Research in Humanoid Design

Vertebral Column for Humanoids

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Vertebral column

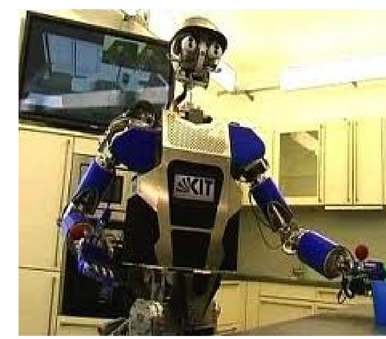
- Humans
  - Small yaw moves: keep balance
    - Compensate for yaw moment between support foot and ground
  - Quasi-static/dynamic bending motion:
    - Sitting down on a chair, and standing up
    - Picking up objects on the floor, and standing up
    - Lying down, standing up from lying position
  - Combination of moves:
    - Increase manipulation space of upper body

Walking or wheeled-base robots

- From 1 up to 4 serial DOF
- yaw joint
  - Asimo (Honda), Hubo (KAIST), Johnnie/Lola (TUM), …
  - Larger strides, compensation of yaw moment, increase of working space
- + pitch joint:
  - Twendy (Waseda), Justin (DLR), REEM B (PAL Rob.), HRP series (Kawada)
  - Whole body motion (sit, lye, flex, etc.)
- + roll joint:
  - Armar-III (KIT), Wabian (Waseda) (alternate knee stretching walk)

