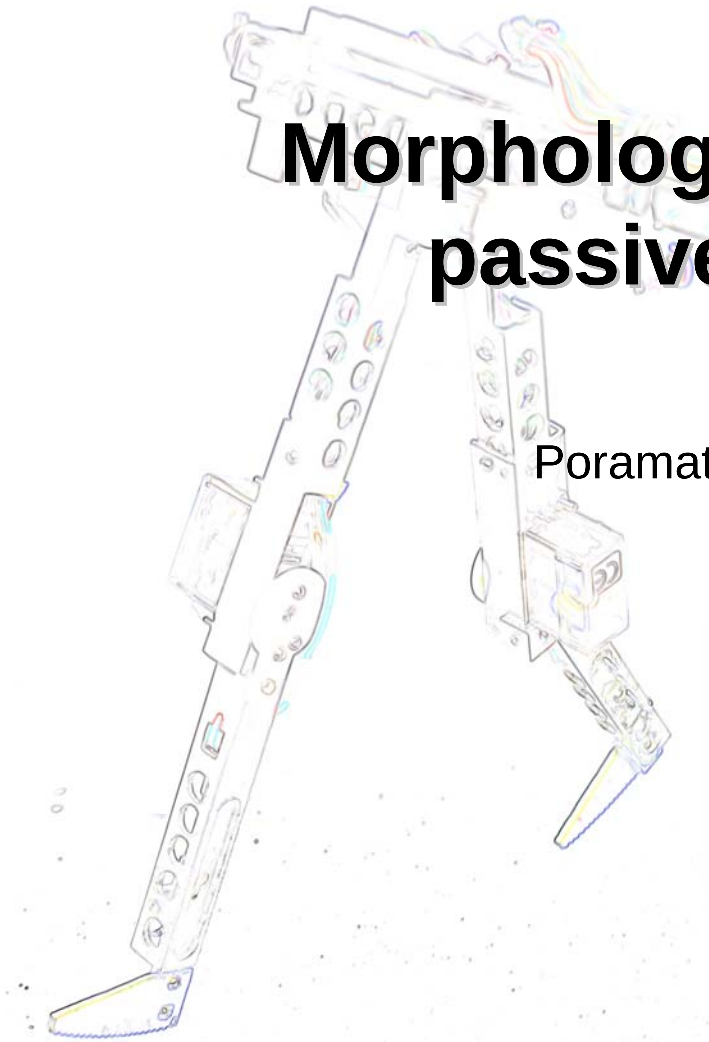
Morphology, control and passive dynamics



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Morphology = the structure and mechanical characteristics of the robot body

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Not only Kinematics and Dynamics of robots but also the control required for robot behaviors

Well designed morphology

reduction in control &improved controllability

- Passive dynamics (Collins S. [1], etc.)

- Extending idea from Passive dynamics to running robots (Tao G. [3], Kimura H. [4], etc.)

- Climbing robots (Metin S. [5], etc.)

- Underwater robot (Edward C. [6])

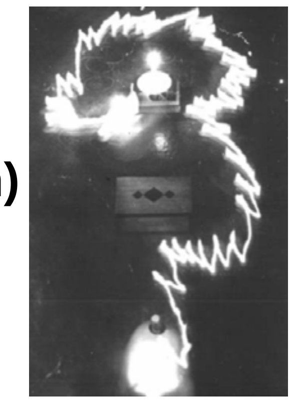
Poor designed morphology

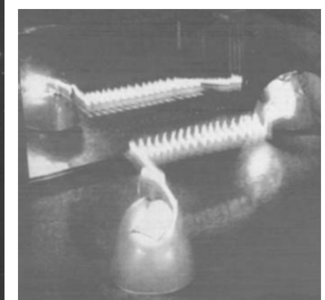
low controllability
require complex control algorithm
inadequate for the task

Morphology and **Control**

[Gray Walter's Turtles, 1953]

Behavior genration (agent-environment interaction)





Embodied AI

[R.A. Brooks, 1980s]

Special Issue on Morphology, Control and Passive Dynamics:

(Robotics and Autonomous systems (Vol. 54))

The collection of papers:

→ **1.** The conceptual advances in understanding the interaction between morphology, control and behavior.

2. A novel technique for enhancing controllability using morphology design.

→ **3.** Analytical methods and computational tools for investigating the effect of morphological characteristics on dynamics and behavior.

4. New control methods for better exploiting the dynamics of a given morphology for control.

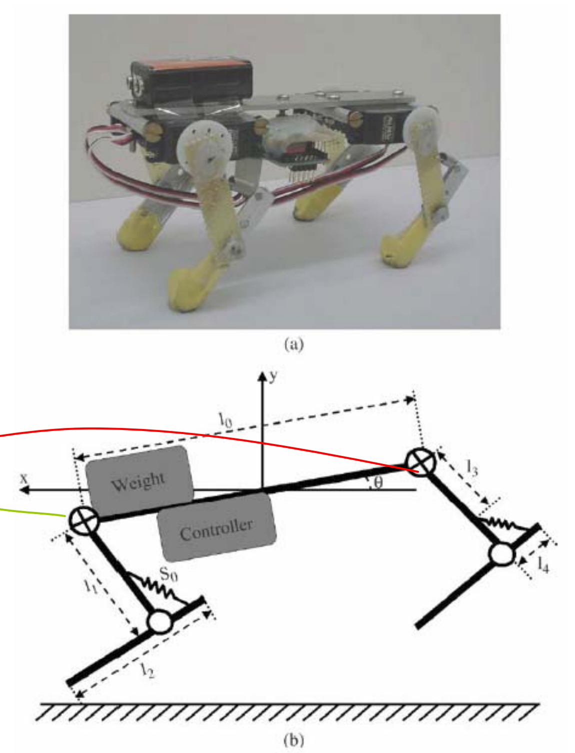
1. *Sensing through body dynamics* (F. Iida, R. Pfeifer)

Goal: Exploring design principles of the whole body dynamics for the purpose of sensing

4-legged robot: spring-mass model with four active joints, rubber surface at the ground contact in each leg (for higher fiction in walking forwards)

Motor control: Central Pattern Generator CPG and *no feedback*

$$P_f(t) = A_f \sin(\omega t) + B_f$$
$$P_h(t) = A_h \sin(\omega t + \phi) + B_h$$

