ICT-2007.8.5
Embodied Intelligence
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Future and Emerging Technologies

OCTOPUS

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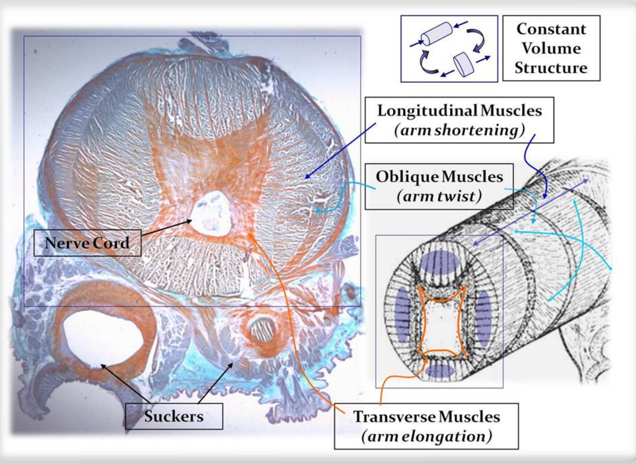
The octopus as a paradigm for Embodied Intelligence and as source of inspiration for Soft Robotics

What is special in the octopus

The octopus has **no rigid structures** and it can flexibly squeeze into very small apertures or adapt the shape of its body and arms to the environment.

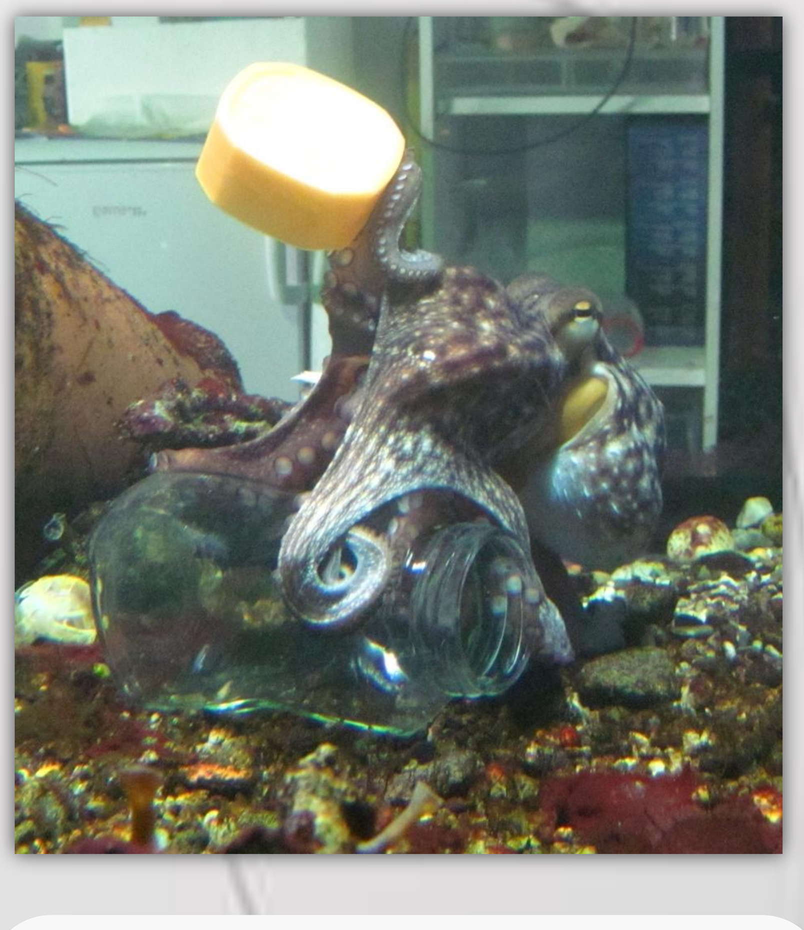
In the special muscular structure (***muscular hydrostat***) of the octopus arms, muscles are packed in a three-dimensional array, and have constant volume during movement.



By opposing or promoting the movement, muscles serves as modifiable skeleton, allowing the octopus to actively **control the stiffness** of its arms.

The octopus effectively uses the arms to locomote on the diverse substrates of the sea bottom and to reach, grasp and even manipulate objects with **unexpected precision**.

The control of this **large number of degrees of freedom** is highly distributed and is simplified by the use of stereotyped movements.
The octopus shows a rich behavioural repertoire, with also learning, memory and camouflage capabilities.



