ISSN 0543-5846
METABK 63(1) 9-12 (2024)
UDC – UDK 669.18:669.187:621-229:531.65.517=111

KINEMATICS SIMULATION OF TEMPERATURE MEASURING ROBOT FOR STEELMAKING FURNACE

Received – Primljeno: 2023-05-17
Accepted – Prihvaćeno: 2023-08-20
Original Scientific Paper – Izvorni znanstveni rad

Aiming at the temperature measurement in the refining process, a temperature measurement robot that can go deep into the furnace for temperature measurement is designed. Based on the D-H parameter modeling method, the kinematics of the manipulator is modeled, and the forward and inverse kinematics of the manipulator are solved. The workspace of the manipulator is simulated by Monte Carlo method on MATLAB, and the joint trajectory of the manipulator is planned by using Robotics Toolbox. The angular displacement, angular velocity and angular acceleration curves of each joint are obtained through simulation. The simulation results show that the manipulator runs smoothly and continuously, meeting the requirements of kinematics.

Keywords: steelmaking; furnace; mechanical arm; kinematic analysis; trajectory planning

INTRODUCTION

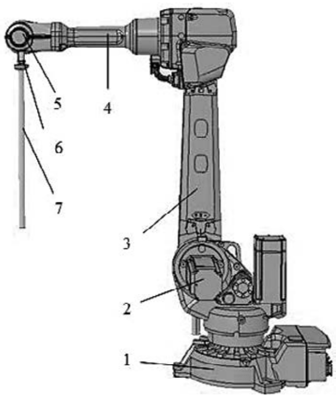
In the field of metallurgy, especially refining, temperature measurement is a necessary step. In the past, temperature measurement and sampling operations in steelmaking workshops were usually carried out by operators holding temperature measuring devices [1]. In order to improve work efficiency, reduce labor costs, and reduce the probability of safety accidents, it is necessary to develop a robot that can replace operators for temperature measurement.

In recent years, the manipulator has been widely used in the industrial production field. At present, it is mainly used in the fields of welding and handling. In the industrial detection field, the movement accuracy of the manipulator is required to be higher. Therefore, when designing a temperature measuring robot, it is necessary to solve the forward and inverse kinematics, use the Monte Carlo numerical method to analyze and draw the workspace, and use the Robotics Toolbox toolbox to plan the joint trajectory of the manipulator, To verify whether the motion process of the robotic arm is smooth.

DESIGN AND KINEMATICS ANALYSIS OF TEMPERATURE MEASURING ROBOT

According to the temperature measurement requirements in metallurgical processes, the structure of the temperature measurement robot has been designed. The robot structure includes a controller, a six degrees of freedom manipulator and a temperature measuring device. The manipulator includes a base, a boom, a jib, a wrist and an end effector. The three-dimensional model is shown in Figure 1. The large arm is connected to the base, and the end effector is equipped with a temperature measurement device for temperature measurement work.

The pose of the temperature measuring device at the end of the temperature measuring robot is composed of the motion combination of various rods. The D-H method is used to establish the linkage coordinate system of the temperature measuring robotic arm. The modeling method jointly proposed by Denavit and Hartenberg in the D-H coordinate system can easily and effectively model the robot linkage and joints. Extract four coordinate parameters from the robot, namely: joint angle, link length, link offset, and link curvature [2]. After extraction, the standard D-H parameters of the robot are obtained, as shown in Table 1.



1 - base; 2 - Joint drive motor; 3 - boom; 4 - jib; 5 - wrist; 6 - effector; 7 - temperature measuring device

Figure 1 3D model of temperature measurement robot

Based on the D-H parameters of the robotic arm, use the Robotics Toolbox toolbox in MATLAB software to

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Table 1 **D-H parameters**

i	θ_i/°	α_i/°	a	d_i/mm
1	θ_1	-90	160	0
2	$-90+\theta_2$	0	550	0
3	θ_3	-90	130	0
4	θ_4	90	0	650
5	$90+\theta_5$	-90	0	0
6	θ_6	0	0	90

call the Link function and SerialLink function to establish the robotic arm model. Create a mechanical arm link model using the Link function, as shown in Figure 2.

