University of Zurich[UZH]

robotics

Welcome

The ShanghAI Lectures
An experiment in global teaching

Today from the
BioRobotics Institute of the Scuola Superiore Sant'Anna
Pontedera (Pisa), Italy

14 November 2013

欢迎您参与
"来自上海的人工智能系列讲座"

University of Zurich[UZH]

Table of contents

University of Zurich[UZH]

Today's program (CEST)

9:30	Cecilia Laschi: welcome to Lecture 5: Soft Robotics and Bioinspiration I
9:35	Fabio Bonsignorio: Hello from Tokyo
9:40	Danica Kragic: From scene segmentation to task based grasping
10:15	Coffee break
10:20	Cecilia Laschi: How an octopus can help building a robot
10:55	Bram Vanderborght: Hard Work for Robotics from Soft Actuators
11:30	Wrap up

University of Zurich[UZH] robotics Swiss National Centre of Competence in Research ai lab The ShanghAI Lectures 人工智能 上海授课

How to interact

- raise your hand (if you are in a VideoC participating site)

- use the question board:
http://shanghailectures.org/node/2740

- use the Facebook page:
https://www.facebook.com/shanghailectures

- use Twitter:
tweets mentioning #SHAIL or @shanghailecture are listed

Soft Robotics and Bioinspiration:

how an octopus can help building a robot

Image: Massimo Brega, The Lighthouse

Cecilia Laschi

The BioRobotics Institute

Scuola Superiore Sant'Anna, Pisa, Italy

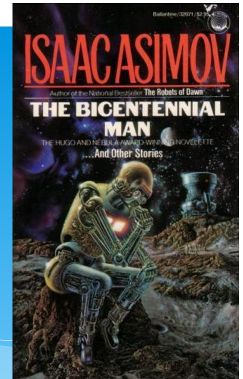
Lecture 5: Soft Robotics and Bioinspiration I

November 14, 2013

Outline of the lecture

* Evolution of robotics: how the need for bioinspiration brought a need for soft bodies and then a need for controlling them
* What an octopus can teach us in building and controlling a soft robot: the magic of muscular hydrostats and embodied intelligence
* From biology to robotics: the case of the OCTOPUS robot
* What is it for? Unexpected applications of octopus robots…
* Conclusions: take the momentum of soft robotics and let’s make this scientific challenge grow

Evolution of robotics



Industrial robotics:
birth and growth of theories and techniques for robot control

Service robotics:
birth and growth of theories and techniques for robot perception & action (behaviour) control

Structured enviroment

Unstructured enviroment

Photo: Center for Robot-Assisted Search and Rescue

Evolution of robotics: need for bioinspiration

ISTITUTO DI BIOROBOTICA

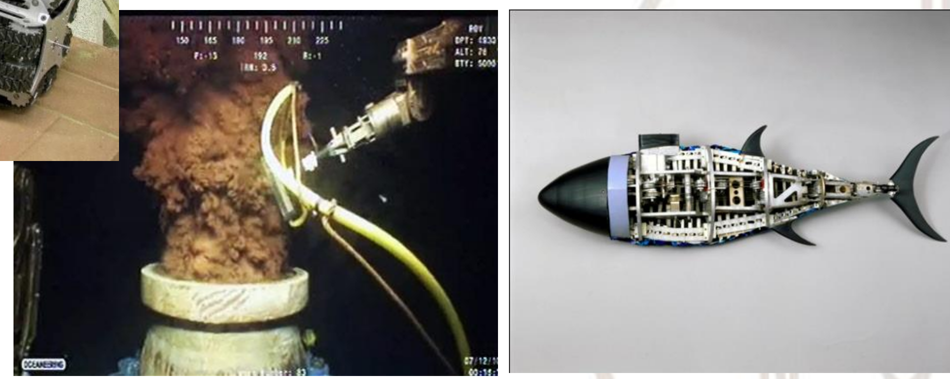
Scuola Superiore Sant'Anna

Robots outside factories…

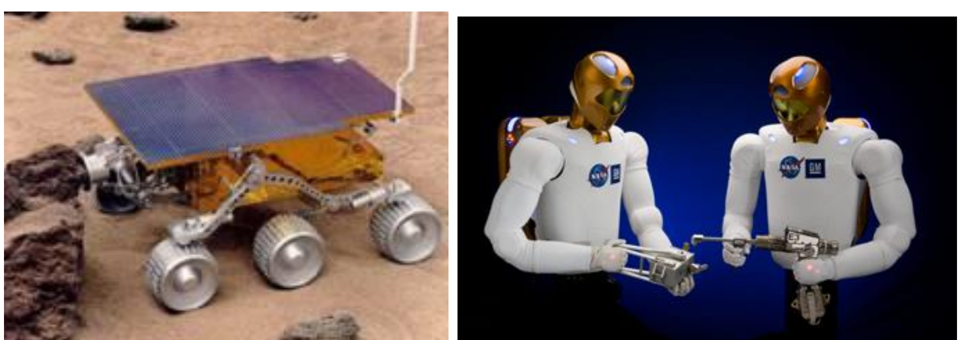
…having to operate in the real world, they need to manage uncertainties and to react to changes in the environment

Biological systems represent an excellent source of inspiration

Rescue



Underwater



Space

- **Unstructured environment**
- Perception
- Reactive behaviour
- Workspace shared with human beings

Bioinspiration: need soft robot bodies

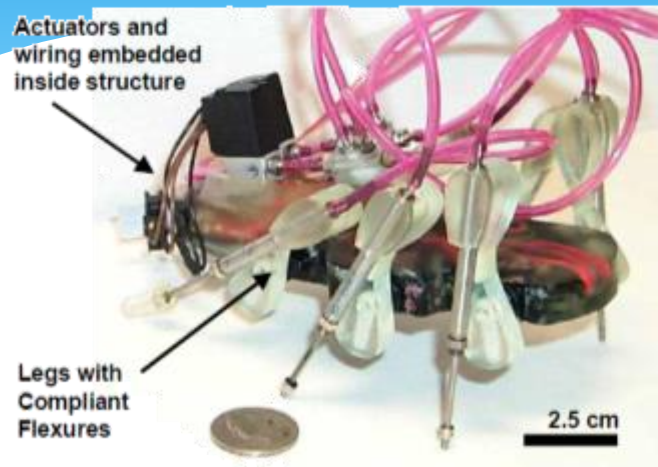
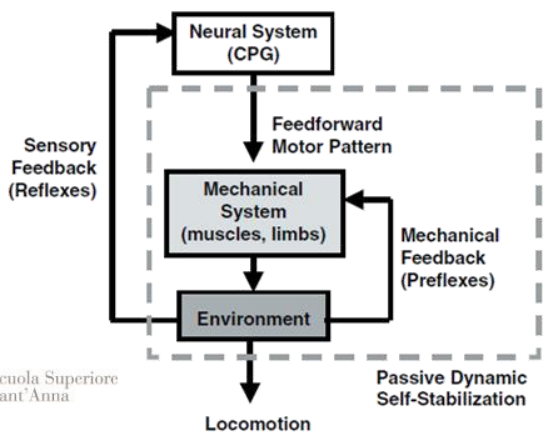
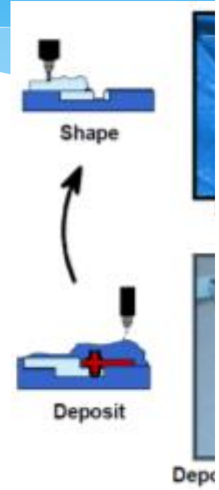


Figure 1. "Sprawlita", a dynamically-stable running hexapod based on functional principles from biomechanical studies of the cockroach. The prototype was fabricated using Shape Deposition Manufacturing and is capable of speeds of approximately 3 body-lengths per second.





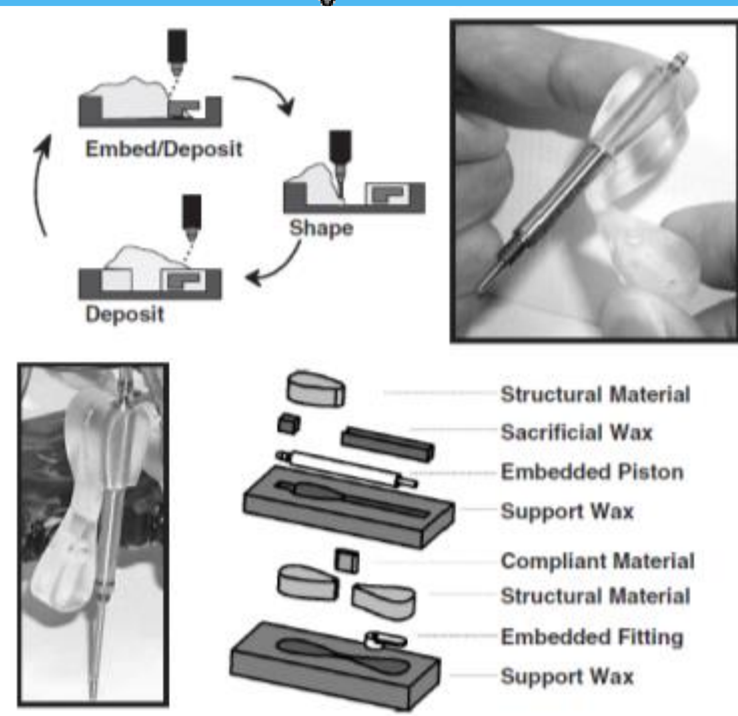


Fig. 7. Process plan for the robot legs. The figure shows the alternating layers of hard and soft material and embedded components used to make the compliant legs.

Shape Depo-
lanufacturing
isists of alter-
les of mate-
osition and
he hexapod's
wiring were
inside the
f the body. As
the figure,
first placed in
geometry of
us step, and
ed by depos-
rial in the

J.G. Cham, S.A. Bailey, J.E. Clark, R.J. Full, M.R. Cutkosky, "Fast and Robust: Hexapedal Robots via Shape Deposition Manufacturing", *The International Journal of Robotics Research*, Vol. 21, No. 10–11, 2002, pp. 869-882.

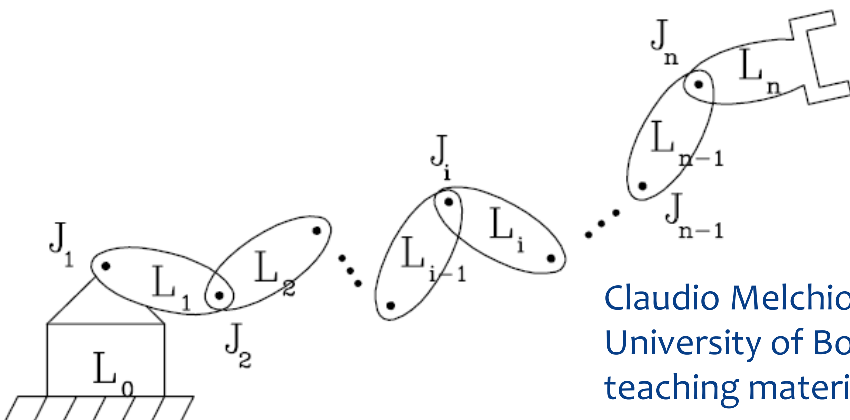
Few fundamental definitions of robot

Kinematic Model

Homogeneous Transformations are used for the definition of the kinematic model.

A robotic manipulator is a mechanism composed by a chain of rigid bodies, the *links*, connected by *joints*.

A *reference frame* is associated to each link, and homogeneous transformations are used to describe their relative position/orientation.



Claudio Melchiorri, University of Bologna, teaching material

The robot arm is a serial **chain** of three **rigid bodies** called robot segments.

T. Bajd et al., *Robotics*, Springer, 2010

Most theories and techniques for robot control are based on the fundamental assumption that a robot is a kinematic chain of **rigid links**.

How to control a soft robot?

