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Overview of the development history and current design status of quadrupedal animal robots

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Abstract: Since the 1880s, humans have continued to make significant advances in quadrupedal machinery. In comparison to bipedal and wheeled robots, quadrupedal robots offer greater dexterity and stability. They are capable of traversing challenging terrains, exhibiting remarkable adaptability and carrying capacity. They are well-suited for tasks such as patrol, search and rescue, detection, and exploration. The purpose of this paper is to provide an overview of the development history of quadrupedal robots, to examine the design principles underlying their construction, and to offer insights into the prospects for future research in this field. To this end, we have selected a number of representative robots for analysis.

1. History of the development of quadrupedal robots

In 1870, Chebyshev constructed the world's inaugural quadrupedal robot.The link1 of this robot rotated around the A1 axis,propelling the P1 end in motion (As shown in Figure 1).This robot was capable of standing and walking at slow speeds, yet its simplistic structural design prevented it from adapting to varying terrain, limiting its mobility to flat surfaces.

The first invention in history to be patented for a footed machine was a horse-riding machine filed by L.A. Rygg with the U.S.Patent Office in 1893.The rider provided power through pedals, which in turn utilized cranks and connecting rods for transmission to move the machine forward. This is regarded as a pivotal moment in the evolution of quadrupedal robots.

Since 1976, Japan's Tokyo Institute of Technology has developed the KUMO-I quadruped robot, the PV-II and TITIN series quadruped robot, which exhibit a variety of walking gaits and high adaptability as quadruped robots[1].

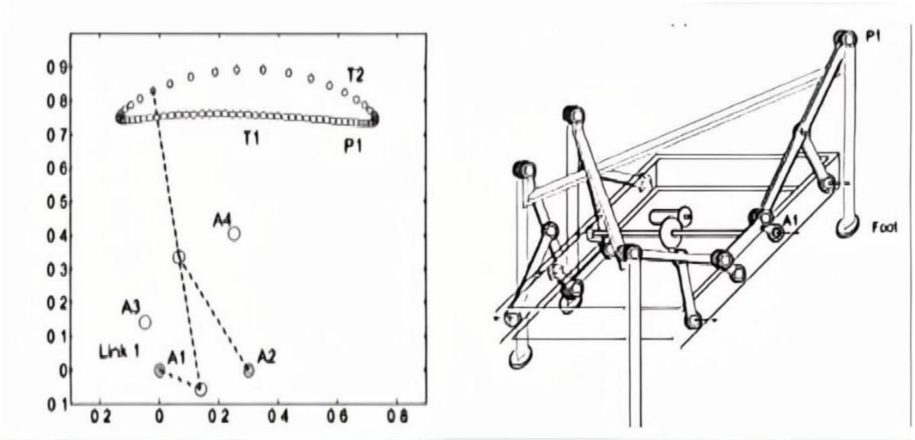

Figure 1: Chebyshev Walking machinery (a) footstep movement trajectory (b) mechanical structure

In 1986, M. Raibert of the Massachusetts Institute of Technology developed the inaugural walking and fully dynamically stabilized quadruped robot (As shown in Figure 2). M. Raibert initially addressed the challenge of dynamic stabilisation of a single-legged robot, subsequently applying this expertise to the problem of dynamic stabilisation of a multi-legged robot. This resulted in the development of a fully dynamically stabilised quadruped, comprising a distinctive hip gimbal and linear actuators structure that enables the quadruped to walk or run while maintaining dynamic stabilisation. In 2005, M. Raibert's company Boston Dynamics introduced Big Dog, a quadrupedal robot that can run with a load of 45 kilograms and move at speeds of up to 6.4 km/h. Big Dog incorporates the structural characteristics of mammalian bodies, possesses articulated limbs with a maximum climbing angle of 35 degrees, and is capable of traversing snow and mud with ease. The robot, named Big Dog, has a speed of 6.4 kilometers per hour, a maximum climbing angle of 35 degrees, and the ability to walk freely in snow and mud. Its design is inspired by the mammalian carcass, with articulated limbs that absorb shock and dampen vibration. The robot has 16 degrees of freedom, allowing it to move both laterally and vertically. A gasoline-powered engine drives the hydraulics that control the movement of each limb section. A gasoline engine drives a hydraulic system that controls the movement of each limb. Subsequently, Boston Dynamics unveiled the LS3, which boasts enhanced load capacity and movement speed, and the Wild Cat, which is adept at rapid jumps and turns and can traverse complex roadways at speeds of up to 16 kilometers per hour.

