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Walking Mechanism and Gait Design of a Novel Compound Quadruped Robot

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Abstract—**A novel compound quadruped Robot is designed in this paper. The proposed walking mechanism contains four compound mechanical legs. Each compound leg mimic the walking mechanism of human which has a waist, a right leg and a left leg. The new robot combined the quadruped robot and the biped robot rationally which makes it have agility, high speed, high stability and high load capacity at the same time. The walking process is divided into three types: linear walking, steering and lateral walking. The regular and periodic motion of the legs makes the control simple which doesn't need complicated inverse kinematics and dynamics.**

Keywords-quadruped robot; compound mechanical leg; gait analyse

I. INTRODUCTION

The animals on the earth have a strong ability to move. Some animals can run with fast speed, some animals can bear a heavy load, some animals can climb trees, and so on. Robots with feet just use the principle of bionics and mimic the motion mechanism and process of animals. What the researchers need to do is to decrease the gap between robots and animals and to make a better replica of the animals. With the researches going deeply, the robots can even surpass animals and humans in some respects. At present, robots with two feet, four feet, six feet or eight feet are most used. Among them, robots with four feet have higher stability and load capacity than robots with two feet. And the moving mechanism and control of them are more simple than the robots with six or eight feet. Therefor, quadruped robot has a wider application prospect especially in some special terrains.

Previous research tried to simplify and mimic the motion principles and mechanism of the animals [1-4].Yet, the real biological principles and mechanism are very complex and perfect. Researchers began to study the motion structure and principle deeply to improve the bionic level. Muscle-like actuators, especially artificial pneumatic muscles, have been paid increasing attention [5-7]. The control system and sensor system for the robot are also improved [8-9]. To improve the speed of the robot, in early 2012, Boston Dynamics developed a quadruped robot named cheetah which can run at a high speed of 29 km/h and then, it made a record of 45.5 km/h[10].As the fastest land animal, the cheetah can run with a speed in excess of 32 m/s. The running frequency of it is about 3 Hertz. With each gait cycle, the animal covers an impressive 10 meters [11].

High load capacity and high stability are other two important factors for the quadruped robots. In 2006, Boston Dynamics developed a quadruped robot named “Big Dog” [12-13]. It can bear a load of 50 kg. The second generation of Big dog was developed in March 2008 with a maximum load of 154kg.In 2012, Boston Dynamics developed the quadruped robot LS3, which has the ability to carry more weight with higher speed than Bigdog. But, it is hard for the quadruped robot to have high speed, high load capacity and high stability at the same time.

In this paper, a new quadruped robot is designed. It reasonably combines the quadruped robot with the biped robot which makes it have the advantages of both of them. The moving process of the new quadruped robot is analyzed and gaits are planned.

II. WALKING MECHANISM DESIGNE OF THE COMPOUND QUADRUPED ROBOT

Fig. 1 shows the walking mechanism of the new compound quadruped robot. The whole walking mechanism of the robot consists of four compound mechanical legs, two in the front and two in the back, which are symmetrically distributed on both sides of the robot. Each compound leg imitates the human’s walking structure, which consists of the waist, the left leg and the right leg as shown in Fig.2. Just like human, the left and right legs contain a thigh and a calf respectively. The upper end of the waist and the robot body are connected by a rotating joint named waist joint. Through the rotation of the waist joint, the walking direction of the mechanical leg can be changed. The lower end of the waist is connected with the left and right legs by two rotating joints named hip joints. The thigh and the calf is connected by a knee joint. Through the rotation of the knee joints and the hip joints, the leg can move forward or backward. The body of the robot can be driven by the legs accordingly just like four people carrying the body of the robot together on their shoulders.

During walking, the robot always keeps four feet on the ground, which improves the load capacity and stability of the robot. The left and the right legs walk alternately just like four people walk with the same paces, which improves the speed of the robot. The new robot has both the advantages of a biped robot and a quadruped robot.

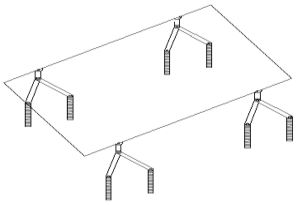

Figure 1. Diagram of walking mechanism of the compound quadruped robot

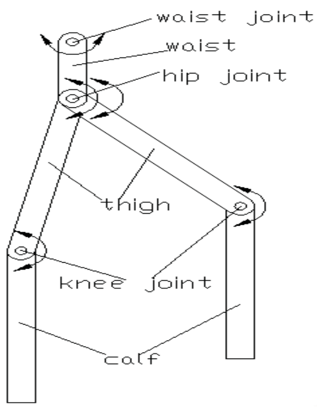

Figure 2. Diagram of the compound mechanical leg

III. GAIT ANALYSIS OF LINEAR WALKING

To walk along a line, the four compound mechanical legs should walk toward the same direction. The rotation of waist joints are used to adjust the direction of all the mechanical legs. So, before the legs walk, the four waist joints should rotate first which will be finished in two steps: First, left foreleg and right hind leg stand to support the body of the robot, the waists of right foreleg and left hind leg rotate to the required direction. Then, right foreleg and left hind leg stand to support the body of the robot, the waists of the left foreleg and right hind leg rotate to the required direction.

