

Robotics design challenge (MATLAB/SIMULINK)

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March 30, 2023

Abstract

1 Introduction

Our product is a type of mechanical equipment used for automated welding. Our robotic arm can be widely used in various welding operations in the manufacturing industry, including automotive manufacturing, aerospace, construction, and manufacturing.

Our product has many advantages. Firstly, it can improve production efficiency and quality by reducing the negative impact of human factors on production through automated welding operations. Secondly, it can reduce the danger of the work environment.

In summary, the four-arm welding robot is an efficient and accurate welding device with many advantages. It will become an important part of automated production in the manufacturing industry, providing a reliable solution for various production operations.

2 Task 1

2.1 How original and unique is the designed robot?

After discussion and doing some references, our group decide to make our robot arm as a four-arm robot and define the robot arms and joints, because there are some advantages of four-arm robot:

- better accuracy and stability of the movement;
- bigger working arrangement;
- better loading allowance;
- better collaboration.

And there are also some unique assessments of our four-robot arms can meet:

- The welding robot arm allows more precise control of the welding position and angle.
- The stability in high temperature, low temperature and hazardous gas environments ensure safe and stable welding.
- Compared to manual welding, welding robots can automate welding work, thus increasing productivity and reducing labor costs.
- To make sure the arms and joints will not clash into each other.
- Risk of joint interference: Do kinematic analysis to determine the minimum spacing and range of the movements between the joints and the robot arms, so that we can avoid the interference of the clash of the joints.
- Simulation analysis: After setting the exact parameters of the arms and joints, we use MATLAB to do simulation of real situations, and make sure the clash of the joints and arms won't happen.
- Design concept: After doing some researches of designing the robots, we consider the working arrangement, the stability of the robots and its operability. In order to achieve the function of welding in an exact area, we finally make the definitions of the parameters of all the arms and joints.

2.2 Property of all the arms and the joints

We have designed 4 joints for the robot, 2 of which are revolute type and 2 are prismatic type. At the same time, there are four corresponding robotic arms, whose parameters are shown in the following table:

Name	Body Mass (kg)	Center of mass	Inertia (I_{xx} I_{yy} I_{zz}) ($kg \cdot m^2$)
R1	10	(0 0 0)	(0.27 0.27 0.8)
R2	10	(0 0 0)	(0.27 0.27 0.8)
P1	1.5	(0 0 0)	(0.07 0.07 0.07)
P2	1.5	(0 0 0)	(0.07 0.07 0.07)
Tool	1.2	(0 0 0)	(0.002 0.002 0.004)

Table 2.1: Experiment parameters

Joint	Type	Position Limit (rad & m)	Joint Axis
1	revolute	$[-5\frac{\pi}{180}, 5\frac{\pi}{180}]$	[0 0 1]
2	revolute	$[-30\frac{\pi}{180}, 30\frac{\pi}{180}]$	[0 1 0]
3	prismatic	$[-0.5, 0.5]$	[1 0 0]
4	prismatic	$[-1, 1]$	[0 1 0]
Fixed	revolute	N/A	N/A

Table 2.2: Experiment parameters

This is a schematic diagram of the robot in MATLAB.

2.3 Collision discussion

Our designed robot is free from collisions. In most cases, collisions occur on the two arms of the rotating joints whose rotation angle is greater than $\pm 90^\circ$. For our designed robot, the total range of motion for the two movable joints is $\pm 35^\circ$, so there is no collision. Additionally, the animation of the robot's movement trajectory can be viewed in the dynamic image in Figure 8.

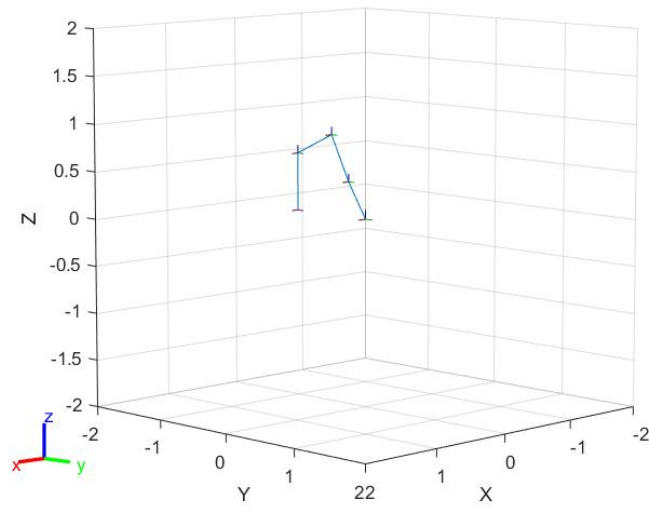


Figure 2.1: Force vs deformation and total moment diagram

3 Task 2

Here are the reachable workspace for the robot designed in Task 1.

