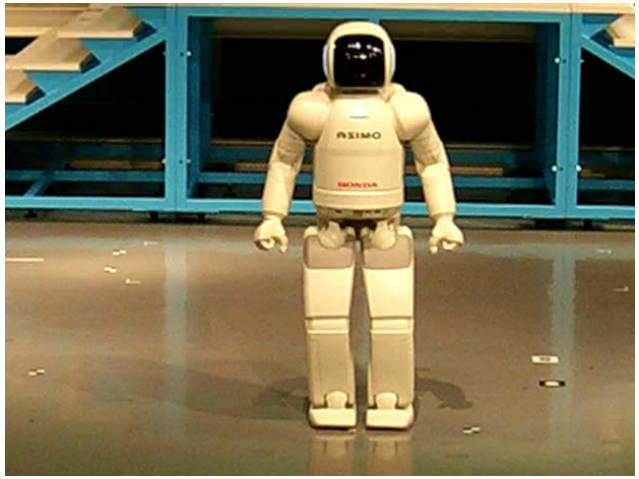
New actuators required

Suitable for static and known environments (often industrial settings)

Unsuitable for dynamic unknown environments (including humans)

Stiff actuation

- No energy storage
  - (also recuperation in batteries in robotics not efficient)
- No shock absorption
  - Damage on harmonic drives
- Unsafe
  - Kept away from humans



ASIMO

HRP2
AIST

Active – passive compliant actuators

Active Compliant

Compliant behaviour of a stiff actuator by software control

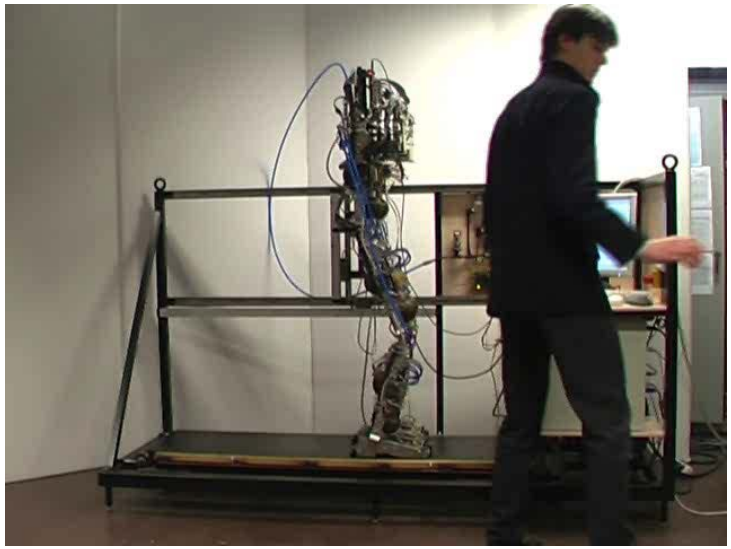
- Limited bandwidth
- No energy can be stored
- Power is required both to accelerate and decelerate a mass.

DLR lightweight arm

Passive Compliant

Actuators with an elastic element (spring)

- Unlimited bandwidth to impacts
- Passive compliance
- Energy storage

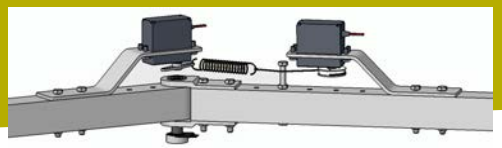


Use of springs in biological systems

The basic mechanisms of energy conservation using springs have been demonstrated in a wide variety of animals that differ in leg number, posture, body shape, body mass, or skeleton type




VIA: review



Active impedance | Inherent | Inherent

ELSEVIER

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Variable impedance actuators: A review

B. Vanderborght[f], A. Albu-Schaeffer[a], A. Bicchi[b, e], E. Burdet[d], D.G. Caldwell[e], R. Carloni[c], M. Catalano[b, e], O. Eiberger[a], W. Friedl[a], G. Ganesh[d], M. Garabini[b], M. Grebenstein[a], G. Grioli[b], S. Haddadin[a], H. Hoppner[a], A. Jafari[e], M. Laffranchi[e], D. Lefeber[f], F. Petit[a], S. Stramigioli[c], N. Tsagarakis[e], M. Van Damme[f], R. Van Ham[f], L.C. Visser[c], S. Wolf[a]

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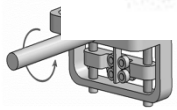
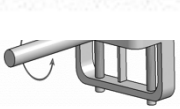
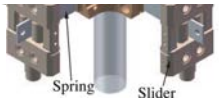
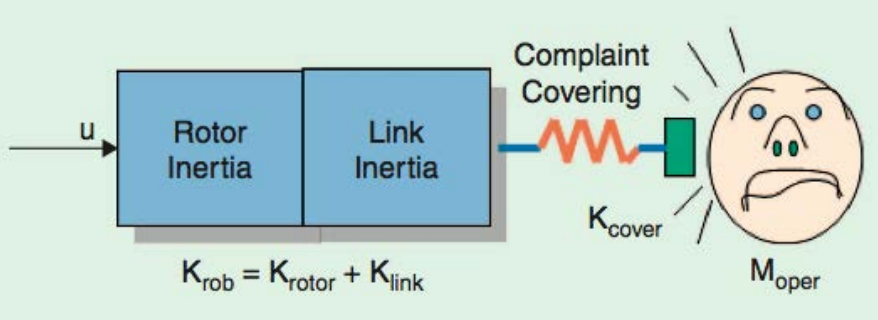
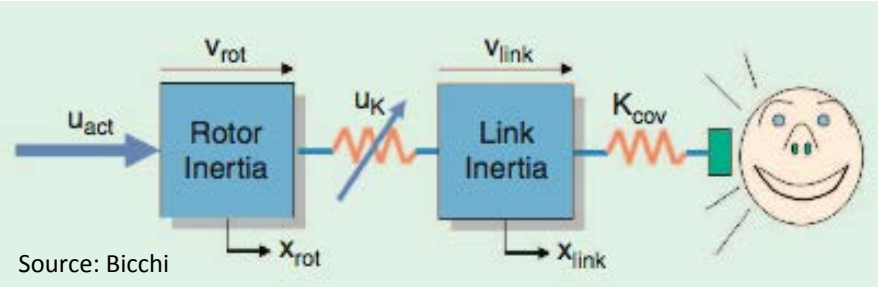




