Biorobots and their practical application

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Abstract: *The seminar paper focuses on the topic of biologically inspired robots or, shortly, biorobots. In the introduction, it goes over the topic of biomimicry and how it can aid with robot design when trying to achieve a specific goal, be it a certain form of locomotion, behavior, or appearance of the robot. Secondly, the paper delves deeper into how exactly biorobots differ from conventional robots and why one might be preferred over the other. Lastly, the paper focuses on a selection of existing biorobot projects with the focus being mainly on how they mimic their biological counterparts and how they are to be or are already utilized for real world applications.*

Keywords: *bio-inspired, biorobot, biorobotics, biomimicry, robot, robotics*

1 Introduction

To be bio-inspired, a biorobot must obviously utilize biomimicry, which is a designing approach that takes a direct inspiration from nature by copying it or trying to imitate it to a various degree of success [1].

For example, when tasked with the objective of making a flying robot, an engineer could naturally turn their attention to birds or insects and by observing that they fly thanks to their wings conclude that the robot must have wings too in order to fly. Or that a robot that is meant to swim should have fins like a fish and one that is meant to walk should have two or more legs like most land animals. After all, environmental pressures have propagated these traits over the generations, and, therefore, they are evolutionary tested for the purpose they are meant to achieve.

By observing the natural world, one can thus find a solid basis for a technical solution to whatever their technical problem might be. By studying natural design and examining how it works, one can then copy or at least closely imitate the design artificially. In some cases, even possibly improve upon it.

2 Biorobots vs. Conventional Robots

Like any other machine, a robot is created to fulfill a specific task. Generally, this means performing a set of complex movements, either on a predetermined path or an adaptive one. This task can be anything from moving an object from one place to another to monitoring the environment with the use of various sensors. The task itself inevitably dictates the shape and size of the robot.

Conventional robots are generally made of rigid materials like metals. They are made for tasks like heavy lifting, performing repetitive actions, precise and steady maneuvering, or working in inhospitable environments or with dangerous substances.

On the other side, Biorobots have very diverse material composition ranging from being made of only rigid materials to being completely soft. While materials like steel offer structural support, soft materials offer higher flexibility, deformability, and reduced weight. Therefore, soft robots can mold themselves to the shape of their surroundings, cushion impacts without taking damage or move in ways that would have been impossible for their rigid counterparts. However, robots that are entirely soft are harder to control as their movement might be quite unpredictable and unprecise, and they cannot exert large forces because of the dampening capabilities of soft materials. Therefore, biorobots tend to combine both rigid and soft materials [1],[2].

However, using soft materials is not the only way biorobots imitate nature. Biorobots often employ animal-like locomotion, such as walking, slithering, rolling, undulating, or gliding, which allows them to move more effectively travel through environment that a conventional robot could not. For example, a walking robot can easily travel through an uneven terrain a wheeled robot would struggle with. By employing structures such as those resembling gecko's adhesive setae, a robot can gain the ability to climb vertical surfaces [1],[2]. By utilizing specific material properties, for example a photothermal reaction of graphene, a robot made with no joints can still move by repeatedly shrinking and expanding itself [9].

Due to the nature of their design, biorobots tend to be tailored to a very specific purpose unlike conventional robots, so they are not as versatile and are generally only good at doing one single task. At the same time, their specialization means that they also tend to be very efficient at doing this one specific task.

3 Biorobot projects

The projects have been separated into four categories: Aquatic, Terrestrial, Aerial and Insects.

3.1 Aquatic

3.1.1 Eelume [3]

Just like a snake or an eel, Eelume has a long, slender body that allows it to pass through narrow gaps, and, thanks to its body being segmented, has a wide range of motion.

However, unlike either of the aforementioned animals, its modular design allows it to change length by adding or removing modules according to the requirements of the task it is meant to perform. These modules can carry anything from sensors, cameras, tools, thrusters, batteries to even lights.

