Bio-Inspired Soft Robotics for Exploration of Unknown Environments

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2. Background
3. Exploration of Unknown Environments
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Introduction and Motivation

In real-world robots need to act in a **changing environment** and **manage uncertainties**.

- Real-world conditions can change over time
- Rigid robots can not face uncertainties in real world conditions

A soft robot can overcome challenges

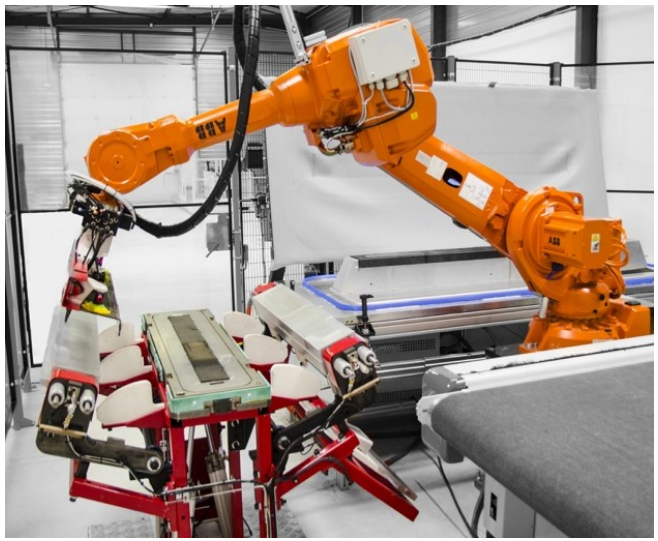

Figure 1: Rigid robot

Figure 2: Soft robot

Figure 1: https://www.compositesworld.com/blog/post/automated-preforming-intelligent-automation-systems
Figure 2: https://3dprint.com/80143/3d-printed-jumping-robot/

Introduction and Motivation

What is Soft Robotics?

- **bio-inspired** on **soft-bodied** living beings
- mimic capabilities of **animals**
- **physical** properties are different from rigid robots
- **dynamic** interaction with the changing environment

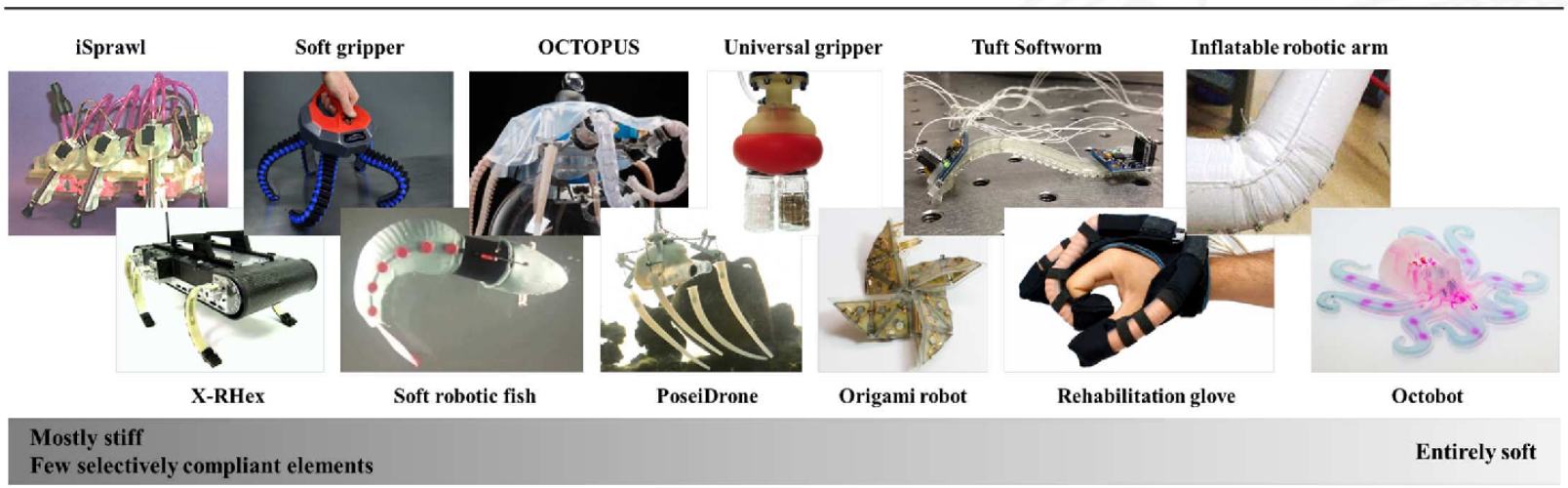

Figure 3: Soft robots classification [1]

Introduction and Motivation

How are soft robots bio-inspired?

