Overview of Biomimetic Robotics

Robotics Mechanical Systems Advanced Research Report

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This report gives an overview of the current status of biomimetic robotics. It covers the currently available types of robotics and the industries these machines are used in. It also briefly explores the future prospects of this field.

Keywords—biomimicry; robotics; nature;

I. Introduction

Humans have been inspired by nature's naturally evolved creations and have been mimicking it for many years. Both Leonardo DaVinci and the Wright brothers took their flying inspiration from birds (Frishberg n.d.) and the creator of Velcro, George de Mestral, was inspired by the hooks of burseeds (Lurie-Luke n.d.). Since then advances in both robotics and artificial intelligence have allowed the field of biomimetic robotics to develop (Mattar n.d.). Applying biomimicry principles to our technologies allows us to understand, adapt and solve complex control, manipulation and manoeuvrability problems (Frishberg n.d.). While biomimetic robotics spans over a large number of fields, this paper will mainly focus on materials, locomotion and behaviour.

II. Types of Mimicry

Within the field of biomimicry, there are a numerous of areas of interest. A number of these areas are discussed below.

A. Material

As discussed in (Lurie-Luke n.d.), biomimetic materials can be categorised into four different groups:

i. "smart materials inspired by nature's ability to react and change in response to external stimuli
ii. surface modifications which include novel surface topographies with improved functions
iii. material architectures which feature novel shapes and structural arrangements
iv. technologies which are based on enhancing existing systems using specific parameters of an adaptation (rather than developing an entirely new technological platform)"

One example of a material reacting to its environment is evident in butterfly wings. Butterfly wings allow light to reflect off of them which allow them to change colour. An iridescent coating has been created using similar principles which allow vehicles, such as some Range Rover models, to have a colour which does not fade and changes colour depending on how the sun is reflected off it (Frishberg n.d.).

B. Locomotion

Biomimicry also has a major impact on robotic locomotion and kinematics. As with materials, the locomotive biomimicry can be put into a number of categories:

i. "improvement based on movement kinetics
ii. improvement based release mechanisms (means of dispersal across an environment)
iii. improvements based on structural configuration (energy efficient shapes)" (Lurie-Luke n.d.)

Inspiration for mimicry can come from both animals and humans.

1) Animals

A lot of research has gone into trying to figure out how different animals travel. These include animals from all three physical environments: land, sea and air (Lurie-Luke n.d.). Animals such as fish and squids, to two-, four- and six- legs robots have been investigated (Frishberg n.d.).

a) Soft Robotics

One form of biomimetic robotics that has recently advanced by mimicking animal materials is the field of soft robotics. Soft robotics allows for soft and deformable robotics (Guizzo n.d.). This material is already being used in a number of robots. In 2013 a company named Festo designed their 'AqauJellies 2.0" soft robot (Festo, n.d.).

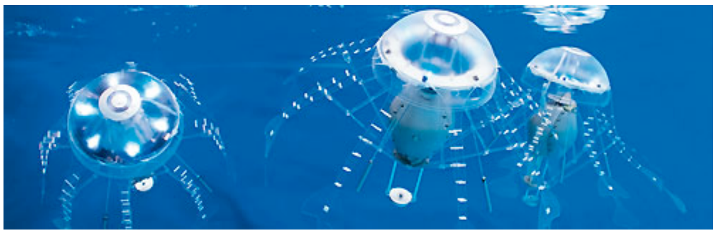

Figure 1: Festo AquaJellies 2.0 (Festo, n.d.)

The propulsion of this soft robot is controlled by alternating between tension and pressure flanks. This causes the robots 'tentacles' to move in a wave-like motion, bending when under tension and then relaxing. This is very similar to the way jellyfish move in real life.

Additionally, researchers at Harvard University have created a robot that is inspired by animals that lack internal skeletons such as squids and starfish. (Shepherd, 2011).