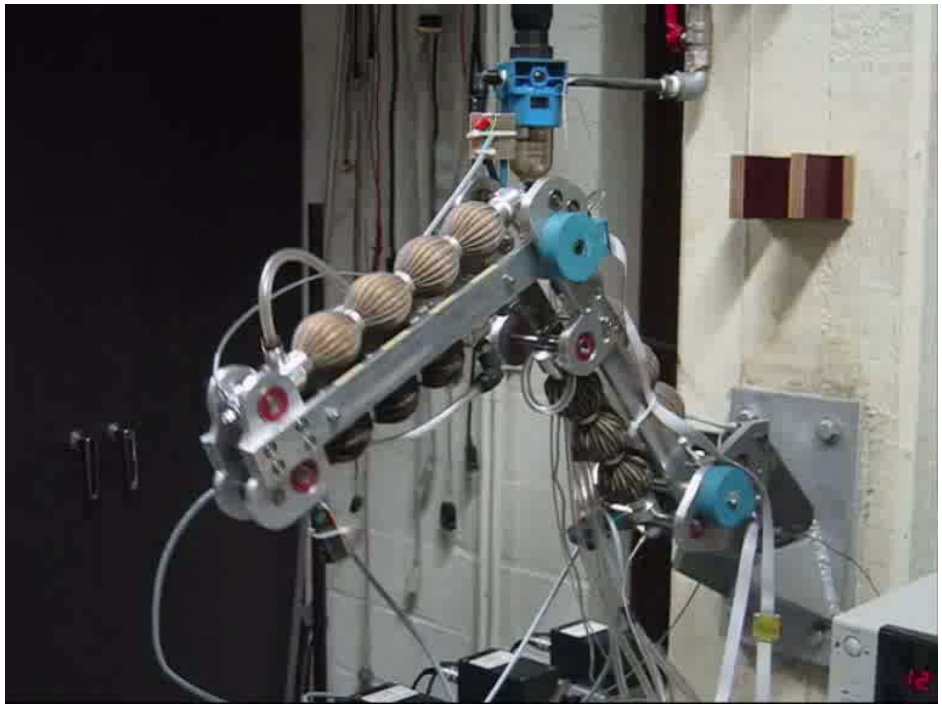


Compliant actuation
Safety: pneumatic softarm

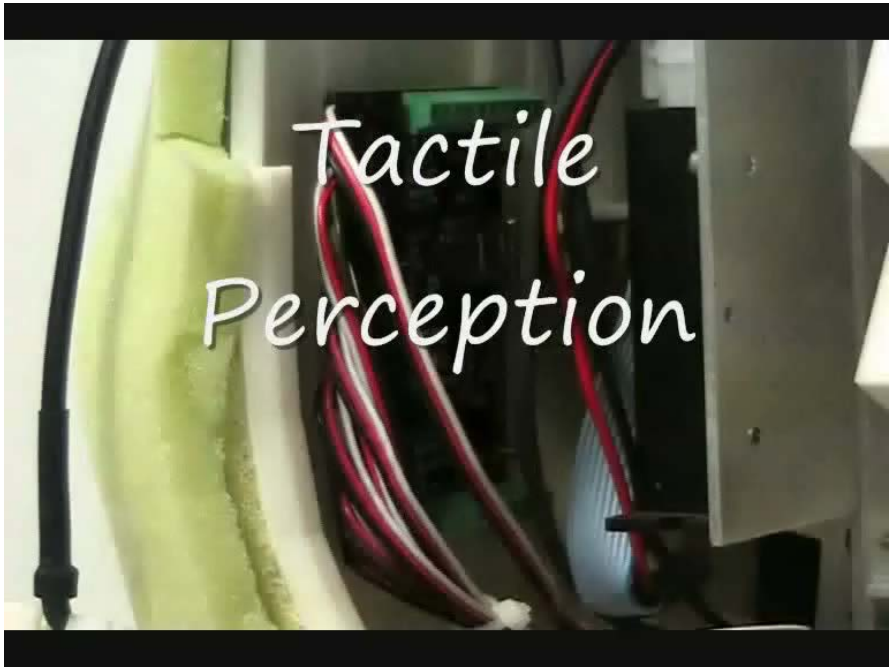




Source: Bicchi

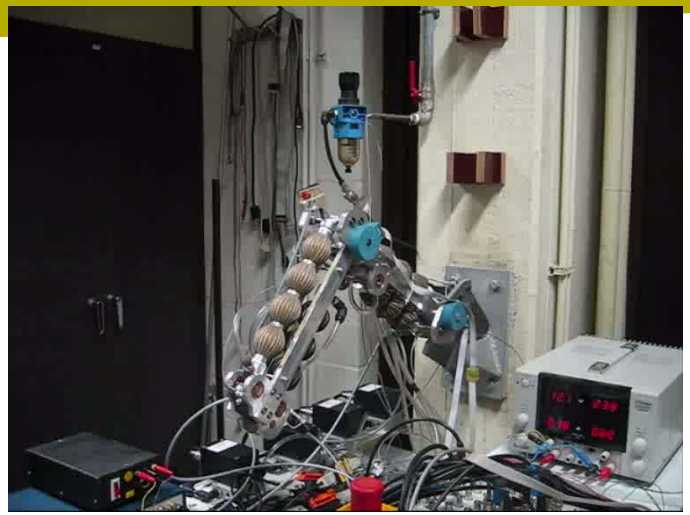


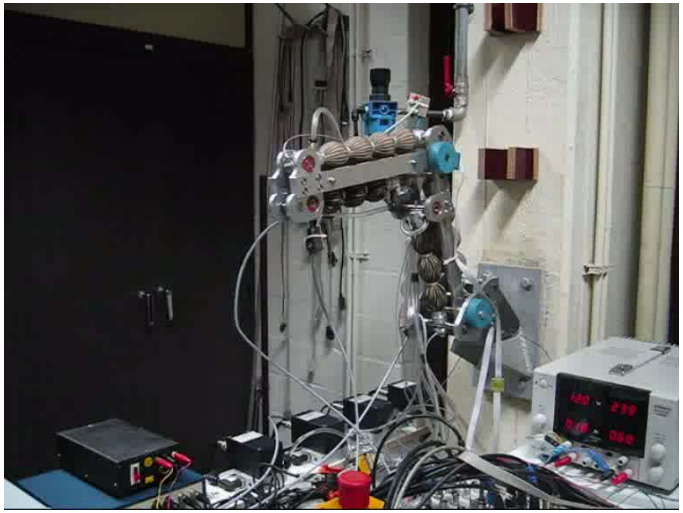
Compliant Actuation
Safety: social robot Probo



Scoial robot Probo VUB

Compliant actuators
Hardware is not always enough for safety





- *Passive actuators can store energy which is a potential danger if not properly controlled*
- *Use of proxy based sliding mode controller*

	Step		switch between trajectories		Tracking error for sinus
	HIC	Fmax	HIC	Fmax	
PID	4.81	1524	3.02	1004	0.0146
PSMC	0.1	233	0.03	132	0.0053

PID = unsafe →
PSMC = safe →

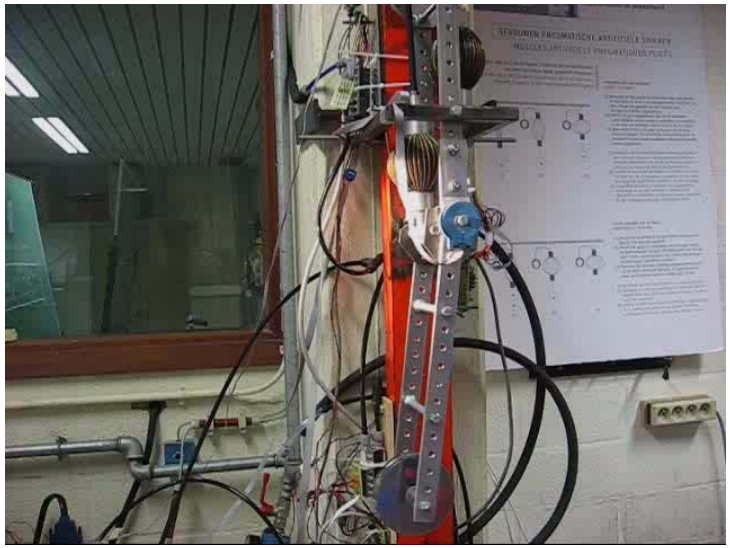
Compliant actuators
Force interaction for gait rehabilitation

