Modèles de genou pour la marche bipède

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- The more sophisticated knee prosthesis use polycentric mechanisms with four or five axis.

- The four-bar structure gives a greater stability of the knee joint during a walking gate without active actuation of the knee than a single axis knee prosthesis.

  C.W. Radcliffe, Prosthetics and Orthotics International.

- The most important part of bipedal robots uses a single axis knee joint.

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- We purpose to use a cross-four-bar articulation for a bipedal robot and to compare the performance obtained with a single axis knee joint and with this articulation.
- We generate a set of optimal trajectories for the two types of knee articulations by parametric optimization.
- We study a planar biped.
- The trajectories are composed of single support phases and impulsive impacts.

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The Human knee joint

The Human knee joint

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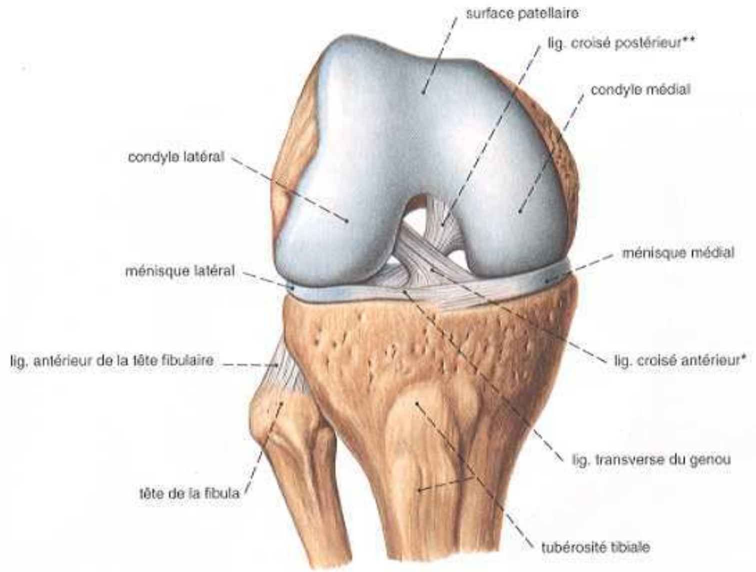

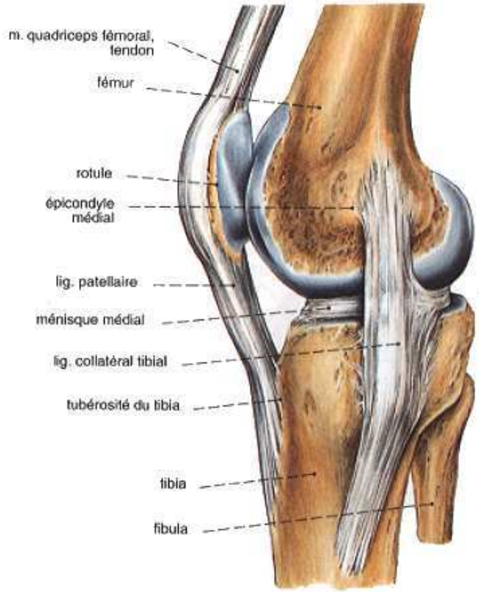

The human knee is a complex articulation with more than one degree of freedom. The knee joint allows a rolling and a sliding of the femur on the tibia in the sagittal plain. These movements are limited by the articular surfaces and the ligaments.

