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Quadruped-imitating robot leg rod joint driving torque virtual prototype simulation

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Abstract. Based on the motion principle of the double-half-revolution mechanism, a new type of quadruped-imitating robot is designed. It mainly consists of body suspension, wheel leg support and walking-leg. In order to simplify its walking-leg mechanism, each leg rod joint is directly driven by a steering gear. The virtual prototype model of the robot is established based on SolidWorks. The motion constraint relationship of legs and the three-dimensional collision properties between the stride rod and the ground are set. According to the kinematic coupling relationship of the legs, the driving speed of each joint is set. For two typical working conditions of the robot: walking on flat ground and climbing over vertical obstacle, the driving torques of the leg joints, such as the first swivel arm, the second swivel arm and the stride rod, are simulated respectively. The driving torque curves of leg joints are obtained under different working conditions. The results provide a reference basis for the steering engine lectotype design in the future.

1. Introduction

Walking robots are able to walk on uneven or soft ground with no obvious reduction in efficiency, and have better maneuverability and terrain adaptability. They are very suitable for applications in complex road conditions and are attracting more and more attention. Reasonable leg mechanism is the basis of walking robot design.

Most walking robots have a multi-degree-of-freedom linkage structure [1, 2] or a multi-joint structure that imitates the appearance of the human or animal legs [3, 4]. The typical representatives include Japan's Roller-Walker [5], Germany's BISAM [6], and the United States' BigDog [7] and so on. The bionic robot designed by Beijing University of Aeronautics and Astronautics has double four-bar leg [8], the quadruped bionic robot designed by Shanghai Jiaotong University has hybrid bionic leg, which is composed of a 4-bar mechanism of 1 degree of freedom and a planar parallel mechanism of 2 degrees of freedom [9]. The above robots have good road surface adaptability, but the leg mechanisms and their motion control are relatively complicated. Anhui University of Technology designed a double-half-revolution wheel-leg [10], which uses two-stage planetary gear train in series to achieve the leg rods drive. Due to the influence of backlash of gear transmission, the transmission accuracy of leg rods still need to be improved. In order to improve the transmission accuracy of leg rods and to make the leg structure more compact, a new kind of quadruped-imitating robot is proposed in the paper. The virtual prototype model of the robot is established, and the simulation analysis of driving torque is carried out, in order to obtain the driving torque curves of the leg rod joints for a reference of steering gear selection.

2. The principle of the quadruped-imitating robot

The quadruped-imitating robot mainly consists of body suspension, wheel leg support and walking-leg, and its principle is shown in figure 1. The walking-leg is based on the movement principle of the double-half-revolution mechanism [10], and it's composed of a first swivel arm, a second swivel arm and two stride rods on the front and back. The leg rods are connected with each other by revolute pairs, and the joints are directly driven by steering gears. Each stride rod of the robot has the same rotation speed, and the angle between two stride rods on the same side is always 90°. The rotating speed ratio of the first swivel arm, second swivel arm and stride rod is 4:2:1 and the stride rods on the same side complete the walking action alternately. The wheel leg support is connected with the robot body suspension through the revolute pair, and the steering control of the quadruped-imitating robot is realized by driving the steering gear on the wheel leg support.

The required driving torque on the joint of leg is constantly changing when the robot is walking. The purpose of this paper is to study the changing rule of the driving torque of each leg joint when the robot is walking and to provide a theoretical basis for seeking the best driving scheme.

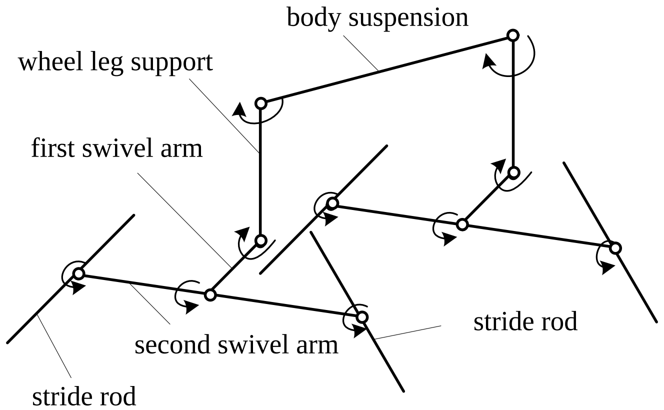


Figure 1. The principle of the quadruped-imitating robot

3. Virtual prototype model of the quadruped-imitating robot

The basic design parameters of the quadruped-imitating robot are shown in table 1. First of all, 3D model of the robot is established in SolidWorks software, and the unnecessary details such as screws and steering engines are simplified. Secondly, the motion coupling relationships between legs are defined in SolidWorks Motion, that is, the speed ratio between the first swivel arm, the second swivel arm and the stride rods is 4: -2: -1, in order to satisfy the rotational characteristics of the double-half-revolution mechanism. Finally, the damping spring, motion drive is set and three-dimensional collision properties between the stride rod and the ground is set too. The virtual prototype model of quadruped-imitating robot is shown in figure 2.

