STUDIES AND RESEARCH ON THE LOCOMOTION OF MOBILE ROBOTS INSPIRED BY BIOSYSTEMS

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Abstract: In the first part of the paper are presented aspects regarding the locomotion of biosystems. In the second part, the robots from biosystems are classified into two categories: robots with single locomotion and robots with hybrid locomotion. Robots with hybrid locomotion are further classified and examples from specialized literature are presented. At the end of the paper are presented the development trends of robots in this field.
Keywords: robots, bioinspired, locomotion, hybrids.

1. Introduction

With the technological development it can be noticed that there is an increasingly accelerated development of robots, especially of mobile robots. Mobile robots have become increasingly popular in various fields of activity, such as commercial and industrial.

The biological world is vast and very diverse, the total number of species that populate our planet is almost nine million. Such a variety of life forms provides an important source of inspiration for specialists. This inspiration is reflected in the large number of robots that have been built to date. The solutions offered by nature represent the solutions that over time have been optimized.

Currently, a lot of mobile robots are developed for the terrestrial environment and also for aquatic or aerial environments and look similar to their counterparts in nature.

An important step in the process of achieving a bioinspired system is the research of the multiple biological solutions inspired by nature that can be used to solve a particular problem [1].

This step involves the search for biological species that perform certain biological tasks. Instead of watching at random, it is proposed to see biological species based on the taxonomy (the science that defines biological species based on common features) [2].

Further, this paper present: the classification of locomotion in the living world, the modes of locomotion of biological species, aspects regarding the locomotion of bioinspired robots and the trends in the field of bioinspired robotics.

2. Classification of Locomotion in the Living World

The world of living world species is vast and varied, influencing the design of the mobile robots that are inspired by it.

The list of species in the living world can be classified according to their abilities or nature, as follows [2]:

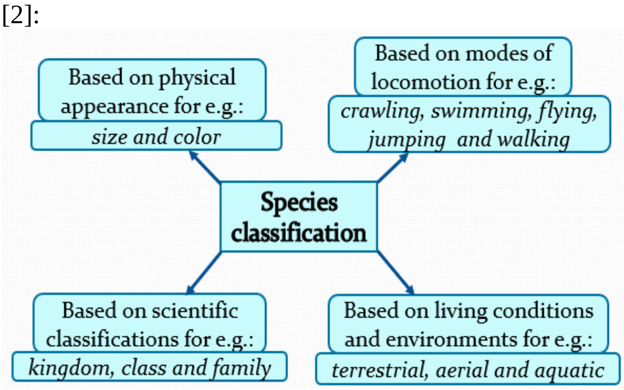


Fig. 1. Species classification.

Depending on the environment in the living world we identify the following categories of locomotion:

a) at the limit of separation between two environments. In this case, the movement can take place at the limit between water and land (animals moving on the bottom of the waters), at the limit between air and dry (animals moving on the surface of the earth, by crawling or walking) or at the limit between air and water (animals moving on the surface of the water).

b) in the same environment (in water or in air). Locomotion in the same environment can be swimming (aquatic locomotion) and flying (air locomotion) [3].

3. Modes of Locomotion of Biological Species

The modes of locomotion of biological species relate to how these species move in nature from one place to another.

In the paper [4], the locomotion of biological species is classified in two main categories:

• - horizontal locomotion
• - vertical locomotion

Space locomotion results from the combination of these two kinds of locomotions.

The process of conceiving a bioinspired system begins, by analyzing the species that have common characteristics and their locomotion capabilities [4].

Category 1: Species performing locomotion in a horizontal plane

Most species change their mode of locomotion to cross different types of terrain, for example, to pass obstacles such as ground holes and uneven surfaces [5].

From this, several species can be selected that can change their shape to perform several modes of locomotion [6].

The species in this category that attracted the researchers' attention are [4]: Mount Lyell salamander, Woodlouse insect, Moth caterpillar, golden spider, Cebrennus Rechenbergi spider.

These species move through one or more locomotion modes.

