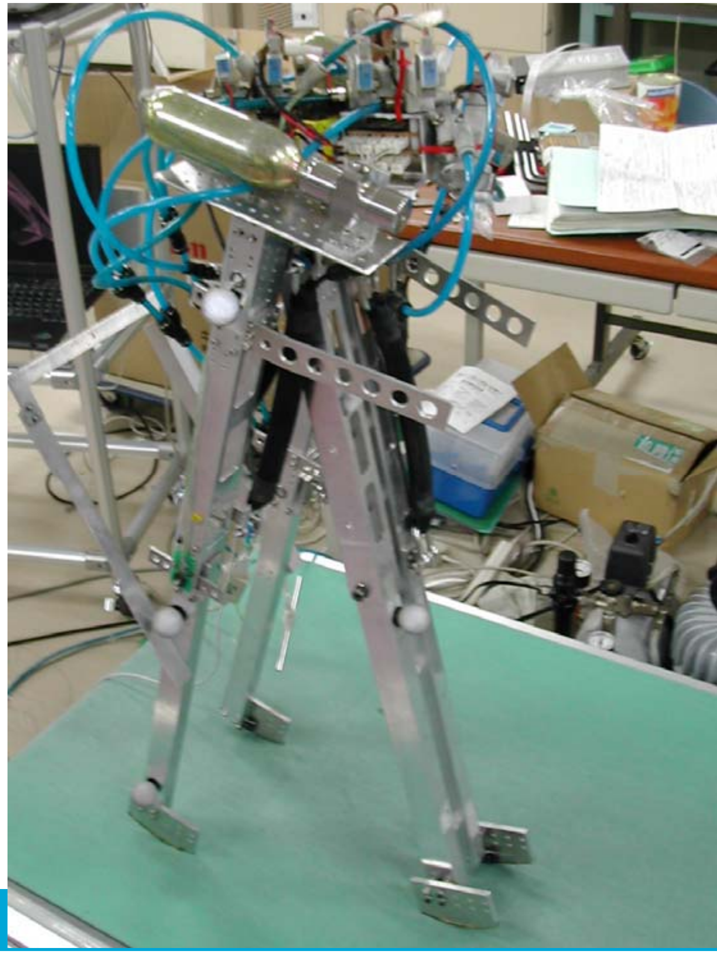
Simulation and Control of a pneumatically actuated dynamic walking robot



MSc Project in the Hosoda laboratory, Osaka University

空脚

Final presentation in Japan

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Systems and Control

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Overview

- Introduction
- My project
- Model of biped robot *Que-kaku*（空脚）
- Model of pneumatic actuator
- Dynamic simulation with timing control
- Controller design
- Conclusions

Problem statement

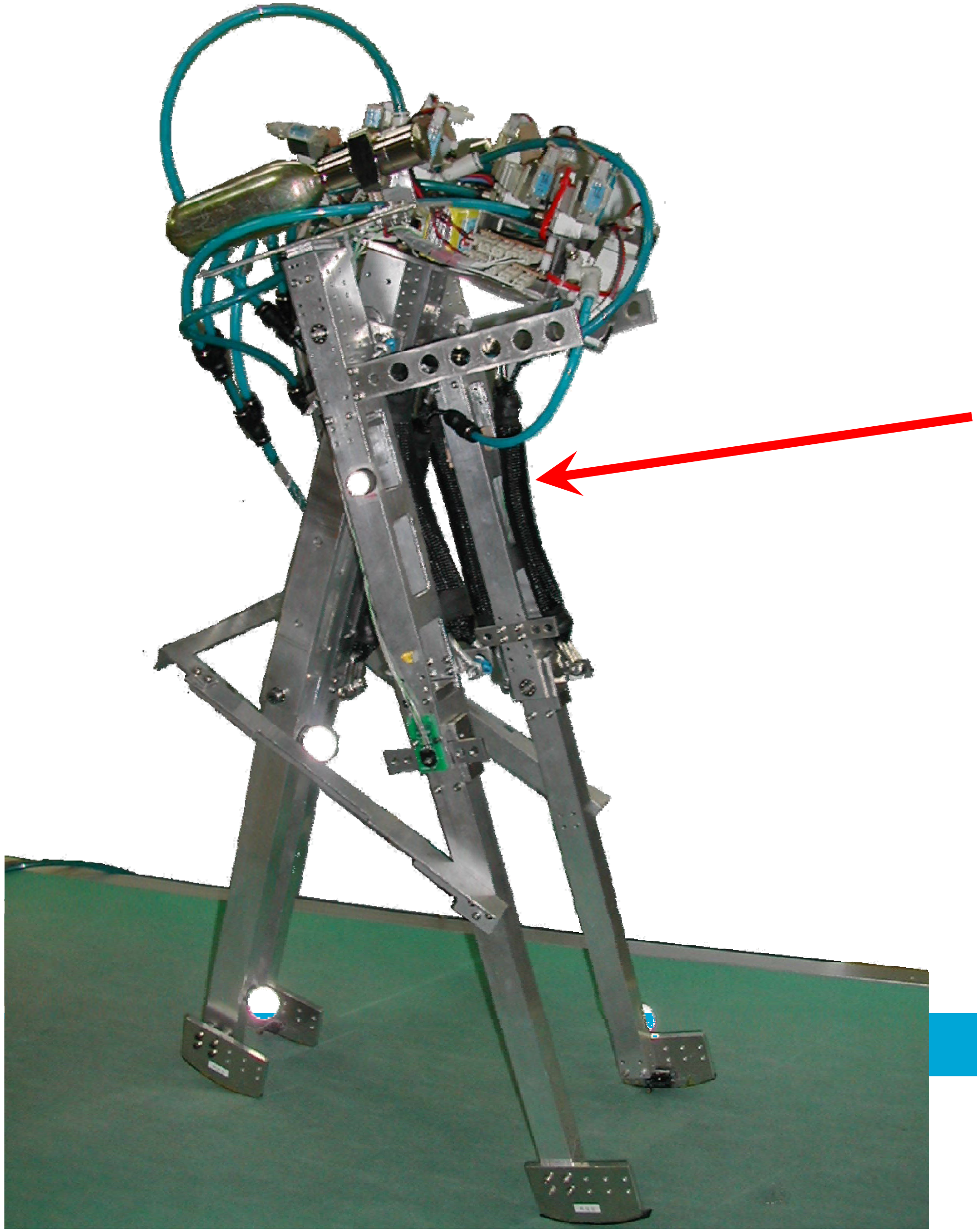
- Trajectory following robots are not energy efficient
- Dynamic walking robots have a limited stability