Just like an eel, it is mean to permanently reside underwater. Either out in the water performing its tasks, or in a standby mode in a docking station, where it is meant to charge, swap out modules and upload its data for further processing. Thanks to having a complementary docking station, it can remain in its area of work, effectively removing the need for remotely operated vehicles, and thus saving time and money, and keeping personnel from being put into potentially dangerous situations.

Its potential utilization field is quite large. However, its current main area of focus is in the oil and gas industry as a means to inspect and maintain pipelines, or intervene in case of an emergency, such as having to shut a valve in order to prevent a leak. It has also been envisioned to possibly help monitor offshore wind farms, fish farms or general quality of water.

Current version of Eelume is not autonomous and thus must be remotely controlled with the help of several cameras mounted on the robot's body. However, an autonomous version is already in works.

3.1.2 SoFi [5]

Mimicking a fish both in appearance and locomotion is the main goal of the SoFi "Soft Fish" project. Just like a real fish, it uses fins to direct its movements in water and can control its buoyancy like a fish does with its swim bladder.

The outside shell of the robot is made of silicone rubber and flexible plastic, which allows the robot to move in an undulating motion, as well as provide a cushioning and protection of the internal parts in the case of a collision, which means the robot can perform more daring maneuvers without the risk of being damaged.

It can maneuver independently for up to forty minutes at a time or be remotely controlled by a diver. It moves around by undulating its tail, which is achieved with a hydraulic pump that alternatingly pushes water in the two chambers situated inside the tail, causing the tail to repeatedly flex in one direction then other. Moving up and down is achieved by pitching the side fins and the buoyancy control unit adjusting the pressure of compressed air in the body of the robot. The robot can dive up to the depth of more than 50 feet.

The robot was developed for the purpose of documenting marine life from as up close as possible. Future improvements of the project are planned to come in the form of an upgraded design and attaching a camera that will allow the robot to follow behind a real fish. Several more SoFis are also being built to be used by biologists for monitoring real fish behavior.

Figure 1: Eelume [4] and SoFi [6]

3.2 Terrestrial

3.2.1 Salto [7]

Salto takes its inspiration from a galago, an African primate whose primary method of moving around consists of big, long jumps, which it is capable of thanks to its ability to supercrouch. Salto was designed to achieve the same as can be seen both from its design and its own name, which is an abbreviation for "Saltatorial Locomotion on Terrain Obstacles".

The robot consists of a single leg, which can achieve the same supercrouch position as a galago. The longer the robot stays in this position, the more energy it can transfer into a jump. When crouched, the energy is stored in a spring, which is kept stretched by a motor. The robot is capable of reaching a maximum height of 1.2 meters in a single jump with the robot itself being not even thirty centimeters tall.

As of now, at full charge, the robot can run for up to ten minutes while continuously jumping or bouncing in place. It cannot autonomously move around yet, but on flat surfaces, it can maintain its balance without outside help thanks to its internal inertial measurement unit. Other simple movements can be achieved with the use of a radio controller. Complex movements like navigating through an obstacle course or jumping onto a moving target can be achieved with the help of a motion capture system and a computer, which take the burden of measuring of Salto's position in space and then calculating its next action away from the robot and simply direct Salto where to go and how to adjust itself to achieve this.

The goal of Salto is for it to eventually aid with search-and-rescue missions, such as in collapsed buildings where it might be dangerous or impossible for human rescuers to move through the rubble. Its unique, lightweight design allows it to jump over obstacles, leap over gaps in the ground and bounce off tilted surface (even a completely vertical one like a wall) to gain altitude or to get in otherwise inaccessible places.

3.2.2 Geca [9]

Taking inspiration both from a gecko and a caterpillar, Geca-robot is one of its kind of a hybrid biorobot. It combines the gait of a caterpillar and the directional adhesive property of gecko feet.