Category 2: Species performing locomotion in a vertical plane

It is known that moving in the horizontal plane, on a flat surface, is much simple for animals compared to moving on vertical and sloping surfaces. One of the main reasons is because moving in the horizontal plane does not require much effort against the force of gravity. Most of these species have a unique adaptation of their locomotion by climbing in nature.

Usually, they all have the fastening capabilities, strong grip and the locomotion mechanism allows them to keep their body center of gravity as close as possible to the obstacle or object they are crossing.

The species in this category that have attracted attention of the researchers are [4]: *the common spider*, the *common snake and the gecko.*

The species presented above in this two categories are used to develop robots with multimodal locomotion (robots with hybrid locomotion).

4. The Locomotion of Bioinspired Robots

4.1 Singular Locomotion

Below in this paragraph are presented some examples from the specialized literature with singular locomotion. By singular locomotion we will refer to a single locomotion modality made by the robot.

- *Walking locomotion*

The Stickybot [7] has the Gecko lizard as its inspiration model. An important feature of this lizard is the fingers cover. This feature has contributed to important discoveries of great importance in the field of designing climbing mobile robots.

The "sticky" fingers of the lizard, can help develop a dry and self-cleaning adhesive.

Figure 2 show the Stickybot and his basic components [7]. The fingers have the arching capacity facilitating their detachment from the locomotion surface.

Fig. 2. Stickybot, bioinspired robot capable of climbing on smooth surfaces [7].

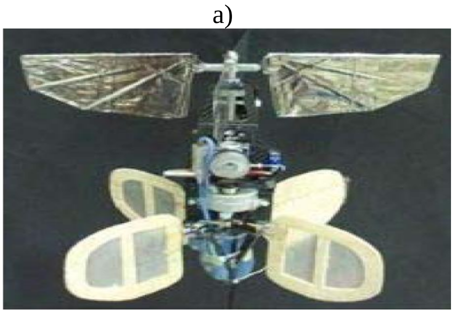
-*Flying locomotion*

The flying locomotion, generated by the beating of the wings, offers more advantages compared to the drone locomotion generated by the propellers. Robots with such locomotion can move at low speed and are able to make sudden turns. Like animals, the vortex created by the wings has the role of creating the force necessary to guide the robots to the sky.

As part of the Micromechanical Flying Insect (MFI) project at Berkeley, the authors developed an 25 millimeters long autonomous robot, with the purpose of being used for search, rescue, monitoring and knowledge [8].

This model is based on biomimetic principles that capture part of the exceptional flight performance made by flies. The design, piezoelectric actuators and the flexible structure of the chest together with the wings, need a certain energy, this being generated by lithium batteries charged by photovoltaic cells (Fig. 3 a), [8].

a)



b)

Fig. 3. Insect-type microrobots
a) The microrobot developed in the MFI project b) Mentor flying robot [8].

Another example of an air locomotion robot is the Mentor robot, a four-winged robot (Fig. 3 b) developed at the University of Toronto. It's considered to be the first robot that managed to achieve the agility of a hummingbird [8].

The Mentor robot is 30 centimeters long and weighs about 500 grams, the researchers who made it hope to reduce it to the size and weight of a hummingbird.

4.2. Hybrid Locomotion

Hybrid locomotion is the type of locomotion that combines two or more modes of locomotion.

The hybrid locomotion mode, generated by combining *jumping* or *running* with *flight* and *gliding*, is used in nature by numerous animals and birds for efficient movements in their natural habitat.

So far, there are few achievements of robots capable of bioinspired hybrid locomotion.

A classification of robots for this mode of locomotion could be as follows (Fig. 4):

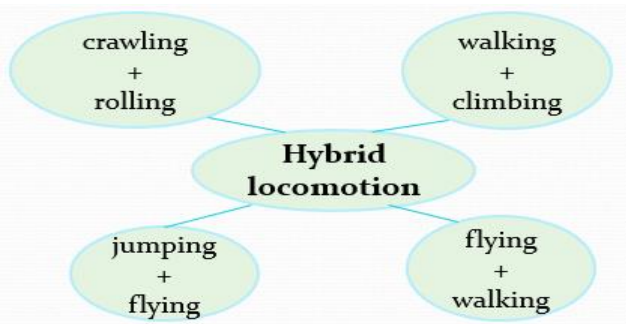


Fig. 4. Classification of hybrid locomotion.

