Research Of Bio-Inspired Compliant Legged Robot Designs

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Abstract. With the rapid advancements in technology, particularly in material science and kinematics, bio-inspired compliant legged robots are garnering global attention for their superior efficiency and adaptability across diverse environments. Those robots have significant advantages over traditional counterparts that lack flexibility for real-world application. This burgeoning field of research is increasingly focused on the practical applications of bio-inspired robotics, drawing inspiration from a wide range of creatures, from mammals to arthropods, which serve as exemplary models for efficient locomotion. The unique locomotive strategies of these biological entities, characterized by their resilience, agility, and energy efficiency, are being meticulously studied and replicated in robotic designs. These robots, equipped with compliant mechanisms and advanced materials, promise to revolutionize the way this paper approach tasks in challenging environments, from disaster recovery operations to environmental monitoring. The emphasis on mimicking the intricate movements and physical adaptations of these creatures not only enhances the robots' operational capabilities but also opens new avenues for innovation in robotic mobility and interaction with complex terrains.

Keywords: Amplifiers; Optical Fiber; Bismuth-Doped.

1. Introduction

A robot is a machine designed to execute one or more tasks automatically with speed and precision. There are as many different types of robots as there are tasks for them to perform. A robot can be autonomous, semi-autonomous, or remotely controlled. It may operate in a controlled environment such as a factory, or in the wild. Robotics integrates various disciplines, including mechanical engineering, electrical engineering, computer science, and others. In order to create machines capable of performing tasks in an automated fashion, robots are often required with precision and efficiency beyond human capabilities. Bio-inspired compliant legged robot designs are at the forefront of robotic innovation, and aim to mimic the efficiency, agility, and adaptability of biological organisms in robotic form. Drawing inspiration from the animal kingdom, these robots leverage flexible materials and structures to achieve a level of dynamic interaction with their environment that rigid robots cannot match. This approach not only enhances the robots' ability to navigate complex terrains but also significantly improves their energy efficiency, since they can utilize natural dynamics for movement. Such designs often incorporate elements like soft actuators to closely duplicate the locomotion and behavior of animals. By studying and emulating the biomechanics of creatures ranging from insects to mammals, engineers and researchers are developing robots capable of performing a variety of tasks. This emerging field not only pushes the boundaries of robotics but also offers profound insights into the workings of natural systems. Also, this scientific field anticipates a future where robots can seamlessly integrate into and interact with the natural world.

2. Bio-Inspired Compliant Legged Robot Designs

Based on the survey of existed compliant legged robots, there are several priorities, what subsequent researchers should focus on, and obstacles in further development of compliant legged robots. For the research priority, compliant mechanism and compliant robot legs will be frequently used in running robot. Furthermore, adding spine, cooperating with other parts of robot, in robot and developing advanced material would be the major research field. The challenges could be concluded in four parts. First, the bionic principles of animal locomotion and their implementation in legged robots inevitably exhibit differences. Second, traditional actuation system puts limit on robot's performance. Third, nowadays material and design technologies constrain the production of robots. Fourth, running robots require complex modeling and complicated control system [1].

His study introduces a novel underactuated hexapedal robot, inspired by the passive dynamics observed in rapidly running arthropods like cockroaches, achieving significant speed and agility. The robot, weighing 24 grams and measuring 10 cm in length, can run at speeds up to 14 body lengths per second and execute dynamic turning maneuvers. Its design incorporates parallel kinematic mechanisms and viscoelastic polymer legs with tunable stiffness, produced using the scaled smart composite microstructures (SCM) process. The research validates the lateral leg spring (LLS) locomotion model, which demonstrates that dynamic turns are feasible through the modulation of leg stiffness. In both straight ahead running and turning, the approximate speed of robot was 1.4 m/s or 14 body lengths/s, showed in Fig.1. Data for the left turn show a mean turning rate of approximately 75 degrees per second, while the mean turning rate for right turns is approximately 50 degrees per second with significantly more variation in the data, showed in Fig.2. A pioneering aspect of the design is the incorporation of active stiffness control in the legs through shape memory alloy, enabling the robot to perform nearly gymnastic 90° turns in just five strides. This work not only showcases a significant advancement in robotic design for rapid and agile movement but also suggests potential applications in areas requiring efficient navigation [2].