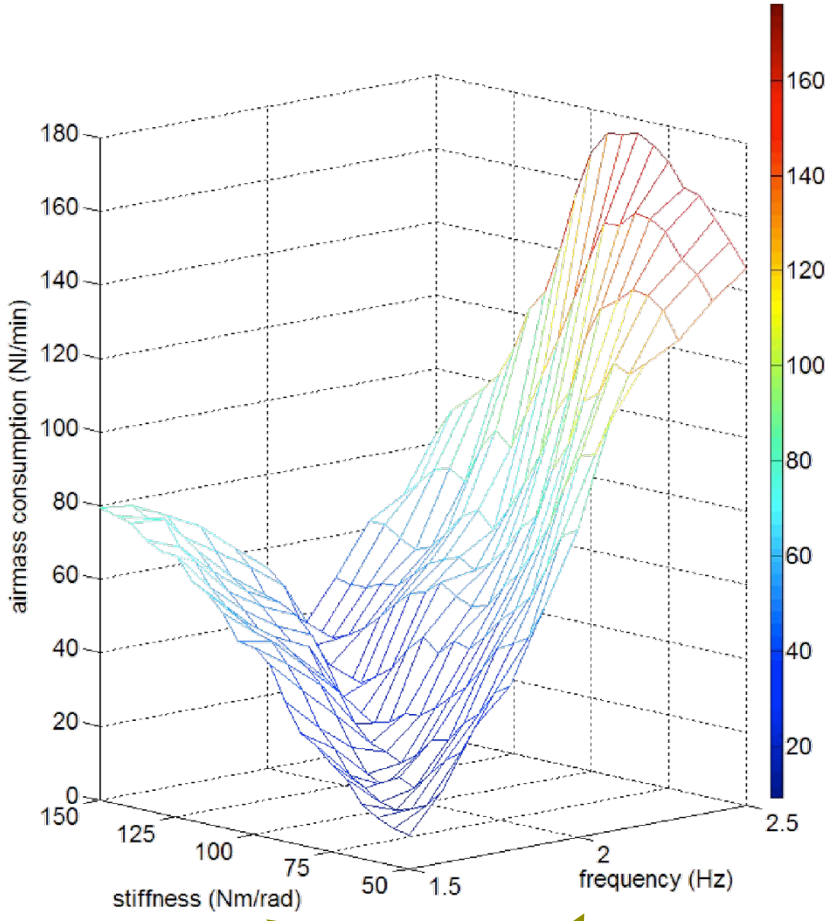
Knexo VUB

ALTACRO VUB

Compliant actuators
Energy efficiency

Choosing optimal stiffness reduces the energy consumption
Developed a compliance controller to select the optimal stiffness.

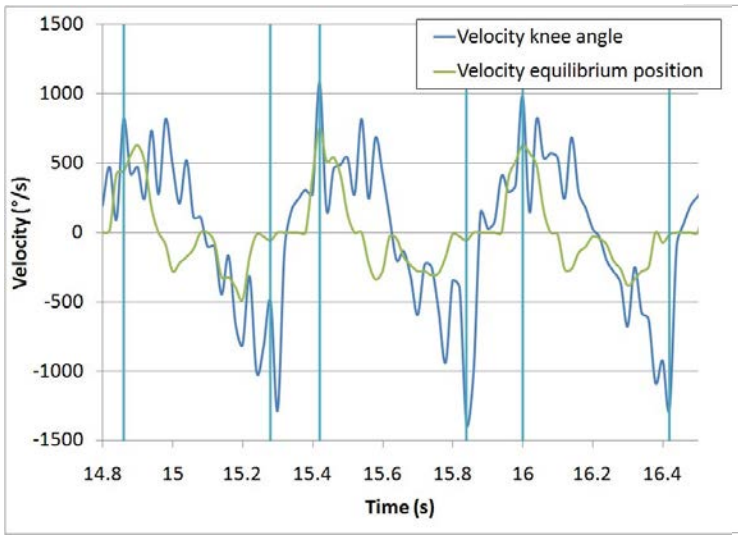


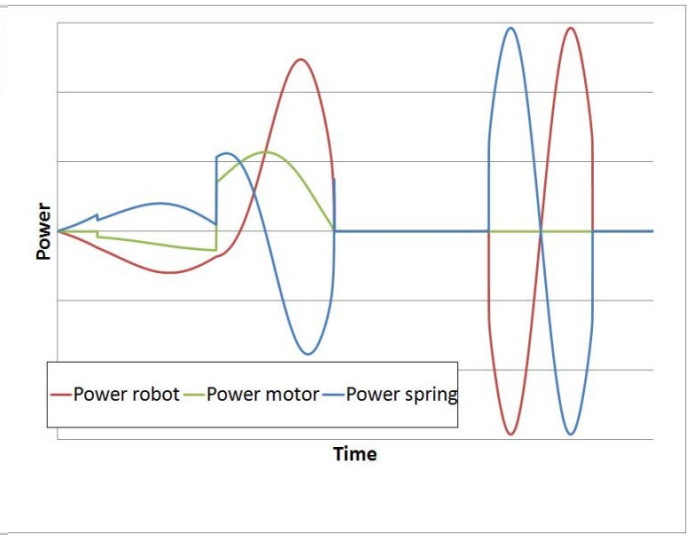


$$\tilde{p}_1 = p_m + \Delta\tilde{p}$$
$$\tilde{p}_2 = p_m - \Delta\tilde{p}$$

Compliant actuators
Exploitation natural dynamics: Veronica

Compliant actuation
Explosive motions: Chobino

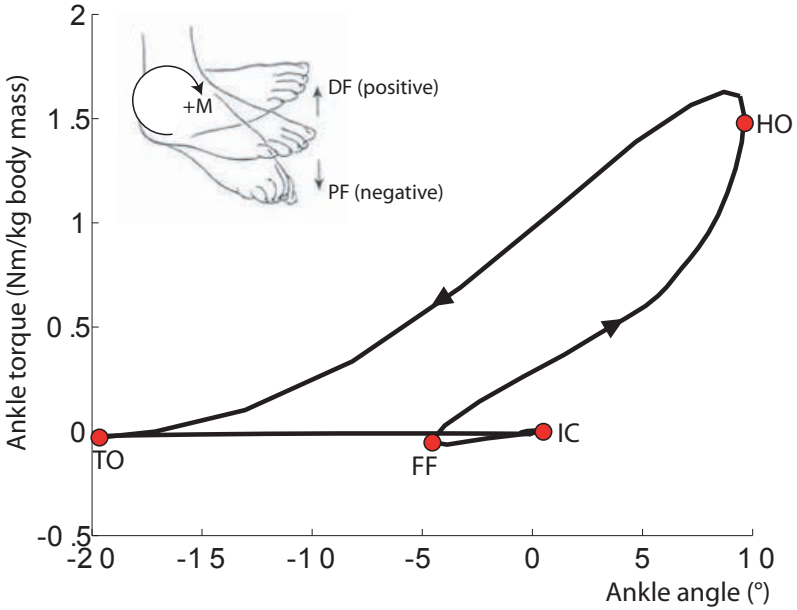


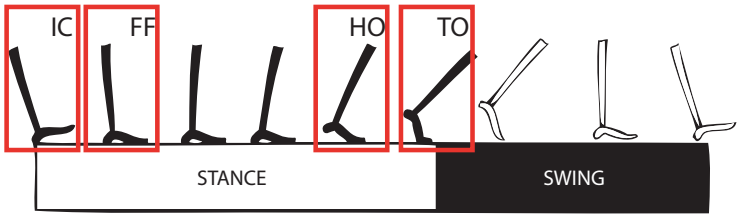


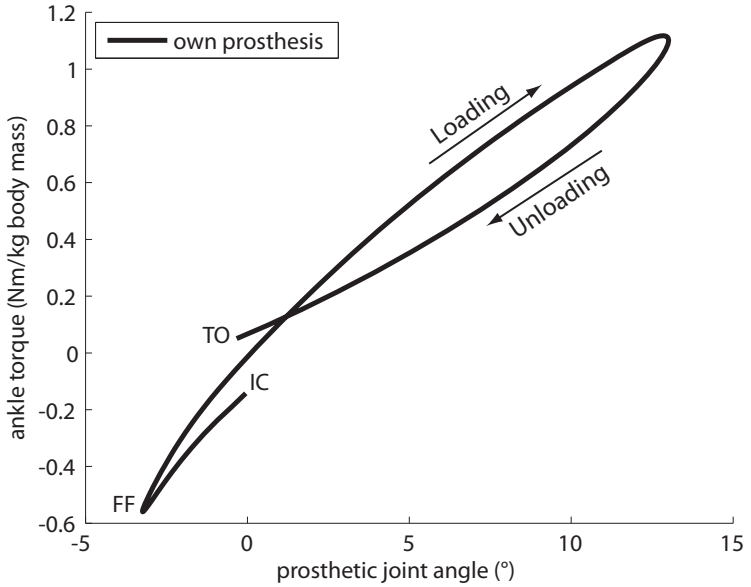
Energy is stored during one phase and released during next phase
Less powerful motor is needed

