

The application of the efficiency movement of animals in robotics

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Abstract. In recent decades, robotics has witnessed exponential growth and widespread application across various domains such as manufacturing, healthcare, agriculture, and civil engineering. However, the significant energy consumption of current robotic systems has become a limitation for robotics. The efficiency movement of animals, which can be used to design and apply in robotics, can help reduce energy consumption. This review explores whether animal movements can contribute to energy savings in robotics. It seeks the existing applications of biological movement principles in robotic systems, analyzes the rationale behind their animal models, and discusses the challenges faced. By studying this paper, it is concluded that the biological movement can save energy and provide insights for the future development of energy-efficient, bio-inspired robotic systems.

Keywords: Robotics, Energy Efficiency, Bionics, Robotics Movement.

1. Introduction

In recent decades, robotics has experienced exponential growth all over the world. In modern daily life, everyone can witness their existence. For example, robotics can be applied in manufacturing and the healthcare domain [1], which can help to improve efficiency and save labor costs. However, despite their widespread application, the drawback of current robotic systems is the high energy consumption. Robotics may waste a lot of electric power since present robotics prioritize their own performance more than energy consumption, and it has been widely applied worldwide. These reasons would waste too much energy and increase the cost of their functioning.

Moreover, it may even cause chaos in the energy-providing system. Above all, it is necessary to save electricity. According to research, the bio-inspired design, which simulates animals' movement and structure, can save 25% of its electric energy compared to the traditional robotics arm [2]. For example, if one traditional industrial robotics arm consumes 4 kWh when it works, the bio-inspired robotics arm will save 1 kWh, which will light one hundred 10-watt light bulbs for the whole hour. This highlights the significant potential of animal movement efficiency in solving the energy challenges of robotics.

This article focuses on three core research objectives. The first goal is to investigate which movements of animals can contribute to saving energy in robotics and explain why this biological movement principles can be used to enhance energy efficiency. This article may also explore how the structure works and the designs that can be applied to robotics. The second goal is to determine whether some biological movement has been successfully used in robotics and how much energy can be saved during its general application. Some specific cases of bio-inspired robots and analyzing their energy efficiency improvements may be involved in this part. The third goal is to determine why these animals are chosen and the challenges they face during the application or studying process. Some examples or data analyses may be presented in this part.

2. Energy Consumption Issues in Modern Robotics

Robotics has spread widely all over the world. They have already changed how every industry works and satisfy societal needs. In manufacturing, robotics has already become the symbol of modern production. According to the H2020 Robotics Multi-Annual Roadmap [1], robotics has already been widely popular in manufacturing, healthcare, agriculture, civil, etc. In the manufacturing

domain, robotics can be helpful in manufacturing companies. In particular, the robotics arms are widely applied in these companies, such as car manufacturing, electronics production, and consumer goods. For example, manufacturing companies have a growing demand for robotic arms in Europe, and the density of robotic arms is trending to converge [3]. These robotics arms can handle complex tasks with accuracy and enhance production efficiency. The healthcare domain can also benefit from robotics. Robots may assist medical personnel in looking after patients, such as lifting and moving patients, monitoring vital signs, and even helping finish surgeries. For instance, some skin surgeries have been carried out using robotics, which can significantly enhance the accuracy of the surgery and save the medical workers' energy [4]. In agriculture, the explosive population growth has led to a growing demand for food, which has led to the need for more efficient farming production. Therefore, robotics needs to be applied since it can increase efficiency. These robots can operate 24 hours per day and can seed, harvest, cultivate, and even monitor the growth of the crops [5]. In civil engineering, robotics has totally changed the construction logic and improved efficiency. Due to the growing city population, the need for building and houses is also increasing. Huge machines, such as digging machines and tower cranes, are the most common in civil engineering. They can be controlled by a robotic system and perform tasks like lifting heavy materials [6]. Another fun fact is that elevators appeared earlier than modern buildings. The application of elevators also represents the application of robotics in citizens' modern lives. However, such robotics have been applied in many domains, representing so much electric power that the robotics consume. If some wasted electric power can be saved, it can be easier for robotics to spread worldwide. So it is meaningful to learn and discuss how to save energy.