WIKIPEDIA
The Free Encyclopedia

- Main page
- Contents
- Featured content
- Current events
- Random article

Robot kinematics

From Wikipedia, the free encyclopedia

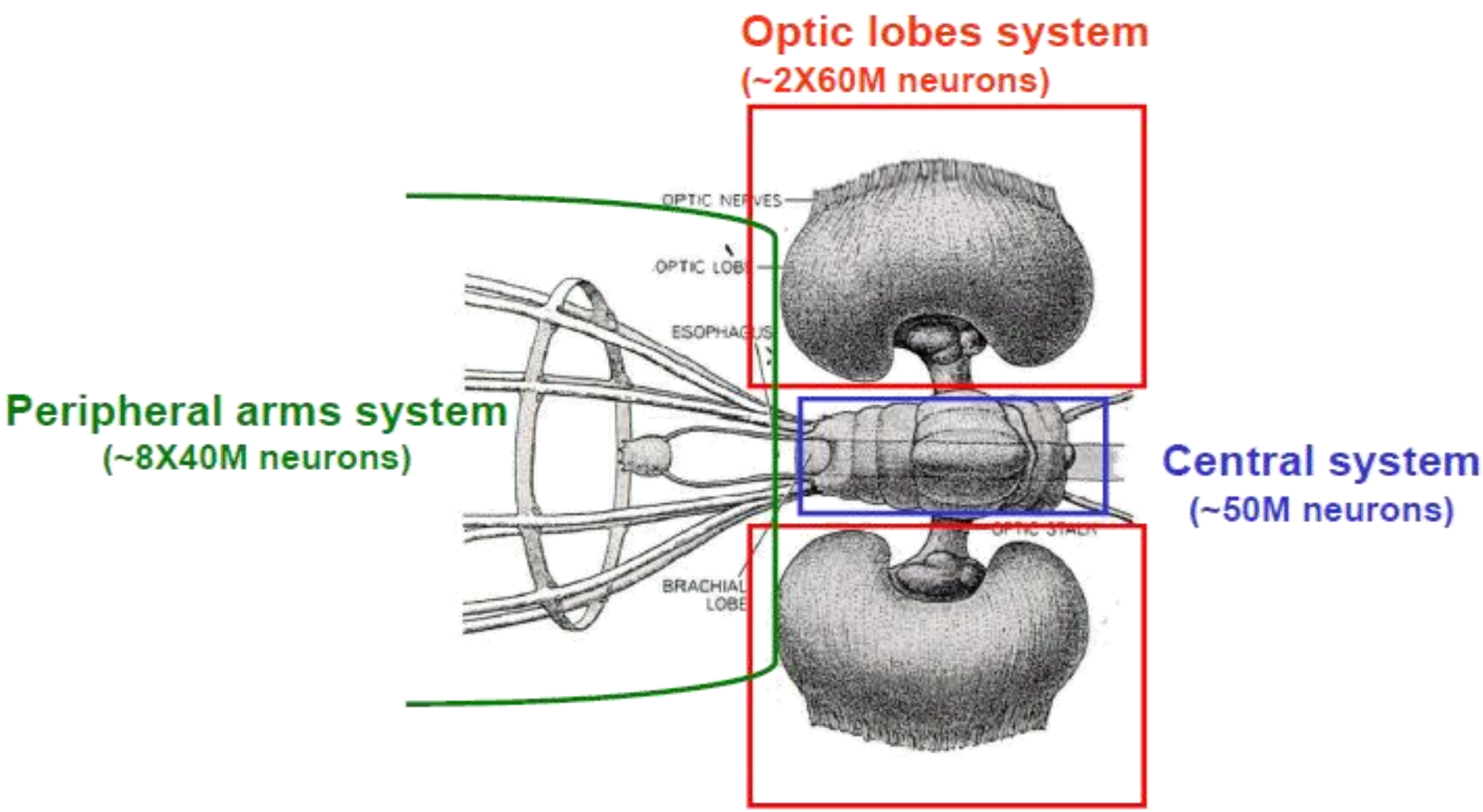
Robot kinematics applies geometry to the study of the movement of multi-degree of freedom kinematic chains that form the structure of robotic systems.[1][2] The emphasis on geometry means that the links of the robot are modeled as rigid bodies and its joints are assumed to provide pure rotation or translation.

Robot kinematics studies the relationship between the dimensions and connectivity of kinematic chains and the position, velocity and acceleration of each of the links in the robotic system, in order to plan and control movement and to compute actuator forces and torques. The relationship between mass and inertia properties, motion, and the associated forces and torques is studied as part of robot dynamics.

What an octopus can teach us:

1. we don’t need ‘bones’
2. we don’t need much central processing for control

The octopus' nervous system is composed of three anatomical and functional sub-systems



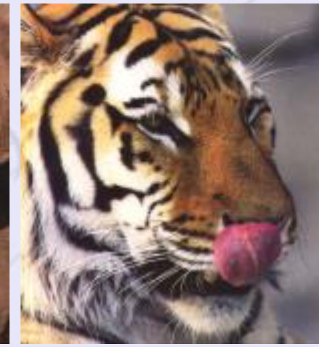
From Benny Hochner

The octopus solutions:

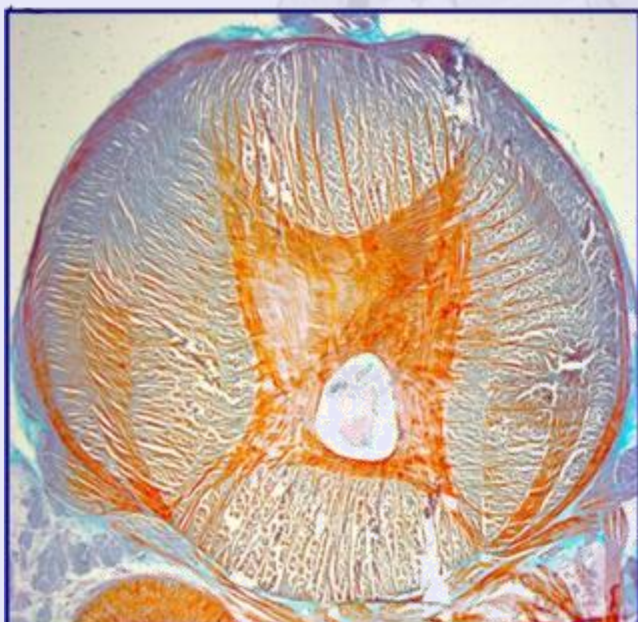
1. Muscular hydrostats: modifiable skeletons, variable stiffness

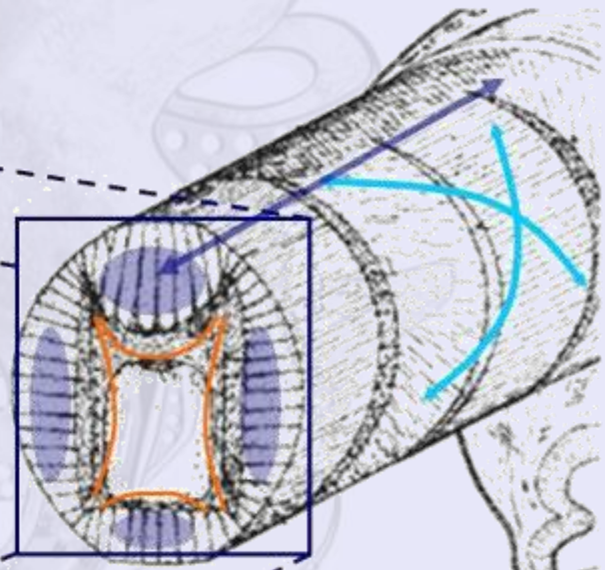
The octopus muscular hydrostat

Constant volume during contractions



- Longitudinal muscles
- Transverse muscles
- Oblique muscles





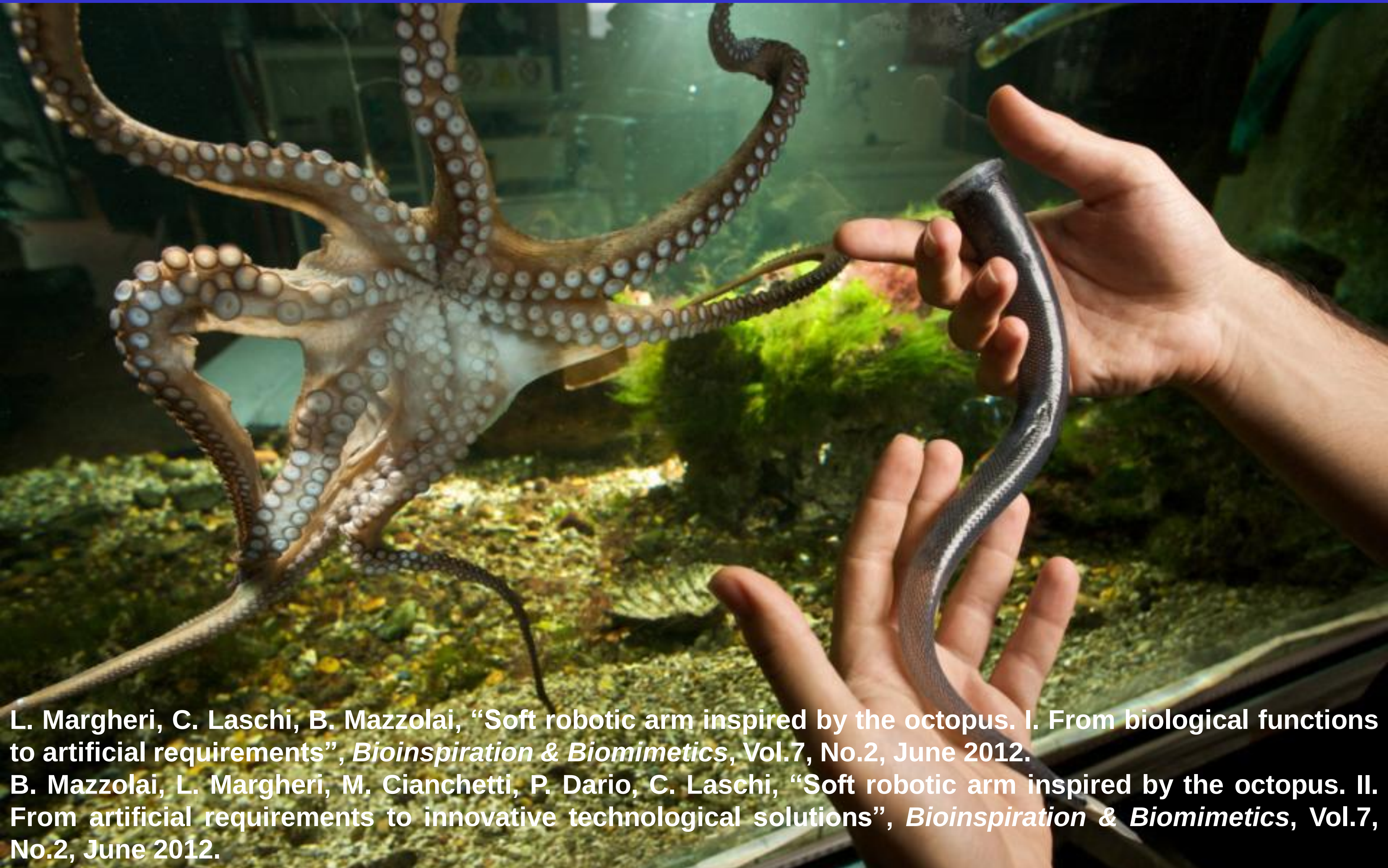
Muscular system as a modifiable skeleton

The octopus solutions:

1. Muscular hydrostats: modifiable skeletons, variable stiffness
2. Distributed control, embodied intelligence, or morphological computation

THE BIOROBOTICS INSTITUTE
Scuola Superiore Sant'Anna

From biology to robotics



L. Margheri, C. Laschi, B. Mazzolai, "Soft robotic arm inspired by the octopus. I. From biological functions to artificial requirements", *Bioinspiration & Biomimetics*, Vol.7, No.2, June 2012.

