Inverse kinematic control algorithm for a welding robot – positioner system to trace a 3D complex curve

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***Abstract*— The welding robots equipped with rotary positioners have been widely used in several manufacturing industries. However, for welding a 3D complex weld seam, a great deal of points should be created to ensure the weld path smooth. This is a boring job and is a great challenge - rotary positioner system since the robot and the positioner must move simultaneously at the same time. Therefore, in this article, a new inverse kinematics solution is proposed to generate the movement codes for a six DOFs welding robot incorporated with a rotary positioner. In the algorithm, the kinematic error is minimized, and the actual welding error is controlled so that it is always less than an allowable limit. It has shown that the proposed algorithm is useful in developing an offline CAD-based programming tool for robots when welding complex 3D paths. The use of the algorithm increases the accuracy of the end-effector positioning and orientation, and reduces the time for teaching a welding robot – positioner system. Simulation scenarios demonstrate the potency of the suggested method.**

***Keywords*—Welding robot, inverse kinematics, robot offline programming, robot with positioner**

I. Introduction

In recent years, the creation of the movement codes for a welding robot cooperated with a rotary positioner are crucial in welding 3D complex joints. In practical, the welder must teach robot following each point which is belong to a specific weld path. When welding a 3D freeform curve, a positioner and the robot have to move simultaneously. In this situation, the robot and a positioner are unified to become a redundant robotic system. Teaching such the robot to move relative to and cooperate accurately with the positioner carrying a workpiece is challenging. Therefore, to increase the quality of the welded parts and efficiency of the welding process, CAD-based offline programming methods which take into account the optimal solution of the inverse kinematics for the welding robotic systems is a practical need.

In the literature, there has been a great deal of scientists concentrate on offline programming and programming optimization for a welding robot with a positioner [1-7]. A clear determination of the direction of the weld under the influence of gravity is considered by Pashkevich et al. [1]. The minimization of the positioner motion for an arc welding robot system was studied in [2]. An off-line programming program for a welding robot was built in [3, 4]. A method to optimize the redundant robot motions for the fiber placement process is investigated [5]. The optimal process planning for a welding robot with a positioner was well investigated in [6,7].

Although the offline programming methods for a welding robot with a positioner have been addressed in the past, however little attention has been paid to a robust inverse kinematic control algorithm for calculating the motions of the redundant robotic system (a welding robot and a rotary positioner) when welding a 3D complex curve. Most of the previous methods considered the linear or circular weld seams when computing the motions of the positioner and the robot. In contrast to the previous investigations, this study develops an effective and robust computation law which is originated from our earlier investigation in [8]. The kinematic modelling of the robot – positioner system is treated as the kinematic modelling of a closed kinematic chain of a 5-axis CNC [9-12], a serial – parallel robot [13] or a redundant manipulator [14]. In this manner, the robot and the positioner are considered as two collaborative manipulators, one manipulator carrying the welding torch and one manipulator carrying the workpiece. The two manipulators are constrained through the welding path during the processing time. In order to formulate the kinematics model of the welding system, the two kinematic chains of the robot and the positioner are unified as an open redundant serial kinematic chain for the entire robotic system. The first joint of the unified kinematic chain is the revolute joint of the rotary positioner, and the last link of the robotic system is the end-effector – the welding torch. Since the robot – positioner is a redundant and complex robotic system, in this paper, the inverse kinematic solution is numerically searched in the joint space. In particular, the tracking error is ensured in allowable limit. Numerical examples show the robustness and effectiveness of the algorithm developed in this study.