- *Goal:* Design a Limit Cycle Controller (LCC) for an actuated dynamic walking robot.
  The controller should improve the robot's stability.

My project steps:

- ✓ Make dynamic model and simulation of pneumatic walking robot (*Que-kaku*) in Matlab.
- ✓ Make model of McKibben muscles.
- ✓ Implement McKibben muscles in the simulation.
- ✓ Evaluate current timing based controllers (FF)
- ✓ Simulate and implement FB controller [Takuma]
- ✓ Simplest walker model to 'predict' the next step

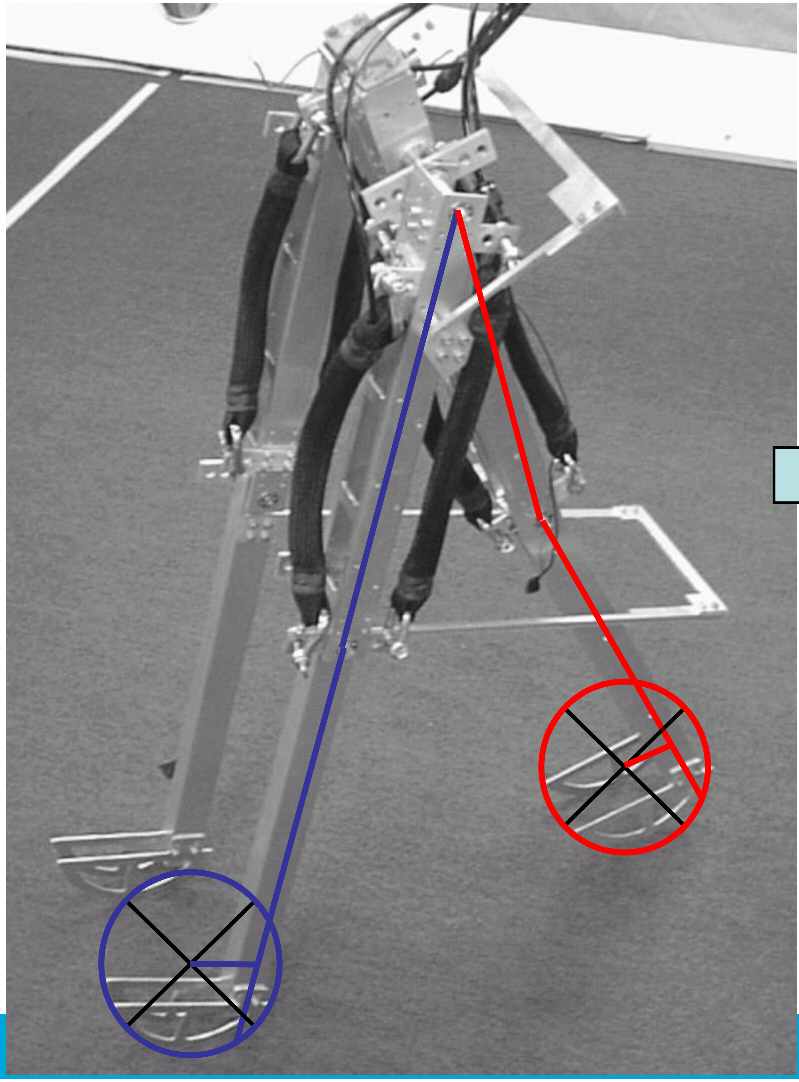
Robot in Hosoda laboratory

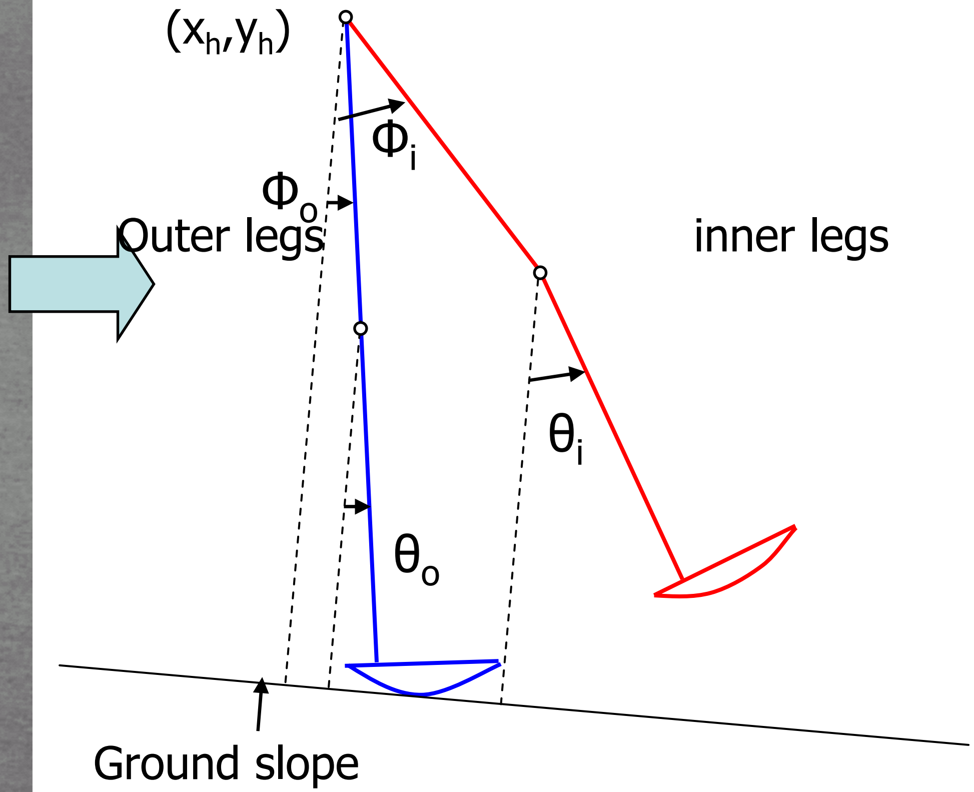


- Based on *Mike* by DBL
- 2D biped robot with knees
- Actuated by McKibben pneumatic muscles

DBL

Robot model definition