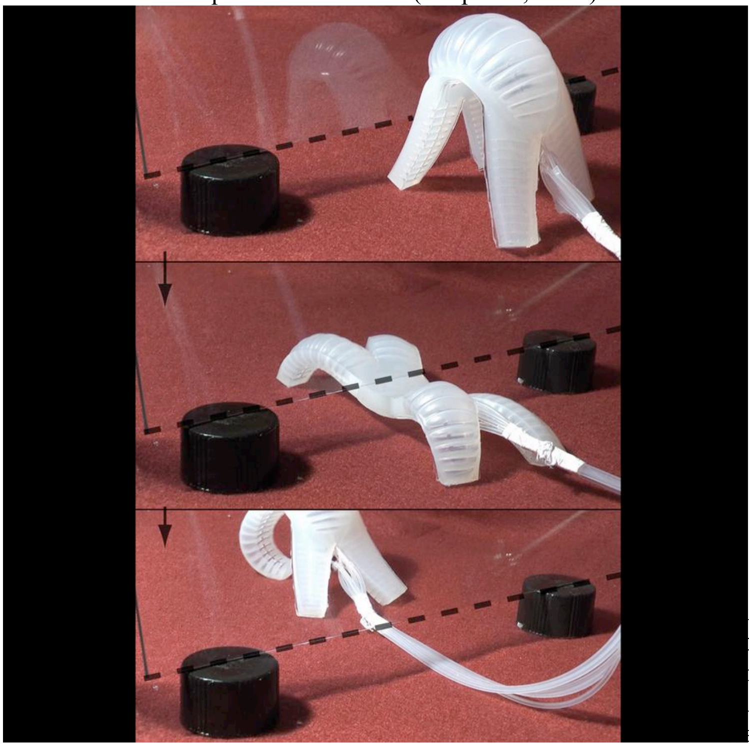

Figure 2: Harvard University tetrapod (Shepherd, 2011)

This robot uses a mixture of crawling and undulating gaits. As with the 'AquaJelly' *(Fig. 1)* the robot flexes when pressurised. As the robots structure is separated into a number of compartments, different areas can be pressurised allowing different movements. The soft material of the robot allows it to move underneath an obstacle as can be seen in *Fig. 2.* This task would be almost impossible for a hard robot. Soft robots tend to be very flexible and this makes them very resilient and hard to damage (Shepherd, 2011).

b) Birds

As previously discussed, the biomimicry of birds has been around ever since humans wanted to fly. Travelling through air and water share similar properties. In the air however thrust has to be generated. Festo created both marine *(Fig. 3)* and air *(Fig. 4)* biomimetic robotics and filled the air robots with helium

Figure 3: Festo AquaPenguin

Figure 4: Festo AirPenguin

Another robot that has been designed to mimic a bird is the obotSwift (Lurie-Luke n.d.). The RoboSwift is a micro roplane with moveable wings. It has a streamlined design th allows its to adjust the wing area and camber in the same ay a swift would.

c) Insects

Insects also have many properties that humans have learnt a lot from. The locomotion of cockroaches has been investigated during the development of "iSprawl" (Lurie-Luke n.d.). The iSprawl, like a cockroach, has 6 legs and by modelling it on the cockroach allows it to investigate natural locomotion dynamics and the optimal arrangement of 6 legs.

Another robot inspired by insects is Boson Dynamics' 'Sandflea' (Boston Dynamics, n.d.).

Figure 5: Boston Dynamics Sandflea (Boston Dynamics, n.d.)

The ‘Sandflea’ *(Fig. 5)* robot mimics the way in which fleas can jump and this robot can jump an impressive 1-8 metres. It is extremely robust and water resistant, allowing it to recover well from falls undamaged.

d) Mammals

The gait of much larger mammals has also been researched. Boston Dynamics’ ‘Cheetah’ robot is based off the cheetah which is the fastest land animal. By mimicking this animal, it has allowed the creation of a robot that can travel 29 mph which is a land speed record for legged robots (Boston Dynamics, n.d.).

Another biomimetic mammal that has been mimicked is the Kangaroo. Kangaroos are well known for their ability to jump and stabilise themselves. Festo’s BionicKanagaroo (Fig. 6) is able to store the energy of its jumps just like a real kangaroo. (Festo, n.d.)

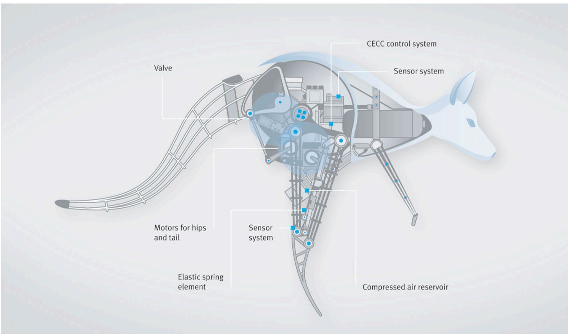

Figure 6: Festo BionicKangaroo

2) Human Limbs

As well as mimicking animals to learn and develop our technologies it has also be beneficial learning from our own bodies. There are many people who have physical disabilities who may be aided by biomimetic technologies.

a) Bionic limb

Human hands are often mimicked in robotics due to curiosity over its complexity (Mattar, n.d.). There is a number of advantages to having a bioinspired hand rather than a gripper. For example, by increasing the number of degrees of freedom it allows the robot to grasp a wider variety of shaped objects (Fig. 7) (Mattar, n.d.). Additionally, by mimicking the human hand it allows the user to fully control it in a more intuitive manner.

