The locomotion of an underwater soft robot as a case study for further investigating morphological computation and embodied intelligence

Francesco Corucci
M.Eng. B.Eng. in Computer Engineering
1st year Ph.D. Student in BioRobotics
f.corucci@sssup.it

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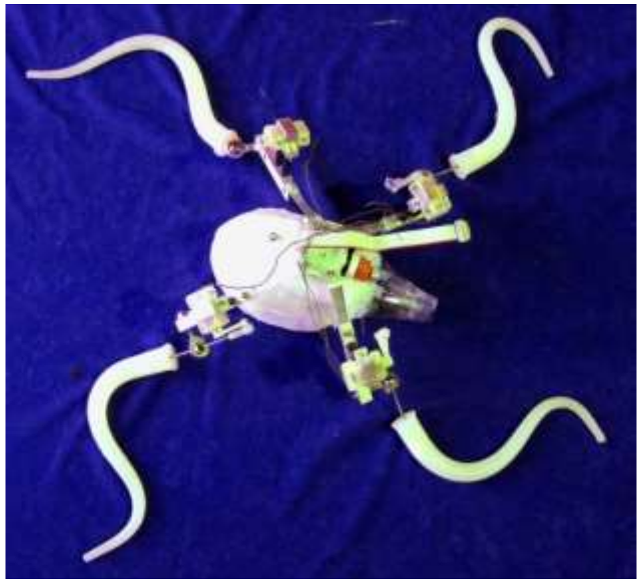
Motivations

- An *underwater* *soft* robot is an interesting case study to investigate *embodied intelligence*
  - Stressed interaction with the environment
  - Rich morphology
  - Possibility to change its shape, online

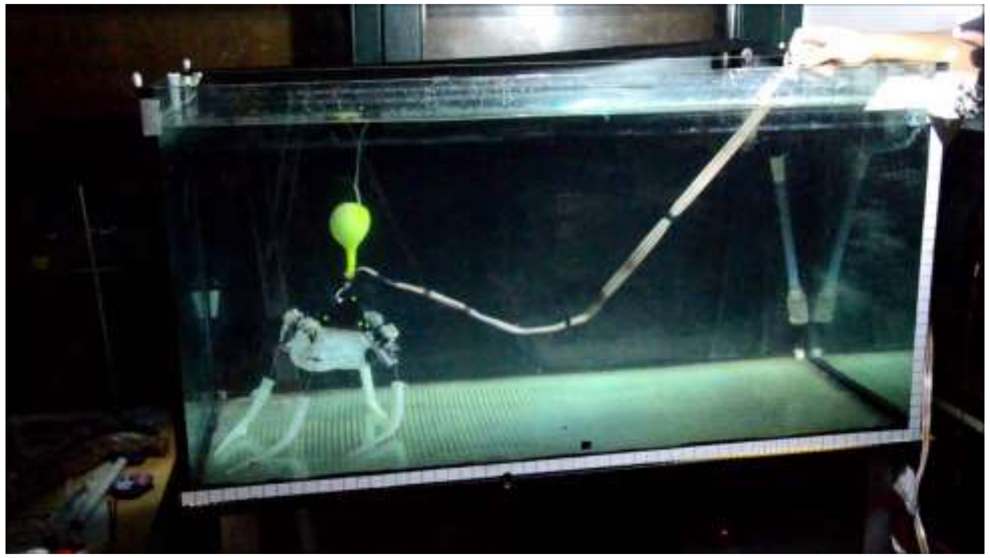
- The locomotion of a robot with such features is the focus of this work
- Particularly, extending previous work on crawling, we focus here on bipedal walking

Robot and tank experiments

- ***Octopus*-inspired soft robot, featuring:**
  - a crawling module: four radially distributed legs, made of silicone, actuated in *feed-forward*
  - a floating module: entailing a separation between Center of Mass (CoM) and Center of Buoyancy (CoB), that *passively* confers to the robot a suitable posture for bipedal walking
  - a swimming module: not used in this work



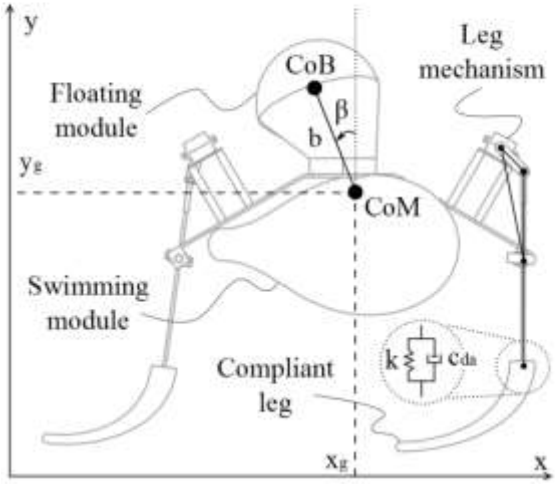
- **Tank experiments:**
  - Speed increase (w.r.t. crawling) consistent with biological observations (~3 times)
  - Data collection (CoM trajectories were recorded)

