Design of Control System for Multi-joint Robot Based on STM32

Ren Bin
School of Electronic Engineering and Intelligence, Dongguan University of Technology, Dongguan, China, 523808

Abstract: The motion of Bionic Hexapod spider robot is relatively flexible. It has high comprehensive performance and research value whether it is the stability of motion, the load capacity of fuselage, or the difficulty of control. In this project, a Bionic Hexapod spider robot with STM32 chip as the core control is designed. Combined with the actuator control board design action, the STM32 chip built-in timer is used to generate multiple PWM signals to drive the steering gear motion, so that the robot can achieve different posture. At the same time, a wireless remote controller based on NRF24L01 wireless module is designed to expand the usability of the project. On the basis of the simulation, the actual operation principle of the robot is verified, which lays a good theoretical foundation for the continuous improvement of the robot in the future.

1. Introduction
Multi-joint robot is called spider robot because it draws lessons from the spider's body structure in nature. Compared with wheeled and tracked robots, the motion mode of multi-joint robot is more adaptable to the ground and less limited, but its design is relatively more complex, and its control system algorithm is more complex, which is the difficulty of multi-legged robot.

The significance of studying bionic hexapod spider robot in this topic lies in exploring the functions of biped robot in human daily life, and how to simulate and realize basic functions by designing experiments. Predictable functions include earthquake rescue and disaster relief, un-manned transportation and intelligent mine clearance. The control system of bionic hexapod spider robot designed in this paper makes use of various automation related technologies such as bionics principle, single chip microcomputer technology, motion control, mathematical modeling simulation and so on.

2. Mathematical modeling and performance analysis of the system

2.1 The relationship between the bottom design and gait of bionic hexapod spider robot
The arrangement of legs of bionic hexapod spider robot has a great influence on the stability and motion performance of the fuselage. According to the movement of joints at the bottom of the fuselage, it can be generally divided into three layouts: round, oval and rectangular. By analyzing the bottom figure of the bionic hexapod spider robot, it is assumed that each leg of the robot swings at the same angle, that is, when the fan-shaped areas swept by the legs of the robot are consistent, as shown in Figure 1.

It can be seen that under the condition of controlling a single variable, when the circular layout moves, the robot legs do not interfere with each other best; By controlling a single variable, it can be concluded that when the rectangular layout moves, the distance of the robot's legs is the largest.
Combining the advantages and disadvantages of the two, it is found that the elliptical layout is the most comprehensive, so most designers will choose this layout when designing the scheme, which is closest to the natural arthropod body structure from the perspective of bionics.

In 1968, McGhee and Frank first studied the periodic gait of a multi-legged walking robot in straight line motion, and made a mathematical definition to describe and analyze the gait\(^1\). In 1976, McGhee and Iswandhi put forward the concept of static stability margin (SSM)\(^2\). It is defined as the minimum distance between the center of gravity projection point and each side of the supporting polygon, and the mathematical expression is:

\[
S_{ssm} = \min_i (d_i) \tag{1}
\]

In the mathematical expression: \(S_{ssm}\) is static steady-state margin; \(f_i\) is the number of support legs; \(d_i\) is the distance from the center of gravity projected to the \(i^{th}\) edge of the polygon. At that time, the center of gravity projection exceeded the steady state range, and the robot was in an unstable state; On the contrary, it is in a stable state. When the bionic hexapod spider robot moves, the hexagonal bottom always envelops the projection of the center of gravity of the fuselage, so the gait of the bionic hexapod spider robot can keep stable.

According to the above considerations and analysis, in order to ensure the flexibility of the motion space and sufficient steady-state margin of the bionic hexapod spider robot, it is verified that the elliptical layout is the best scheme.

2.2 Kinematics analysis of one foot of bionic hexapod spider robot.

When analyzing the kinematics of swinging legs, the solution of forward kinematics is to know the position and posture of the fuselage and the size of three rotating joints, and to solve the position coordinates of the end point of the foot\(^3\). Using D-H method, a coordinate system is established on a leg, and the four coordinate systems respectively represent the basal joint, thigh joint, calf joint and sole.

