Locomotion in Modular Robotics Roombot Modules

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Goal of the project

- Explore locomotion possibilities of a modular robot
  - Made of Roombot modules and passive elements
  - Looks like a piece of furniture

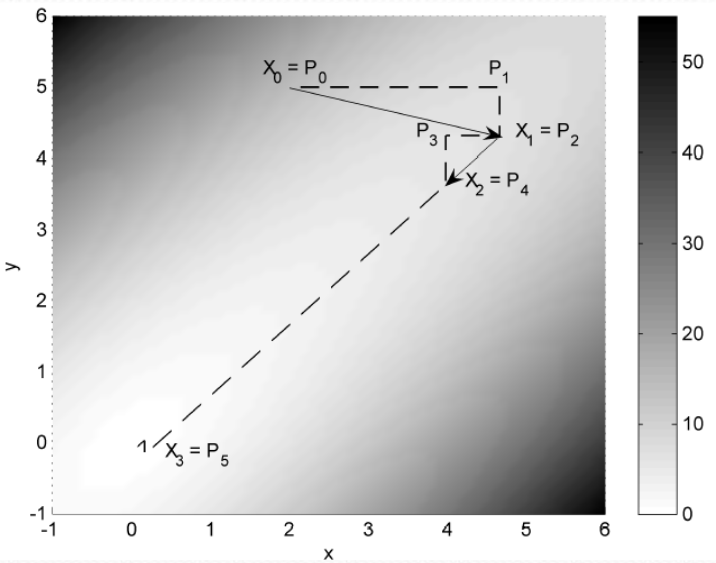
  - Three robots tested, with three different strategies
  - Allows a global view on Roombot locomotion possibilities, and a discussion about the different parts of the project
    - (CPG, Optimization, Simulation World, Robot Structure,…)

Theoretical Background (1)

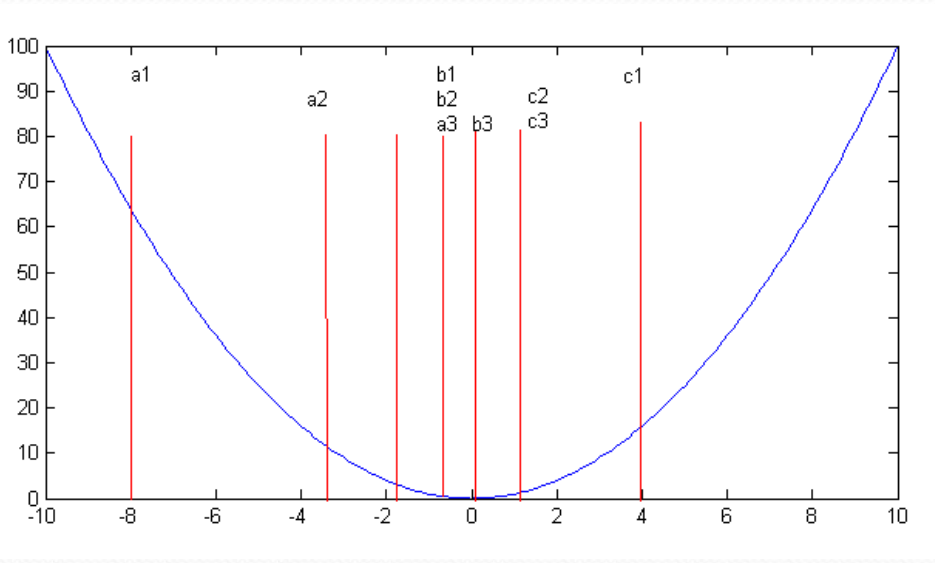
- Optimization algorithms
  - Powell's optimization (nD)
    - Direction set algorithm
    - Gradient descendant
  - Golden Section Search method (1D)
    - Gradient descendant
    - Efficiency related to the behavior of the fitness function
  - Systematical Search (1D and 2D)
    - Not optimal at all in terms of computation cost
    - But, systematical VS gradient descendant

Theoretical Background (2)

- Optimization algorithms (2)



Powell's Algorithm
(Jerome Maye)



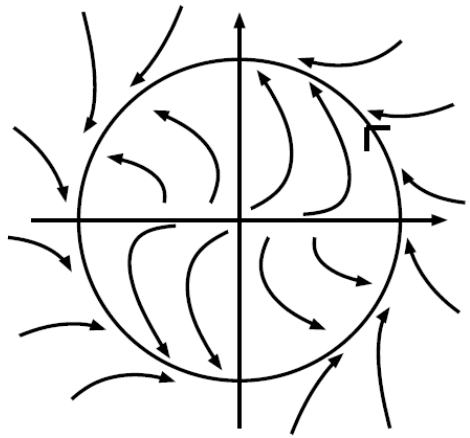
Golden Section Search Algorithm

Theoretical Background (3)

