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Co-simulation System for A Humanoid Robot Based on Pro/E ADAMS and MATLAB

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Abstract: This study describes the modeling and simulation methods for a humanoid robot. Firstly, the 3-D mechanical model of the humanoid robot is established using Pro/E, then, the established model is imported to the ADAMS, which is a useful software package for modeling and simulation of complex mechanical dynamic models. However it has some disadvantages with respect to the motion planning and controller-design. So, another software package, Matlab/Simulink, is used to make the controller-design and system analysis become easier and convenient. During the simulation, the designed joint angles are inputted to the platform, then ADAMS gains joint torques from motion controller, which is designed in MATLAB and then the robot performs the designed motions in ADAMS. The simulation and experimental results prove that the designed joint angle trajectories are followed well.

Key words: Humanoid robot, Co-simulation, ADAMS, MATLAB

INTRODUCTION

Humanoid robot is a new kind of robot, it mainly imitate the form and behavior of people. Because the humanoid robot is closer to the human in shape, it is easy to be accepted by people, so it can supply better service to human. Compare with wheeled robot, bipedal robot can adapt to more complex environment.

The first humanoid robot was developed by Kato *et al*. (1974). However a humanoid robot is a complicated system. If we manufacture the physical prototype directly, it is not only spend a lot of financial and material resources but also difficult to obtain the optimized mechanical structure (Ma *et al*., 2010). In order to improve the design efficiency and cut down the cost of scientific research, we propose to make a virtual simulation platform before creating the physical model. The virtual design method can avoid deducing the tedious dynamics equations and saving time for calculation; therefore it can improve the design efficiency and reduce developing costs (Gao *et al*., 2012). Some dynamic engines have been developed for simulation, such as Open Dynamics Engine (ODE). ODE is one of the simulation systems that easy to be used, however it is difficult to construct a complex model and the simulation accuracy is not very well. In this study, we choose ADAMS and MATLAB to precede the co-simulation. The Matlab/Simulink make the robot model easy and convenient to be used and the build in dynamic solver of ADAMS can run in a high speed and has a high reliability (Zhen *et al*., 2009).

VIRTUAL PROTOTYPE ROBOT SYSTEM

The mechanical model for a humanoid robot is designed using the Pro/E, then they are imported into ADAMS and then mechanical parameters are defined. After that, the 3-D mechanical model is prepared for simulating.

3D model: In ADAMS, although the mechanical system of parts library can be used to create geometric model, it is difficult to build a complex 3-D model (Wu and Zhao, 2010). So in this study, the model is established using a professional model building software, Pro/E. In the robot model, each arm has 4 Degrees of Freedom (DOFs), each leg has 5 DOFs and the robot torso has 6 DOFs. The total DOFs of the whole robot is 24. To reduce the structure size, each joint uses harmonic gear reducer and flat servo motor. The assembled model of robot is shown in Fig. 1.
Robots Simulation System

ADAMS is a powerful software in the respect of kinematics and dynamics simulation. After the 3-D model of humanoid robot is built in the Pro/E, it is saved as parasolid format file; so the model can be easily imported into ADAMS (Wu and Yao, 2010). ADAMS can automatically create separate parts for each entity with the assembly information retained. But it is necessary to redefine each part's material and the information between them such as the motion pair, force and so on (Gong and Liu, 2008). In order to simulate the actual system better, the virtual prototype is configured to have the same or the similar properties with the physical model.