Robot model definition (2)

For the four parts of the robot, the parameters are:

- Length - from knee-joint to hip-joint or to the floor.
- Mass
- Center of Mass (distance of CoM to higher joint)
- Inertia
- For the lower legs: Shape and location of the feet

For the dynamic walking robots these parameters greatly determine the walking behavior and stability of the robot

Preliminary experiments

Change valve opening durations independently:

- *Se* Extensor exhaust duration
- *Sf* Flexor supply duration

Observe the muscle pressure, hip angles and step time

Walking in different environments:

- Treadmill on low and high velocity
- Linoleum floor
- Carpet

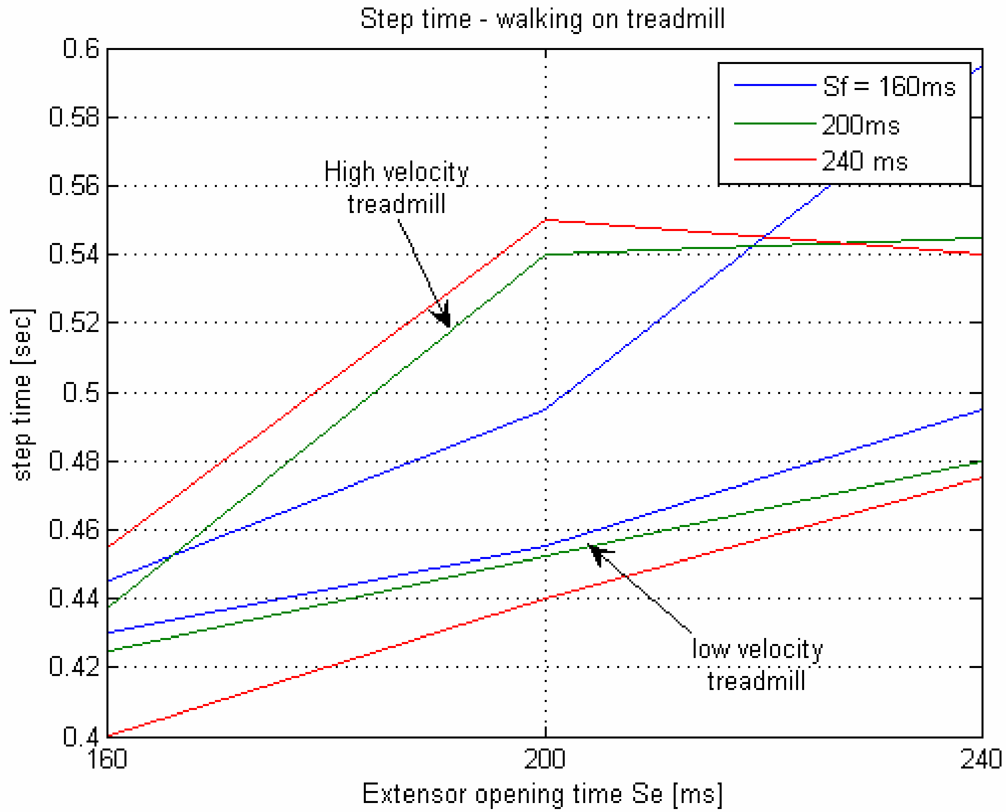
TUDelft DCSC DBL

Preliminary experiments (2)