II. Kinematic Modelling and Robust Inverse Kinematic Algorithm

In this section, a welding robot 6-DOFs FD-V8 with a rotary positioner (Fig. 1) are considered, in which the kinematic diagram is described in Fig. 2. The reference frame

$(OXYZ)_0$ is fixed to the base. $(OXYZ)_5$ and $(OXYZ)_6$ are the frames of the end-effector and the swivel table. All of frames are assigned following the Denavit-Hartenberg (D-H) notation. The parameters of the unified kinematic chain are described in Tab 1. The transformation matrices of all frames are determined by homogeneous transformation D-H matrices $\mathbf{H}_i^{i-}$,. = ÷ which is presented as

$$\mathbf{H}_i^{i-} = \begin{bmatrix} \end{bmatrix} \quad (1)$$

Fig. 1. The welding robot – positioner system FDV8

TABLE I. KINEMATIC PARAMETERS OF LINKS

Link	θ_i	d_i	a_i	α_i
1	q_1	d_1	a_1	$-\frac{\pi}{2}$
2	q_2	0	a_2	0
3	q_3	0	a_3	$-\frac{\pi}{2}$
4	q_4	d_1	0	$\frac{\pi}{2}$
5	q_5	0	0	$-\frac{\pi}{2}$
$6\,(E_1)$	q_6	d_6	0	$-\frac{\pi}{4}$
E	q_7	d_7	a_7	$-\frac{\pi}{2}$

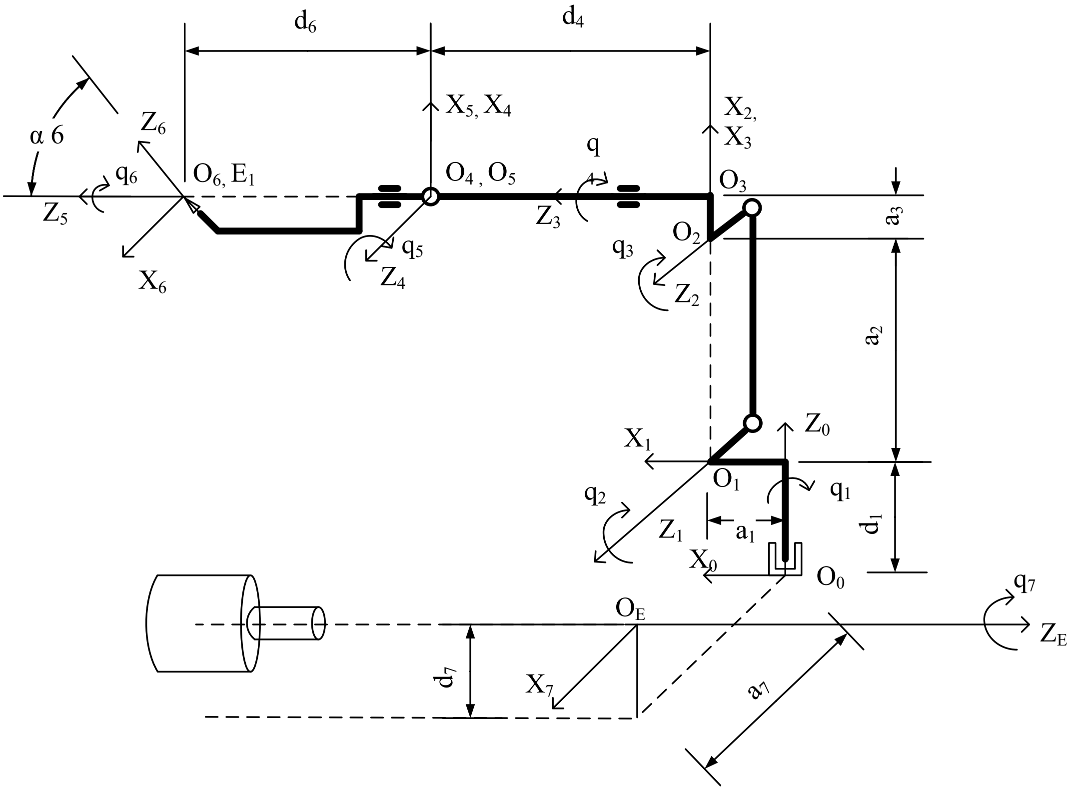

Fig. 2. The kinematic model of the robot – positioner FDV8

The location and direction of the end-effector can be determined as

$$\mathbf{H}_7^0 = \mathbf{H}\ \mathbf{H}\quad \mathbf{H} = \begin{bmatrix} \mathbf{A} & \mathbf{r} \\ & \end{bmatrix} \quad (2)$$

Where, $\mathbf{A}_n$ is the rotational matrix and $\mathbf{r}_E = \mathbf{x}$ is the position vector of the end-effector point.