3. Bio-Inspired Principles for Efficiency

3.1 Biological Energy Distribution Mechanisms

As mentioned above, given the widespread use of robotics, it is essential to save the electricity used by robotics. Researchers have developed various methods to improve the efficiency; among them, bio-inspired robotics can show a significant promise. For example, the first method is autonomous legged robotics based on bionic multi-stage energy supply [7]. According to this article, this method gains principles from the biological energy supplementation mechanisms, where animals can efficiently manage energy usage during movement. To improve the efficiency of legged robots, the simulation of the biological energy supplement can be carried out. It is a multi-stage energy supply system with a low-pressure variable pump and other high-voltage sources. This idea can optimize the energy distribution. On the contrary, the single-stage energy supply system, which is a standard energy supply system, has only one composition. Compared to the normal one, the multi-stage system can offer some advantages. For example, the system's efficiency can be higher, and energy can be saved. By adjusting the energy supply strategy based on the environment, energy waste can be minimized. However, the system also brings challenges; the trim control is tough.

3.2 Structural and Movement Adaptations in Animals

The second method is the distributed energy form from the Bio-inspired Robotics and Enabling Technologies [8]. According to this article, the traditional energy distribution system method often relies on centralized batteries in robotics, which has many drawbacks. For example, the batteries are too heavy, which adds to the overall weight of the robotics. The weight may limit the design of robotics, which will increase the complexity of the design. The weight may also limit the flexibility and universality of robotics. At the same time, the energy density of the centralized batteries is low. The robotics' lasting time may not be long enough, increasing the recharging frequency. However, in contrast, the biological method, which applies the distributed energy form, can improve the energy density and operational reliability, as energy can be supplied where and when it is needed most. This method indicates that energy storage is distributed in the robotics' structure and does not rely on a centralized energy form. Then, the weight can be reduced as well. And finally, save the energy of

robotics. The above articles discuss biological movement in theory. But has such technology already been put into practice? This question requires further examination.

4. Applications of Animal-Inspired Robotics

4.1 Reindeer-Inspired Legged Robotics for Rough Terrain

Several biological movements have been applied in practice. According to this article [9], one notable application is the development of a brand-new mechanical foot inspired by the structure of a reindeer's foot. Traditional mechanical feet often struggle with attachment to complex surfaces and consume much energy, particularly when operating in uneven terrains. However, the newly developed mechanical foot has better attachment performance and energy-saving than the traditional one. The reason behind such improvement is quite simple: the new mechanical foot utilized the structure of a reindeer's foot. The reindeer has a foot structure suitable for migrating to complex environments, including snow, ice, and rocky terrain. Such a biological structure can help to improve the energy efficiency and angle during the movement. During the development, researchers have overcome several technical problems, such as transmitting the structure of the reindeer's feet to the mechanical feet. By designing and testing, these problems have been overcome. The mechanical foot has a power range from 2.77 to 27.85 W, which can be 94% of the energy in the traditional mechanical foot. This reduction in energy usage makes applications such as search-and-rescue robots operating in remote environments possible, where energy supply is limited.

4.2 Fish-Inspired Swimming Robots for Underwater Efficiency

Some other animals are also the basis of these robots. According to Towards power cost analysis and optimization of a multi-flexible robotic fish [10], the development of flexible robotic fish was inspired by natural fish. Fish have evolved efficient swimming mechanisms, flexible bodies, and streamlined shapes that can minimize drag and energy consumption. Traditional underwater vehicles often use propellers, which may waste much energy and be less flexible. However, flexible robotic fish, which simulate the movement of natural fish, can save a lot of energy. Though the challenge of the flexible deformation mechanism's complexity still exists, the principle of natural fish can be applied to mechanical fish. The energy can be saved, and the movement can be more flexible with such a structure. The energy saving achieved by such robotic fish is noticeable; the robotic fish can save 28.3% of the COT compared to traditional water robotics. The COT measures energy efficiency, which is calculated as the energy consumed per unit distance traveled per unit mass. This improvement in energy efficiency makes the robotic fish suitable for long-time underwater missions, such as environmental monitoring, fish catching, and underwater exploration.