- *Crawling and rolling locomotion.*

Figure 5 shows the Cebrennus Rechenberg hunting spider. The Scorpio robot has a diameter of 300 mm [9] and is inspired by the design of this hunting spider, also known as the Moroccan spider "flic-flac".

Similar to its counterpart, the robot inspired by this spider is capable of *crawling and rolling*.

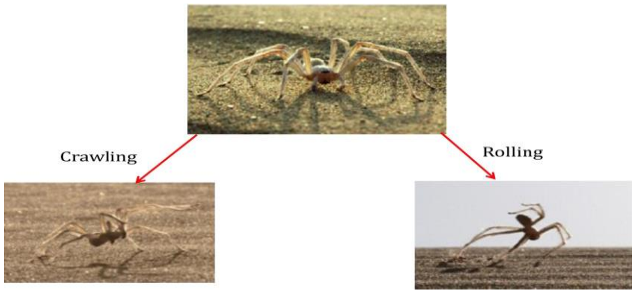


Fig. 5. Cebrennus Rechenberg spider [9].

Figure 6 shows the Scorpion 1.2 robot and its transformation phases. Scorpio 1.2 is the second iterative prototype of the Scorpio1.x family that weighs about 1.2 kg [9]. This robot is equipped with a video camera and CM 50 controller that controls the walking transformation.

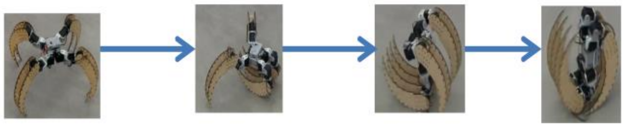


Fig. 6. Scorpio robot 1.2 and the transformation phases [9].

The robot can *crawl and roll* by transforming the configuration of the legs, which is achieved by controlling the rotations of the actuators that operate them. Figure 7 shows the transformational phases between crawling and rolling.

The robot is also able to recover from a fall or rollover, this aspect being very important and is desirable for any robot that is designed to cross extremely complex terrains.

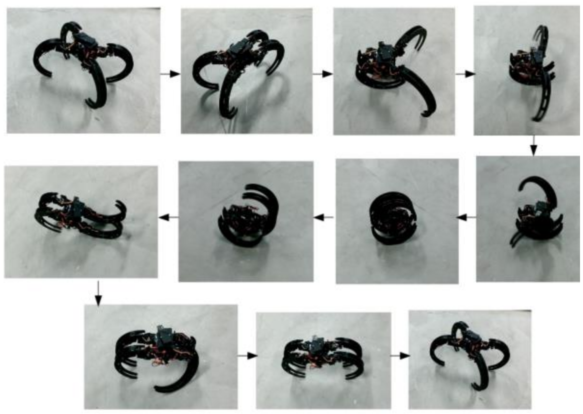


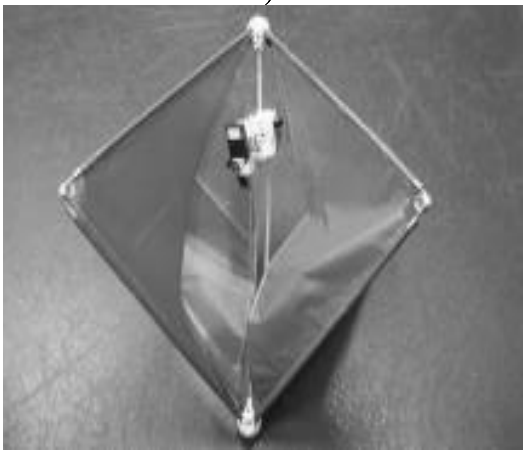
Fig. 7. The crawling-rolling transformation phases of the Scorpio robot [9].

-Hybrid locomotion by jumping and gliding

In this category, the main mode of locomotion is realized at ground level, mainly by jumping and continued by gliding. This particularity helps the robot to travel the distance with minimal effort.

