Gait Analysis and Realization of Quadruped Bionic Robot with 8 Degrees of Freedom

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***Abstract*—Since the quadruped bionic robot can be widely applied to different terrains, the research on it has always been the focus of robotics-related field. This paper designs a quadruped bionic robot with 8 degrees of freedom. We analyze stability and movement speed of the robot in different gaits. The gait focuses on crawl in triangular gait and trot in diagonal gait. In the case of using 8 degrees of freedom (two per leg), through gait analysis, 3D modeling, physical testing and using larger sole to improve stability, the designed quadruped robot can achieve stable and fast movement.**

I. INTRODUCTION

At present, many industries, like catering and transportation, have used wheeled robots to simplify the delivery process [1]. Wheeled robots have higher requirements on the ground. They do not have functions such as going up or down stairs and crossing obstacles. Compared with wheeled robots, footed robots have low requirements on terrain. Not only can they move on flat ground, but also move on rugged terrain [2]. They have a wide range of adaptability. Common footed robots include biped, quadruped and hexapod. Compared with biped robots, quadruped robots have better stability. Compared with hexapod robots, the structure is simpler and easier to control [3]. Therefore, we design a quadruped robot. Through gait analysis, 3D modeling, and physical testing, the designed quadruped robot can achieve stable and fast movement. It is hoped that it can be applied in fields such as education and teaching, science and technology competition, or life practice.

II. GAIT ANALYSIS

Common quadruped gaits include crawl, walk, pace, trot, and run [4]. By observing the postures of animals at different moments in the process of movement, we find that when crawling or walking, one foot is generally in the air to move forward, and the other three feet are used as support to contact the ground and immobilize. When pacing, trotting or running, one of the two feet is vacant, and the others are used as support. For the latter, if four feet are divided into two groups: support and vacant, different gaits will be grouped differently [5]. When pacing, take body forward as the reference, two left feet are one group, two right feet are another group, alternately complete the support and vacant. While trotting, two diagonally opposite feet are a group, in other words, left front foot and right rear foot are one group, right front foot and left rear foot are another group, alternately supporting and vacant. Run can be seen as moving forward by jumping. The two front feet are a group, and the two rear feet are another group. It should be noted that run is quite special. There is a certain amount of stagnation time between alternate support and vacant, which means all four feet are in the air.

With reference to the gait of quadruped animal, according to the number of supporting legs in each posture and the grouping method of the supporting legs when it is moving under normal conditions, we divide the gait of the quadruped bionic robot into a triangular gait (three leg support on the ground), pace gait (one group of feet on the same side supports the ground), and diagonal gait (one group of feet that are diagonal supports the ground). A and B will compare the performance of each gait from the perspective of speed and stability.

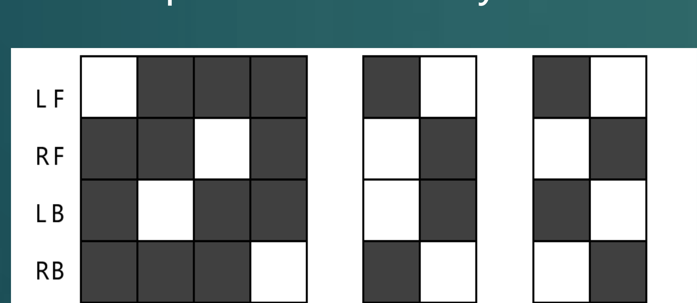

Fig. 1. Timing diagram of each foot support or step forward in the three gaits.

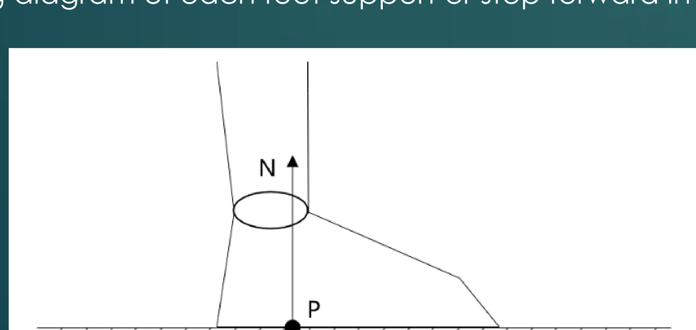

Fig. 2. The equivalent of the force of ground on the foot..