- Central Pattern Generator (1)
  - Derived by Ludovic Righetti at BIRG

$$
\begin{aligned}
\dot{x} &= \alpha(\mu - r^2)x - \omega y \\
\dot{y} &= \beta(\mu - r^2)y + \omega x \\
\omega &= \frac{\omega_{stance}}{e^{-by} + 1} + \frac{\omega_{swing}}{e^{by} + 1} \\
r &= \sqrt{x^2 + y^2}
\end{aligned}
$$

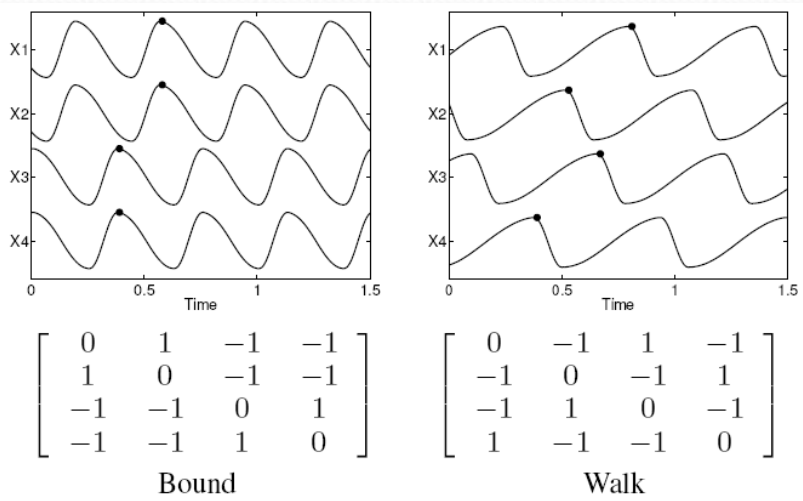
Equations of the CPG
(Ludovic Righetti)



Limit cycle behaviour
(Ludovic Righetti)

Theoretical Background (4)

- Central Pattern Generator (2)
  - Possibility of coupling different CPG
  - Sensors Feedback

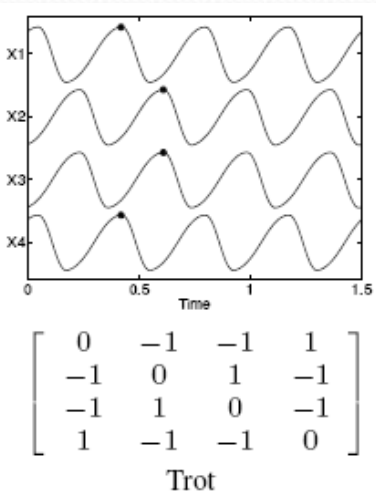


$$\begin{bmatrix} 0 & 1 & -1 & -1 \\ 1 & 0 & -1 & -1 \\ -1 & -1 & 0 & 1 \\ -1 & -1 & 1 & 0 \end{bmatrix}$$

Bound

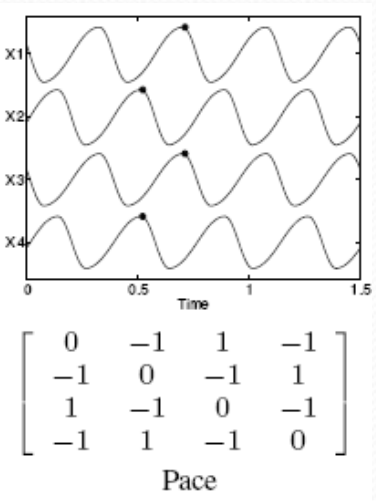
$$\begin{bmatrix} 0 & -1 & 1 & -1 \\ -1 & 0 & -1 & 1 \\ -1 & 1 & 0 & -1 \\ 1 & -1 & -1 & 0 \end{bmatrix}$$

Walk



$$\begin{bmatrix} 0 & -1 & -1 & 1 \\ -1 & 0 & 1 & -1 \\ -1 & 1 & 0 & -1 \\ 1 & -1 & -1 & 0 \end{bmatrix}$$

