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Realization of rectangular fillet weld tracking based on rotating arc sensors and analysis of experimental results in gas metal arc welding

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ABSTRACT

In order to improve the welding quality and efficiency of the rectangular fillet weld in the shipyard and the steel structure workshop, reduce the labor cost, and improve the welding automation, it is necessary to study a welding robot that can track rectangular fillet weld. The working principle of the rotating arc sensor has been studied, and the mathematical model of the space posture of the arc welding gun has been established. The equivalent link coordinate systems of the wheeled mobile robot have been built, and the jacobian matrix of the robot and its inverse matrix have been calculated. The transformation from the operational space speed to the joint space speed has been realized by using the inverse matrix of the jacobian matrix, and the trajectory planning of the welding robot has been finished. The tracking algorithms of the linear fillet weld and the rectangular fillet weld have been studied, and the rectangular fillet weld tracking experiment has been done in the laboratory and the factory. Experimental results showed that the welding robot can track the rectangular fillet weld with high accuracy and good reliability.

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1. Introduction

Welding is one of the most effective ways of metal connection, the cost is low, and the connection is reliable. In the steel structure workshop and the shipbuilding industry, there are a large number of rectangular fillet welds. The automatic welding carriage can weld the straight welding seam, and the welding point locates in the line that passes through two points where two guide wheels contact the vertical steel plate of fillet weld. When the welding seam is curve, the welding point deviates from the welding seam, so the automatic welding carriage cannot weld the rectangular fillet weld. The size of the mechanical arm is big, and it is not convenient to move, so it cannot weld the rectangular fillet weld in a narrow place. Therefore, the rectangular fillet weld is welded by the manual welding. During the welding process, there are arc light, splash, and toxic gas. The working environment is very bad, which makes that the workers are easy to suffer from all kinds of diseases, and the welding quality is poor. In addition, the welding efficiency is low, and the cost is high, so it is necessary to research a kind of welding robot that can track the rectangular fillet weld.

There are electromagnetic fields, strong arc light, spatter, and smoke during the welding process, so many sensors cannot work normally, but the visual and arc sensors are widely used in tracking the welding seam. Ku et al. [1] studied development of a mobile welding robot for double-hull structures in shipbuilding. Liu et al. [2] designed robot welding seam tracking system with structured light vision. Nele et al. [3] established an image acquisition system for real-time seam tracking. Gu et al. [4] analyzed autonomous seam acquisition and tracking system for multi-pass welding based on vision sensor. Xu et al. [5] established computer vision technology for seam tracking in robotic GTAW and GMAW, a set of special vision system had been designed, which could acquire clear and steady real-time weld images, and results showed that the precision of this vision based tracking technology was very high. Chen and Feng [6] studied the model of underwater wet welding process based on visual and arc sensors. Xu et al. [7] developed real-time seam tracking control technology during welding robot GTAW process based on passive vision sensors, a segmented self-adaptive PID controller was introduced, and experiments showed that the seam tracking accuracy could meet the requirements of quality control of seam forming. Shen et al. [8] proposed real-time seam tracking technology of welding robot with visual sensing. Xu et al. [9] studied the real-time tracking information of three-dimension welding seam in robotic GTAW process based on composite sensor technology, the paper designed a set of composite sensor system, which could acquire three-dimensional welding seam information, and the results demonstrate that the error was very small, which was accurate enough to meet the requirement of the real-time tracking and controlling. Wang [10] proposed three-dimensional vision-based sensing of GTAW a review. Because of the influence of the strong arc light and smoke, there are a lot of noises in the images when the welding seam is identified by using the visual sensor, so the filtering algorithm, the deviation identification algorithm and the control algorithm

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are complex. In addition, the amount of calculation of the image processing is big, so it is not conducive to the real-time tracking of the welding seam. When the arc sensor is used in tracking the welding seam, the welding point is the detecting point, the real-time performance is strong, and it is not influenced by arc light, spatter and smoke, so it is widely used in the tracking system of the fillet weld. Kim and Na [11] studied an arc sensor model for gas metal arc welding with rotating arc about dynamic simulation of wire melting, and it was clarified how the characteristics of the welding power source affected the sensitivity of the arc sensor. Kim and Na [12] studied an arc sensor model for gas metal arc welding with rotating arc about simulation of an arc sensor in mechanically rotating gas metal arc welding, and a mathematical model for the dynamic behaviour of the electrode melting rate and arc length was presented. Lee et al. [13] developed a high speed rotating arc sensor system for tracking complicate curved fillet welding lines. Kim and Rhee [14] designed the arc sensor model by using multiple-regression analysis and a neural network, and different types of regression models were developed. Yoo et al. [15] proposed end point detection of fillet weld using the mechanized rotating arc sensor in GMAW, and a geometrical sensing model was developed. Shi et al. [16] studied the mathematical model of the rotational arc sensor in GMAW and its applications to seam tracking and endpoint detection, and the mathematical model could be helpful for the interpretation and improvement of arc sensing systems. Xu et al. [17] researched the acquisition and processing of real-time information for height tracking of robotic GTAW process by arc sensors, this paper designed a set of arc sensor system for height tracking of weld seam, which was accurate enough to meet the requirements of the height tracking and controlling, and the experimental results showed that the height error between the calculated arc length and the real arc length was very small.

