Proceedings of the 2013 International Conference on
Advanced Mechatronic Systems, Luoyang, China, September 25-27, 2013

The Compliance Control Study of Chinese Chess Robot in Cartesian Coordinate System

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***Abstract*—This paper mainly introduces a Chinese chess robot system in Cartesian coordinate. The overall structure of the robot is gantry type, and can carry all pieces to everywhere on chessboard. Using lead screw and rail structure in mechanical design, each axis is driven by servo motor. A four-dimensional force sensor is installed between pneumatic gripper and the end of arm. And also this paper has done some research on compliance control used on the robot. Compliance control strategy is applied in Chinese chess robot's movement that achieves coordination of each motion axis and precise positioning of each piece. Using VC software platform in PC, created a chess interface to facilitate human-machine communication.**

Keywords—Cartesian coordinate; Chinese chess robot; motion control; compliance control

I. INTRODUCTION

Chinese chess has a long history in China, and is common in people's lives as a recreational activity. In this paper, based on the Cartesian coordinate, developed a kind of Chinese chess robot system which made the arm move following people' mind by a virtual chessboard in PC. Chess robot can realize decorate pieces, move pieces, capture pieces, take back pieces and so on.

With the development of science and technology, robots are more and more used everywhere of industrial manufacture and people's life, especially in the field of high-end manufacturing, and can realize move, machining, assembly and so on. As a typical robot of articulated robots, chess robot is based on the basis of a single linear motion and a plurality of the combination of the articulated robot arm, and achieves the overall coordination of movement[1]. The study of compliance control for Chinese chess robot can achieve the motion planning and control, precise positioning and motion optimization to robots.

II. THE STRUCTURAL DESIGN OF CHESS ROBOT

Robots in Cartesian coordinate usually have three axes; each axis of movement typically corresponds to the Cartesian coordinate in the X-axis, Y-axis and Z-axis. Generally the X-axis and Y axis are in the horizontal plane; Z axis is perpendicular to the horizontal axes. In most cases, each axis of Cartesian coordinate is vertical each other. In practical applications, some actuator or some more other axes can also be added to the end of Z axis, constituting more degrees of the robot. According to different work, the robots can achieve different functions with various actuators. Since relatively few degrees of freedom in Cartesian coordinate, the movement in several directions without coupling and the motion control algorithm is relatively easy to implement, more and more these robots are being used in various fields.

Chinese chess robot main structure consists of two parts: mechanical body and control cabinet. The overall structure of mechanical body is gantry type, which can achieve different movement in horizontal, longitudinal vertical and vertical direction. The mechanical body is shown in Figure 1.

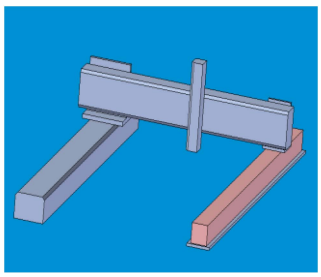

Fig. 1 The mechanical structure of Chinese chess robot

Most axes are linear motion unit in Cartesian coordinate, and each axis is an independent movement unit, which is made up of aluminum or steel support and slider that can move on them[2]. The robot' drive system is mainly made up of drive motor and synchronous belts that drive slider move along the linear-guide. Three axes motion are linear motion of Chinese chess robot, their mechanical structure contain rail, slider and lead screw which lead is 20mm / r in X direction, and 10mm / r in Y and Z direction. The Chinese chess robot is shown in Figure 2.

This work is supported by Shandong Provincial Natural Science Foundation (ZR2012FQ022) and Shandong Provincial Development plan of Science & Technology (2012GGC01019)

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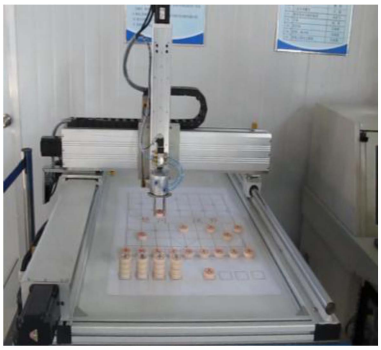

Fig. 2 Chinese chess robot

The Chinese chess robot's board is a stand chessboard. There are many grooves at each fixed point to place pieces and positioning easily. There is a four-dimensional force sensor fixed between pneumatic gripper and the end of arm, which can get the real-time contact force between piece and circumstance, provide feedback to the accurate positioning of the pieces. The suitable position of piece is shown in Figure 3.

