Modeling and Simulation of Dual Arm Robots using Simscape and MATLAB/Simulink

Hiep Dam Dinh
Faculty of Engineering Mechanics and Automation,
University of Engineering and Technology
Vietnam National University, Hanoi
Hanoi, Vietnam
damhiep99@gmail.com

Ngoc-Linh Nguyen*
International School
Vietnam National University, Hanoi
Hanoi, Vietnam
nlnguyen@vnu.edu.vn
*Corresponding Author

Abstract—Nowadays, cooperative dual arm robots are employed in a variety of industrial settings. This is mostly due to the fact that those robotic systems can handle bulky objects and assemble complex industrial parts reliably and precisely, as in the manufacturing of metal sheet profiles and welding on production lines with huge machinery. It follows that dual-arm robots are typically favoured for dangerous jobs like the transportation of active uranium in nuclear power plants or the disposal of explosive ordnance. Due to the lower joint torque requirement for the same operation, a dual arm robot is preferable to the single arm robot version. In this paper, we will show how dual arm robots can cooperate to move objects in space. The inverse kinematics and kinematics equations are then solved when the geometrical structure of the robot is revealed. The 3D design of the robot carried out by Autodesk Inventor software are presented. After that, 3D model of robot is converted into MATLAB/Simulink and Simscape to mimic the motion of objects being moved by dual arm robot. Some simulation test cases have been carried out to verify the movement as well as the precision of the movement of robot. Finally, conclusions and the future works were pointed out.

Keywords—Dual arm robot, cooperative motion control, trajectory manipulation, Simscape and MATLAB/Simulink

I. INTRODUCTION

Robotics has attracted increased attention in recent years, and it is a hot area of many researches. Many structures of robots have been constructed by researchers to meet demands of human life [1]-[6]. Among these robots, the redundant dual-arm robot is becoming increasingly in many industrial applications [3]-[6].

Dual-arm robots have recently gained more attention due to its advantages over typical single-arm robots, such as higher payload capability, bigger workspace, and greater flexibility. As a result, dual-arm robots have been used in a variety of high-tech applications, including intelligent assembly, out-of-space maintenance, and elderly person assistance [7]-[9]. However, due to the increased complexity in motion control and path planning, control problem of dual-arm robots is difficult. As a result, this paper will examine the anatomy of a dual-arm robot before proposing a control strategy for coordinating two hands to do the same task.

In this article, we will study the structure of a dual-arm robot with a hinged joint and then use a PID control strategy to control two arms into one task. Firstly, the structure of dual-arm robot is described. Then, the kinematic problems (forward and inverse) are discussed in detail. In the next part, a 3D model of dual arm robot is designed using the Inventor software. This 3D design model then is imported into the MATLAB/Simulink software to simulate the operation procedure. The final section provides the overall results as well as suggestions for further research.

II. STRUCTURE AND KINEMATIC PROBLEM OF A DUAL ARM ROBOT [1][11]

Figure 1 makes clear that the dual-arm robot structure is divided into two primary parts. Each part consists of an arm with two hinge joints. These two parts are mounted on a fixed rack and cooperate to carry out the specific task that the user has requested. In this article, a robot is required to place objects in the desired locations.

A. Forward kinematics

First, we calculate the position of arm 1:

\[ x_{\text{Arm}1} = L_1 \cos(\theta_1) + L_2 \cos(\theta_1 + \theta_2) + \frac{d_2}{2} \]
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\[ y_{\text{Arm1}} = L_1 \sin(\theta_1) + L_2 \sin(\theta_1 + \theta_2) \]

Next, we have the same type of kinematic equation for arm 2:

\[ x_{\text{Arm2}} = L_3 \cos(\theta_3) + L_4 \cos(\theta_3 + \theta_4) - \frac{d_2}{2} \]

\[ y_{\text{Arm2}} = L_3 \sin(\theta_3) + L_4 \sin(\theta_3 + \theta_4) \]

Based on the position of two arms, we can then calculate the position of object m.

\[ x_m = L_1 \cos(\theta_1) + L_2 \cos(\theta_1 + \theta_2) + \frac{d_2}{2} - \frac{d_1}{2} \]

\[ y_m = L_3 \sin(\theta_3) + L_4 \sin(\theta_3 + \theta_4) \]

**B. Inverse kinematics**

We take arm 2 into account and establish its coordinate system at the rotation joint \( B_1 \) (Fig. 3). We may use the Pythagorean theorem to get the length of side \( B_1B_2 \) from triangle \( \Delta B_1H_2B_3 \) which is a right triangle at \( H_2 \).

\[ B_1B_2^2 = H_2B_3^2 + HB_3^2 \]

\[ \iff B_1B_3^2 = X_{B_3}^2 + Y_{B_3}^2 \]

\[ B_1B_3 = \sqrt{X_{B_3}^2 + Y_{B_3}^2} \]