•The **step time** increases with the valve opening times →

•The **hip angle** at moment of heel strike increases with the valve opening times

•The muscle **pressure** increases with *Sf* but decreases with *Se*



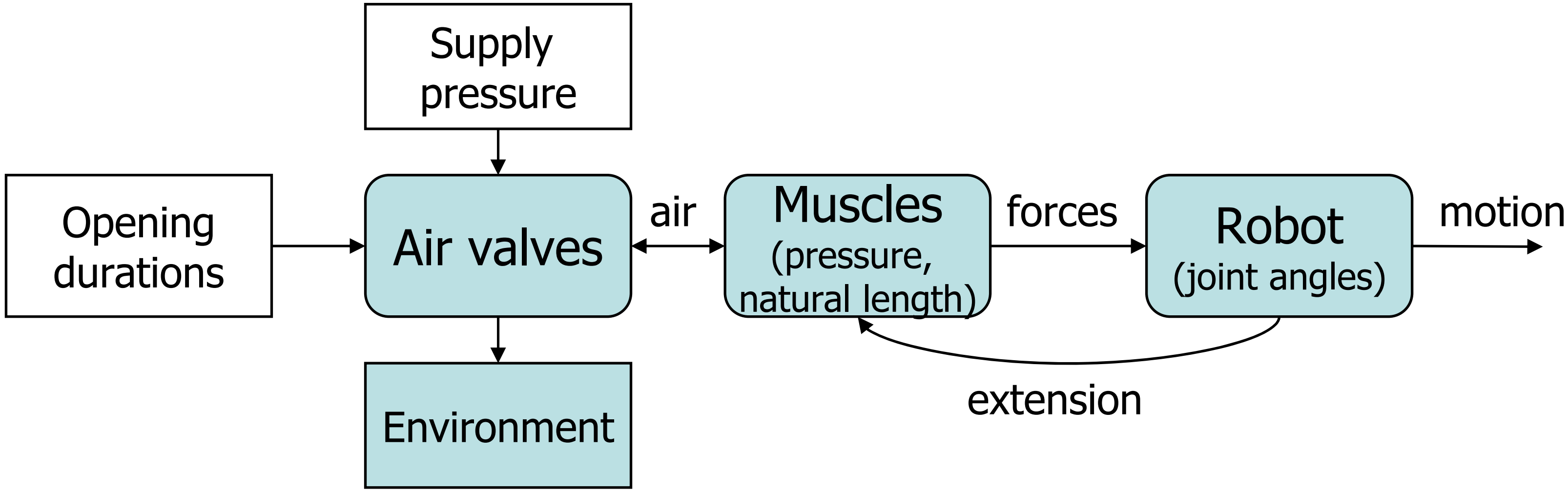
McKibben pneumatic muscles

- Efficient actuation for dynamic walking robots
- Difficult to control due to nonlinear behavior

- A simple linear force model is made,
  based on static measurements

[Shadow company: shadow.org.uk]

McKibben pneumatic muscles (2)



- Pressure = f(supply pressure, open times)
- Natural length = f(muscle properties, pressure)
- Extension = f(natural length, robot state)