One such robot is the Glumper robot made at the University of Bath [10].

a)

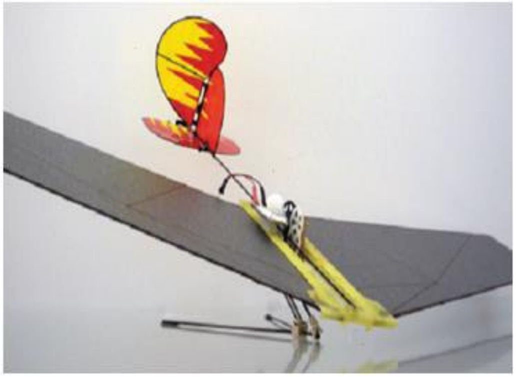


b)

Fig. 8. The Glumper robot [10].

The robot has 4 octahedral-shaped legs, and a weight of about 0.7 kg, being relatively heavier than the other jumping robots (Fig. 8). Each leg contains a thin membrane that acts as a wing while jumping. This membrane ensures long jumps and a low impact force on landing. Its octahedral structure is supported by carbon fiber-reinforced plastic tubes along its edges. Wing-shaped membranes fixed between the elements of the leg open as the robot jumps. Glumper can jump up to 1.17 m.

Another robot model belonging to this category made at the Ecole Polytechnique Federale de Lausanne (EPFL) called Jumpglider, is shown in Figure 9 [11].
With its own weight of just 7 grams, this mini robot moves through jumps and gliding.



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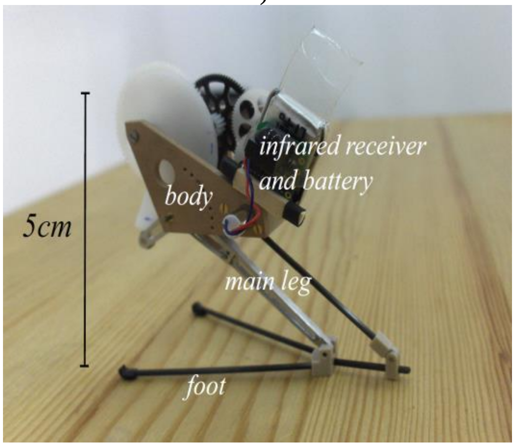


b)

Fig. 9. a) The Jumpglider robot [11].
b) The mechanism of the Jumpglider robot [11].

The main benefits of jumps are the ability to pass major obstacles and low energy consumption compared to the modes of locomotion like crawling, walking or running. [4].

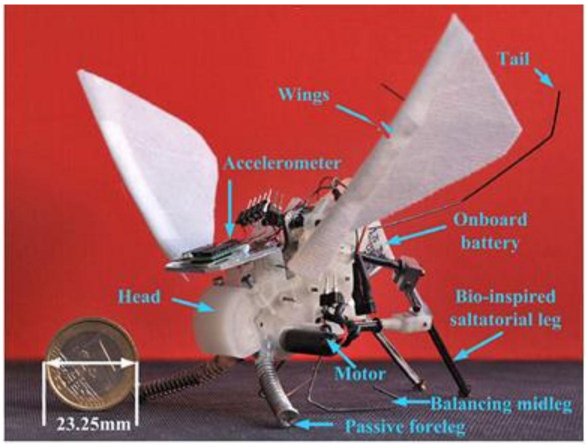
The authors of references [12], [13], [14], inspired by the biological world, namely bats, butterflies and grasshoppers, developed the three models of the robot's wings. The results showed that rigid wings due to their simple design and lower weight offer good performance in terms of distance traveled and low energy consumption.

When launched from a height of 2 m, it is able to travel a distance of about 4.5 m. This type of robot is very effective for jumping from heights, imitating mammals that jump from a height and glide to travel great distances, thereby consuming less energy.

Grillo (Fig. 10) is a minirobot inspired by biosystems, which moves mostly by jumping. So far, three versions of the minirobot have been developed: Grillo, Grillo-1 and Grillo-2.25.