- Animal-like behavior
- Soft body parts made of soft material
- Compliance and deformability in the interaction with the environment
- Capable of fast adaptation to the environment like living beings

Figure 4: Bio-inspired soft robot

Figure 5: Octopus

Figure 4: https://www.chemistryworld.com/news/chemical-powered-robot-octopus-is-a-real-softie/1017324.article
Figure 5: https://blogs.scientificamerican.com/octopus-chronicles/hey-how-old-is-that-octopus/

Soft Robots vs Rigid Robots

Soft robots	**Rigid robots**
Soft, flexible and stretchable material	Hard material with invariant properties
Inherent compliance match with its environment	Smooth contact with the environment by sensors
Continuum topology with infinite DOF	Finite DOF(rigid elements connected by joints)
Safe and adaptive to operate in unknown environments	Unsafe with limited adaptability to operate in unknown environments
High level of bio-inspiration	Low level of bio-inspiration
Low accuracy can be tolerated	High accuracy is required
Low weight and cost	High weight and cost

Table 1: comparison [2]

Background

A typical soft robot composed of[3]:

- Soft material
- Stretchable electronics
- Control system
- Multimodal sensors
  - Tactile sensing
- Actuation system
  - Variable length tendons
- Computation system

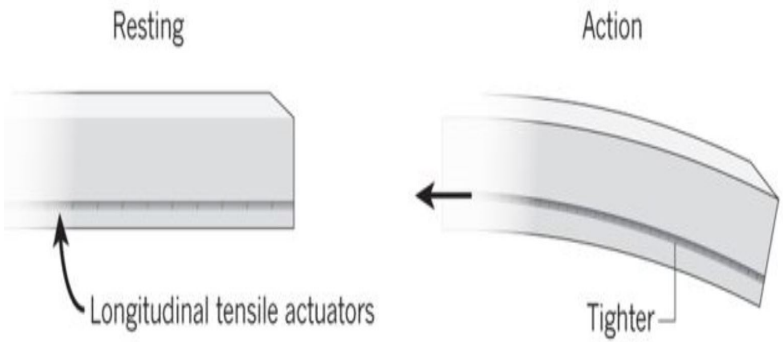

Figure 6 : variable length tendon [3]

Figure 6: https://www.nature.com/articles/nature14543

Background

Capabilities:

- Stretchability
- Squeezability
- Swimming
- Jumping

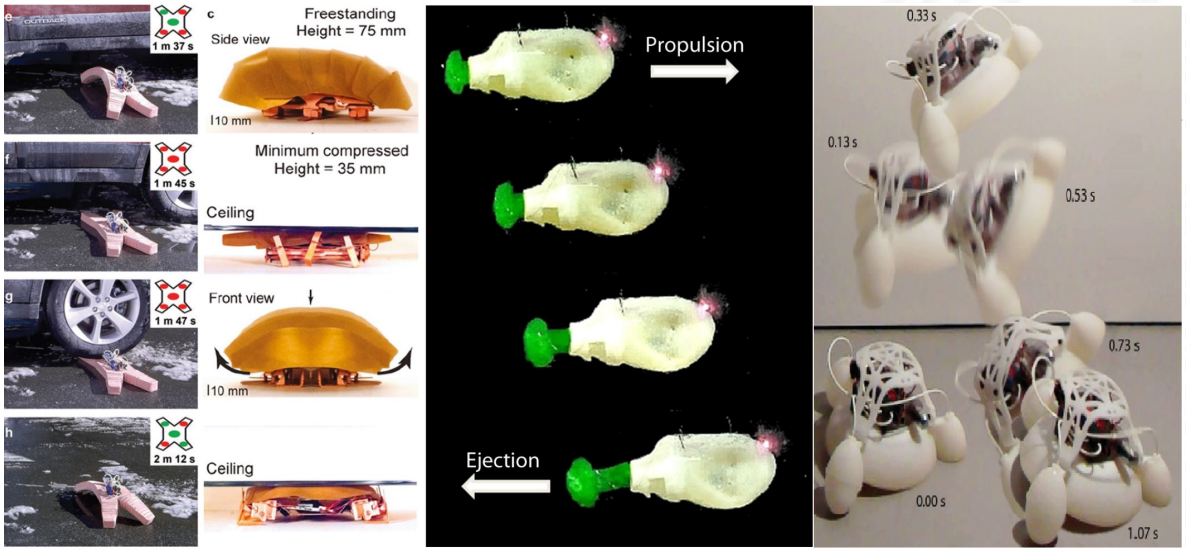

Figure 7: soft-robot capabilities [2]