Walking or wheeled-base robots



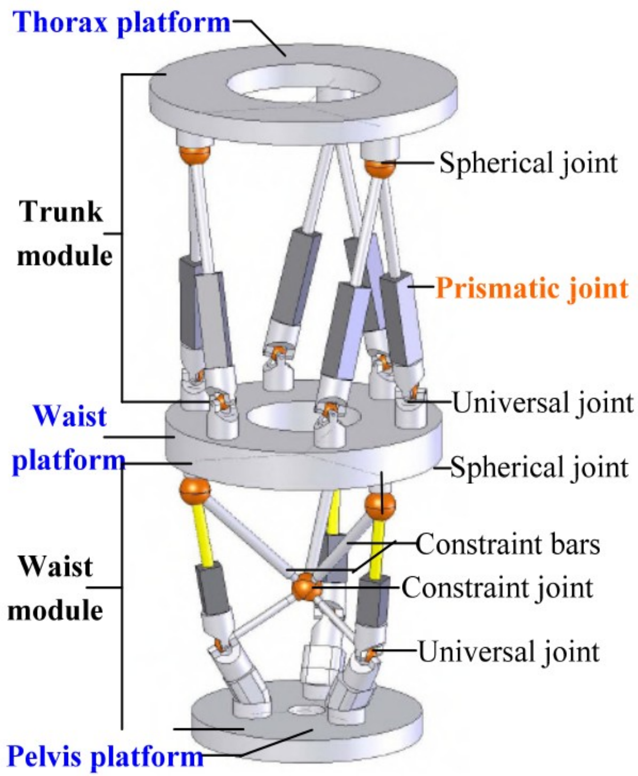




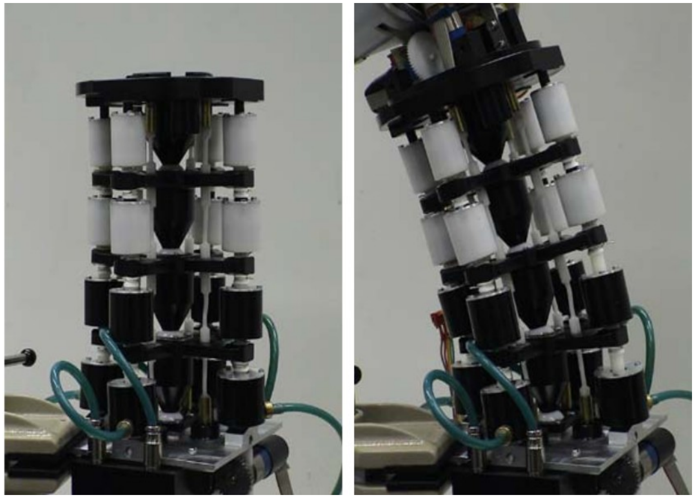
Parallel mechanism

- Stewart Platform: 6 UPS legs

Waist-trunk system
(Ceccarelli et al)
Univ. of Cassino



- Hydraulic



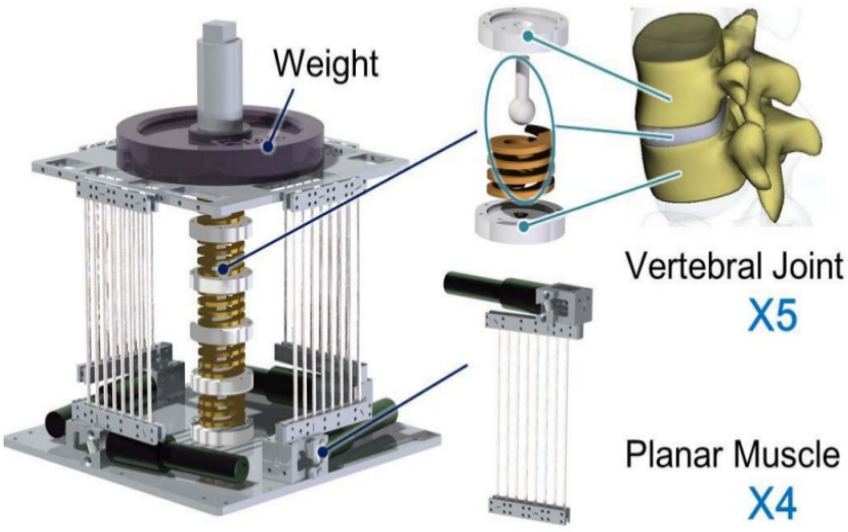
Robota's spine
Hydraulic (EPFL)

Ape robot
(DFKI)

