Research on Kinematic Trajectory Simulation System of KUKA Arc Welding Robot System

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Abstract. In this paper, the simulation trajectory simulation of KUKA arc welding robot system is realized by means of VC platform. It is used to realize the teaching of professional training of welding robot in middle school. It provides teaching resources for the combination of work and study and integration teaching, which enriches the content of course teaching.

1. Arc welding KUKA robot system and kinematic modelling

1.1. Arc welding KUKA16 robot system
In this paper, KUK16 model of arc welding robot as the background of the robot movement trajectory simulation.


Figure 1. The physical robot.

Robot is composed of the robot body, robot control cabinet, teaching box composition. KR16 arc welding robot mainly by the welding system mainly includes the robot system, welding system, the surrounding equipment, safety devices and other accessories and other components. Welding system mainly by the welding power supply, robot wire feeder, cable assembly, robot welding gun, as shown in figure 2. Other accessories include anti-collision, clear gun shear mechanism, dust removal equipment.

Figure 2. The composition of the arc welding robot.

1.1.1 Robot body. KUKA16 model body weight 45kg, the shape of the structure from the 6 joints, each rotation joint and joint movement has a degree of freedom [1], that is the number of robot joints is its degree of freedom, so the robot has six free degree. Each joint is driven by a servo motor. A4, A5, A6 three joints to determine the location of the hand, the robot can be configured according to the function of the corresponding end of the corresponding device. In this paper, the end of the robot is equipped with arc welding torch; the other three joints A1, A2, A3 control robot pose. As shown in figure 3.
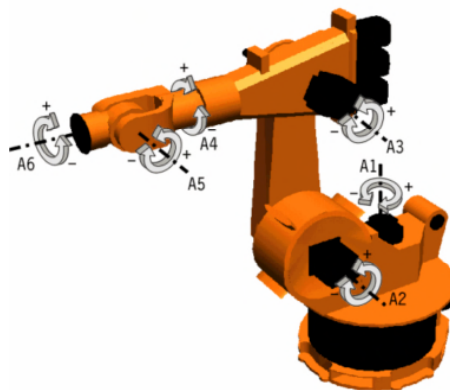
Figure 3. The main body of the robot

Robot mechanism performance indicators are measured by multiple aspects of the main consideration of two points: First, the economy, the second is the use of performance. The standard is: 1) the degree of freedom of the robot, that is, the number of independent coordinates required for the joint movement of the object space; 2) the working range, that is, the range of the end of the torch, the working range of the robot is 1600mm; 3) ; 4) repeat positioning accuracy.

Table 1. The partments of KUKA16 robot.

Structure		Vertical multi-articulation (6 degrees of freedom)
Maximum Single axis operating range	Axis 1 (turn around)	±185◦
	Axis 2 (Upper arm)	+35°, -155°
	Axis 3 (Lower arm)	+154°, -130°
	Axis 4 (Wrist turn)	±350◦
	Axis 5 (Wrist swing)	±130◦
	Axis 6 (Wrist turn)	±350◦
	Axis 1	$156°/s$
	Axis 2	$156°/s$
	Axis 3	$156°/s$
	Axis 4	$330°/s$
	Axis 5	$330°/s$
	Axis 6	$615°/s$

1.1.2 Control cabinet. The teaching robot uses KRC2 KUKA robot second generation control system. Use familiar Windows system interface, standard industrial computer, hard disk, optical drive, floppy drive, print interface, I/O signal, a variety of bus interface, remote diagnosis and other configurations. The exterior of the control cabinet and the internal control components are shown in figure 4 and figure 5.


Figure 4. External components of the control cabinet.
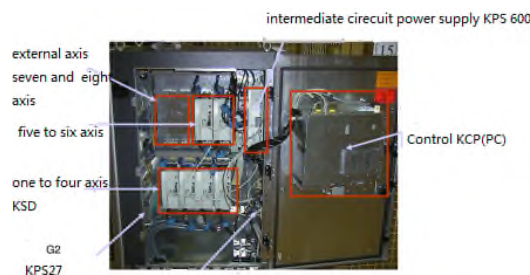
Figure 5. Internal components of the control cabinet.