The robot's body is completely soft, which gives it an extreme degree of deformability. It has a rectangular shape that consists two bigger pieces of PDMS (polydimethylsiloxane) with the space between them filled with alternating strips of PDMS and graphene, which act as the caterpillar's body—the 'muscle' of the robot. It also has two sets of triangular PDMS micropillars on its bottom part, which provide adhesion to terrain like a gecko's feet do—the 'feet' of the robot.

When exposed to light with wavelengths ranging from ultraviolet to infrared, the muscle of the robot deforms due to the photothermal effect of the graphene, which causes the muscle to heat up and expand, and front feet to slide forward while the back feet remain anchored where they are. When the light-off state occurs, the muscle begins to cool down and shrink once more and because of the directional adhesiveness of the micropillars the front feet remain anchored while the back feet slide forward. The robot always moves forward in the direction being pointed to by the triangular micropillars, allowing for a stable and reliable locomotion without slipping on both smooth, rough and even wet terrain with the maximum slope of roughly thirty degrees in both upward and downward direction.

Because the locomotion is driven by photo-irradiation, the robot can be controlled remotely with impulses of various lengths, intensity, and wavelengths. The robot has been tested for the working temperatures ranging from -7 °C to 100 °C and can carry up to fifty times its body mass, which could be used to carry small tools through tight spaces or even inside the vessels of a human body if successfully micro-scaled.

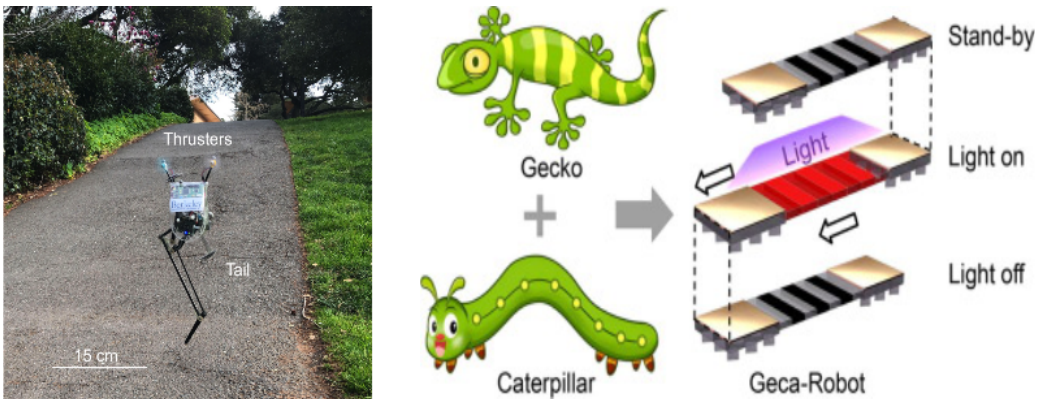

Figure 2: Salto [8] and Geca [9]

3.3 Aerial

3.3.1 Bat Bot B2 [10]

As the name suggests, Bat Bot has been inspired by bats, with the main focus being on the wings and mimicking the way they work. A bat's wing is extremely flexible, which aid the bat when in flight. At the start of the downstroke, they fill up with air which is later expelled at the end of the motion when the wings are their lowest position. This amplifies the power of the flap and thus gains a greater lift for the bat, making it more efficient.

The 'bones' of the bat wing were simplified in the robot design to create a less articulated but still effective joint. The wing membrane itself is made of a highly stretchable, ultrathin, custom-made silicone material that must allow for a change of shape as the wings flap. The flap of the wings is controlled by a crankshaft, which is driven by a brushless DC motor. The robot is equipped with a control board, an inertial measurement unit, a magnetic encoder on each of its joints and data acquisition unit, which collects sensor data and that of the actuators.

The robot is capable of five main motions that a biological wing is capable of. When in flight, the robot operates autonomously and can remain airborne for up to thirty meters. The robot can fly in a straight-line, turn by moving both wings independently of each other and even perform a "shark-dive" maneuver by moving its hind limbs.