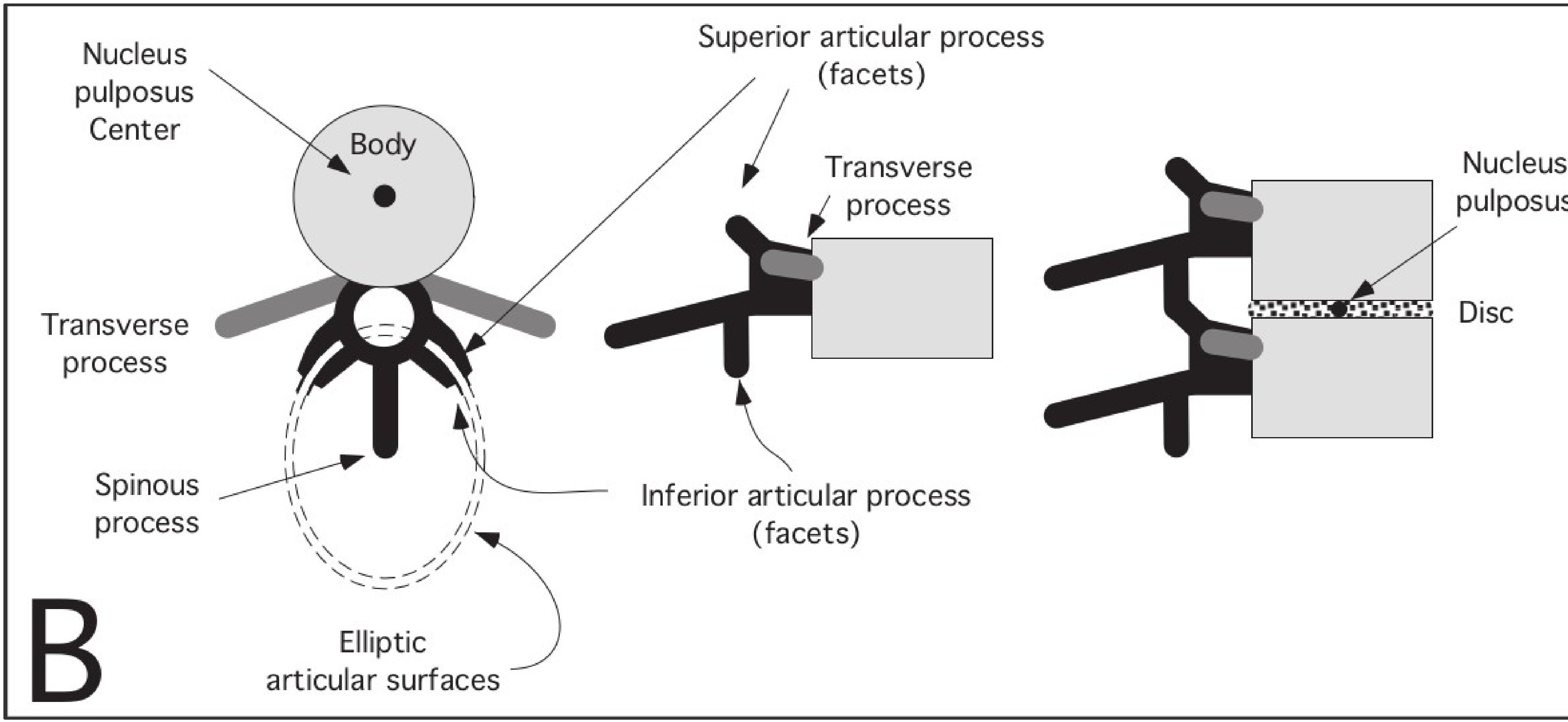
Parallel mechanism

- Bioinspired: musculo-skeletal humanoids
  - Cla, Kenta, Kojiro, Kotaro (Univ. Tokyo)
  - Kenzoh