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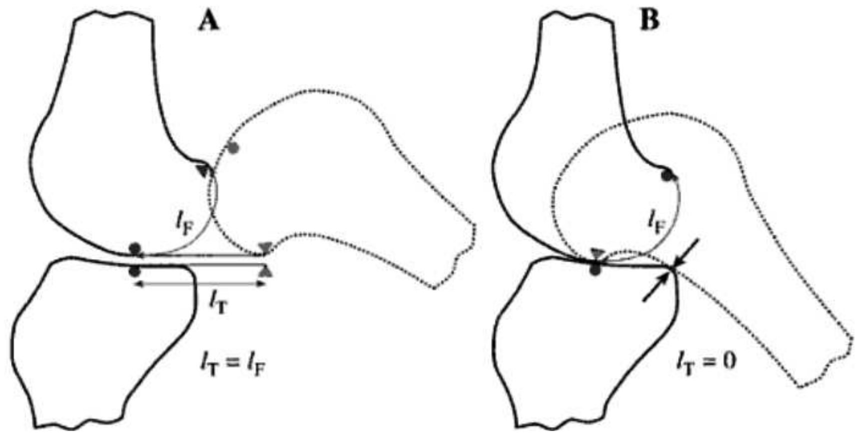
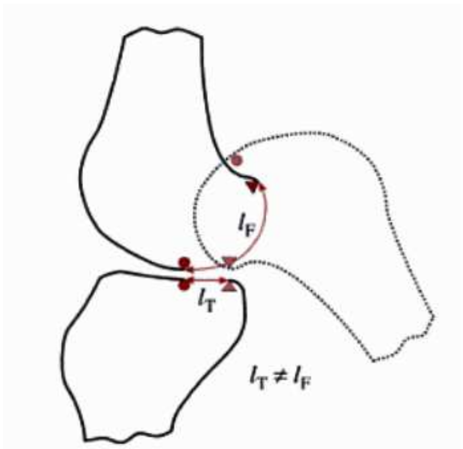
The knee movements



In the human case, the rolling of the femur on the tibia gives a greater flexion and prevent the erosion of the articular surfaces.



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Different solutions for the knee joint of a bipedal robot

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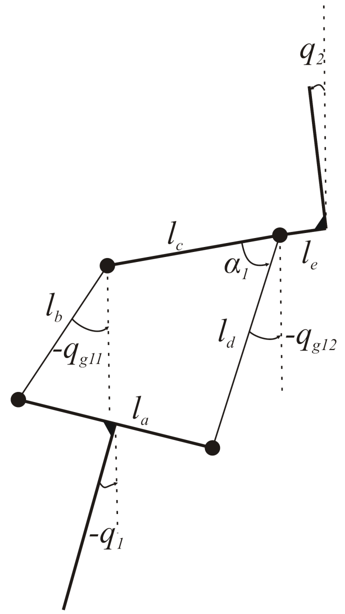
The four-bar knee



This structure gives a rotation and a translation on the knee joint but a singularity appears during the flexion.

Four axes knee, PROTEOR ©

A.Hamon, Y. Aoustin, Humanoids 2009.