The creators see the future of the robot as a replacement to traditional quadrotor drones in situations where it might be dangerous or impossible for them to maneuver

3.3.2 Humming Bird [12], [13]

The uniqueness of a hummingbird lies in its ability to not only fly but also hover in place, which gives it an amazing level of control and maneuverability. This is achievable thanks to its small size and ability to flap its wings extremely quickly when compared to other birds. For these reasons, the hummingbird robot tries to match both factors very closely.

The robot's wings are made from a combination of carbon fiber and a flexible membrane and can move independently of each other. The robot exists in two sizes. The larger version weighs 12 grams, has a wingspan of 170 millimeters and a wingbeat frequency of 34 Hertz, and can carry up to 27 grams of additional weight. The smaller version weighs less than1 gram with a wingbeat frequency four times that of the large version—the smaller the model, the higher the frequency and the more efficient flight. Despite this, the robots are very quiet.

The robot also contains an AI that has been trained with the use of machine learning under several different flight conditions, so the robot is capable of an autonomous flight. It can perform stable hovering, move from point to point, even follow complex paths. It can also sustain a damage to its wings and still maintains stable flight. It can also sense its surroundings as in detecting barriers upon which it will change its trajectory accordingly. Current version is powered by an external energy source, which tethers them to the ground, but future versions are planned to have portable batteries and possibly also be equipped with cameras or a GPS system.

The creators believe that the robot could be useful for rescue operations, such as in collapsed buildings where there is limited space and maneuverability. Thanks to its silent run, it could also be used for covert operations, surveillance and even studying real hummingbirds in their natural habitat.

Figure 3: Bat Bot B2 [11] and Humming Bird [14]

3.4 Insects

3.4.1 Hexapod [15]

Like beetles or bugs, Hexapod too has six legs and a hard exoskeleton. However, its shell is not made of chitin but instead of plastic and it stands much larger with a body length of about 130 millimeters.

The uniqueness of Hexapod is that it requires almost no assembly. Its legs are pushed back and forth by bellows that shrink and expand as the turning crankshaft pumps fluid into them. Both the hydraulic fluid and the rigid and flexible solids that make up the robot are 3D printed during a single run of the 3D printer—an approach that is referred to as “printable hydraulics” by the creators. This means there is no need for assembly except for mounting a DC motor to turn the crankshaft and adding a battery to power the motor. There can also be additional hardware added to enable remote control with the use of a smartphone.

Because most 3D materials are relatively cheap and the robot contains few electronic components, Hexapod is ideal for mass-production. It could potentially be used for cleaning-up nuclear sites where radiation levels are too high for humans and conventional electronics to survive.

However, as of now, a single Hexapod takes about 22 hours to print, which means that a larger scale production will likely not occur until 3D printers are capable of higher production speed.

3.4.2 Water Strider [17]

This microrobot is built to skate atop the surface of the water just like a real-life water strider and to achieves so utilizes several of its designing features among which is a combination of being extremely light as well as having superhydrophobic legs, which helps it to not sink below the water surface.

The microrobot is made of an acrylic plater, a micromotor, foam and several types of metal wires, which are covered in superhydrophobic TiO2 coating, which aids the robot in staying atop the surface of the water as a twice as much force is needed to submerge it than if it were without the coating. The robot moves by paddling its legs, which is achieved by coupling shape memory alloys and a micromotor, which is not powered by an external power source, but instead utilizes the current that is produced as the result of the oxygen reduction reaction taking place between the different metals of the legs and the water they are in contact with. The superhydrophobic coating improves not only buoyancy of the robot but also enhances the output current of this chemical reaction.

Because the microrobot is self-powered, there is a certain weight saved on not having to carry an external power source and thus an additional load can be added without the robot sinking. The output voltage generated by the legs can also be enhanced by using an integrated power management circuit. Both these factors mean the robot can carry and power a sensor, such as a temperature sensor or for example to light a LED. This gives this microrobot a potential for environmental monitoring.

