Research on Gait control algorithm of Bionic Hexapod Robot System based on Adams and Matlab

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Abstract. The control algorithm of bionic hexapod robot based on biological control algorithm has been designed and realized. Through the establishment of virtual prototype physical model by Adams, Adams and Matlab simulation software is realized to carry out joint simulation of the robot to verify the feasibility of the algorithm. At the same time, the algorithm was improved according to the emerging problems. Firstly, the gait control model of hexapod bionic robot is established in Matlab/Simulink, and pure theoretical simulation is carried out for it as the control system part of the joint simulation system. Secondly, a three-dimensional solid model of hexapod bionic robot is established in SolidWorks, which is then imported into the mechanical simulation software for kinematic analysis to verify the constraint relationship of the virtual prototype model, and the corresponding Simulink file is exported through the Adams/Controls interface module as the mechanical system part of the joint simulation system. Finally, Adams and Matlab are used for joint simulation of the robot to verify the feasibility of this algorithm and lay a foundation for the construction of entity prototype.

1. Introduction

Bionic hexapod robot has a relatively complex control system. Since it has six mechanical legs, each of which is composed of three joints (ankle, knee and hip) and contains a total of 18 active joints, each joint needs to be adjusted one by one in order to adapt to a certain geographical environment, which consumes a lot of time and energy. Therefore, before making a physical prototype of hexapod robot, it is necessary to establish a virtual prototype system and study a stable gait control algorithm applied to the gait control of hexapod robot, so as to improve the intelligence of the robot. Adams is a very convenient virtual software for prototype analysis, which can realize kinematics, dynamics, statics analysis and mechanical simulation of virtual mechanical system. In addition, the software also has a number of interfaces for users to secondary development. Matlab/Simulink simulation software facilitates the establishment of dynamic system modeling environment with the advantage of clear structure flow, fine simulation, high efficiency and flexibility. The joint simulation system of hexapod bionic robot gait control algorithm has been established by Adams and Matlab/Simulink, which can give full play to their advantages, simulate the gait of the robot, reduce the development cycle, and provide reliable technical basis for the real hexapod robot gait control.
2. Mechanical system of bionic hexapod robot

2.1. Establishment of three-dimensional solid model of hexapod bionic robot

Adams software has a strong analysis ability in dynamics, kinematics and static mechanics, but this software has a big gap in 3D modeling ability compared with pro-e, SolidWorks and other software. The mechanical structure of physical hexapod robot so complex that it is difficult to accurately establish its three-dimensional solid model just by using Adams software. Therefore, SolidWorks software is used to establish the three-dimensional solid model of hexapod bionic robot. Assume that all parts of the robot are rigid bodies with uniform density under ideal conditions. According to the biomimetic principle, the leg structure with three degrees of freedom has obvious advantages in the leg structure design of robot. It is easy to assemble with a large range of motion. The three degrees of freedom are divided into ankle joint, knee joint and hip joint according to the order from the foot end to the body. Starting from the whole body, the three leg segments are respectively basal, femoral and tibia in sequence, and the length of each leg segment is 25mm, 140mm and 130mm respectively. The hip joint of the middle part of the body is offset by 10mm outwards compared with the hip joint of the hind leg and front leg. Considering about the flexibility and working efficiency of hexapod bionic robot, it accords with the structural design of robot legs. the three-dimensional solid model of the hexapod bionic robot is shown in figure 1.

![Figure 1. Three-dimensional solid model of hexapod bionic robot.](image)

2.2. Establishment of mechanical simulation system of bionic hexapod robot

Firstly, establish the virtual prototype model of the hexapod bionic robot with SolidWorks software and store the file with ‘.xt’ as its extension. Second, combine the file imported into the Adams simulation software, then to import each model of in the virtual prototype in Adams simulation software which is carried out in accordance with the physical prototype in the related definitions, including material properties, name, etc. It can make virtual prototype and physical prototype more close to the physical properties by setting, so that the simulation results more truly reflect the movement law of physical prototype. The related attribute parameters of each component of the designed robot are shown in table 1.

| Structural | length/cm | material       |
|------------|-----------|----------------|
| Body (length) | 180       | aluminum alloy |
| Body (width)  | 80        | aluminum alloy |
| Base section | 25        | aluminum alloy |
| Section      | 140       | aluminum alloy |
| Shank        | 130       | aluminum alloy |