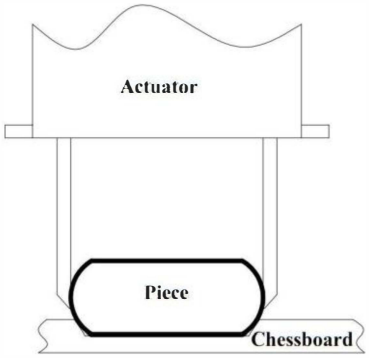

Fig. 3 The suitable position of piece

III. DESIGN OF CONTROL SYSTEM

The Chinese chess robot control system consists of the motion controller, drive system, and sensors. Control system is the soul of robot and provides an important guarantee to realize flexible movement. The function of controller is based on the user-written program to issue control instructions, and receives feedback information to judgment processing information.

a) Hardware Design

Three axes for motion, jointing coordination, opening and closing the gripper should be control by motion controller in Chinese chess robot. Motion controller is the core of whole control system, which can accept variety of directives from PC. Then motion controller sends directives which were processed to each drive unit, and also accepts sensor's signals to make corresponding operation. The whole control structure is shown in Figure 4.

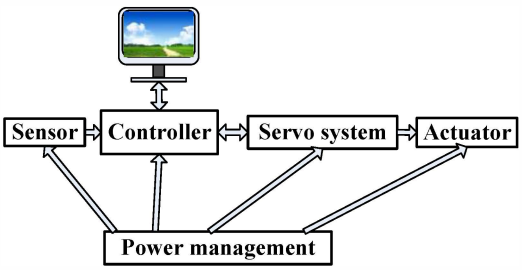

Fig.4 The structure of control system structure

On Chinese chess robot, GE-400 card is selected as the motion controller which can control four servo motors or stepper motors. VC, Delphi, VB software can be used as the development environments to this controller. In view of the chess robot's human-computer interaction interface is developed by VC, so this paper selected VC software to develop on motion controller.

There is a photoelectric sensor at each end of rail to limit the stroke and make the actuator move in permitted distance. In order to get the 0 point accuracy, took one limit signal to the controller' home port.

b) The Establishment of Cartesian Coordinate System

The study of algorithm is based on Cartesian coordinate which took longitudinal, horizontal and vertical direction as X-axis, Y-axis and Z-axis. The Cartesian coordinate system is shown in Figure 5.

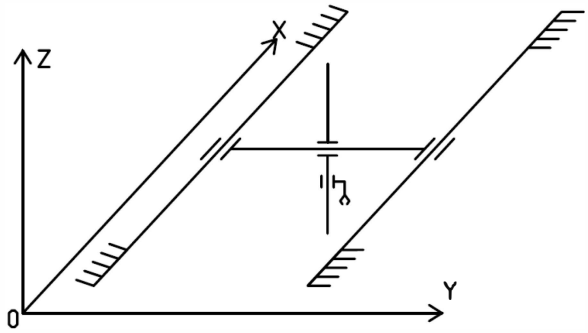

Fig. 5 The Cartesian coordinate of chess robot

c) Trajectory Planning and Implementation

In Cartesian coordinate, in order to accelerate the velocity of mechanical arm, the actuator' trajectory should be planning to short his movement distance and time. Chessboard is a planar structure, so that movement of chess robot is in a plane generally. To reduce the stroke of movement, the basic motion should along the straight line between two points, which requires the X-axis and Y-axis linear interpolation in both directions. Before moving, the controller should judge the distance before X-axis and Y-axis, and take the longer as the basic distance which would take time T at the speed V_0 that is set in initialization calculations. That is $T=\Delta L_{max}/V_0$. Then

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controller could calculate the speed of the shorter one: $V_s=\Delta L_{min}/T$.

