Application of ADAMS User-Written Subroutine to Simulation of Multi-gait for Spherical Robot

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Abstract - Considering the complexity of robot structure and the influence of experimental environment, an Adams and Cbased method for multi-step joint simulation of robots was proposed. It is of great significance to the verification control program. Unlike the joint simulation of Adams and MATLAB, the simulation method does not need to build Simulink block diagram and only bases on the programs. After completing the establishment of Adams mechanical motion model, the user subroutine can be written on the basis of the previous control program, and the interface call can be realized. The simulation results show the effectiveness and accuracy of the scheme. In addition, a gait experiment was performed on the robot. It is concluded that the simulation results can present the real situation well.

Index Terms -Spherical Robot; Virtual Prototype; Cooperative Simulation

I. INTRODUCTION

Robotics is a high-tech that combines computer, artificial intelligence, and bionics. It is an area where contemporary research is very actively and widely used [1][2]. The application of robots is an important indicator of the level of industrial automation in a country. The robots not only don't replace artificial labor in a simple sense, but also a kind of anthropomorphic electromechanical device that combines human characteristics and machine specialties. It has a quick response and judgment ability to the environment, and the machine can be used for a long time. The ability to work continuously, with high precision and resistance to harsh environments, in a sense, a product of the evolutionary process of the machine. It is an important production and service equipment for industrial and non-industrial industries, and is also indispensable in the field of advanced manufacturing technology.

The robot industry will become a hot industry in the future, but the production process of robots is not so easy, but from the design and production of robot mechanical structures, the processing and wiring of circuit boards and the assembly of robots require a lot of manpower, material and financial resources. The experiment is also a long process. Robot's simulation prepares for the experiment. Different from the joint simulation of Adams and MATLAB, the simulation method does not need to build Simulink block diagram and base on the C language [3][4]. Therefore, the co-simulation based on Adams and C language proposed in this paper does not need to consume a lot of materials, and the simulation effect of the program has certain guiding significance for the experiment of the robot.

The first part of this paper built the model of spherical robot in Adams software, modified the basic properties of the model, and proved the reliability and validity of the model in the Adams software [5]-[8]. The second part written the user subroutine. Considering the difference between the model simulation and the actual experiment, it is necessary to change the actual control code into the code that the simulation model can recognize [9]-[10]. The third part is the joint simulation of Adams and C language. It is simulated on the spherical robot model after the successful Adams model test. The fourth part is the result analysis and conclusion. The simulation figures of Adams and C language co-simulation is given.

II. MODELING AND KINEMATIC ANALYSIS OF THE ROBOT

A. Modeling design

SolidWorks was used to design the model of the robot. The upper part of the robot is mainly composed of a semicircular spherical shell, a stereo camera and an acoustic communication. The lower part is mainly composed of a bottom plate and four driving units. Each drive unit consists of a water jet propeller and three servo motors.

The robot realizes different gaits by changing the rotation angle of the three joints, such as crawling, rotating, etc. Each leg has two degrees of freedom, and the joint can rotate up to 160 degrees and withstand a force of 3.6 kg. By changing the direction of the four water jet propellers and the amount of spray force, the attitude adjustment and depth control in the water can be achieved. A single water jet propeller can generate a force of up to 3.8N.

B. Forward and inverse kinematics

This part is mainly to convert the end position of each leg into the rotation angle of each joint. First, we need to build a

three-dimensional model, the coordinate direction of the robot should be consistent with the calibration chart [11]-[14].



Fig. 1. The overview structure of the Spherical robot

Here we'll only analyze the first quadrant of the leg end: given the end position point and segment a, b, c (the length of each segment of the leg), to calculate the rotation angle of the servo motor.