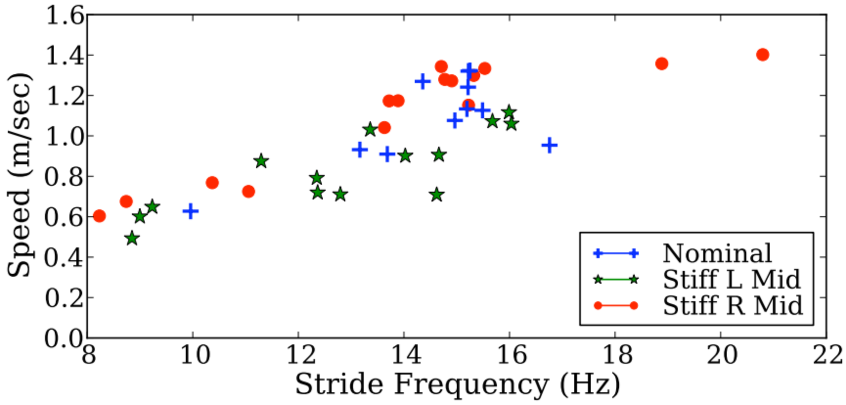

Fig. 1 Forward speed vs. stride frequency [2]

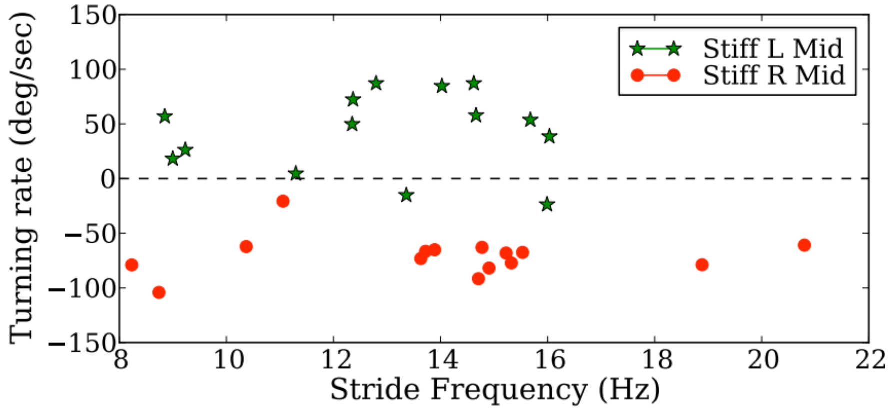

Fig. 2 Turning rate vs. stride frequency [2]

This research acquires inspiration from small jumping creatures. The robot is able to use catapult-like jump, based on the mechanism that stores and release elastic energy. Its compliant front legs are entirely passive, which is capable of reserving energy by utilizing portion of impact of landing. The average jumping length of 320 mm is in accordance with the reference take-off velocity of 1.5 m/s. As expected, the mean speed is strongly affected by the time needed to repeat the jump. The jumping robot is able to repeat the jump every about 900 ms. the spring's stiffness and its capacity for extension are carefully calibrated to meet design and energy requirements, ensuring that premature loss of contact with the ground is avoided. It also means that the robot doesn't take off before its legs are fully extended [3].

The study presents a novel approach to designing compliant robot legs inspired by the limb structures of the Chinese mitten crab which is indicate in Fig.3. Utilizing a combination of hard and a flexible thin-wall spring steel sheet (FSSS) to mimic the crab's exoskeleton and muscles, researchers developed a leg that can bend and stretch through a single motor actuation. Through kinematic modeling, rigid-flexible coupling dynamic simulations, and prototype testing, scholars verified the effectiveness of this design. Furthermore, based on experimenters designed a multi-legged robot with eight compliant legs, which incorporate crab-like gaits to enhance its adaptability across various terrains and tasks, such as traversing low channels, walking on slopes, and carrying loads. The study demonstrates that the single-motor-actuated compliant legs, combined with the dynamic coupling with the robot's rigid body, with ground clearance and adaptive walking capabilities. This leg design methodology offers a compact, lightweight, mechanically simple, safe, and easily controllable solution for developing multi-legged robots for applications like environmental monitoring and search operations (Fig. 4) [4].