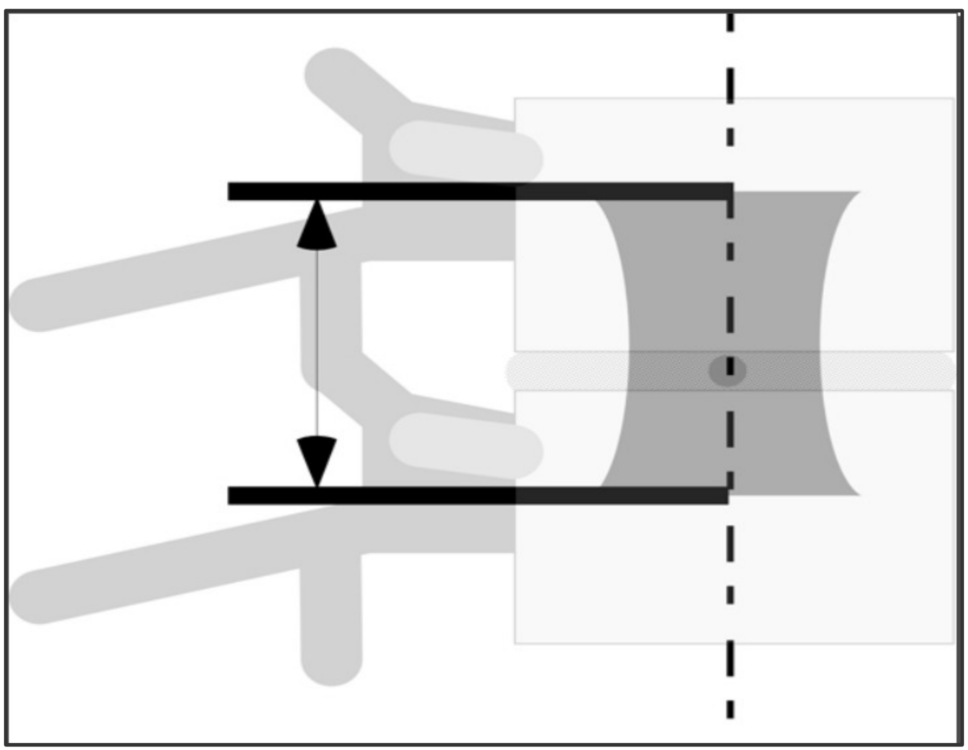


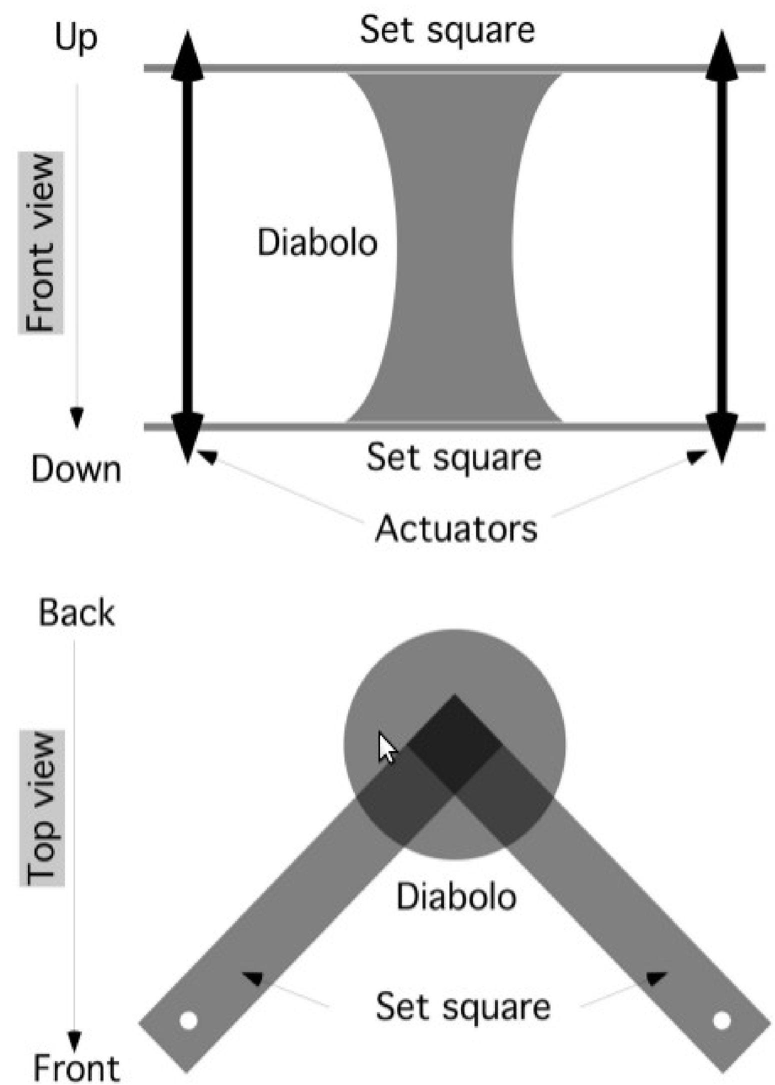
Human vertebra



Idea: use of a windsurf silent block

- Imitate the human vertebra
- Add compliance to the vertebra mechanism
- Parallel actuation mechanism

