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THE APPLICATION OF INTELLIGENT WELDING ROBOTS AND VISUAL DETECTION ALGORITHMS IN BUILDING STEEL STRUCTURES

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Abstract. In order to understand the application of welding robots in building steel structures, the author proposes a research on the application of intelligent welding robots in building steel structures. The author first analyzed the characteristics of complex and diverse structural forms of building steel structure components, small batches, no repetitive components, diverse welding joint forms, low precision of components and assembly control, and proposed specific requirements for the application of intelligent welding robots, such as fast programming to meet diverse structural forms, rich and powerful welding process databases, and high adaptability to parts and assembly deviations. Secondly, it is described that existing welding robots have mature contact sensing and arc tracking functions, have offline programming software, and can achieve thick plate groove welding. They already have the technical foundation to achieve automatic welding in building steel structural components. Finally, combined with practical cases, taking a commercial building project as an example, the construction land area is 31689m2, using Q460GJC steel, with a maximum plate thickness of 100mm, the steel structure includes extended arm honing frame, radial separation frame, ring separation frame, and other contents, and is connected to the core tube as a whole. Describe the application content and methods of robot technology in the manufacturing of building steel structures, including parameter selection, programming methods, welding processes, and more. In order to achieve the goal of automatic welding of building steel structure robots. According to the application results, compared with traditional manual welding, intelligent Robot welding welding has higher efficiency and better quality, which is worth popularizing and applying comprehensively. Comprehensive comparative analysis, compared with manual welding, intelligent Robot welding has the advantages of higher efficiency and more stable quality, and has the technical conditions for comprehensive promotion.

Key words: Intelligent welding, Robots, Building steel structure

1. Introduction. With the rapid development of the construction steel structure industry, there are more and more steel structures for large-span, venue, and super high-rise buildings, and the types of components are becoming increasingly complex. Their design and production accuracy requirements are high.

At present, the low efficiency and unstable quality of manual welding operations often become the biggest obstacles to improving production efficiency and product quality stability. The improvement of welding level, especially automatic welding level, in steel structure manufacturing enterprises is the key to achieving rapid development of steel structure technology, the actual production components are shown in Figure 1. Although the welding workload in the construction steel structure manufacturing industry is large, there are significant difficulties in achieving fully automated welding due to the current non-standard design of construction steel structures, multiple types of components, small batch production of single pieces, complex processes, and low cutting and assembly accuracy in the previous process; However, the continuous innovation of advanced welding technology in the steel structure manufacturing industry and the application of efficient and intelligent welding equipment are gradually improving the quality of steel structures. At present, the vast majority of steel structure enterprises are still in the wait-and-see stage in the application of welding robots, considering the high cost and immature application of welding robots. With the development of the welding robot industry, the application of robots in the welding of U ribs and plate units in bridge projects is relatively mature; And in non bridge projects, enterprises have already put welding robots and supporting tooling systems into actual component production lines; Under the booming trend of robotics, the emergence of small welding robots and emerging technologies is also driving the application of intelligent steel structure welding. Welding robots have been

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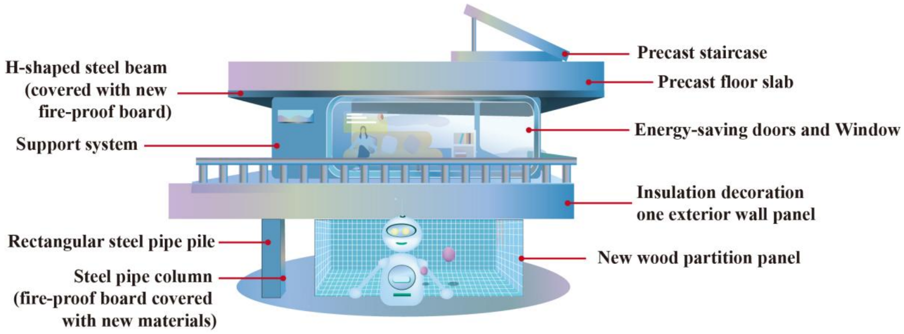

Fig. 1.1: Application of Intelligent Welding Robot in Building Steel Structures

widely used in industries such as automotive manufacturing and medical devices due to their high efficiency, performance, and quality. These products have the characteristics of standardization and large batches.