Background

Applications:

- Assistance for humans
- Rehabilitation
- Wearable robots
- Search missions
- Monitoring and exploration

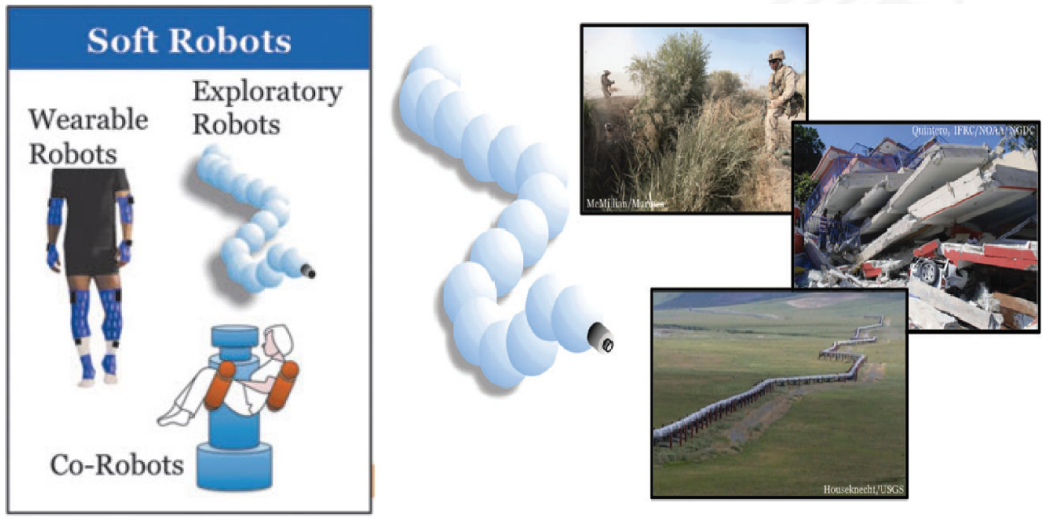

Figure 8: soft-robot applications[4]

Exploration of Unknown Environments

What means an exploration of unknown environments?

- Exploration of unstructured environments
- A rough terrain or deep bottom of the sea
- No external or just minimal information about the environment
- Information of the targets or the environment itself can change.
- Study marine life or explore a terrain,etc
- Terrestrial, underwater, space exploration, etc

Exploration of Unknown Environments

How soft robots perform exploration of unknown environments?

- Physical properties to move across the environment
- Random explorations in contrast to rigid robots(they need a path plan).
- Soft-body made of soft-materials helps to adapt to different environments
- Safer and flexible than rigid robots

Soft robots for exploration

Terrestrial exploration[5]:

- Rigid robots with legged or wheel locomotion perform exploration of terrains
- A rough terrain is the cause of unstable locomotion
- Soft robots are capable of a dynamic adaptation to real environments

Figure 9: Soft robot exploration

Figure 10: Rigid robot exploration

Figure 9: https://3dprint.com/80143/3d-printed-jumping-robot/
Figure 10: https://infoscience.epfl.ch/record/255680

A soft robot for random exploration of terrestrial environments

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A Soft Robot for Random Exploration of Terrestrial Environments

- A soft robot for exploration of rough or uneven terrains
- The soft robot has an intelligent and mechanical component
- Intelligence is evidence on random search strategy

A Soft Robot for Random Exploration of Terrestrial Environments

Random Search strategy[6]:

- Amount and quality of information changes over time
- Search rule can switch from deterministic to probabilistic strategies
- Random search locate sources by increasing regions to cover

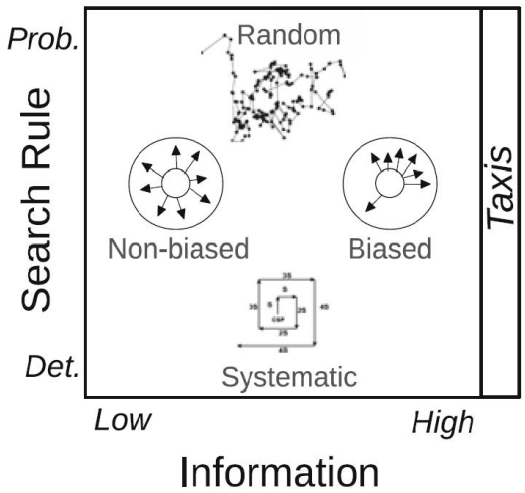


Figure 11: Search strategies[6]

A Soft Robot for Random Exploration of Terrestrial Environments

- Random Search[6]:
  - individuals need to find its target without the use of any (or minimal) external information available.
  - Search strategies based on to modify the (random) patterns of motion to maximize the success probability.
  - The usual way to determine success is through the first-passage time probability $f(x, t, x_0)$
  - $f(x, t, x_0)$ probability to reach the position x for the first time after a search process of duration t which started at x_0.
  - The function $f(x_t, t, x_0)$ represents the probability that the individual hits the target located at position x_t for the first time at time t .