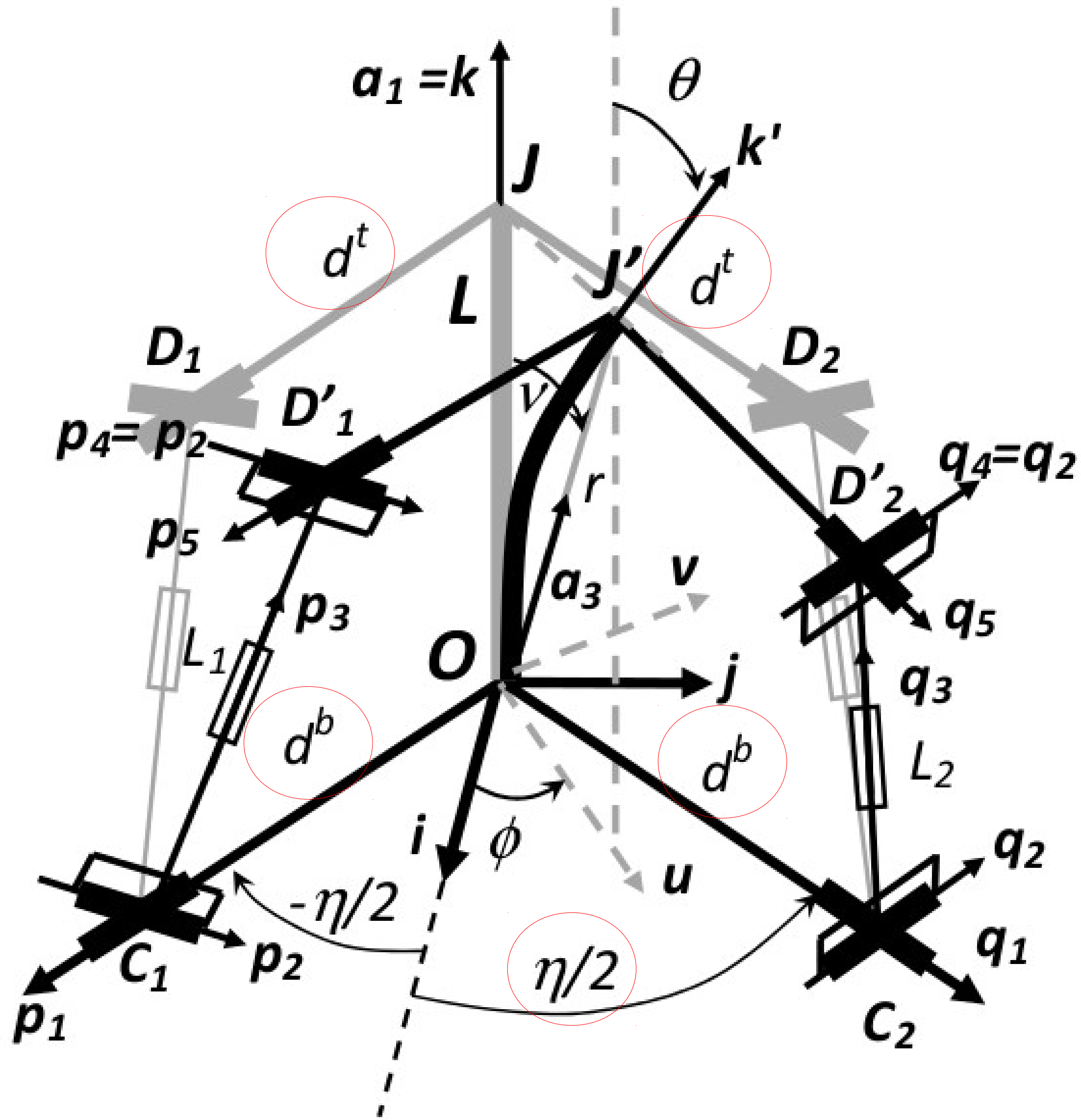




Optimization of vertebra mechanism

Kinematics of each actuator arm: U<u>P</u>U

- Angle between arms: η
- Distance of arm to center at the top: d^t
- Distance of arm to center at the bottom: d^b



Model of central rod

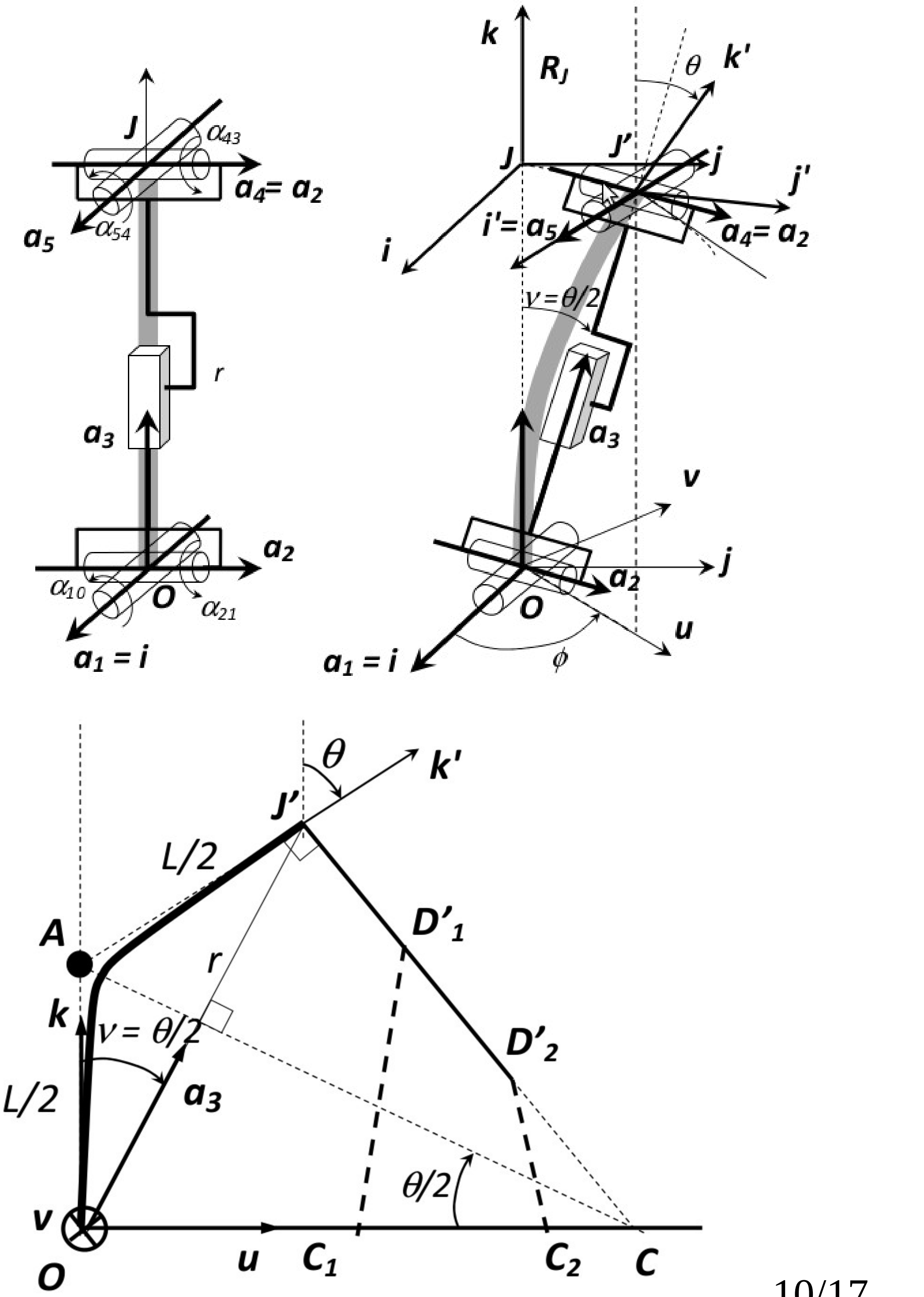
- *UPU kinematics of central chord*
- *With constraints to match the silent block behavior:*
  - *length of chord depends on bending angle:*