When some pieces should be taken out of chessboard, the robot need to remove these pieces to a pile, and it would make the Z-axis move together. Meanwhile, the speed of the third axis is $V_z = \Delta L_z / T$, the controller would send pulses to different servo drivers.

IV. Study of Compliance Control

The study of compliance control began in the 1950s on force sensing of master-slave manipulator. Robots in the operating process often carry out the work according to pre-programmed which made according to the position generally. But robots must keep properly contact force, to overcome the constraints of the environment, or to overcome the compliance of the environment because of different factors from environment[3]. To make the robots response the changes in the external environment, the feedback of general strength, vision, and temperature should be gotten.

The compliance control theory, including active and passive type, was usually used on robots all kinds of fields. Robots use feedback of force to make control strategy to control force is active; and robots produce natural external forces to submit to environment with some auxiliary supple body is passive [4]. The active one has many control strategies, such as stiffness control, impedance control, admittance control, hybrid force / position control, the implicit force control and so on. The impedance control strategy is used in the Chinese chess robot in this paper. The structure diagram of impedance control is shown in Figure 6.

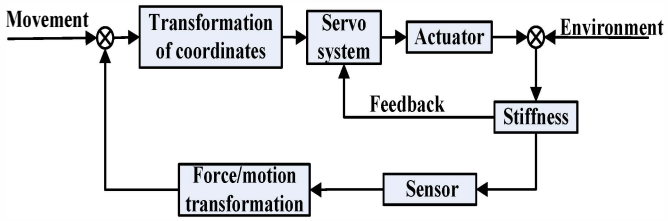

Fig. 6 The structure diagram of the impedance control

There must be some error in movement of actuator when pieces were placed because of grooves in chessboard as shown in Figure 7. And these errors should be corrected.

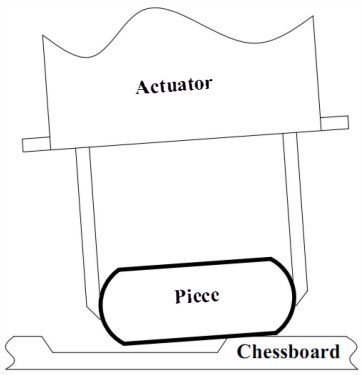

Fig. 7 Error in movement of actuator

Impedance control is used on Chinese Chess robot. Impedance control realized the control to system by adjusting the relation of force and position. This relation is called target impedance, such as type 4-1.

$$F - F_d = Z(X - X_d) \tag{4-1}$$

The F , F_d , X , X_d are force, anticipant force, position and anticipant position. Impedance control can be shown by using mass - spring - damper system, and if moving would realize, the force will occur. The impedance control generally is shown by second order differential equation. The second order impedance is target impedance which is build based on errors of trajectory. The errors come from interaction force between actuator and grooves. The type 4-2 shows the mathematical expression.

$$M_d \ddot{X} + B_d \dot{X} + K_d(X - X_d) = -F \tag{4-2}$$

X , $\dot{X}$, $\ddot{X}$ -the position, velocity and acceleration vectors of X, Y, Z directions (Matrix: 3 * l);

M_d , B_d , K_d are 3 * 3 matrixes of expectant inertia matrix, damping and stiffness;

F is force vector when actuator contact the chessboard (Matrix: 3 * l).