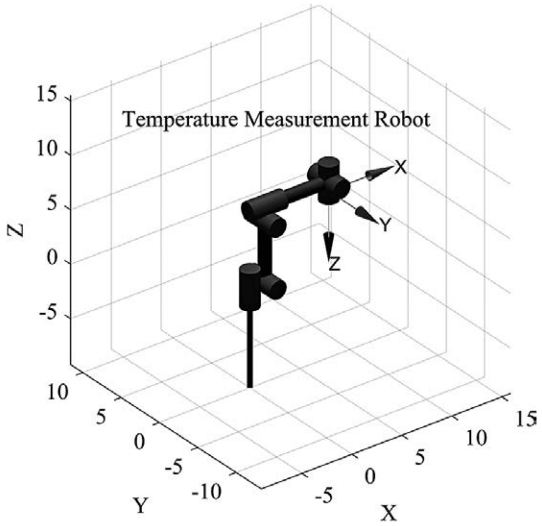


Figure 2 Mechanical arm MTLAB model

Positive kinematics is to know the rotation angle and displacement of each joint of the manipulator, and to obtain the end pose of the manipulator through coordinate transformation. The joints of the robotic arm are connected through connecting rods. By calculating the transformation matrix between adjacent members, and then multiplying each transformation matrix in sequence, the transformation matrix of the coordinate system can be obtained to determine the end pose of the robotic arm.

Inverse kinematics is to calculate the displacement and angle required by each joint when the manipulator moves to this position with known end pose [3].

SPATIAL ANALYSIS AND SIMULATION OF MANIPULATOR

The workspace is the collection of areas that can be reached by the temperature measuring device at the end of the robotic arm during the temperature measurement process, which is related to the placement position of the robotic arm. Therefore, it is necessary to analyze the workspace of the robotic arm. This article adopts the Monte Carlo numerical method and uses MATLAB software to analyze the workspace of the robotic arm [4]. The specific process of the Monte Carlo method is shown in Figure 3.

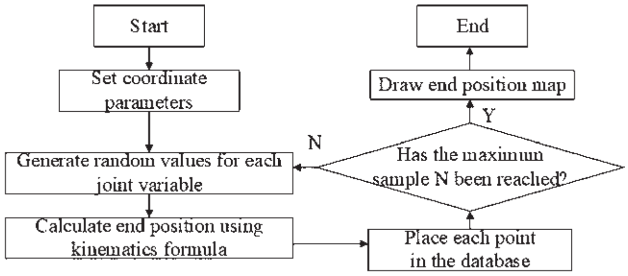
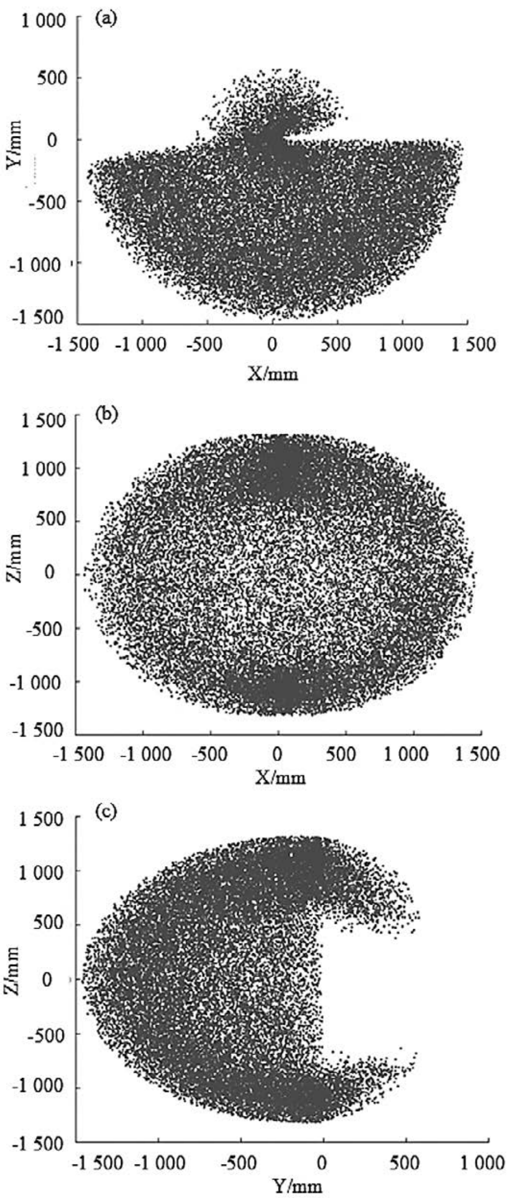