    $r = L.c(\theta/2)$

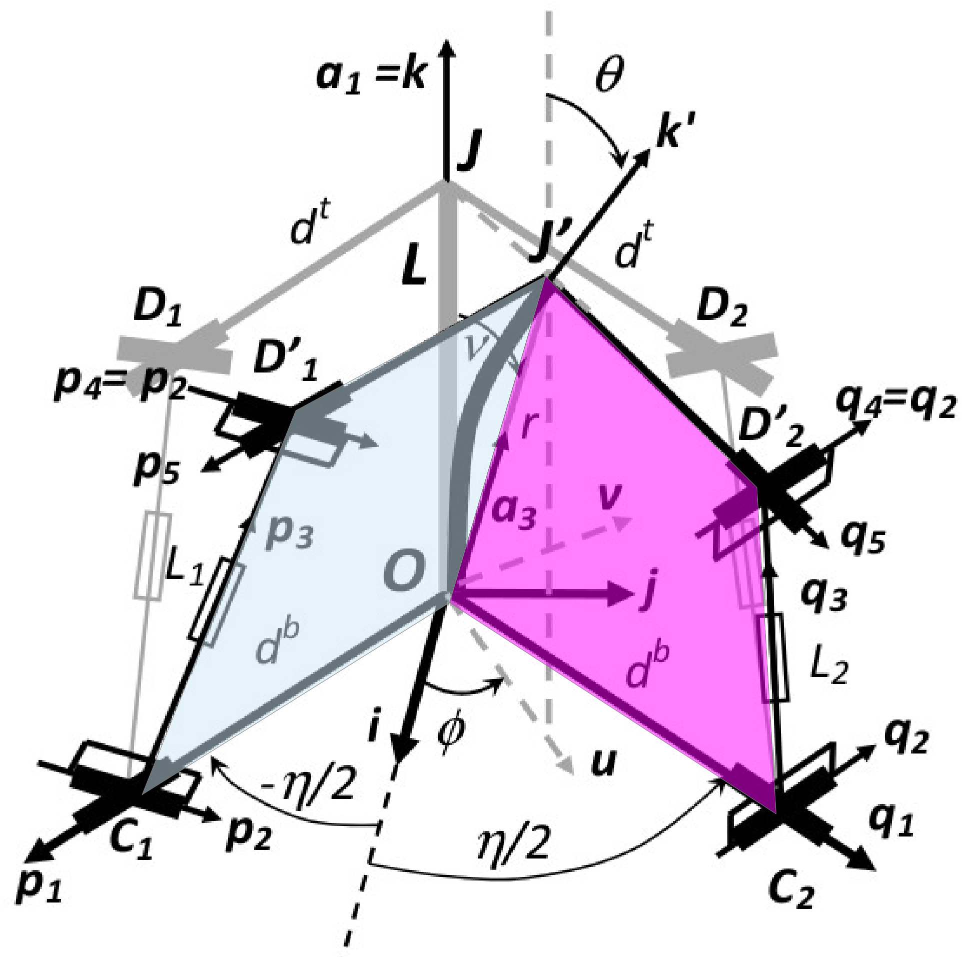
  - *Symmetry top/bottom => equality of Universal joint angles*

    $\alpha_{54} = \alpha_{10}$

    $\alpha_{43} = \alpha_{21}$



Mechanism mobility = 2 (pitch + roll) interesting property: left and right quadrangles are planar