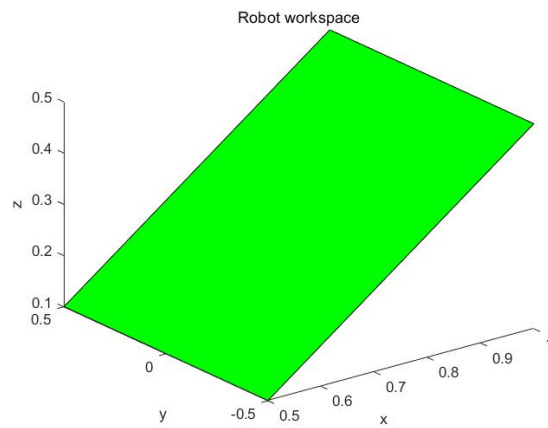


Figure 3.1: Experimental results

4 Task 3

Here are the drawing of the kinematic diagram using the Denevit-Hartenberg frame rules for the robot designed in task 1.

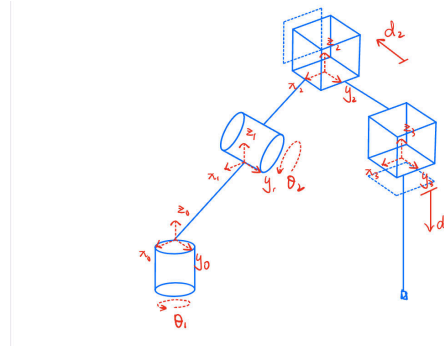


Figure 4.1: Experimental results

5 Task 4

5.1 Simulink

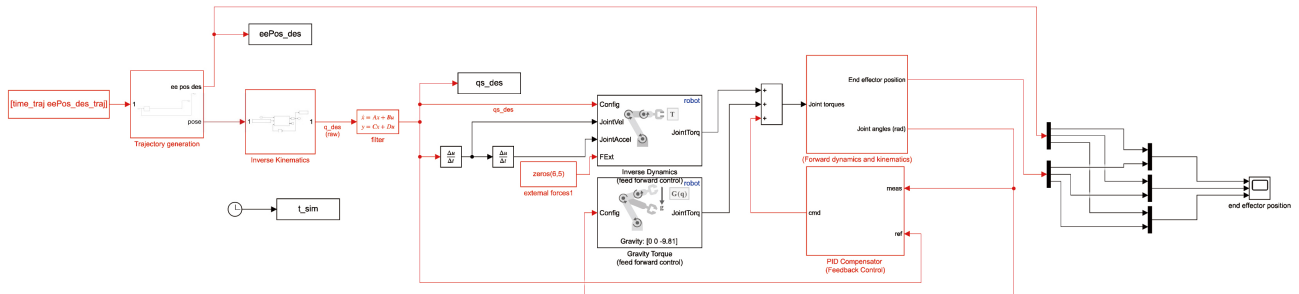


Figure 5.1: plastic modules of rectangular section

Tidy of the model

To ensure aesthetic appeal, a modular design approach was adopted, where different modules represent different functionalities, thereby making the overall model's operation flow appear clear and concise.

Trajectory generation

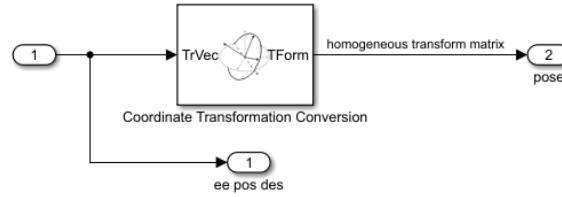


Figure 5.2: plastic modules of rectangular section

Trajectory generation module is an important component of robot motion planning, as it allows robots to move safely and efficiently in complex environments. This module is to convert signals from one coordinate system to another so that we can have easier control of the system. Additionally, the trajectory needs to be smooth, so that the robot does not make sudden changes in direction or speed that may destabilize the system or cause discomfort to human users.