As shown in figure 5, the internal components of the control cabinet are controlled by the computer section. The robot body shaft, the external shaft drive control circuit, the middle control power supply G1 KPS600, the supply power supply G2 KPS27 composition. The robot body has 6 axes, can add 6 external shaft, more than 2 external shaft control cabinet need to add the top cabinet, set the top cabinet can be equipped with four external shaft drive. Computer control PC part shown in figure 6. In the computer control part of the COM interface, you can store the file.
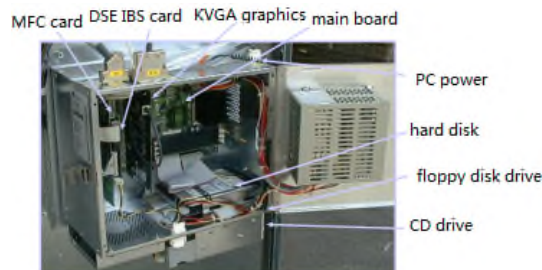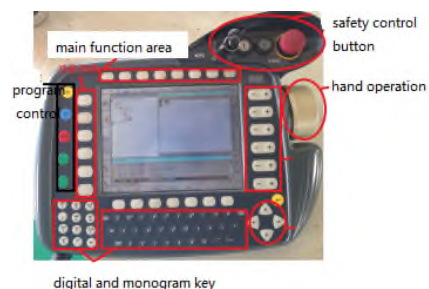

Figure 6. Composition of the computer PC.

1.1.3 Demonstration system. Demonstration system is the machine man-machine interaction interface, through the teaching device can manipulate the robot movement, to achieve different forms of welding trajectory, complete teaching programming [2]; to set the movement coordinates, to achieve TCP and external axis calibration, through the display program Status code information on the machine fault diagnosis and maintenance; but also to achieve the safety of the role of the robot, the appearance of teaching parcels shown in figure 7.

The display of the LCD screen is a VGA color image can be intuitive to show the operation of the robot and programming action. The system is used in our familiar Windows operating system, many features in the user interface is similar to the PC, so the operator is easy to get started. On the right side of the display there is a flange on the right side of the wheel, which is used in combination with a permitted switch on the back of the monitor to move the robot, and the operator is free to use it. The appearance of the entire KCP in accordance with the principles of ergonomic design, user-friendly design, light and smart, easy to operate.

Figure 7. Appearance of the demonstrator.   **Figure 8.** The function of the demonstrator.

The demonstrator is mainly composed of several parts shown in figure 8, and the operation safety control button area can perform the welding mode adjustment, the driving setting, the emergency stop button and so on, and plays the role of safety protection during the operation. The main function of the operating menu has files, edit, configure, display, prepare to run, instructions, craft and help. The file editor is mainly used to manage the file saved by the welding program. The configuration and display are for the system setting of the robot body. The function of the running menu is mainly to measure, check the zero point, set the robot parameters and install the additional software. Instructions and processes used in the programming of welding robots programming statement writing and welding procedures of the switch, the role of help is the operator encountered difficulties in the operation of the guide.

1.1.4 Welding system. The welding system is an important part of the arc welding robot. The welding system directly affects the weld quality. The welding system in this paper mainly includes the German EWM welder, the welding wire system and the clear gun program, as shown in figure 9 and figure 10.

Figure 9. The welding machine of PHOENIX 522.   **Figure 10.** The wire feeding mechanism.

2. Programming languages
KUKA robot programming instructions according to the functional division can be divided into: motion control, environment definition settings, computing functions, program control input and output functions. Motion control has two control methods, PTP control (Point to Point) trajectory control and CP Continuous path control [3]. The point-to-point control method is to control the location of the torch through the position of the robot, not taking into account the trajectory path between the point and the point; the continuous trajectory control is to control the trajectory between the two points, interpolate a lot of short points to complete the continuous Of the curve trajectory. Trajectory interpolation methods are: linear interpolation method, circular interpolation method, free curve interpolation, joint interpolation.