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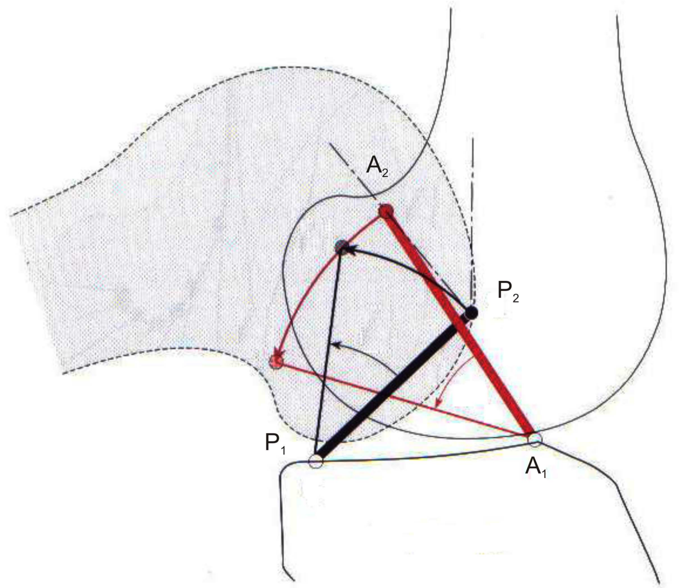
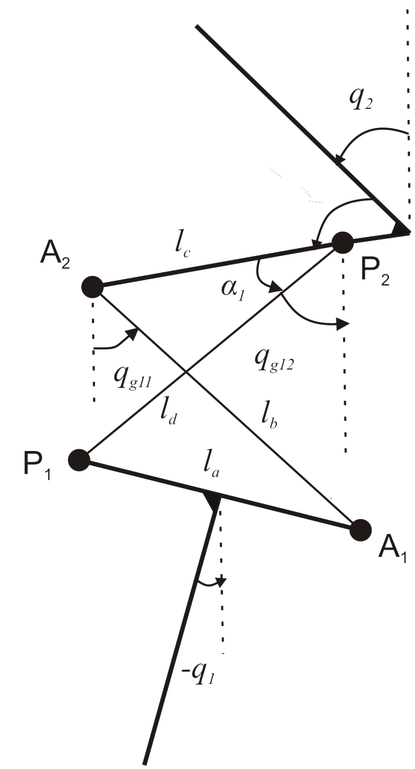
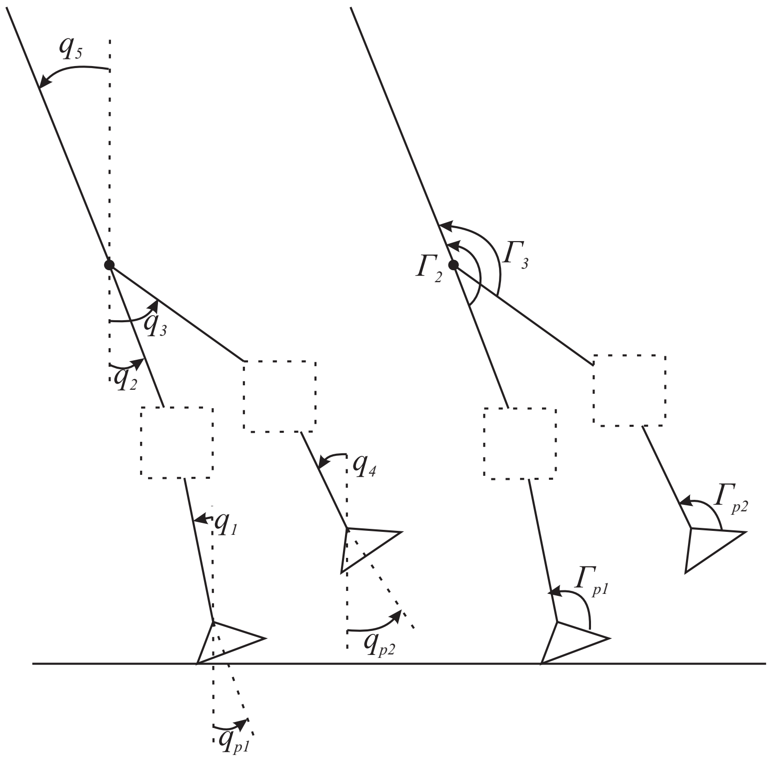


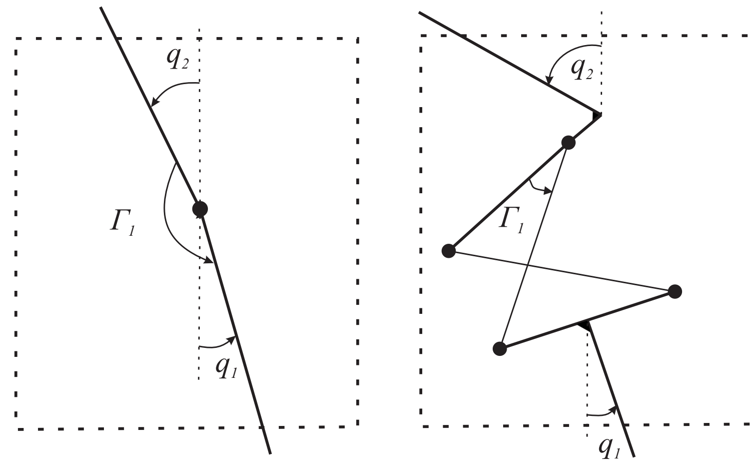


This structure gives a rotation and a translation on the knee joint without singularity in the flexing area.