Figure 7: ShadowRobotics Dexterous Hand (Shadow Robotics, n.d.)

b) Artificial Muscles

Another thing that has aided the creation of biomimetic limbs is the development of artificial muscles. The ‘muscles’ are mimicked using Electro-active Polymers actuators. It has been found that actuators using these materials behave very similar to biological muscles (Mattar, n.d.).

c) Exoskeletons

A final example of human based biomimetic robotics is exoskeleton (Fig. 8). Exoskeletons have been used in a number of different applications. Military personnel have used them in order to prove extra strength, allowing them to carry heavier equipment. Additionally, it has been used in rehabilitation (Gopura, n.d.), allowing users to move joints they may not have the strength to do so otherwise.

Figure 8: RexBionic (Rex Bionic, n.d.)

C. Behaviours

As well as looking at the physical properties of nature there is also a lot to learn from their behaviour. As discussed in (Lurie-Luke n.d.), a single ant on its own is limited by what it achieves, however when a number of ants are put together they act as a unit which is known as a swarm. By implementing this swarming behaviour within robots it allows robots to work together to achieve a much larger and more complicated task which would be impossible to achieve alone.

III. APPLICATIONS

Biomimetic robotics are used in a number of different applications. These range from medicine to space to the defence sector. In all these fields, nature has provided a way of improving the required technologies.

A. Medicine and Surgery

As discussed earlier, biomimetic robotics plays a large role in the creation of bionic limbs and exoskeletons. Assistive biologically inspired robots provide an important rehabilitation role. (Gopura, n.d.) Another way in which nature can help aid medicine is in relation to drug delivery technology. Animals such as sea anemones and corals have stinging cells that can inject the skin. This is particularly beneficial for transdermal drug delivery as it would allow for the skin barrier to be penetrated. (Esther Shaoul, 2012)

Soft robotics can also be used to assist minimally invasive surgeries. Using an octopus inspired robot allows the soft instrument to reach areas of the body that solid instruments may struggle to reach. Additionally, due to soft robots having the ability to stiffen varying parts, there is the possibility of it being able to hold organs out the way while working on another part of the body (T Ranzani, n.d.).

B. Automobile

Biomimicry is also used in the automotive industry. With the increased research in self-driving cars, the need for reliable collision avoidance systems has increased. In 2008, Nissan engineers looked at the behaviour of bumblebees in order to tackle this problem (Frishberg n.d.) as bumblebees are well know for avoiding obstacles when travelling at speed.

C. Military

The military have also invested in a lot of money towards biomimetic robotics. Boston Dynamics' 'Big Dog' robot is a rough terrain robot using animal-like mobility.

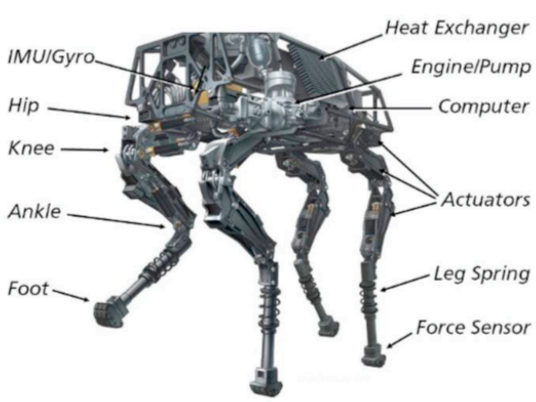

Figure 9: Boston Dynamic Big Dog (Raibert, 2008)

'Big Dog' *(Fig. 9)* can access areas where wheeled and tracked robot cannot go allowing it to acts a way of carrying bags for the military.

D. Space

In (Frishberg n.d.), it is noted that biomimetic robotics can also prove beneficial in space explorations. By imitating the chimpanzees knuckle walking it would allow for the creation of a robot that could walk on two and four feet thereby increasing the effectiveness when exploring difficult terrain.