Optimization process

- Mass *M* over vertebra at height h_G
- Minimize average actuator force magnitude over bending space

$$< |F_a| > \;=\; \sqrt{< F_a^2 >}$$

$$< F_a^2 > \;=\; \frac{1}{2}\frac{\Gamma_a}{\Omega_0}$$

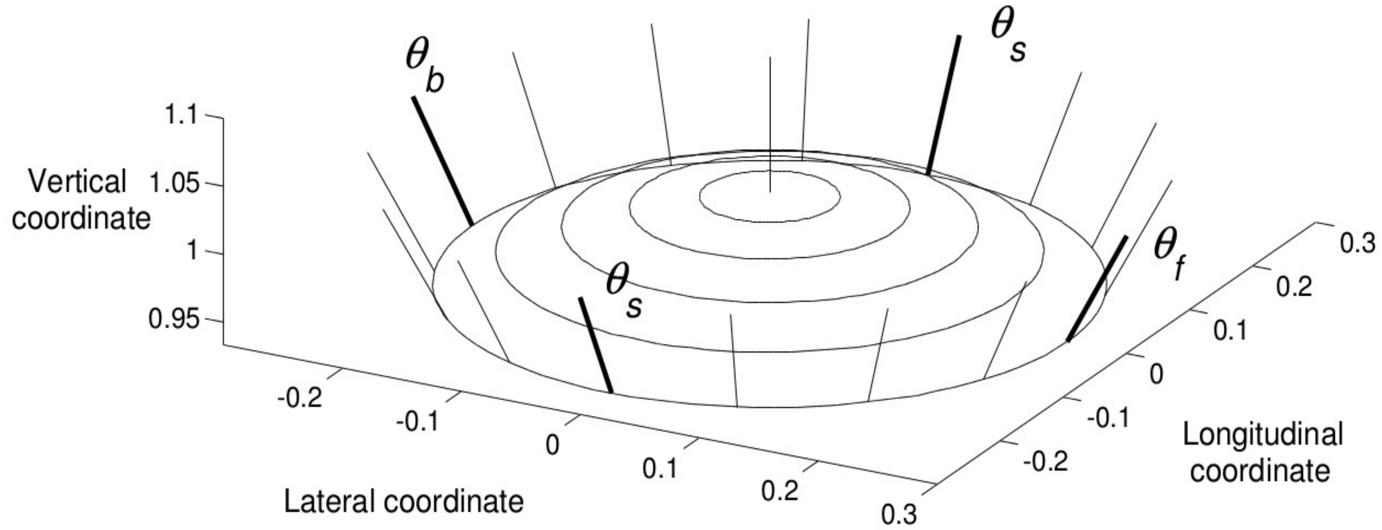
$$\Gamma_a \;=\; 2\int_{\phi=0}^{\pi}\int_{\theta=0}^{\theta_l(\phi)} (\boldsymbol{F_1}^2 + \boldsymbol{F_2}^2).\sin\theta d\theta d\phi$$

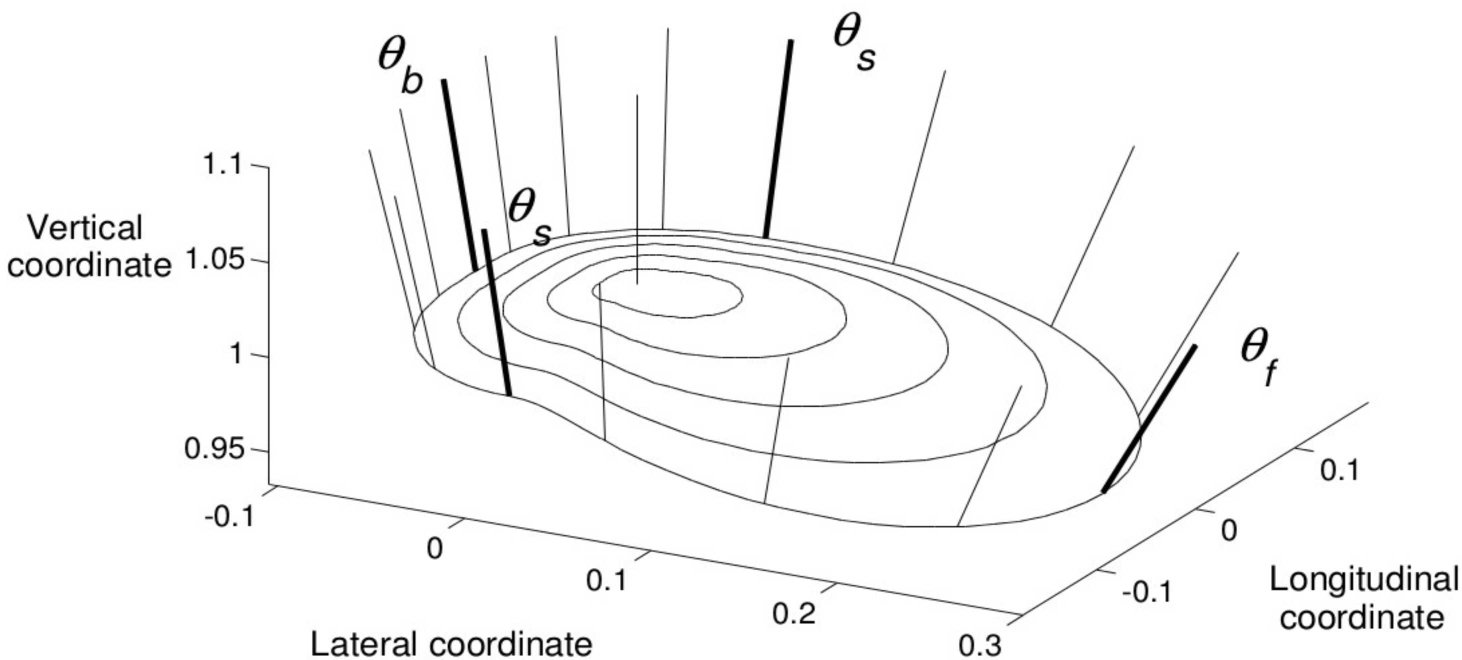
$$1 - \Delta\ell^* \leq \min_{\theta,\phi}(L_1, L_2)/L$$

