Modeling and simulation of multi-footed wheel robot based on ADAMS

Cheng LIU, Dong ZHAO, Weitao HUANG, Xianjiang MENG, Wenhao Du

School of Mechanical Engineering, University of Jinan, Jinan, Shandong, 250000, China
*me_zhaod@ujn.edu.cn

Abstract. To reduce the complex mechanism and difficult control of multi-legged robot, the overall design of the new multi-footed wheel robot was carried out according to the previous research results—multi-footed wheel mechanism. A new multi-wheeled robot model was built by using SolidWorks. External data planning was carried out for dynamic force data curve of the motor. In ADAMS, the kinematics characteristics and data of the multi-footed wheel robot were obtained through simulation analysis of the model by interpolation method. The rationality of mechanism design and driving stability were verified by simulation analysis.

1. The introduction
With the expansion of human exploration to the nature, the wheeled and tracked robots haven’t been adapt to the complex and varied terrain. But the foot robot shows a greater advantage in the movement of the obstacles, the relief surface and other complex terrain. The typical feature of the foot robot is discrete foothold. So, it can move quickly in an efficient way in some complex terrain only by constantly selecting very small support surface [1,2]. In recent years, foot mobile robots have played an important role in many fields and become an important tool for industrial application and scientific exploration in the new era [3].

At present, many domestic and foreign institutions or universities have done a lot of studies on foot robots, which are widely used in military transportation, field rescue and other fields [4]. For example, Boston Dynamics’ Big Dog [5] can move at a speed of 6.4 km/h and climb at a maximum slope of 35°. In contrast, the research on foot robots in China started relatively late, and there is a big gap in speed, bearing capacity and motion stability with those of foreign foot robots.

Based on the previous research results, this paper designs a new multi-wheeled robot with simple structure and easy operation. A simplified model of Multi-footed wheel robot was established by using 3D modeling software. The model is imported into ADAMS software for simulation analysis to obtain kinematic characteristics of robot motion mechanism, which provides theoretical basis for subsequent prototype trial-production.

2. Robot mechanism design
The multi-footed wheel robot designed in this paper (as shown in Figure 1) is mainly composed of four multi-footed wheel mechanisms [6] and a body. In the multi-footed wheel mechanism (as shown in Figure 2), the eccentric shaft is fixedly connected with the mounting seat, the driven gear is bolted to the driving wheel, and the driving wheel and the slave wheel are connected to an eccentric shaft by bearing and are hinged together by a foot rod assembly. The multi-footed wheel mechanism is
arranged symmetrically on both sides of the body. Each multi-footed wheel mechanism is equipped with a walking drive motor and a steering drive motor. The walking drive motor is placed on one side of the multi-footed wheel mechanism and drives the star-shaped wheel to rotate through a reducer. The steering motor is located above the multi-footed wheel mechanism and is fixed to the car body.

![Diagram of the model](image1)

1. Multi-footed wheel mechanism; 2. The body; 3. Steering motor; 4. Drive motor

Figure 1. General assembly diagram of the model

![Diagram of the multi-footed wheel mechanism model](image2)

1. Bearing; 2. Foot bar assembly; 3. Star-shaped wheels; 4. Fixed seat assembly; 5. Stepping motor; 6. Reducer; 7. Driving gear; 8. Driven gear; 9. Eccentric shaft

Figure 2. Assembly diagram of Multi-footed wheel mechanism model

2.1. Motor selection

To calculate and select the drive motor [6], the parameters which are shown in Table 1 must be specified at first.

| Parameter                  | Value | Unit  |
|----------------------------|-------|-------|
| Load mass                  | 40    | kg    |
| Gear mass                  | 1.44  | kg    |
| Walking radius             | 0.15  | m     |
| Maximum rotation speed     | 20    | rpm   |
| Gravitational acceleration | 10    | m/s²  |
| Gear radius                | 0.068 | m     |
| Acceleration response time | 0.25  | s     |
| Overall transmission ratio | 13.56 |       |

Table 1. parameter determination of multi-footed wheel robot motor
(1) Calculation of inertia

Load inertia:

\[ J_1 = \frac{1}{2} M_1 \cdot a^2 \]  

(1)

The inertia of the gears:

\[ J_2 = \frac{1}{2} M_2 \cdot R^2 \]  

(2)

The total inertia:

\[ J = J_1 + J_2 \]  

(3)

(2) Torque calculation

Load torque (the maximum torque in lifting stage):

\[ T_1 = M_1 g (a \sin 30° + R) \]  

(4)

Starting torque:

\[ T_2 = (J_1 + J_2 + J_m) \cdot \omega_0 = J \cdot \frac{V \cdot 2\pi}{60} \cdot \omega_0 \]  