IV. FUTURE WORK

There are still many aspects of nature that we are still trying to learn from to improve our technologies and robots. One example is the creation of self-assembled robots. This stems off the idea of swarm behaviours and would allow a robot to modify itself to create the ideal structural arrangement (Lurie-Luke, n.d.). This also brings us into biological biomimicry where researchers are trying to use genetic algorithms and neural networks to create the idea of intelligent robotics.

As well as this there is still many materials in nature that people are investigating. The chameleon and cuttlefish are able to change their colour which could be of particular interest to the military for camouflage (Lurie-Luke, n.d.).

V. CONCLUSION

In conclusion, it is clear to see that biomimetic robotics has many applications. It allows humans to build on what nature has taken years to create as inspiration for our own technologies.

VI. BIBLIOGRAPHY

Boston Dynamics *CHEETAH - Fastest Legged Robot*, [Online], Available: HYPERLINK "http://www.bostondynamics.com/robot_cheetah.html" http://www.bostondynamics.com/robot_cheetah.html [23 April 2016].

Boston Dynamics *Sand Flea Jumping Robot*, [Online], Available: HYPERLINK "http://www.bostondynamics.com/img/SandFlea%20Datasheet%20v1_0.pdf" http://www.bostondynamics.com/img/SandFlea%20Datasheet%20v1_0.pdf [12 April 2016].

Festo *AquaJelly*, [Online], Available: HYPERLINK "https://www.festo.com/net/SupportPortal/Files/42072/Festo_AquaJellies_en.pdf" https://www.festo.com/net/SupportPortal/Files/42072/Festo_AquaJellies_en.pdf [12 April 2016].

Festo *Bionic Learning Network Projects 2013*, [Online], Available: HYPERLINK "https://www.festo.com/group/en/cms/10223.htm" https://www.festo.com/group/en/cms/10223.htm [12 April 2016].

Festo *BionicKangaroo*, [Online], Available: HYPERLINK "https://www.festo.com/group/en/cms/10219.htm" https://www.festo.com/group/en/cms/10219.htm [23 April 2016].

Frishberg, M. (2015) 'What Would Nature Do? The Rise of Biomimicry', *Research-Technology Management* , vol. 58, no. 6.

Gopura , R.A.R.C., Bandara, , Kiguchi, and Mann, (2016) 'Developments in hardware systems of active upper-limb exoskeleton robots: A review', *Robotics and Autonomous Systems*, vol. 75, January, pp. 203-220.

Guizzo, E. (2012) 'Soft Robotics [Turning Point]', *Robotics & Automation Magazine*, vol. 19, no. 1, pp. 128-125.

Lurie-Luke, E. (2014) 'Product and technology innovation: What can biomimicry inspire?', *Biotechnology advances*, vol. 32, no. 8, pp. 1494-1505.

Mattar, E. (2013) 'A survey of bio-inspired robotics hands implementation: New directions in dexterous manipulation', *Robotics and Autonomous Systems*, vol. 61, no. 5, May, pp. 517-544.

Raibert, M., Blankespoor, , Nelson, and Playter, (2008) 'Bigdog, the rough-terrain quadruped robot', *In Proceedings of the 17th World Congress*, vol. 17, no. 1, pp. 10822-10825.

Ranzani, T., Gerboni, , Cianchetti, and Menciassi, (2015) 'A bioinspired soft manipulator for minimally invasive surgery', *Bioinspiration & biomimetics*, vol. 10, no. 3, May.

Rex Bionic *Rex Bionic*, [Online], Available: HYPERLINK "http://www.rexbionics.com" http://www.rexbionics.com [23 April 2016].

Shadow Robotics *Shadow Dexterous Hand*, [Online], Available: HYPERLINK "http://www.shadowrobot.com/products/dexterous-hand/" http://www.shadowrobot.com/products/dexterous-hand/ [23 April 2016].

Shaoul, , Ayalon, , Tal, Y. and Lotan, (2012) 'Transdermal Delivery of Scopolamine by Natural Submicron Injectors: In-Vivo Study in Pig', *PloS one*, vol. 7, no. 2, February.

Shepherd, R.F., Ilievski, , Choi, , Morin, S.A., Stokes, A.A., Mazzeo, A.D., Chen, , Wang, and Whitesides, G.M. (2011) 'Multigait soft robot', Proceedings of the National Academy of Sciences, 20400-20403.