Research has shown [15], that the wings could be used to extend and stabilize the robot's jump. Using this idea, the updated version of the Grillo-2, it was designed in the hope of achieving higher and longer jumps.

The latest Prototype Grillo-3 was produced with passive wings and tails to increase stability during a jump (Fig. 10).



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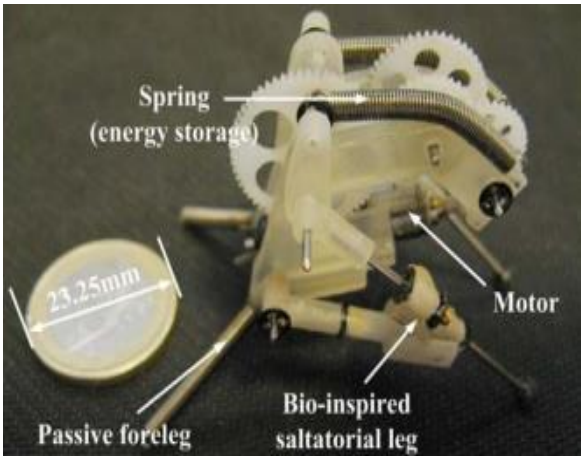


b)

Fig. 10. a) The Grillo robot [15].
b) The Grillo robot mechanism [15].

-Hybrid locomotion by jumping and flight

Robots in this category use flight generated by the beating of wings to increase their ground locomotion capabilities through speed and the ability to cross inclined surfaces.

By adding the wings to the Dash terrestrial robot, the DASH + Wings robot was obtained, (Fig. 11), which increased the locomotion capacity. It was found that the speed of the DASH + Wings robot is double (1.29 m/s) compared to dash (0.68 m/s) and the wings have an increased angle of ascent (from 5.60 to 16.90 degrees).

The DASH + Wings robot has opened new directions of research in wing-assisted running. This combination (wing-assisted running) is considerably increasing the locomotion capacity of birds on the ground.

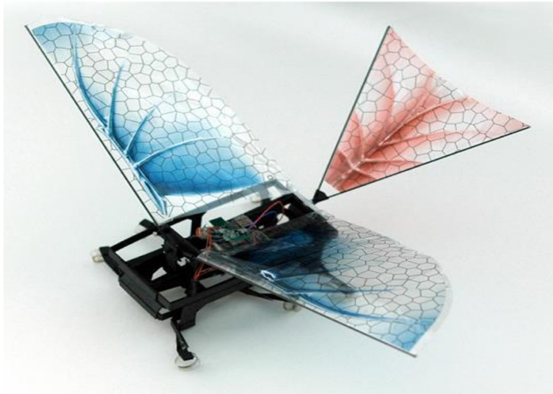


Fig. 11. The UCB Dash robot + Wings [11].

The bipedal Bolt robot shown in Fig. 12 is a robot capable of two type of locomotion: aerial and terrestrial, in indoor environments. Weighing only 11.4 grams and a wing opening of 28 cm, it can perform the ground-to-air transition in less than a meter. To reduce weight, a single motor is used that drives the legs and the wings.

The Bolt robot provides a useful platform to perform different experiments that highlight the usefulness of hybrid locomotion and its efficiency in crowded environments.

Fig. 12. The UCB Bolt robot [11].

-Hybrid locomotion by flight and walking

To these robots with the main mode of locomotion by flight to increase their mobility are added locomotion on the ground.

Malv is a robotic structure capable of aerial and terrestrial locomotion (Fig. 13). Due to its potential, it can be used in reconnaissance missions for law enforcement agencies in neighborhoods, where human deployments are very dangerous.

