Research on Biologically Inspired Hexapod Robot’s Gait and Path Planning

LUO Qingsheng, ZHANG Hui, HAN Baoling, ZAHO Xiaochuan

Abstract—Realistically there are many robot joints in the biologically inspired hexapod robot, so they will generate many complexities in the calculations of the gait and the path planning and the control variables. Facing this status quo, we mainly adopt Solidworks as well as MSC.ADAMS to simulate and analyze the prototype model of the robot. By the simulations on our design, the applicability of the tripod gait is validated, and the scheme which uses cubic spline curve as the endpoint of foot’s path is feasible. In this paper, the simulation principles, methods, and processes of the hexapod robot are illustrated. Finally, we find a methodology to get the robot inverse solution in ADAMS, and simplify the theoretical calculation, and further more improve the efficiency of the design.

I. INTRODUCTION

Biologically inspired hexapod robot is an advanced robot which has multi-link and multi-DOF (degree of freedom), and its kinematics and dynamic characteristics are rather complicated. Therefore, in order to improve the development level of this kind robot, it is highly necessary for us to exploit a simulation system which can satisfy the demands of kinematical and dynamic analysis. As it is known to us, ADAM is an excellent software in the virtual system field, which can construct the virtual prototype according to the pragmatic kinematics system of the research object. Besides, the working characteristics are analyzed before the construction of the physical prototype, and moreover better ameliorated and optimized. However, the 3-D modeling function of ADAMS is relatively weak. So the combination of the Solidworks and ADAMS is proposed, it is used to simulate the kinematical aspect of biologically inspired hexapod robot. Finally this method improves the research efficiency and shortens the research period as well as research funds, and it realizes the high quality, high efficiency, low cost overall design.

Figure 1. Biologically Inspired Hexapod Robot

II. BIOLOGICALLY INSPIRED HEXAPOD ROBOT

A. Biologically Inspired Hexapod Robot

The whole structure modeling and leg kinematics diagrams of the hexapod robot are shown in Figure 1 and Figure 2 respectively. In this robot, every leg all adopts three-rotation-joint structure. In this robot the root joint is used to side rotation, and its rotation angle scope is [-45°, 45°], and the length of the coxa is 56mm; the hip joint is used to pitch, and the pitch angle scope is [-45°, 135°], and the length of the femur is 217.04mm; the knee joint is used to flexion and extension, and this angle scope is [0°, 135°], and the length of the tibia is 244.04mm. Every joint in the robot is drove by an independent motor, and this arrangement has an advantage in the compacted structure, and it will leave enough space for the dexterous motion of each foot. Due to the hinge of the leg joint, the robot will show great gesture restoring ability when walking even in the unstable environment.

III. PRINCIPLE ANALYSIS OF BIOLOGICAL INSPIRED HEXAPOD ROBOT’S GAIT

The tripod gait is the typical gait of the hexapod robot to realize walking. Its core idea is to divide the six legs into two groups (the former leg and latter leg in one side, and middle leg in the other side constitute one group). One group’s function is to support the robot body and promote the robot walking forward (named stance phase), the other group’s function is to swing for the preparation for the next stance (named swing phase). So the alternative and cycling of the stance phase and the swing phase constitutes the kinematics procession of the robot.

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LUO Qingsheng is with the School of Mechanical-electronic Engineering, Beijing Institute of Technology, Beijing, 100081, China (corresponding author to provide phone: 86-010-68947261; e-mail: luoqsh@bit.edu.cn).

ZHANG Hui is with the School of Mechatronical Engineering, Beijing Institute of Technology, Beijing, 100081, China (corresponding author to provide phone: 86-010-68949640; e-mail: zhanghui@bit.edu.cn).

HAN Baoling is with the School of Mechanical and Vehicular Engineering, Beijing Institute of Technology, Beijing, 100081, China (corresponding author to provide phone: 86-010-68942306; e-mail: hanbl@bit.edu.cn).
In the robot field, the time sequence variation of stance phase and swing phase is called gait. As for the robot which is walking in the uniform speed, its foot-phase presents the cycle variation law. Due to the cycle variation of the gait, so it is called cycle gait. The time of one cycle is $T$, and in one cycle the time of the stance phase is $t$, so the load factor of the foot is $\beta$. It is calculated in the following equation:

$$\beta = t/T$$  

In one cycle, the moving forward distance of gravity center is called a step ($s$), and in the stance phase one foot’s moving distance relatively to the body is called a stroke ($R$), and the relationship between the two factors is showed in the following equation:

$$R = s \cdot \beta$$  

In order to easily describe the robot, we number every leg, and group the six legs (shown in Figure 3), among which number 1, 3, 5 constitutes group A, in other hand number 2, 4, 6 constitutes group B. For the biological inspired hexapod robot, there are three steps [2] [3] to design a simple straight walking function:

1. As shown in Figure 3a, all six legs are on the ground for the stance adjustment.

2. As shown in Figure 3b, when group A’s legs all swing, at the same time group B’s legs support the body and promote the body moving forward $s/2$.