At present, the level of welding automation in industrialized countries around the world has reached as high as 80%, resulting in significant advantages in terms of efficiency and quality. According to the estimated consumption of welding materials for manual and automatic welding, the nominal degree of welding automation is 30%, which is a significant difference compared to this. With the development of building welding structures towards large-scale, heavy-duty, and high-precision parameters, the low efficiency and unstable quality of manual welding operations often become the biggest obstacles to improving production efficiency and product quality stability. In order to meet the special requirements of high-strength, thick plates, and long welds, the improvement of welding level, especially automatic welding level, is the key to achieving the rapid development of steel structure technology. Therefore, rapidly improving the level of welding automation has become an urgent and important task [1].

2. Literature Review. Intelligence and interconnection have become the mainstream direction for the future development of welding robots. The so-called intelligence mainly refers to the precise tracking and sensing of welding seams. In order to replace manual welding operations, robots need to accurately track welding based on the actual situation of the groove. Therefore, the mainstream development trend is to shift from a single teaching type to a multi-sensor and intelligent flexible processing system centered on intelligence. At present, most of the intelligent welding robots retained in the market are still teaching type, and the precise tracking and sensing technology for welds is not yet mature, and there is still great room for improvement.

Compared to the slow progress of intelligence, there has been significant progress in the interconnection of welding robots. The welding robot regional interconnection technology introduced by China Construction Steel Structure Co., Ltd. has been successfully applied to the on-site installation of steel components. Interconnection technology connects welding robots and terminal devices through regional networks, enabling remote information operation of welding. This not only improves welding efficiency, but also ensures the safety of operators.

At the same time, the real-time operation of the welding site can also be synchronized to the company's monitoring system through the network, further strengthening the control of welding quality. The intelligent and interconnected development of welding robots is the overall trend of their future development, and they will also make significant progress in other areas, such as automatic cleaning of welding slag, welding of complex components, and long installation time before welding, which require step-by-step technological breakthroughs, these are not bottlenecks that constrain the development of welding robots. Driven by market demand, the future development potential will be enormous. The position of the steel structure industry in the national economic development system is irreplaceable. With the increasing domestic steel production year by year, the application of welding technology in construction is also becoming increasingly popular, which has a huge impact on engineering safety and functional applications.Diaz-Cano, et al., propose an online robot programming approach that eliminates the traditional unnecessary steps in robot welding, allowing the operator to complete

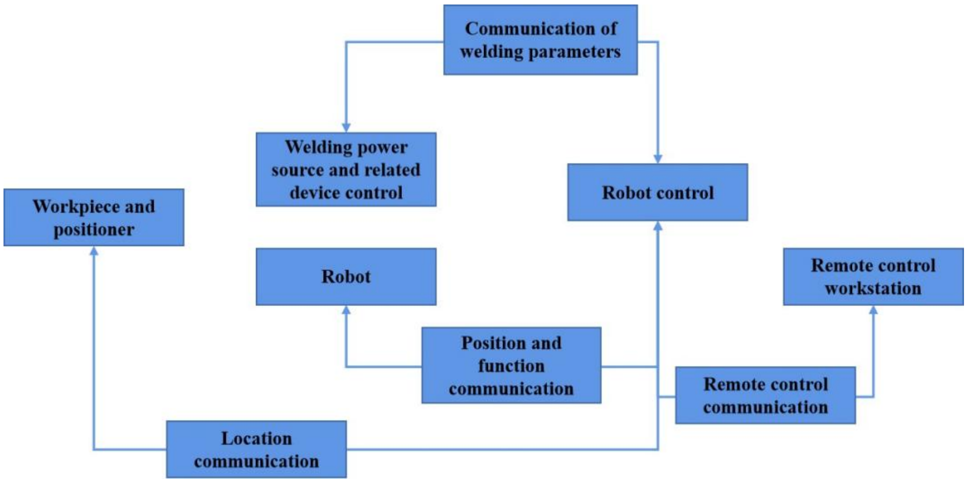

Fig. 3.1: Typical Welding Robot System Structure

the welding task by performing only three steps[2].Canfield, S. L. et al., propose a collaborative robot model and model calibration strategy to aid teaching and monitoring of welding tasks. This method uses a torque estimation model based on robot momentum to create an observer to evaluate external forces [3,4].