KUKA robot movement has three main ways, namely, point to point PTP, linear LIN, and circular CIRC.

The form of PTP is to determine the route from point to point, and the trajectory between points and points is not precisely determined, so there are many possible paths.

Linear motion LIN, Robot axis installation TCP or workpiece reference point along the line to move to the end of the way to control the robot torch to the specified speed along the exact path to reach the specified end.

Circular CIRC interpolation motion, TCP or workpiece reference point along an arc to the target point. Use the start point, the auxiliary point, and the end point to define the path. The direction of the entire path has been changed, CIRC movement in the case of accurate positioning of the CIRC movement, the robot accurately stopped at the end of each.

The current robot programming has teaching programming, offline programming and robot language programming. At present, most of the operation of the KUKA arc welding robot is taught by teaching. Teaching programming is simple, reliable, fast, for the simple part of the majority of enterprises using teaching programming. However, teaching programming has a drawback, mainly for motion control and sequential action as the center, if the teaching programming is not the result of our imagination, to re-teach. The off-line programming can be far away from the complex welding environment, in the simulation environment to achieve the welding path; therefore, off-line programming is generally used in large quantities to repeat the production of complex shapes of the workpiece.

3. Robot coordinate system setting
Arc welding robot commonly used coordinate system with the base coordinates, joint coordinates, tool coordinates, workpiece coordinates (also known as the target coordinate system) and table coordinate system. And the earth directly in contact with the base coordinate system, also known as the earth coordinates, often used Cartesian coordinate system, is to control the overall coordinate system of the robot; robot at work, the direct impact of the operation of the tool coordinate system and workpiece coordinates, the two The study of coordinates is also a long-term problem of arc machining robot kinematics. The coordinated movement of the two plays an important role in the application of motion simulation software in the next section.

The tool coordinate system is called the hand coordinate system, which is the robot end operator. For the arc welding robot is the welding torch, in order to study his movement, the fixed coordinate system origin set in the folder or the end of the torch or the middle of the middle of the folder position [4]. In order to describe the robot end position we usually use a matrix T to represent. The tool coordinate system is called the hand coordinate system, which is the robot end operator. For the arc welding robot is the welding torch, in order to study his movement, the fixed coordinate system origin set in the folder or the end of the torch or the middle of the middle of the folder position. In order to describe the robot end position we usually use a matrix T to represent.

$$T = [n \ \ o \ \ a \ \ p] = \begin{bmatrix} n_x & o_x & a_x & p_x \\ n_y & o_y & a_y & p_y \\ n_z & o_z & a_z & p_z \\ 0 & 0 & 0 & 1 \end{bmatrix} \tag{1}$$

Referring to figure 11 where the z-axis is represented by the vector a, the y-axis is represented by the azimuth vector o, and the x-axis is determined by the right-hand rule: $n = o \times a$ is denoted by the vector n. Where vector P describes the position of the robot in the base coordinate and is used to determine the robot end position. The vectors a, n, and o are used to describe their gestures.
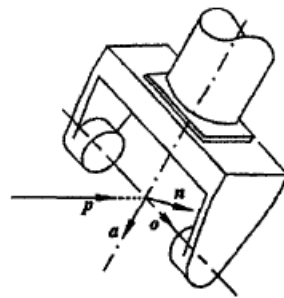
Figure 11. The tip position of the robots.

For joint robots, the motion of each joint will have an effect on the end pose. Their movements are independent of each other, and each joint move around the respective coordinate system. Therefore, it is necessary to use the homogeneous coordinate transformation of the previous section to complete the coordinate transformation between the two coordinate system.