(5)

Taking the parameters (shown in table 1) into formula 4 and formula 5, the total torque can be calculated as below:

\[ T = T_1 + T_2 = 58.03 \text{N} \cdot \text{m} J = J_1 + J_2 \]  

(6)

So, the performance parameters of the motor shall be determined as below.

\[ V_m = V \cdot Z_1 \cdot Z_2 = 271.2 \text{r/min} \]  

(7)

\[ T_m = T / Z_1 / Z_2 = 4.28 \text{N} \cdot \text{m} \]  

(8)

The Mige’s F86-H145 stepping motor (as shown in figure 3) is selected based on the calculation results above. And the dynamic torque curves of the stepping motor are shown in figure 4.

According to the dynamic torque curve of stepping motor F86-H145, the torque is about 6N•m when the motor speed is 271.2r/min, which will meet the walking requirements of multi-legged robot.

3. Simulation and analysis of multi-wheeled robot

In this section, the motor dynamic torque curve is externally programmed to obtain the relevant data of motor speed and torque which will be imported into ADAMS. SPLINE interpolation is used to get SPLINE function of speed and torque by ADAMS. The simulation of MOTION will be driven based on the SPLINE function. The kinematics characteristics of multi-wheeled robot walking in a straight line are obtained by the ADAMS simulation, and the rationality of motor selection and robot structure design is verified at the same time.

3.1. Establishment of simulation model

When the simulation model is established, the robot's external structure is simplified without changing the quality of parts, overall dimension and the position of the centroid. The simplified model was imported into ADAMS, and the constraints and drivers were also added to the model (as shown in Figure 5).
The dynamic torque curve of stepping motor F86-H145 was extracted from the dynamic torque data between the rotation speed 0rpm and 300rpm. According to the dynamic torque curve of the motor, the torque values at different key points were shown in Table 2.

| Speed (rpm) | Torque (Nm) |
|-------------|-------------|
| 0           | 8           |
| 25          | 7.8         |
| 70          | 7.7         |
| 175         | 7.2         |
| 300         | 6           |

The data were saved in TXT format, whose first column was the motor speed and second column was the motor output torque. And the data were imported into ADAMS to get the SPLINE function. In this paper, Akima fitting method was used as the interpolation method. Its function was expressed as follows:

AKISPL (First Independent Variable, Second Independent Variable, Spline Name, Derivative Order)

In the above formula:
First Independent Variable—the First Independent Variable in spline;
Second Independent Variable (optional) —The Second Independent Variable in spline;
Spline Name—The Name of the data unit Spline;
Derivative Order—the Derivative Order of the interpolation point, usually 0.

The driving function of the driving was as follows:
AKISPL(WZ(MRAKER_x), 0, SPLINE_1,0)
MRAKER_x was the name of the center of mass of the driving wheel.

3.2. Simulation analysis
In this study, ADAMS/View module was used to simulate the linear motion of the robot. The changing curves of driving wheel speed and acceleration was shown in figure 6.
As shown in Figure 6, the rotation speed and angular acceleration curves of the driving wheel varied significantly between 0s and 0.015s. It showed that the multi-footed wheel robot would bounce due to the rapid change of acceleration, which would have a great impact on the multi-wheeled robot. The robot started to walk smoothly after 0.015s. At this stage, the acceleration curve of the driving wheel had no obvious change, and the speed of the driving wheel was rising steadily. This showed that the design of the machine was reasonable.

The rotation speed and acceleration curve of the driving wheel fluctuated significantly at the initial position, which would affect the stability of the robot's linear walking. Changing the initial value of the driving moment, the robot simulation test was performed again, and the change curves of the driving wheel's speed and acceleration were shown in Figure 7.

Comparing with Figure 6(b) and Figure 7(b), it could be seen that the acceleration of the driving wheel after adjustment was significantly reduced. It could be seen from Figure 7(a) that the overall change of the driving wheel speed curve showed a steady upward trend without obvious abrupt changes. The robot moved in a straight line without bouncing, and the whole machine ran smoothly.

4. conclusion
This paper designs a new multi-footed wheel robot based on previous research results. The driving motor was calculated and selected according to the walking power demand of the robot. The simulation model was built in Solid works. In ADAMS, a spline curve driving function of angular
velocity and torque was applied to the driving wheel. The kinematic parameters of the robot's driving wheel were obtained based on the simulation. The simulation results verified the accuracy and walking stability of the robot. And the Stepping motor of F86-H145 could meet the requirement of robot walking in straight line. The analysis in this paper laid a good foundation for the further optimization design of multi-footed wheel robot and the establishment of experimental prototype.

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