Trot



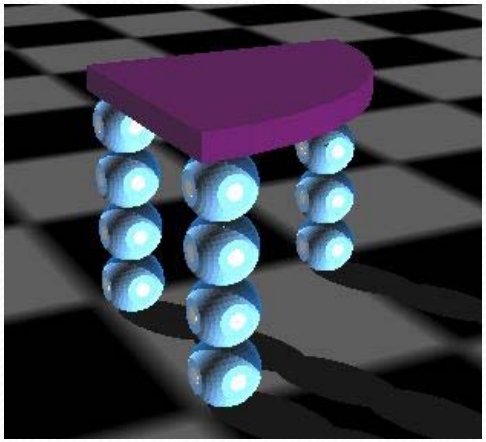
$$\begin{bmatrix} 0 & -1 & 1 & -1 \\ -1 & 0 & -1 & 1 \\ 1 & -1 & 0 & -1 \\ -1 & 1 & -1 & 0 \end{bmatrix}$$

Pace

Gait Matrix
(Ludovic Righetti)

Methodology

- Three Robot tested



Chair Robot

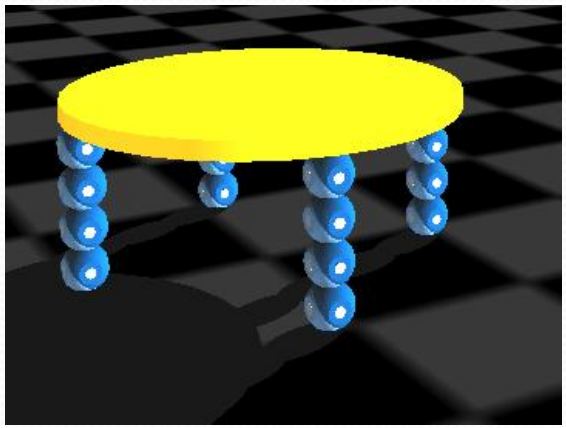
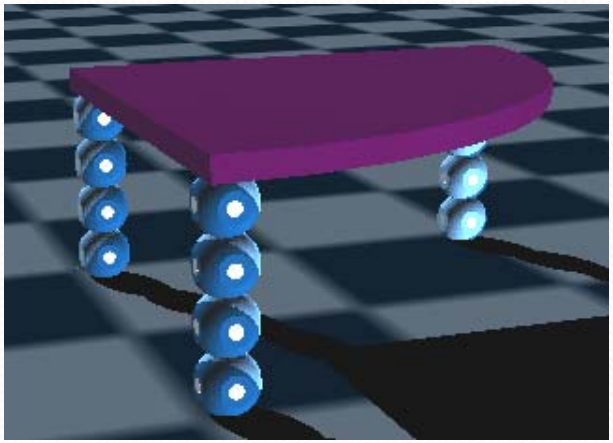
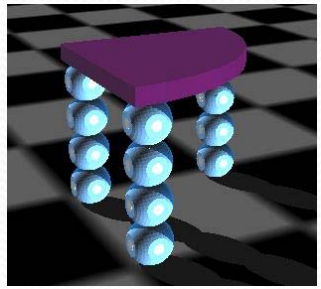


Table Robot

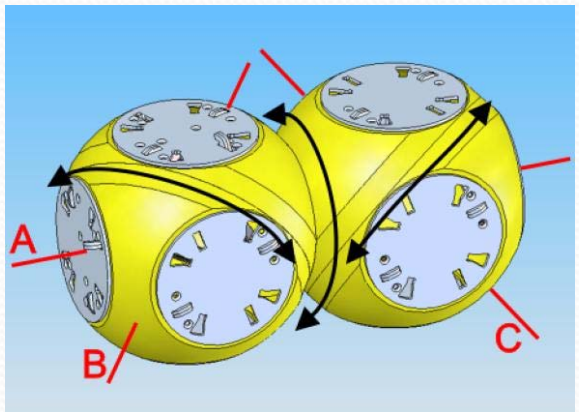


Big Chair Robot

Chair Robot (1)



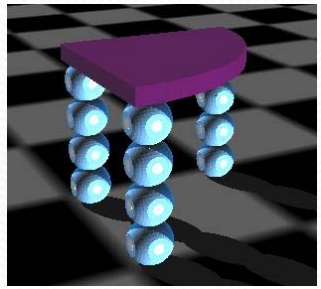
- Methodology
  - One CPG per motor
  - Reduction of the number of open parameters :
    - Offset and amplitude of the three motors of one module
    - All modules have the same command for their 3 motors
    - +1 parameter (w_swing/w_stance) which leads to 7 open parameters
  - Powell + Golden Section Search



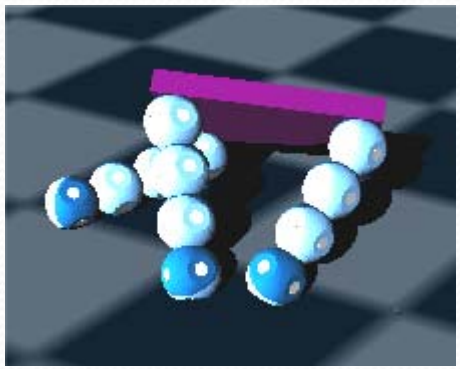
Roombot Module

(Alexander Spröwitz)