Assume that the desired path $\mathbf{x}_d(t)$ of end-effector in workspace respect to time is provided. Define the joint variable vector as below

$$\mathbf{q} = \quad \dots \quad q_7 \;{}^{T} \qquad (3)$$

The forward kinematic equations are established as

$$\mathbf{x} = \mathbf{f} \;\; \mathbf{q} \qquad (4)$$

The velocity equations are described as

$$ \qquad (5)$$

The Jacobian matrix $\mathbf{J}(\mathbf{q}) = \frac{\partial \mathbf{f}}{\partial \mathbf{q}}$ is presented as

$$\mathbf{J}(\mathbf{q}) = \left[\quad \right] \qquad (6)$$

The welding robot FDV8 is a redundant system. The inverse kinematic problem is considered from (5):

$$ \qquad (7)$$

where, the pseudoinverse $\mathbf{J}^*$ is proposed as [8]

$$\mathbf{J}^* = \quad)^{-} \qquad (8)$$

And we have the inverse kinematic solution of redundant robot based on closed-loop algorithm is determined as [8]

$$ \qquad (9)$$

where, $\mathbf{K}_p$ is a symmetric positive definite matrix, $\mathbf{I}$ is the unit matrix with size $7\times$ and $\mathbf{q}_0$ is the initial joint vector. The algorithm is implemented in MATLAB/SIMULINK environment as presented in Fig. 3.

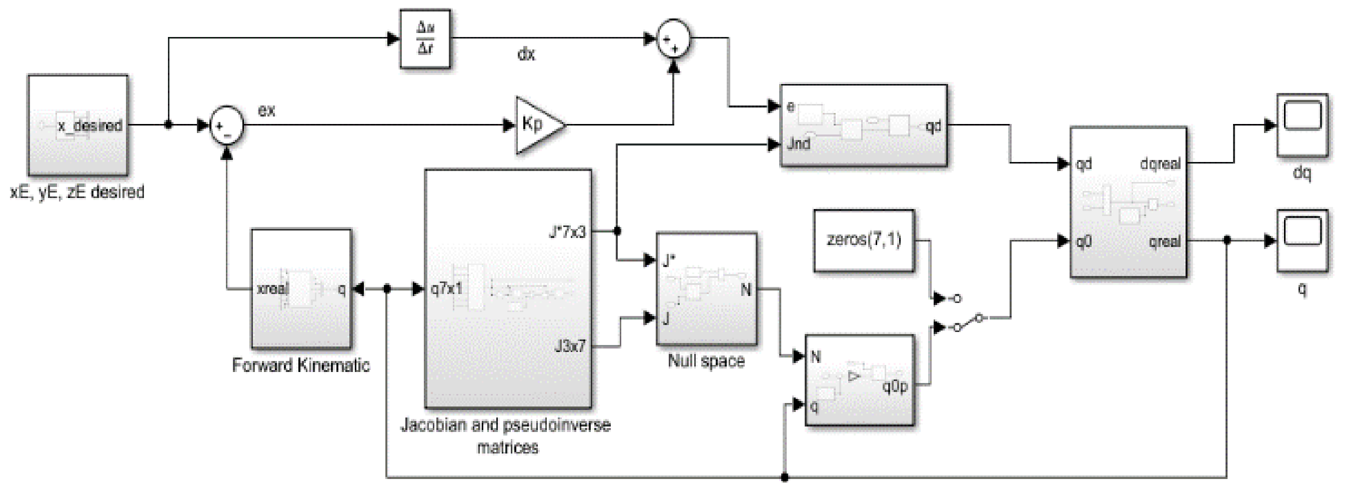

Fig. 3. The inverse kinematic algorithm implemented in SIMULINK

III. NUMERICAL EXAMPLE AND SIMULATION

In this section, the inverse kinematic algorithm constructed for the welding robot FDV8 is demonstrated. The desired welding path is given as follows.

$$ + \quad \frac{\pi}{2} \quad \frac{\pi}{2} \qquad (10)$$

Note that the tool path (14) shown in Fig. 5 is a complex 3D curve. Teach the robot and the positioner by using the teach pedant to weld this curve is challenging. This is a good example of welding path to demonstrate an offline programming algorithm.