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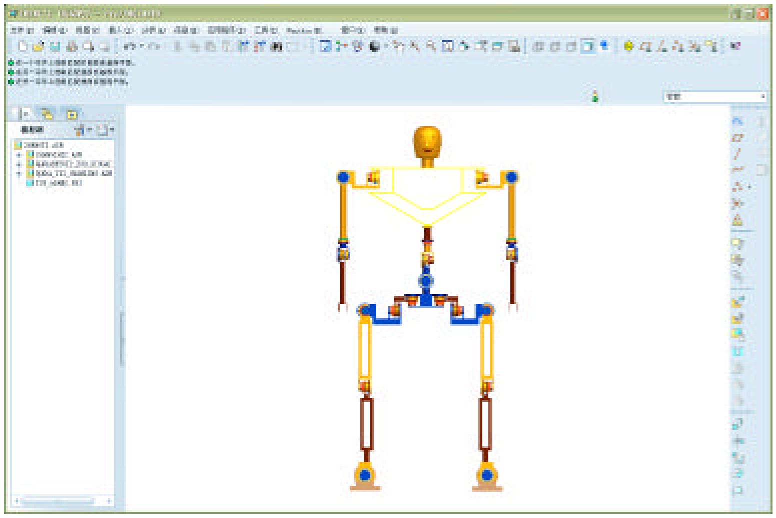

Fig. 1: Assembled humanoid robot model in Pro/E

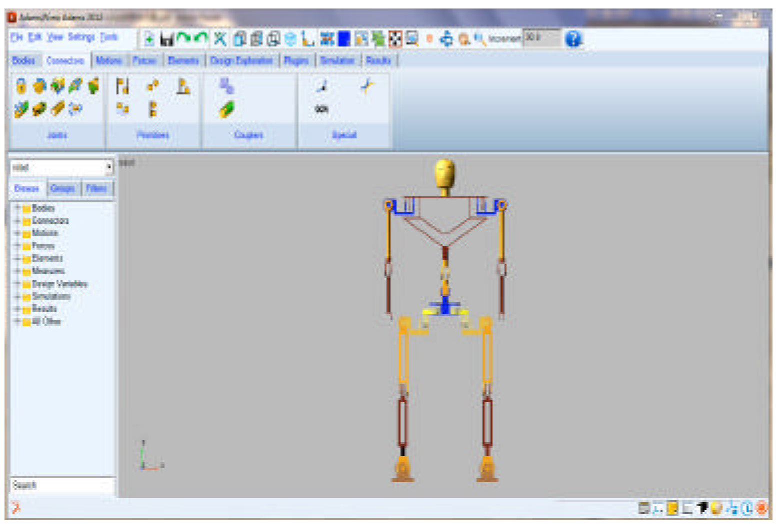

Fig. 2: Constrained robot system in ADAMS

The parts without relative movement will be fixed together and rotate constraints are defined at the rotational joints (Wang *et al*., 2009). After every constraint is defined, the movement relationships between parts are determinate, thus it is ensured that, during the simulation, the robot has the correct relative motion between all joints. The constrained robot system imported into ADAMS is shown in Fig. 2.

Robot control system: ADAMS can implement some simple control schemes; for the complex control scheme, it is difficult to meet the requirements. In order to achieve the complex control scheme, utilize the extension module of ADAMS, ADAMS/Controls, establish connection with MATLAB and in MATLAB/Simulink module to establish control scheme.

Control structure: Robot system is a multi-input, multi-output and strong coupling complex electromechanical system, it is very difficult to achieve high precise of controlling the system (Shi *et al*., 2008). Here, control the motion of the system; make sure it can implement accurate movement according to the given input signal. The joint simulation control system structure, as shown in Fig. 3.