Chobino IIT-VUB

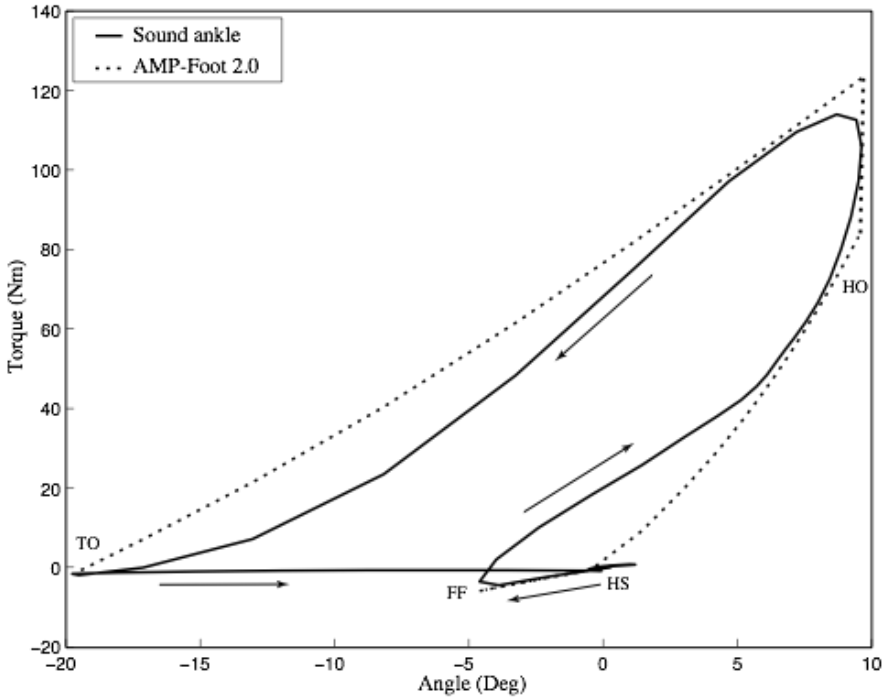
Compliant actuation
Explosive motions

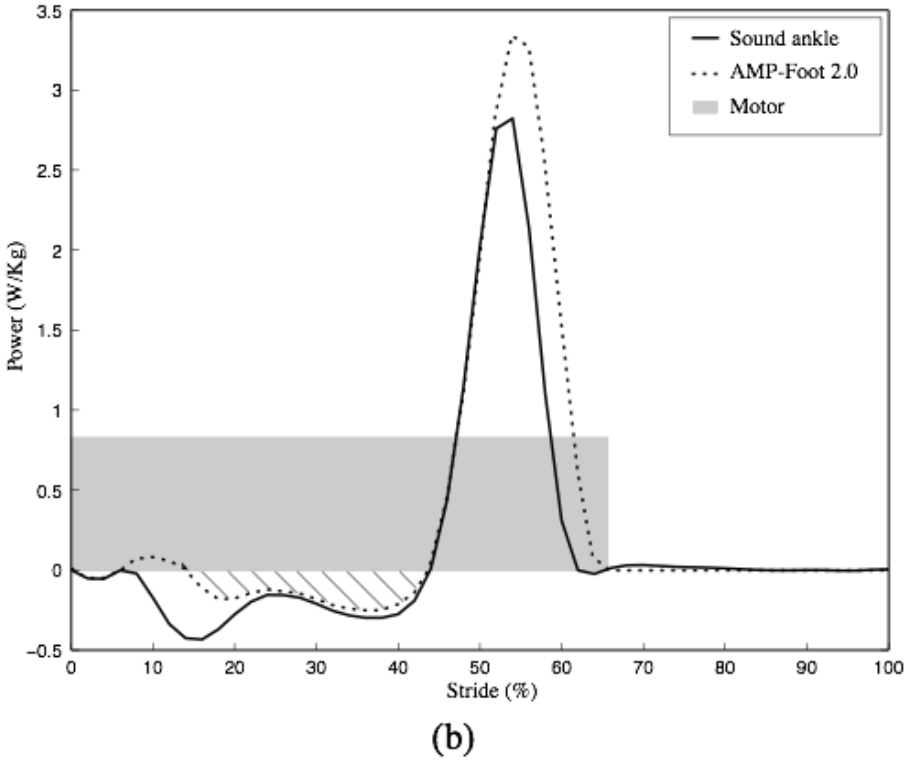






Human ankle requirements

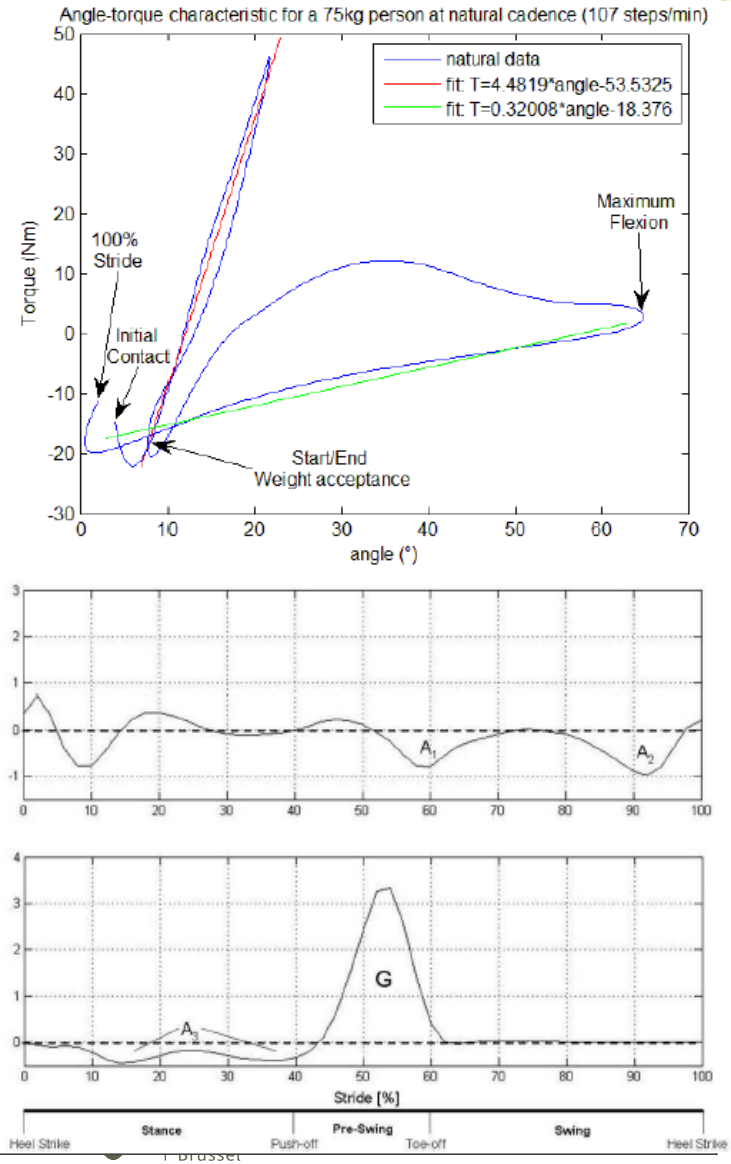




!! Motor works during the complete stance phase !!