Figure 3 Monte Carlo method flow

Simulate and analyze the workspace of the robotic arm in MATLAB through the Monte Carlo method steps mentioned above [5,6,7]. Set the range of joint variables based on the actual working conditions of the robotic arm.

By using the Rand function, generate random variable values for each joint, calculate the position of the end effector, take 30000 random coordinate points, ob-



(a) - XOY plane; (b) - XOZ plane; (c) - YOZ plane

Figure 4 The projections of the end motion of the manipulator on the coordinate planes tain the workspace of the robotic arm, and draw a point graph, as shown in Figure 4.

From Figure 4, it can be seen that the diameter range of the area that the robotic arm can reach on the XOZ plane is 0,5 to 1,5 meters, and the farthest movement distance on the Y-axis can reach 1,5 meters. This robotic arm can meet the spatial requirements for temperature measurement in the steelmaking furnace.

TRAJECTORY PLANNING OF ROBOTIC ARMS

In order to ensure that the end of the robotic arm reaches the working position smoothly and stably, and the trajectory is continuous, it is necessary to plan the trajectory of the robotic arm. During the temperature measurement process of the robotic arm, the basic action of the robotic arm is generally to move the joint to extend towards the steelmaking furnace, rotate the joint for posture adjustment, and accurately reach the end below the page. Here, we model the robotic arm and plan the joint space for its basic movements.

Use the jtraj function in the Robotics Toolbox to plan the joint space of the welding robotic arm. The jtraj function call format is [q, qd, qdd]=jtraj (q_0, q_f, t), given the initial angle q_0, angle qf at the endpoint position, and simulation time t, for trajectory planning; q is the planned trajectory, and qd and qdd are the angular velocity and angular acceleration of each joint of the trajectory planning respectively. Take the starting point as the initial position q_0=[1,5 -0,5 -0,4 -0,9 1,5 0,25], as