The 8 arms are a fascinating model of dexterity, with unique motor capabilities:

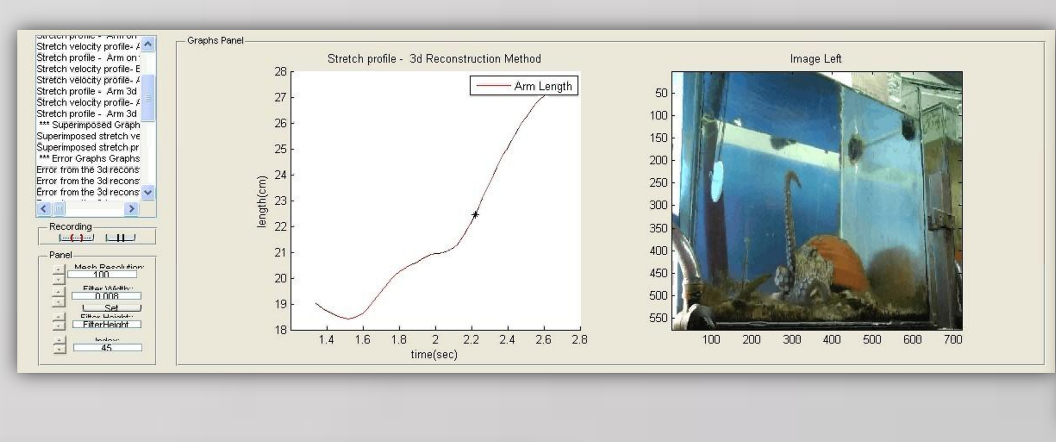
- **No rigid structures**: virtually **infinite** number of DOF
- **All-direction** bending
- 70% of **elongation** of each arm
- **Variable and controllable stiffness**
- 40N pulling **force** (1 arm, @3/4 of length)
- **Manipulation** capability with unexpected **dexterity**
- **Distributed control** (50x10^{6}neurons/arm, more than in the brain)

Need for quantitative data on the octopus anatomy, neurophysiology and biomechanics, to set the specifications for the design of the octopus-like robot

Bioengineering and biological methods are applied to study, measure and model octopus performance, with results of **new scientific data** beyond the state of the art, as well as **novel design principles and specifications for robotics** purpose.

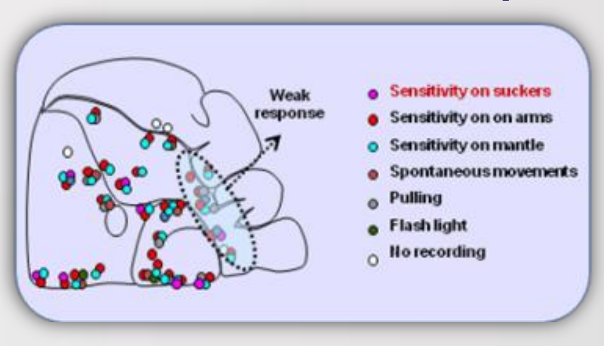
New approaches on kinematics and dynamics modelling of the octopus arm