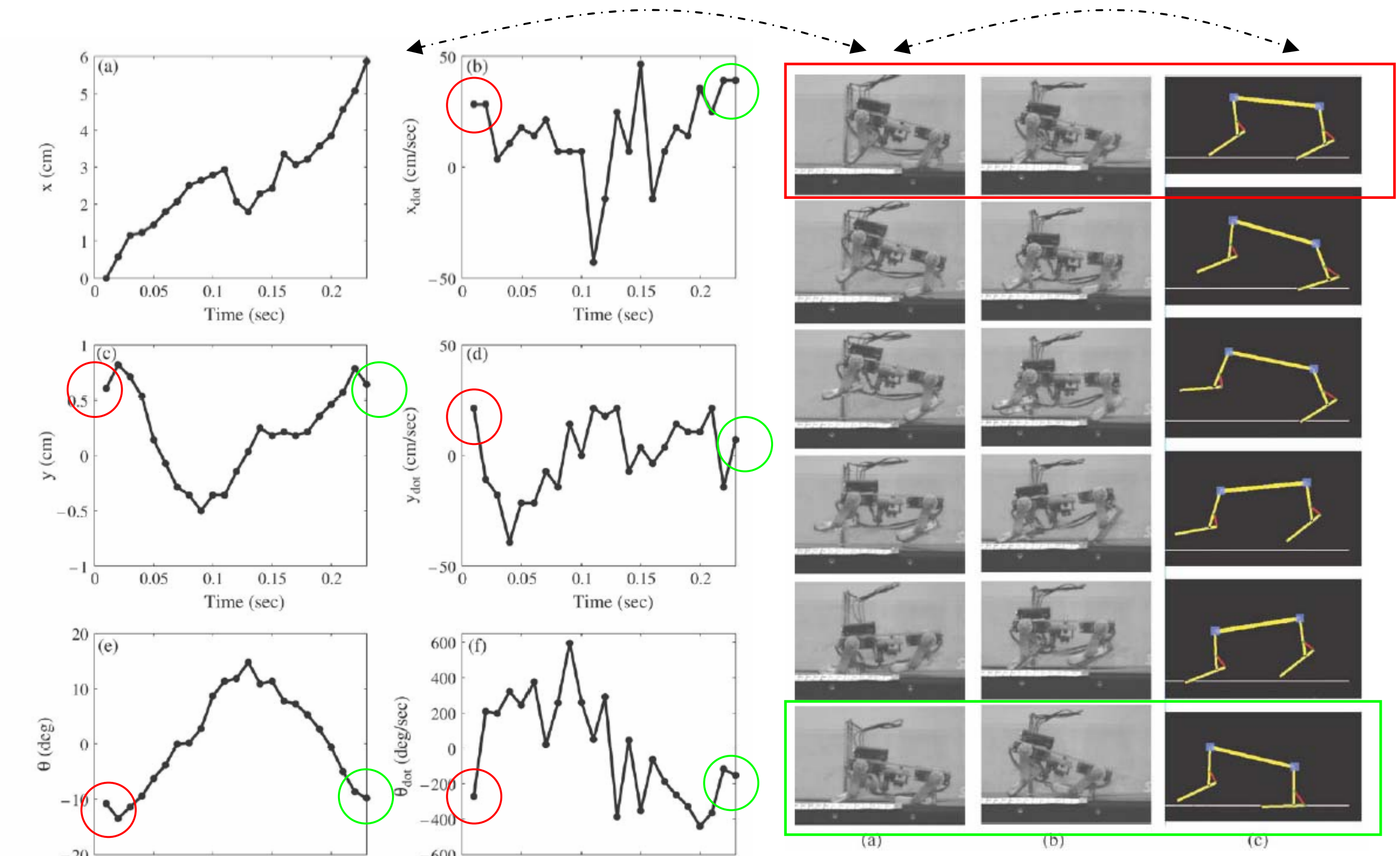


Experiments:

1. Testing on a real machine to obtain data

2. Using simulation and compare to the real one

Experiment 1 (Real machine): The stability of the locomotion method without sensor feedback (periodic gait pattern)

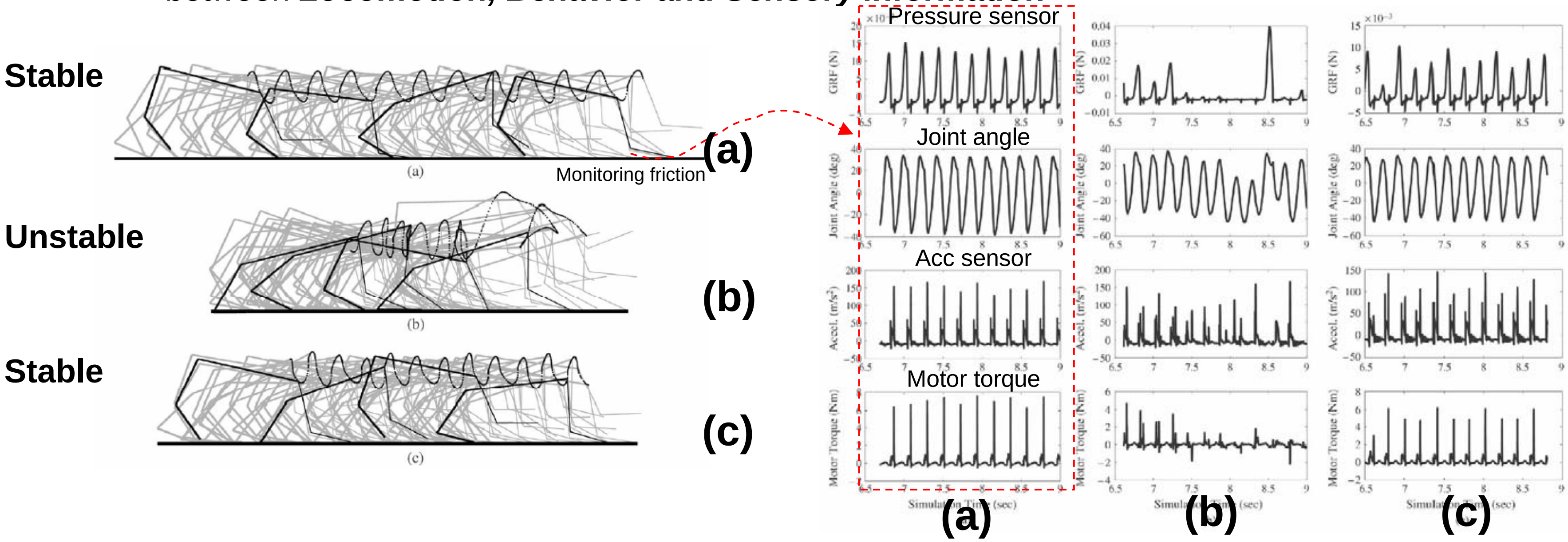


Gait 0 (Hopping higher)Gait 1 (Larger forward velocity)