Parameters of the links of the robotic system are as follows.

$a_1 = \quad = \quad = \quad =$

$d_4 = \quad = \quad = \quad =$

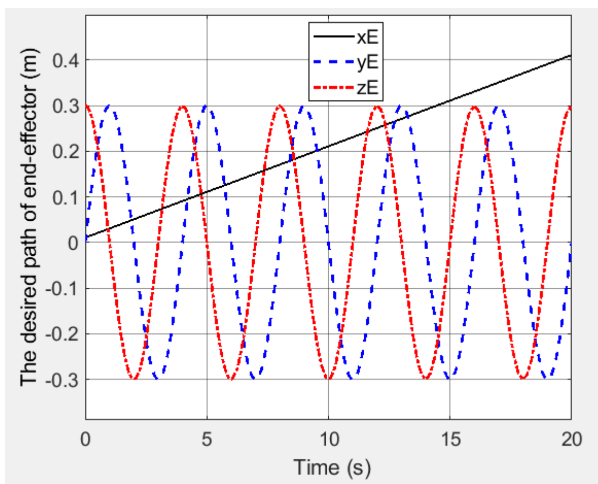

Fig. 4. The desired path of the end-effector

The desired path and velocity of the end-effector are shown in Figs. 4-6. The calculation results are presented in Figs. 7-10. Fig. 7 shows the joint variable values. It is shown that the displacement value of joint 2, joint 3 and joint 5 are bigger than the other ones. The joint velocities are presented in Fig. 8 while the rotation of the positioner (joint 7) is described in Fig. 9. The errors between the desired and calculated paths are shown in Fig. 10. The maximum value of the error is $0.8\times$.