Tools for 3D motion capture, kinematics and dynamics analysis and modelling

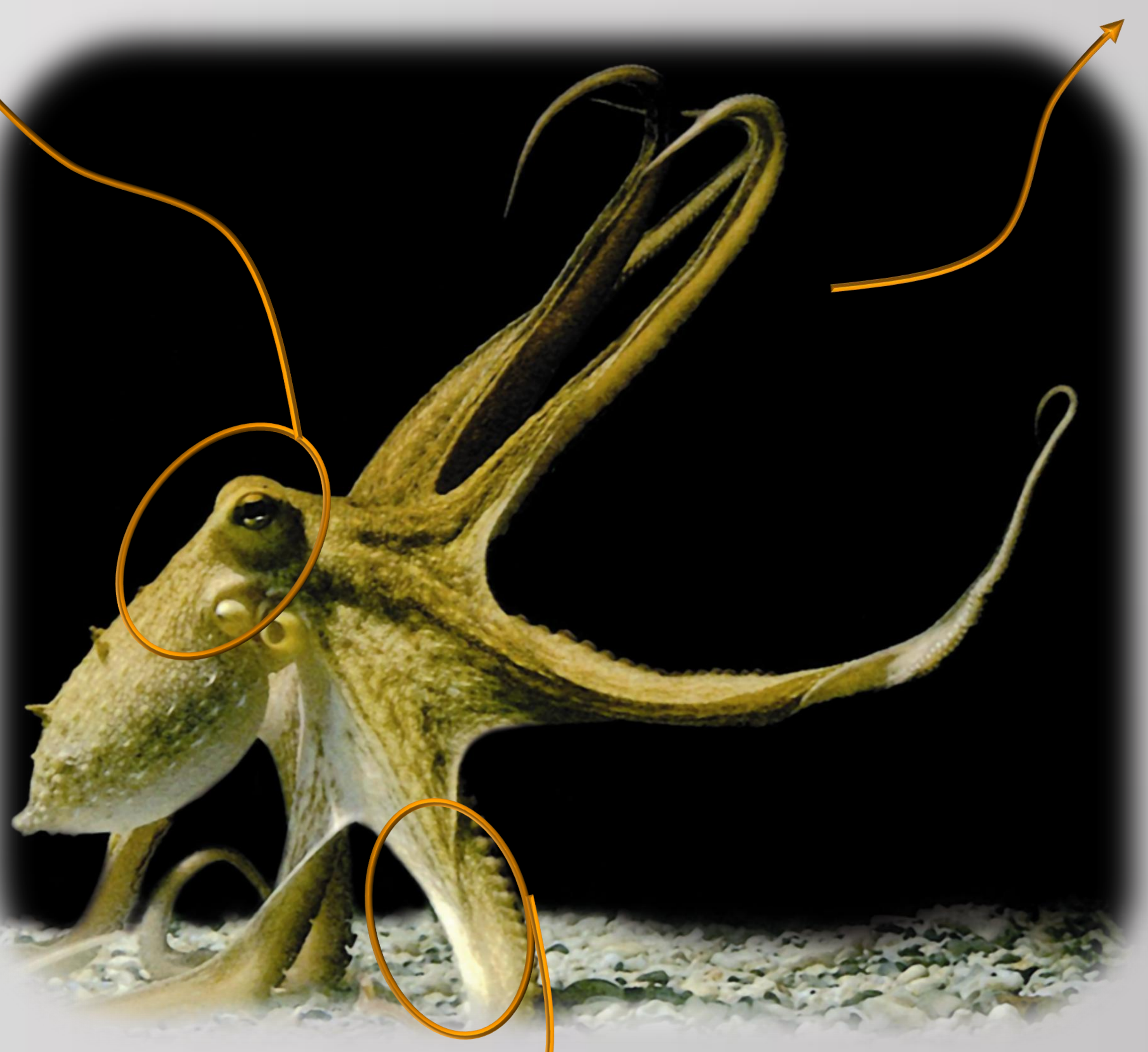


New ideas from the octopus neurophysiology for the design of control systems

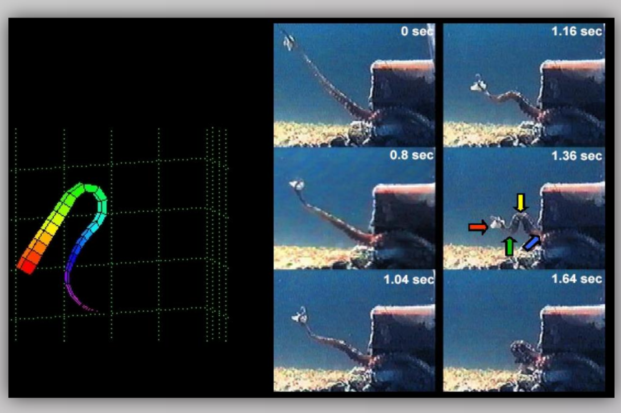
Study of the organization of higher motor centers in the octopus brain

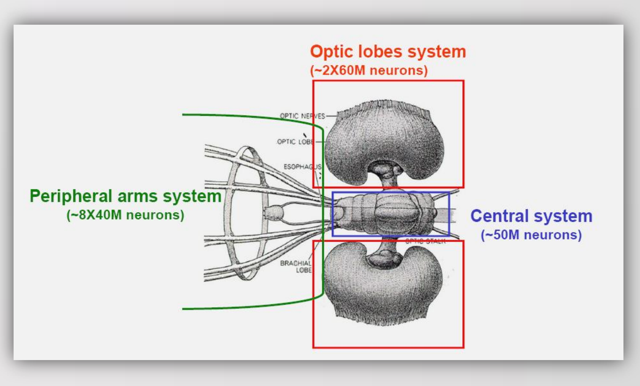


- Evidence of a non-somatotopic organization of the octopus brain and distributed motor processing.
- The octopus has the largest nervous system among invertebrate (5M neurons), with a highly distributed organization.
- The control of the large number of degree of freedom is simplified by stereotyped movements.