Experiment 2 : Simulation model in Mathworks MathLab 7.01 with SimMechnics toolbox

- 5 body segments
- Linear springs
- Two motors at hip and shoulder joints
- Angular sensors
- Ground friction model

Experiment 3: Using the simulation to characterize the relation between ***Locomotion, Behavior and Sensory information***



(a) W = 4.7 Hz, Phase = 0.3
Friction = 0.9 (static), 0.8 (dynamic)

(b) W = 4.7 Hz, Phase = 0.3
Friction = 0.7 (static), 0.6 (dynamic)

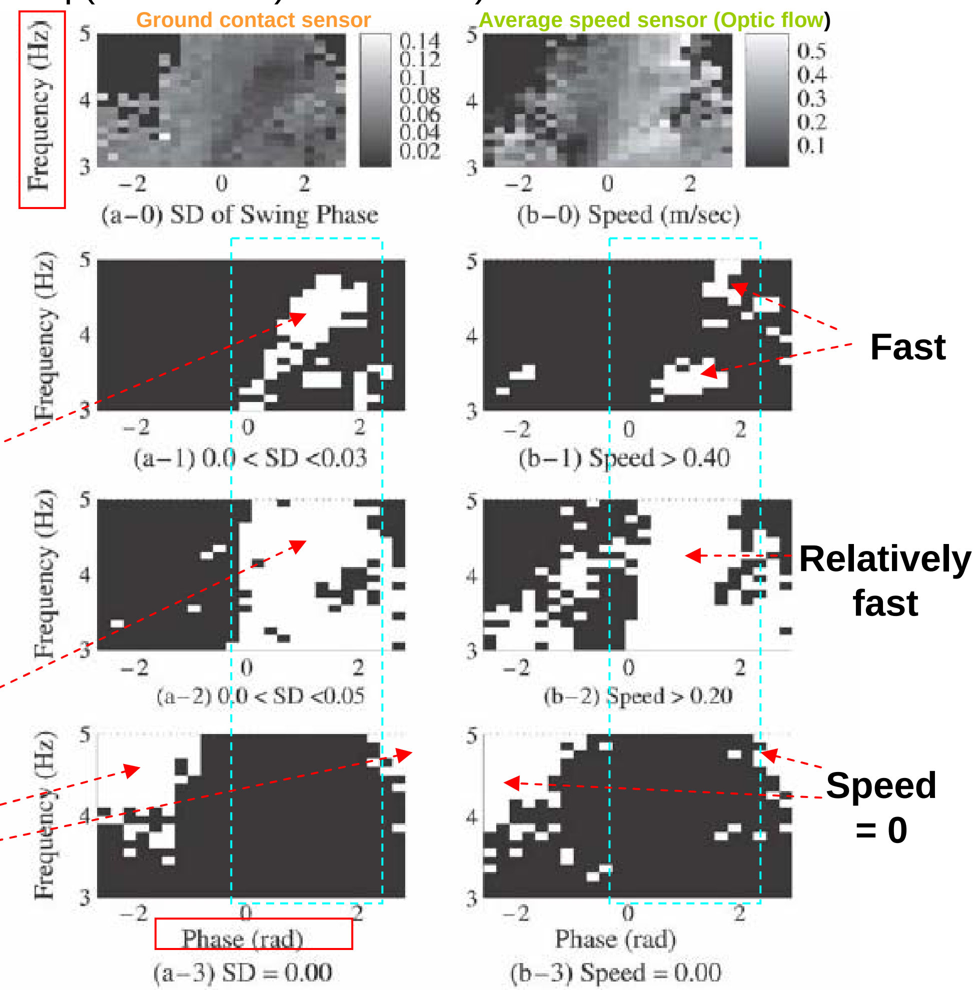
(c) W = 4.9 Hz, Phase = 0.4
Friction = 0.7 (static), 0.6 (dynamic)

Experiment 4: Sensing body dynamics (varying Freq (w = 3-5 Hz) and Phase)

Using sensor information to analyzing temporal patterns

- *A ground contact sensor* at the fore foot

- *The average forward speed* of locomotion (assume that the robot has a vision sensor measuring optic flow)

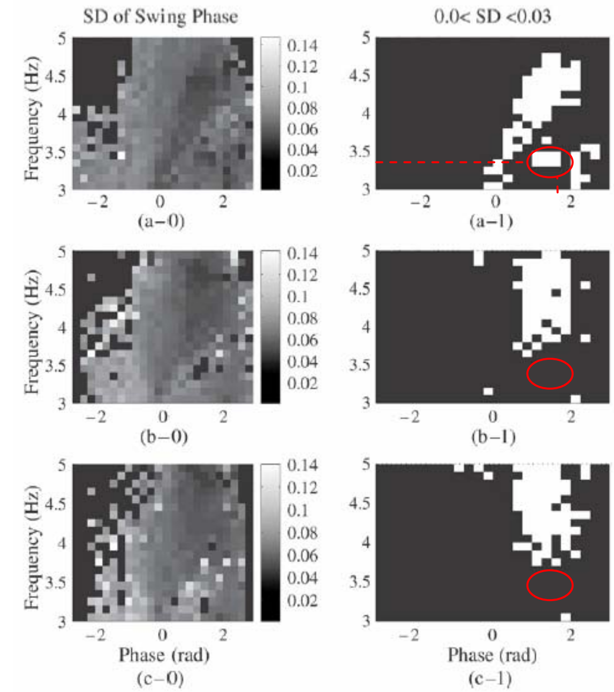


Experiment 5: Sensing physical properties

5.1 Varying body mass (0.5, 1.0, 1.5 Kg.):

- Ground contact sensor (GS)
- Speed detector sensor (vision (VS)