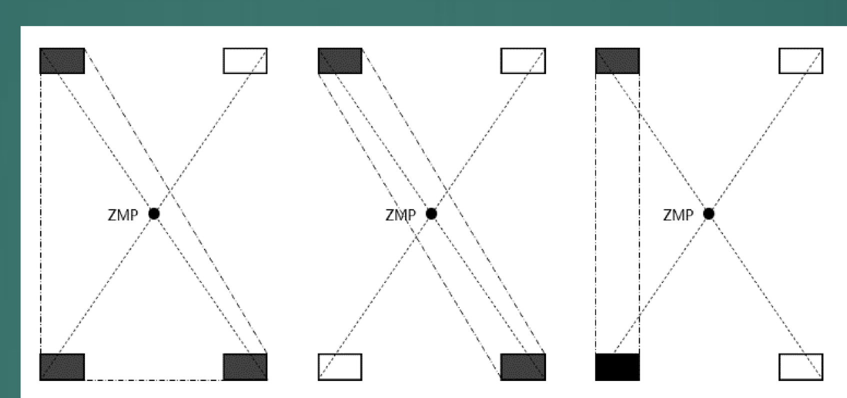

Fig. 3. The positional relationship between ZMP and supporting polygon in the three gaits.

III. STRUCTURAL DESIGN

After referring to and simplifying the body structure of quadruped mammals, we use 8 degrees of freedom to explore the forward gait of the quadruped robot. Each leg has 2 degrees of freedom as the knee joint and hip joint of the quadruped robot. Both degrees of freedom rotate forward and backward. The ratio of the thigh between the joints to the calf from the knee joint to the foot is 1:1.3, and the leg type is full elbow. The quadruped robot model is drawn using the 3D drawing software SOLIDWORKS, as shown in Fig. 4.

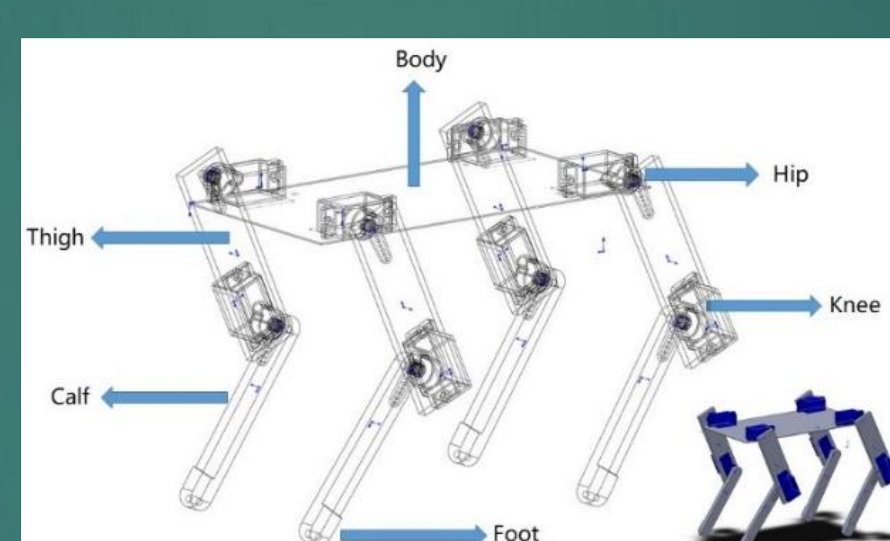

Fig. 4. Quadruped robot model.

IV. HARDWARE IMPLEMENTATION

Common joint drive methods of robots include motor drive, artificial muscle drive and so on [8]. Because artificial muscles are expensive and unnecessary, motor-driven methods are used. Generally, there are three types of motors suitable for joint drive: DC motor, stepper motor and steering gear. Table I is a comparison of the three.