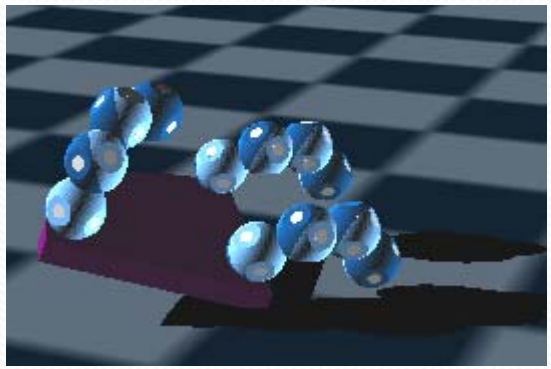
Chair Robot (2)



- Results
  - Maximal Distance Covered : ~ 4 m in 20 seconds , (12 m)
  - Instabilities of the robot

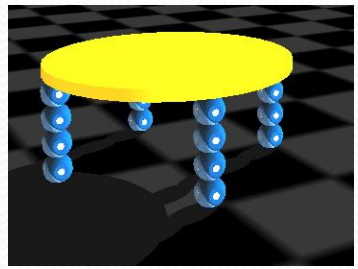


Here the robot collapses because of too low maximal Torque (4Nm)

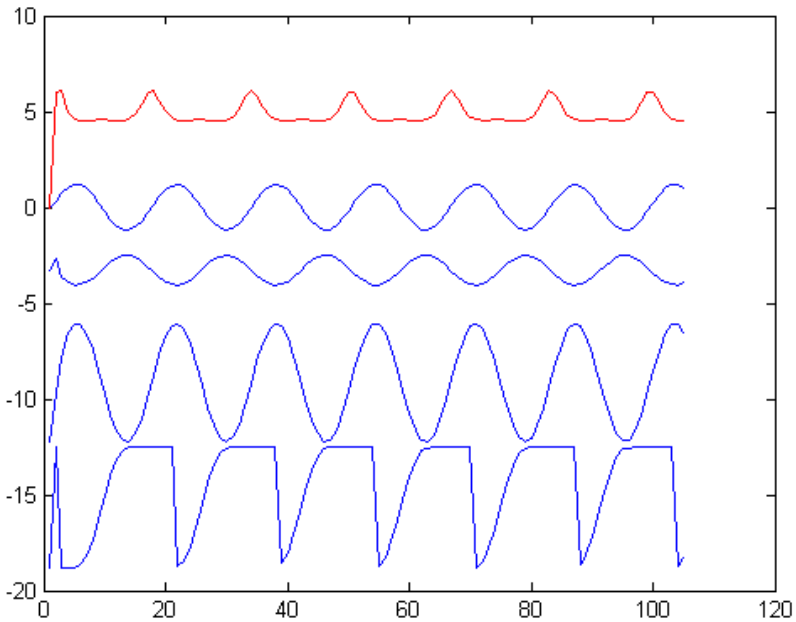


The robot falls because of too high maximal torque (8Nm)(instability of the robot structure)

Table Robot (1)

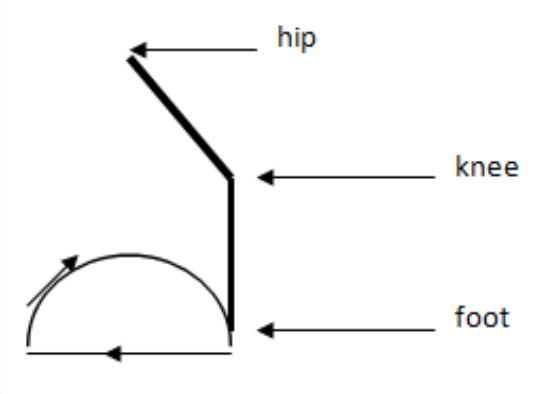


- Methodology(1)



vertical component of the foot position

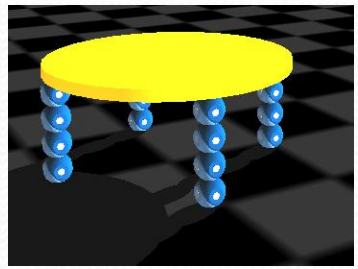
S1
S2
S3
S4



Desired foot pattern

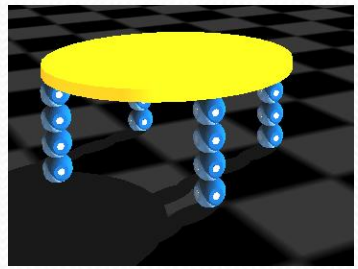
Command of the 4 motors (blue) and resulting position of the foot of one leg (red) among time