P. Klein and P. Sommerfeld, Biomécanique des membres inférieurs, 2008.

Study of the effect of the knee structure on the bipedal robot





Objective : to compare the energy consumption during the walking of a bipedal robot in function of the type of knee joint.

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Optimization problem and comparison of energy consumption

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- Objective : design a set of optimal reference trajectories for different speeds in function of the knee joints.
- Method : solving of a parametric optimization problem under constraints with a Sequential Quadratic Programming (SQP) algorithm.
- Condition : cyclic trajectories composed of single support phases and impulsive impacts.
- Criterion :

$$C_\Gamma = \int_0^T \sum_{j=1}^{6} |\Gamma_j \dot{\Theta}_j| dt$$

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Dynamic contraints :

- no sliding of the support foot.

$$f.|R_z| \leq |R_x|$$

- no rotation of the support foot.

$$ZMP_{min} \leq ZMP \leq ZMP_{max}$$

Technologic constraints :

- $|\Gamma_j| \leq \Gamma_{max}$, $|\dot{\Theta}_j| \leq \dot{\Theta}_{max}$, $\Theta_{j_{min}} \leq \Theta_j \leq \Theta_{j_{max}}$.
- ...

Problems of the cross four-bar knee

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We need to consider the constraints of the closed structures in the dynamic model :

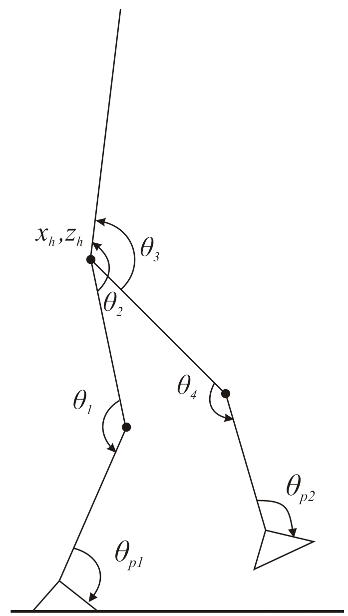
- Define the constraint equations of closed loop for each knee.
- Use the jacobian of the constraint equations with Lagrange multipliers.

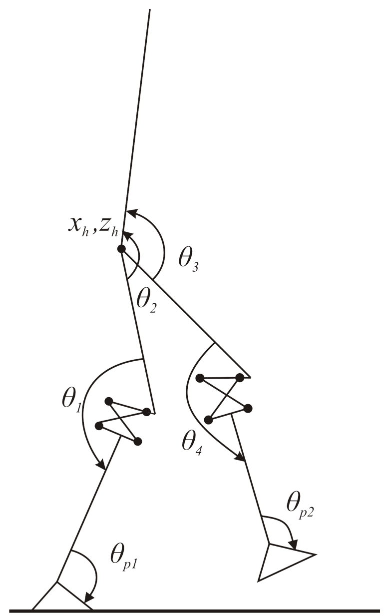
$$A(X)\ddot{X} + H(X, \dot{X}) = D_\Gamma \Gamma + J_c^T \lambda \tag{1}$$

λ represents the cohesion forces in the closed structures.