A Soft Robot for Random Exploration of Terrestrial Environments

- Mechanical Design
  - Two propellers
  - Soft cage tensegrity structure
  - A self-righting mechanism
  - A simple design and control

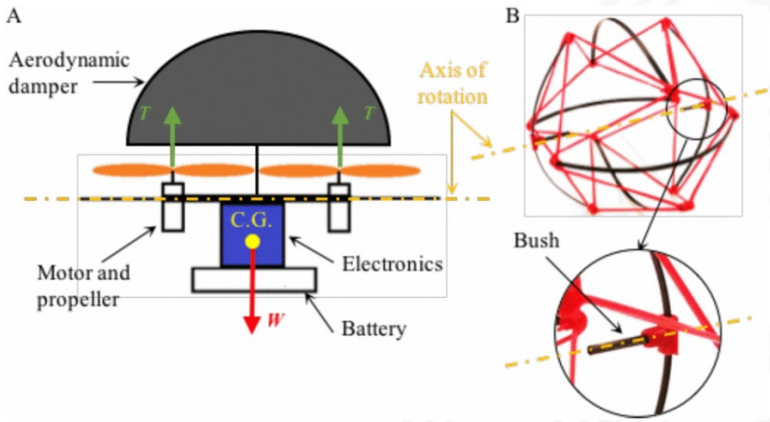


Figure 12: Soft robot components[7]

A Soft Robot for Random Exploration of Terrestrial Environments

- Locomotion
  - Two patterns of locomotion.
  - Propellers lift the robot

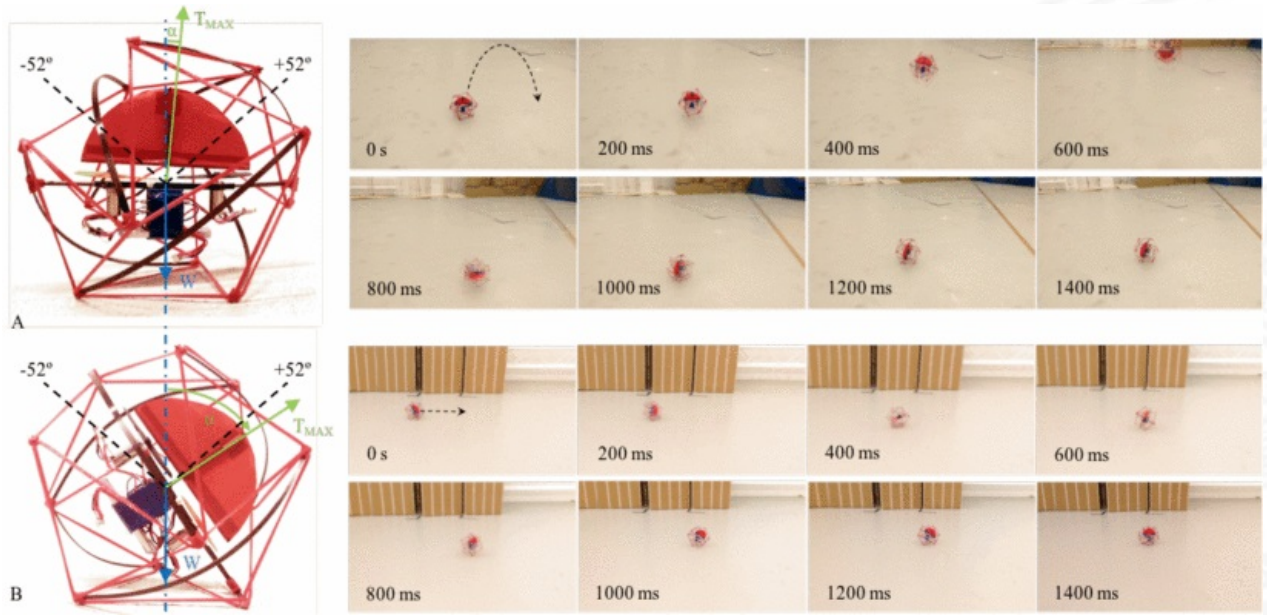


Figure 13: Soft robot locomotion[7]

A Soft Robot for Random Exploration of Terrestrial Environments

- Implementation and Experimentation
  - High jumps to avoid obstacles and explore uneven terrains
  - Jumping height reaches a maximum average value of 150 cm.
  - The area coverage ratio area of cells visited by the robot and total area of the arena.

