Gait Design and Simulated Analysis of Quadruped Robot

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Abstract
This paper analyses the gait design and simulated analysis based on STC90C516RD + design process. The 12-way steering gear is set up in the joint part of the quadruped robot. By changing the duty cycle of the output PWM signal to control 12 way steering angle and speed, the purpose of controlling various gait of Quadruped Robot can be achieved. This paper mainly analyzes and designs the two gaits, circular-step and push-ups. This paper mainly analyzes and designs the two gaits, circular-step and push-ups. The whole design includes the kinematics analysis, gait analysis and structure design. A three-dimensional model is established base on SOLIDWORKS and simulation of the model is introduced into the ADAMS. At last the result of simulation is obtained to verify the design process.

Key words: Quadruped Robot, PWM Signal, Gait Analysis and Design, Simulated Analysis.

1. INTRODUCTION

With the progress of science and technology and the needs of society development, the technique of robot is extensively used in the product of industry and society life. Industrial robots, for example, are widely used in manufacturing industries to replace humans with higher risk factors.

Since 1960s, quadruped robots appeared in people's perspective (McGhee, 1967). The real first quadruped robot in the world is made by Frank and McGhee in 1977. This robot has good stability of gait motion, however, the disadvantage is that the joint of the robot is controlled by a state machine which is composed of a logic circuit. Therefore, the behavior of the robot is limited, and it only takes the form of a fixed movement. In the 1980s and 1990s, the most representative of the quadruped robots is the TITAN series developed by Japanese Hirose Shigeo laboratory (Raibert, 1990). It has been able to realize the crawling gait, ambling gait, trotting gait, pacing gait and other symmetrical gait. Contemporaneously, the quadruped robot designed by MIT (Raibert) in America in 1984 is also very representative. The robot leg adopts telescopic structure, achieves touchdown buffer and jump by using the cylinder. It can use trot, pace and bound gait to run fast and stably (Seok, 2014). The Department of mechanical information science, University of Tokyo, Japan developed a quadruped robot with intelligent behavior based on vision. The Institute of mechanical engineering, Nan yang Technology University, Singapore developed a quadruped robot which is mainly used in the research of mechanical structure design, motion control and gait analysis. The development of the quadruped robot starts late in China, but develops really rapidly. Starting from the beginning of the 1980s, the robot research Institute of Shanghai Jiao Tong University carry out researches on JTUWM series of Quadruped Robots in 1991. The QW-1 quadruped robot developed by Tsinghua University has realized the Omni-directional movement under the static gait. Shandong University (Rong, 2014), National University of Defense Technology, Harbin Institute of Technology, Beijing Institute of Technology (Li, 2014) and the Shanghai Jiao Tong University developed a number of hydraulic driven quadruped robots in 2013, which has a substantial increase compared with the previous electric drive robot in terms of moving speed and weight bearing capacity.

This paper regards the quadruped robot as the example, and mainly talks about the design process of the quadruped robot which based on STC90C516RD+. Meanwhile, gait design of the two gaits-circular-step and push-ups are conducted. A three-dimensional model is established base on SOLIDWORKS, simulation of the model is introduced into the ADAMS and the results of simulation are obtained to verify the design process.

2. CONTROL SYSTEM DESIGN of THE QUADRUPED ROBOT

This design uses STC90C516 microcontroller and Complex Programmable Logic Device (CPLD) to achieve the production of PWM. Because CPLD has his own parallel processing ability, coupled with a large number of IO interface, the MCU can control a lot of steering gears at the same time. It can save a lot of space to prepare for the follow-up work.

But the ability of CPLD can’t handle affairs, so in the actual application, CPLD needs the cooperation of MCU. Control system of "PC + serial port + Slave computer" is selected. If not, the direct connection of the
steering engine by the microcontroller complicates the single-chip processing, but this will make the circuit simple. The design of the control system structure is shown in Figure 1.

![Figure 1. The control system structure](image)

3. THE GENERATION of PWM

The motion of quadruped robot is mainly controlled by the rotation angle and speed rotation of the steering gear. The control of the steering angle and the rotation speed is controlled by the change of the duty cycle of the PWM signal.

This design needs the single chip microcomputer to produce a clock cycle for PWM 20ms signal, and use the interrupt program to adjust the level of the control port. The flow of generating PWM signal is shown in Figure 2.

![Figure 2. The flow of generating PWM signal](image)
4. GAIT DESIGN of TWO TYPES of QUADRUPED ROBOT

The overall gait design of the quadruped robot includes circular gait and push-up gait (Kavraki L., 1996; Back S, 1999).

4.1. Circular Gait Design

With reference to Figure 3 we can see that, from the initial position shown in Figure 3 (a), two legs fold pairwise and maintain a state of distribution in the positive direction. That is the principal plane of the leg is perpendicular to the direction of walking shown in figure 3 (b). Then let the quadruped robot clockwise circle, and get ready for action before making a circle shown in figure 3 (c). Then turn the legs on the diagonal to the position of the Figure 3(d) in a clockwise direction. And then, another preparation for the next circling is done, as shown in Figure 3(e). With the reciprocating motion, the robot will be delight in circling and never get tired of it.