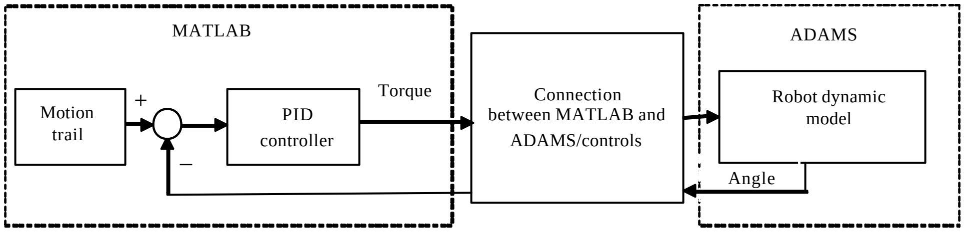

Fig. 3: Structure of robot motion control system

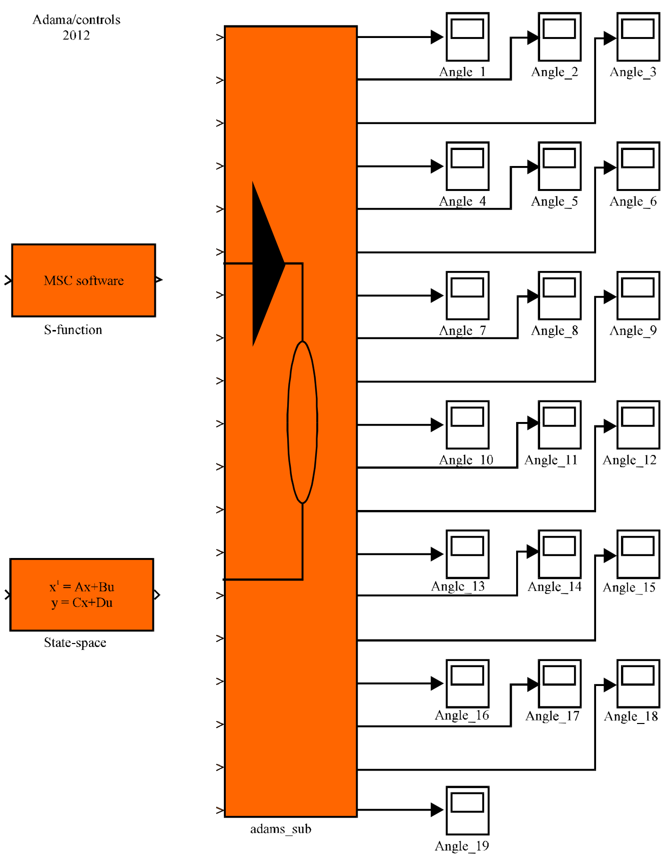

Fig. 4 Co-simulation subsystem

Establishment of the joint simulation system: In order to achieve the ADAMS and MATLAB co-simulation, that the input and output variables need to be defined in the ADAMS system and then export the M files which MATLAB can identify. Here, the primary mission is to control the robots movement stability; through PID controller to adjust the size of torque, thereby control the movement of each joint, which makes the system has good stability, quickness and accuracy (Yin *et al*., 2005).

Define the joint angle and angular velocity as the outputs; the input is torque at each joint which was modified by PID controller (Qin, 2008). In the model, the inputs and outputs of 19 joints are defined. Through set the type of simulation, Adams can exchange the real-time data with MATLAB/Simulink, at the same time, observe the motion of robot. Thus complete closed loop control system, so as to achieve precise control of the motion state. MATLAB control subsystem is shown in Fig. 4.