B. Mazzolai, L. Margheri, M. Cianchetti, P. Dario, C. Laschi, "Soft robotic arm inspired by the octopus. II. From artificial requirements to innovative technological solutions", *Bioinspiration & Biomimetics*, Vol.7, No.2, June 2012.

Biomimetics: smart solutions from Nature

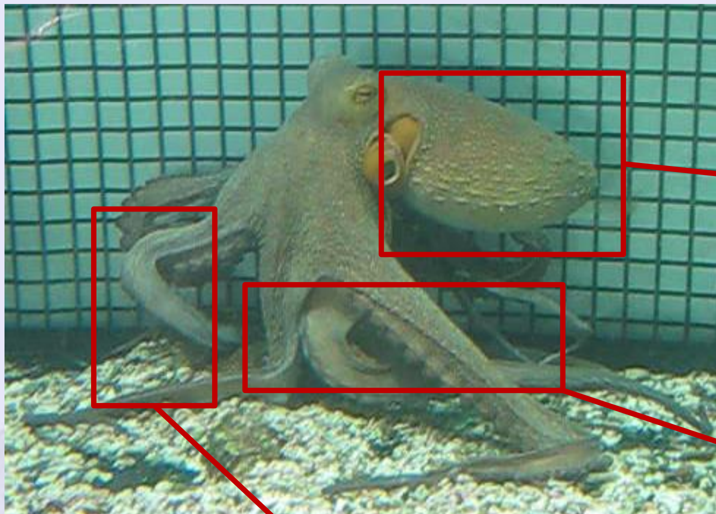
Nevertheless... Natural selection is not Engineering

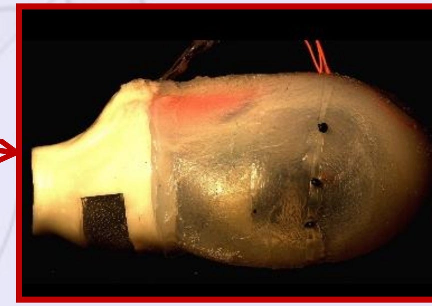
Organisms that are capable of surviving are not necessarily **optimal** for their technical performance. They need to survive long enough to reproduce. **Models are never complete or correct: need to interpret with caution.**

"We think blind copying is exactly what you don't want to do," says Robert Full, a biologist at the University of Berkeley, California. *"You will fail miserably, because nature is way too complex."*

One cannot **simply copy** Nature, but rather carefully **choose** Nature’s behaviour of interest, and **extract** the underlying **key principle** at a level of description that is actually possible to implement.

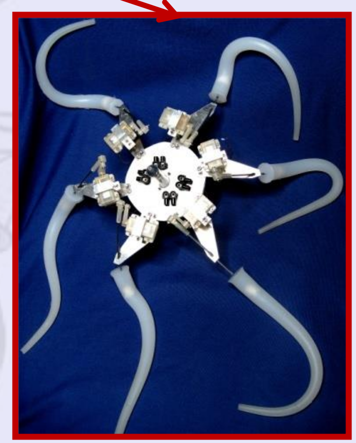
What is special in the octopus





Swimming

Manipulation



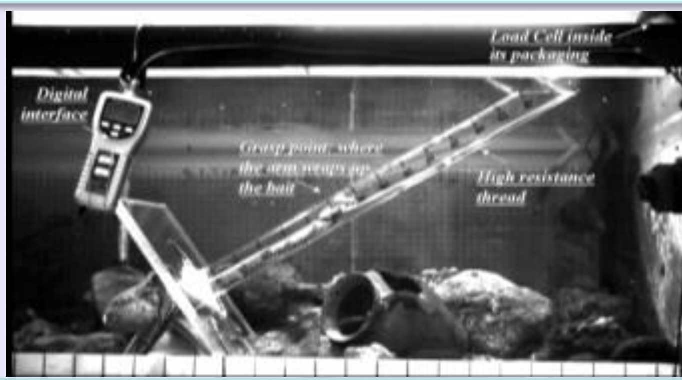
Locomotion

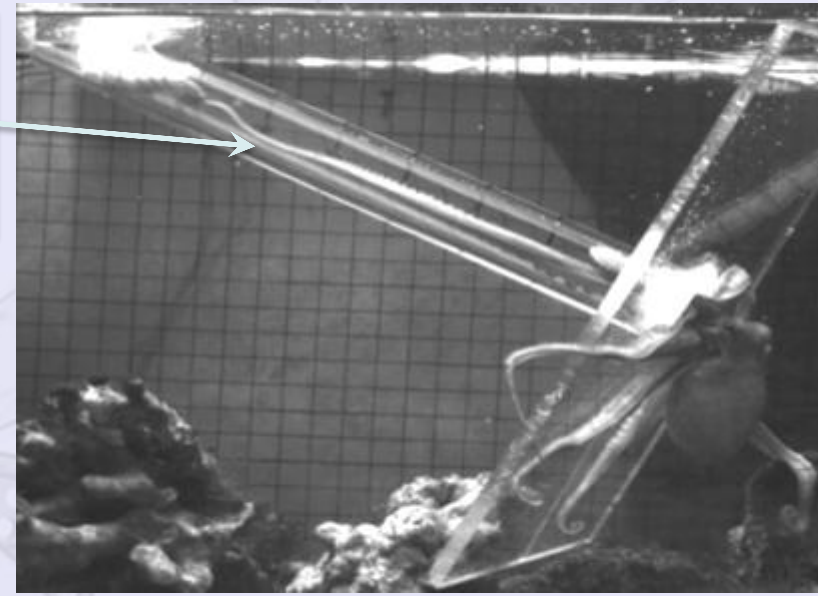
Measurements and analysis of the octopus arm

Results on Octopus Biomechanics

Arms Elongation :

70% of arms mean elongation corresponding to 23% of diameter reduction



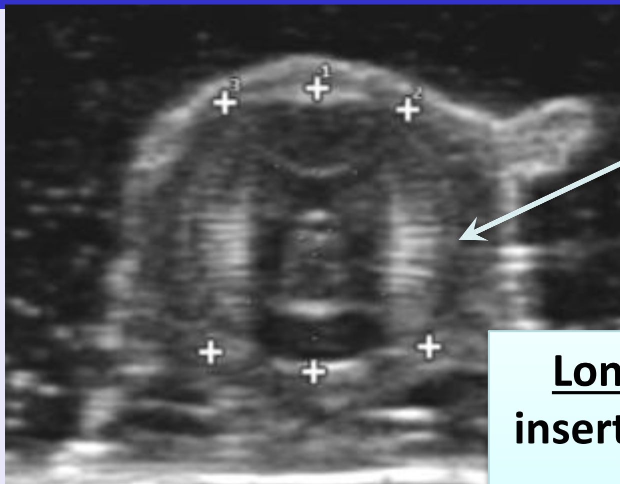


Arms Force :

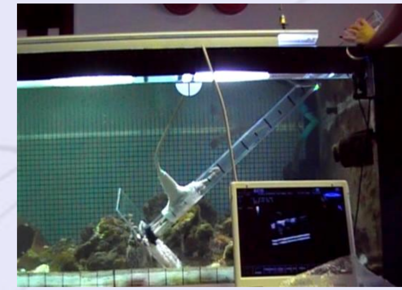
Max Pulling Force	Mean Pulling Force	Grasp Point Position	Contraction Time
49.8 N @ 400 mm (m=1600g) 28.6 N @ 200 mm (m=476g)	40N with arm length 400 mm	0.75 of total arm length	1-2 sec

Margheri L., Mazzolai B., Ponte G., Fiorito G., Dario P., Laschi C. (2010) Methods and tools for the anatomical study and experimental in vivo measurement of the Octopus vulgaris arm for biomimetic design, IEEE RAS / EMBS International Conference on Biomedical Robotics and Biomechatronics (BioRob 2010), Tokyo, Japan.

Measurements and analysis of the octopus arm



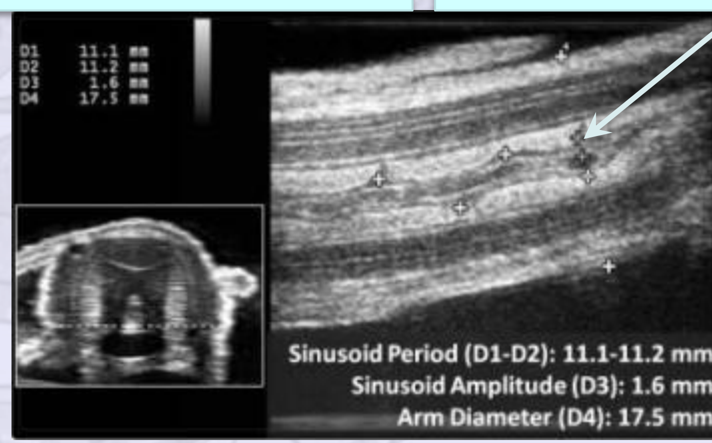
Results on Octopus Anatomy



<u>Transverse Muscles</u>:
small decrease in diameter allows large elongation (constant volume property)

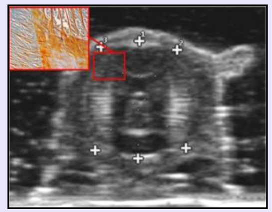
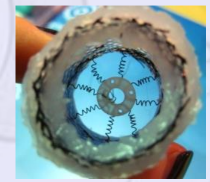
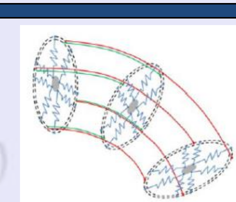
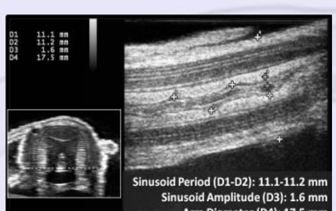
<u>Longitudinal Muscles</u>:
insertion points along the arm allow local bending

<u>Nerve cord</u>:
sinusoidal arrangement allows arms large elongation without mechanical constraint



L. Margheri, G. Ponte, B. Mazzolai, C. Laschi, G. Fiorito, “Non-invasive study of *Octopus vulgaris* arm morphology using ultrasound”, *The Journal of Experimental Biology*, Vol.214, 2011, pp.3727-3731.

From biology to robotics

		Biological Specification (*Octopus vulgaris*)	Robotic Solution and Performance
Transverse Muscles	**Design Arrangement**		 **Patent pending**
	Mechanical performance	70% of arms mean elongation corresponding to 23% of diameter reduction	Input to model for the design of the SMA: · NiTi Alloy mechanical properties · Wire diameter · Average spring diameter · Number of coils · Heat treatments
Longitudinal Muscles	**Design Arrangement**		
	Mechanical performance	**Max Pulling Force**: 49.8N @ 400mm (m=1600g) 26.8 @ 200mm (m=476g) **Mean Pulling Force**: 40 N with arm length 400mm (~100g) **Time**: 1-2 sec.	· Longitudinal cables · sheaths to reduce friction and avoid silicon damages · Calibration parameters (*t, F*)
Grasp Point Position		0.75 of total arm length	End effector position and active arm length
Nerve Cord Arrangement	**Design Arrangement**	 Sinusoidal arrangement at the arm rest length while has a distension during the elongation	Wire sinusoidal arrangement 

Margheri et al., *Bioinspiration & Biomimetics*, 2012.
Mazzolai,et al., *Bioinspiration & Biomimetics*, 2012.