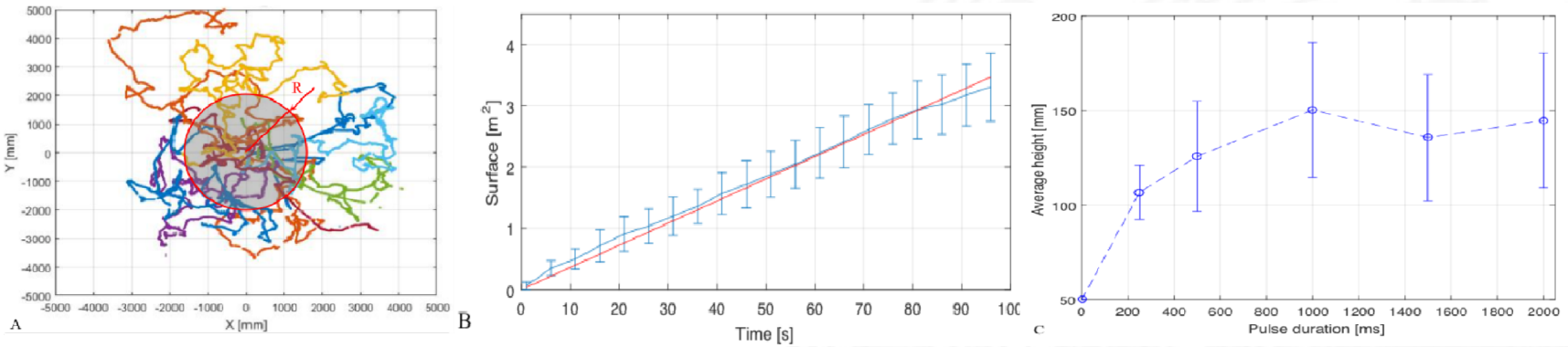
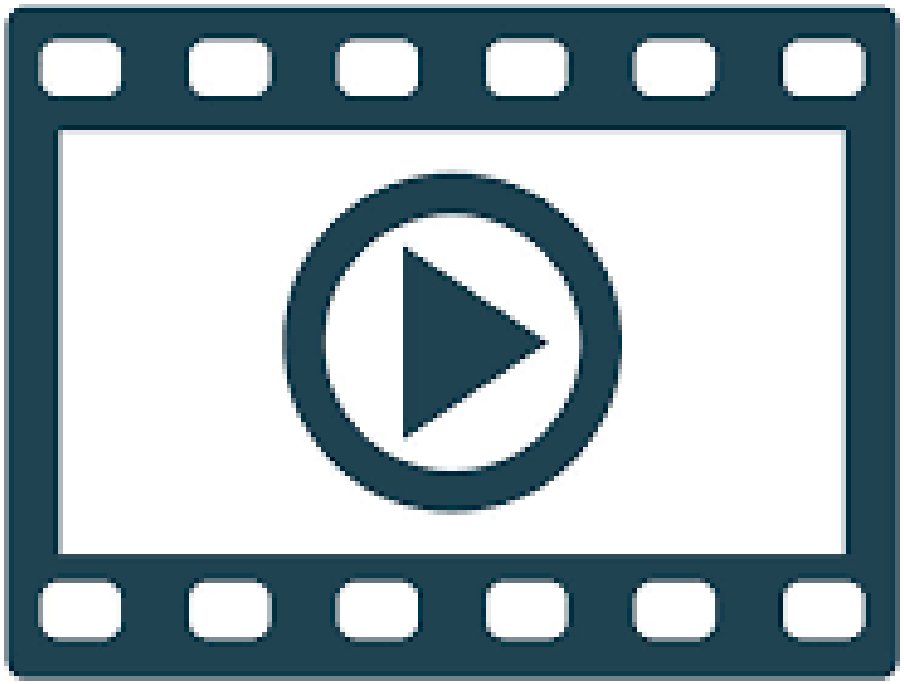


Figure 14: **A**.Track path of robot, **B**.Robot average rate of coverage, **C**. Jumping height [7]

A Soft Robot for Random Exploration of Terrestrial Environments



Soft robots for exploration

Underwater exploration[5]:

- Requests of marine life exploration
- Crawlers(rover-like vehicles) explore the sea.
- Crawlers have some disadvantages
- Underwater soft robots mimic the capabilities of marine animals for exploration.