In this way, basic mathematic model was transformed.

$$M = \sqrt{x^2 + y^2} \tag{1}$$

$$N = M - a \tag{2}$$

That's the cosine function:

$$\angle 2 = \arccos \frac{b^2 + (z^2 + N^2) - c^2}{2*b*\sqrt{z^2 + N^2}}$$
(3)

$$\angle \alpha = \angle 1 + \angle 2 = \arctan\left(\frac{z}{N}\right) + \arccos\frac{b^2 + (z^2 + N^2) - c^2}{2*b*\sqrt{z^2 + N^2}}$$
(4)

Similarly,

$$\angle \beta = \arccos \frac{b^2 + c^2 - (z^2 + N^2)}{2^* b^* c}$$
(5)

$$\angle \gamma = \arctan(\frac{y}{x})$$
 (6)

At this point, the model is built. Mathematical model as shown below. In certain conditions, the simulated joint coordinate system and the real coordinate system are different, so that it is necessary to change the direction of the servo motor rotation.



III. CO-SIMULATION OF ADAMS AND C PROGRAMMING

A. Virtual prototype model establishment

Model our spherical robots in the SolidWorks environment. Each individual component is designed and finally assembled into an overall model. After checking the model with SolidWorks, saved in Parasolid(*.x_t) format. Open Adams, enter into the GUI and click [file/import] in the menu bar, then select File Type as Parasolid (*.xmt_txt, *.x t....) to import the model.

The second step sets the model properties. The parts of the model in SolidWorks was represented in the Adams model, but they can't move and it looks bare. We need to change the quality, torque, color and name of each part to meet our requirements. Because there is no actual servo motor in the simulation experiment, we need to add the rotating joint to the connections of the robot, and use the rotating joint motion to move in a specified function. In addition, we also need to add ground and give contact to the part to realistically reproduce the experimental scene. The ground plane was built to improve the simulation's third dimension. We can give the rotation a simple function to see if the robot can move.



Fig. 3. Model of robot in Adams

B. Preparation of user subroutines

MSC.ADAMS software not only provides a convenient user interface, but also has a powerful analytical solution function, which contains a very rich library of functions for users to use.

In general, the model in our MSC.ADAMS can perform most functions by using the functions that come with the software. However, the gait of the robot is complicated, and a gait consists of several joints acting together, and it has time limits.

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Using Adams' own functions is complex, user-defined subroutines can use the programming language (C++ or FORTRAN) to define the elements of the model or specific output items without reducing the simulation speed, more versatile and effective than functional expressions.

However, there are three difficulties in programming the Adams software. The first point is to find the template of the driver pair, based on which we can modify. The second point is that the program we wrote is given the end position, and we need to find the angles of each servo. The third point is that the Adams software does not rotate the corresponding angle for an angle value. It is necessary to calibrate the relationship between the joint angle of the simulation model and the given value. The rotation joint was added into model, so the template of motsub.c that comes with Adams was used. The motsub subroutine is used to calculate the hinge displacement, velocity and acceleration of motion, which is used to drive the motion of the robot joint.

Since the robot has a total of twelve joints, that is, 12 motions, in the user subroutine development, 12 motion subroutines are also used to drive different joint rotations. The second solution is listed in the modeling chapter. Creating a project in VC++.Write the above code to convert the end position to the steering corner. For the third problem, let's make a simple crank rotation model to find the relationship between the given value and the angle of rotation. When the return value is VALUE=6.283, the crank rotates once, and we get the minimum corner unit return value of 0.017452. Within a certain range of time, we can determine a return value.

We describe the motion of the robot by a number of piecewise functions. The whole process is continuous, Piecewise functions should not have singularities.

I ABLE I				
SUBROUTINE SOURCE CODE				
Algorithm ADAMS User-Written Subroutine				
1: IF (time<0.3) {value[0]=0.36883*time; return;}				
2: IF (time<0.6) {value[0]=0.11065;return;}				
3: IF (time<0.9) {value[0]=-2.1688*time+1.41195;return;}				
4: IF (time<2.9) {value[0]=-0.5404;return;}				
5: IF (time<3.4) {value[0]=1.3021*time-4.31649;return;}				
6: IF (time<7.8) {value[0]=0.11065;return;}				
7: IF (time<8.3) {value[0]=0.51303*time-3.89095;return;}				
8: IF (time<9.8) {value[0]=0.367163;return;}				