Table1. The parameters of the quadruped-imitating robot

Parameters	Length(mm)	mass (kg)	Number
First swivel arm	50	0.10	2
Second swivel arm	160	0.16	2
Stride rod	140	0.09	4
Wheel leg support	225	0.37	1
Body suspension	450	0.58	1

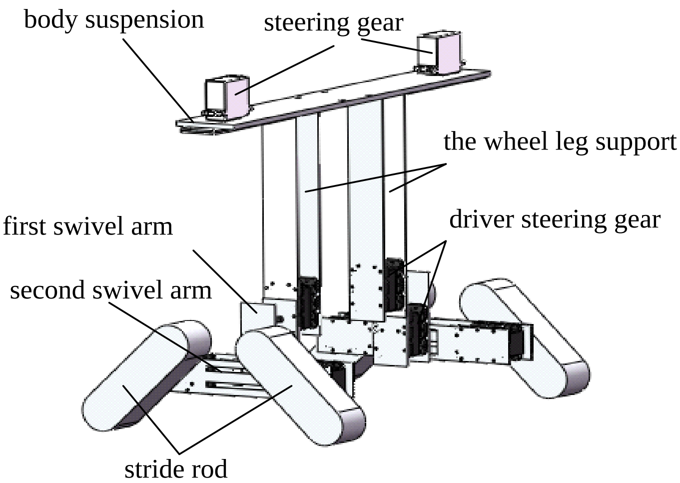


Figure 2. The virtual prototype model of quadruped-imitating robot

4. Driving torque simulation of the quadruped-imitating robot

4.1. Driving Torque Simulation when walking on flat ground

When the quadruped-imitating robot walks straight on the flat ground, the simulation analysis of the driving torque of the leg joint is carried out. According to the motion characteristics of the double-half-revolution mechanism, when the rotation speed of the first swivel arm is set to 12 RPM, the rotation speed of the second swivel arm and the stride rod is respectively 6 RPM and 3RPM, and then one stride cycle is 5 seconds. In order to compare the simulation results, the simulation time is set to 25s, and then the entire simulation process is 5 steps. The simulation of walking on the ground is shown in figure 3, and figure 3 (a) is the initial state. At this moment, the two stride rods incline 45 ° or135° to the horizontal plane.

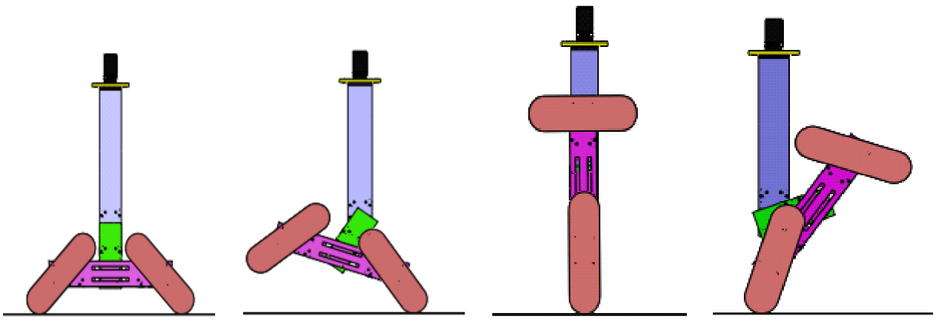


Figure 3. Simulation process of the quadruped-imitating robot when walking on flat ground

The simulation results show that the driving torque required for each leg rod joints of the robot changes periodically, as shown in figure 4- figure 6. It can be seen from the simulation curve in figure 4 that during the first 0-5 second stride cycle, the driving torque of the first swivel arm changes cyclically twice and the torque gradually increases to 0.6N·m, then decreases to almost zero gradually. The average value of the torque is 0.38 N·m. It can be seen from the simulation curves in figure 5 that in a single stride cycle, the driving torque of the second swivel arm gradually decreases from 1.35 N·m to almost zero and then gradually increases to 1.35 N·m. The average value of the torque is 0.85 N·m.