Table Robot (2)

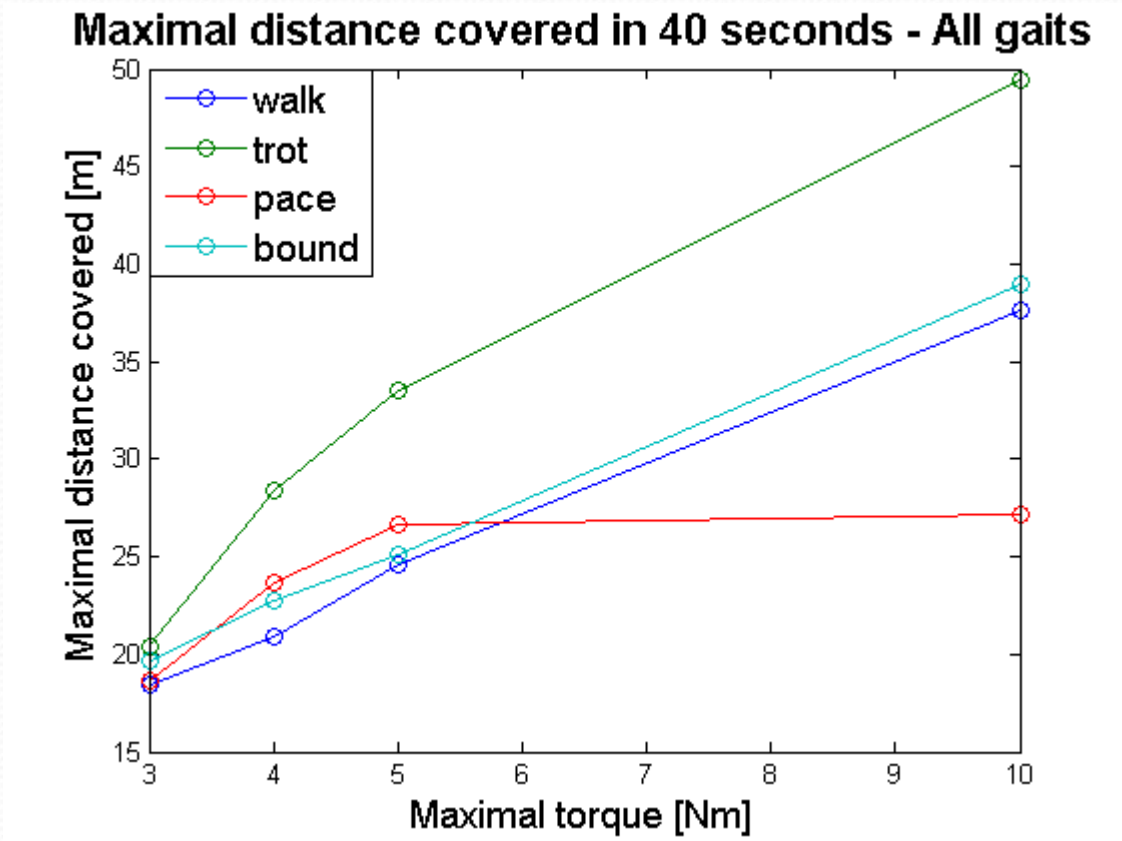


- Methodology (2)
  - One CPG per leg
  - 2 open parameters: w_stance and w_swing
  - Systematical search
  - Implementation of gaits matrix (trot, walk, bound, pace)
  - Tested with different maximal torque values (3, 4, 5 and 10 Nm)

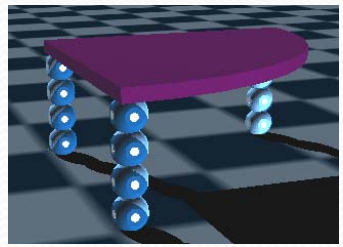
Table Robot (3)



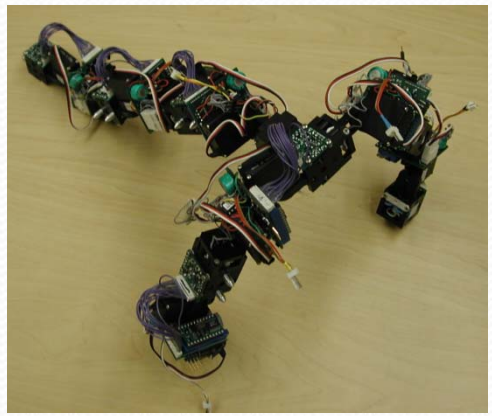
- Results



Big Chair Robot (1)