Ground contact sensor

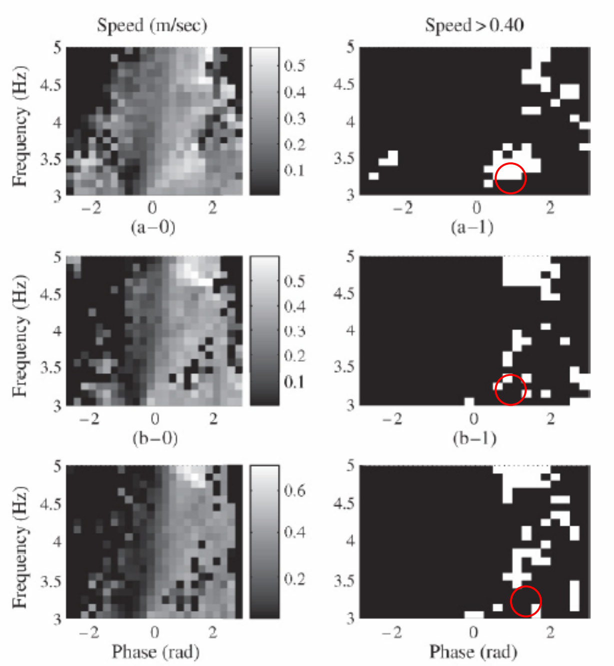


0.5 kg

1.0 kg

1.5 kg

Average speed sensor (Optic flow)



0.5 kg

1.0 kg

1.5 kg

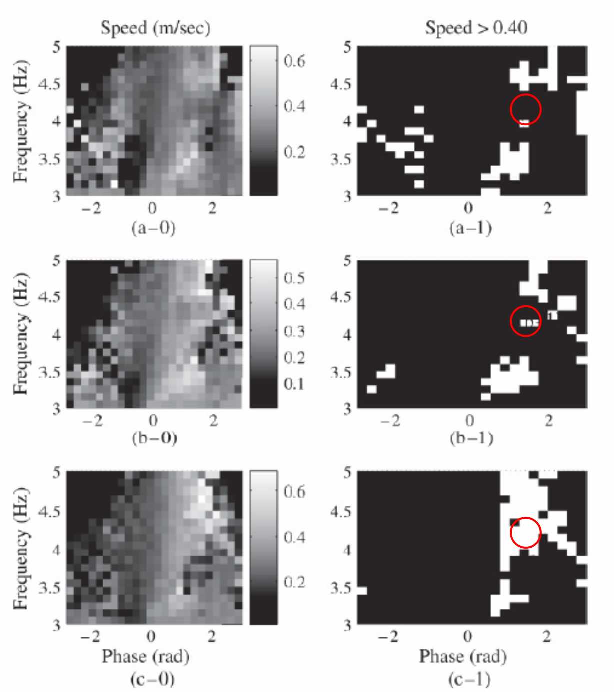
The difference of the body mass can be identified by GS and VS

Experiment 5: Sensing physical properties

5.2 Ground friction (0.5, 0.65, 0.8):

- Mass = 0.5 kg
- Ground contact sensor (GS)
- Speed detector sensor (vision (VS)

Average speed sensor (Optic flow)

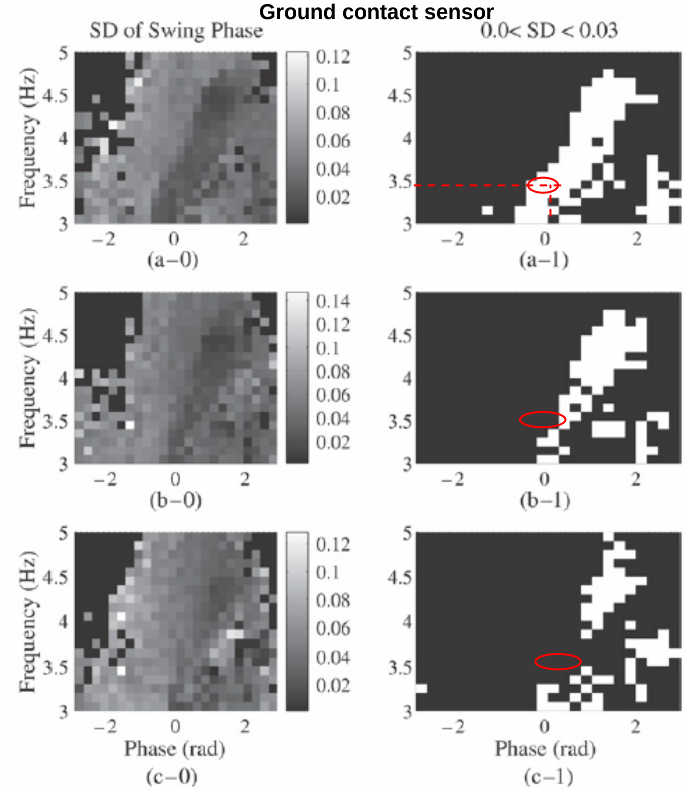


0.5

0.65

0.8

Ground contact sensor



0.5

0.65

0.8

The difference of the ground friction can be identified

by GS and VS

Conclusion

- Applying the sensory information from different channels, e.g. pressure sensor on the foot, locomotion speed, force sensor on the leg joints, etc., to let the robot understand its situation or environment condition

- They can be used to determine the stable behavior patterns

-The body dynamics can be exploited for sensing

- The physical properties (body weight, friction) are reflected to the sensory information

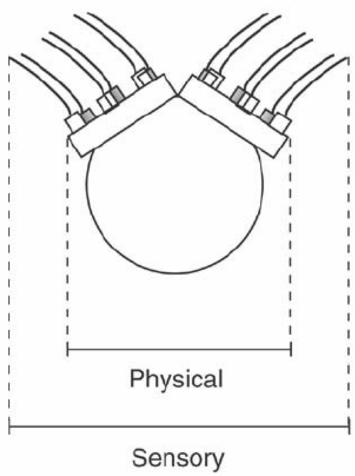
3. On the influence of morphology of tactile sensors for behavior and control (M. Fend, S. Bovet, R. Pfeifer)

Goal: - Investigating the relation between the morphology of the sensor distribution on the robot body different tasks (obstacle avoidance and wall following)