In this paper, the coordinates of the KUKA16 arc welding robot coordinate, the Word coordinates (using Cartesian coordinates, the origin on the robot body base), TOOL coordinates, the origin of the robot 6-axis flange center point, Base coordinates (workpiece coordinates), The origin on the workpiece. In the joint coordinate system, each axis of the robot can operate in both positive and negative directions. The rotation of each axis in Cartesian coordinates is shown in figure 12
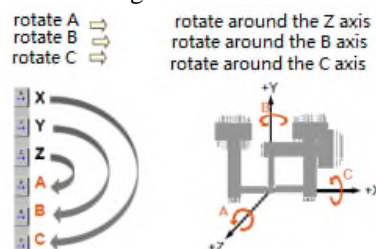
Figure 12. The rotation of the descartes coordinate

## 4. Kinematics modelling of the robot

Robot kinematics is the theoretical basis for the study of the simulation of arc welding robot. There are two main problems in the research of robot kinematics, one is kinematics and the other is inverse kinematics.

The so-called positive kinematics is known as geometric parameters of the robot bar and the joint variables, the end of the actuator relative to a given coordinate system position and attitude, the given coordinate system is the robot system in the earth coordinate system, the world coordinate system (World Coordinate).

Inverse kinematics and positive kinematics are antisplot modes, known geometric parameters of the bar, given the position and attitude of the end effector relative to the overall sitting association, and determining the size of the joint variable. In general, the joints of the robot arm are independent variables, the end of the actuator position changes are usually reflected in the overall coordinate system, therefore, according to the end of the actuator in the overall coordinate system to determine the robot joint variables to be carried out The movement is the inverse of the kinematics solution. The solution of this problem is one of the important contents of the robot motion control system.

KUKA16 arc welding robot kinematics modeling First of all, the kinematics analysis of the robot, the establishment of the corresponding robot model is to achieve the robot control and motion trajectory simulation of the prerequisite. In order to obtain the KUKA robot motion model, the direct method is to study the KUKA robot motion algorithm. As the manufacturers of robot control system internal kinematics algorithms are confidential, so many of the robot to study. The D-H parameter design method is used to study the D-H parameter design method. In this paper, the KUKA16 arc welding robot is used to design the D-H rules. The specific rules of the D-H parameter method are not specified in this paper.

In the analysis, the joints of the robot are simplified as rods, and the connection between the joints is not affected. The simplified result will not affect the analysis results. Figure 13 is to simplify the KUKA robot coordinate system, combined with the geometric dimensions of the robot parameters DH kinematic parameters are shown in table 2.
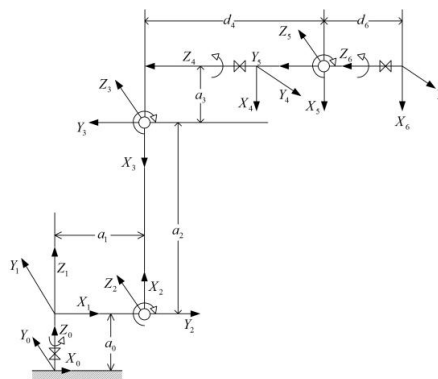

Figure 13. The coordinate system of the robot.

Table 2. D-H parameters.

Joints	θ_i (°)	α_{i-1} (°)	a (mm)	d (mm)	Joint angle range
1	$-\theta_1$	-90	260	0	-185~185
2	θ_2	0	680	0	-155~35
3	$\theta_3 + 90$	90	35	0	-130~154
4	$-\theta_4 + 180$	90	0	670	-350~350
5	θ_5	-90	0	0	-130~130
6	$-\theta_6$	0	0	0	-350~350

In the table, θ_i indicates the rotation angle around the z-axis joint, d indicates the vertical distance between the common lines of the two links. α_{i-1} refers to the twist angle of the connecting rod, and a represents the joint offset, which refers to the distance between the two joints.
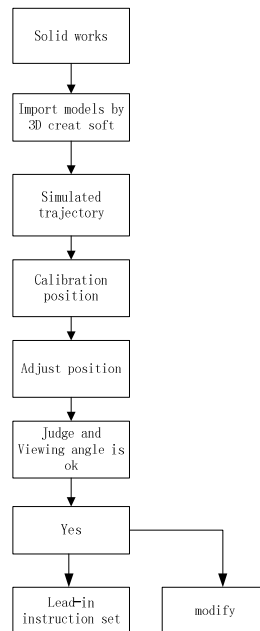
Figure 14. The robot trajectory simulation flowchart.