We first calculate the path coordinate points and time series from the code, and use them as input parameters for trajectory calculation. Through trajectory calculation, we can obtain the expected end-effector position and the motion trajectory data applicable to each point after coordinate transformation (which is a 4001×3 data, recording the three-dimensional coordinate points of the path every 0.01 seconds and simulated for a total of 40 seconds).

5.2 PID design

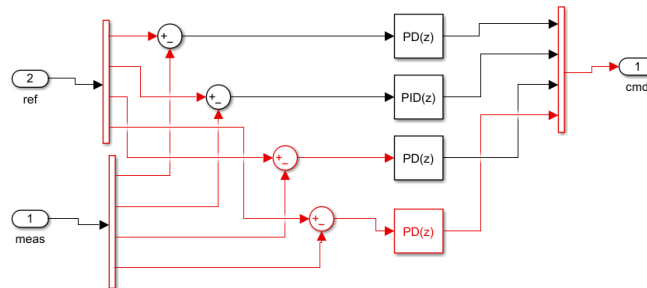


Figure 5.3: plastic modules of rectangular section

With the aim of having better accuracy of the end effect position, we add a feedback control module.

Feedback control is a control technique used in engineering to control a system by adjusting its behavior based on measured output signals. In feedback control, the output of the system is measured and compared to a desired end effect position. The difference between the measured output and the desired end effect position is called the error signal, which is then used to adjust the system's behavior through a feedback loop.

In the PID control module, we subtract the desired data from the actual data to obtain the error value, which is then used for PID calculation. We noticed that joints 1, 3, and 4 only use PD controllers because these three joints require a fast response speed and low overshoot, and have lower requirements for steady-state error. For joint 2, which uses a PID controller, it is sensitive to steady-state error due to its rotation around the y-axis. Although there may be difficulty in tuning, we successfully completed the debugging process.

5.3 Results

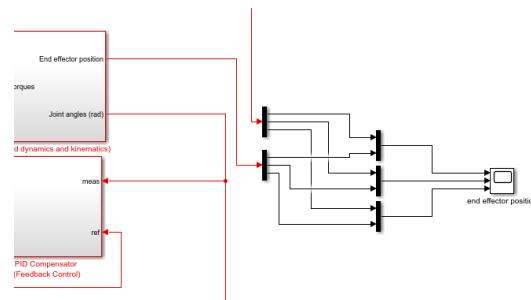


Figure 5.4: plastic modules of rectangular section

Finally, set the end effector positions and the desired end effector positioins as the input, draw the plot with their x y z positions followed by the time respectively.

Input torque

Joint angle

As we can see in the 'joint angle error' plot, The error of joint1 angle does not exceed the limit of 10^{-3} , but it fluctuates throughout the process; The error of joint2 angle is the largest, and it nearly reaches 0.02, the error tends to be stable except for large fluctuations at the peak throughout the