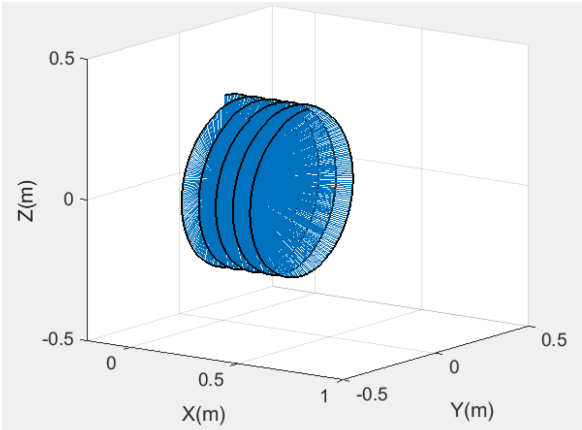

Fig. 5. The desired path in the workspace

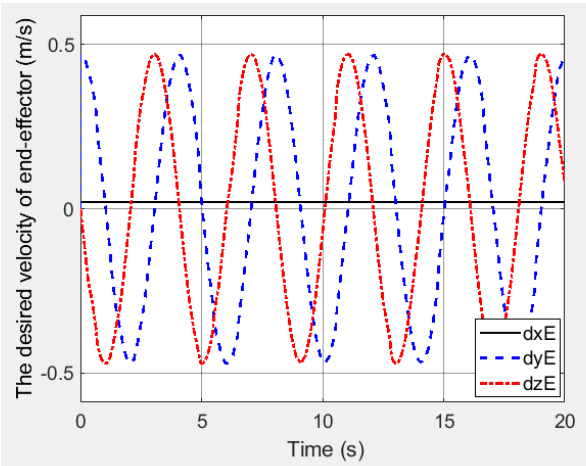

Fig. 6. The velocity of the end-effector

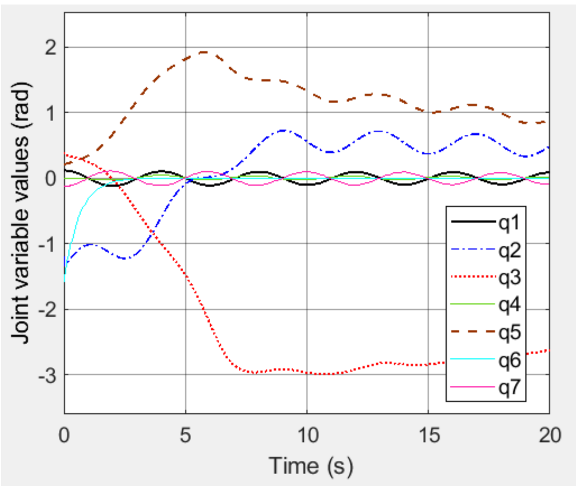

Fig. 7. The joint movements

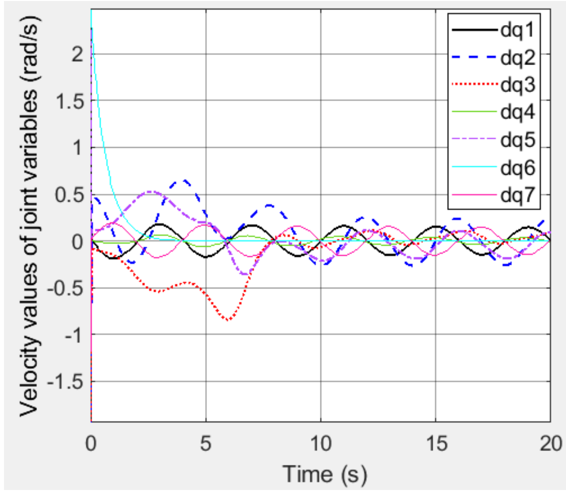

Fig. 8. The joint velocities

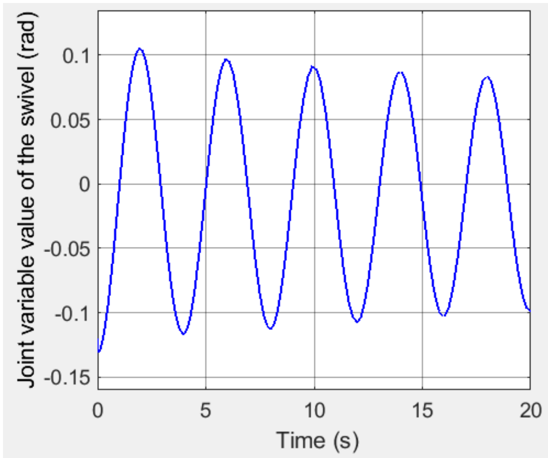

Fig. 9. The rotation of the positioner

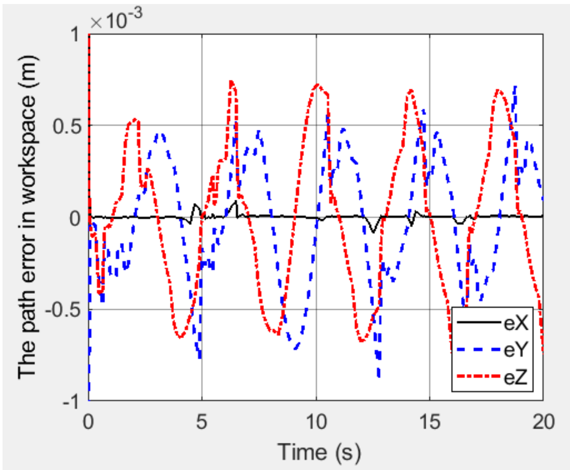

Fig. 10. The path errors

IV. CONCLUSION

A new inverse kinematic algorithm for a welding robot cooperated with a rotary positioner was successfully constructed in this paper. By using the proposed computation law, the error between the desired welding path and the actual welding path is minimized which can be controlled via the control parameters $\mathbf{K}_p$. The numerical example and simulation results show and the robustness of the algorithm and the effectiveness of the proposed method. The maximum value of the tracking error in the example is smaller than

$0.001mm$ that demonstrates a desired accuracy of the kinematics model and the computational results.

Experiments and a complete postprocessor for the robotic system will be the future work of our research.

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