Results

walking rate $0.6\ m.s^{-1}$, $h = 5cm$





Rotoide case

Cross four-bar case

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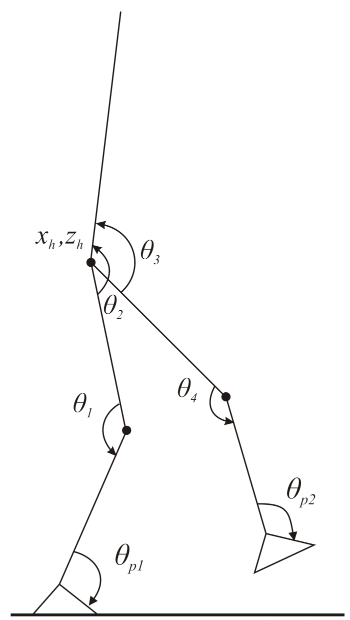
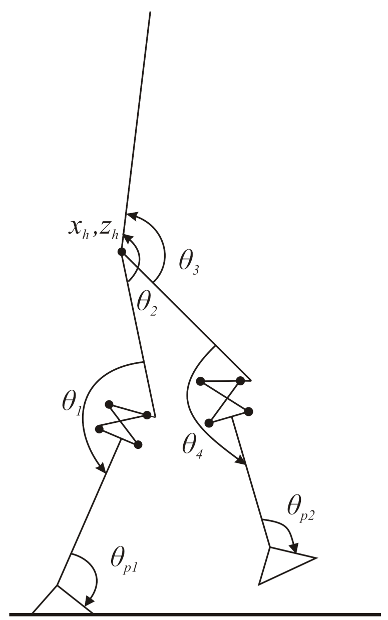
walking rate $0.6\ m.s^{-1}$, $h = 10cm$



Rotoide case



Cross four-bar case

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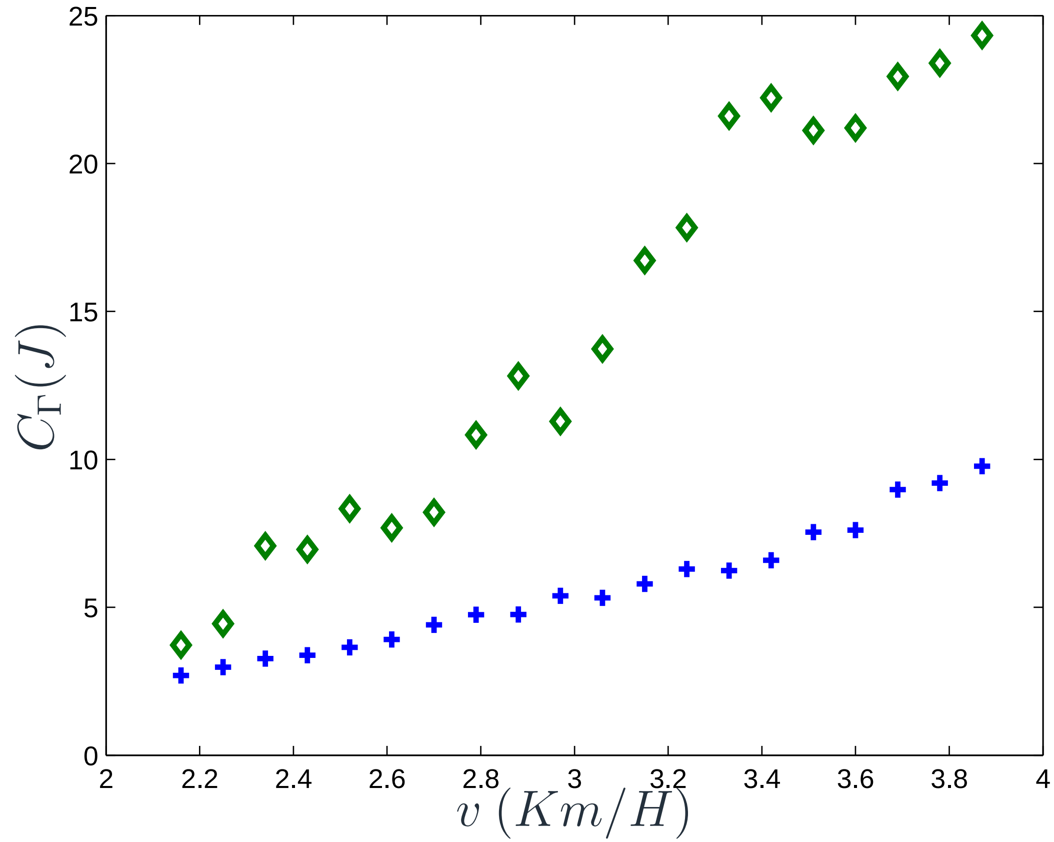
Comparison of the energy consumption ($h = 5cm$):