AMPfoot 2.0

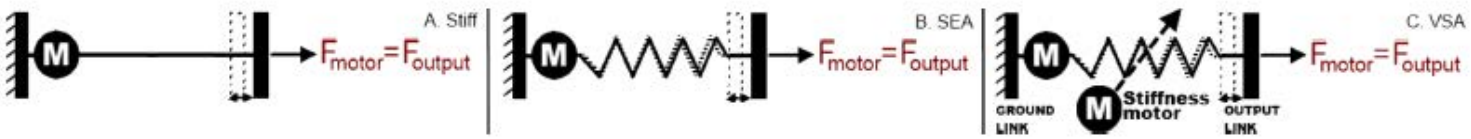
Cyberlegs



Cyberlegs VUB-SSSA

Remaining problems

- All torque goes through motor



- When position/equilibrium position does not change
  - Mechanical power = 0
  - Electrical power != 0 (low energy efficiency)
- Size electric motor/gearbox is proportional to required torque, so still heavy motors.
- Copper losses in electric motor proportional to (torque ≈ current)^2.

Challenge

- Compliant actuators are able to reduce power requirements, but not torque
- Actuators are not yet able to
  - Work energy efficient (robots work at about 1%?)
  - Provide enough torque
  - Different applications impossible
- Challenge is to improve:
  torque/mass ratio + improve energy efficiency

Observation

- Mammalian skeletal muscle
  - Average specific power density: **0.041W/g**
  - Max efficiency: **20%**

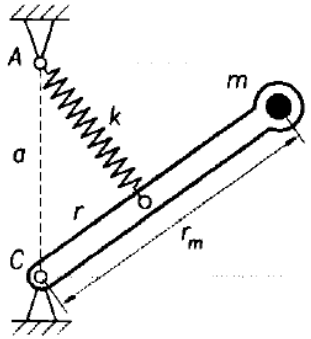
- Electric motor
  - Average specific power density: **0.5W/g**
  - Max efficiency: **80%**

Electric motor is not the problem.
The way transmissions and springs are used need drastic improvement, since all torques on the joint are maintained by the motor.

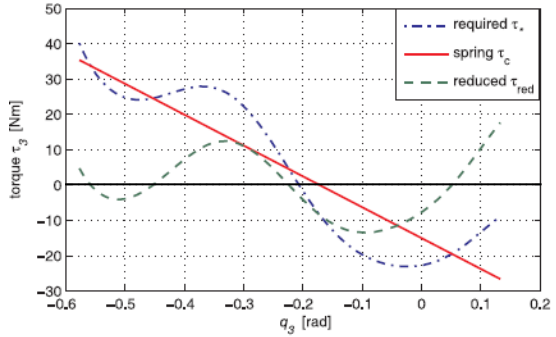
Use of parallel springs

- Fixed spring for load cancellation:

(Anglepoise lamp)

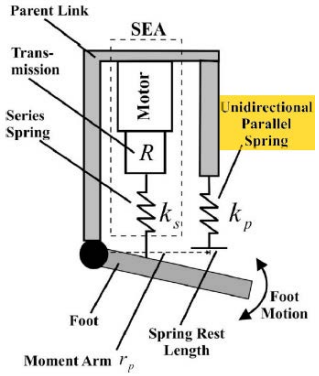


(Herder, 2001)

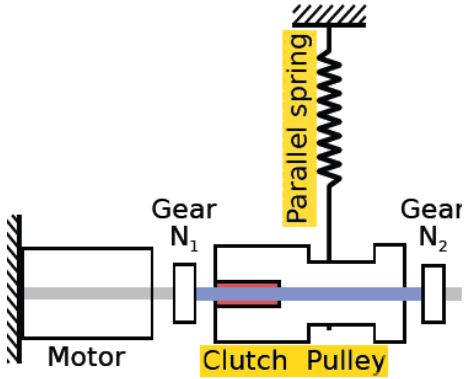


(Mettin, 2010)

- Switchable spring for load cancellation:



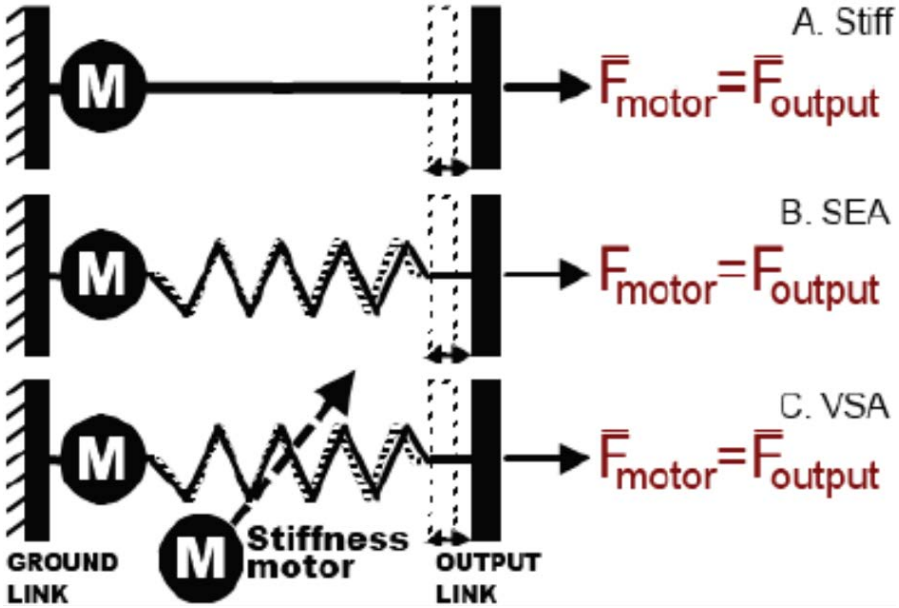
(Au, 2009)

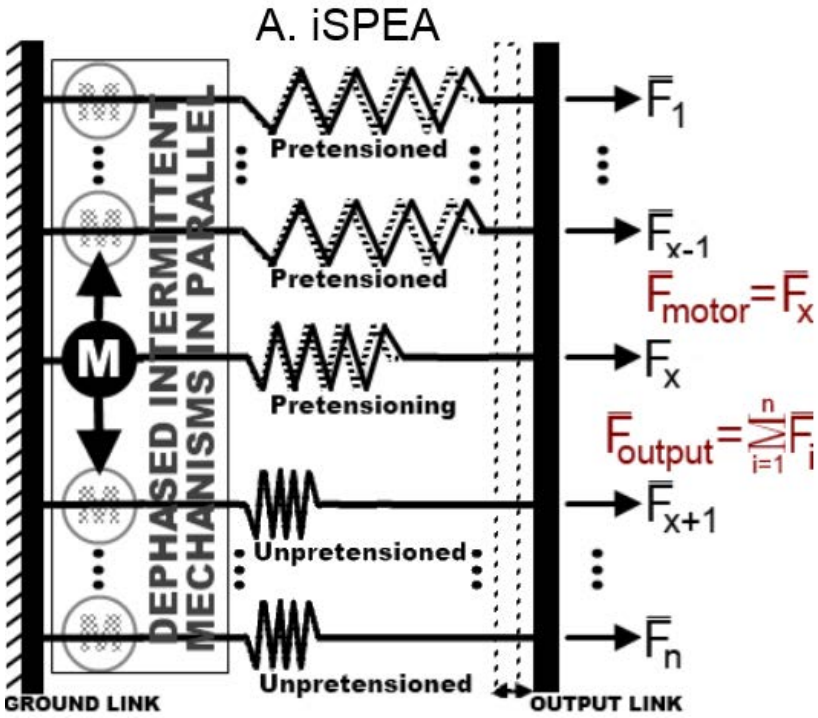


(Haeufle, 2012)

Problem: recoil the stored energy and induce joint motions that counter desired ones.