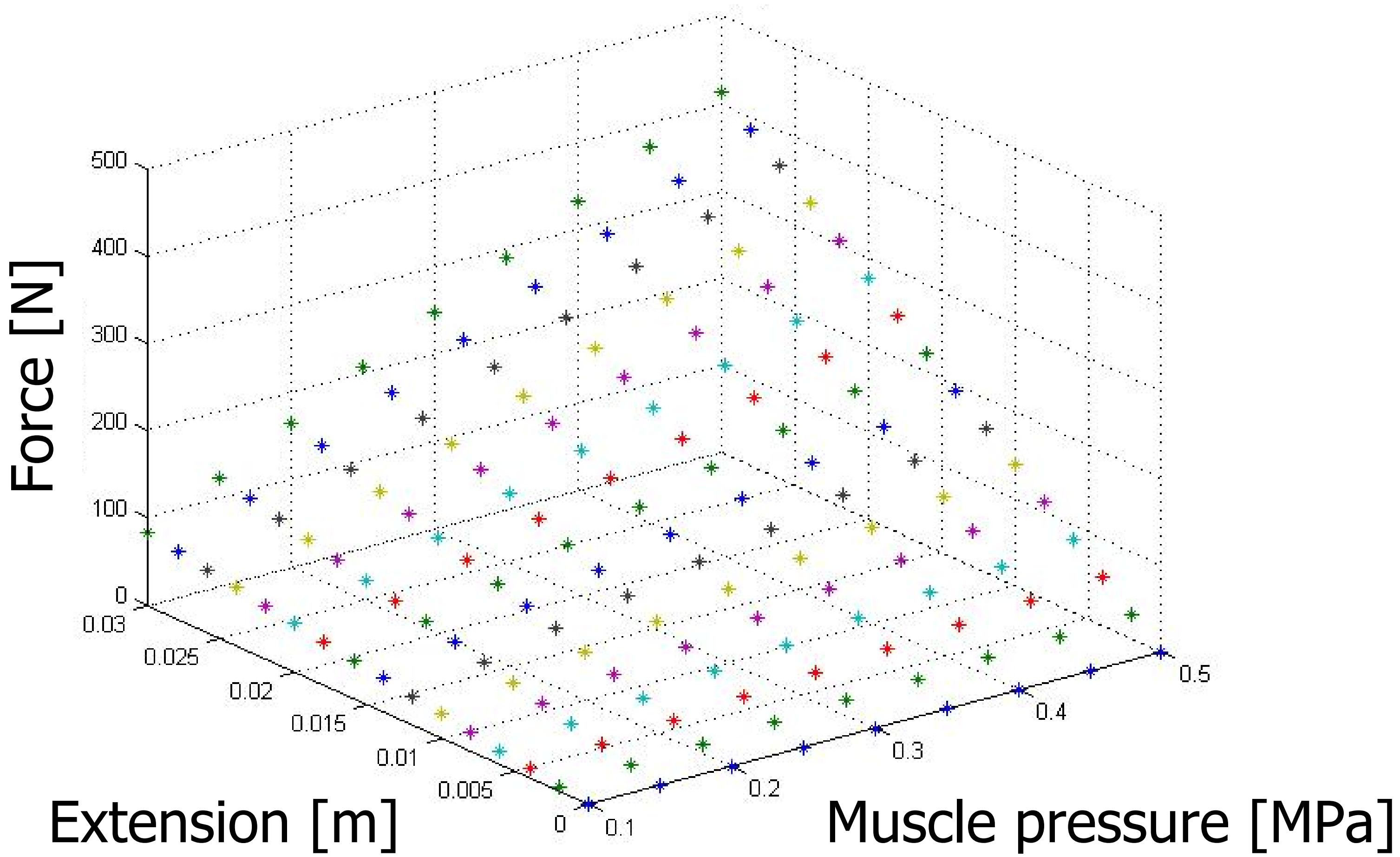
McKibben muscle model

Analytical model: $$f = \frac{b^2 P'}{4\pi n^2}\left(3\frac{L^2}{b^2} - 1\right)$$ [van der Linde '01]

Simple linear model: $$f = K_f \cdot ext + D_f \cdot \dot{ext}$$

- Stiffness: $$K_f = c_1 \cdot pressure$$
- Damping: $$D_f = K_f \cdot c_2$$

McKibben muscle model (2)



Using McKibben muscles

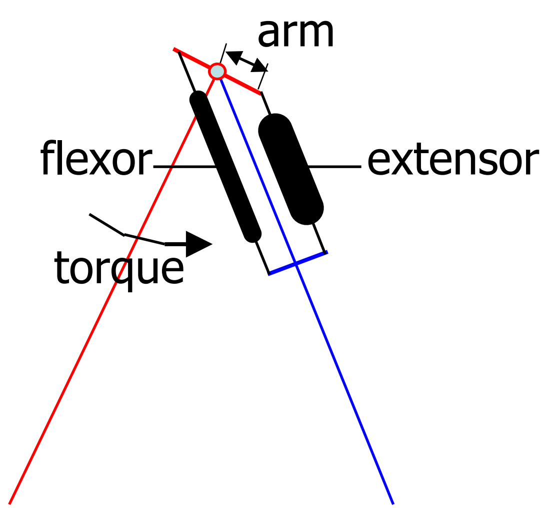
To control a simple joint, 2 muscles are needed:
an **extensor** and a **flexor** muscle.

The resulting joint torque depends on:

- Force of the two muscles
- Moment arm of the muscles

$$\tau = \left(f_{extensor} - f_{flexor} \right) arm$$

Stiffness and **compliance** can be controlled by changing the two forces simultaneously



Controller design

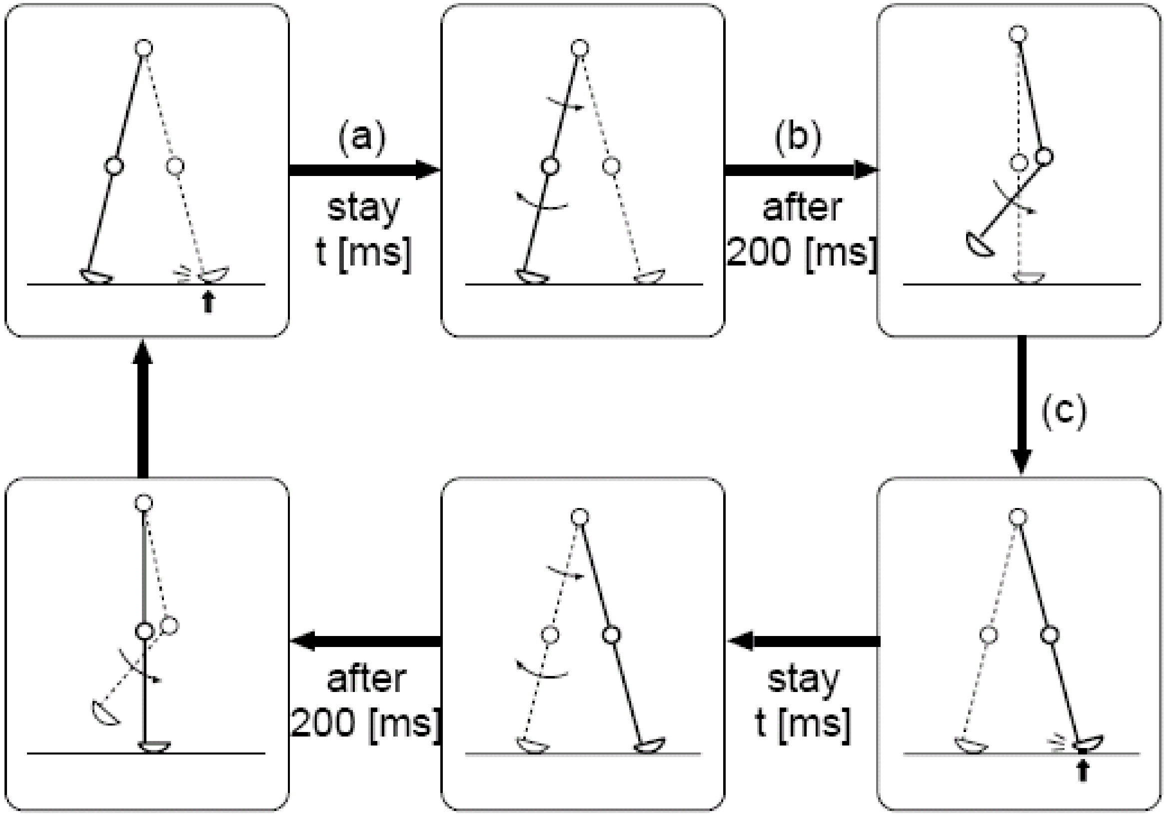
- Design a Limit Cycle Controller (LCC) to improve the robot's stability and robustness