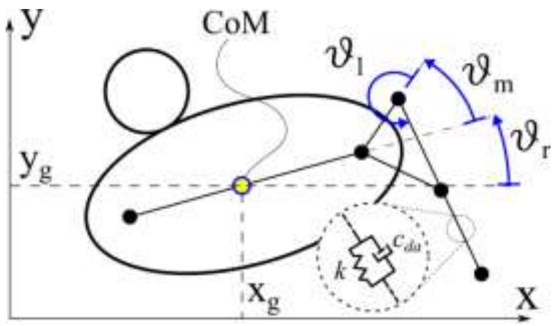


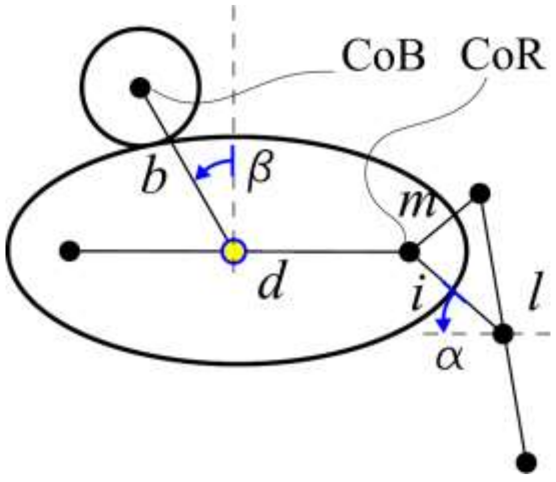
Model and validation

- **Sagittal-plane model of robot dynamics**
  - Separation of CoM and CoB
  - Compliant legs modeled as *spring-damper* systems

- **Parameters estimation performed by means of *genetic algorithms***
  - Bounded minimum optimization problem
  - <u>Target</u>: 4D *features vector* (a^*, f^*, μ^*, s^*) characterizing the gait, extracted from data collected in tank experiments
  - <u>Fitness</u>: sum of normalized squared errors between target and simulation features vectors





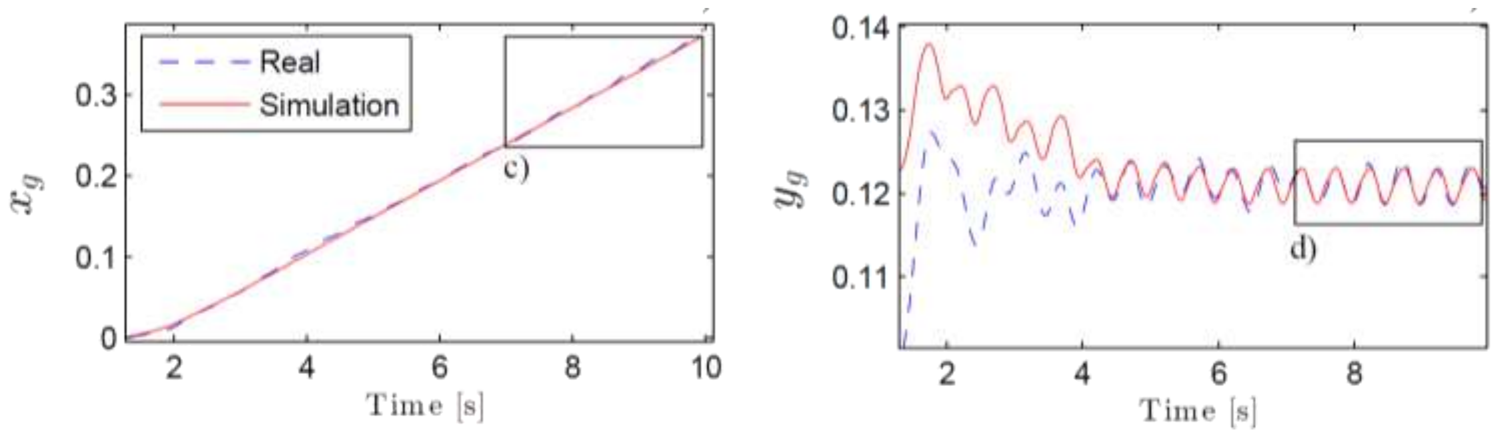


Results – Model validation

- Good convergence at the target (residual error $\sim 10^{-6}$)
- Once provided with estimated parameters, the model closely matches the trajectories of the actual robot in tank experiments
- Despite the wide bounds imposed, physically plausible parameters
- Relevance of hydrodynamic parameters (added mass, added inertia, drag)