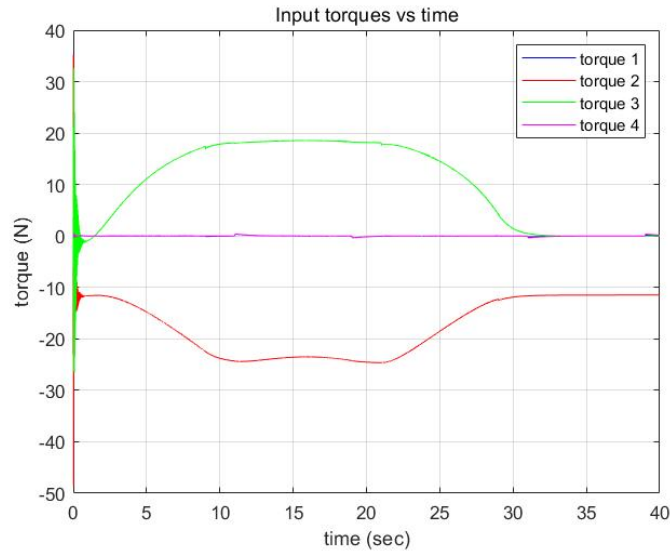


Figure 5.5: plastic modules of rectangular section

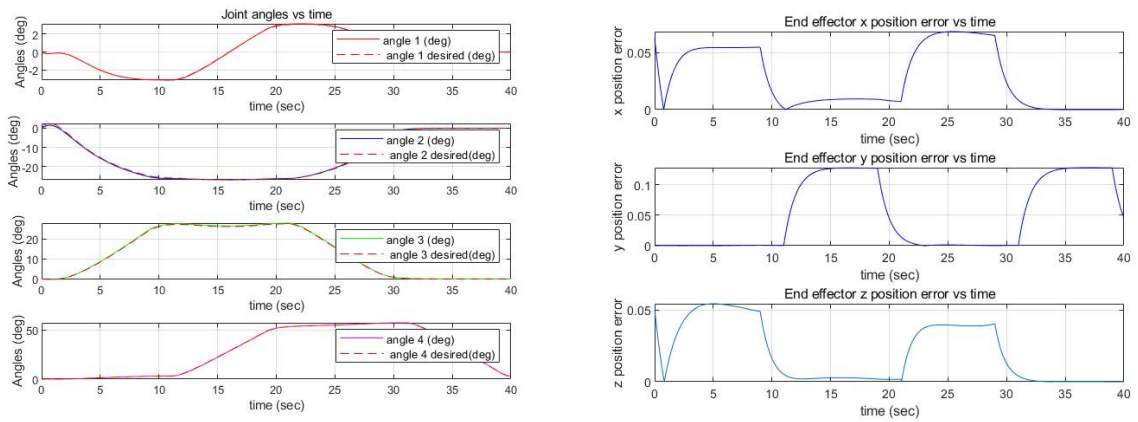


Figure 5.6: plastic modules of rectangular section

process; Both the maximum error of joint3 angle and joint4 angle are below 5×10^{-3} , but joint3 angle error are steady increase to the maximum error, and remain stable on the maximum angle error; as for joint4 angle, there is almost no error in the first ten seconds, and there is always a period of stability after the changes of the error. Overall, the errors are small and will not have a significant impact on the operation of the robot.

End Effector Position

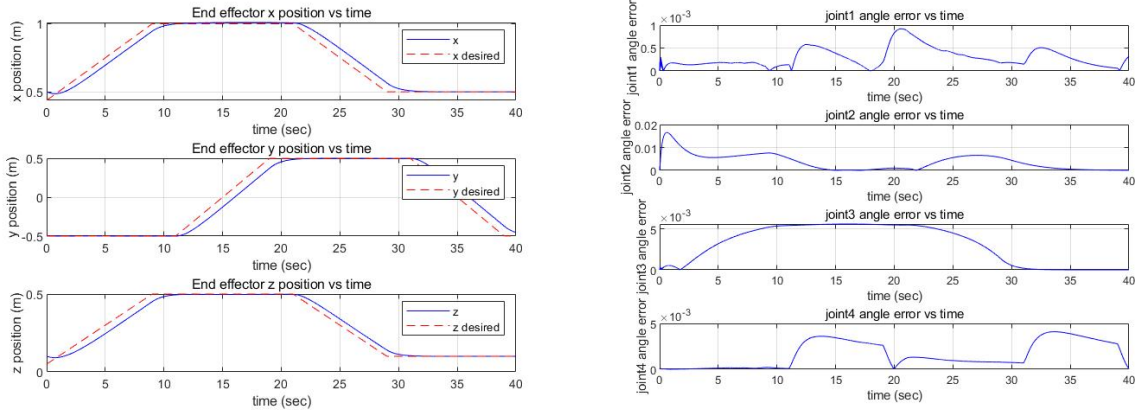


Figure 5.7: plastic modules of rectangular section

As we can see in the 'end effector position error' plot, the maximum error in end effector position on the x and z axes is below 0.05, while the maximum error on the y axis is slightly over 0.10. The errors in the x and z axes fluctuate simultaneously, while the error in the y axis gradually increases as the errors in the former axes begin to decrease. There is a small amount of error throughout the entire process, but it is not significant. It has almost no impact in reality.

6 Conclusion