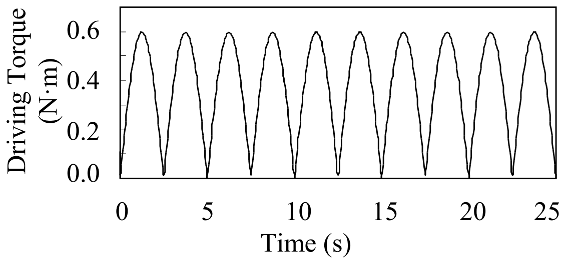


Figure 4. The driving torque required for the first swivel arm

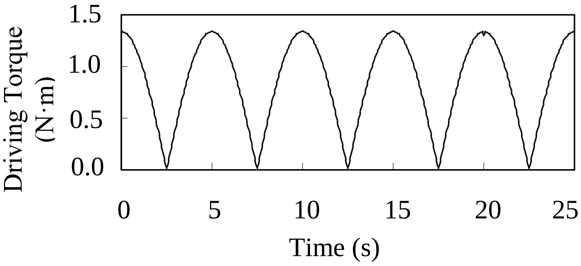


Figure 5. The driving torque required for the second swivel arm

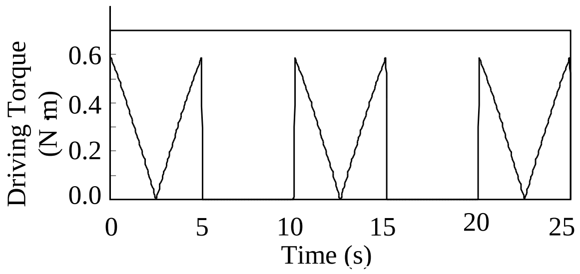


Figure 6. The driving torque required for the stride rod 1

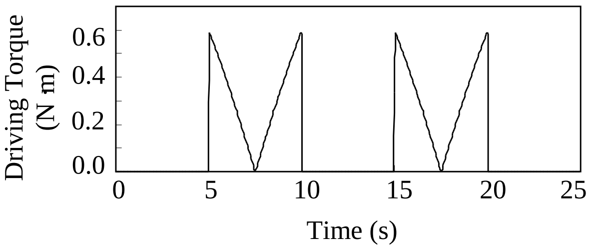
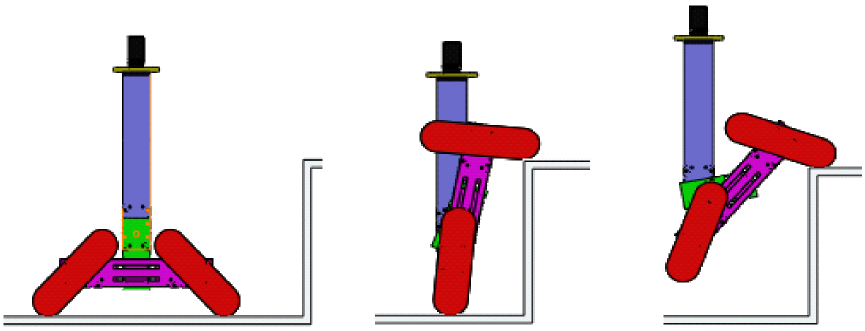


Figure 7. The driving torque required for the stride rod 2

When the quadruped-imitating robot walks on the flat ground during the first step cycle (0-5 seconds), the stride rod 1 comes into contact with the ground as the supporting leg. At this time, the stride rod 2 is off the ground. The simulation process is shown in figure 3. The simulation curve of the driving torque required for the movement of the stride rod 1 is shown in figure 6. The value of the driving torque decreases gradually from 0.59 N·m to almost zero when moving to the pose of figure 3 (c), and then increases gradually. When completed a stride cycle, the value of the driving torque reaches a maximum of 0.59 N·m at 5 seconds. In 5-10 seconds, the quadruped-imitating robot begins to step again: the stride rod 1 leaves the ground, then the stride rod 2 contacts with the ground. Therefore, during the 5-10 seconds, the driving torque of stride rod 1 is zero. The simulation curve of the driving torque required for the movement of the stride rod 2 is shown in figure.7, and its variation rule is the same as that of the stride rod 1. In the process of continuous stride movement, the stride rod 1 and the stride rod 2 contact with the ground alternately, and the required driving torque also varies alternately.