→ The interaction with the underwater environment is remarkable: *can we exploit it to our benefit?*

k	dr	c_{sf}	c_{dfmul}	$\overline{M}$	X_{uu}	$\overline{J}$	Fitness
216.5	0.37	0.65	0.83	4.64	121	0.014	$9.1647 \cdot 10^{-6}$



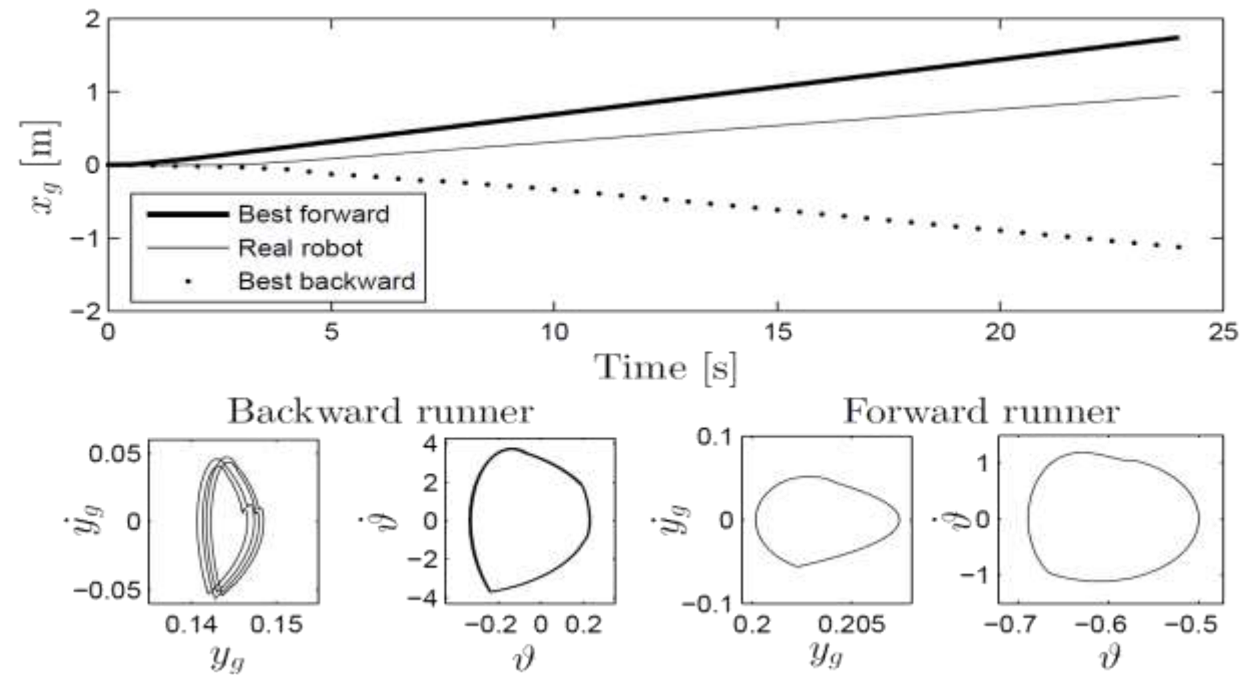
$\overline{err_y} = 0.0037\, m$, $\min(err_y) = 1.6 \cdot 10^{-6}\, m$, $\max(err_y) = 0.02\, m$

$\overline{err_x} = 0.003\, m$, $\min(err_x) = 0.00014\, m$, $\max(err_x) = 0.0068\, m$

Changing shape, changing behavior

- Preliminary tests were conducted in order to investigate how online morphological modifications can be exploited to achieve a diversity of behaviors
- Using the validated model, the position of the CoB was varied and the resulting gait was analyzed

→ With the <u>same feed-forward activation</u> a variety of *stable* locomotion patterns arose (forward, backward, different speeds)



- A deeper characterization is needed, but we envision interesting possibilities

Future work (short term)

- Investigate how online morphological changes can be controlled in order to *switch* among different stable locomotion patterns
- Exploit the proposed model and methodologies for the *optimal design* of an *under-actuated soft robot*
- By adopting evolutionary techniques, *co-evolve morphology and control* in order to take full advantage of the rich morphology and interaction with the environment of the robot

Future work (long term)

- A brain-less robot is just the starting point
- Exploit the rich morphology and interaction with environment to *emerge* more complex behaviors

Some required steps:

- Enhance the robot with appropriate sensors in order to produce *rich, correlated flows of sensory information*
- Investigation of *neural models*: what level of detail is needed in order to rise something «intelligent»?

Thank you for your attention

Hope to meet you all at the poster session

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