In addition, it is necessary to add driver and constraint pair to the virtual prototype model. Among them, the joints of hexapod robot are all revolute joints, which add revolute pair constraints. The positions of the rest parts are relatively fixed, so fixed pair constraints are added to ensure that the correct motion relations between the parts of the virtual prototype can be achieved during the simulation.
After the constraint pair is added, the driver function needs to be added for the 18 joints of the robot, through which each joint of the robot can rotate correctly. First, set 18 state variables shulu_1, shulu_2, shulu_3... Shulu_18 , which is used as the input state variable. The variable is defined as a real-time expression, indicating that the value of the variable is a function expression varying with time. The driver function here is VARVAL function, and the 18 driver functions corresponding to the 18 joints are VARVAL(.model_1.shulu_1), VARVAL(.model_1.shulu_2), VARVAL(.model_1.shulu_3)…, VARVAL (.MODEL_1.Shulu_18). After adding constraint pair and joint drive, the Simulation Control module in Adams software is needed to verify the correctness of the virtual prototype model of hexapod bionic robot, and the verification results are shown in table 2.

| Parts          | Number |
|----------------|--------|
| Gruebler       | 6      |
| Mobilecomponent| 102    |
| Revolute Joints| 18     |
| Motations      | 83     |

It is easy to see that the virtual prototype model of hexapod bionic robot includes 18 joint drive, 18 fixed constraint of rotation constraints, as well as 83, a total of 102 moving parts. The virtual prototype model has been proved accurate, so the virtual prototype model can be used as the next step of Adams and Matlab joint simulation system of mechanical system.

3. Control system of hexapod bionic robot

The control system of hexapod bionic robot is built based on Matlab/Simulink platform. The Central Pattern Generator (CPG) is a control method designed according to the control principle of the lower nerve centers of animals. Multiple Central neurons jointly constitute the CPG of organisms, among which, neurons include excitatory neurons and inhibitory neurons. CPG can generate stable oscillation signal through self-excitation without external feedback or high-level control signal at the same time. It can also regulate and set the external feedback and high-level control signals when there are external feedback and high-level control signals. This system fully studies the CPG control method, and designs the control system model and related algorithms in combination with the actual gait control of hexapod robot. The algorithm has good reliability through joint simulation verification.

3.1. Single neuron model and simulation curve

As a basic control module, CPG can be fully used in robot motion control. Neurons are the most basic processing units for motion control. Neurons are mainly composed of cell body, dendrites and axons. Neuron modeling is the beginning of CPG modeling. The purpose of neuron modeling is to describe or simulate the behavior of nerve impulses of neurons after being stimulated. Neuronal cells usually exhibit excitatory and inhibitory states. We call the input of a neuron the sum of the output of other neurons acting on that neuron through the synapse.

In fact, during the occurrence of pulses, neurons show fatigue and self-inhibition characteristics (also known as adaptability). That is to say, when neurons are stimulated at the beginning, their output will increase rapidly, and gradually decline after a certain period of time, eventually reaching a stable state. Moreover, we have learned that in CPG, the connections between synapses of various neurons are plastic and can display various patterns to complete different rhythmic movements.

Previous studies by Japanese scholars have confirmed that neural network can form CPG model, and the mathematical model of single neuron is as follows:
Among the equation:

\[
\begin{align*}
Tr \frac{du}{dt} + u &= s - bv \\
Ta \frac{dv}{dt} + v &= y \\
y &= g(u - \theta) \\
g(x) &= \max(0, x)
\end{align*}
\]

Among the equation: \( u \) denotes Membrane potential of neurons; \( v \) denotes Neuronal fatigue or adaptability; \( s \) denotes A constant slowly varying excitation; \( Tr \) denotes Rise time constant; \( Ta \) denotes The time delay constant of the adaptive function; \( b \) denotes Neuron self-inhibition coefficient; \( y \) denotes The output of neurons; \( \theta \) denotes Output threshold.

A single neuron will get continuous high-order output after being excited. Since a single neuron cannot oscillate with each other, it eventually tends to be stable, which also means that a single neuron cannot be directly used as a control signal.

3.2. Single oscillator (two mutually inhibiting neurons) model and simulation curve

In order to improve the output signal of neurons, flexor neurons and extensor neurons can be inhibited by each other to act as joint oscillator.

According to Simulink simulation as shown in figure 2, the states of extensor neurons, flexor neurons and the output of two mutual inhibitory neurons can be obtained as shown in figure 3, figure 4 and figure 5.

![Figure 2. CPG model of a single oscillator (two mutually inhibiting neurons)](image)

![Figure 3. State curve of extensor neurons.](image)

![Figure 4. State curves of flexor neurons.](image)

![Figure 5. Output curves of two mutually inhibiting neurons.](image)
According to figures 3 and 4, flexor and extensor neurons are excited alternately, and the phase difference between their output signals is always PI. Figure 5 is the waveform of the mutual suppression output of two neurons. The signals generated are oscillating regularly and can constitute an oscillator, which can be used to control the rhythmic movement of robot joints.