New concept: series-parallel elastic actuation (SPEA)

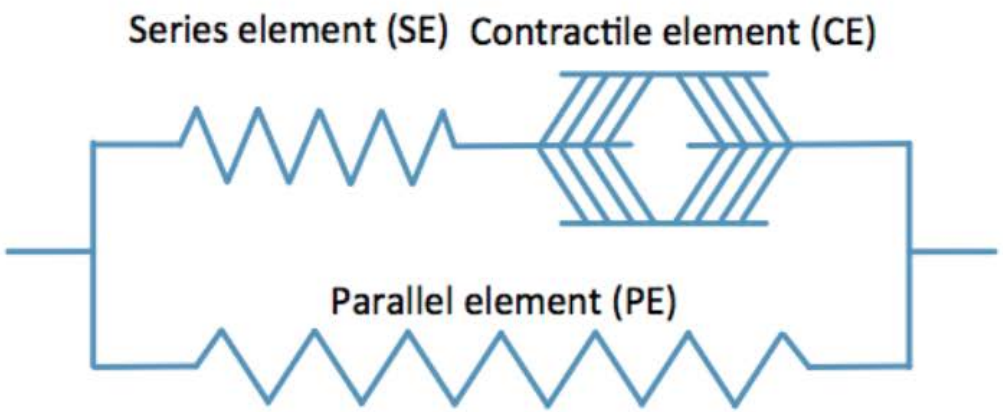


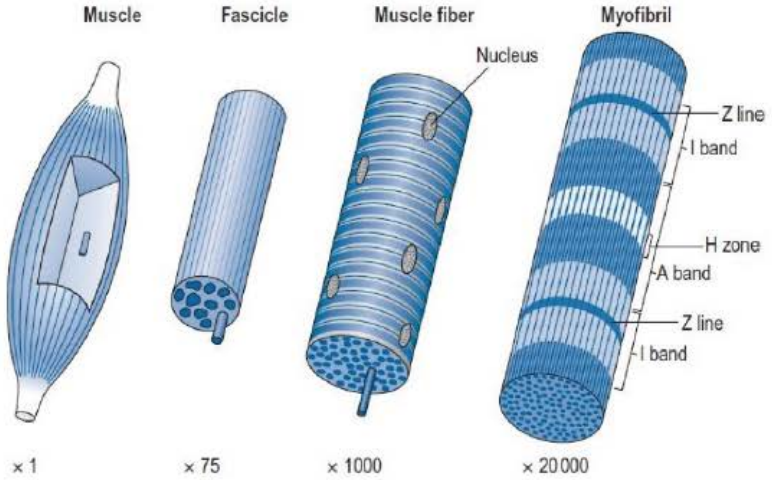


Variable recruitment and locking of parallel springs

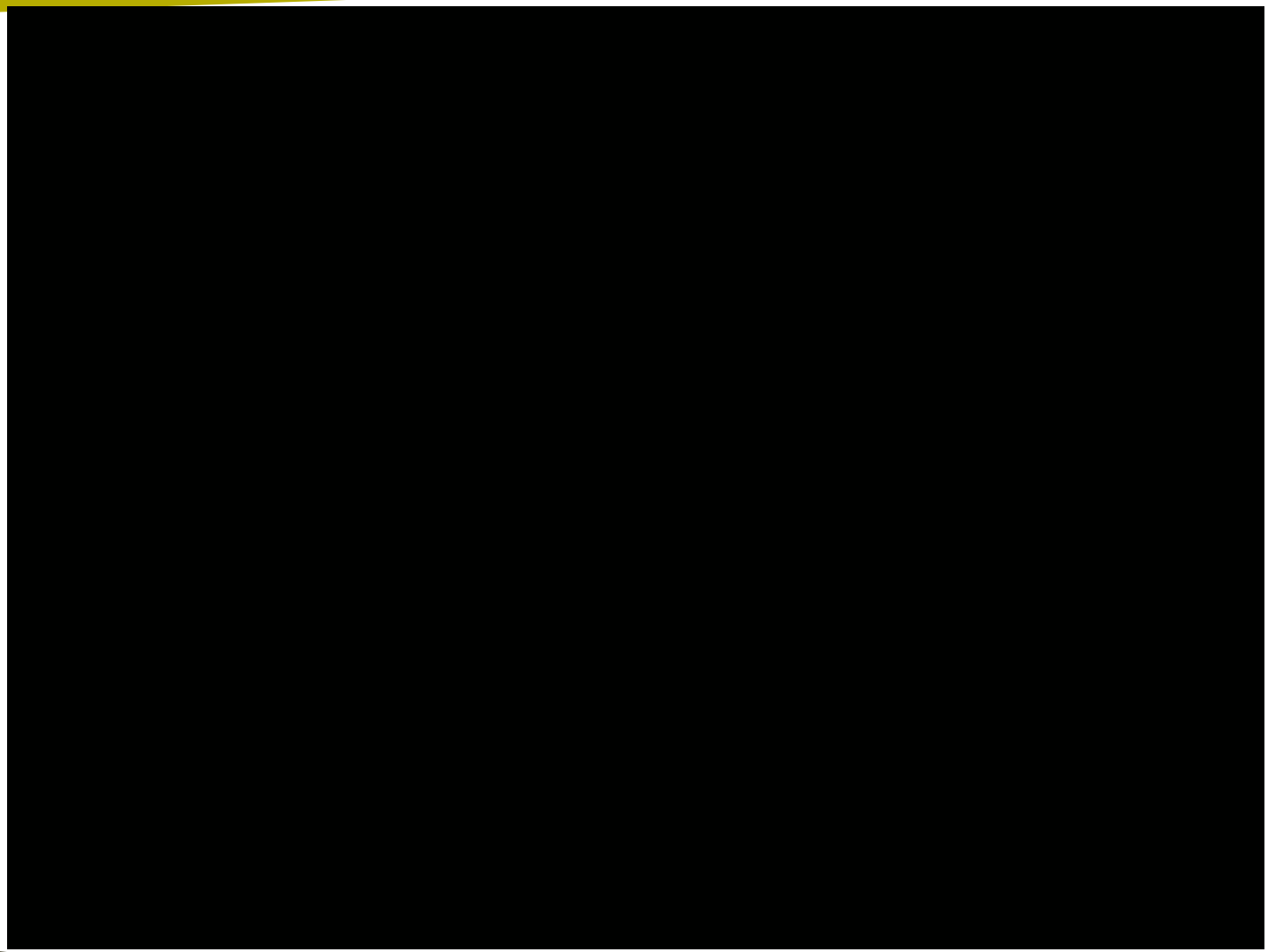
Dephased intermittent mechanisms in parallel