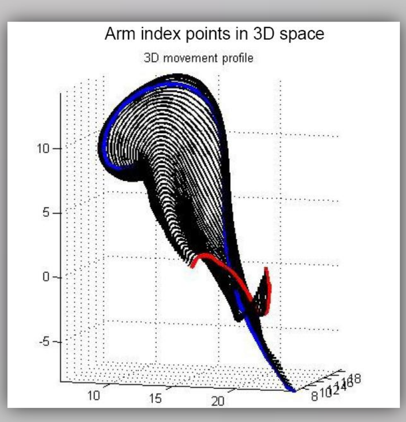


Analysis of stereotyped arm movements (reaching, fetching)

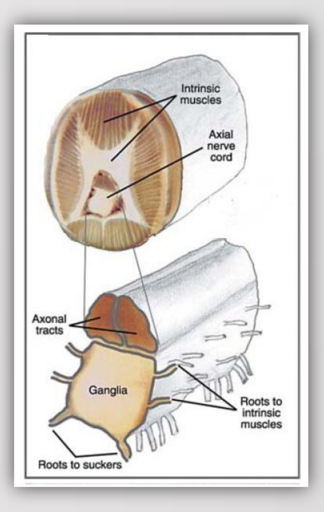




Study of motion primitives

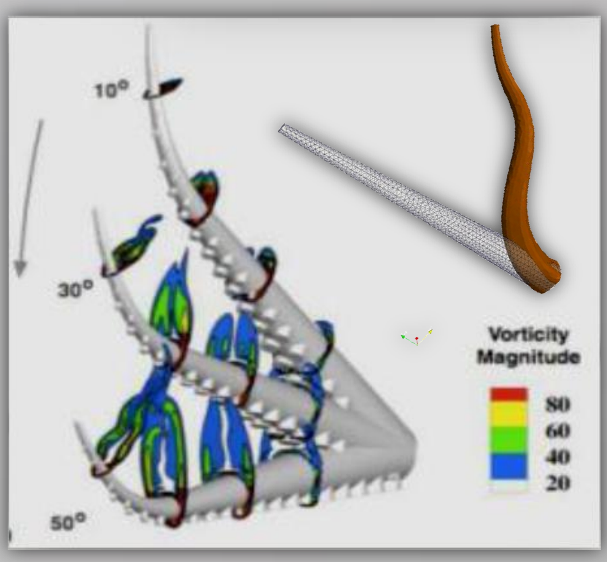


Study of the organization of the motor and sensory peripheral nervous system of the arm



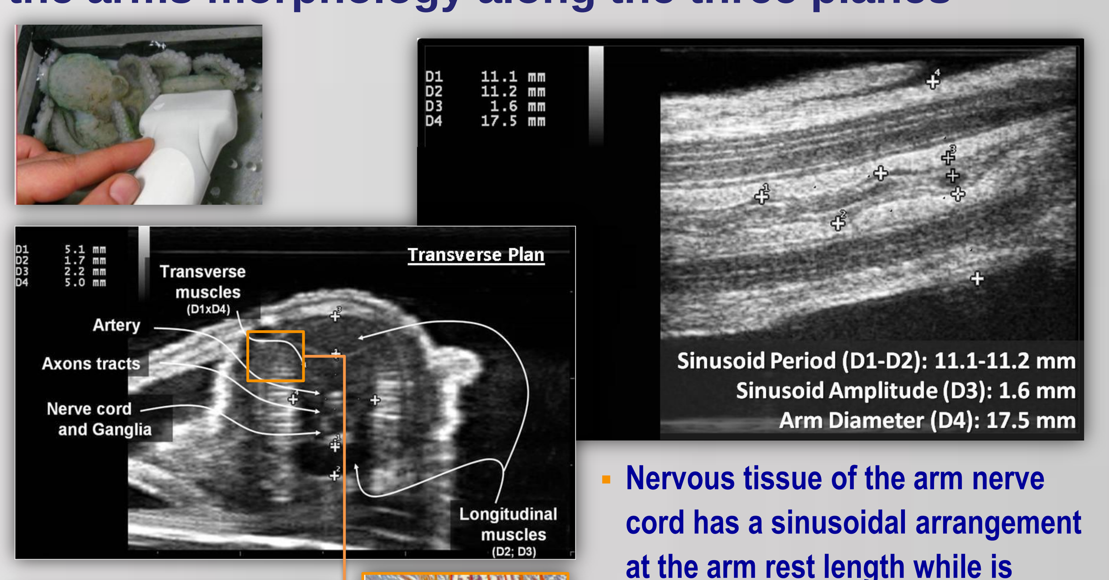
- Electrophysiological studies correlating kinematic parameters with muscle activity to understand dynamic aspects of movements generation and control.
- Characterization of elongation and bend propagation during reaching movement.