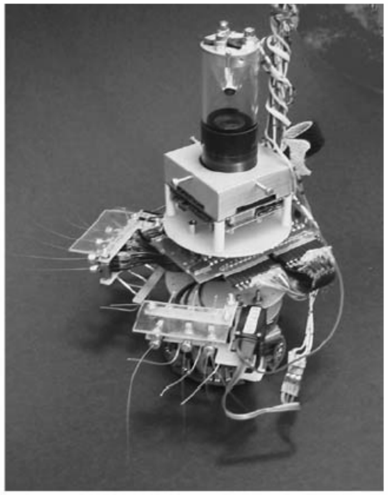
- Reducing the amount of processing in the brain of the agent by using the appropriate morphology of the sensors

Mobile robot with the whisker arrays

Motor control: Reactive control



(a)


(b)

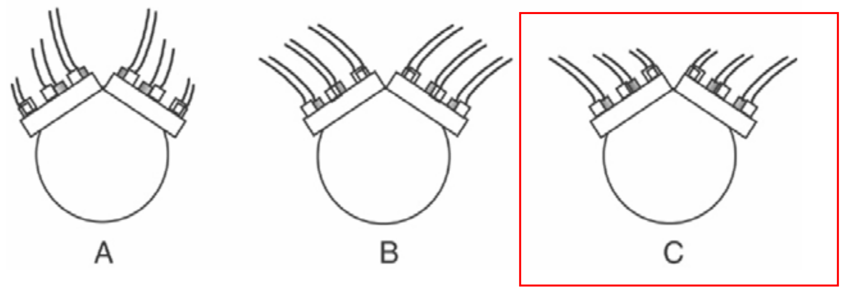
Experiments:

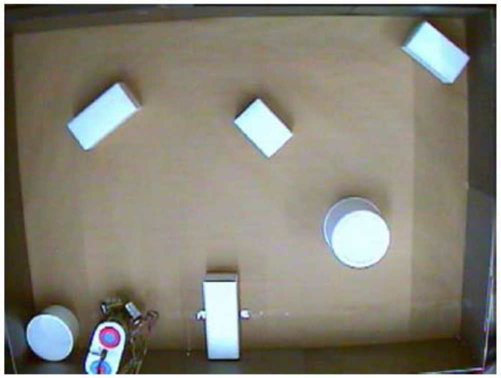
1. Testing 3 different morphologies of the sensor mounted on the robot for obstacle avoidance task (reactive controller).

2. Using learning algorithm to the controller and then using evolutionary algorithm to optimize the controller and the morphology of the whiskers for obstacle avoidance task.

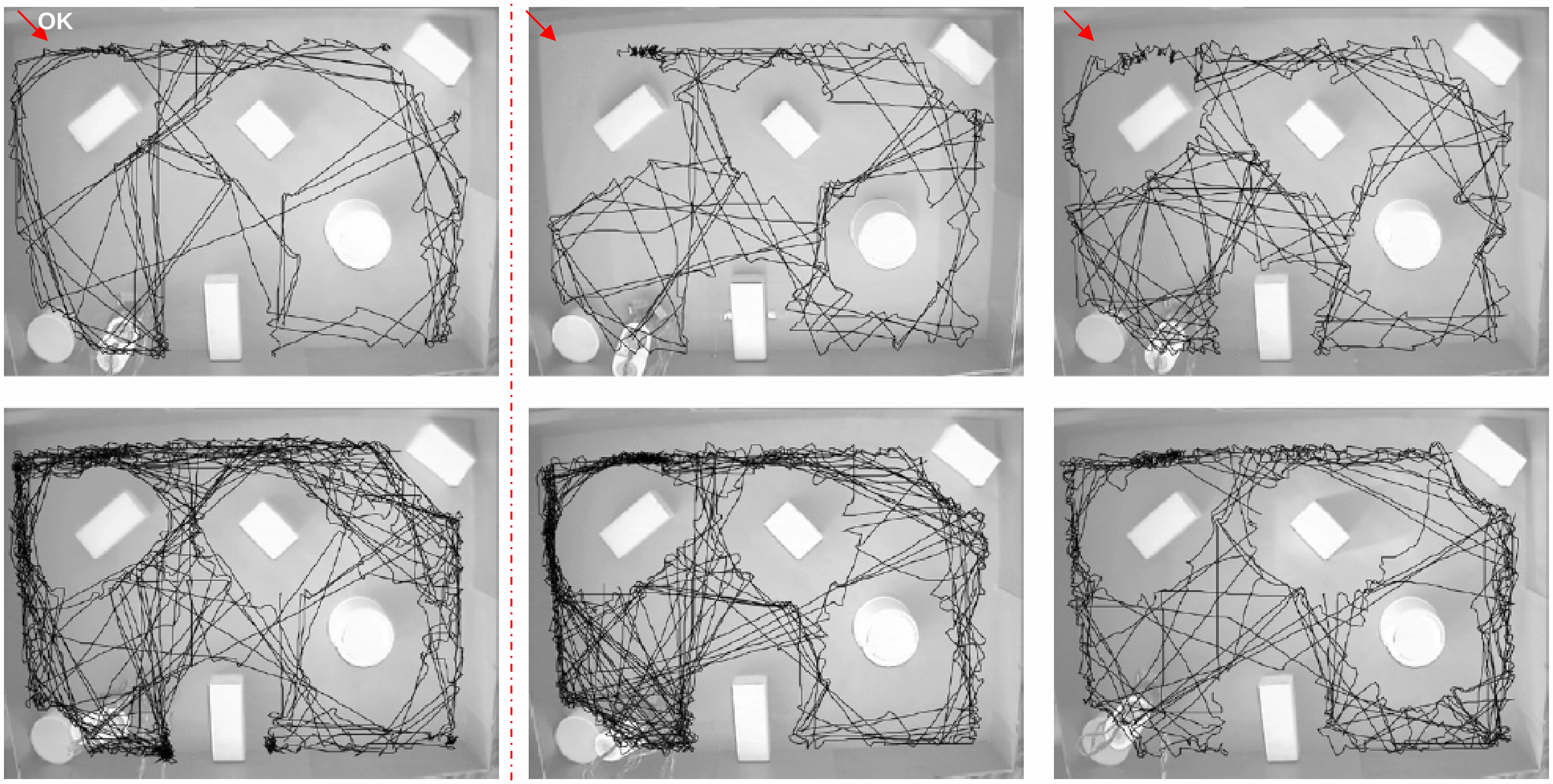
3. Evaluating the same morphologies as (1) and (2) on a different task " wall following"