$$\max_{\theta,\phi}(L_1, L_2)/L \leq 1 + \Delta\ell^*$$

- 2 kinds of bending
  - Isotropic bending of 30 [deg]
  - Anisotropic bending, similar to human trunk bending ratio, 30[deg] forward, 15[deg] laterally, 10[deg] backward

Optimization process





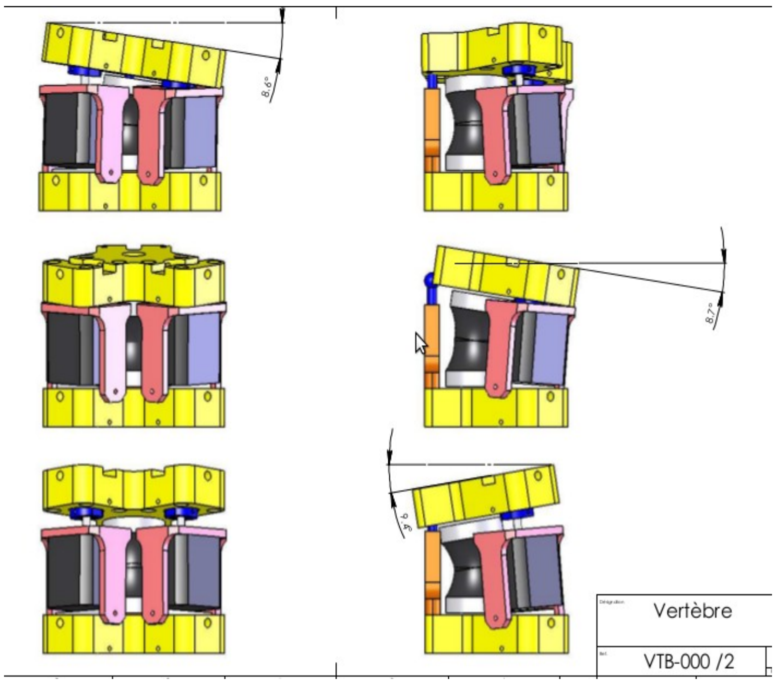
Optimization setup

- *M* = 20 kg
- $h_G / L = 1.33$
- *Extension/compression of actuators: 20%*
- *Calculations of average*
  - *actuator force*
  - *shear force*
  - *compression/extension force*
  - *twist torque*
- *Determine the three parameter values (top arm distance to center, bottom arm distance to center, arms angle) that minimize the force/torque quantities*

Results

- Anisotropic bending: actuators must be placed forward, isotropic: does not matter
- Bottom distance must be longer than top distance (this is to reduce shear forces and twist torque), both depend on bending angle
- Isotropic bending, arms angle = 90[deg]
- Anisotropic bending, arms angle ~ 80[deg]
- Data on shear, compression/extension forces and twist torque useful to design suited silent block

1st prototype with windsurf diabolos



Related papers

- C. Cibert, V. Hugel. Compliant intervertebral mechanism for humanoid backbone: Kinematic modeling and optimization

  Mechanism and Machine Theory, 66, 32-55. 2013
- C. Cibert, V. Hugel. Bio-inspired compliant spine for humanoid robot a degrees of freedom challenge

  IEEE RO-MAN, 1-5. 2012.
- M. Souissi, V Hugel, P Blazevic. Influence of the number of humanoid vertebral column pitch joints in flexion movements.

  5th International Conference on Automation, Robotics and Applications (ICARA). 277-282. 2011.