Octopus-like robot arm

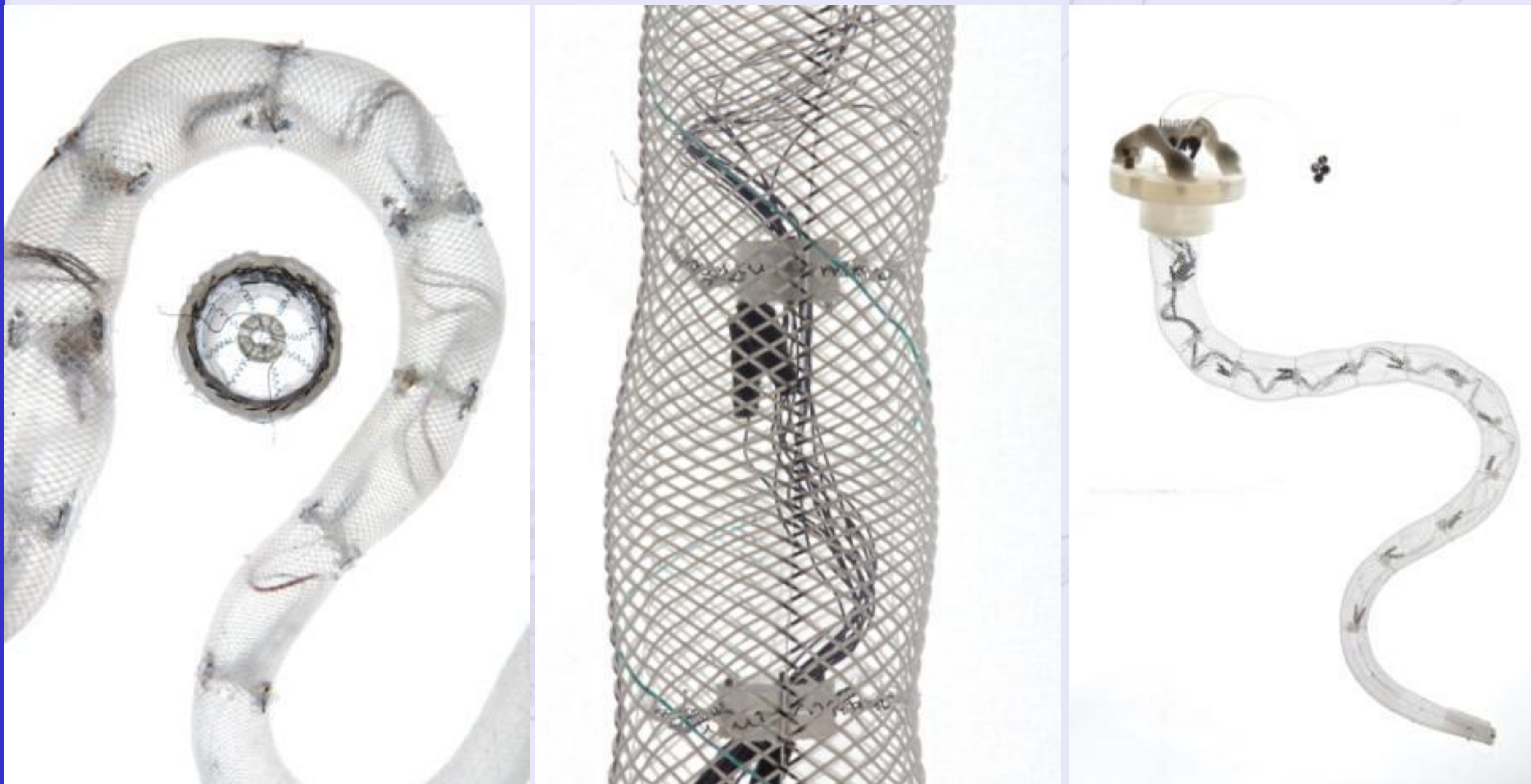
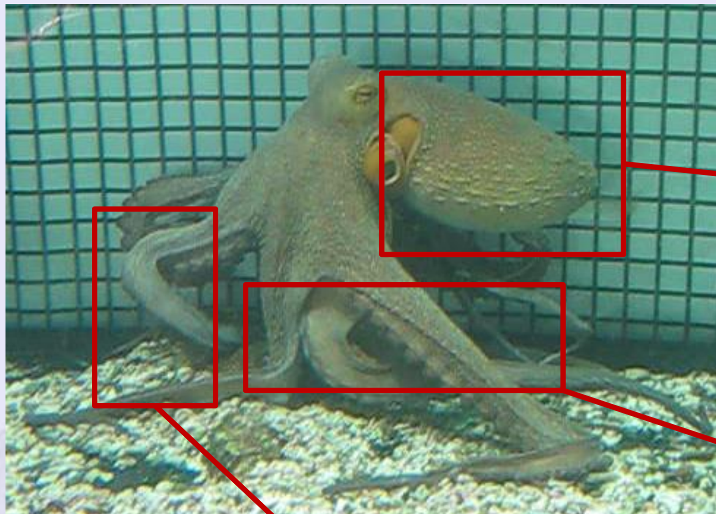


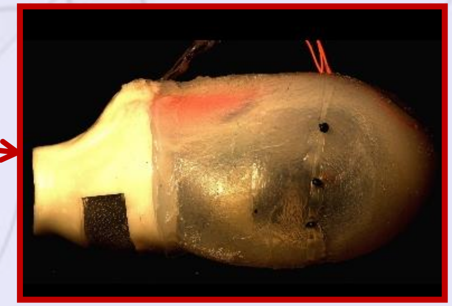
Photo by Massimo Brega, The Lighthouse

4 longitudinal cables, from base to tip

12 transverse actuators, 8 SMA springs each, uniformly distributed along the arm

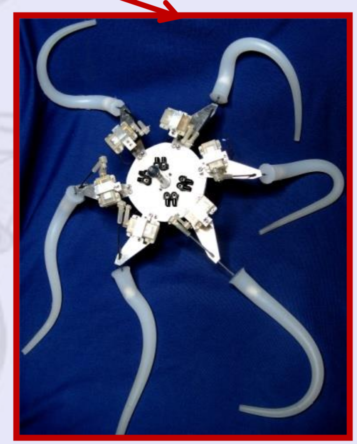
What is special in the octopus





Swimming

Manipulation

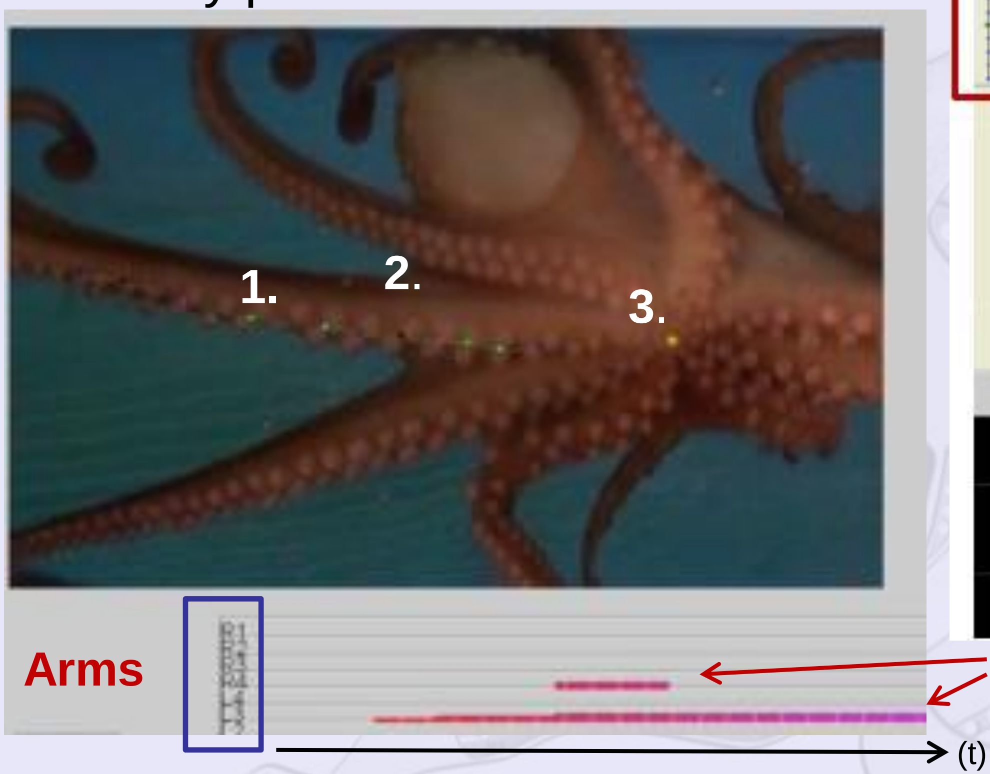


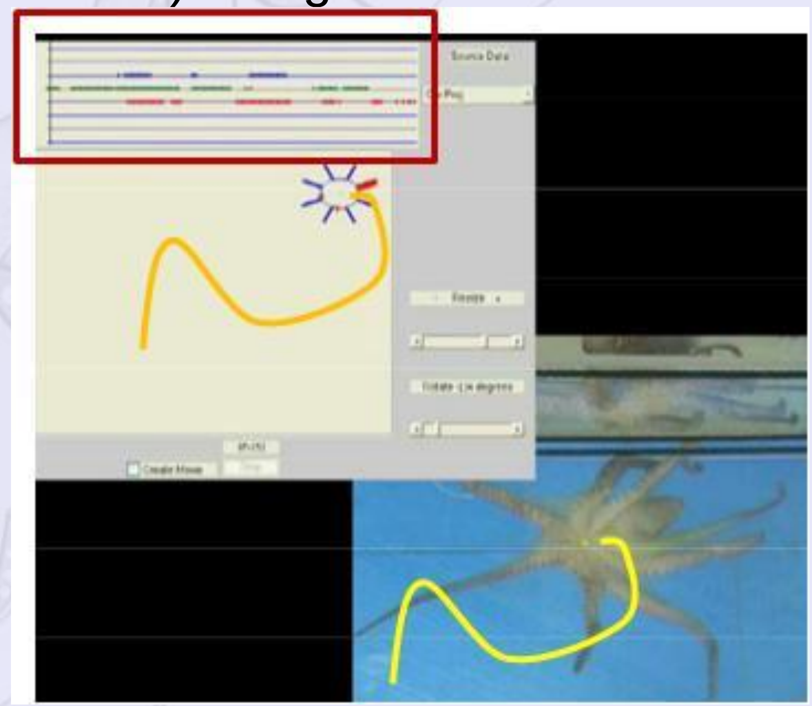
Locomotion

Studying crawling in the octopus

Octopus recorded from underneath, during crawling, using a tank with a transparent bottom and a mirror, to analyse:

1. which suckers were attached to the ground
2. how much the arm (that had suckers attached) elongates
3. the body position over time