Due to the small size of the designed quadruped robot, we use steering gear as joint drive. In the selection of model of the steering gear, priority is given to the steering gear with good stability. During operation, the mechanical characteristics should be hard and not easy to shake. At the same time, the response speed of the steering gear must be fast. Finally, we choose the digital steering gear mg90s with high cost performance. This kind of steering gear uses metal gears with good mechanical characteristics. The rotation angle range is -90°~90°. Under the input voltage of 4.8V, the steering gear's torque is 2kg/cm. The maximum speed is 0.11s/60°. Compared with analog servos, it can be fixed at a certain angle only by inputting the PWM signal once. The PWM period used by mg90s servos is 20ms, and different pulse widths make the servos rotate at different angleThe torso part is made of acrylic sheet with the length of 150 mm, the width of 80 mm, and the thickness of 3 mm with high hardness and light weight. The necessary perforations are made for the assembly part. The joint connector is made of PLA+ material with high rigidity, which is realized by 3D printing [10]. We use several screws to assemble the torso and limbs.s [9].

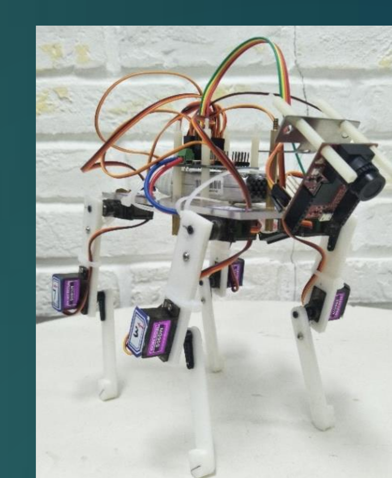

Fig. 5. 8-DOF quadruped bionic robotl..

V. TEST AND ANALYSIS

- In the standing state, the quadruped robot uses a full-elbow leg type. We test the time and stability from lying down to normal standing. The robot can stably get up within one second. Then we apply longitudinal and lateral thrusts to body after getting up, there is no shaking.
- When standing still, we test the stability after lifting the foot. When one foot is lifting alone, the body is stable and it is not easy to tip over with thrust. When the same side foot is lifting, the body is tilted toward the side of the lifted foot. When two diagonal feet are lifting, the body is stable but will be tilted after applying thrust.
- When moving forward, we test the movement distance and usage time of the three gaits after one cycle. The triangular gait's movement distance is similar to diagonal gait, but the time used is 1.8 times that of the latter. While pacing, although the gait takes a short time, it will fall after lifting its feet, there are a lot of energy lost laterally, thus the distance of forward movement is much smaller than other gaits.
- Although the joints can only rotate back and forth, the robot can still achieve the function of turning. The inertial force generated by the acceleration of one leg after the body is tilted can be used to change the direction of the robot. However, the turning effect is different on the ground with different friction coefficients. The controllability is poor.

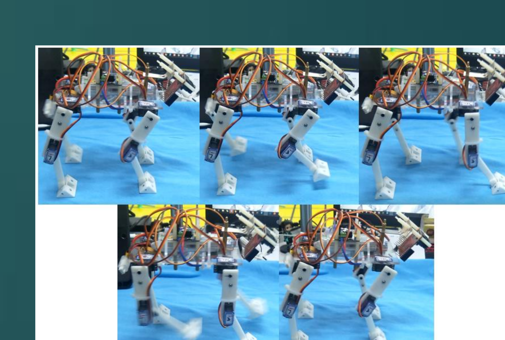

Fig. 6. Improved diagonal gait

VI. CONCLUSIONS

By comparing the speed and stability of different gaits, using 8 degrees of freedom to realize the triangular gait, pace gait and diagonal gait, adjust the size of the feet, so as to make the robot produced able to move forward steadily and quickly in diagonal gait. Although the turning can be completed by the moment of inertia generated by the rapid swing of the legs, the stability and controllability are poor. In addition, the quadruped robot adopts open-loop sequential control, no feedback link, with no autonomy. In future work, we will improve the forward motion and enrich the degrees of freedom to make the quadruped robot more flexible. Through the combination with camera and obstacle avoidance sensors, the information of environment will be fed back to the MCU, then make corresponding adjustment actions so as to make the robot have a certain degree of autonomy.