Like animals

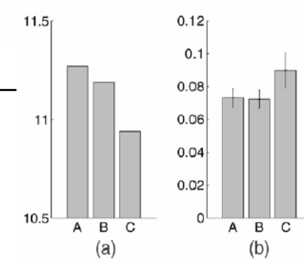




Experiment 1: The performance of the robot system is evaluated by how evenly the experimental space is covered and how much the robot wiggles (how often the robot changes direction)

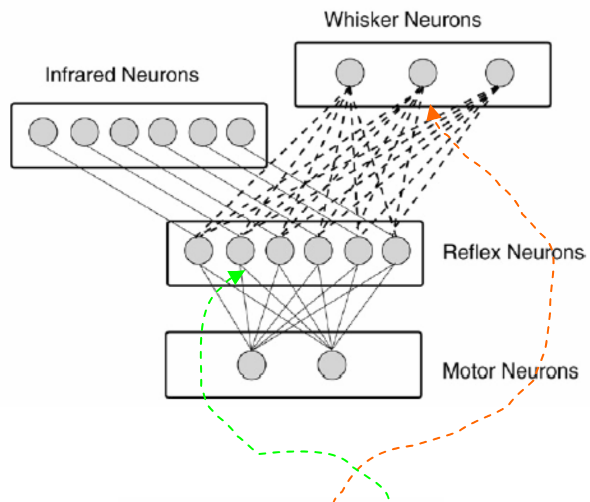


(a) Morphology A. (b) Morphology B. (c) Morphology C.



Experiment 2: Learning of obstacle avoidance on the robot

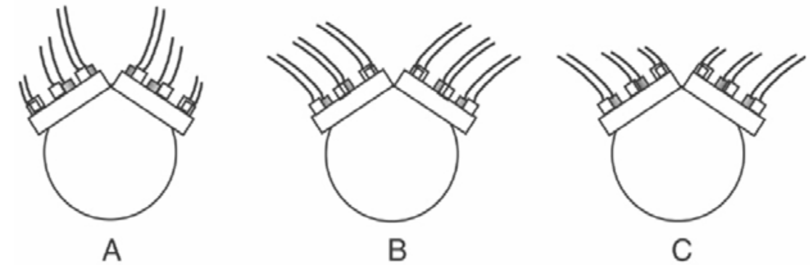
Distributed adaptive control: IR sensors used as the pre-wired reflex; Wij = 0



$$\Delta w_{ij} = \eta \cdot a_j \cdot a_i$$

Learning time is limited to 2 mins

\+



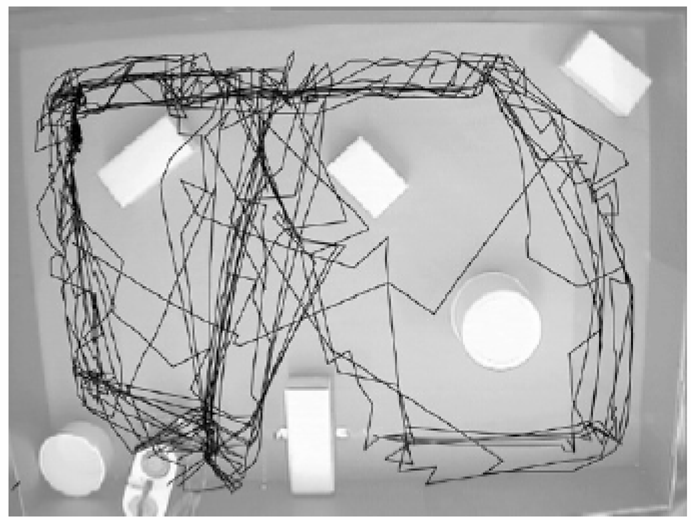
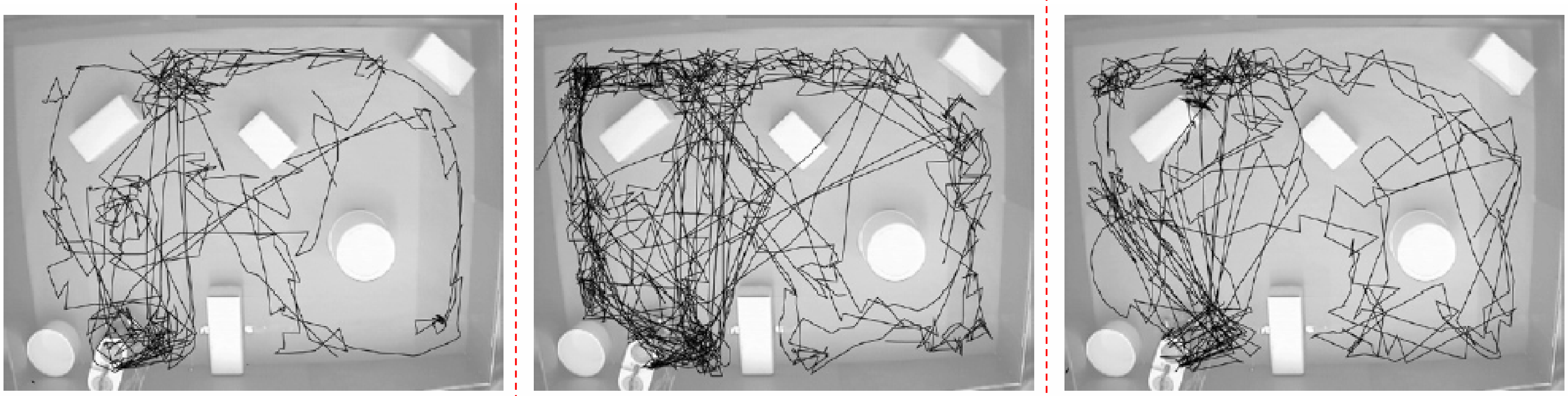


Fig. 7. Trajectory of the robot avoiding obstacles using IR sensors only.

Results



(a) Morphology A. (b) Morphology B. (c) Morphology C.

Fig. 8. Experiment 2: cumulated trajectories for the three morphologies A (a), B (b) and C (c).