After that, the waists will not rotate during the whole linear walking. The left and right leg of each compound mechanical leg walk alternatively and the four compound mechanical legs all walk forward periodically with the same foot span and direction. The linear walking can be realized very conveniently.

If the motors rotate backward, the robot can walk backward. During walking, after the direction is adjusted through the rotating of the waist joints, the robot will walk with the same foot span and the same direction. The waist joints will not rotate any longer. The hip joints and knee joints just rotate periodically. So, the control is simple and easy. The walking speed can be easily adjusted through adjusting the rotating speed of the motors within a certain range.

IV. GAIT ANALYSIS OF STEERING

A. Analysis of Steering Process

During walking, the robot needs to steer sometimes. There are two ways of steering: dynamic steering and static steering. steering while walking is called dynamic steering which needs large steering radius. The calculation and control are complicated. Static steering means that centroid of the robot is stationary, which requires less steering radius and is easy to calculate and control. Static steering is adopted here for the compound quadruped robot.

The rectangular represents the body of the robot as shown in Fig.3. Points labeled 1, 2, 3, and 4 represents the connecting points between the upper end of the waist and the body of the robot. The two diagonal lines of the rectangular intersect at point labeled O, and O is also the centroid of the robot. While steering, O remains static and the robot rotates around O in the horizontal plane. Because the robot need to walk step by step, the whole steering process is also divided into several steps according to the rotation angle needed. The rotation angle of each step is called step-rotation-angle. The number of steps needed can be calculated according to the rotation angle needed and the step-rotation-angle. Each compound leg consists one left leg and one right leg. The one which is close to the center of the robot is the inner leg, and the one far from the center of the robot is the outer leg. During steering, the outer leg of each compound leg walk forward and the inner leg just follow.

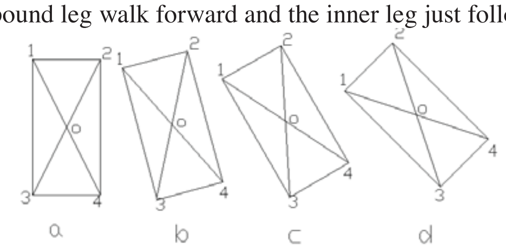

Figure 3. Steering diagram of the robot

B. Analysis of Steering Principle

As shown in Fig.4, points labeled 1, 2, 3, and 4 are the initial positions of the connecting points between the upper ends of the waist and the body of the robot. Points labeled 1', 2', 3' and 4'are the positions reached by points 1, 2, 3 and 4 after the robot walks a step forward. Then 1, 2, 3, 4 and 1', 2', 3', 4' are all located at the same circumference with the center of O and the radius of R. R means half of the diagonal length of the rectangular which is a constant. Since that the outer leg and the inner leg are symmetrically distributed on both sides of the bottom of the waist, the horizontal distance between the bottom of the waist and the upper end of the outer leg or the inner leg is ΔL.Points labeled 5, 6, 7 and 8 represent the upper ends of the four outer legs.Points labeled 5', 6', 7', 8' represent the new positions of 5, 6, 7 and 8 after the robot walks one step forward. The ideal trajectory of 5, 6, 7 and 8 is the circle with the center of O and radius of R' as shown in Fig. 4. Yet, the robot walks along a straight line actually during every step which is different from its ideal trajectory. Line 55', 66', 77', 88' are the real direction of the outer legs and the length of lines 55', 66', 77', 88' represents one step length. Suppose the initial walking direction of the robot is along line 42.So,the waist joints must rotate to adjust the legs to move along line 55'，66'，77'，88' before walking. Then the outer and inner legs walk alternatively as stated above to make the body of the robot move forward. Every time, before the robot walk a step forward, the walking direction must be adjusted first.