4.2. Driving Torque Simulation when climbing over vertical obstacle

When the quadruped-imitating robot climbs over vertical obstacle, its virtual prototype model is the same as that of walking on flat ground, except that the flat ground is changed to vertical obstacle. So the modeling and simulation of the quadruped-imitating robot are not described in detail. In order to analyze and compare with the walking process on the ground, the simulation time is still set to 25 seconds, and the whole simulation process has 5 steps. The simulation process is shown in figure 8. The required driving torque of each leg rod is shown in figure 9- figure 12. In figure 9, the driving torque curve of the first swiveling arm is basically similar to that of the flat ground walking simulation. In figure 10, the driving torque curve of the second swiveling joint is basically similar to that of the flat ground walking simulation too. However, at 8 seconds, the curves of the driving torque required for the two arms all have a sudden change value, and both momentarily become larger. At this moment, the stride rod 1 of the robot starts to climb the obstacle, as shown in figure 8 (b).



(a) (b) (c)

Figure 8. Simulation process of the quadruped-imitating robot when climbing over vertical obstacle

Figure 11 shows that the required driving torque is significantly greater than that of walking on flat ground when the stride rod 1 is climbing the obstacle at 8 seconds. From the maximum value of 0.84N·m, it gradually decreases to the minimum, and then increases to 0.59N·m (i.e. returning to the normal state of walking). Figure 12 shows that the stride rod 2 comes into contacting with the ground as a supporting leg from 5 seconds, and the required driving torque gradually decreases from the maximum of 0.59 N·m to minimum, and then gradually increases. At 8 seconds, the curve suddenly disappears, the stride rod 2 leaves off the ground at that time, and the stride rod 1 begins to climb the obstacle.

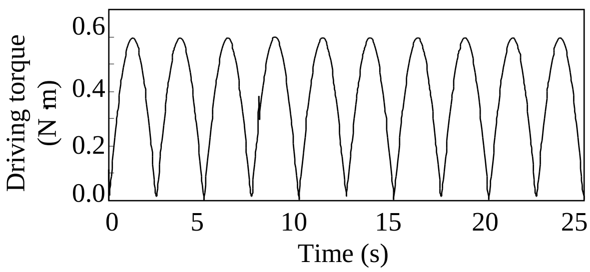


Figure 9. Driving torque required for the first swivel arm

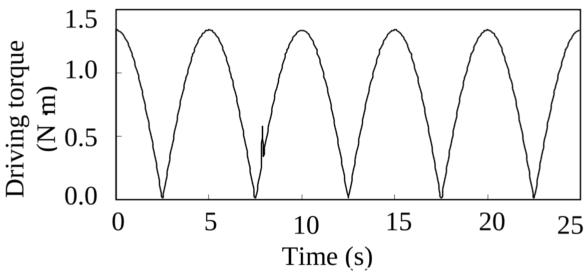


Figure 10. Driving torque required for the second swivel arm

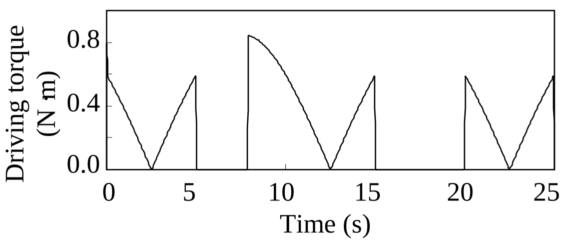


Figure 11. Driving torque required for the striding rod 1

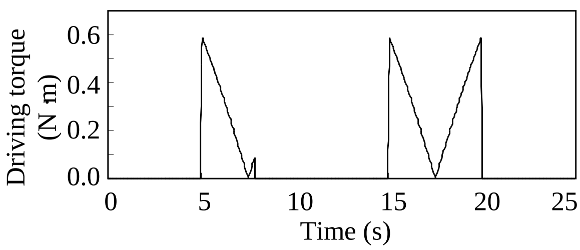


Figure 12. Driving torque required for the striding rod 2

5. Conclusion

Based on the Solidworks software, the 3D model of the servo-driven quadruped-imitating robot is created and its virtual prototype is established in Solidworks Motion. For two typical working conditions of the robot: walking on flat ground and climbing over vertical obstacle, the driving torques required for the leg joints, such as the first swivel arm, the second swivel arm and the stride rods, are simulated respectively. The driving torque curves of leg rod joints are obtained under different working conditions, which provide a reference for the selection of driving steering gear of each leg rod joints.

Acknowledgments
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