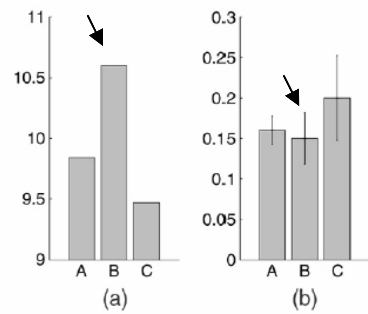
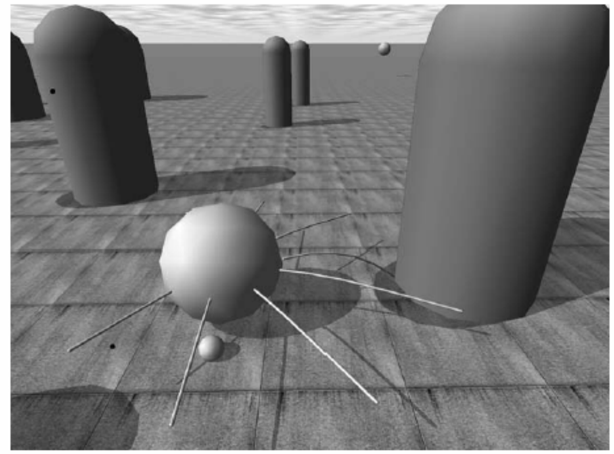


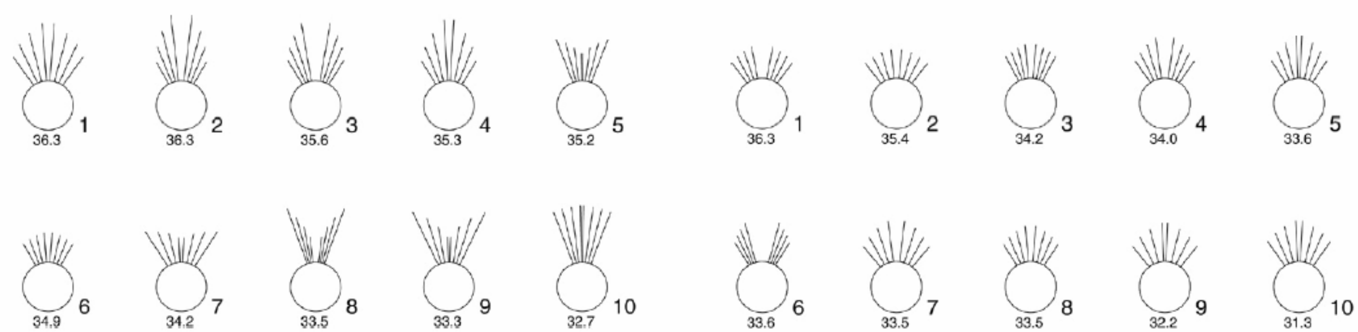
Fig. 9. Experiment 2: entropy (a) and wiggle (b) in morphologies A, B, and C.

Experiment 3: Using Co-evolution to optimize the controller, the morphology of the whiskers and the influence of different whisker properties (rigid and flexible)

$$F = a \cdot N_{\text{target}} - b \cdot N_{\text{collision}} + c \cdot N_{\text{move}}$$



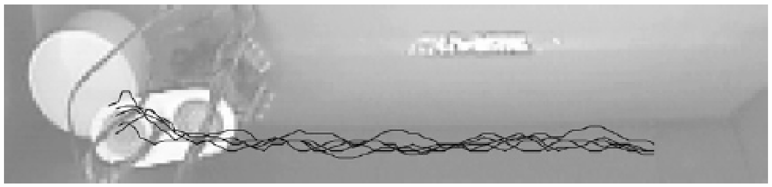
Almost like Morphology A



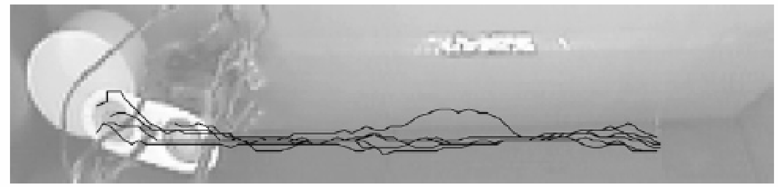
(a) Flexible whiskers. (b) Rigid whiskers.

Fig. 11. Morphologies of the best-performing agents found by artificial evolution. The morphology of the fittest agent found after 500 generations is shown for each one of the 10 evolution runs. The fitness of each agent is indicated by the number underneath.

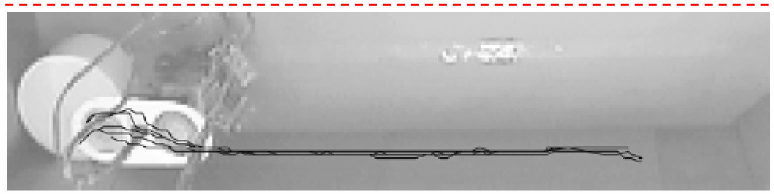
Experiment 4: Wall-following with the reactive controller



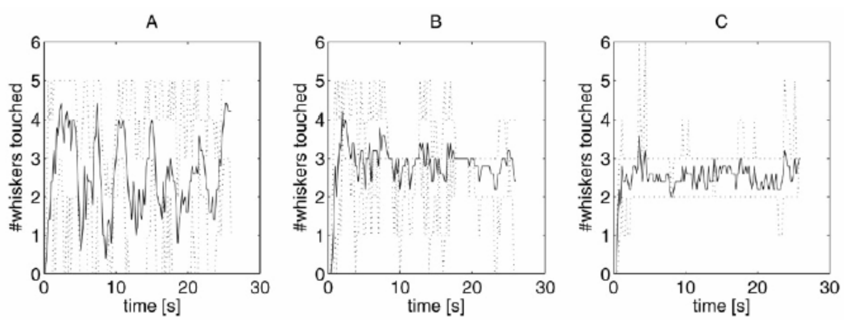
(a) Morphology A.



(b) Morphology B.