Only the hip joint is considered in this project

Controllers:

- Feed forward (FF) controller
- Feedback (FB) control
- Model-based control

FF control – timing based



[Hosoda 2004]

Stable walking due to good hardware design

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Simple feedback control

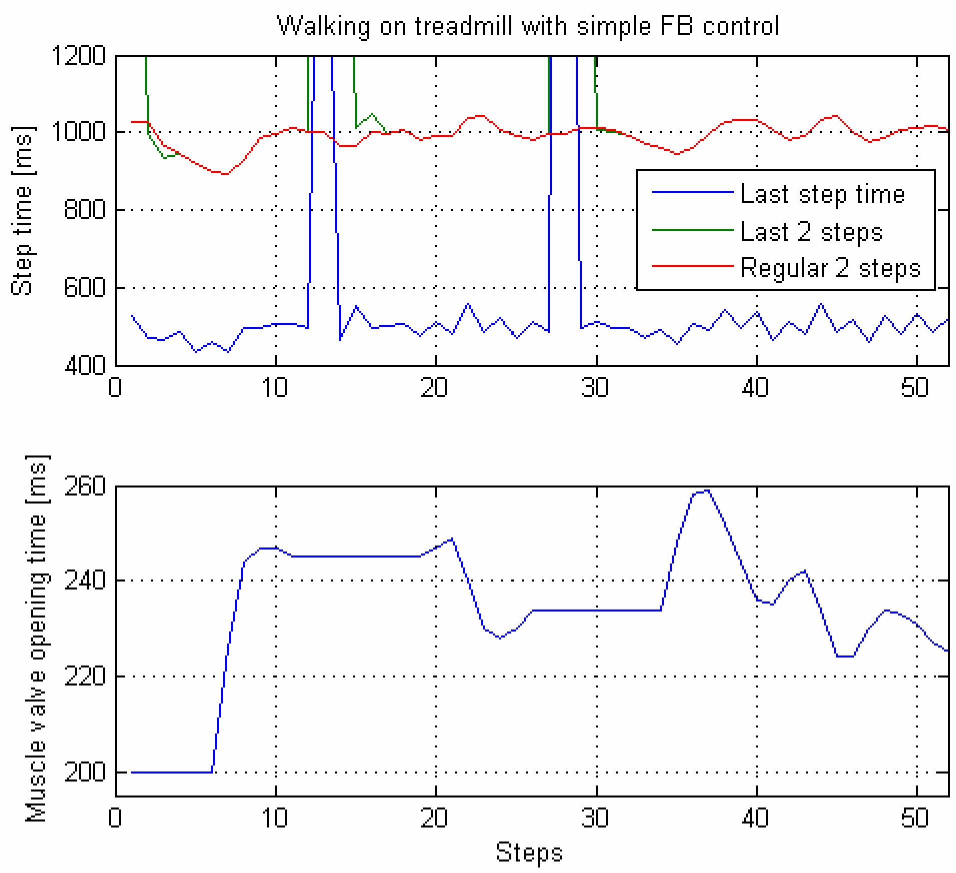
- Regulating the step time of the robot.
- The controller changes the valve opening times to control the step time to a desired value.