At present, the structural form of steel structure buildings is complex. Introducing welding robots into the technology can lead the industry to gradually develop towards digitization and industrialization, fully meeting the requirements of technological innovation and environmental protection, and comprehensively improving the quality and efficiency of steel structure welding.

3. Research methods.

3.1. Technical methods for the application of intelligent welding robots . In the welding of structural components in industries such as bridges and construction machinery, there are problems such as large workpiece sizes and plate thicknesses, poor welding groove processing, and poor accuracy in workpiece assembly, in order to achieve good welding results, robots need to have sensing and tracking functions equivalent to human vision, touch, and other senses - that is, tracking and correction functions. The welding robot system can achieve functions such as finding the starting point of welding and tracking the weld seam through devices such as contact sensors, arc sensors, and laser tracking sensors (Figure 3.1).

3.2. Contact sensing function. The contact sensing function is a collection of starting point sensing, 3-directional sensing, welding length sensing, arc sensing, root gap sensing, multi-point sensing, etc. The robot senses voltage through the end of the welding wire (or welding gun nozzle), detects deviation and groove size of the welding workpiece, and remembers the position of the workpiece or weld seam.

Through the combined application of these functions, the welding process can be unaffected by errors caused by workpiece processing, assembly welding, and welding clamp positioning. It can automatically find the starting position of the weld seam and identify the weld seam situation, compensate for weld seam offset, deformation, length, and groove width changes, and ensure that the robot can weld smoothly. The principle is shown in Figure 3.2, and the contact sensing function is mainly used for locating the starting point of the weld and locating the groove [5,6].

(1) Finding the starting point of the weld seam. The starting point of the weld seam is located by sensing the surface of the workpiece in three directions, in order to perceive the actual position of the component weld seam to be welded [7,8]. The deviation between the actual position and the position of the component weld surface during teaching is calculated through a program, and then the deviation is added to the welding position during programming to find the correct welding position, correct the welding position deviation caused by assembly, assembly, and welding, and achieve the goal of ensuring welding quality.

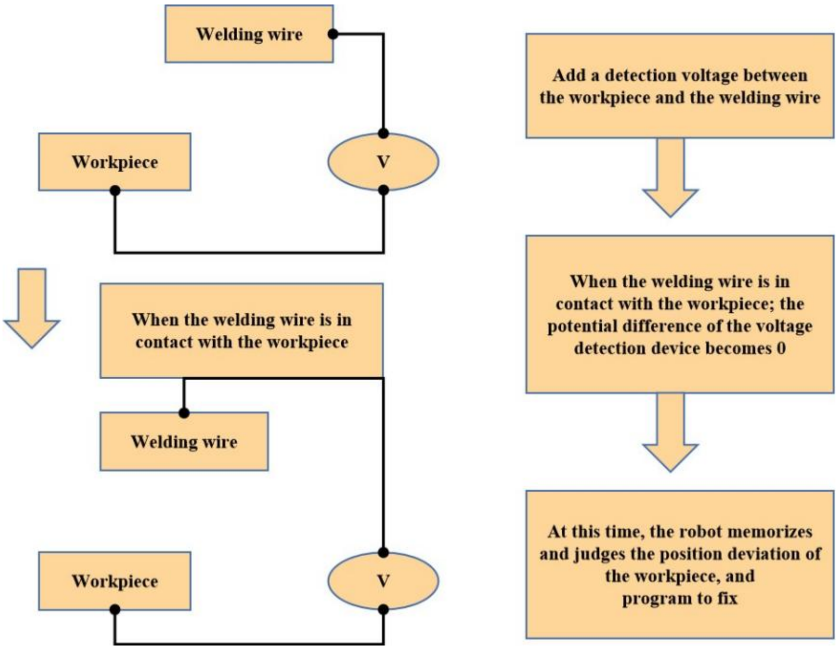

Fig. 3.2: Schematic diagram of contact sensing function

(2) Groove sensing and groove positioning sensing. Through the contact sensing of welding wire (or welding gun nozzle), the specific position of the weld groove can be quickly and conveniently found, and the width and depth of the groove can be automatically detected. At the same time, the groove angle can be calculated, which can be provided for the welding program to judge and adjust.