Biological evidence





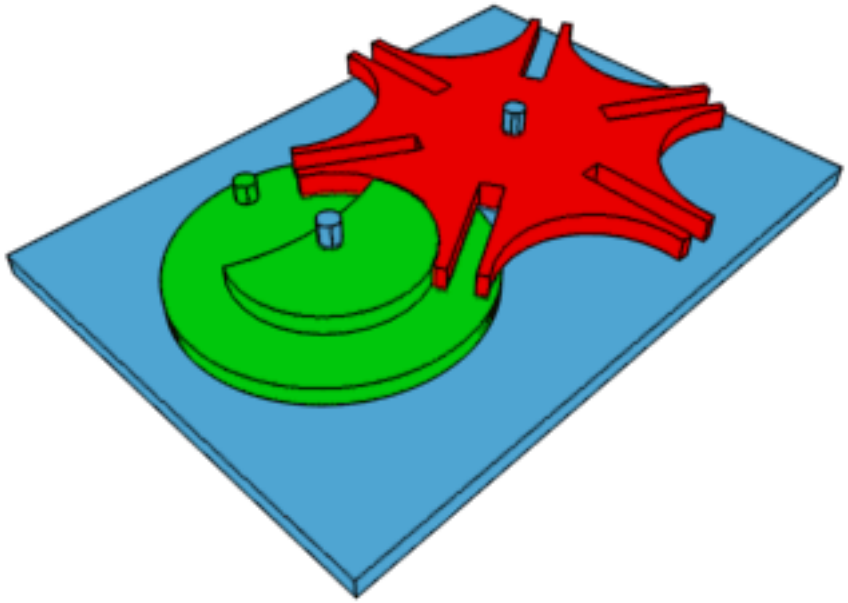
SPEA Proof of Concept



Intermittent mechanisms

Intermittent ↔ Variable recruitment

Locking phase ↔ Load cancellation

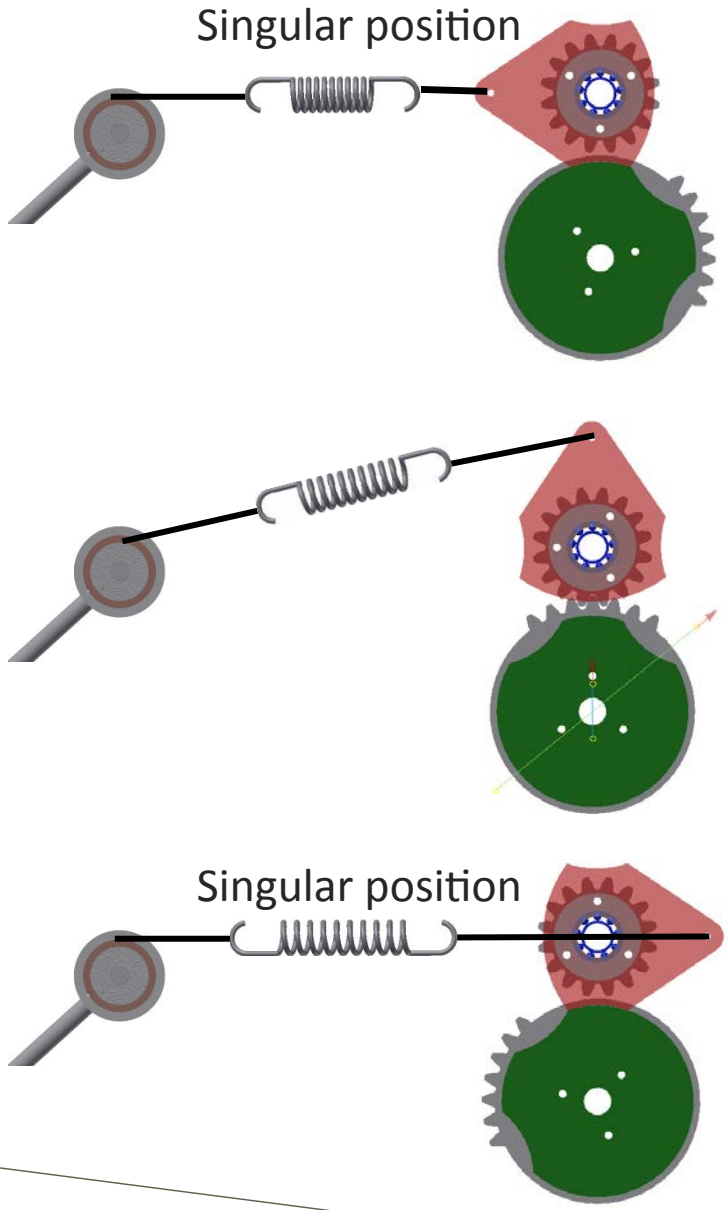


Geneva mechanism

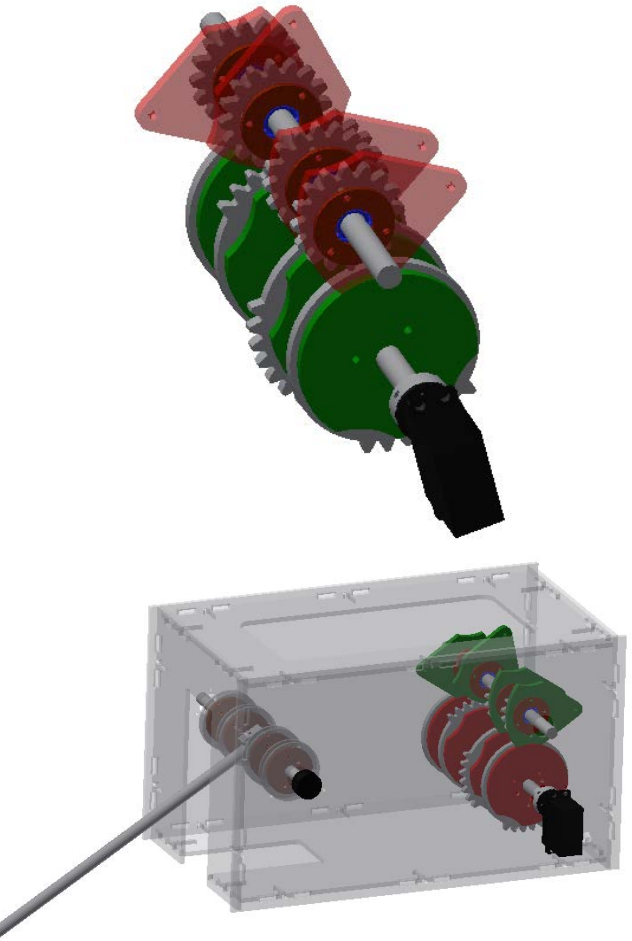
Mutilated gears

Dephased intermittent mechanism

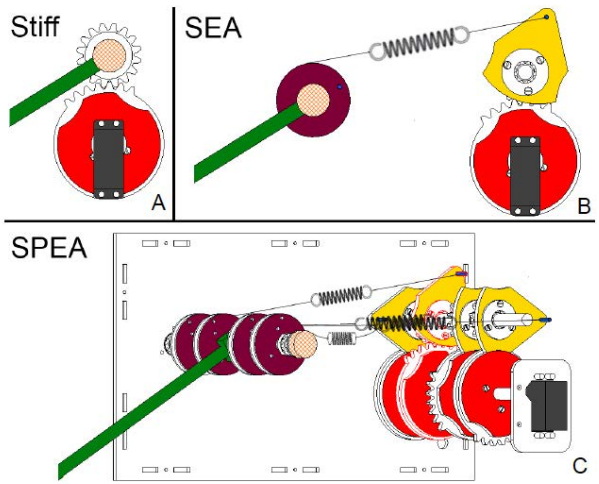
(Bickford, 1972)