(c) Morphology C.



smooth

Conclusion

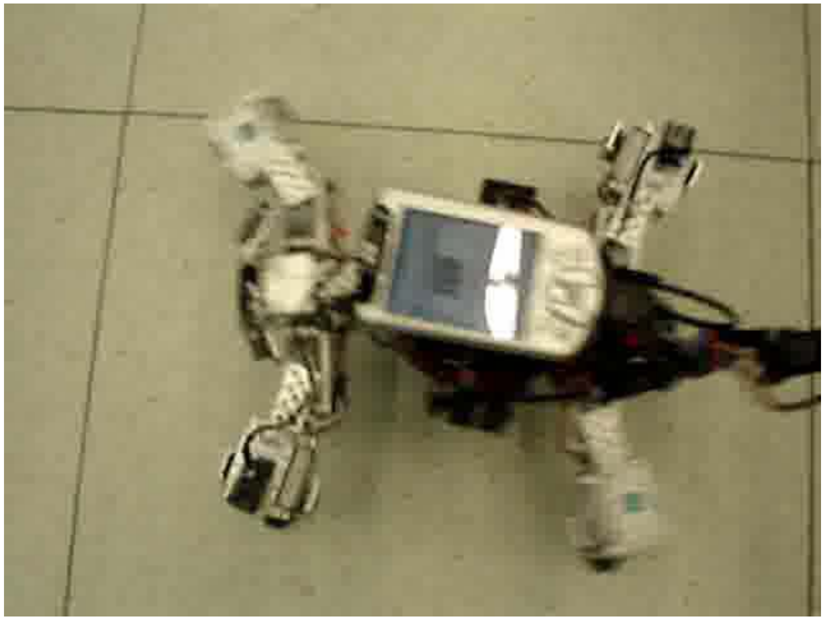
- Morphology A = suitable for obstacle avoidance

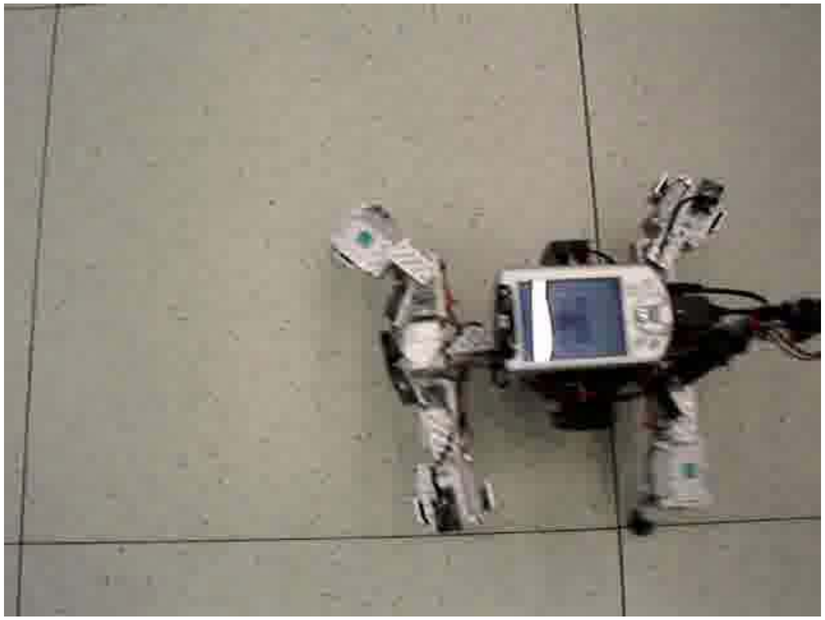
- Morphology C = suitable for wall following , similar to animals, e.g. rat

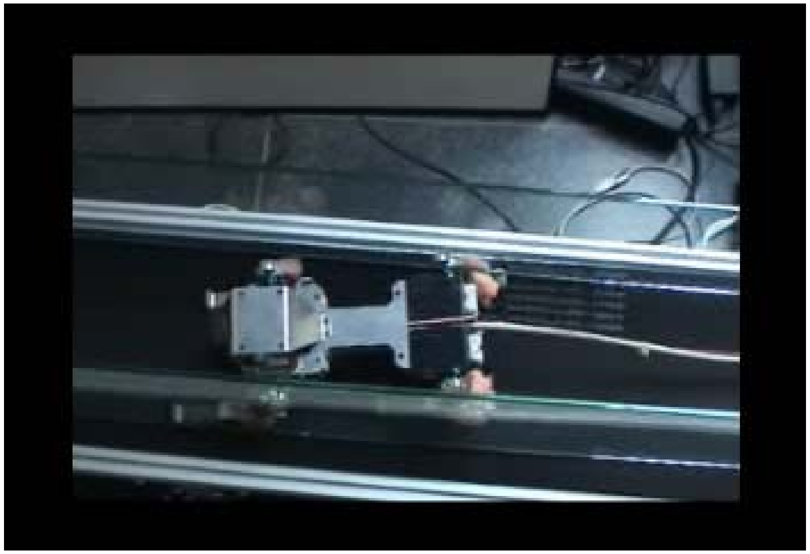
- Rat uses its whisker mostly for wall following while it uses also another sensor system, e.g. vision, for obstacle avoidance task

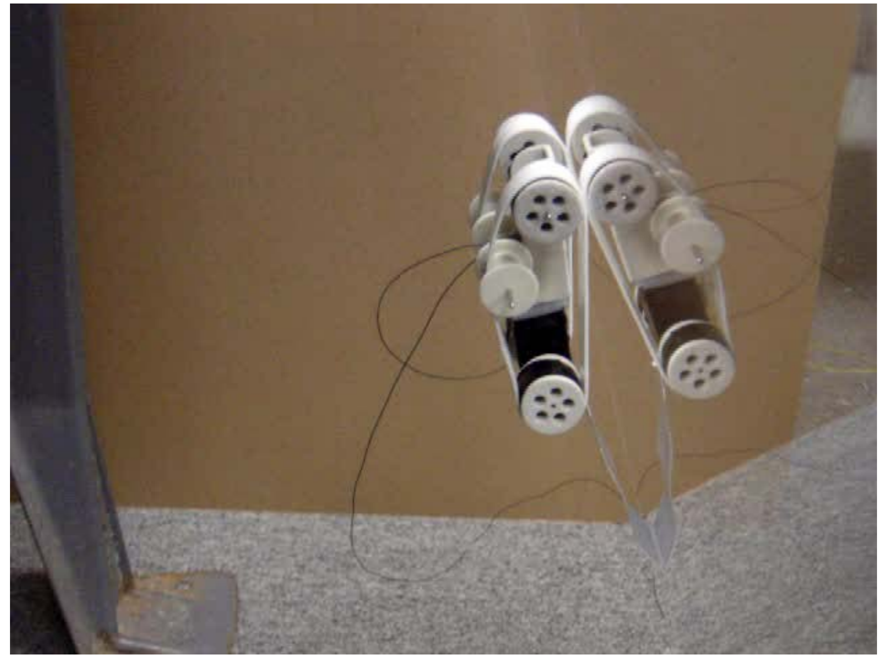
-The performance of the system can be enhanced with an appropriate morphology

Example:









Thank you for your attention