Dynamic Modeling and Cooperative Process Simulation in Cooperative Dual-Arm Robot Based on Adams

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Abstract. The demand of cooperation task of cooperative dual-arm robot in industrial automation production is increasing day by day. It is analyzed that the kinematics and dynamics mathematical model of the cooperative dual-arm robot with six degrees of freedom in one arm and the relationship is constructed between the arms’ position and the attitude for the robot in the paper. The mechanical characteristics of the cooperative tasks are analyzed that contains carrying, assembling and processing in the industrial field. The dynamic simulation software Adams is used for the simulation calculation and analysis. It is obtained that the position and attitude transformation characteristics of the forward kinematics solution through the simulation analysis, and the curve of the distribution force for the dual-arm in the process of cooperation is obtained. It provides the basis for setting up the reasonable driving force distribution and load distribution when realizing the task for dual-arm robot in cooperation.

Keywords. Dual-arm robot; cooperative process; dynamic modeling; Adams.

1. Introduction
With the stage of rapid development on cooperative robot technology, the research is increasing on motion control of dual-arm cooperative robot and bringing about new changes [1]. Dual-arm robot can achieve dual-arm coordinated control to complete basic industrial operation tasks. To ensure that the dual-arm can cooperate and contact each other in the same system, the dynamic model is the key to study the complex operations such as assembly, handling, machining and so on [2].

In order to realize the accurate arms’ motion control for cooperative dual-arm robot [3], it is necessary to analyze its motion and dynamics, including both forward kinematics modeling analysis and inverse kinematic solution, meanwhile, inverse kinematics is one important index basis for its control accuracy of motion feedback link. There are three typical methods to solve mechanical analysis of cooperative dual-arm robot [4]: geometric method, analytical method and numerical method. The kinematic modeling is divided into two hypothetical models, one is about closed-loop control system that formed between the cooperative dual-arm robot and the interactive object. Contact force condition in the interaction relationship is the main research object that between the target and the cooperative dual-arm. The force distribution is further analyzed by modeling that between the target body and the robot’s dual-arm [5], it is established that the dynamic equation of mixed multibody system. The other is to consider only the load situation and the force distribution between
the dual-arm, it is assumed that the force between the target bodies is constant [6], it is analyzed that the force distribution and dynamic parameters between dual-arm under this condition.

2. Kinematics Modeling of Dual-Arm Cooperative Robot

2.1. The Coordinate Systems Definition for Dual-Arm Cooperative Robot

In order to describe the relationship between the arms’ position and motion of dual-arm cooperative robot, it is defined that coordinate system for dual-arm cooperative robot according to the structure of the system, as shown in figure 1: the first is the spatial inertial coordinate system : O-XYZ, the left arms coordinate system from one to six of the cooperative robot: O_{L1}-X_{L1}Y_{L1}Z_{L1}, it is called coordinate system 1; O_{L2}-X_{L2}Y_{L2}Z_{L2}, it is called coordinate system 2; O_{L3}-X_{L3}Y_{L3}Z_{L3}, it is called coordinate system 3; O_{L4}-X_{L4}Y_{L4}Z_{L4}, it is called system 4; O_{L5}-X_{L5}Y_{L5}Z_{L5}, it is called coordinate system 5; O_{L6}-X_{L6}Y_{L6}Z_{L6}, it is called coordinate system 6; the right arms coordinate system also obey the same rule above (the following coordinate systems from 7 to 12): O_{R1}-X_{R1}Y_{R1}Z_{R1}, O_{R2}-X_{R2}Y_{R2}Z_{R2}, O_{R3}-X_{R3}Y_{R3}Z_{R3}, O_{R4}-X_{R4}Y_{R4}Z_{R4}, O_{R5}-X_{R5}Y_{R5}Z_{R5}, O_{R6}-X_{R6}Y_{R6}Z_{R6}.

Figure 1. The coordinate system for dual-arm cooperative robot.

2.2. Coordinate Transformation of Motion Process

$L_{i}$ represents the vector direction of the one arm; $R_{i}$ represents the vector direction of the other arm. It confirmed and obtained the following equation as follows: Yaw angle (relative to $Y_{i}$ axis), Pitch angle (relative to $Z_{i}$ axis), roll angle (relative to the $X_{i}$ axis). Transformation Matrix can be expressed that from coordinate system $i$ to coordinate system $i+1$:

\[
A_{i\rightarrow i+1} = \begin{bmatrix}
1 & 0 & 0 & \cos \alpha & \sin \alpha & 0 \\
0 & \cos \beta & \sin \beta & -\sin \alpha & \cos \alpha & 0 \\
0 & -\sin \beta & \cos \beta & 0 & 0 & 1 \\
\end{bmatrix}
\]

(1)

It satisfies the following formula according to the vector direction of the left/right arm that the relationship of coordinate transformation between any single arm in dual-arm robot:

\[
\begin{bmatrix}
\alpha_{iL,R} \\
\beta_{iL,R} \\
\gamma_{iL,R}
\end{bmatrix} = \begin{bmatrix}
\cos^{-1}(L_{iL,R}(L_{iL,R}^{-1}))^{-1} & |x| \\
\cos^{-1}(L_{iL,R}(L_{iL,R}^{-1}))^{-1} & |y| \\
\cos^{-1}(L_{iL,R}(L_{iL,R}^{-1}))^{-1} & |z|
\end{bmatrix} \cdot \begin{bmatrix}
\cos^{-1}(R_{iL,R}(R_{iL,R}^{-1}))^{-1} & |x| \\
\cos^{-1}(R_{iL,R}(R_{iL,R}^{-1}))^{-1} & |y| \\
\cos^{-1}(R_{iL,R}(R_{iL,R}^{-1}))^{-1} & |z|
\end{bmatrix}
\]