3.3. Six hip joint models and simulation curves

The movement process of hexapod robot is obtained according to the movement set of all legs, while the movement of single leg is completed according to the coordinated movement of ankle joint, knee joint and hip joint. Each leg of the hexapod robot has three joints, a total of 18 active joints. Assuming that all 18 active joints are controlled by CPG method, the control network model will be very complex. Therefore, the CPG method is adopted to control the six hips of the hexapod robot, while the motion of the six ankles and six knees are controlled by the joint mapping function is used to indirectly.

The gait of hexapod robot is abundant, such as undulating gait, quadruped gait and tripod gait, among which the tripod gait is the best in ensuring high speed and stability at the same time. So the tripod gait is used as an example to study the gait of hexapod robot in this paper. The relationship between promotion and inhibition of hip joints of each leg is shown in figure 6, where the solid line represents promotion and the dotted line represents inhibition. Figure 7 is the simulation model of six hip joints, and the simulation output curve is shown in figure 8.

According to the output curve, Leg1, Leg3 and Leg5 are in the same phase while Leg2, Leg4 and Leg6 are in the same phase, and the phase difference between the two groups is PI. When walking with a three-legged gait, the two legs of the robot alternately become supporting phase and swinging phase. The swing of the legs in the same group is the same, so the waveform is the same. The simulation results show that the CPG simulation model of hexapod bionic robot can complete the gait simulation of three legs.
3.4. Knee and ankle joint simulation models of hexapod bionic robot
Combined with the previous experience of debugging physical hexapod robot and hip waveform, the paper use Simulink to design and generate the MATLAB Function module for the knee and ankle joints. The simulation model is shown in figure 9. Waveforms of knee and ankle joints of the two groups of legs are shown in figure 10.

4. Co-simulation system
The specific steps of co-simulation are as follows:
Step 1: Import the three-dimensional solid model of hexapod bionic robot established in SolidWorks into Adams, and add different constraint pairs for each joint and component.
Step 2: Determine input and output variables. Matlab and Adams are a closed-loop control process instead of a single input and output. A total of 16 state variables are set in Adams simulation software, including 18 input variables that drive the rotation of robot joints and one robot displacement output variable, as shown in figure 11.
Step 3: Use Simulink to design the control system. Control the movement of each joint of the robot through the written function and module library. The co-simulation model is shown in figure 12.
Step 4: Set simulation parameters to simulate the model. The Adams/PostProcessor module is used to process the simulation results, and the real-time gait of the hexapod bionic robot is analyzed in the form of animation.

![Adams input and output](image1)

**Figure 11. Adams input and output.**

![Joint simulation model of hexapod bionic robot](image2)

**Figure 12. Joint simulation model of hexapod bionic robot.**

5. **Simulation results and analysis**

Taking the most representative gait, the three-legged gait of the hexapod bionic robot, as the research object, the simulation duration of the robot in Adams/Matlab joint simulation platform is 10s while the period is 2s. The robot works in the adjusted state from 0 to 1.5s, while in the first working cycle from 1.5 to 3.5s and the second working cycle from 3.5 to 5.5s and so on. The six legs of the robot are divided into two groups. Leg1, Leg3 and Leg5 are the same group of legs while Leg2, Leg4 and Leg6 are the other group of legs. The two groups of legs alternately become the supporting phase and the swinging phase, and the swing form of the same group of legs is the same. When one group of legs works in the swinging phase, the legs of this group swing forward, while the other group of legs kick backward in the supporting phase so that the hexapod bionic robot can complete the forward movement. The reason why the hexapod bionic robot can achieve fast and steady movement with the tripod gait is that the legs of the same supporting phase can form a triangle bracket in real time to support the robot body. The following is the motion decomposition process of robot within 0–3.5s.
As can be seen from figure 13, the hexapod bionic robot will achieve the correct forward movement according to the set three-footed gait, and the two groups of legs will move forward alternately (left). While swinging the legs forward, the supporting legs will kick back to push the robot body forward. The regular periodic rhythm is reflected in the walking process.

The virtual prototype of hexapod bionic robot is constructed by Adams, while the model of control algorithm is established in Matlab/Simulink, and the control algorithm is used for virtual prototype joint simulation. The control algorithm designed in this paper can fully meet the requirements of physical robot motion control through simulation verification, which provides important technical support for further completing the gait control of physical prototype.

6. conclusion
This paper uses mechanical simulation software Adams, 3d modeling software SolidWorks and Matlab software to complete the establishment of virtual physical prototype of hexapod bionic robot, 3d solid modeling and the establishment of joint simulation system. Through the joint simulation, not only can the dynamic motion process of virtual prototype model of hexapod bionic robot under the control of the control model be intuitively seen, but also the joint debugging of the control system and the mechanical system can be carried out, so that the defects of the control algorithm and mechanical system can be quickly found and optimized immediately. The research method in this paper can shorten the development cycle of intelligent hexapod robot, reduce the research cost, and provide a very important
technical reference for the physical system design, manufacture and intelligent control of hexapod bionic robot.

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