- Experiments: valve opening time ↑ → step time ↑
- OpenTime =OpenTime + K (Desired2steps –Last2steps)
- Using 2 steps to compensate for asymmetry

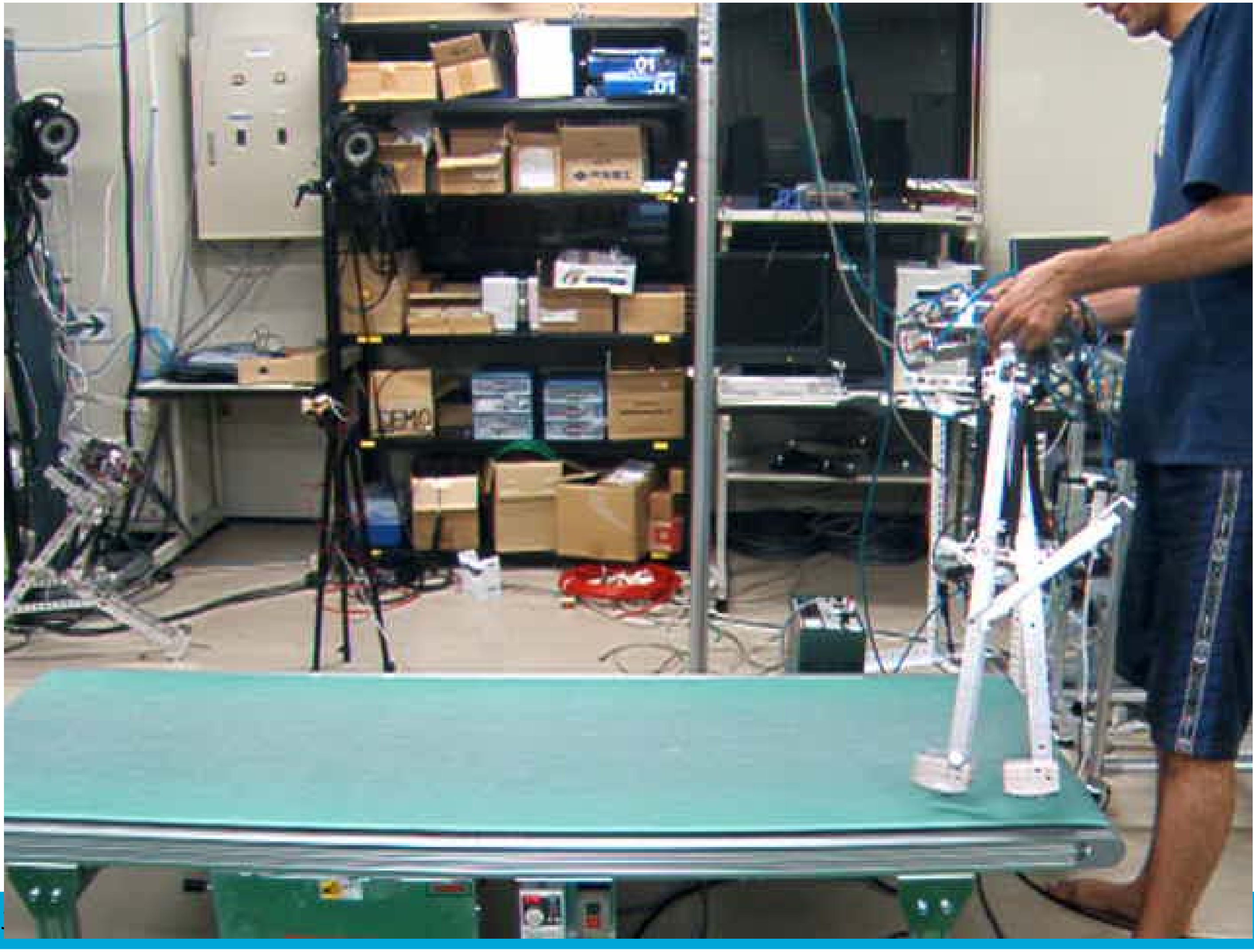
Simple feedback control - experiment

One walking period = two steps should be 1000 ms

Too long step times are ignored for control



Walking experiment



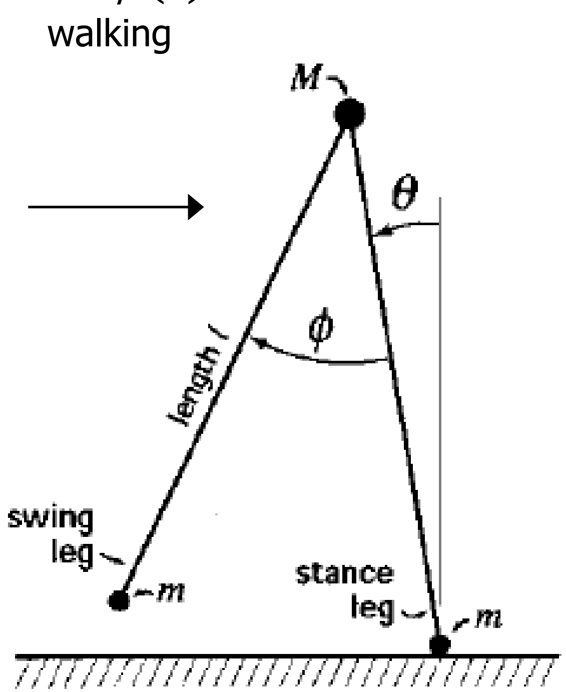
Simplest walker model

Continuous time model with linear spring *k* at the hip:

[Gracia '98, Kuo '02]

$$\ddot{\theta}(t) - \sin\theta(t) = 0$$

$$\ddot{\phi}(t) - \ddot{\theta}(t) - \dot{\theta}^2(t)\sin\phi(t) + \cos\theta(t)\sin\phi(t) = -k\phi(t)$$



Linearized system for small angles:

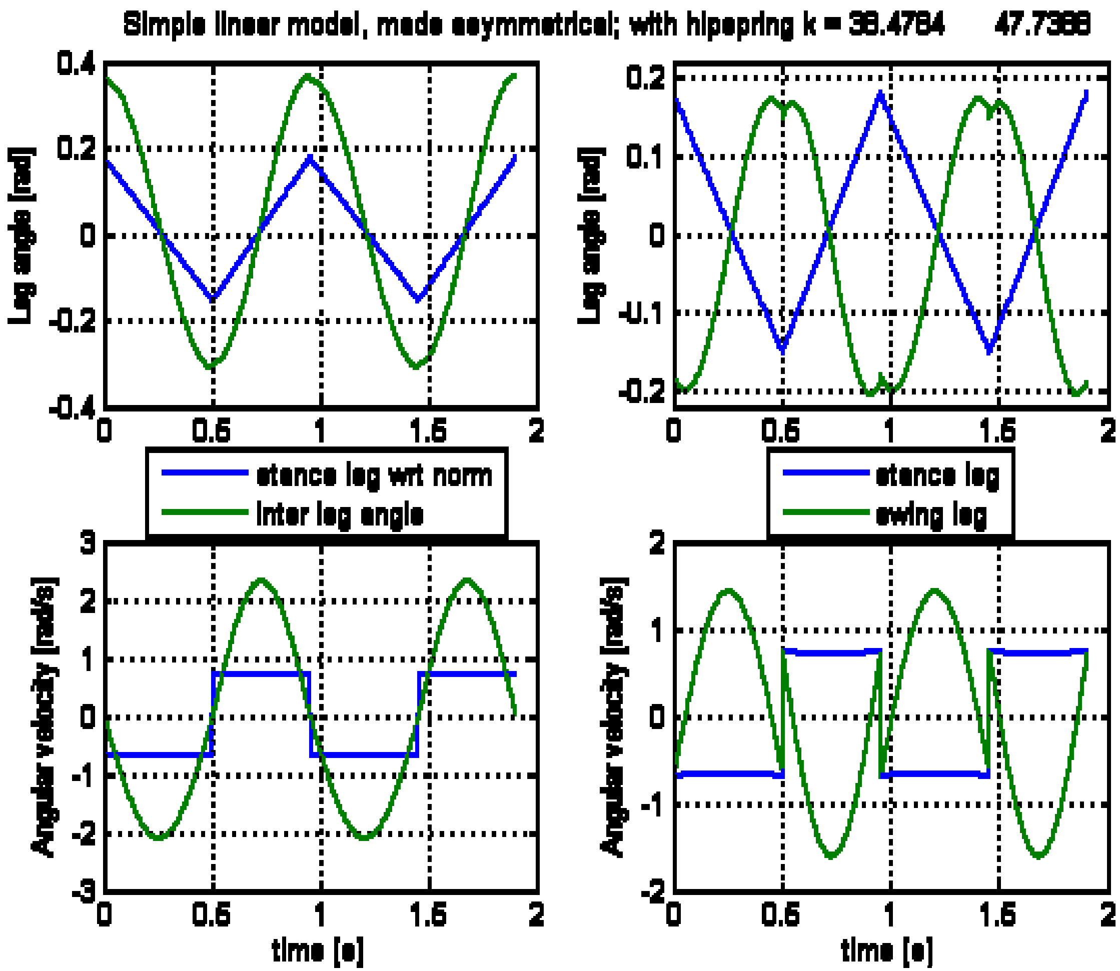
$$\begin{bmatrix} \dot{\theta} \\ \ddot{\theta} \\ \dot{\phi} \\ \ddot{\phi} \end{bmatrix} = \begin{bmatrix} 0 & 1 & 0 & 0 \\ 1 & 0 & 0 & 0 \\ 0 & 0 & 0 & 1 \\ 1 & 0 & -\omega^2 & 0 \end{bmatrix} \begin{bmatrix} \theta \\ \dot{\theta} \\ \phi \\ \dot{\phi} \end{bmatrix}$$

$$\omega \approx \sqrt{k+1}$$

Simplest walker model - simulation

- Simple model, made asymmetric
- Odd and even steps are different

- Hip spring *k* controls frequency and step time



Predict one step ahead

- The simplest walker model should simulate the next step and the resulting **hip angle** and **step time** can be used for FB control.
- Inputs are the initial conditions of the step:
  - Measured hip angle, stance leg angle
  - Estimated angular velocities

- Problem: Behavior of robot changes gradually
- The result of prediction is not good yet

Final idea for controller

- Simple FB controller as described before; regulating the step time
- Additionally reflex-like behavior:
  - If a step is too short due to a disturbance, the next step will be made longer by opening the valves longer

- If time allows I like to give a demonstration later

Conclusions

- The matlab simulation can be used to simulate the walking behavior of the Que-kaku
  - It can be adapted to other robots as well
  - It can be used to test new controllers
- McKibben muscle model is easy to implement
- Feedback can improve the walking behavior of the robot
  - The walking behavior can be automatically changed
  - The robot can handle larger disturbances

Thank you for your attention

- Any questions are welcome

Everybody is welcome for the goodbye-dinner, tomorrow!

- Also after I return to Holland, July 24, please keep in contact: m.j.p.wit@student.tudelft.nl