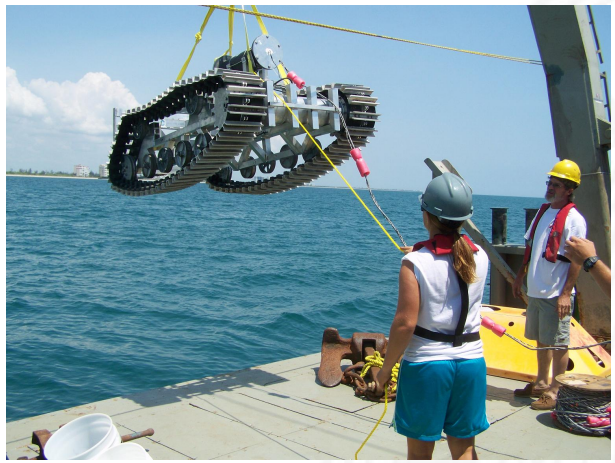
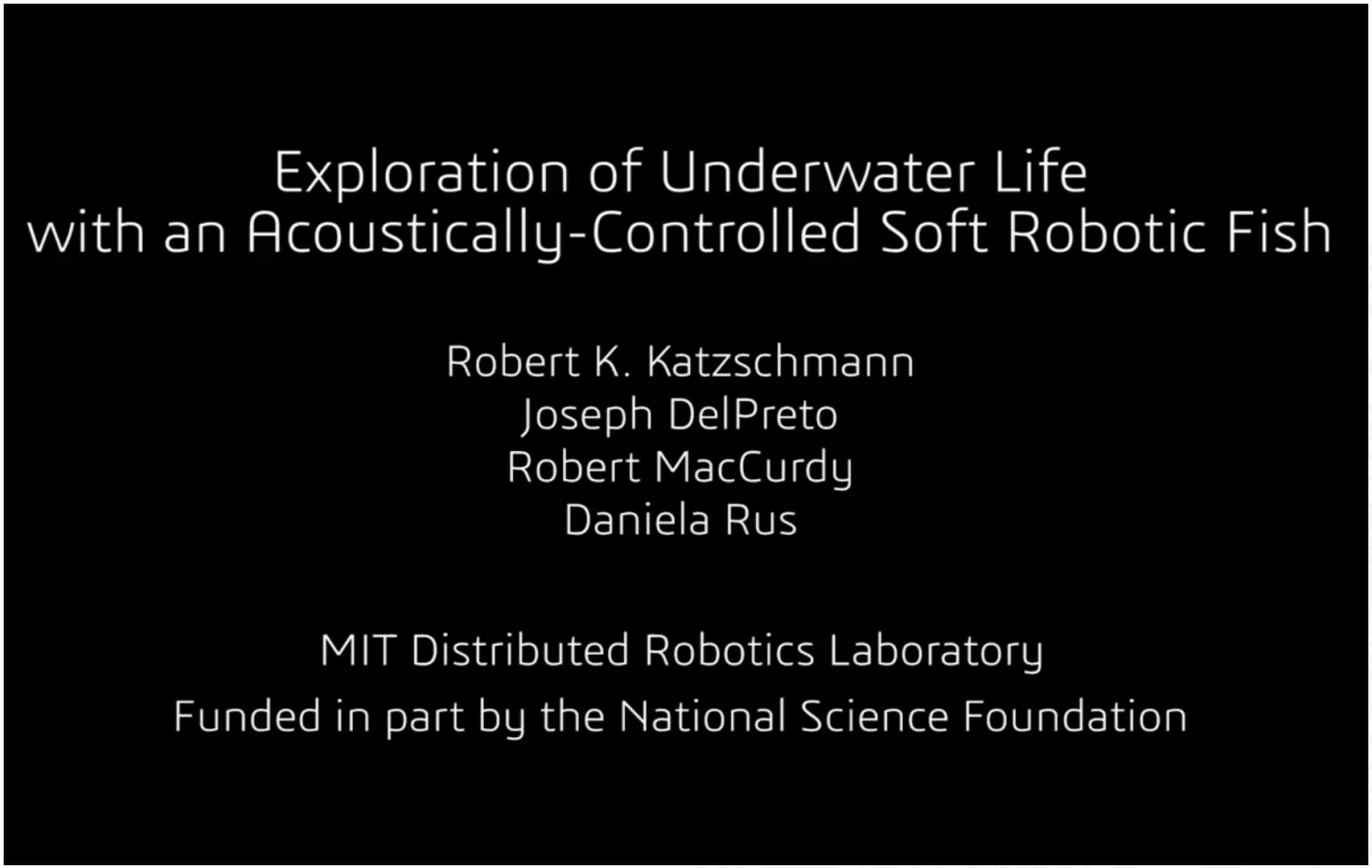