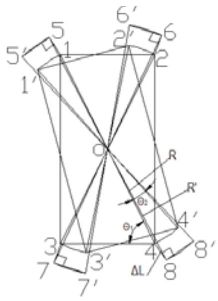

Figure 4. Diagram of steering

As shown in Fig. 4, θ_2 means the angle that the robot rotates around O when the robot walk one step forward. Then, we can get:

$$\mathrm{tg}\frac{\theta_2}{2}=\frac{L}{2R'} \tag{1}$$

where L is one step length while steering, R' means the steering radius of the upper end of the outer legs. Then, (1) can be written as:

$$L=2R'\,\mathrm{tg}\frac{\theta_2}{2} \tag{2}$$

From Fig.4,we can get:

$$R^2+\Delta L^2-R'^2=2R\Delta L\,COS(\pi-\frac{\theta_2}{2}) \tag{3}$$

where R is the radius of the upper end of the waist and ΔL is the horizontal distance between the outer or inner leg and the waist. Then, (3) can be written as:

$$R'=\sqrt{R^2+\Delta L^2-2R\Delta L\,COS(\pi-\frac{\theta_2}{2})} \tag{4}$$

C. Parameter Analysis of Steering Process

(1) step-rotation-angle of the robot

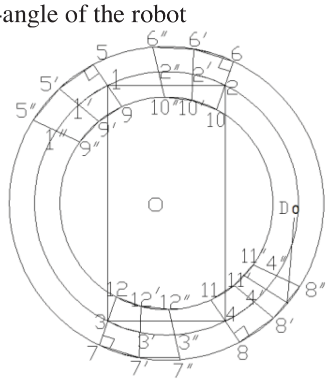

Figure 5. Diagram of steering principle

As shown in Fig. 5, points labeled 1, 2, 3, 4 are the initial positions of the upper ends of the waists, points labeled 5, 6, 7, 8 are the initial positions of the upper ends of the outer legs, points labeled 9, 10, 11, 12 are the initial positions of the upper ends of the inner legs. There are three circles in Fig. 5. The middle circle is the ideal path of points 1, 2, 3, 4. The outer circle is the ideal path of points 5, 6, 7, 8. The inner circle is the ideal path of points 9, 10, 11, 12. Yet, the real paths of points 5, 6, 7, 8 are straight lines labeled 55'5", 66'6", 77'7", 88'8" respectively .And the real paths of points 9, 10, 11, 12 are straight lines labeled 99'9", 1010'10", 1111'11", 1212'12" respectively. The real paths are different from their ideal paths. As shown in Fig. 4 and Fig. 5, the maximum difference of the outer legs D_o is given by:

$$D_o=R'(1-\cos\frac{\theta_2}{2}) \tag{5}$$

The maximum difference of the inner legs D_i is given by:

$$D_i=R''(1-\cos\frac{\theta_2}{2}) \tag{6}$$

where R'' is the radius of the ideal path of the upper end of the inner legs. The less the difference is, the more smoothly the robot steers. So, to decrease the difference, a smaller step-rotation-angle of the robot should be used. Then the steering process should be decomposed into more steps.

(2) The rotation angle of the waist

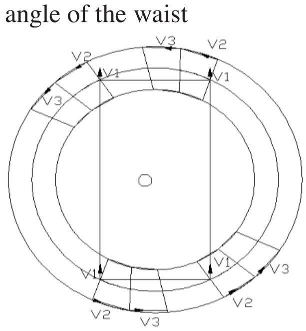

Figure 6. Diagram of turning left

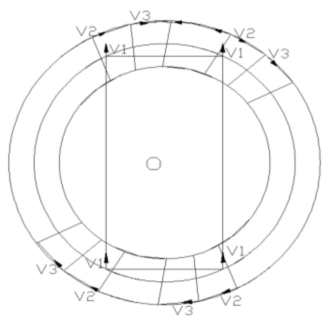

Figure 7. Diagram of turning right

During steering, before each step, the moving direction of the legs should be adjusted through the waist joints. It is supposed that the robot walks along a straight line at first. Fig. 6 and Fig. 7 show the steering diagram of the robot.V_1 is the direction of the first step, V_2 is the direction of the second step and V_3 is the direction of the third step. If the robot needs to turn left as shown in Fig. 6, the waists of the left-front leg and the right-rear leg should rotate $(\theta_1 - \frac{\theta_2}{2})$ clockwise before the first step and rotate θ_2 counterclockwise before other steps. θ_1 is shown in Fig. 4. The waists of the left-rear leg and the right-front leg should rotate $(\theta_1 + \frac{\theta_2}{2})$ counterclockwise before the first step and rotate θ_2 counterclockwise before other steps. If the robot need to turn right as shown in Fig. 7, the waists of the left-front leg and the right-rear leg should rotate $(\theta_1 + \frac{\theta_2}{2})$ clockwise before the first step and rotate θ_2 clockwise before other steps. The waists of the left-rear leg and the right-front leg should rotate $(\theta_1 - \frac{\theta_2}{2})$ counterclockwise before the first step and rotate θ_2 clockwise before other steps.

V. Gait Analysis of Lateral Walking

Sometimes, the robot needs to move laterally and the body of the robot doesn't need to rotate which is shown in fig.8.First, the robot judges the direction to move. Then, it adjusts the moving direction of the legs by rotating the waist joints to the same direction which is finished in two steps. Then the robot's four left legs and four right legs walk alternatively just like the linear walking.