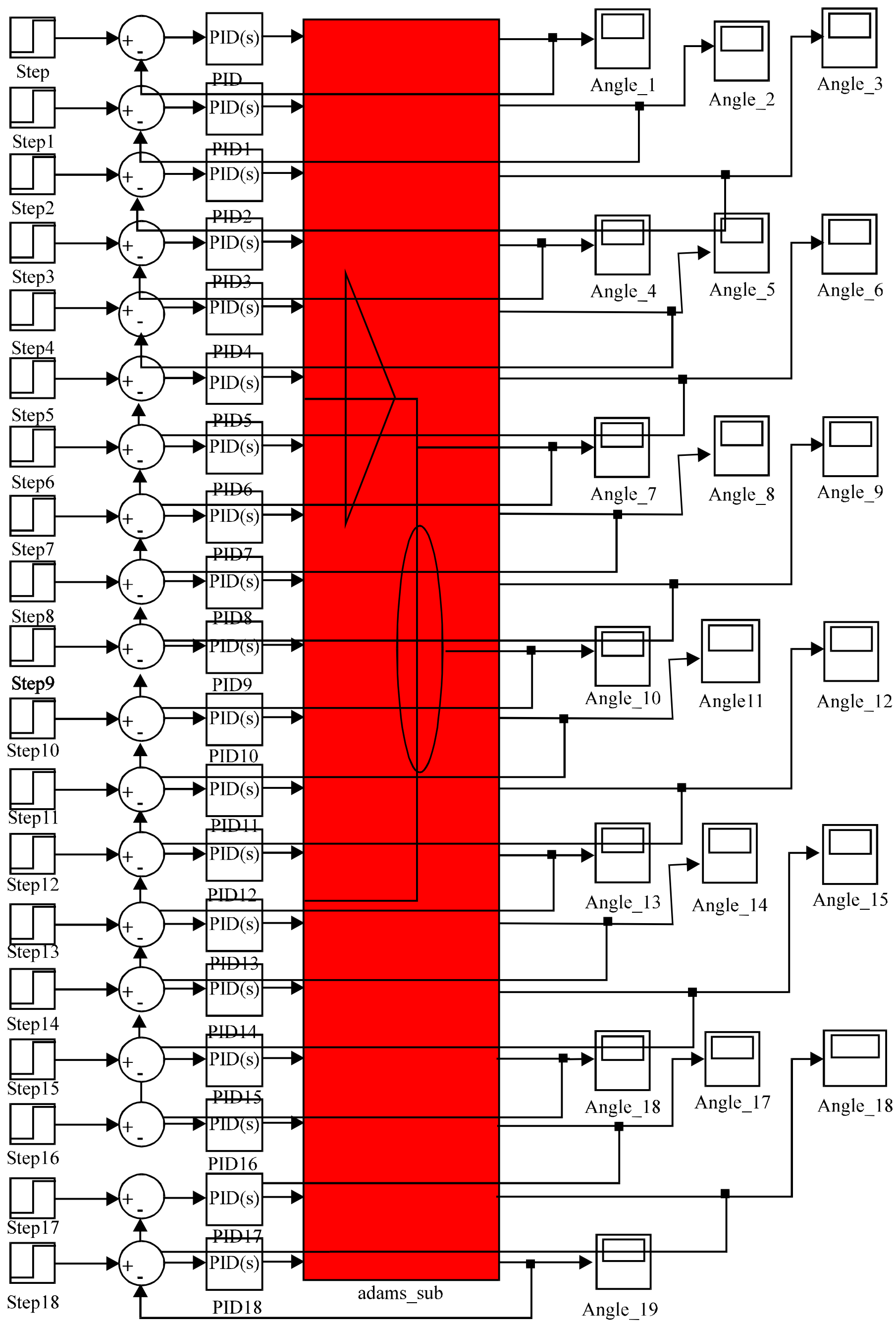

Fig. 5: Structure of combined simulation control system

SIMULATION RESULTS AND EXPERIMENTS

Simulation results: Robot system is a multivariable strong coupling mechanical and electrical system, during the simulation it was simplified to a linear multivariable decoupling system (Wu and Wu, 2012). Adopt PID controller to control each joint, ensure that the robot can achieve high precision of position tracking (Cheraghpour *et al*., 2011). Co-simulation system is shown in Fig. 5.

In order to validate the performance of the co-simulation system, elbow joint, for example, use sine signal and step signal respectively to test the response characteristics of co-simulation system. Response curves are shown in Fig. 6 and 7.