- Methodology
  - Taking inspiration from the CONRO robot
  - Two legs have the same pattern, the third one has a different pattern
  - Powell + systematical search
  - 7 open parameters



Big Chair Robot (2)

- Results
  - Maximal Distance Covered: ~9 m in 20 seconds
  - With “human” solution : 13 m in 20 seconds

    - Maximal torque at 10 Nm
    - Rotational speed at 7 rad/sec

Conclusion

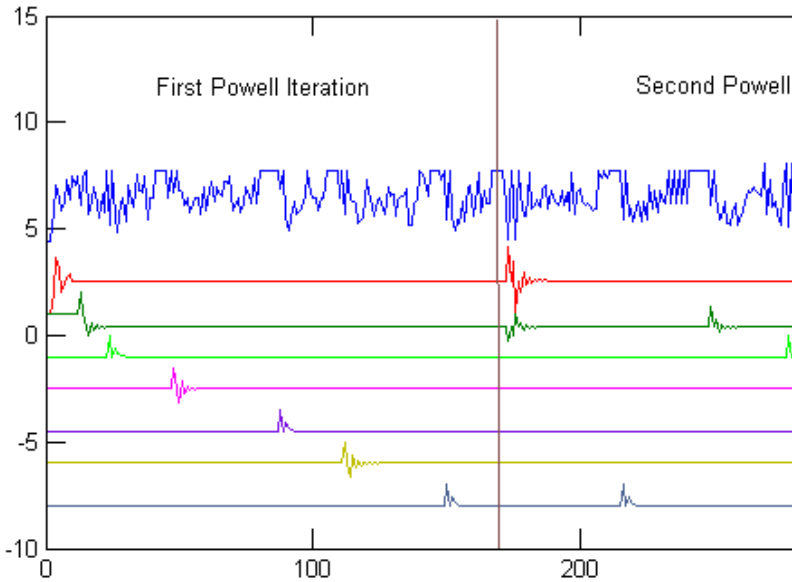
- Good locomotion gaits have be found with reasonable mechanical constraints (like maximal speed and maximal torque)
- In general, human solutions are more efficient than solutions found by optimization

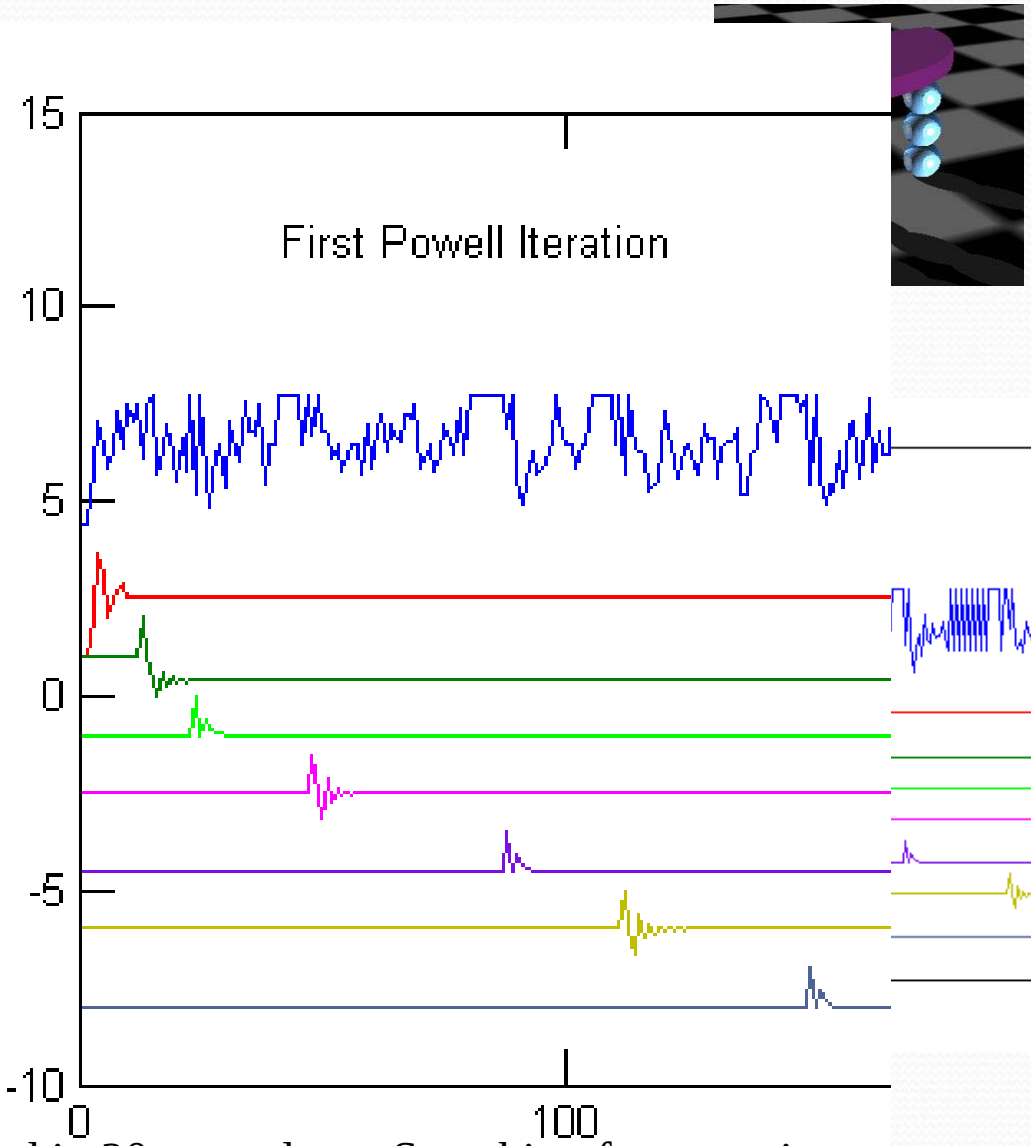
- Future Work
  - Inverse kinematics of the leg
  - New strategies for dealing with noisy fitness function
  - Idea: include more often optimization in various steps