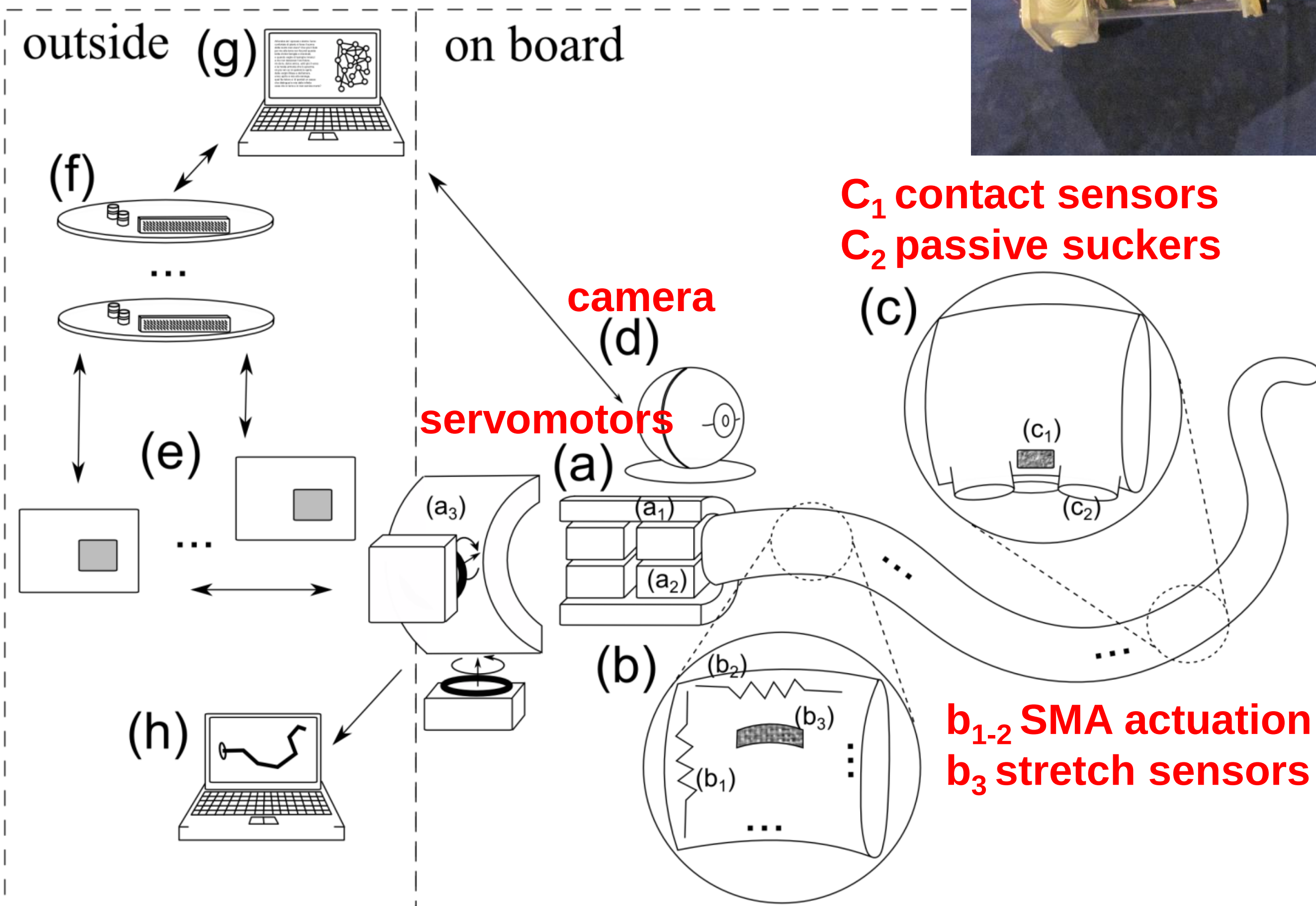


Pink lines show when the arm elongates, with suckers attached to the ground

M. Calisti, M. Giorelli, G. Levy, B. Mazzolai, B. Hochner, C. Laschi, P. Dario, "An octopus-bioinspired solution to movement and manipulation for soft robots", *Bioinspiration & Biomimetics*, Vol.6, No.3, 2011, 10 pp.