3. As shown in Figure 3c, when group A’s legs all fall to the ground, at the same time group B’s legs all swing, for the switch of the supporting legs and the swinging legs. So the procession in one cycle is finished, and the above steps will be repeated for the further procession.

IV. PATH PLANNING OF BIOLOGICAL INSPIRED HEXAPOD ROBOT’S FOOT ENDPOINT

We discover that, in the path planning of the gait, the kinematics features are largely influenced by the choice of the endpoint curve of the foot, and the consistency, stability, aesthetic property and driving torque are all pinned. Especially for the hexapod walking robot, the better endpoint curve of the foot path needs better landing characteristics, velocity and acceleration characteristics. Generally speaking, elementary functions such as linear function, sine function, cycloid, parabola function and so on are used for description of the endpoint curve. But realistically the gait path chosen for the robot’s curve often has a short walking cycle and many the sampling points. And at this time the endpoint curve inevitably results in the sudden change of acceleration, further more the walking stability of the robot will be influenced, besides will result in the overload of the driving dynamo. The polynomial interpolation [4] [5] method is chosen to satisfy the first-order, second-order derivable and continuous function, but due to so many sampling points it will finally generate high order of the polynomial interpolation, and thus result in shaking [6].

Based on the above factors, we choose cubic spline curve as the hexapod robot’s endpoint curve. This choice will not only satisfy the first-order, second-order derivable and continuous function, but also has a smooth curve and lower order.

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Figure 2. A Leg Kinematics Diagram of the Hexapod Robot

Figure 3. Tripod gait diagram for the hexapod robot

V. SIMULATION ON THE KINEMATICS PATH OF THE BIOLOGICAL INSPIRED HEXAPOD ROBOT

After earnestly analysis of the kinematics characteristics of the hexapod robot and path simulation, we establish the flow chart of the simulation, and follow the steps illustrated in the next texts to develop the concrete researches.

A. Generation of the Foot Endpoint Path Curve

In order to let the hexapod walk along the gait as shown in Figure 5, we choose $\beta = 0.5$, $T = 2s$, $s = 200mm$, and design the robot foot endpoint path according to the curve as shown in Figure 5. It can be described from Figure 5 that the foot endpoint path is divided into five parts, among which AB-BC-CD-DE is the swing phase path and AE is the stance phase path. In the swing phase every part is a cubic spline curve which is derivable and continuous in the joined point. In this research, we set the velocity of the starting point A and falling point E zero. The datum of the starting point, falling point and middle point are shown in Table 1. By using the datum in Table1 the author adopts the spline function ‘csape’ in the toolbox of MATLAB for the cubic spline interpolation of the swing phase, and the curves of $x(t)$, $y(t)$, $y(x)$ are showed in Figure 6. Therefore, the discretizations of $x(t)$, $y(t)$ will be saved as *.txt document. It will be used to define the drive of the foot endpoint simulation in ADAMS. The same method is also applicable in the stance phase, so it will not be discussed in this paper.
Figure 4. Flow chart of the kinematics simulation of the hexapod robot

Figure 5. Foot endpoint path of the hexapod robot

B. Modeling on the Virtual Prototype

We use Solidworks to construct 3-D modeling of the hexapod robot. In order to avoid the intricate model as well as not influence the effect of kinematics simulations, we simplify the prototype model by only reserving the key components. After the construction of the modeling, we keep the 3-D modeling as *.x_t file, then add the file and constraints to ADAMS as shown in Figure 7. Here, one should be mentioned, in every leg we add the revolute pairs to root joint, hip joint, and knee joint respectively. Due to the symmetrical arrangement of the six legs and tripod gait, the stance legs and swing legs have the same kinematics characteristics. Therefore, there leaves only three drives to define: stance phase, swing phase, body. After the processesions above, the robot can walk along the predetermined curves.

Before the definitions of the drives of the foot endpoint path, we introduce into the *.txt in order to generate the spline curves. The concrete steps are showed following: In ADAMS choose File → import …→ File Type → Test Data (*.*) → Create Spline→File To Read→ Choose the established file (*.txt) → OK. So the system will generate the spline curve named ‘spline_1’. The same method is applicable in the generation of other spline curves.

The driving equations corresponded to the above curves in the stance phase are showed as following:

\[
\begin{align*}
\text{X-axis} & \quad : \quad \text{if}(t=0,0,\text{if}(t-1:AKISPL(t,0,.jqr2.spline_2,0),200,\text{if}(t-2:200,200,\text{if}(t-3:AKISPL(t-2,0,.jqr2.spline_2,0)+200,400,\text{if}(t-4:400,400,400+AKISPL(t-4,0,.jqr2.spline_2,0)))))) \\
\text{Y-axis} & \quad : \quad \text{if}(t=0,0,\text{if}(t-1:AKISPL(t,0,.jqr2.spline_1,0),0,\text{if}(t-2:0,0,\text{if}(t-3:AKISPL(t-3,0,.jqr2.spline_1,0),0,\text{if}(t-4:0,0,AKISPL(t-4,0,.jqr2.spline_1,0)))))) \\
\text{Z-axis} & \quad : \quad 0
\end{align*}
\]