3.3. Arc tracking function . The arc tracking function is a function that searches for the center of the welding line, corrects the deviation of the welding workpiece in real-time, automatically detects the position of the welding line, and tracks the position deviation based on the feedback value of the welding current during swing welding. Especially in the multi-layer and multi-pass welding process, the workpiece change information obtained during the first layer of welding is utilized, and after the control system organizes and calculates, the results are directly applied to the welding after the second layer. Arc tracking is divided into welding line tracking (left and right direction tracking and up and down direction tracking) and groove width tracking [9].

(1) Welding line tracking. After the position of the starting point is determined, the correctness of the welding direction also needs to be ensured using the arc tracking function. Arc tracking refers to the real-time monitoring of welding voltage and current changes by the welding robot system through software during the welding process, analyzing and calculating the changes in arc length, and correcting the deviation of the weld seam through software adjustment of the robot's posture, thereby achieving seam position tracking.

(2) Groove width tracking. The arc welding robot system detects multiple points on the entire weld seam before welding, calculates the width of the weld seam groove through software, and then obtains the change in the width of the entire weld seam. During the welding process, by automatically adjusting the welding swing amplitude and welding speed, a weld seam with consistent height and shape is obtained, achieving the goal of improving welding quality [10,11].

3.4. Teaching Programming and Offline Programming. All welding robots have the function of teaching programming, which guides the welding gun to the starting point through the teaching box, and then determines the position, motion mode (linear or arc interpolation), swing mode, welding gun posture, and various welding parameters, at the same time, the movement speed of peripheral devices can also be determined through the teaching box. The welding process operations include arc striking, arc extinguishing, and filling arc pits, which are also given through the teaching box. After the teaching is completed, the welding program can be produced. For the welding seams of structural components with complex structures, different shapes, and larger volumes, especially for the production of multi variety, small batch, and single variety, non batch welded structural components, online teaching will inevitably spend a lot of time, reduce equipment usage, and increase the labor intensity of operators. The method of online teaching directly restricts the application of welding robots, as is the case in the steel structure industry [12,13,14].

Offline programming technology utilizes 3D modeling software to copy the real work robot system into a computer, and then imports the component models generated by SolidWorks or ProE software into the robot scene in the computer. The workpiece can be programmed in an offline simulation environment, allowing the robot to complete welding programming independently on the computer without the need for the robot equipment itself. The program for on-site teaching and editing can be copied, translated, and other basic programs that can be read by offline programming software, greatly reducing the preparation time for welding programming and improving the utilization rate of intelligent robots [15].

4. Experimental analysis.

4.1. Project Introduction. Taking a certain commercial building project as an example, the construction land area is 31689m2, using Q460GJC steel with a maximum plate thickness of 100mm. The steel structure consists of extended arm honing frame, radial separating frame, ring belt separating frame, etc., and is connected to the core tube as a whole. The steel used in this project is about 120000 tons, and the cotton frame layer structure is complex. In terms of design, high-strength bolts are used to connect with welding. The weight of a single component is 90 tons, and the welding quality and installation accuracy requirements are strict. The steel is mainly Q345GJC, which is a low alloy high-strength structural steel with a thickness range of 20-130mm. In actual construction, it is controlled according to foreign welding standards [16].

4.2. Application method.

4.2.1. Parameter determination. The robot in this building adopts a modular development route, with trajectories, actuators, multi degree of freedom welding guns, control platforms, and intelligent control modules, which can fully meet the on-site installation and welding needs of steel structures. In order to meet the various welding operation requirements on site, the main parameter selection is: in terms of technical parameters, the robot adapts to the welding position and supports horizontal, vertical, upward and 360° all position welding; Supports straight seams, circumferential seams, and irregular welds, supports circular workpiece sizes with a diameter exceeding 168mm, and the robot's walking speed is between 0-160cm per minute; The angle swing of the welding gun adopts a strip conveying method, with a swing speed of 0-255cm per minute and an amplitude of ±25mm; The horizontal tracking stroke is 200mm, the vertical tracking stroke is 150mm, and the programmable parameter adjustment amplitude is ±20%. In terms of melting efficiency, the efficiency of thick plate long weld welding is 1.5 times higher than that of arc welding; The magnetic adsorption type track of the robot is driven by friction, with a fine and compact body structure and convenient installation [17,18].

The comparative analysis of the technical performance of different mechanisms is shown in Table 4.1. Finally, a cage type positioner continuous flipping device was selected, and two workstations were arranged simultaneously. During welding operations, one workstation could be used for loading and unloading of vertical components, improving efficiency and the utilization rate of welding robots.