Figure 15: Crawler vehicles

Figure 15: web2.fit.edu/programs/8084/ms-ocean-engineering

Soft Robotic Fish for Underwater exploration



Year: 2018

Soft Robotic Fish for Underwater exploration

- Mechanical Design
  - Soft-tail
  - Buoyancy control unit
  - Fish-eyed camera
  - Acoustic transducer
  - Hydraulic soft actuator
  - Mission control system
  - On-board sensors

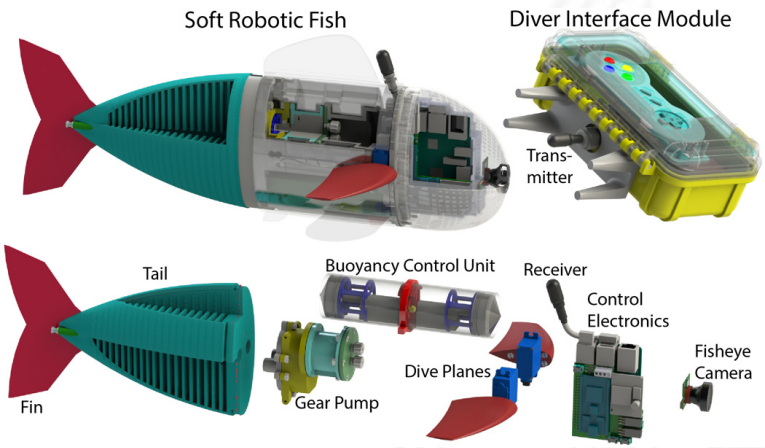


Figure 16: Fish components[8]

Soft Robotic Fish for Underwater exploration

- Acoustic-Controlled communication
  - A diver interface module and an acoustic receiver
  - A human diver use diver interface to steer the robot
  - Diver send commands for tail undulation frequency, depth/pitch and turning angle
  - 16-bit words received it describing the desired fish state.
  - The robot is able to receive commands over a distance of 10m.

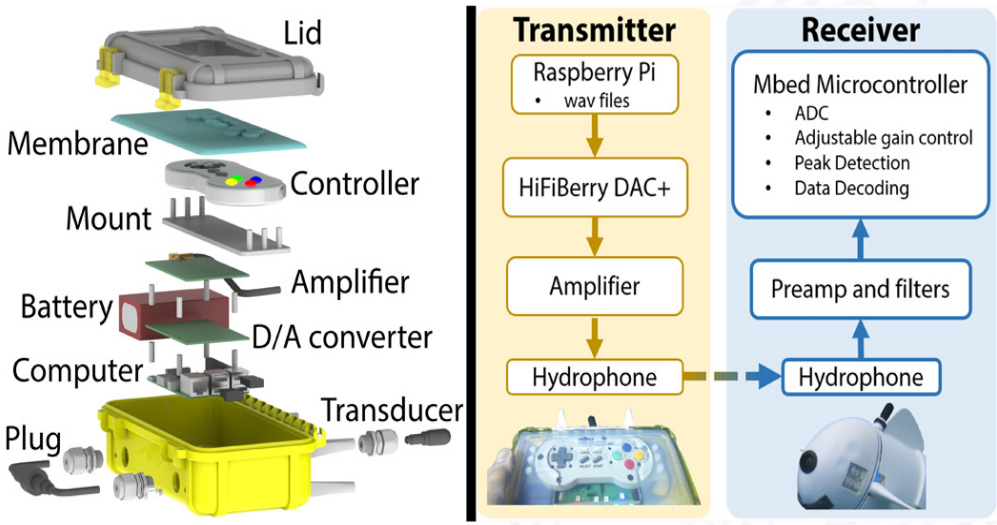


Figure 17: Acoustic-controlled communication[8]

Soft Robotic Fish for Underwater exploration

- Exploration and Locomotion
  - 3D trajectories with undulatory locomotion using a buoyancy control system
  - Hydraulic propulsion system capable of carrying all the fish components
  - A low-pressure pump and a soft fluidic actuator with appropriate size.
  - Navigation at depths up to 18m.