The driving equations of the swing phase are showed as following:

\[
\begin{align*}
\text{X-axis} & \quad : \quad \text{if}(t-1:0,0,\text{if}(t-2:AKISPL(t-1,0,.jqr2.spline_2,0),200,\text{if}(t-3:200,200,\text{if}(t-4:AKISPL(t-3,0,.jqr2.spline_2,0)+200,400,\text{if}(t-5:400,400,400+AKISPL(t-5,0,.jqr2.spline_2,0)))))) \\
\text{Y-axis} & \quad : \quad \text{if}(t-1:0,0,\text{if}(t-2:AKISPL(t-1,0,.jqr2.spline_1,0),0,\text{if}(t-3:0,0,\text{if}(t-4:AKISPL(t-3,0,.jqr2.spline_1,0),0,\text{if}(t-5:0,0,AKISPL(t-5,0,.jqr2.spline_1,0)))))) \\
\text{Z-axis} & \quad : \quad 0
\end{align*}
\]

The driving equations in the body are showed as following:

\[
\begin{align*}
\text{X-axis} & \quad : \quad -100*\text{if}(t=0,0,t) \\
\text{Y-axis, Z-axis} & \quad : \quad 0
\end{align*}
\]

Rotations in X-axis, Y-axis, Z-axis : 0

Here, in one simulation, the simulation time is 4s, and number of steps are 1000. After the simulation, open the after-dispose module and plot the angle curve, angle velocity curve, angle acceleration curve of number 1 leg. They are showed in Figure 8, 9, 10. Due to the symmetrical arrangement, other legs are all same to the number 1 leg except the different sequences.

| Table I. Datum Satisfied the Predetermined Curves |
It can be found in the figures above that the angle curve of every joint is smooth, and the corresponding angle velocity curve is relatively smooth except the time when the leg is in the changing state (between stance phase and swing phase). The angle acceleration curves of knee joint and root joint are relatively ideal, and their peak values are less than $500^\circ/s^2$. However, the peak value of the hip joint is relatively larger but still less than $500^\circ/s^2$, which is in the controllable scope. So, based on the analysis above, the choice of cubic spline curve as the foot endpoint path is totally feasible.

**C. Inverse Kinematics Solution**

Inverse kinematics solution, namely, is to conduct the kinematics laws of the main components on the conditions of the driven components. The traditional method of the inverse kinematics solution is to establish D-H coordinate system, and adopt coordinate transformation to get the solution. This method not only has many approaches and intricate calculations, but also probably cannot get the unique result. On the other hand, we can easily get the inverse kinematics solution by the kinematics simulation in MSC.ADAMS. By the angle measurements in every joint, we can get kinematics curves of every joint. As shown in Figure 7, 8, 9. We can save the results as spline curves: 'genguanjie_spline', 'kuanguanjie_spline', 'xiguanjie_spline'. Then establish the kinematics constraints in every joint: 'genguanjie_motion', 'kuanguanjie_motion', 'xiguanjie_motion'. The kinematics functions of the joints after cubic interpolation method are showed as following:

\[
\text{AKISPL}(\text{time},0,\text{genguanjie_spline}, 0)*\pi/180 \\
\text{AKISPL}(\text{time},0,\text{kuanguanjie_spline}, 0)*\pi/180 \\
\text{AKISPL}(\text{time},0,\text{xiguanjie_spline}, 0)*\pi/180
\]

Here, one should be mentioned. The unit of the angle is radian, so we should change the measurement into radian unit.

Then the kinematics drive of foot endpoint is disabled to realize the motion displacement, namely the kinematics drives of joints will displace the drives of endpoint component [8]. At the same time we define the contact constraint between the foot endpoint and ground. We define large enough friction coefficient, and time of the simulation 4s, number of steps 1000. The simulation result is showed in Figure 11. It can be seen from the figure that the robot walks straight forward with no tumbles, no slippages and no interventions. And the foot endpoint curves are accordance to the designed curves. So the feasibility and the correctness are approved.

![Figure 6. Foot endpoint path curve after cubic spline interpolation](image)

![Figure 7. Angle curve, angle velocity curve, and angle acceleration curve of root joint](image)

![Figure 8. Angle curve, angle velocity curve, and angle acceleration curve of hip joint](image)

![Figure 9. Angle curve, angle velocity curve, and angle acceleration curve of knee joint](image)

**VI. CONCLUSIONS**

In this paper, we adopt Solidworks as well as MSC.ADAMS to simulate and analyze the prototype model of the robot. The applicable tripod gait and the feasible cubic spline curve are approved. The joint angle curves have obtained by the path planning and simulation. This method avoids the intricate calculations on the inverse kinematics solution. And it improves the efficiency of the design on the biologically inspired hexapod robot, and the method has a...
theoretical meaning and practical merit in robot technology field.

Figure 10. Simulations on proximal physical robot

REFERENCES