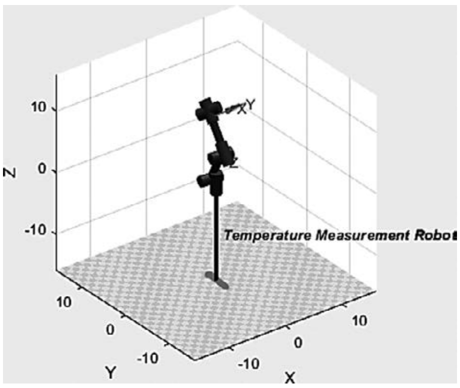


Figure 5 The position of the robotic arm in the q_0 state

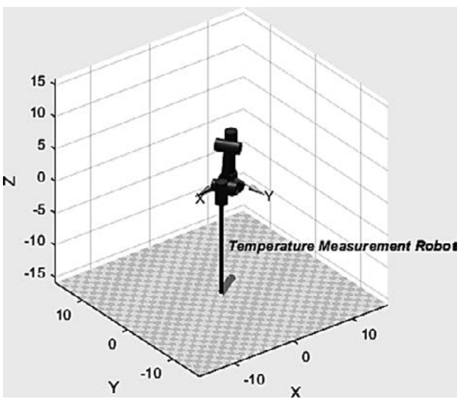


Figure 6 The position of the robotic arm in the q_f state

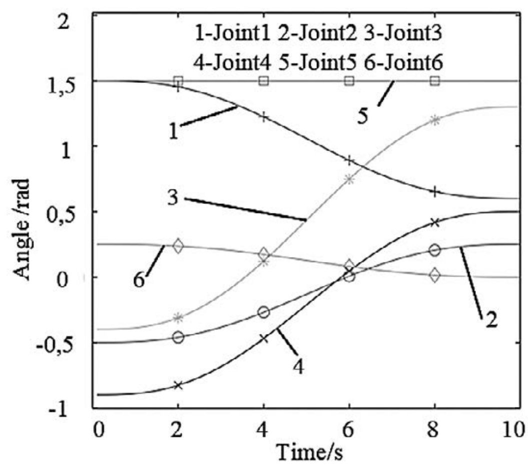


Figure 7 Angular displacement diagram of each joint

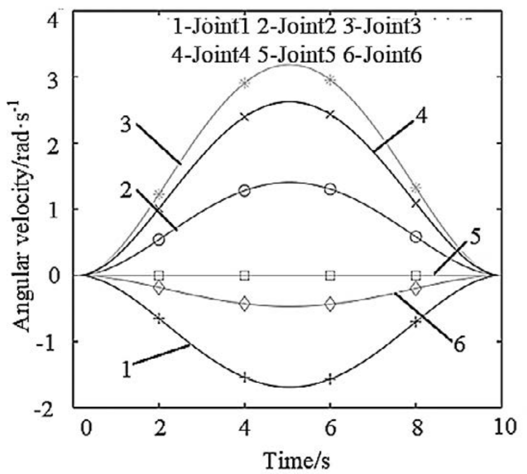


Figure 8 Angular velocity diagram of each joint

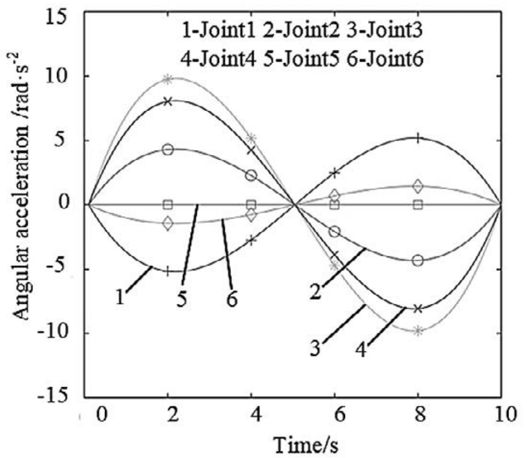


Figure 9 Diagram of angular acceleration of each joint

shown in Figure 5, and set the endpoint as q_f=[0,6 0,25 1,3 0,5 1,5 0], as shown in Figure 6. Use the established robotic arm model to plan and simulate the joint trajectory of each joint.

The movement time is set to 10 s, and the plot function is called to obtain the time varying curves of the angular displacement, angular velocity, and angular acceleration of each joint, as shown in Figures 7-9.

By conducting trajectory planning simulation on the robotic arm, the relevant motion parameters of each joint can be intuitively seen. By observing the motion curves of each joint in Figure 7, Figure 8 and Figure 9, it can be seen that the acceleration or angular acceleration of each joint corresponds to the speed change curve, and the displacement, speed and acceleration curves of the manipulator are smooth and stable in the process of motion, and there are no discontinuities or sudden changes with time. Therefore, joint space planning is reasonable, indicating that the robotic arm can continuously and stably reach the position for temperature measurement work.

CONCLUSION

A 6-degree of freedom robotic arm is designed for automatic temperature measurement in refining furnaces, which can penetrate deep into the furnace for temperature measurement work, replacing manual temperature measurement and reducing labor intensity.

The D-H method is used to establish the kinematics model and link coordinate system of the temperature measuring manipulator, and the forward and reverse kinematics of the manipulator are theoretically deduced and solved. And the workspace of the robotic arm end was analyzed using MATLAB software and Monte Carlo method. The simulation results verify that the robotic arm meets the workspace requirements.

The robot toolbox in MATLAB is used to establish the simulation model of the manipulator, and joint space planning is carried out for the manipulator to reach the target working position, and the kinematics curves related to each joint are obtained through simulation. The analysis and simulation results show that the robotic arm operates smoothly, with continuous trajectory and no sudden changes. The designed robotic arm can smoothly reach the designated position for temperature measurement work.

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Note: The responsible translator for English language is Y. Huo - North China University of Science and Technology, China