4.3. Programming method. This welding robot system supports three programming methods:

(1) Online teaching programming. Online teaching programming cannot be widely applied in building steel structures due to long equipment usage time and low efficiency, and can only be used as a supplementary application for on-site adjustment.

(2) Offline teaching programming. Through traditional offline teaching programming software, offline programming of all steel structure components can be achieved, meeting the requirements of welding usage. However, due to the numerous types of building steel structures, the standardization of welding structural components is not high, and the 3D models generated by the CAD software currently used by steel structure enterprises cannot be directly imported into offline programming software, and the 3D models of components need to be

Table 4.1: Comparative Analysis of Technical Performance of Different Mechanisms

Types	Work situation	advantage	disadvantage
L-type 90° flipping device	Build and purchase on the jig frame, and after welding on each side, flip the device with $N \times 90^\circ$ flip, experimental full position welding	Moderate price Can achieve continuous automatic welding	Unable to synchronize with robot control system
Continuous flipping of cage positioner	Built and loaded into a cage positioner, capable of achieving 360° continuous rotation	Can be linked with the robot control system to meet the requirements of continuous automatic welding	Relatively high price The system is relatively complex

rebuilt, it will consume a lot of time in modeling and editing robot action trajectories in offline programming software, so traditional offline programming software is difficult to meet the needs of actual production.

(3) Intelligent rapid programming software. In order to address the above issues, an intelligent and fast offline programming software has been developed. The rapid programming system adopts parameter driven, similar to building blocks, to construct a model of the welded part. The H-beam, box column, and cross column are defined as the main body of the workpiece, and the rib plate, bracket, and combined bracket are defined as modules, by inputting the size parameters of the main body of the workpiece, the size parameters and quantity of the module, and the parameters of the installation position on the main body of the workpiece, the two-dimensional model of the workpiece, the three-dimensional model that can be recognized by the offline teaching software, and the Robot welding implementation program are automatically generated. At the same time, according to the input size information, the welding database of the corresponding weld is automatically selected (Figure 4.1). The automatically generated robot program can be verified in an offline system.

The application of intelligent rapid programming software has greatly improved the welding programming time of building steel structure components, shortened the ratio of programming time to welding time, and laid an important technical foundation for the promotion and application of building steel structure welding robots. Online teaching programming requires a long investment time and low work efficiency, making it difficult to fully utilize in building steel structures and can only assist in on-site adjustments. In offline teaching, programming of all steel structure components can be achieved, fully meeting the requirements of welding applications. However, due to the variety of steel structure types, the standardization level of structural components is low, and the 3D model generated by the CAD software used by the enterprise cannot be directly imported into offline software. Therefore, it is necessary to rebuild the model and spend a lot of time editing the robot's motion trajectory, which is not in line with actual needs. In this regard, the building adopts intelligent offline programming software, which is parameter driven and similar to the principle of building blocks to construct a welded workpiece model. It uses box shaped columns and cross column workpiece bodies to support and strengthen modules such as plates, and automatically generates a two-dimensional model. By inputting parameters such as workpiece body parameters, size, quantity, etc., the offline teaching software of the three-dimensional model is recognized. Based on the input size information, a matching database is automatically selected, Enable the robot program to be verified in the offline system, saving more programming time, and effectively ensuring the welding efficiency of the steel structure of this project.

4.3.1. Welding process. This type of robot can walk along a predetermined route, repeatedly operate a certain process for a long time, and is easy to track and control. The system operation is stable and reliable, with high work efficiency. It is suitable for prefabrication and welding at various locations on site, and can effectively solve the problem of automatic welding for long welds and multi-position steel structure installation in construction projects. In this project, the application of welding robots includes the following content. In the welding of the extended arm truss, the truss layer of this project is a key and difficult welding point, mainly