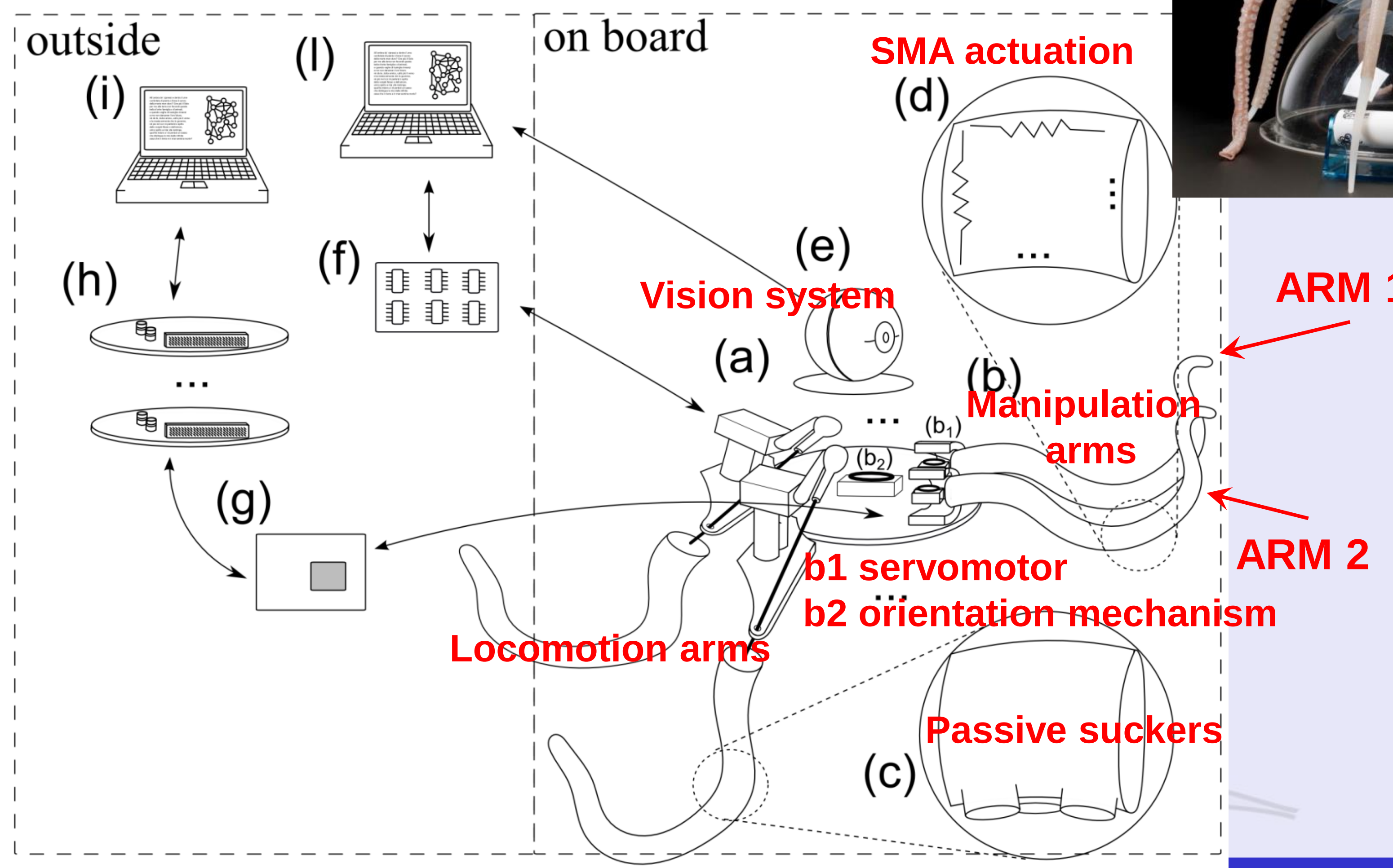
OCTOPUS Robot

Octopus-like robot arm

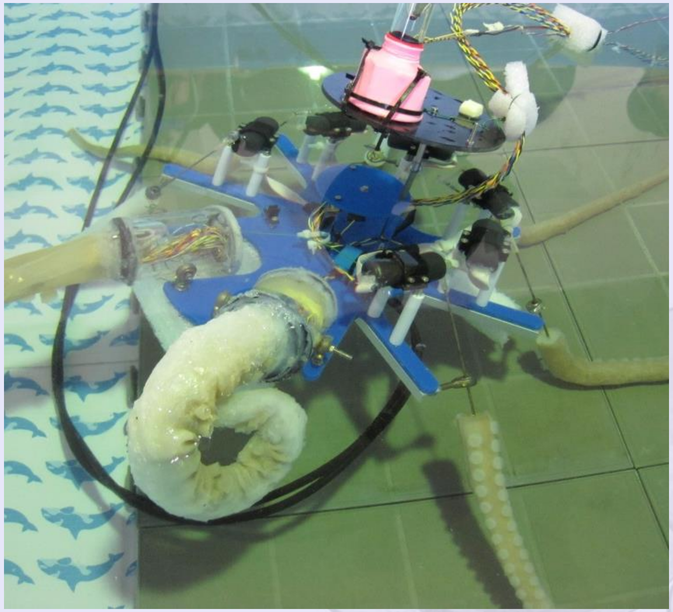


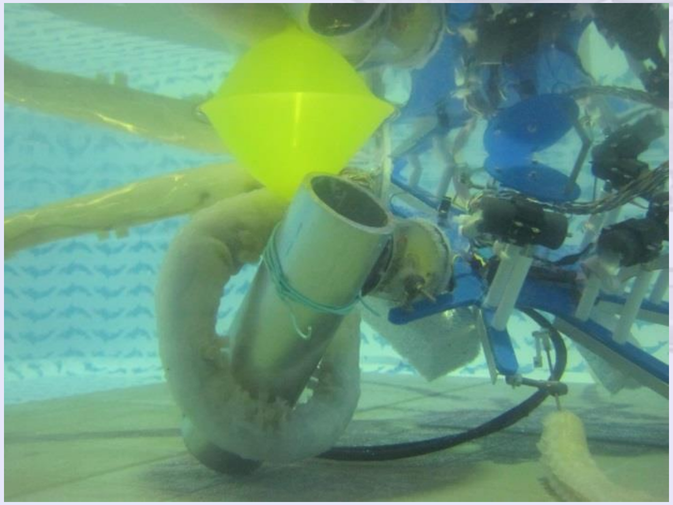
OCTOPUS Robot

Multi-arm robotic octopus prototype



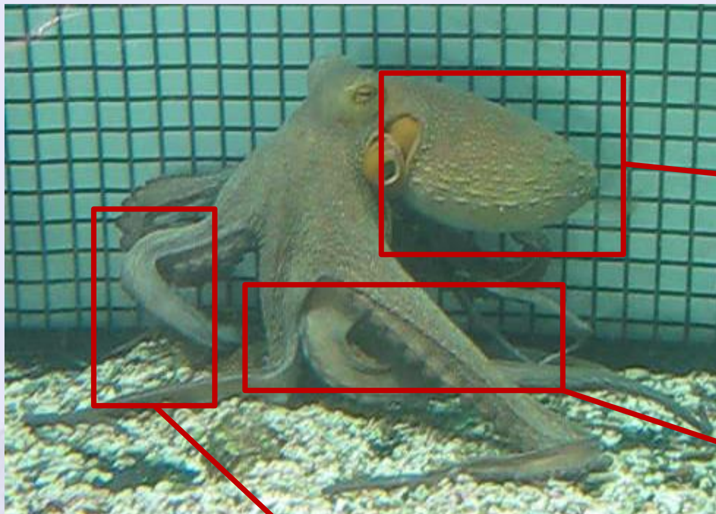
Multi-arm robotic octopus prototype

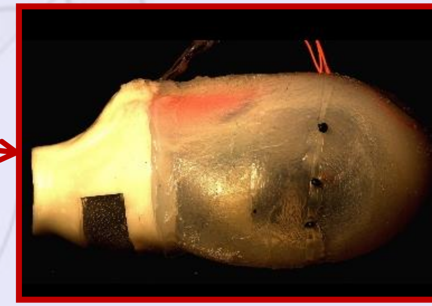




OCTOPUS

What is special in the octopus





Swimming

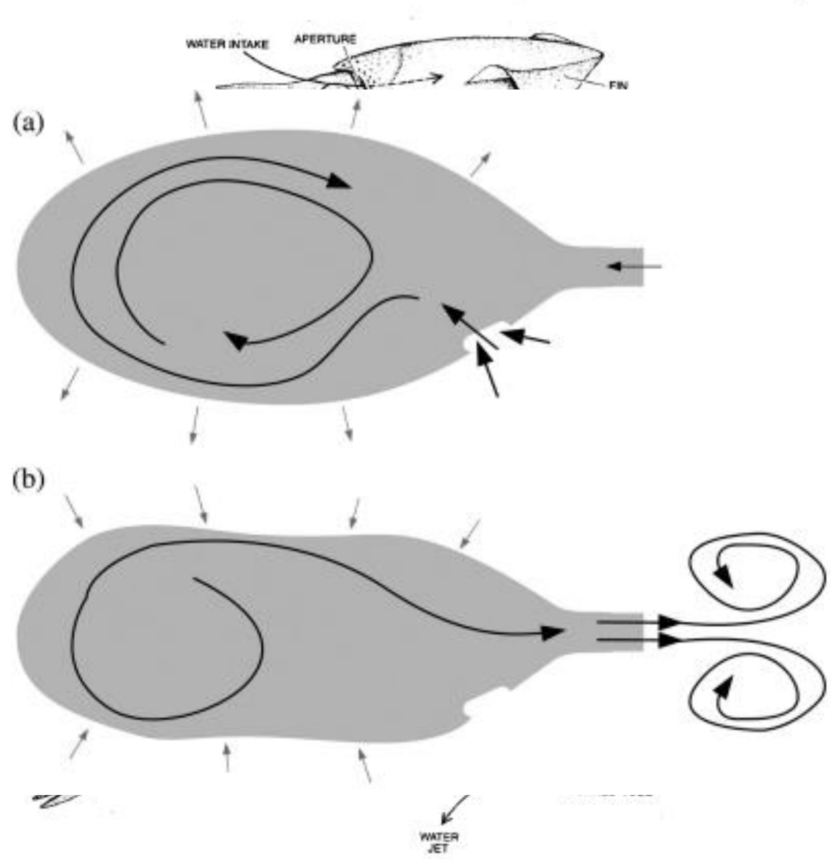
Manipulation

Locomotion

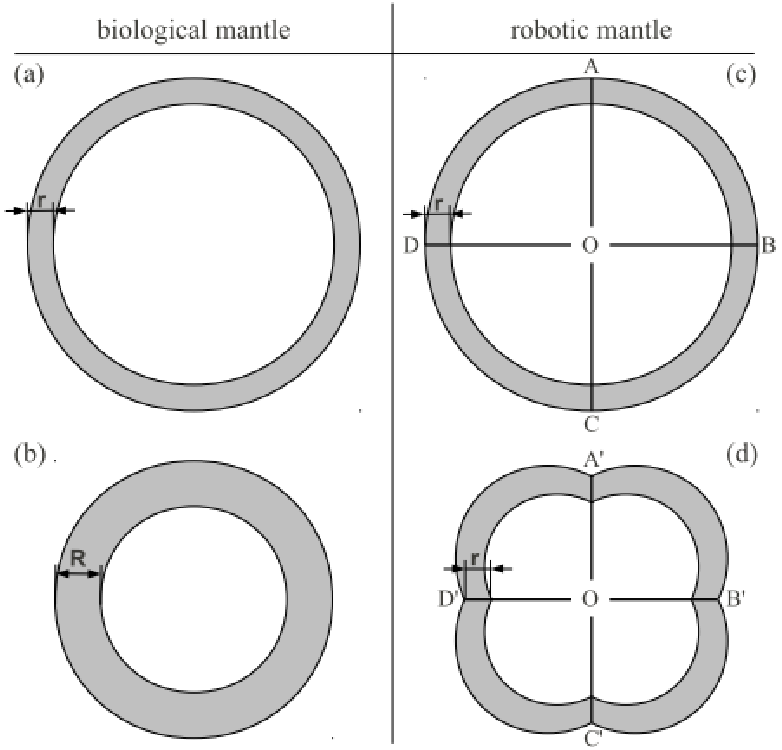
OCTOPUS

Pulsed-jet propulsion in cephalopods

How does a cephalopod swim?



How do we translate this into a soft vehicle?



Giorgio Serchi F., Arienti A. and Laschi C. (2013) Biomimetic Vortex Propulsion: Toward the New Paradigm of Soft Unmanned Underwater Vehicles, *IEEE/ASME Transactions on Mechatronics*, 18(**2**), pp. 484-493

Modeling pulsed-jet thrusting

$$M_{tot}\frac{dU}{dt} = -\frac{1}{2}C_d U^2 A_{ref}\rho - X_{AM}\frac{dU}{dt} + q\frac{dm}{dt},$$

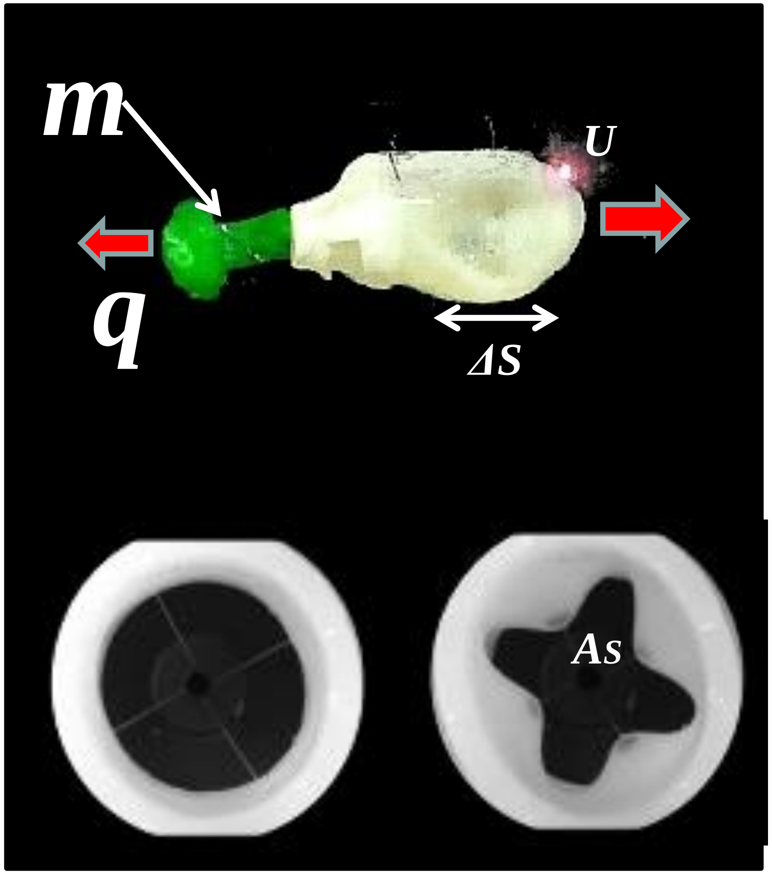
$$\frac{dm}{dt} = \rho\frac{d}{dt}\left(\Delta S A_s\right)$$

$$\Delta S = C_s c.$$

$$q = C_f\frac{1}{\rho A_N}\frac{dm}{dt} - U,$$

$$q = \frac{C_f}{A_N}\left[\frac{d}{dt}\left(\Delta S A_s\right)\right]^2 - U.$$

$$q\frac{dm}{dt} = \left\{\frac{C_f}{A_N}\left[\frac{d}{dt}\left(\Delta S A_s\right)\right]^2 - U\right\}\left[\rho\frac{d}{dt}\left(\Delta S A_s\right)\right]$$

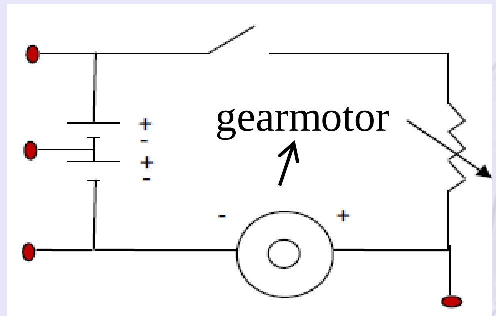


Prototype of the soft swimming robot

❖ <u>MANTLE</u>

- hollow cylinder in silicone ECOFLEX 00-30
- jet output nozzle
- passive valve

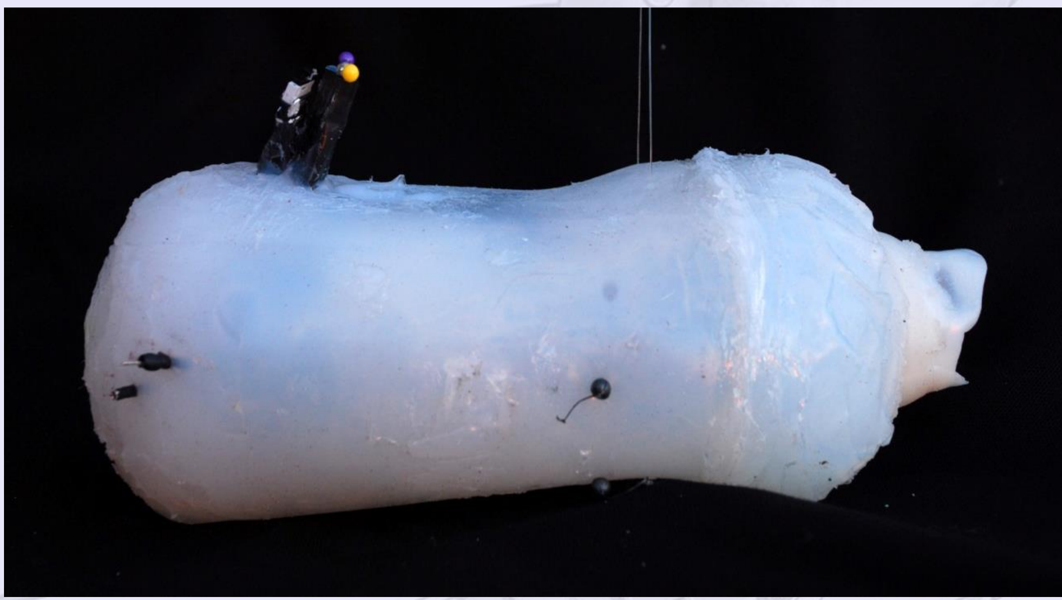
❖ <u>ELECTRIC CIRCUIT</u>



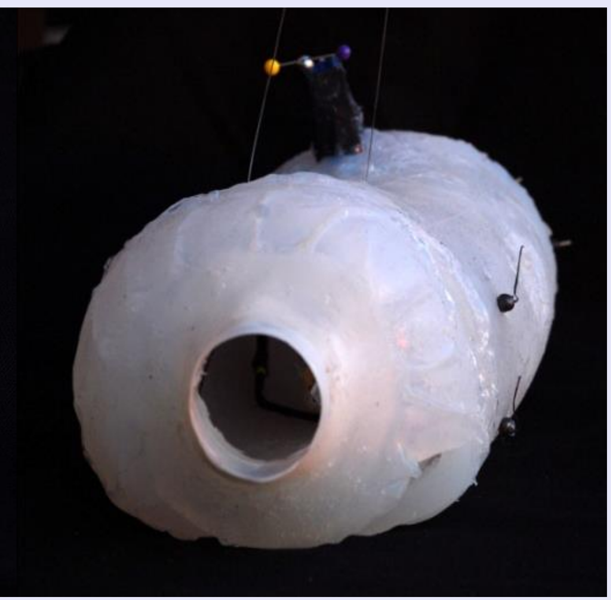
❖ <u>ACTUATION COMPONENTS</u>

- Polymorph structure
- rod adapted to the shaft
- 4 nylon cables

<u>SIDE VIEW</u>



<u>BACK VIEW</u>



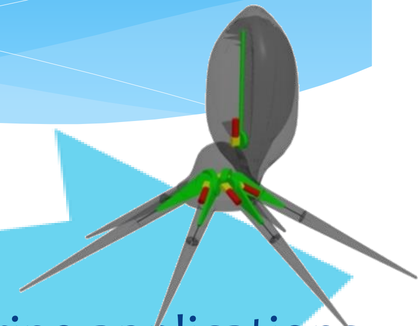
Computational Fluid Dynamics Aided Design of the Propulsion Systems of a Bioinspired Robot Octopus - OctoProp (Marie Curie Reintegration Grant**)**

Start date: March 1st, 2011; Duration: 3 years

Principal Investigator: Francesco Giorgio Serchi, Coordinator: Cecilia Laschi (SSSA)

Soft Robot applications

Biomedical applications: the STIFF-FLOP endoscope



Industrial project with STMicroelectronics and SAES Getters

Marine applications: the PoseiDRONE soft underwater robot

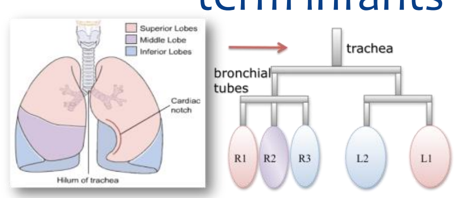
The initial challenge: can we build robots with soft materials?