Results (1)

- Chair Robot (1)

  Variation of parameters and f

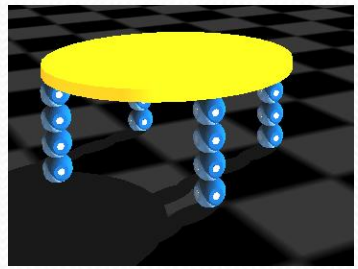




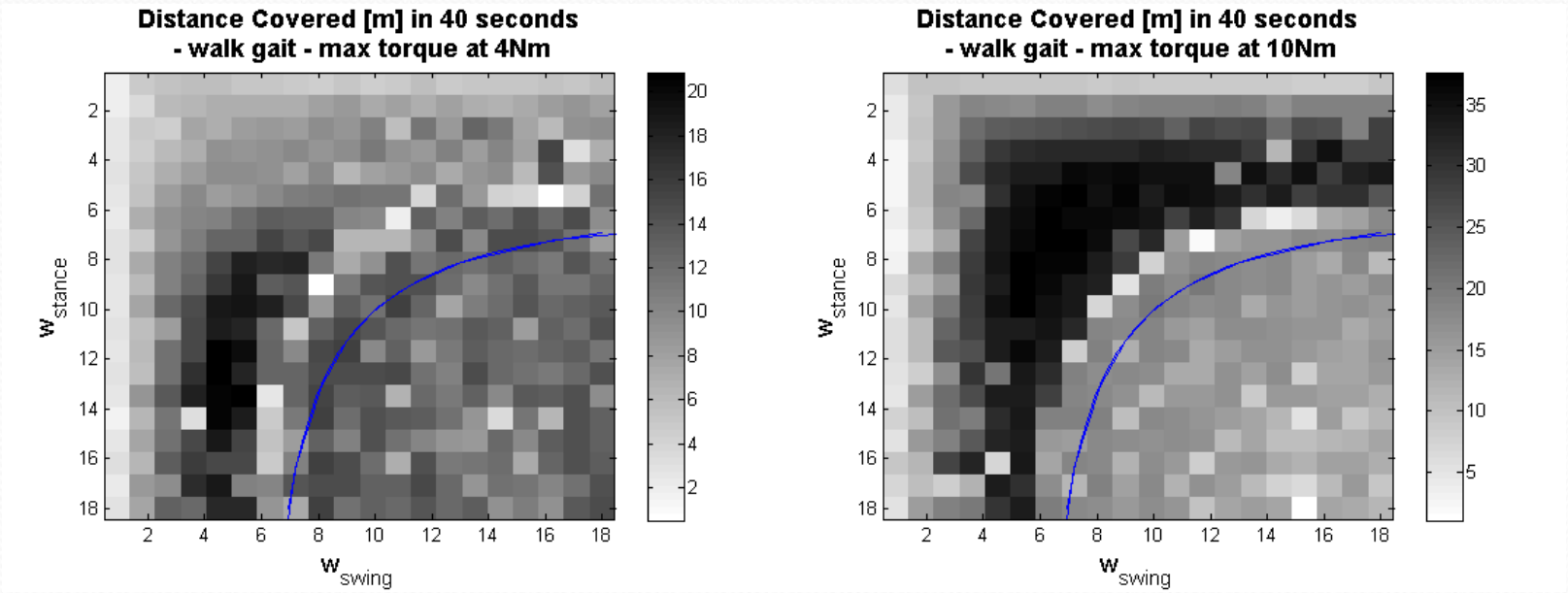
Fitness function: Distance covered in 20 seconds -> Searching for a maximum