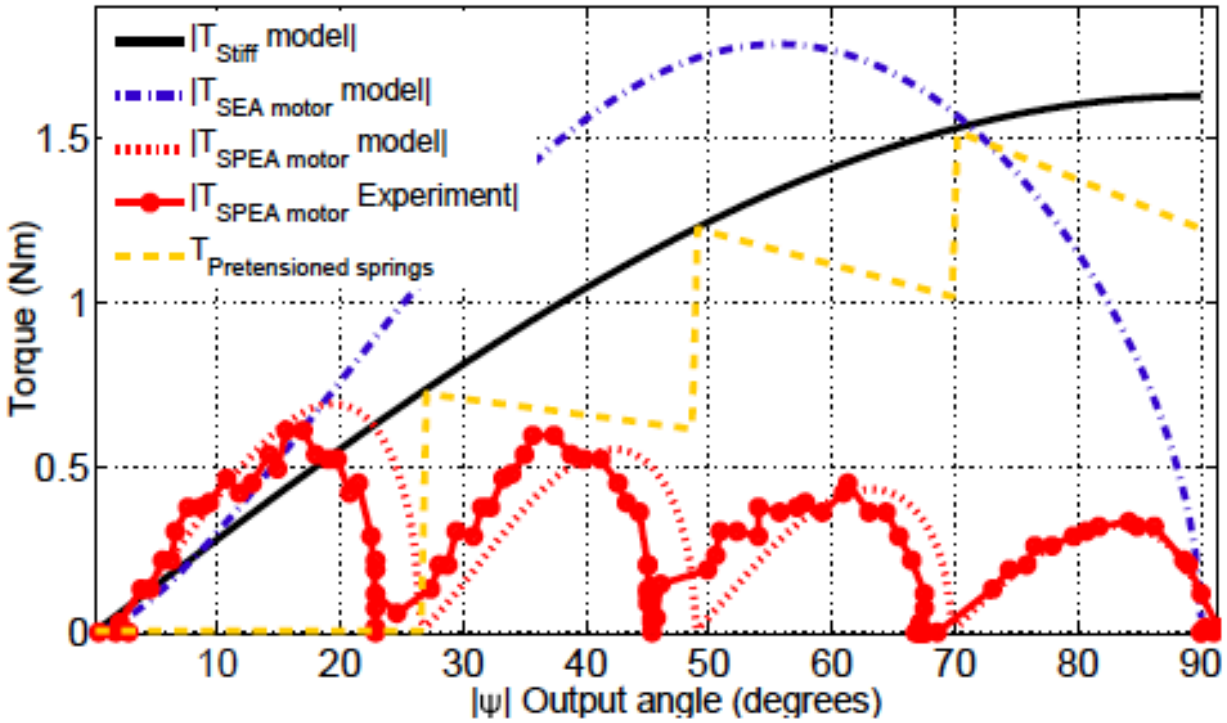


SPEA Proof of Concept



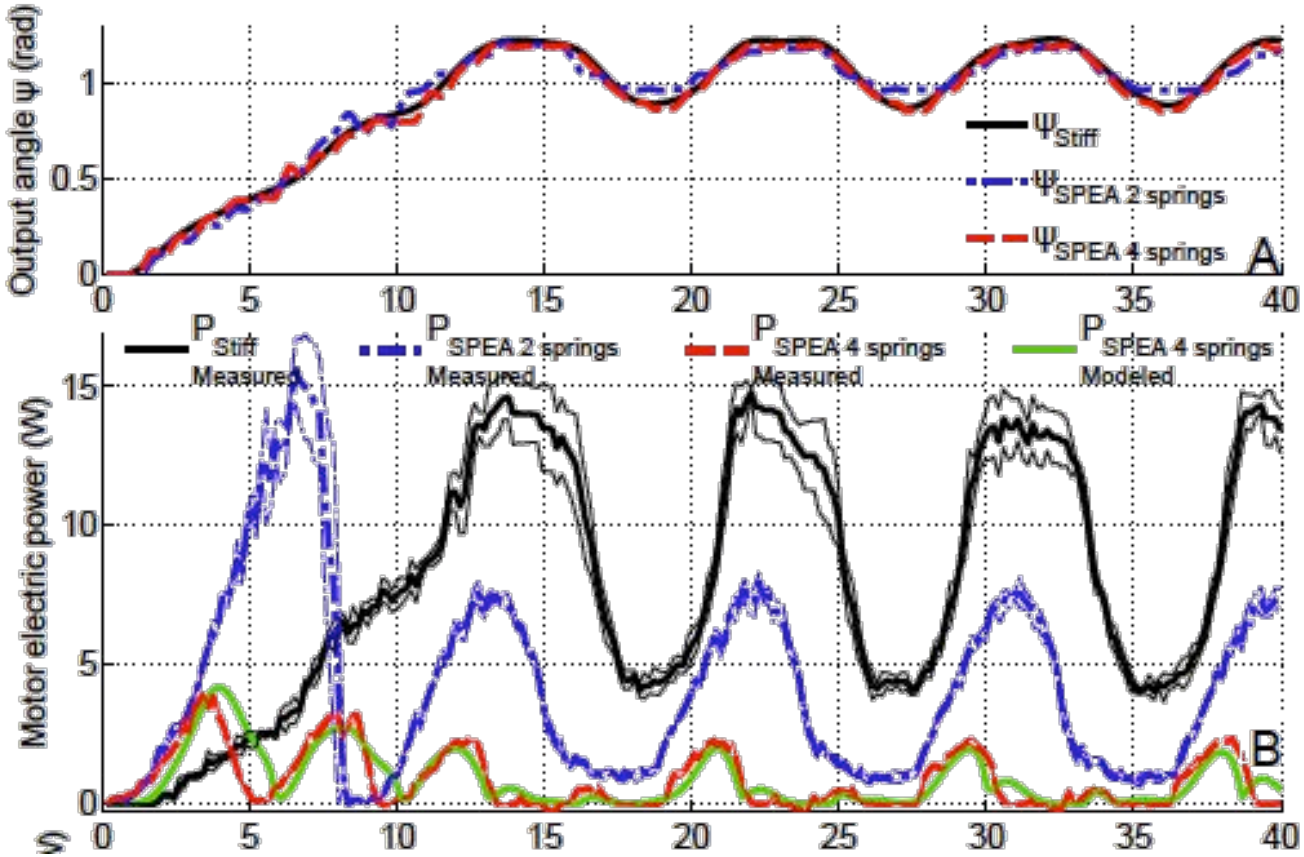
SPEA torque





- Maximum motor torque stiff actuator (black) and SEA (green) are similar
- SPEA motor torque (red) clearly lowered and model matches
- Delivered torque by the locked springs (yellow) increases

SPEA power



- Performed mechanical work is equal for the 3 actuators
- # springs in the SPEA increases, energy consumption decreases

$$P_{output} = T_{output} * v = (T_{springs} + T_{motor}) * v$$

Conclusion

- Compliant actuators investigated for safety, energy efficiency, robustness, explosive motions
- Requirements for torque/mass and efficiency not yet reached for different applications (power augmentation, running robots, manipulators...)
- Use of switchable parallel and serial elastic elements
- PoC showed feasibility for improved torque and efficiency
- Preliminary idea that needs (lot of) further development and research (over ERC grant)
  - Complex mechanical model
    - Brain: 85 billion transistors – PC: 2,6 billion transistors
    - Body: 800 muscles and much more muscle fibers – Robot: 50-70 actuators.
  - Reduced forces through the parts, redundant
  - Additive manufacturing techniques to build it (not any more with nuts and bolts).

More info: http://mech.vub.ac.be/robotics
Publications: http://www.vub.ac.be/infovoor/onderzoekers/research/person_pub.php?person_id=25221

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