As discussed above, such efficient robotics have already chosen some animals to simulate. The principles behind robotics are not hard to find, but why choose these animals as the base for robotics? This question needs to be discussed further.

4.3 Rationale for Animal Selection

The selection of specific animals as model to design robotics is based on their structure, which evolved for the complex environment and energy saving. The reindeer and the fish are chosen for several reasons. The reindeer is chosen for its adaptation to several complex environments. For example, the feet are composed of three layers with a porous structure [11]. The structure of its feet helps the reindeer adapt to the severe environmental conditions with many advantages. For example, this structure can efficiently reduce weight and pressure on the ground and prevent sinking on soft surfaces like snow. It would also provide insulation, protecting the reindeer's feet from extreme temperature changes. Additionally, the flexible foot enables it to fit and cross over the uneven terrain, improving stability and reducing energy loss during movement. These adaptations make reindeer feet an ideal model for robotic feet operating in challenging environments.

The fish is chosen for its flexible and streamlined body. Due to its body structure and muscle strength, the fish can swim underwater at high speeds [10, 12]. The streamlined body minimizes the drag under the water, allowing fish to swim faster with less energy. Also, the muscle arrangement enables the fish to swim freely and flexibly. Their speed can reach 2.5 to 4 BL/s. Such characteristics of natural fish make them suitable models for robotic fish.

In general, the above animals are chosen for their characteristics. Their body structure has evolved to handle complex and frequent environments over millions of years. Also, learning their body can save energy. Robotic designers can create more efficient, adaptable, and suitable systems for further applications by simulating these animals and their structures.

5. Challenges

5.1 Ethical challenges

Despite the promising results of bio-inspired robotics, several challenges still exist. One of the significant challenges is in the domain of ethics and security, according to Sophia Lin [13], especially in the ethical aspects. For example, when applying robotics, people may worry about ethical problems, such as arguing and debating for enhancement versus restoration. Additionally, long-term clinical studies are required to ensure the safety and effectiveness of medical robots, which can be time-consuming and costly. The military competition, which may damage the world's peace, may be brought to the world again.

5.2 Material challenges

A similar challenge can be witnessed in the materials fields. For example, soft muscle, which aims to simulate the flexibility of biological organisms, relies heavily on advanced materials. However, Maxwell Hammond wrote in his article that the artificial muscles have expanded the potential function of soft robotics. However, the design of soft robots is still in early stages [14]. One key issue is the still-developing models for the newly available materials [15]. These materials often have complex mechanical properties and are difficult to control, making it challenging to design soft robots. Also, the artificial muscles may limit the durability or energy efficiency compared to their biological counterparts.

5.3 Algorithmic challenges

Furthermore, the complexity of biological movement itself presents a challenge. Biological movements need multiple systems to cooperate to achieve efficient movement. It can be highly complex if researchers try to simulate this coordination in robots. Developing control algorithms that balance biological movement's dynamic and adaptive nature requires a deep understanding of biology and robotics. Some articles about this area can be found [16], which can also be used to control muscles. But more research may also be required.

6. Conclusion

In conclusion, the efficient movement of animals can provide a promising future for robotic systems. The research reviewed in this paper pointed out that bio-inspired design can help improve robotic efficiency. Movement of reindeer should be the base for legged robotics since the reindeer's feet can tread uneven ground, and their feet, through millions of years of evolution, can naturally have better structures to save energy. For underwater robotics, the natural fish should be the base since the fish has a streamlined body and a rational muscle structure, which can help them swim freely and efficiently. For legged robotics, 6% of energy can be saved, while for underwater robotics, 28.3% can be saved by learning from a fish's body. The field of bio-inspired robotics can be continued by understanding whether animal movements contribute to energy efficiency, finding practical applications, and overcoming associated challenges. Future work should build on these findings,

focus on overcoming the current challenges, and explore new animal models and movement principles.

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