This paper added a reference value: F_d and took force error signal as drive signal of target impedance. That's $e_f = F_d - F$. The new target impedance model is shown as type 4-3.

$$M_d \ddot{X} + B_d \dot{X} + K_d(X - X_d) = -e_f \tag{4-3}$$

In type 4-4 , the $E = X - X_d$, the type will be:

$$M_d \ddot{E} + B_d \dot{E} + K_d E = e_f \tag{4-4}$$

Because the target impedance matrix M_d , B_d , K_d , stiffness matrix K_e are diagonal matrix generally, the target impedance model and the environment are decoupled in all directions. So this paper considers one-dimensional of Chinese

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chess robot operation space. Using f_d, f, M, b, k instead of F_d, F, M_d, B_d, K_d, the above equation becomes 4-5.

$$m\ddot{e}+b\dot{e}+ke=f_d-f \tag{4-5}$$

Then investigating the two robot's motion space: free space and contact space. In free space, the contact force f = 0, that's 4-6.

$$m\ddot{e}+b\dot{e}+ke=f_d \tag{4-6}$$

When the position has known, if the expected force f_d is 0, the actuator would keep contact with chessboard.

V. Simulation of Impedance Control

Inputting a sinusoidal signal $X=\sin t$ which amplitude is 1, start time is 0 seconds, simulation steps of 0.1 seconds and the simulation time is 10 seconds to this system. The simulation of position tracking to actuator is shown in Figure 8.

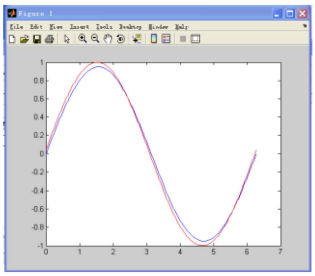

Fig. 8 The position tracking curve

In Figure 8, the blue line represents the input sine curve, the red line is the following curve, and the error curve is shown in Figure 9.

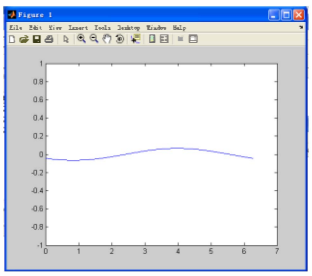

Fig. 9 The error curve

This paper selects one direction as the target of the four-dimensional force sensor; and the force trace curve is shown in Figure 10.

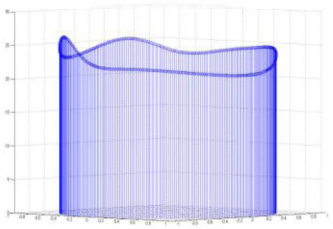

Fig. 10 The force trace curve

VI. Interface Design

The Chinese chess robot' interface in PC is developed by VC software. Robot can take pieces to the place in chessboard following the virtual chessboard. The interface is shown in Figure 11.

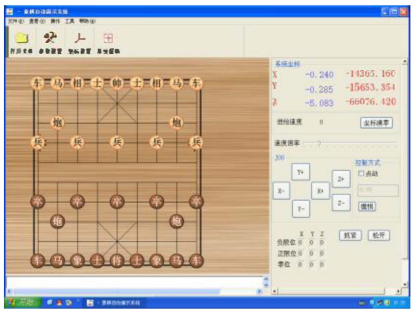

Fig. 11 The interface of Chinese chess robot

Two people can play chess by interface of Chinese chess robot, and the robot's actuator takes the pieces to the corresponding place on chessboard. People also can set all kinds of parameter on interface, such as speed, acceleration, 0 reset of each axis, the 0 position setting and so on. The coordinate system of virtual chessboard is shown in Figure 12.

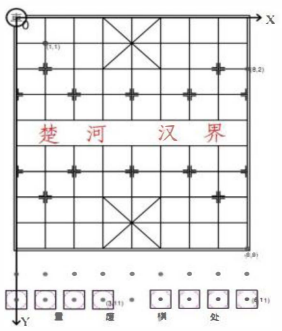

Fig.12 The coordinate system of virtual chessboard

VII. Summary

This paper has designed a kind of Chinese chess robot in Cartesian coordinate. The robot's structure is simple and practical. The compliance control is used to make servo motors positioning more accurately. The controller can get force signal, limit signal, and send pulses which is calculated to

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corresponding servo drivers. The human-machine interface is developed by VC software, can realize information transmission easily, and realize the consistency of virtual and reality.

In the future research, visual recognition technology would be introduced, then the Chinese chess robot will be more intelligent[5][6].

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