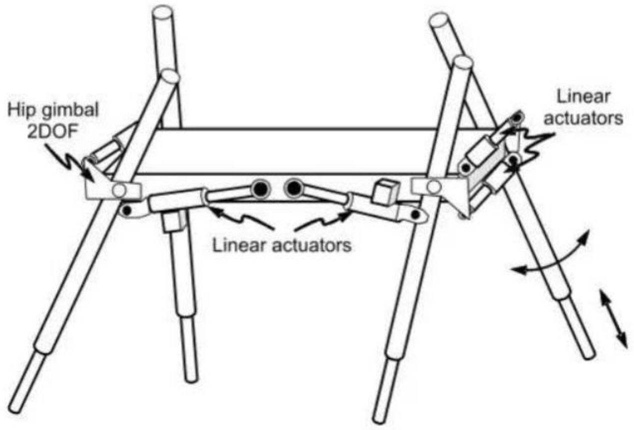

Figure 2: Raibert Dynamic stabilization of a robot with four legs

In November 2017, Boston Dynamics presented its latest quadruped robot, Spot Mini. Measuring approximately 0.84 meters in height and weighing approximately 30 kilograms, Spot Mini is capable of walking or running freely with a payload of 14 kilograms. The Spot Mini robot is equipped with a robotic arm at the front of its body, which enables it to stand up if it falls. Furthermore, the robot is equipped with a gripper at the top of the arm, which enables it to manipulate objects in a flexible manner. The Spot Mini robot is equipped with 17 degrees of freedom, with five on the upper arm and the remaining 12 evenly distributed between the limbs. The robot is powered by a battery-powered hydraulic system that controls the movement of each limb, enabling flexible body movement. The arm of the Spot Mini robot is equipped with a camera that assists the robot in accurately locating the target object.[2]

By this point in time, the design and manufacturing technology of quadruped robots had become more sophisticated, enabling them to exhibit certain movement capabilities, adjustability, and transport functions.

2. Designed to improve basic performance

Since the beginning of the 21st century, human beings in the field of quadrupedal robots have continued to achieve results. Quadrupedal robots now have the ability to move in complex environments, but they remain less agile than dogs or wolves and other animals. The bulky nature of quadrupedal robots, coupled with their lack of flexibility, renders them ill-suited to undertake heavy responsibilities in the field of rescue and disaster relief, military transportation, and other such endeavors. Consequently, some researchers have initiated efforts to enhance the performance and adaptability of these robots in specific scenarios.

In their design, Elvedin Kljuno, Jim Zhu, and Robert L. Williams drew inspiration from quadrupeds. They used stretchable, elastic, cable-driven joints and mounted the motors on the torso to reduce the weight and inertia of the legs, thereby reducing the overall weight and energy consumption[3].

In addition, to reduce weight and improve transmission accuracy, the team of Ming Lu, Baorui Jing, Hao Duan, and G. Gao designed the legs of the quadruped robot in a horizontal configuration with the drive ends aligned. They then used an inverse kinematics algorithm to analyze the rotation angles of the quadruped robot's actuators. In particular, the team designed and tested the gait of the quadrupedal animal robot's four legs by experimentally measuring the standing, walking, and trotting data to verify the validity of the end-of-foot trajectory and the stability of the gait[4].

In another step, Mingfang Chen's team developed a novel electric leg mechanism for the quadruped robot to ensure stability during motion and reduce the inertia associated with leg swing. In further research, Mingfang Chen developed an improved foot trajectory based on a composite pendulum, which improves the rationality of the foot trajectory [5].

The team led by Junxiao Cui proposed a tension leg structure that combines a tension leg structure with a rigid mechanism to enable the quadruped robot to better adapt to the terrain through its dynamic morphology capability.The team validated the quadruped robot's high load capacity and terrain adaptability based on dynamic morphology through two repeated experiments. In addition, the quadruped robot with tensegrity legs is capable of dynamic morphology, which enables it to adjust leg length to overcome obstacles and walk upright or inverted[6].

A team of researchers at ETH Zurich has developed an all-terrain wheeled robot dog, designated as ANYmal,(As show in Figure 3).The researchers have equipped the dog's four legs with drive wheels with hub motors, while maintaining a similar appearance to other quadruped robots in terms of the mechanical body.This allows the dog to increase its speed of movement through the wheels without compromising its ability to cope with complex terrain as a quadruped robot[7].

Figure 3: Whefoot robot dog ANYmal

3. Designed to fit specific scenarios

In order to adapt the quadrupedal robot to specific environmental conditions, researchers have also designed a series of innovative structural elements.