What is it for?

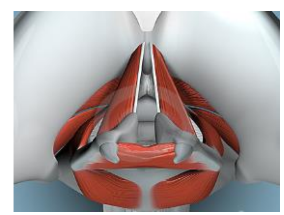
The OCTOPUS robot

Realistic simulators of body parts

Breathing lungs of pre-term infants



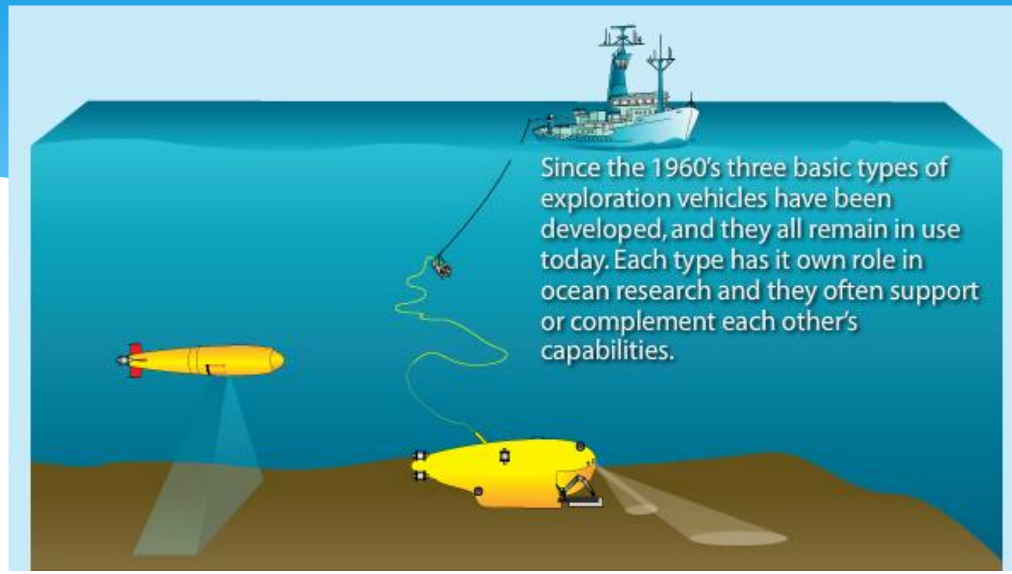
Robotic larynx



THE BIOROBOTICS INSTITUTE

Scuola Superiore Sant'Anna

Underwater robots

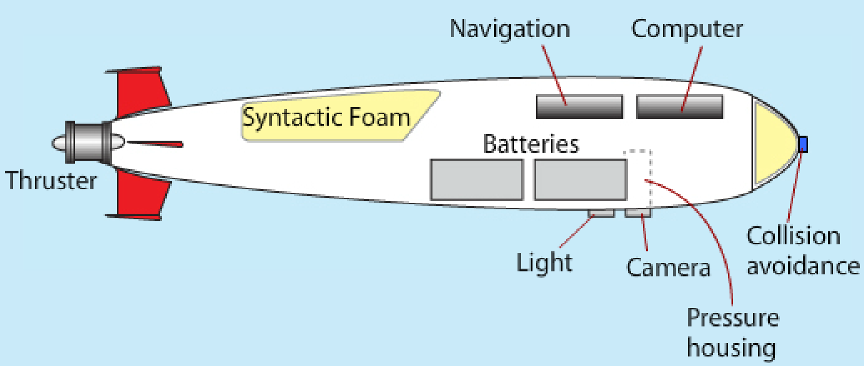


AUV

***A**utonomous* ***U**nderwater* ***V**ehicle*

Has:
- Thrusters
- Batteries
- Navigation
- Onboard computer
- Pressure housing

Does not have:
- Tether
- Manipulator arm
- Sample basket
- Personnel sphere

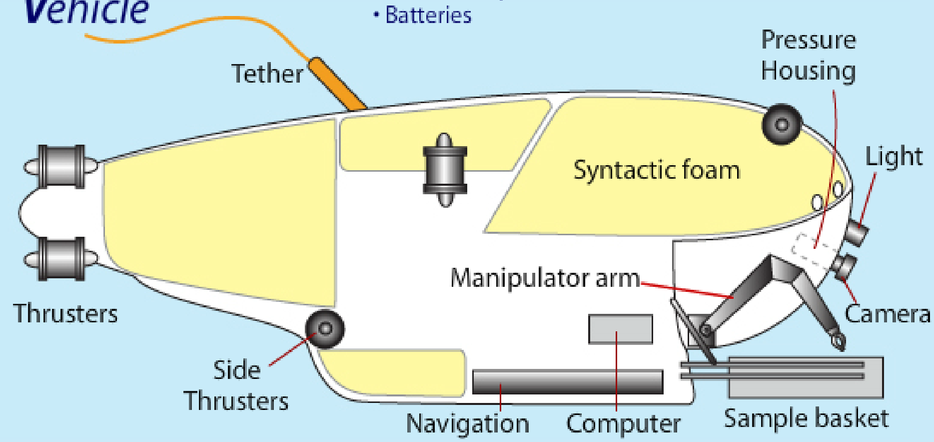


ROV

***R**emotely* ***O**perated* ***V**ehicle*

Has:
- Thrusters
- Navigation
- Sample basket
- Tether
- Manipulator arm
- Onboard computer
- Cameras

Does not have:
- Personnel sphere
- Batteries



What are ROV/AUV good at?

PETROLEUM INDUSTRY

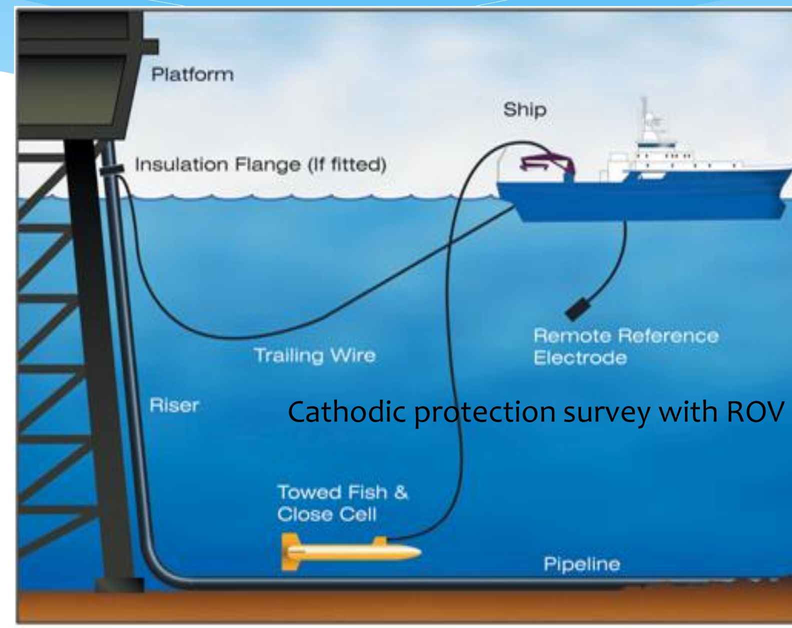
* Measurements
  Cleaning sand and mud
* Bolt torquing
* Cable cutting

MILITARY INDUSTRY

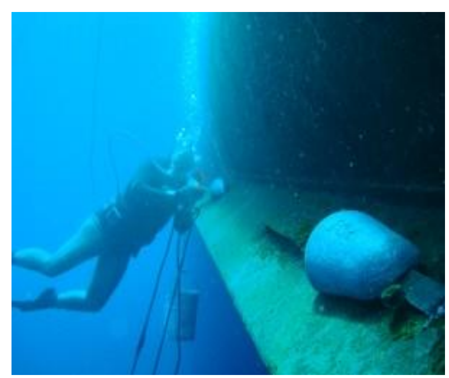
* Mine Countermeasures
* Salvage
* Torpedo recovery
* Accident investigation

ARCHEOLOGY

* Underwater excavations & site testing
* Underwater digital photography and videography
* Management of submerged cultural resource



Cathodic protection survey with ROV



THE BIOROBOTICS INSTITUTE

Scuola Superiore Sant'Anna

What are ROV/AUV not able to do?

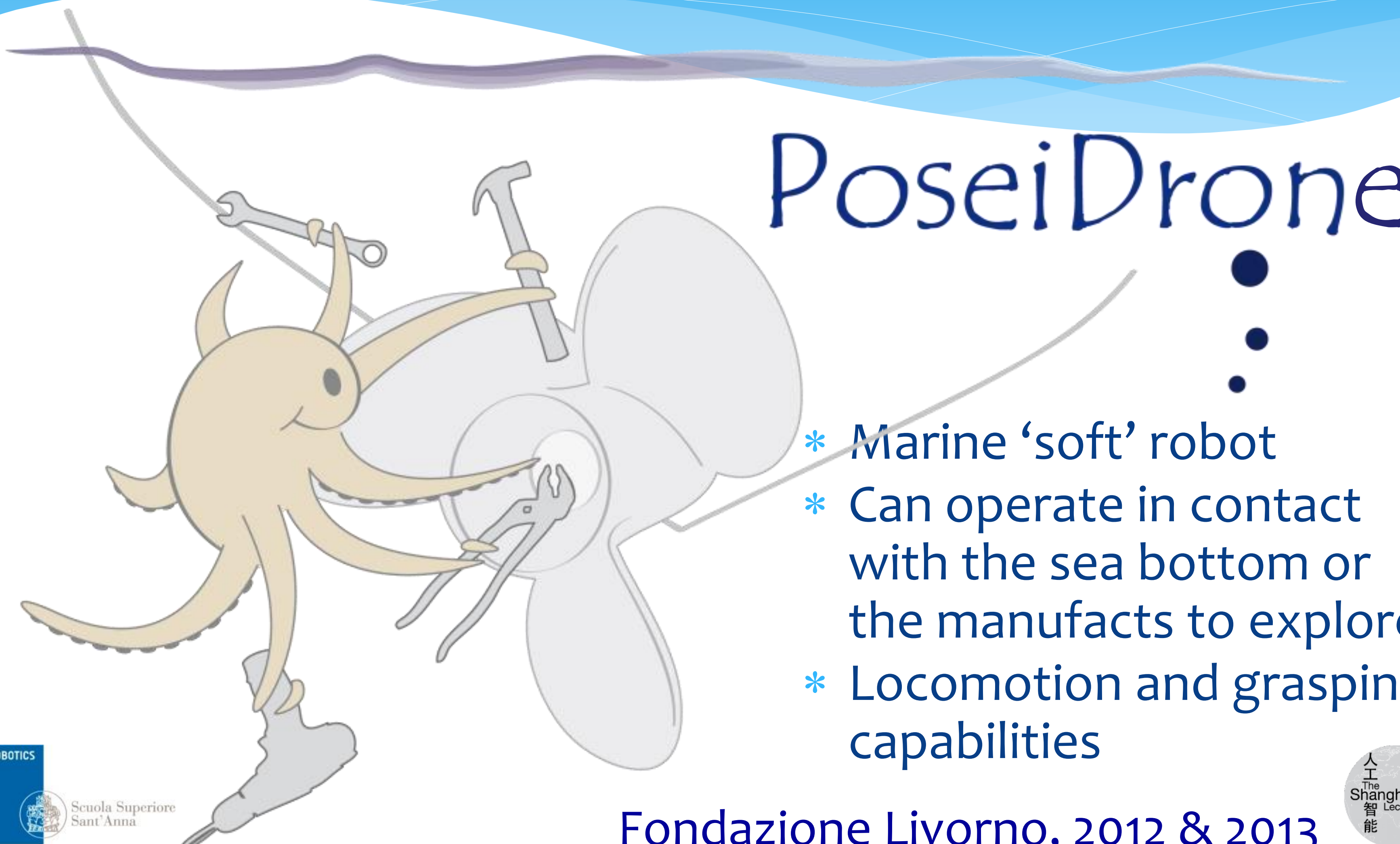
* Underwater painting
* Welding (dry or wet)
* Marine growth removal
* Mooring chain inspection
* Jetty inspection & maintainance
* Marine construction support
* Cropping and rebalancing of damaged propeller