5. Application of trajectory simulation of the arc welding robot

The software in the arc welding robot simulation is in Visual Component Suit 3D Creat simulation software to achieve. Arc welding robot teaching system is based on the interactive computer graphics technology and robot kinematics theory to support the basis of geometric modeling is generated in the three-dimensional drawing software and display. In the process of teaching practice, the use of the software simulation function, help to establish the concept of robot theory, improve the practical operation of the robot programming capabilities. With the software, students in the practice process can simulate the welding process, and experience the application of positioning function, better grasp the welding process of welding gun posture settings and changes, improve welding quality. In the simulation of the use of the process [5], the software has a strong real-time and authenticity of the characteristics, to simulate the image and the actual work of production status is very similar. But the important problem that exists in the simulation is the deviation between the simulation and the actual product, which is what we are going to solve.

The following is mainly for this problem made the following study to complete the simulation trajectory process shown in Fig. 14.

5.1 Solid works software

SolidWorks is a professional three-dimensional mechanical modeling software, can be features, database and parametric design. Has a strong design product features, the use of stretching, rotating, shell, feature array and other functions can be achieved complex geometric model. Using SolidWorks, you can also dynamically observe the movement of parts, modeling can be generated after the workshop general drawing drawings. In the production of weldment model, you can call the model library to create tubes, rods, angle iron, etc. to model. The software is one of the most powerful software in 3D drawing software.

In the simulation, SolidWorks draws a 1: 1 three-dimensional model according to the drawing size, and saves the model as .STL format. Load the .STL file through the third-party simulation software to open the model.

5.2 Visual component suit 3D creat software

Visual Component Suit 3D Creat is developed in the Windows environment, with a reusable 3D intelligent database, a powerful graphics editing authoring environment, can be quickly created and released 3D set up to achieve automation control, is a powerful Simulation software. The software can provide special programs to add interface ADD-ON to extend the software function of the application. You can also embed the 3D creat window in other programs. In the third-party software or production line controller can be based on COM-based interface for production verification and optimization design. The software is mainly used in process and mechanical simulation, storage and logistics simulation, off-line programming and robot unit development and flexible manufacturing system simulation and so on [6].

In this paper, the application of ADD-ON embedded in the development of the welding process, can be combined with KUKA robot to achieve offline programming function, the software embedded in the VB development of the main window of the teaching software as a function module call, through visual teaching The method enables students to have a clearer understanding of the movement of each axis of the robot during the welding process.

6. Summary

With the Chinese manufacturing 2025 and industrial 4.0 put forward, the industrial intelligence and automation should meet higher requirements. As an important part of the industrial robot family, the welding robot is widely used in the ship, automobile, home appliance and other industries. In order to meet the requirements of automation development, the robot has strengthened the professional basis and general education of the robot, so that the students can adapt to the job and brand application, The simulation system based on VC platform is developed to help the professional teaching of welding robot.

7. Reference

[1] Ni N 2005. *Neural network based welding robot CO2, welding process parameter optimization,* HeFei University of Technology.

[2] Tian Z Q 2004 *Research and development of a robot mechanism with five degrees of freedom and kinematic analysis*. Xi'an University of technology.

[3] Zhang X 2006 *Research and implementation of five DOF serial robot control system*. Northeastern University.

[4] Li X X 2014 *Space operation trajectory and welding torch attitude design of arc welding robot*. Shenyang University.

[5] Zhao Y Y. *Inverse kinematics analysis and Simulation of robot arm chess game*. Qiingdao University.

[6] Kang D 2013 *Design and implementation of curriculum management system based on project teaching*. Zhongshan University, 10.