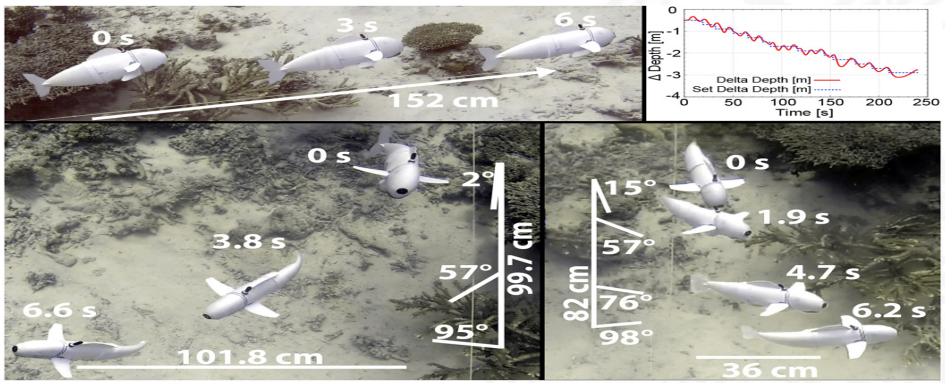
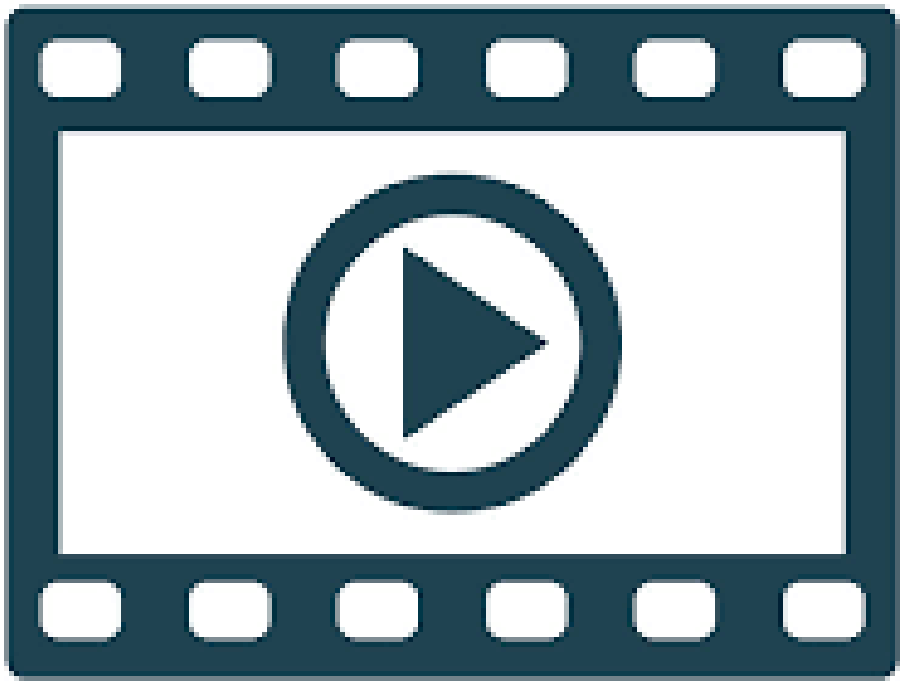


Figure 18: Fish components[8]

Soft Robotic Fish for Underwater exploration



Discussion

- The terrestrial soft robot exceeds performance compared to a rigid robot
- The bio-inspired jump and rolling patterns allows to explore and cover different areas of the environment
- The random search applied for exploration outperform systematic strategies in unknown environments
- Still improvements need to do for make the jump more efficient
- Is possible to use several units of the robot to cover a big area of exploration

Discussion

- Soft robotic fish is able to swim and explore in complex environments for prolonged periods of time
- Acoustic communication system of fish robot provides an alternative to divers for remote exploration of coral reefs
- The hydraulic system is a key to achieve a different range of swimming speeds and perform exploration
- Robotic fish still not capable of autonomous exploration
- Might be possible on future to use several numbers of robotic fish for exploration

Summary

- Soft robots allow exploration of complex environments without developing complex control mechanism or trajectory plans.
- Still soft robot need to overcome weak points to improve its performance on an exploration of diverse environments
- A soft-body allows a better and natural movement for exploration of underwater or terrestrial locations
- Rigid robot is the still the usual choice for exploration of unknown environments but soft robots would be able to surpass them.

Thank you for your attention.

Summary

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Thank you for your attention.

Questions?

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