Still in this triangle, we can find the angle \( \gamma \).

\[ \gamma_2 = \sin^{-1} \frac{H_2B_3}{B_1B_3} \]

Using the cosine theorem in triangle \( \Delta B_1B_2B_3 \), we have:

\[ B_2B_3^2 = B_1B_2^2 + B_1B_3^2 - 2 \times B_1B_2 \times B_1B_3 \times \cos \beta_2 \]

\[ \iff \beta_2 = \cos^{-1} \left( \frac{B_1B_2^2 + B_1B_3^2 - B_2B_3^2}{2 \times B_1B_2 \times B_1B_3} \right) \]

\[ \iff \theta_3 = 180^\circ - (\gamma_2 + \beta_2) \]

\[ B_1B_3^2 = B_1B_2^2 + B_2B_3^2 - 2 \times B_1B_2 \times B_2B_3 \times \cos \alpha_2 \]

\[ \iff \alpha_2 = \cos^{-1} \left( \frac{B_1B_2^2 + B_2B_3^2 - B_1B_3^2}{2 \times B_1B_2 \times B_2B_3} \right) \]

\[ \iff \theta_4 = \alpha_2 + 180^\circ \]

**III. MECHANICAL DESIGN**

Inventor software was used to develop the robot’s 3D design (Fig. 4). The design consists of a table, two arms, and a rectangular box. The individual components of the two arms are the main body, the right arm (arm 1), the left arm (arm 2), and the motor.
The dual-arm robot’s main body connects the right and left branches. Two SERVO motors that control the initial stage of the two arms are mounted on the machine’s main body. This machine body is fixed to the table through the base and circular column.

For controlling motor position, use PID (Fig. 9). The dual-arm robot’s motors and joints are directly linked, so the angle of rotation of the motor likewise determines the angle of rotation of the joints (Fig. 10).

The SimMechanics toolbox will be used to import the dual-arm robots’s CAD model created in the Inventor software environment in the preceding section into MATLAB/Simulink. With the connections between the stages, we can create the SimMechanics model of the robot (Fig. 11).

Sensors were implanted to determine the end location of the manipulators that had passed to evaluate the Robot’s performance and movement accuracy. Therefore, we can compare the real position of the robot arms with the desired position.
B. Simulation results

We let the two robot arms come from different locations to test their synchronization. The two arms will simultaneously move to the object’s location. The object will then be gripped by the two arms and moved to the next position.

In 1st test: Arm 1 has an initial position of $A_3(872, 800)$, while arm 2 has an initial position of $B_3(-472, 400)$. The object will be positioned at $O(0, 610)$ and moved via locations $(400, 1010)$, $(-200, 410)$ consecutively. All of the locations listed above are coordinates based on the reference system shown in Fig. 1.

Graph X coordinate graph of arm 1 with the reference system shown in Fig. 2.

Graph Y coordinate graph of arm 1 with the reference system shown in Fig. 2.

Graph X coordinate graph of arm 2 with the reference system shown in Fig. 3.

Graph Y coordinate graph of arm 2 with the reference system shown in Fig. 3.
In 2nd test: Arm 1 has an initial position of \( A_3(400,350) \), while arm 2 has an initial position of \( B_3(-200,700) \). The object will be positioned at \( O(0,610) \) and moved via locations \((200,810), (-400,550)\) consecutively. All of the locations listed above are coordinates based on the reference system shown in Fig. 1.

Graph X coordinate graph of arm 1 with the reference system shown in Fig. 2.
Fig. 24. X Arm 1-axis graph

Graph Y coordinate graph of arm 1 with the reference system shown in Fig. 2.

Fig. 25. Y Arm 1-axis graph

Graph X coordinate graph of arm 2 with the reference system shown in Fig. 3.

Fig. 26. X Arm 2-axis graph

Graph Y coordinate graph of arm 2 with the reference system shown in Fig. 3.

Fig. 27. Y Arm 2-axis graph

Fig. 28. Graphs of desired rotation and actual rotation of the rotary joint 1

Fig. 29. Graphs of desired rotation and actual rotation of the rotary joint 2
Fig. 30. Graphs of desired rotation and actual rotation of the rotary joint 3

Fig. 31. Graphs of desired rotation and actual rotation of the rotary joint 3

Fig. 32. Error graph X Arm 1

Fig. 33. Error graph Y Arm 1

Fig. 34. Error graph X Arm 2

Fig. 35 Error graph Y Arm 2

V. CONCLUSION

This paper focus on modeling and simulation the operation of dual arm robot by using Simscape and Matlab/SIMULINK software. To validate the operation of the model, a 3D model of robot is constructed, calculated, simulated, and tested. The results show the 3D model has been worked.

In the upcoming study, we will compare and improve numerous control approaches, as well as investigate various path planning techniques. We will also examine higher-degree-of-freedom dual-arm robots and employ sophisticated control strategies to increase efficiency.
REFERENCES