(2)

Equations (1) and (2) are further simplified as follows:
2.3. Kinematical Equation for Dual-Arm Cooperative Robot

According to the vector direction of the left/right arm, \( L_i, R_i \), relative tectonic movement equation is as follows:

\[
\begin{align*}
L_i &= (dy/dx) L_i^x \\
\omega_{li} &= (dy/d\theta_j) \theta_{li} \\
\beta_{li} &= dy \left( dy/d\theta_j^2 \right) \theta_{li} \\
R_i &= (dy/dx) R_i^x \\
\omega_{ri} &= (dy/d\theta_j) \theta_{ri} \\
\beta_{ri} &= dy \left( dy/d\theta_j^2 \right) \theta_{ri}
\end{align*}
\]  

(5)

In equation (5), \( v_{li} \), \( v_{ri} \) represent respectively velocity of Left/right arm ends (the center of mass) in their respective coordinate systems, \( \omega_{li} \), \( \omega_{ri} \) represent respectively angular velocity of the left/right arm ends (the center of mass) in their respective coordinate systems, \( \beta_{li} \), \( \beta_{ri} \) represent respectively the left/right arm ends (the center of mass) in their respective coordinate systems.

2.4. Dynamical Equation for Dual-Arm Cooperative Robot

According to Hertz contact force model [7], which is established to calculate interaction contact force between objects, based on the relative basis of elasticity theory. Which establishing the Mechanical relationship of dual-arm Robot (the left/right arms) in the process of cooperation, contact force model between robot arms’ ends(left/right) is established as equation (6):

\[
\begin{align*}
L_i \times \omega_{li} L_i m + J \cdot \left( dy/d\theta_j^2 \right) \theta_{li} + J \cdot \left( dy/d\theta_j^2 \right)^2 \theta_{li}^2 &= M_{li} \\
R_i \times \omega_{ri} R_i m + J \cdot \left( dy/d\theta_j^2 \right) \theta_{ri} + J \cdot \left( dy/d\theta_j^2 \right)^2 \theta_{ri}^2 &= M_{ri}
\end{align*}
\]  

(6)

where \( J \) stands for rotational inertia in the corresponding direction, are the torque moment for the left/right arms.

3. Dynamic Simulation Analysis with Adams

3.1. Dual-Arm Robot Model for Simulation

The initial parameters of the dual-arm robot digital model are listed that using for simulation based on ABB YuMi [8], the YuMi is a man-robot cooperative dual-arm robot for small assembly, equipped with flexible manipulator, feed system, workpiece positioning system based on camera and accurate
robot control system, the simulation in this paper simplifies one degree of freedom joint for each arm, the following simulations are based on this condition. The main performance parameters [9] are as follows table 1.

| Parameters | IRB 14000 |
|------------|-----------|
| Payload (kg) | Reach (mm) | Accuracy (mm) | Footprint (mm²) | Weight (kg) |
| Data       | 0.5       | 559          | 0.02           | 399x497      | 38          |

The schematic structure is as follows figure 2 that digital model is imported into ADAMS.

![Figure 2. The digital model modified for ABB YuMi robot.](image)

### 3.2. The Conditions for Adams Simulation Including Palstance and Collison

It is established [10] by the Solidworks computer software that the ABB YuMi digital model, then importing it into ADAMS software by changing this model into an intermediate format(-x-t) for constructing dynamics simulation and analysis for contact force, carrying on the simulation of dual-arm robot to get the associated data curve, the movement condition is as shown table 2.

| Conditions | The initial conditions-palstance (rad/s) |
|------------|----------------------------------------|
|            | 1\(^{\text{st}}\) Joint(s)  | 2\(^{\text{nd}}\) Joint(s)  | 3\(^{\text{rd}}\) Joint(s)  | 4\(^{\text{th}}\) Joint(s)  | 5\(^{\text{th}}\) Joint(s)  | 6\(^{\text{th}}\) Joint(s)  |
| Left arm of robots | 0.10   | 0.10   | 0.15   | 0.15   | 0.10   | 0.10   |
| Right arm of robots | 0.10   | 0.10   | 0.15   | 0.15   | 0.10   | 0.10   |
| End conditions | Collision contact |

### 3.3. Simulation Curves of Analysis Results

Obtaining the simulation results with ADAMS/PostProcessor module and shown in the form of graph, kinematics characteristic curve of all the arms are given as shown figures 3 and 4.

According to the simulation of ADAMS, dynamic characteristic curves can be obtained easily and comprehensive, these include the force curves and torque curves for left/right joints, there are elaborate display shown in figure 5, and the torque of the motion for cooperative robot are shown in figure 6.
Figure 3. Kinetic characteristic curve of dual-arm cooperative robot.

(a) The center of mass displacement of the arms
(b) The center of mass velocity of the arms
(c) The acceleration of the arms
(d) The Angular velocity of the arms

Figure 4. Angular Acceleration curves of dual-arm cooperative robot.

(a) the force of the joints
(b) the torque of the joints

Figure 5. Dynamic characteristic curves of dual-arm cooperative robot.
4. Conclusions
By establishing the dynamic digital model for motion and force simulation of dual-arm robot, with the initial conditions-palstance of two arms (12 joints), the correctness of the mathematical robot model is verified. The motion process of each joint of the left/right arm is stable and reliable. The contact impact force and moment are within the allowable scope value. Dual-arm robot can effectively complete the task of dual-arm cooperation with the left/right arm for contact collision within the scope of allowable.

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