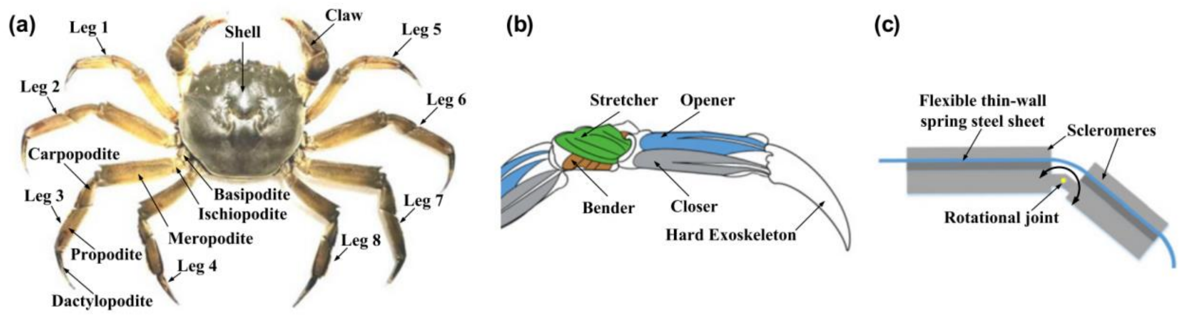

Fig. 3 Crab-inspired compliant leg design method for legged robots. (a) The body structure of Chinese mitten crab. (b) motion mechanism of crab legs. (c) Crab-limb inspired novel joint mechanism for legged robots [4]

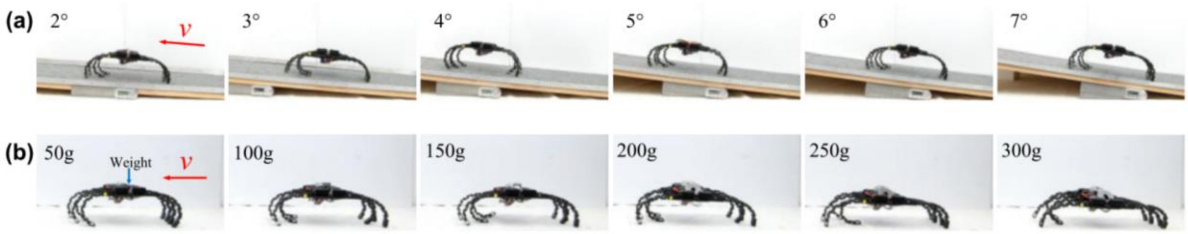

Fig. 4 Slope climbing and weight carrying abilities of the robot. (a) Pictures of the robot walking on slopes of 2◦, 3◦, 4◦, 5◦, 6◦, and 7◦, respectively. (b) Images of the robot carrying different weights of 50 g, 100 g, 150 g, 200 g, 250, and 300 g, respectively [4].

The development of robots inspired by biology is taking robotics into exciting new areas, especially for working in natural settings. These robots are special because they use ideas from how living things move and control their actions, making them very strong and able to adapt to different situations. When designing robots, whether they are stiff or flexible, a big question is figuring out how to balance the robot's own decisions with automatic responses to the environment. Studies on robots with legs show how tricky it can be to manage how they touch the ground, while research on soft robots reveals their ability to handle bumps, change their shape, and be safe around people and in nature [5].

A robot, designed after the basilisk lizard, has been shown in Fig.5 could move across water surfaces effectively. This paper focuses on creating a design that allows the robot to move efficiently both on land and water. It introduces a flexible footpad that can convert elastic energy into forward movement, using a model called the pseudo-rigid-body model for this purpose. By dynamically modeling the footpad and the robot, it establishes a standard for effective movement on land. When moving on water, the flexibility of the footpad helps in reducing the drag force. The paper also explores an optimized design that considers movement in both environments and analyzes its stability through something called the Poincare map [6].