The size of the rectangular fillet weld is not constant in the factory, the working space is narrow, and one rectangular fillet weld has four right-angle fillet welds, so it is difficult to track the rectangular fillet weld. In recent years, research of the rectangular fillet weld tracking in a narrow space is fewer. In order to reduce the welding cost, and improve the welding quality and efficiency, it is necessary to research a kind of autonomous mobile welding robot, and it can track rectangular fillet welds of various sizes, so some economic and social benefits can be generated by using this robot.

2. The mathematical model of the rectangular fillet weld

Fig. 1 shows some rectangular fillet welds in the steel structure workshop and the mathematical model of the rectangular fillet weld. and Fig. 1(a) shows that the steel beam consists of many rectangular fillet welds. In order to improve the strength of the steel beam and the ability to resist bending, and reduce the weight of the steel beam, the cross section of the steel beam is usually the H shape. During the manufacturing process of the steel beam of the H shape, many rectangular fillet welds need to be welded. Fig. 1(b) shows the real figure of two rectangular fillet welds, four sides of the rectangular fillet weld are short, and the working space is very small, so the welding quality and efficiency will be affected.

Fig. 1(c) shows the mathematical model of the rectangular fillet weld, and a rectangular fillet weld consists of four right-angle fillet welds(②, ④, ⑥, ⑧) and four linear fillet welds(①, ③, ⑤, ⑦). Because of the assembly error, the angle of the right-angle fillet weld is not 90°, and it is a value between 80° and 100°. Because of the deformation of the steel plates, the fillet weld is not a straight line, and it is the space curve fillet weld actually. If the linear fillet weld and the right-angle fillet weld can be tracked by the welding robot, the rectangular fillet weld tracking will be realized.

Many steel structure factories use the automatic welding carriage to weld the straight-line welding seam, but it cannot weld the space curve

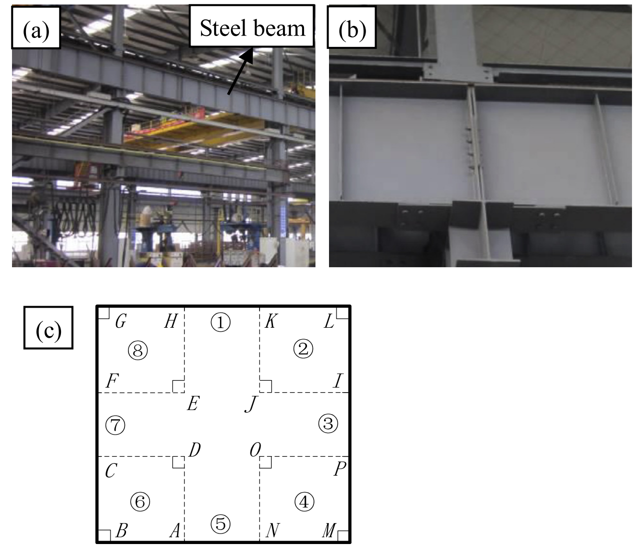

Fig. 1. Some rectangular fillet welds in the steel structure workshop and the mathematical model of the rectangular fillet weld. (a) the steel beam consists of many rectangular fillet welds; (b) the real figure of two rectangular fillet welds; (c) the mathematical model of the rectangular fillet weld.

fillet weld and the right-angle fillet weld well. The steel beam is big, and it is not convenient to be moved. In addition, the size of the mechanical arm is big, and it also cannot move independently, so the mechanical arm cannot be applied in welding the rectangular fillet weld in the steel beam. At present, the rectangular fillet welds are mainly welded by the manual welding. In order to improve the welding quality and efficiency, and enhance the welding automation, it is necessary to research a kind of welding robot with light weight and small size.

3. The structure of the robot and the whole system of fillet weld tracking and welding

In order to make a clear introduction of the internal structure of the robot in Fig. 2, the shell of the welding robot has been removed. Fig. 2(a) is the real figure, and Fig. 2(b) is the schematic diagram.

The welding robot is made up of the left and right wheels, the vertical slider, the horizontal slider, the rotational joint, the arc welding gun with rotating arc sensor, the ultrasonic sensor, the photoelectric position sensor and the universal wheel. The ultrasonic sensor can measure the distance between the front of the robot and the front steel plate, and it is the linear relationship between the distance and the voltage of the output. The larger the distance is, the greater the voltage of the output will be. When the distance is equal to the set value, the robot begins to track the right-angle fillet weld. The photoelectric position sensor consists of the photoelectric switch and the reflector plate, and the photoelectric switch can send and receive light. The reflector plate is fixed to the horizontal slider, and it will also move when the horizontal slider moves. When the horizontal slider is in the initial position, the photoelectric switch can receive the light reflected by the reflector plate, and the photoelectric position sensor will output a signal. Extension or indentation of the horizontal slider can be identified by using the photoelectric position sensor and the movement speed of the horizontal slider. Rectangular fillet weld tracking can be realized based on the coordinated movement among two wheels, the horizontal slider and the vertical slider. In Fig. 2(b), the equivalent link coordinate systems of the wheeled mobile robot have been built, and the principle of each coordinate system will be introduced in Section 5.1.

Fig. 3 is the whole system of tracking and welding during gas metal arc welding process, and the whole system includes the welding system and the welding seam tracking system. The welding system mainly

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