According to the principle of robot control, the D-H transformation matrix expression of adjacent joints is:

\[
^{i+1}H = Rot(x, a_{i-1}) \ Trans(a_{i-1}, 0, 0) \ Trans(0, 0, 0) \ Trans(0, 0, d_i) \tag{2}
\]

\[
^{i+1}H = \begin{bmatrix}
    c\theta & -s\theta & 0 & a_{i-1} \\
s\theta c_{a_{i-1}} & c\theta c_{a_{i-1}} & s\theta c_{a_{i-1}} & -dsc_{a_{i-1}} \\
s\theta s_{a_{i-1}} & c\theta s_{a_{i-1}} & c_{a_{i-1}} & dca_{i-1} \\
0 & 0 & 0 & 1
\end{bmatrix} \tag{3}
\]

Establish a rectangular coordinate system as shown in Figure 2.
Fig. 2. Establishment of rectangular coordinate system with one leg joint.

Meanwhile, a D-H parameter table is established for one leg of the bionic hexapod spider robot.

| Joint         | $\theta_i$ | $\alpha_i$ | $a_i$ | $d_i$ |
|---------------|------------|------------|-------|-------|
| Basal Joint /1| $\theta_1$ | -90°       | $l_1$ | 0     |
| Thigh Joint /2| $\theta_2$ | 0          | $l_2$ | 0     |
| Calf Joint /3 | $\theta_3$ | 0          | $l_3$ | 0     |

The obtained homogeneous transformation matrix is:

$$H^0_3 = H^0_1 H^1_2 H^2_3$$  \hspace{1cm} (4)

$$H^i_j = 
\begin{bmatrix}
  c \theta_i c \theta_j - c \theta_i s \theta_j c \theta_k - s \theta_i s \theta_j s \theta_k - s \theta_i c \theta_j c \theta_k \\
  -s \theta_i c \theta_j - c \theta_i s \theta_j c \theta_k - s \theta_i s \theta_j s \theta_k - s \theta_i c \theta_j c \theta_k \\
  s \theta_i s \theta_j c \theta_k - c \theta_i c \theta_j s \theta_k - c \theta_i s \theta_j c \theta_k - c \theta_i s \theta_j s \theta_k \\
  0 & 0 & 0 & 1
\end{bmatrix}$$ \hspace{1cm} (5)

Finally, the spatial coordinate values of one leg are obtained:

\[
\begin{bmatrix}
p_x \\
p_y \\
p_z
\end{bmatrix} =
\begin{bmatrix}
l_1 c \theta_1 + l_2 c \theta_1 c \theta_2 + l_3 c \theta_1 c \theta_2 c \theta_3 \\
l_1 s \theta_1 + l_2 s \theta_1 c \theta_2 + l_3 s \theta_1 c \theta_2 c \theta_3 \\
-l_3 s \theta_2 - l_3 s \theta_3
\end{bmatrix}
\]

Therefore, the point $P(p_x, p_y, p_z)$ is the position coordinate of the end point of a leg of the bionic hexapod spider robot.

On the contrary, if we get the point $P$, we can use the existing posture of the bionic hexapod spider robot and combine the existing point $P$, and we can use these known conditions to reverse the angle of each joint, which is the inverse kinematics solution of the robot.

3. Hardware system design

The hardware circuit of the control system is mainly composed of four parts: multi-channel steering engine control board, main control part, communication module and control handle.

3.1 Multi-channel steering gear control panel

In this paper, the mature steering engine controller is adopted, which can reduce the design time and cost and improve the efficiency.
By controlling the values of the steering gear windows, different actions can be realized, and the number of steering gear windows is consistent with the actual number of steering gears. This bionic hexapod spider robot has 18 joints, so 18 steering engine windows are set to control 18 steering engines.

3.2 PS2 control handle
PS2 handle is a mature and fully functional control module, which uses SPI serial communication to send and receive data at the falling edge of clock. The communication timing is shown in Figure 3.

The idea of using PS2 to control the bionic hexapod spider robot is to disassemble the complete operation of the bionic hexapod spider robot into several continuous steps, and then use different keys to represent different steps. In the actual debugging, each step is configured into corresponding different key representations by using the matching host computer software, and finally runs successfully.

![Fig.3. Communication Timing.](image)

3.3 Wireless Controller based on NRF24L01
Although the handle is enough to control most movements of the robot, it has great limitations and small expandability, which is not conducive to the secondary development and project migration. It is necessary to design a wireless control remote controller to expand the usability of the project. In this paper, the control chip NRF24L01 is used to design the wireless controller, and the 2.4G module on the control board is used to send the command of combined keys to control the actions stored in the lower computer, which are then displayed in the OLED module on the control board.