Mainly provided by divers

Safe contact with the environment

THE BIOROBOTICS INSTITUTE
Scuola Superiore Sant'Anna

Soft Robotics for marine applications



* Marine 'soft' robot
* Can operate in contact with the sea bottom or the manufacts to explore
* Locomotion and grasping capabilities

Fondazione Livorno, 2012 & 2013

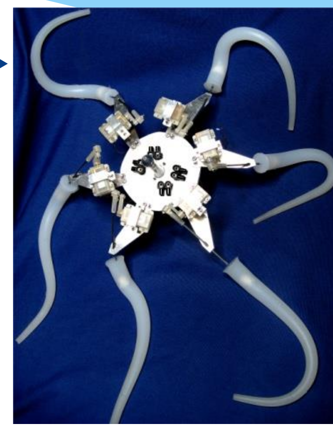
THE BIOROBOTICS INSTITUTE
Scuola Superiore Sant'Anna

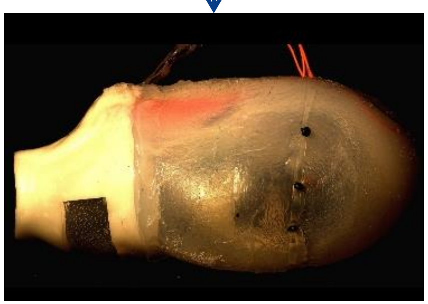
人工智能 The ShanghAI Lectures 上海授课

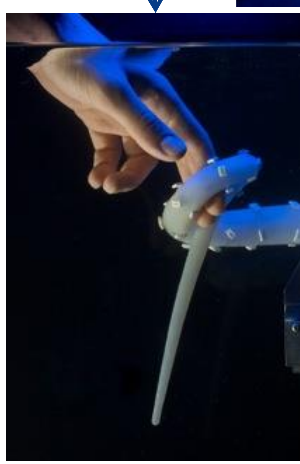
PoseiDrone Project: marine applications for the OCTOPUS robot

Fondazione Livorno, 2012 & 2013

* Crawling
* Grasping
* Pulsed-jet locomotion

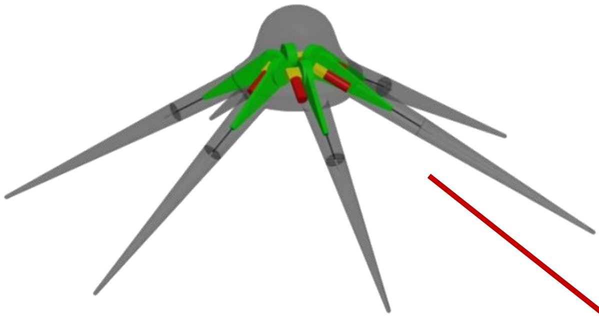


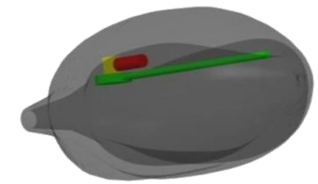




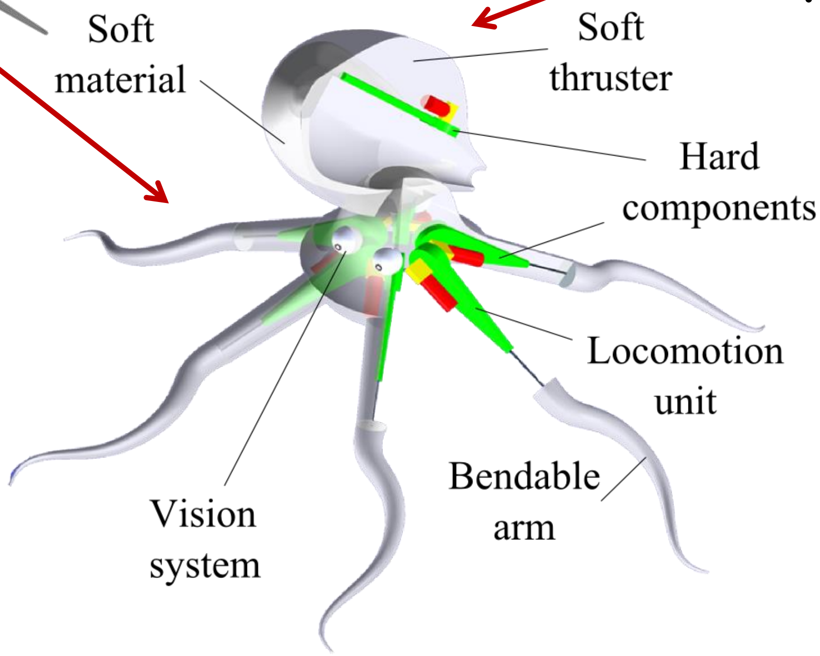
THE BIOROBOTICS INSTITUTE
Scuola Superiore Sant'Anna

Integrated Components: PoseiDRONE





- *F. Giorgio Serchi et al T-MECH 2013*
- *A. Arienti, F. Giorgio Serchi*
  Dispositivo di propulsione acquatica a gett
  pulsati
  Italian patent application, April 2012



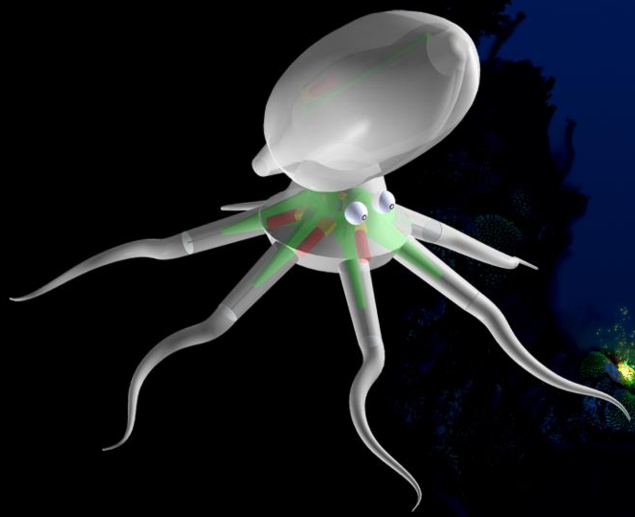
- *M. Calisti et al ICRA 2012*
- *M. Calisti, A. Arienti, M. Giorelli, C. Laschi, B. Mazzolai, P. Dario*
  Robot having soft arms for locomotion and grip purposes
  International patent application November 2011

- *A. Arienti et al OCEANS (Accepted)*

THE BIOROBOTICS INSTITUTE

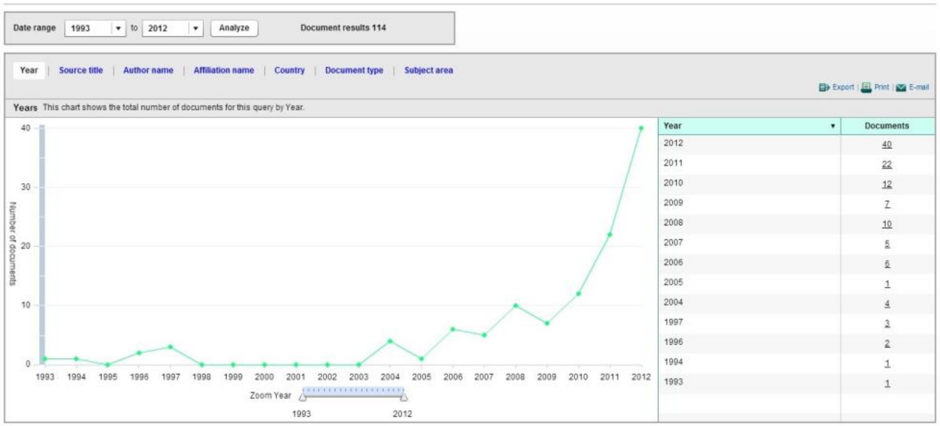
Scuola Superiore Sant'Anna

PoseiDRONE: a Soft Robot for a novel generation of Underwater Vehicles



Fondazione Livorno, 2012 & 2013

Soft Robotics: a growing research field at international level



Year	Documents
2012	40
2011	22
2010	12
2009	7
2008	10
2007	5
2006	6
2005	1
2004	4
1997	3
1996	2
1994	1
1993	1

Figure 2 Total number of papers by year with the words "soft robotics" in title, abstract or keywords

* IEEE-RAS TC on Soft Robotics
* FET-Open CA RoboSoft («A Coordination Action on Soft Robotics»)

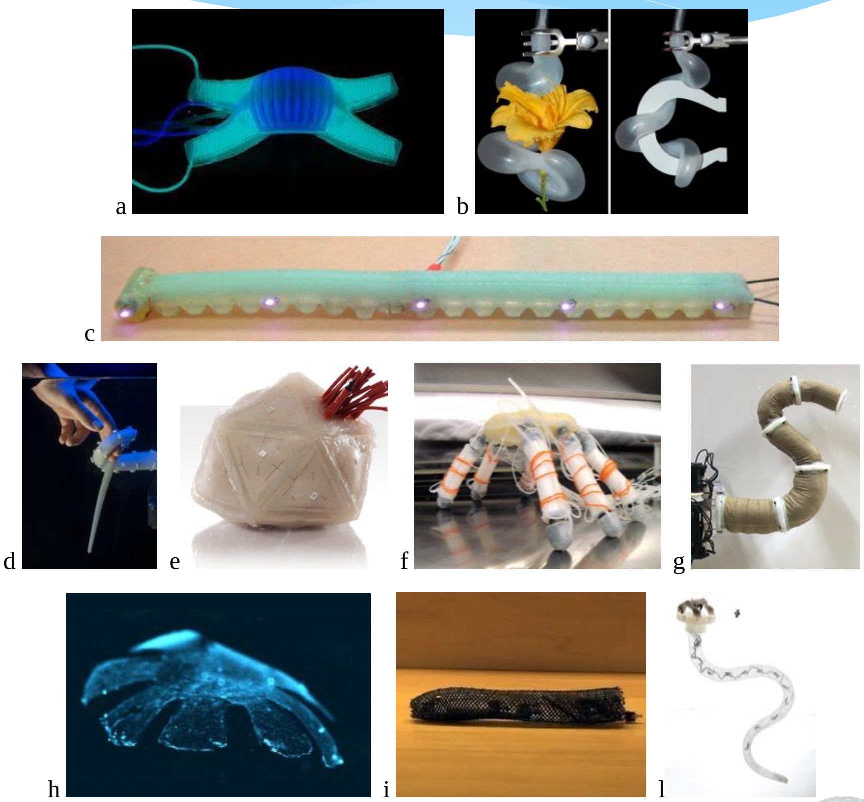


Figure 1: camouflage-able starfish-like soft robot (a); pneumatic tentacle-like soft manipulator (b); caterpillar-inspired soft robot (c); cable driven octopus-inspired soft manipulator (d); rolling soft robot (e); granular jamming based gripper (f); jammable manipulator (g); tissue-engineered jellyfish (h); Meshworm robot (i); flexible octopus-like robot arm (l) .

THE BIOROBOTICS INSTITUTE
Scuola Superiore Sant'Anna

Thanks

Photo by Massimo Brega, The Lighthouse

Soft Robotics Team:

- Paolo Dario
- Matteo Cianchetti
- Laura Margheri
- Marcello Calisti
- Francesco Giorgio Serchi
- Maurizio Follador
- Michele Giorelli
- Federico Renda
- Andrea Arienti
- Ilaria Baldoli
- Alessia Licofonte
- Francesco Rogai
- Serena Tricarico
- Mariangela Manti
- … our octopuses!

- CFD Octo-Prop, Marie Curie
- PoseiDRONE, Fondazione Livorno
- RoboSoft CA, FET-Open
- Smart-e, Marie Curie ITN

www.octopus-project.eu