As of now, the robot can operate as intended for up to 40 minutes before the coating dissolves enough for the microrobot to sink. The coating can, however, be quickly reapplied, so a single microrobot can be repeatedly used without needing to swap out components.

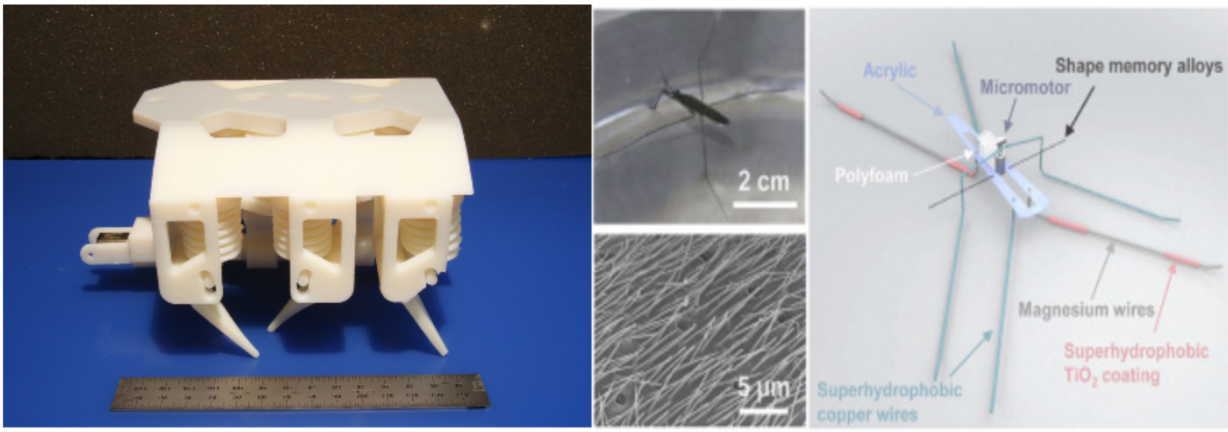

Figure 4: Hexapod [16] and Water Strider [17]

4 Conclusion

As of now, the vast majority of biorobots are used or are planned to be used for collecting data, carrying and operating tools, or performing repairs and monitoring in remote locations that are unreachable by or inhospitable to humans. However, these tasks require a certain level of autonomy from the robot, which is troublesome because the field of artificial intelligence is not yet fully up to the task. While some biorobot projects such as the Humming bird robot [12], [13] have already achieved a certain level of success in this regard, its findings are, unfortunately, not necessarily applicable to other biorobots because of the diversity of the field—biorobots differ in size, shape, form of locomotion and even materials being utilized and thus also inevitably differ in how they must be controlled. Therefore, the usefulness of many biorobots is decreased by the requirement of being remotely controlled by a human or a computer. There are only so many units a computer or a human can manage to control and in the case of connection being lost between the robot and its master, the results might lead to accidents such as the robot getting damaged or somebody getting hurt.

On the other hand, biorobot projects offer an alternative to rigid robots where it might be impractical or impossible to use them. Biorobots also quite often make use of softer materials. Thus, biorobots can be cheaper to make than conventional rigid robots meant to serve the same purpose. Softer materials also offer biorobots certain advantages such as better energy-absorption upon impact. Therefore, biorobots can employ different planning algorithms that take for example more daring turns and collision does not necessarily need to be avoided. Many biorobotic projects also bring into existence completely new materials that might find usage even in other fields beside robotics.

Just like conventional robots, biorobots too have they pros and cons. It is no one size fits all solution, but they offer another approach to solving technical problems. Considering the vast size of the animal kingdom and thus also the immeasurable amount of knowledge that it therefore contains and that is yet to be uncovered, it is inevitable that despite aforementioned problems, the field of biorobotics will continue to grow and expand in the upcoming years.

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