VERTICAL OSCILLATION OF THE HIP TO WALK WITHOUT THINKING

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Context

- Optimal gait with respect to energy consumption
  - The control law will stabilize the motion
  - Sagittal walking: Rabbit, simple control law
  - 3D walking: more complex control
- Computational Morphology [Pfeiffer 2007]
- The gait can/must be chosen to solve the control difficulties

Simplified Model for walking

- Effect of gravity
- Small size of the foot : limited torque at ankle
- Free inverted pendulum

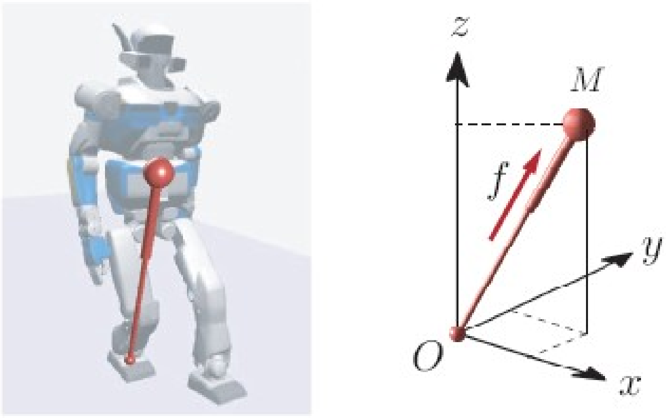


Figure extraite de [Kajita et al. 2009]

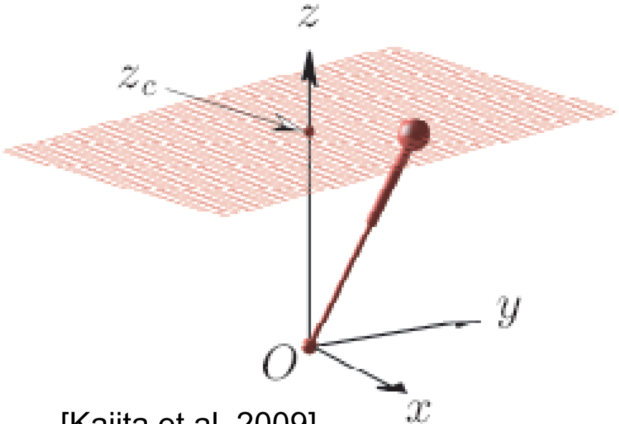
- Length of the pendulum may varie
- Instantaneous double support phase

- [Kajita et al. 2009]S. Kajita, H. Hirukawa K. Harada, K. Yokoi, Introduction à la commande des robots humanoïdes, De la modélisation à la génération du mouvement, Traduit et adapté du japonais par Sophie Sakka, 2009, Springer-Verlag France

Vertical motion of the CoM

- Constant vertical height of CoM : LIP3D
  - Very popular model for walking of humanoid
  - Linear equation for the CoM evolution
  - Decoupling between sagittal and frontal plane
  - Independent from time
  - Use on line when the desired foot position are defined

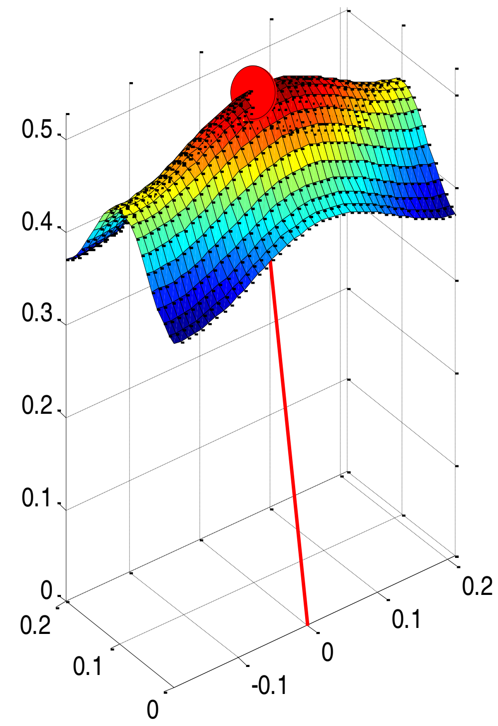
A predictive control is used



[Kajita et al. 2009]