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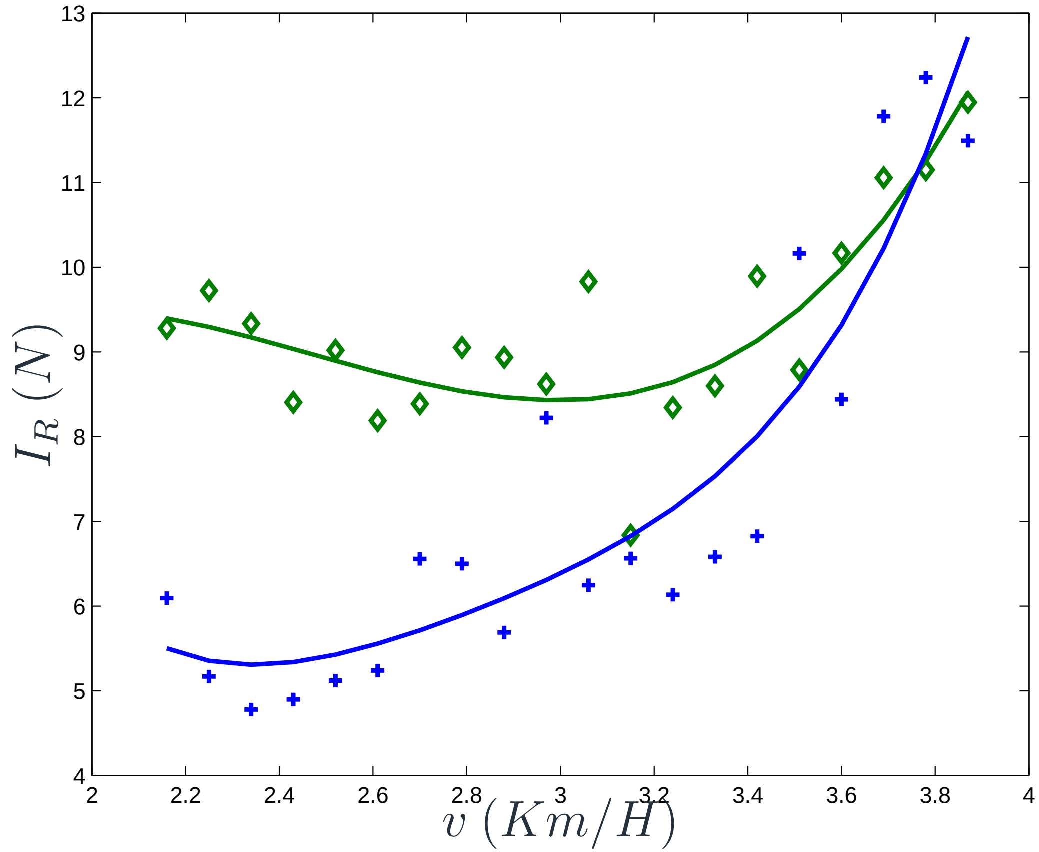
Comparison of the magnitude of the impact :



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Conclusion and perspectives

- Conclusion :
  - The cross four-bar articulation reduces the energy consumption during a walking gait.
  - Reduction of the impact for low walking rates.
- Future works :
  - Extension in 3D.
  - Comparison with human movement.

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Thanks for your attention!