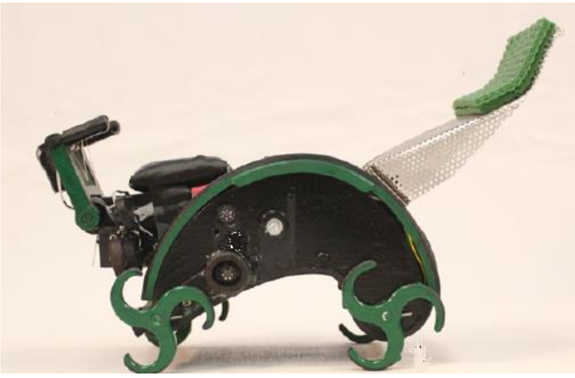
Its hybrid locomotion mode will allow it get closer to the desired area, more efficiently compared to "exclusively aerial" robots. This robot successfully integrates Mini-Whegs wheel design. This hybrid system (Whegs) with wheels and feet gives the robot increased mobility on rough terrain.

Fig. 13. The UFL Malv robot [11].

The latest version of this robot can navigate autonomously between crossing points (without obstacles) via autopilot and GPS. In addition, this version is also equipped with a camera for visual feedback [6].

- Hybrid locomotion by walking and climbing

Robots in this category were inspired by termites. They were programmed and equipped with sensors and they knew exactly where to position the transported load.



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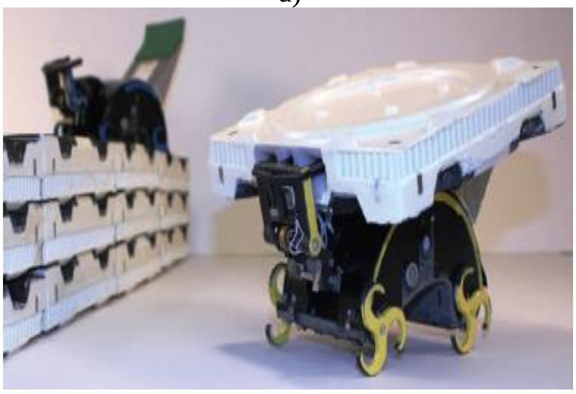


b)

Fig. 14. a) Robot inspired by termites [16].
b) Robot transporting special bricks [16].

The hybrid locomotion system, helps them to move on flat surfaces by walking, and on the inclined surfaces by climbing. Robots don't follow a particular plan and still manage to build complex structures. By their design these robots are able to climb steps the height of a transported brick.

5. Trends in Bioinspired Robotics

One of the current trends, increasingly common, using modular robotic units, is "Robot Swarms".

’’Robot Swarms’’

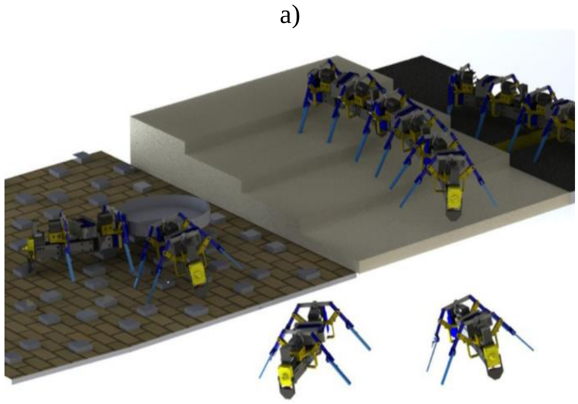
’’Robot Swarms" are cheaper modular robotic units that can be reconfigured as a team based on task. These robots can be more efficient than single robots that are much more expensive and need to be rebuilt according to applications (Fig. 15), [17].

"Robot Swarms" acts independently and in order to perform a task they need to feel not only the environment but also the members around them.

The nature offers many examples that highlight this aspect. By acting independently, bodies cannot perform a specific task, but in coordination with other bodies, they can perform complex tasks or finish a mission. This "multiplication of force" requires individuals to feel not only the surroundings but also their neighbors and communicate with other individuals on their team while working independently. This image has been seen at fish, birds, insects and is an essential aspect for navigating as a herd or horde, feeding, hunting, nests building and surviving in difficult environments [3], [17].

Like a group of pretty simple robots can form to perform a range of activities beyond individual capabilities, through communication and cooperation with team members (Fig. 15).

a)



b)

Fig. 15.a) "Robot Swarms" [17].
b) Four-legged robots Swarm[18]

If robots are designed for navigation, a great challenge is to adapt in case of failures, to be able to recover. This aspect requires a certain physical robustness, resistance to harsh, changing environments and complex handling. It's also essential to have a significant level of autonomy that will lead to complex self-monitoring and self-reconfiguration [17].