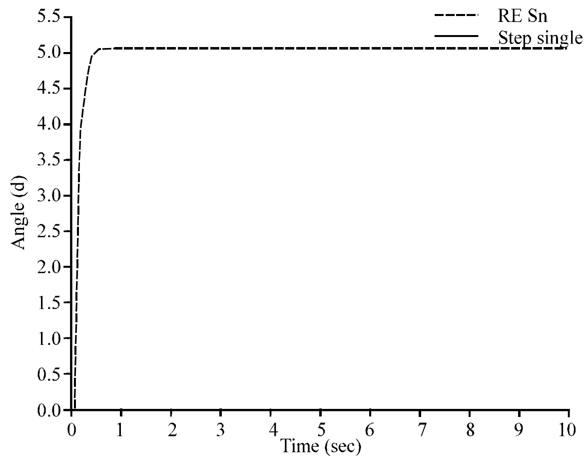

Fig. 6: Step signal response

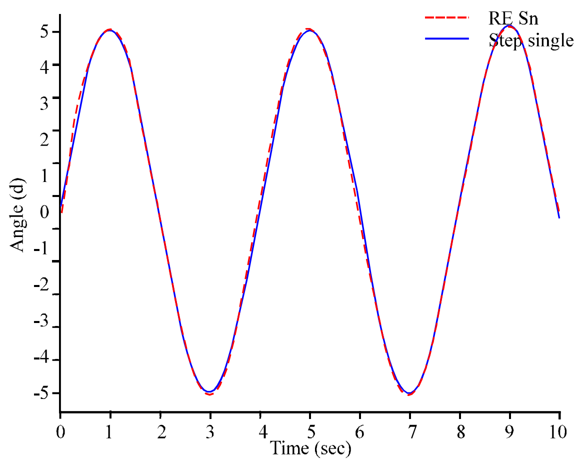

Fig. 7: Sine signal response

The response curves shown in Fig. 6 and 7 illustrate that the response of the control system is well. Under the effect of step signal, the elbow can move from the initial position to the instructions given target position and stay stable, within a short response time. Through co-simulation in Adams simulation we can also see that the elbow drives forearm from initial position rotating to the target position rapidly and keeps immobile. It can be seen from the simulation curves, when given the sine signal instructions, elbow can accurately track the given sine directive, with a small time delay. These simulation results illustrate the system has good trajectory tracking ability.

Experimental results: In order to check the tracking ability of robot in the simulation platform to the human motion, two V.M.SENS sensors were used to detect the orientation of human limbs, such as forearms in this experiment. The V.M. SENS is a low-cost, high performance, miniature, gyro-enhanced Attitude and Heading Reference System (AHRS)/Motion Tracking System. Its internal low-power signal processor provides a quaternion-based Extended Kalman Filter and iMTFusion algorithm to output drift-free 3D orientation as well as calibrated 3D acceleration, 3D rate of turn and 3D earth-magnetic field data.

In the example experiment described in this study, the pitch angle reading from the V.M.SENS sensor, which was mounted on the right or left forearms as shown in Fig. 8, was used for generating the input angles of the corresponding elbow joint. The snapshots of the bending elbow motions are shown in Fig. 9. The input angles reading from the V.M.SENS sensor and the output angles of elbow joints are shown in Fig. 10 (a) and (b), respectively. The experimental results shown in Fig. 9 and 10 indicatethat the bending elbow motions on

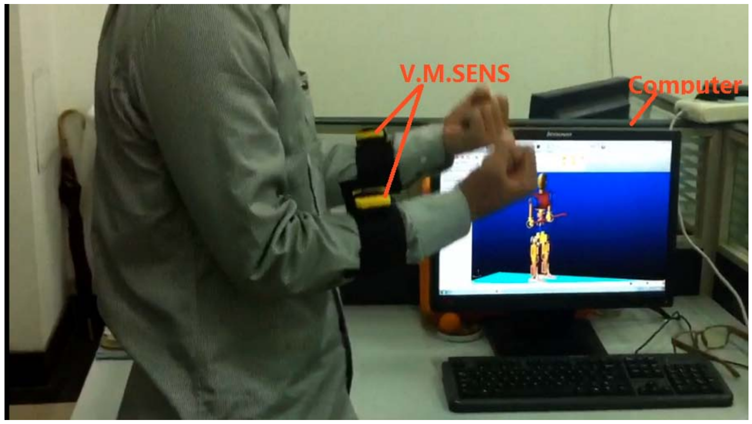

Fig. 8: Sensors and computers in the motion tracking experiment, (a) Human side and (b) Robot side