The traditional rover structures, such as wheeled and leg-wheeled, have been found to have limitations in moving on granular soils on planetary surfaces. Guangming Chen and Long Qiao et al. have proposed a multi-toe quadruped inspired by the desert chameleon animal with some special designs for quadrupedal robots for exploring planetary surfaces, such as the Moon or Mars. Guangming Chen and Long Qiao et al. designed a bionic foot with four toes and a bionic flexible spine, with the objective of enabling the quadrupedal robot to walk in a coordinated manner on granular materials and to have a reasonable steering gait.

Yixiang Liu, Qing Bi and Y. Li In order to make quadrupedal robots with cat-like flexibility and dexterity to pass through various narrow gaps or holes much smaller than their bodies, proposes a design method for a bionic quadrupedal animal robot with a retractable torso.The design incorporates a foldable mechanism with high deformability, integrating multiple spatial multibar rods. Based on this foldable mechanism, a quadrupedal animal robot with a retractable torso is further designed.This torso enables the quadrupedal robot to better handle obstacles such as crevices, gullies, and stairs. Simulation experiments demonstrate that the robot exhibits enhanced step length, reduced transportation cost, and superior high-speed locomotion performance compared to a rigid torso[8-9].

4. Conclusions and Discussion

This paper presents an overview of the development history of quadrupedal robots and provides an analysis of the current research status of quadrupedal robots in terms of design. It includes a discussion of some representative quadrupedal robots as examples. By analyzing these representative robots, it is possible to gain insight into the origin and development of quadrupedal robotics, as well as the challenges and limitations currently faced in the design of quadrupedal robots.

Despite the considerable potential demonstrated by quadrupedal robots in certain areas, there remain limitations in terms of dexterity, payload capacity, and motion speed. These deficiencies constrain the efficacy of quadrupedal robots in real-world applications, particularly in scenarios where rapid responsiveness and optimal task completion are essential.In light of the aforementioned challenges, future research efforts on quadrupedal robots are likely to focus on the following aspects: Firstly, the robot's weight will be reduced by employing advanced materials science and fabrication technologies to enhance its flexibility and adaptability. Secondly, the flexibility of the legs and torso will be improved by optimising the mechanical structure design of the robot to enable a faster motion mode.Thirdly, the design concepts of wheeled robots will be combined with the aim of combining the advantages of wheeled locomotion with the flexibility of quadrupedal locomotion in order to adapt to a wider range of terrains and task requirements.Through in-depth exploration and technological breakthroughs in these research directions, future quadrupedal robots will be able to be more widely and effectively used in areas such as patrolling, reconnaissance, search and rescue, detection, and material handling.

References

[1] Gonzalez de Santos, Pabl. (2007).Quadrupedal Locomotion: An Introduction to the Control of Four-legged Robots. Berlin, Heidelberg:Springer-Verlag Berlin.

[2] Zhu Qiuguo. On the development history, status and future of quadruped robot[J].Hangzhou Science and Technology, 2017(02): 47-50.

[3] Elvedin Kljuno, Jim Zhu and Robert L. Williams, A Biomimetic Elastic-Cable-Driven Quadruped Robot: Design, Dynamics and Controls, 2019.

[4] Lu Ming,Bao Ruijing, Hao Duan and G. Gao, The Design of a Small quadruped Robot with Parallel legs, Complexity, 2022(09):1-11.

[5] Mingfang Chen et al., Single-leg Structure Design and Foot Trace Planning of a New Bionic Quad Robot, Complexity, 2021(02):1-17.

[6] Junxiao Cui et al., Design and Experiment of a New Robot, Mechanical and Mechanical Theory, 2022(05): Vol. 171, pp. 104781.

[7] F.Shi, Circus ANYmal: A Quadruped Learning Dexterous Manipulation with Its Limbs, arXiv: Robotics, 2020.

[8] Bronzati M , Rauhut O W M , Bittencourt J S ,et al.Endocast of the Late Triassic (Carnian) dinosaur Saturnalia tupiniquim: implications for the evolution of brain tissue in Sauropodomorpha[J].Scientific Reports, 2017, 7(1):11931. DOI: 10.1038/s41598-017-11737-5.

[9] Remy C D , Hutter M , Hoepflinger M ,et al.Quadrupedal Robots with Stiff and Compliant Actuation[J].at - Automatisierungstechnik, 2012, 60(11):682-691.DOI:10.1524/auto.2012.1042.