C. Co-simulation of Adams and C Language

Download the user subroutine to compile the necessary "libifcoremd.lib", "libfportmd.lib", "libric.lib", "libmmd.lib", "swml_dispmd.lib" five "lib" files. Here we need to find the template of motsub.c under the solver folder of Adams and the header file of slv_c_utils.h referenced in the template, which is used to define the structure and its input parameters. Put these files in the same folder, select the command prompt in VS, find the newly created folder directory, enter MDI, and then enter cr-u, motsub.c, motsub.dll, etc. step by step according to the prompts. You can generate a dynamic link library. In this paper, motion is modeled, motion mode selects subroutine definition, and the user parameter defaults to 1. The subprogram can be called by inserting the directory corresponding to the dll file, and the Adams interactive simulation is performed.



Fig. 4. The construction of co-simulation system

IV. CO-SIMULATION AND RESULTS ANALYSIS OF MULTI-GAIT

First, the robot model is imported from SolidWorks, then the connection model and motion model are built in Adams software, and then the gait control program is written in Visio studio 2010. In this system, VS 2010 software solves the motion control strategy, and Adams software solves dynamic model of a mechanical system.

Two basic modes of motion of the spherical robot crawling gait and rotating gait are simulated. The robot is headed in the direction of the binocular camera, then the second and third legs are behind, and the first and fourth legs are at the front.

Set the simulation time to 9.8s in the Adams software. That's enough time to complete one cycle. The relationship between the position of the end of the leg and the time in the simulation result, the relationship between the angle of rotation of the leg and time are as shown in the figures below. The actual position point and rotation angle in the robot gait experiment were compared with the simulation results.

Taking HLM-joint of the second leg as an example.

A. The Simulation of Crawling gait

The motion process of robot:

1. The second leg of the robot first moves forward a fixed step(1-1.2s)

2. The first leg moves forward a fixed step (1.2-2.4s)

3. The ball shell moves forward to change the body's position (2.4-4.9s)

4 The third leg takes a fixed step forward (4.9-6.1s)

5. The fourth leg takes a fixed step forward (6.1-7.3s)

6.The ball shell moves forward in a fixed position [15]-

[18] (7.3-9.8s).

The above six steps are one cycle.





Fig. 6. Screenshots of forward gait under the environment of Adams

B. The Simulation of Rotating gait

The motion process of robot:

1. The second leg of the robot is first rotated to the right by a fixed angle(1-1.2s).

2. The first leg is rotated to the right by a fixed angle (1.2-2.4s).

3. The spherical shell is rotated to the right by a fixed angle (2.4-4.9s).

4. The fourth leg is rotated to the right by a fixed angle. (4.9-6.1s)

5. The third leg is rotated to the right by a fixed angle (6.1-7.3s).

6. The spherical shell is rotated to the right by a fixed angle (7.3-9.8s).

The above six steps are one cycle. TABLE III

PART OF THE PROCESS OF MOVING ROTATED				
Time	0-1.2			
Angle Joint Leg	HLM	VLM	LM	
2	0->-28.6	2.4->52.4	85.4 ->55.4	





(b) The relationship between time and angle of joint in the rotate gait Fig. 7. The moving joint curve of the robot's rotate gait.



Fig. 8. Screenshots of rotate gait under the environment of Adams

From the figure 5 and the figure 7, the joints indeed realized the motion, they move in the direction and angle that we expect. From the figure 6 and figure 8, the whole process of simulation can be clearly and intuitively seen.

Then I did an experiment. Because the parameters set are different, the image curves drawn are different, but the observation of the gait movement effect is consistent with the effect of the simulation [19]-[27].



ig.9. The pictures captured in the gait experiment

V. CONCLUSION AND FUTURE WORK

Based on the multi-body dynamics software Adams, a new co-simulation model is studied, which combines the dynamic model with the control model. The control of the simulation process is given to the C program written by the user. The Adams dynamic model simulation and the control model simulation of C are used as two separate modules for the user program to call. Modular dynamics and control co-simulation is implemented in the user program to complete the verification, improvement and optimization of the control module. This method contributes to the robot's control system design.

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