Proposal : Vertical Oscillations

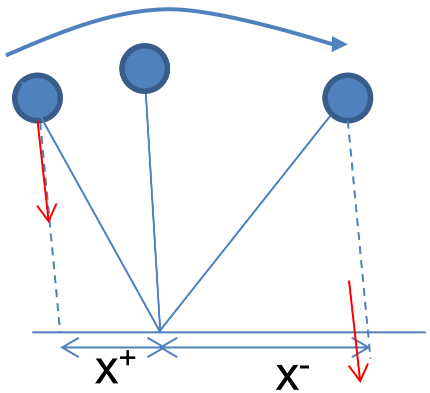
- Vertical height of CoM is imposed
- The height is function of x and y, z=f(x,y)
- Example : sum of sinusoidal functions of x and y
- Inspired from human walk
- Compatible with workspace of the legs



WALKING IN SAGITTAL PLANE

Support phase

- Control objective: z=f(x)
- Transitions : x varies from x^{+} to x^{-}



- Gravity acts via angular momentum

$$(\; - \quad)$$

From x^{+} to 0, decreases
From 0 to x-, increases

- Change of along a support depends on z=f(x), from x^{+} to x^{-}

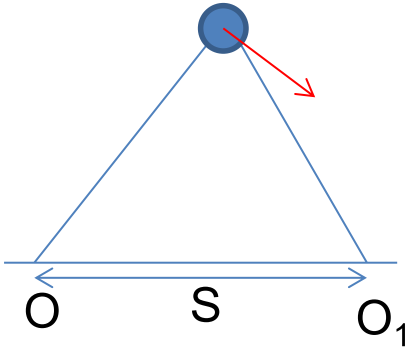
$$(\quad) \qquad (\quad)+V$$

$$V= \qquad (\; — \qquad)$$

Change of support

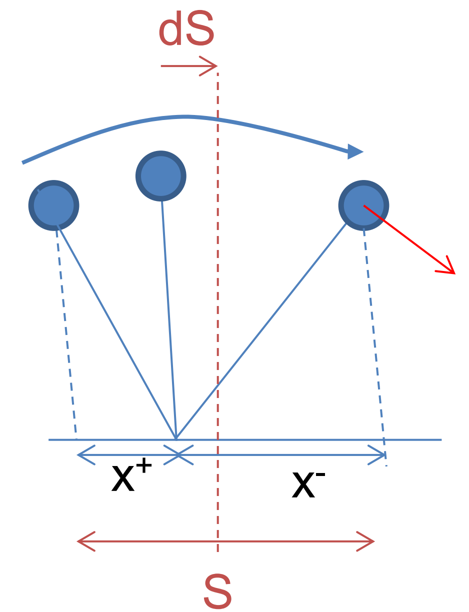
- Change of the point where angular momentum is calculated
  - $\rightarrow \qquad \longrightarrow$
  - $= \qquad = \quad — \qquad (\; — \qquad) =$
  - $\dfrac{(— \qquad)}{(\; — \quad)}$
  - <1 si —

Vertical Oscillations



Cyclic Walking

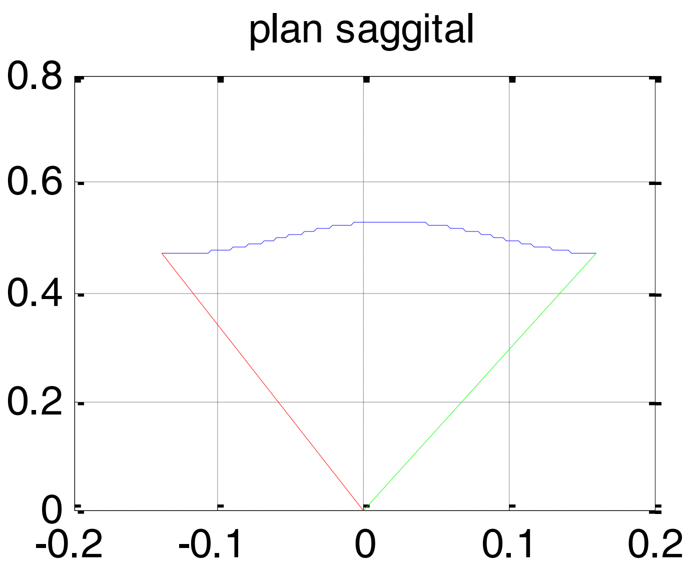
- Same at the beginning of steps k and k+1
  - ( ) ( ))
  - ( ) ——
- Unique velocity
- If δ<1, stable or attractive walking
  - decreases at change of support
  - increases during support
  - | |>| |, CoM is in front of the foot(dS>0)
  - Minimal initial velocity (0)>0