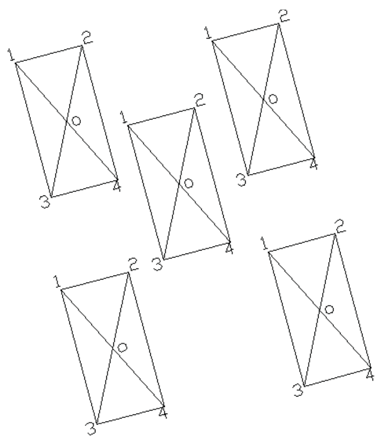

Figure 8. Diagram of lateral walking

VI. Conclusion

In this work, we designed a new type of walking mechanism for the quadruped robot. The new quadruped robot has four compound mechanical legs and simulates the actions of four people carrying a burden on their shoulders. Each mechanical leg imitates the motion mechanism of one person. It reasonably combines the walking mechanism of a biped robot and an ordinary quadruped robot. So, it has the agility and high speed of a biped robot. Its load capacity and stability are also improved compared to the ordinary quadruped robots. The potential of the quadruped robot is developed greatly.

In addition, the robot's walking process is classified into three styles: linear walking, steering and lateral walking, which simplifies the moving process a lot. During steering, the detailed gaits are planned which make the robot use small-step and multi-step strategy to realize fast steering. Furthermore, the periodic motion of the legs makes the control simple which doesn't need complicated inverse kinematics and dynamics calculation.

In the future, the structure and motion parameters of the robot will be optimized. The robot prototype will be made. And the function test on the physical prototype will also be realized.

References

[1] Estremera J, Waldron K J. (2008) Thrust control, stabilization and energetics of a quadruped running robot. International Journal of Robotics Research 27: 1135-1151.

[2] Raibert M, Chepponis M, Brown Jr H B. (1986) Running on four legs as though they were one. IEEE Journal of Robotics and Automation 2(2): 70-82.

[3] Poulakakis I, Smith J A. (2004) Experimentally validated bounding models for the Scout II quadrupedal robot. In: IEEE International Conference on Robotics and Automation; 2004 April 26-May 1; New Orleans, USA. pp. 2595-2600.

[4] Lewis M A,Bunting M R,Salemi B,et al. Toward ultra high speed locomotors: design and test of a cheetah robot hind limb [c]/ / IEEE International Conference on Robotics and Automation. Piscataw ay : IEEE,2011: 1990-1996.

[5] Zhang Taihui, Wei Qing, Ma Hongxu.(2013) Position/force control for a single leg of a quadruped robot in an operation space. Int. J. Adv. Robot Syst. 10: 137. (11)

[6] Albiez J, Kerscher T, Grimminger F, et al. (2003) PANTER-prototype for a fast-running quadruped robot with pneumatic muscles. In: Proceedings of the 6th International Conference on Climbing and Walking Robots. 2003 Sep.17-19; Catania, Italy. pp. 617-624.(14)

[7] Aschenbeck K S, Kern N I, Bachmann R J, et al. (2006) Design of a quadruped robot driven by air muscles. In: IEEE/RAS-EMBS International Conference on Biomedical Robotics and Biomechatronics. 2006 Feb. 20-22; Pisa, Italy. pp. 875-880.(15)

[8] Yamada Y, Nishikawa S, Shida K, et al. (2011) Neuralbody coupling for emergent locomotion: a musculoskeletal quadruped robot with spinobulbar model. In: IEEE/RSJ International Conference on Intelligent Robots and Systems. 2011 Sep. 25-30; San Francisco, USA. pp. 1499-1506.(16)

[9] Wang X,Li M T,Wang P F,et al.Bio-inspired controller for a robot cheetah with a neural mechanism controlling leg muscles [J]. Journal of Bionic Engineering，2012，9 (3) :282－293.

[10] Ding Lianghong. Key Technology Analysis of Big Dog Quadruped Robot. JOURNAL OF MECHANICAL ENGINEERING.2015,51(7):1-23.

[11] Mantian Li, Xin Wang, Wei Guo1, Pengfei Wang and Lining Sun.System Design of a Cheetah Robot Toward Ultra-high Speed.International Journal of Advanced Robotic Systems, 2014.DOI: 10.5772/58563 .

[12] Big Dog Overview[EB/OL]. [2013-05-30]. Htt://www.bostondynamics.com/img/Big Dog_Overview.pdf.

[13] DING Lianghong, WANG Runxiao, FENG Huashan,et al. Brief analysis of a Big Dog quadruped robot[J]. China Mechanical Engineering, 2012,23(5):505-514.