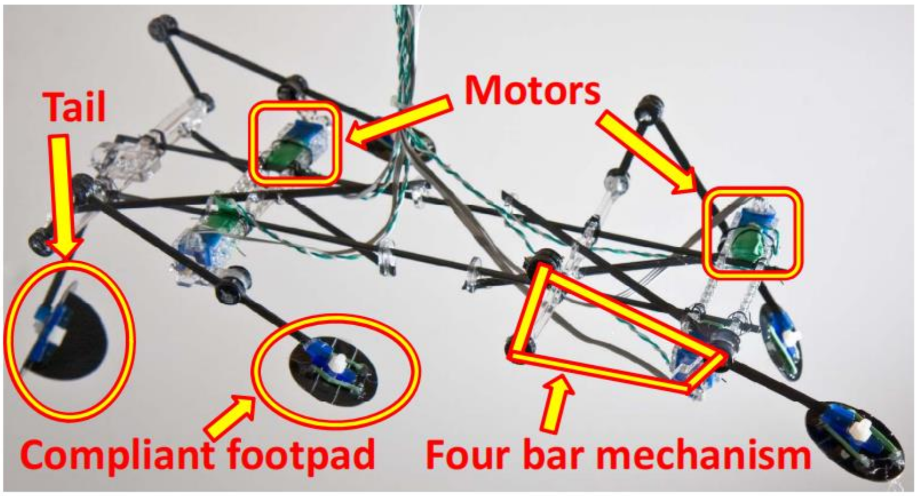

Fig. 5 The lizard-inspired robot [6]

This article presents the creation of a jumping robot, which draws inspiration from the how locusts leap. Initially, the processes of jumping, self-correcting after a fall, changing direction, and modifying the angle of launch are both modeled and simulated. Following this, a three-dimensional design of the robot is developed, which lead to the construction of a prototype. The jumping action is powered by an eccentric cam that compresses torsion springs to store energy and then releases it rapidly. The robot's ability to self-right, change direction, and adjust its jumping angle is facilitated by a rotatable pole leg. This pole leg helps the robot stand up if it tips over. It also allows the robot to make gradual turns. By shifting its center of mass using the pole leg, which is equipped with an additional weight, the robot can jump at varying angles. A prototype of the jumping robot, measuring 9 cm by 7 cm by 12 cm and weighing 154 grams, has been built. Its basic features have been tested: robot can leap over 88 cm high with a launch angle of 80.33 degrees. During a jump, it rotates approximately 277 degrees in mid-air. The robot is capable of self-righting in 9 seconds when it falls to its left or right side, and in 26 seconds when falling forward. It can complete a 360-degree turn in 42 seconds, taking 14 steps to do so, with each step turning it about 25.7 degrees. The launch angle of the robot varies between 80.33 and 86.92 degrees. It is designed to continuously jump, overcoming obstacles such as stairs, and to move forward in outdoor settings with the ability to self-right and steer. The experimental findings are then compared with the simulation results [7].

High-speed movement on land requires robots to handle rapid acceleration and significant stress on their limbs, which gives rise to a difficult balance between making the legs light yet strong. This paper presents an innovative approach to designing a robotic leg, gained inspiration from natural musculoskeletal systems. The key idea is that a design mimicking the alignment of tendons and bones not only adds flexibility to the leg but also lessens the stress on the bones during bending movements. This concept has been incorporated into a new leg design and has been tested through simulations and practical experiments on a built prototype. Furthermore, an optimization strategy is introduced to enhance the ratio of strength to weight. With the tendon-bone co-location design, the bone stress during movement is reduced by as much as 59%. A novel prototyping method using a foam core allows for the creation of structural features in the robotic leg that resemble those in mammalian bones. This technique enables the use of lighter and more cost-effective polymer materials that are faster to produce than traditional methods, potentially significantly reducing the time needed for design iterations [8].

3. Conclusion

In conclusion, the future of compliant legged robots lies in addressing these challenges through innovative design principles, advanced materials, and sophisticated control strategies. By closely mimicking the efficiency and adaptability of biological locomotion, compliant legged robots hold the promise of revolutionizing fields varied from search and rescue operations to environmental monitoring. The ongoing research and development efforts are a testament to the potential of these robots to become more integrated into our lives, which could offer solutions that were once thought to be the domain of science fiction. As this field continues to evolve, sophisticated designs that push the boundaries of what is possible in robotics. Advances in materials science, sensor technology, and artificial intelligence will further enhance the capabilities of bio-inspired robots, making them even more autonomous, resilient, and efficient. The convergence of these technologies promises a future where robots can operate alongside humans and wildlife, performing tasks that were once thought impossible and contributing to a deeper understanding of the natural world.

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