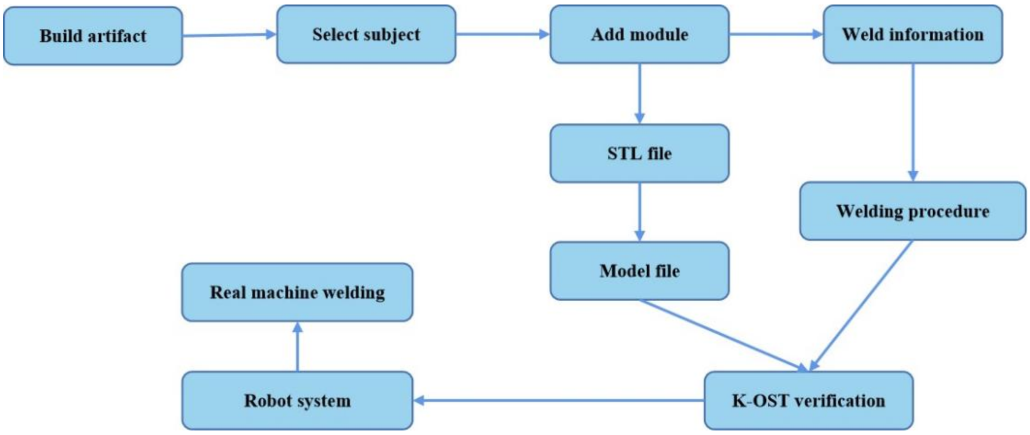

Fig. 4.1: Intelligent Fast Programming Process

Table 4.2: Welding flux parameters of damper quality box

project	numerical value
Number of steel cables	13 pieces
steel type	Q355B
Quality box quality	1100t
Steel plate thickness	85nm
Weld length	10m

made of Q390GJC material. The maximum length of the vertical weld seam of the extended arm truss is 4m, and the plate thickness is 140mm, one weld seam requires two welders to work continuously for 40 hours to complete. According to the relevant regulations for steel structure welding, the difficulty level reaches level D. This project includes a total of eight truss layers, each with a degree of 2-4m, a plate thickness of 80-140mm, and more than 50 welds. Due to the large amount of welding, low manual operation efficiency, and unstable welding quality, robot technology should be introduced to achieve high-altitude welding goals. The welding operator determines the length of the track based on the actual situation on site, configures the power control box, wire feeder, etc. required for automatic welding, and connects the cable to the welding trolley. The cable length is about 25 meters. This equipment can be placed at a high altitude around the car for welding. The welding protection gas cylinder can be connected to the control box through a gas pipe, ensuring that the center of the weld pool is the same as the weld seam during welding, optimizing and improving the welding parameters, and achieving the goal of continuous welding. In the welding of the damper quality box, the equipment is located on the 125th floor, with a height of 27m. There are 4 groups of 13 pieces suspended on the 125-131 floor, and the specific parameters are shown in Table 4.2 [19].

In order to ensure the reliability of root welding, a 5mm gap should be reserved during assembly. Generally, welding wires with a diameter of 5mm should be placed on both sides and in the middle during assembly, and then positioned for welding, the length of the weld seam is between 30-40mm, with a spacing of 400-500mm, it should be positioned at the small groove position, and the end should be spot welded and fixed before polishing smoothly, treat it as the arc starting point for robot operation. After the point welding is completed, use a flame gun to heat and remove the welding wire. Arrange the two robots symmetrically to minimize welding stress and deformation while ensuring welding progress and quality.

4.4. Application effect. In this project, the welding robot was used to achieve the welding objectives of the boom honing frame and the damper mass box. Under the same position and conditions, it has significant advantages compared to traditional welding modes, and the application effect is mainly reflected in: Firstly, the welding quality is high, the appearance is beautiful, the weld seam is smooth with the base material, and the non-destructive testing results meet the standards[20]; Secondly, the welding efficiency is high, and automatic slag cleaning can be achieved during the welding process, achieving continuous operation, which doubles the efficiency compared to previous manual welding; The third is to greatly reduce the intensity of manual work. Technicians only need to adjust the welding parameters. After completing the weld seam teaching activity, the robot can automatically repeat welding, which is very convenient.

5. Conclusion. Currently, there are various forms of construction, and the types of steel structural components are becoming increasingly complex, with the characteristics of small batches without repetition, which puts forward higher requirements for the function of welding robots. In practical projects, appropriate parameters and programming methods should be selected based on the actual situation, advanced and reliable welding processes should be applied to achieve the goal of automatic welding of steel structure components, compensate for the quality defects of previous manual welding, and better meet the requirements of digitalization and technology in steel structure manufacturing, making component manufacturing more efficient and reliable.The application of intelligent and rapid programming software greatly improves the welding programming time of building steel structure components, reduces the ratio of programming time and welding time, and lays an important technical foundation for the promotion and application of building steel structure welding robots.

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