Inspired by self-assembly from nature, a self-assemblable swarm of 1,024 robots was developed at Harvard University (Fig. 15 a) [19]. These kilobots can form various complex 2D shapes.

Researchers at the University of Notre Dame have created swarm-type robots that are capable of crossing complex terrains and pass obstacles in their path. For example, if a robot encounters an obstacle that it cannot pass, the others would intervene to finish the problem collectively (Fig.15 b), [18].

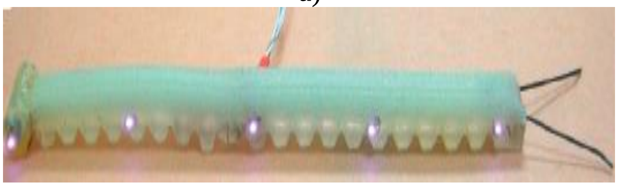
''Soft Robots''

"Soft Robots" is a young but productive field that attracts a growing interest from scientists in robotics and other fields.

Today, many research laboratories are doing their activities on generating new robotic structures that are soft, combining soft materials science and robotics to build new models of robots.

Two models of software robots are shown in figure 16, [20].

a)



b)

Fig. 16. a) Soft robot inspired by the starfish [20].
b) Soft robot inspired by caterpillar [20].

"Soft robots" can show abilities that weren't possible before and that improve robot applications in human-robot interaction, adaptability and autonomous operation.

"Soft robots" can replace rigid robots in natural surrounding and in human tasks as a great alternative where adaptability and safety to uncertainties are key fundamentals. In fact, they can adapt in various environments and move to adapt to the task requirements. They can handle objects that vary in size and shape and due to their specific characteristics allow them to access and work in narrow and confined spaces, to adapt their shape, even to grow and heal [20].

"Soft Robot" presents topical challenges for research in several aspects of manufacturing and control (Fig. 16). The materials used for this type of robots are flexible and deformable, providing additional advantages for animals, such as allowing entry into tight spaces for shelter or hunting.

Figure 17 shows the octobot soft robot made at Hardvard University [21]. The Octobot is entirely soft, autonomous and is controlled via a controller that acts the fluid inside it.

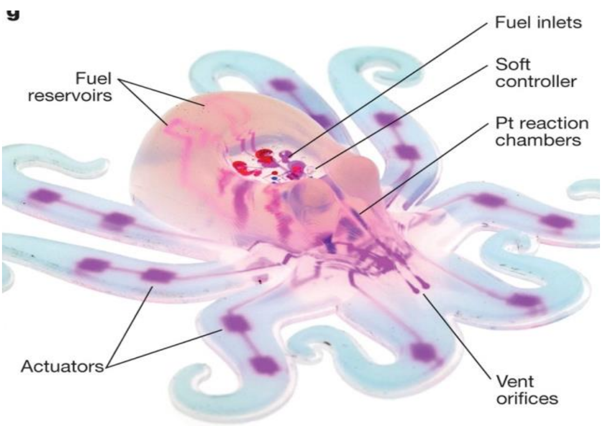


Fig. 17. The Octobot robot [21].

"Soft animals" in the living world have their advantages but also some important limitations, in general the size is reduced because they find it difficult to sustain their own body weight without a skeleton.

Large "soft" invertebrates that have large dimensions are found in water (squid and jellyfish) or underground (huge earthworms), their body being supported by the environment.

6. Conclusions

Biosystems provide an inexhaustible source of models for mobile robotics.

It has been found that many species in nature are able to perform several modes of locomotion, some are even able to change their shape in order to be able to achieve them.

Biosystems inspired robots, can also be classified according to the locomotion modality into two categories: robots with single locomotion and robots with hybrid locomotion (multimodal).

In general, robots with hybrid locomotion can be: by crawling and rolling; jump and flight (gliding and beating the wings); flight and walking, walking and climbing.

Among the development trends of bioinspired robots, the development of swarm and soft robots are identified in the specialized literature.

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