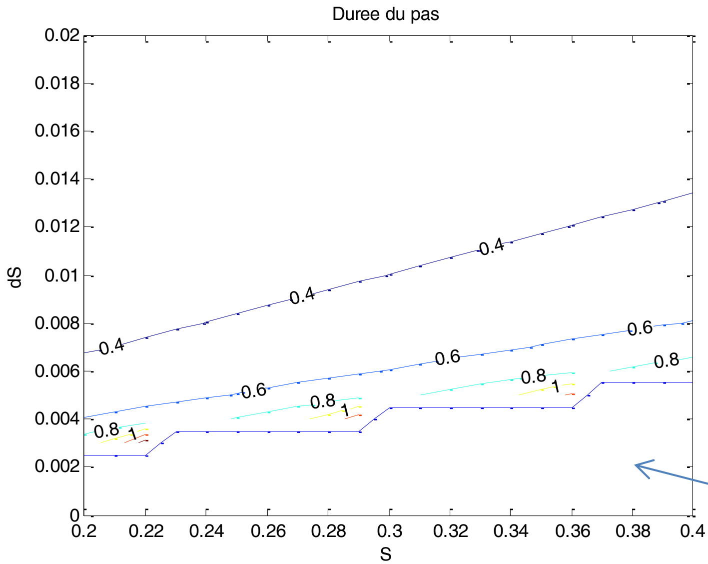


Example

- Z =0.5 + 0.03cos(—— - 0.2);
- S=0.3;
- ds=0.01;

δ = 0.9237 (stable)
Cycle :) = 1.0358
To achieve a step) > 0.6890



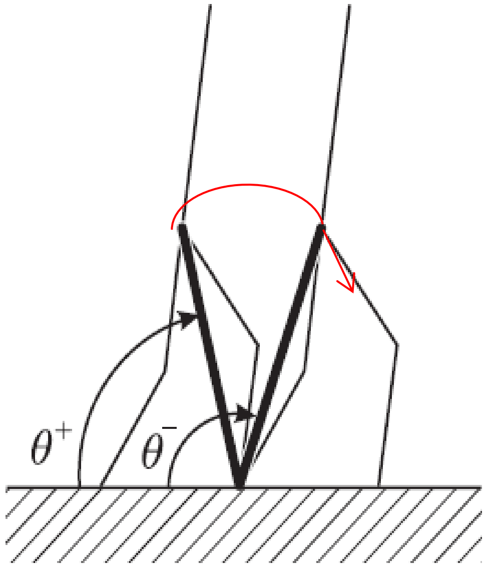


We can chose dS to modify the duration of step

No cyclic walking

Control of Rabbit

- Complete model of the robot
- Joint evolution is function of θ
- Virtual constraints
- Oscillations of CoM (z=f(x))



Conclusions

- Change of angular momentum at support change is important
  - Velocity of the CoM must be directed downward in double support
  - Unique stable walking velocity

- Control objective: insure coordination of posture
  - z(x,y)
  - Change of support
- Choice of the gait produces « robust walking »

A. Berthoz, T. Pozzo, Posture and Gaits ,Elsevier, 1988

Perspectives, Simplified model

- Extendion to frontal plane and synchronization in 3D

- Define non cyclic walking
  - Change of stride, lateral distance, Change of velocity, Start, Stop
  - Use of basin of attraction, transition steps, change of the pose of the legs
- Change in the walking direction

Ching-Long Shih, J. W. Grizzle, and Christine Chevallereau, From stable walking to steering of a 3D bipedal robot with passive point feet, Robotica 2012

- Introduction of double support

Perspectives, Complex model

- Extension to complete dynamic model:
  - Joint reference trajectory expressed as function of x and y
  - Study of the Hybrid zero dynamics

- Use of the simplified model to replace the LIP3D model
  - Prediction of the CoM evolution
  - Use of the inverse kinematic model to define the desired joint configuration
  - Resolved angular momentum control neglected in the model, …