Powell + Golden Section Search

Results (3)

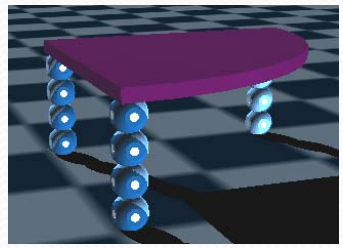


- Table Robot (1)

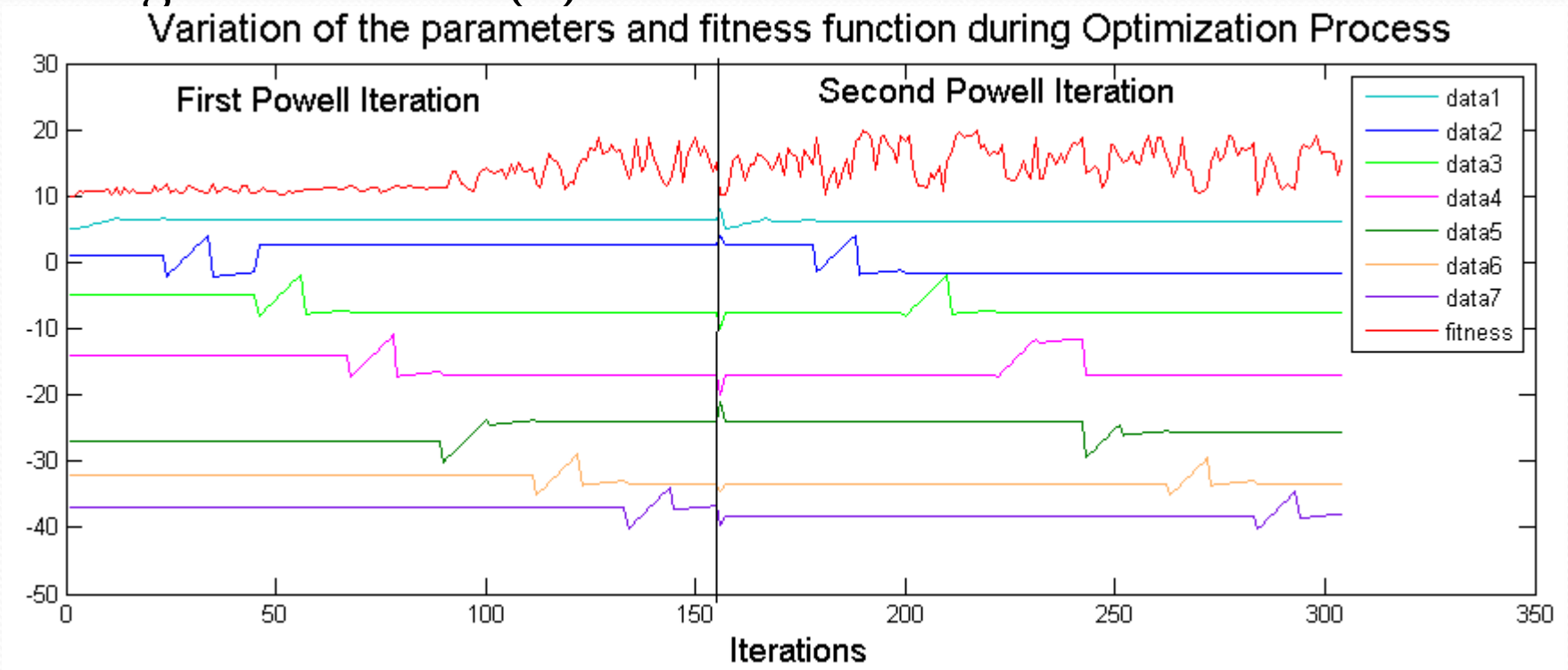


Fitness function: Distance covered in 40 seconds -> searching for a maximum
Systematical search

Results (5)



- Big Chair Robot (1)



Fitness Function : Distance covered in 20 sec -> Searching for a maximum
Powell + systematical search