From the turning gait picture, we can found that keep the initial position at the beginning, leg 2&3 and leg 1&4 pairwise folding. In order to make the Quadruped Robot turning clockwise, leg 2&4 need to do a prepare action before them turn, then turning led 1&3 (Bagchi, 1992). Making leg2 close leg3, leg3 close leg2, leg2 close leg1, leg1 close leg4, makes all the action could be a clockwise entirety. In the next step, turning leg3&1 make legs to do a prepare action before them turn, then turning led 2&4. Circling gait process is shown in Figure 4.

![Figure 3. Circling gait](image)

![Figure 4. Circling gait process](image)
Using Keil writes the program, because in the controller of servo, the range of experiment position is 700 - 2700. In order to achieve the gait (Bonet B, 2001), the servo position will be add in is shown as Table 1.

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Table 1. The servo position of circling gait

4.2. Push-up Gait Design

Push-up gait mainly considers the robot can do push-ups like human. But its mechanism is not the same, the robot has no elbow joint, not like a man in the palm of the ground situation, relies on the biceps and latissimus dorsi muscle strength. So in such circumstances, I firstly set out the front feet. In order to be more close to people's way, affixed front foot and the ground can’t touch around, and have to remain motionless state as push-ups.

From the gait can be seen that at the beginning of the original location, 1, 2 rudders to a certain position to imitate the human arms; 3, 4 rudders to a certain position to imitate the human legs; 7, 8 rudders lift outside to a certain position; 11, 12 rudders lift inside to a certain position. It forms a perfect ready posture to push-up. When 5, 6 rudders lift inside to a certain position concurrently and return to the original position, the reciprocating motion, constitute a complete push-up position (Fukuoka, 2003). Push-up gait process is shown in figure 5.

Figure 5. Push-up gait process

Write the program with Keil and the rudder controller on the steering position (the default for the median 1700) range is 700-2700. After actualizing push-up gait motion, adding motion actuator position is shown as table 2.
5. SIMULATED ANALYSIS of THE QUADRUPED ROBOT

In order to verify the feasibility of the whole design and whether the four legged robot can complete the designed gait smoothly, we take a four legged robot as an example including the simulation and analysis of it.

5.1. Establish a Three-Dimensional Model and Set the Joint Degree of Freedom

Firstly, the three-dimensional model is established by using SOLIDWORKS. Hip joint is between bracket and thigh where we set up a degree of freedom. And the knee joint is between thigh and leg, we set up another degree of freedom here. The whole model sets 8 degrees of freedom totally. As shown in figure 6.

![Figure 6. Three-dimensional model of the quadruped robot](image)

5.2. Import Model, Add The Drive Function

The 3D model is imported to ADAMS software and constraints are created at the hip and knee joints of each leg. A total of 8 rotation pairs are created. According to the trajectory of the quadruped robot, we need to take 8 types of points on the trajectory. The inverse solution is obtained for the angle of the joint. And after importing the ADAMS to form the Spline curve, the driving function is obtained. Taking the hip and knee joint of one leg as an example, the image of the two drive functions is obtained. As shown in figure 7 and figure 8.
5.3. Analysis Of The Motion Trajectory

After all the settings are completed, the simulation of a walking process is carried out. Eight moments’ images of each walking process are shown in Figure 9. From the whole image we can see that the movement tracks at the end of the leg are smooth and continuous. No mutation is found. The trajectories of four legs are similar and only exists a certain phase difference.

5.4. Analysis of The Joint Angle

The two joints of a same leg (hip joint and knee joint) are considered as the analysis object. Simulation data of the street corner of the hip joint and knee joint in single leg are shown in Figure 10 and Figure 11. Comparing the street corner of the joint and the prior input spline curve, we found that they are roughly equal in size, which means that the input drive spline function meets the requirements of the actual motion.
5.5. Measurement and Analysis of Velocity, Acceleration and Displacement of The Leg

During the process of walking, the robot needs to be continuous and steady. No violent mutation is a request for the speed, acceleration and leg movement of the thigh, calf, and joint. It requires its slowly and smoothly change without having a mutation.

Taking a leg (speed of thigh and shank) as an example to illustrate, measurement and analysis of velocity, acceleration and displacement of the leg are shown in figure 12, figure 13, figure 14, figure 15, figure 16 and figure 17. It can be seen from the figure that the velocity, acceleration and displacement of the single leg is relatively flat, and no mutation occurs. The quadruped robot will not fall suddenly. As a consequence, the design meets the requirements of the actual movements.
Figure 13. Simulation data of the Speed of shank

Figure 14. Simulation data of the acceleration of thigh

Figure 15. Simulation data of the acceleration of shank

Figure 16. Simulation data of the displacement of thigh
5.6. Measurement and Analysis of Displacement of The Bracket Centroid Height

The change of the bracket centroid height is an important basis for stable walking of a quadruped robot. The simulation is carried out to measure the displacement of the bracket centroid height. As shown in figure 18. The maximum change of the height of the bracket is not more than 20mm while walking. Its small amplitude allows it to walk pretty smoothly. As a consequence, the design meets the requirements of the actual movements.

6. CONCLUSIONS

The birth of robots has opened up a new era of human science and technology. As a new tool of human being, it plays an important role in industrial production and life service. The popularity of robots for improving productivity is of great significance and great value.

The main content of this design is the control system design of the quadruped robot and the typical gait analysis. At the same time, a detailed description is made of the motion gait of 12 degrees of freedom robot and the simulation analysis is carried out to verify the feasibility of this design. The deficiency is that there is the stability of the robot is slightly worse. Hoping that in the course of future research can be a breakthrough in this area.

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