According to the requirements of the project, the following test actions are designed, as shown in Table 2.

| Movement    | SWL | SWR | SW1 | SW2 |
|-------------|-----|-----|-----|-----|
| Test Mode   | 1   | 0   | 0   | 0   |
| Stopping    | 1   | 1   | 0   | 0   |
| Forward     | 0   | 1   | 0   | 0   |
| Advancing   | 1   | 0   | 1   | 0   |
| Retreating  | 1   | 0   | 0   | 1   |
| Turning     | 0   | 0   | 1   | 0   |
| Provocative | 0   | 0   | 0   | 1   |

Test mode is a link to monitor whether buttons can normally receive settings in wireless communication. In order to monitor that the bionic hexapod spider robot in this design can realize the obstacle avoidance function, it is necessary to set up a forward mode, and then carry out obstacle avoidance test when executing this mode. The bionic hexapod spider robot realizes the functions of advancing, retreating, turning and stopping, and also realizes the functions of complex actions.
3.4 Controller based on STM32
Send the control instruction `uart1_send_str((u8 *)"$ DGT:0-4,1!")` to the multi-way steering engine control board with STM32F1 as the core master, the data in double quotation marks, that is, the machine instructions of the corresponding actions of the multi-channel steering gear control board. Different machine instructions correspond to different actions. When the bionic hexapod spider robot performs actions and encounters obstacles, it will return to the corresponding state through the serial port.

It can be seen that when testing the obstacle avoidance function of the bionic hexapod spider robot, the core control board transmits the corresponding action state through the serial port. When encountering obstacles, the signal of encountering obstacles is transmitted, and the combined action of avoiding obstacles is executed. When it is determined that there are no obstacles, keep moving forward. The whole process is displayed in the upper computer software through serial communication, which plays a great role in verifying the wireless control of bionic spider hexapod robot.

4. Software system design

4.1 Bionic hexapod spider robot based on PS2 handle control
In this subject, the PS2 handle is used to send the corresponding machine instructions, and the multi-channel steering engine control board receives and decodes the corresponding instructions, executes the action instructions previously downloaded into the chip, and finally controls the fuselage to complete the corresponding actions. The flow chart of control degree design is shown in Figure 6.

![Flow chart of control design.](image)

4.2 Control bionic hexapod spider robot based on NRF24L01 controller
Almost all control functions can be realized by controlling the bionic hexapod spider robot with PS2 handle. However, after careful consideration, it is found that the corresponding function keys must be pressed all the time when the handle is used to test the progress. The principle is equivalent to a normally open switch, which cannot be closed all the time after being pressed. Because of this defect, the degree of autonomous motion of bionic hexapod spider robot is greatly reduced, which has a great impact on the future development of more intelligent robot. At the same time, the whole system design relies too much on the matching control equipment, so it is necessary to design a control board as the lower computer to control the bionic hexapod spider robot, and correspondingly add other functions.

After writing the action control program for the lower computer, it is also necessary to send instructions through the control board and wirelessly control the control board to drive the bionic hexapod spider robot to move.

In order to make the control more visual, it is necessary to add an OLED screen to display the sent control instructions on the screen in real time, which is convenient for debugging the sub-sequent action logic.

5. Result analysis
Finally, the motion of the bionic hexapod spider robot can be accurately controlled by controlling the control handle and control board. As shown in figs. 5 to 7.
It can be seen that when designing the gait of bionic hexapod spider robot, it follows the triangle gait, which is also the gait used by most developers.

It can be seen from fig. 6 that when the provocative state is designed, the first foot and the sixth foot are suspended, then swing alternately, and finally switch to the static expansion state, and the whole action group is composed of multiple action states. However, in the actual debugging process, because there is no stable output power supply, the lithium battery on the fuselage has the problem of charging consumption, and the voltage is always insufficient. At the same time, the quality of domestic steering gear is also insufficient, because it is easy to produce the phenomenon of rudder shaking. At the same time, it cannot be ruled out that the function library packaged by the bottom multi-channel steering gear control board is not optimized well, resulting in inevitable rudder shaking.

6. Conclusions
In this paper, a Bionic Hexapod spider robot with STM32 chip as the core control is designed. Combined with the actuator control board design action, the STM32 chip built-in timer is used to generate multiple PWM signals to drive the steering gear motion, so that the robot can achieve different posture. On the basis of the simulation, the actual operation principle of the robot is verified, which lays a good theoretical foundation for the continuous improvement of the robot in the future.

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