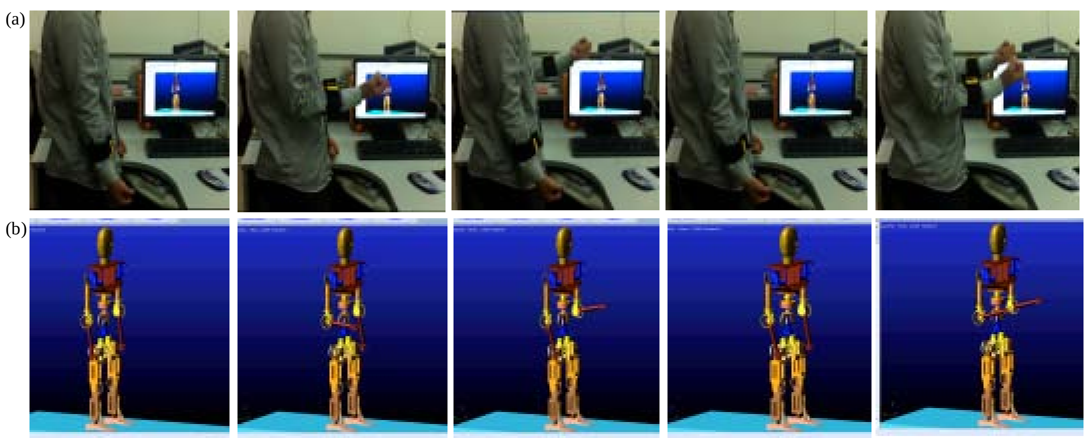

Fig. 9 Snapshots of motion tracking experiment, (a) Input angles from V.M.SENS and (b) Output angles of robot joints

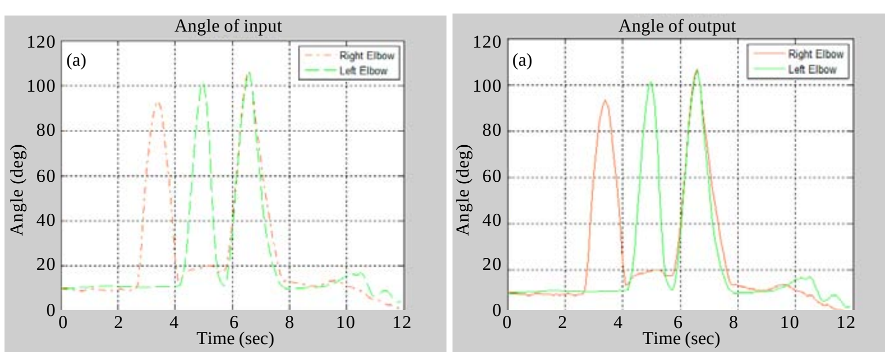

Fig. 10 Joint angles in the motion tracking experiment

the human side were followed well by the virtual robot model in the Co-simulation platform. Since the robot models in the ADAMS have the same dynamic characters to the real robot, the co-simulation system proposed in this study is expected to be helpful for planning a good robot motion or improving the mechanical design of a real robot.

CONCLUSION

The virtual humanoid robot platform was developed based on Pro/E ADAMS and MATLAB. The feasibility of robot system was verified through the co-simulation results and some experimental results. During the simulation process, a large number of design parameters were acquired, that contributes to the design and development of the physical prototype. This method also provides a new method for the design of robot system. In order to improve the design parameters, a virtual prototype model can be developed in computer and then all kinds of dynamic performance analysis can be carried out on the model, finally the optimal design scheme can be obtained.

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