Hydrodynamics and elastodynamics models of the octopus arm

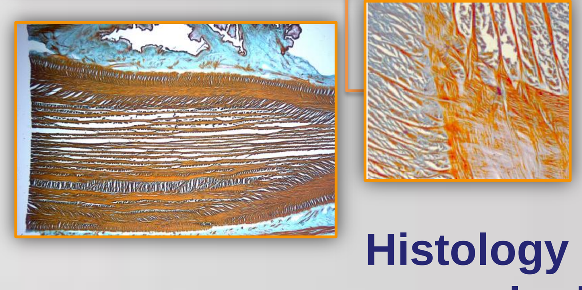


New insights on the octopus arm anatomy and biomechanics for soft robotics design

Ultrasound imaging is applied to investigate in vivo the arms morphology along the three planes



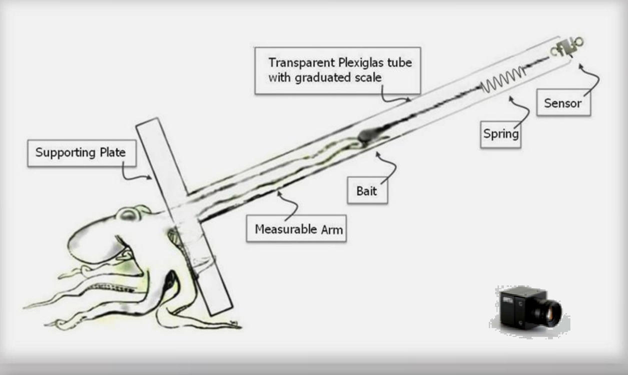
- Nervous tissue of the arm nerve cord has a sinusoidal arrangement at the arm rest length while is extended during elongation. The wave-like structure allows arms to achieve large elongation without mechanical constraint.



Histology and CryoSEM to investigate muscular insertions and arrangement

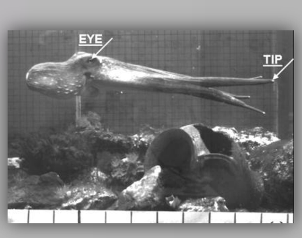
- Longitudinal muscles have insertion points along the arm allowing local bending.
- Transverse muscles have a radial net configuration with straight interweaving of transverse muscle fibers.
- Trabeculae have a key-role in maintaining circular the transverse section during contraction.

New bioengineering instruments and methods for the mechanical characterization of the arms



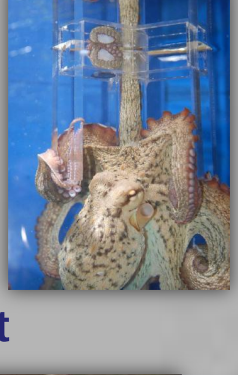
- Measure of arms elongation.
- Measure of arms pulling force
- Measure of shortening and longitudinal stiffening.
- Analysis of the jet propulsion swimming and measure of the arm reference length.

Arms Elongation	Arms Force			
70% of arms mean elongation corresponding to 23% of diameter reduction	Max Pulling Force 49.8 N @ 400 mm (m=1600g) 28.6 N @ 200 mm (m=476g)	Mean Pulling Force 40N with arm length 400 mm	Grasp Point Position 0.75 of total arm length	Contraction Time 1-2 sec

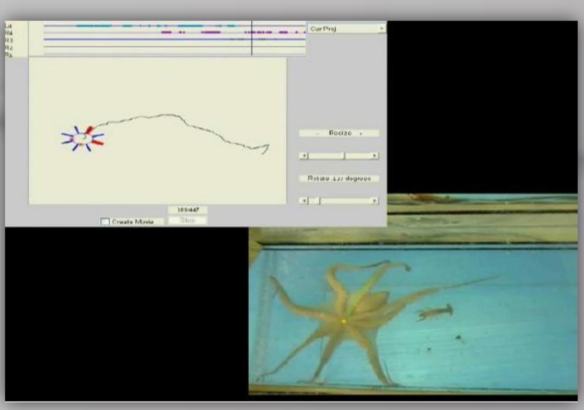


Stress-strain and cutting tests on the arm skin

Octopus behavioural experiments to study arms use and motor coordination based on visual or tactile stimuli



Characterization of multi arms coordination and study of the octopus crawling movement



Novel design principles for soft robotics

New science and new knowledge on octopus anatomy, neurophysiology, mechanics, kinematic and dynamic modelling, and behavior

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