ARTICLE IN PRESS

Optics and Laser Technology xxx (xxxx) xxx–xxx

Contents lists available at ScienceDirect

Optics and Laser Technology

journal homepage: www.elsevier.com/locate/optlastec

Full length article

A precise seam tracking method for narrow butt seams based on structured light vision sensor

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HIGHLIGHTS

- The structured light vision sensor could acquire image including narrow butt seam.
- The structured light vision sensor could achieve narrow butt seam detection.
- The seam tracking of narrow butt seam in both X and Z directions could be realized.
- The seam tracking accuracy could meet the requirement of narrow butt welding.

ARTICLE INFO

Keywords:
Seam tracking
Structured light vision
Narrow butt seam
Image processing
Fuzzy-PID controller

ABSTRACT

At present, most popular approaches of seam detection are based on structured light vision sensors owing to features of high accuracy and robustness. However, the deformation of laser stripe is not obvious enough when it is projected onto narrow butt seam, whose width is less than 0.2 mm, so the traditional structured light vision sensor cannot detect the seam feature of narrow butt seam. In this paper, a precise seam tracking method for narrow butt seams based on structured light vision sensor is proposed. Firstly, a new structured light vision sensor with optical filters and an extra LED light is developed to filtered out most of noises from strong arc lights and acquire the image including laser stripe and narrow butt seam. In addition, an image processing method for the vision sensor is designed to obtain welding torch deviations of narrow butt seams both in horizontal and vertical directions. Based on the obtained deviations, two independent Fuzzy-PID controllers are designed to achieve seam tracking control accurately. Finally, in order to verify the effectiveness of the proposed method in this paper, a welding experimental system is setup and welding experiments are carried out. Experimental results demonstrate that this method can meet the requirement of narrow butt seams tracking accuracy.

1. Introduction

At present, the application of industrial robots has developed rapidly in the welding process. However, majority of them belong to teaching-and-playback robots. They have two serious shortcomings. On the one hand, they need lots of teaching time reducing the work efficiency. On the other hand, the seam position often varies due to thermal deformation and inconsistency of welding gap. The teaching-and-playback robots move along the recorded path and they cannot self-rectify torch position leading to low welding quality.

In order to overcome above-mentioned shortcomings of teaching-and-playback robots, lots of seam tracking methods have been proposed. The seam tracking method contains two primary technologies including sensing technology and motion control technology. In the past few decades, many different sensing methods have been used in seam tracking systems including ultrasonic sensing [1], inductive sensing [2], arc sensing [3], laser displacement sensing [4] and magneto optical sensing [5]. In recent years, vision sensors have attracted much attention owing to features of high accuracy, non-contact and abundant information [6–13]. The vision sensor mainly consists of two types: active vision and passive vision. Structured light vision regarded as a typical representative of active light vision is widely employed because of the features of monochromaticity and anti-interference of the laser light. At present, many structured light vision sensors have been designed by Meta Vision and Servo Robot. The principle is that the laser stripe is projected onto the work-piece and the deformation of laser stripe appears in the welding groove. However, the deformation of laser stripe is not significant enough when it is projected onto narrow butt

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https://doi.org/10.1016/j.optlastec.2018.08.047
Received 23 February 2018; Received in revised form 26 June 2018; Accepted 29 August 2018

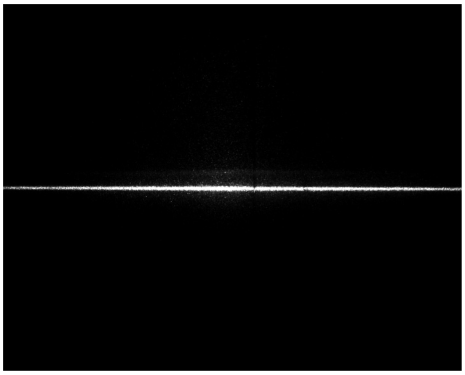

Fig. 1. The captured image of a narrow butt welding seam with a laser stripe.

seam, whose width is less than 0.2 mm, as shown in Fig. 1. Therefore, traditional structured light vision sensors without extra LED light are not applicable in narrow butt detection. In order to achieve narrow butt detection, many other visual methods based on passive vision are proposed [14–17]. However, these methods using monocular vision can only achieve seam tracking in the horizontal direction. Fang et al. [18] proposed a method, which combines natural light with structured light to measure the torch deviation in the horizontal and vertical directions. However, the structure light was only used to detect the torch deviation in vertical position. Meanwhile, this system lacks robustness and easily be interfered by arc lights, because the natural light is adopted. Wang et al. [19] proposed a narrow butt seam detection method based on narrow depth of field lens in laser welding. Measurement accuracy for the seam width and seam position were 6 μm and 8 μm, respectively. However, the cameras field of view was 1.3 mm^2, which limited its application in industry.

There are two types visual control methods including image-based visual servoing (IBVS) and position-based visual servoing (PBVS) [20]. For the IBVS, the visual control precision depends on image Jacobi matrix and image Jacobian matrix may be singular, so inverse Jacobian matrix cannot be obtained to achieve control. In addition, the image feature selection has obvious influence on seam tracking effect. What's more, in order to get depth information, the camera calibration and hand-eye calibration is also needed the same as PBVS method. The PBVS achieves three-dimensional (3-D) reconstruction and designs controller in 3-D space. Because its control method is simple, the PBVS method is used to achieve narrow butt seams tracking.

Due to the nonlinear and time-varying characteristics of welding process, the traditional control method is difficult to achieve satisfactory results for the seam tracking. Therefore, many intelligent control methods are proposed for seam tracking. Gu et al. [21] designed a Fuzzy-P controller to achieve welding seam tracking control accurately. The Fuzzy-P controller contained fuzzy controller and proportion controller. The fuzzy controller was used for small offset and the proportion controller was used for large offset. However, the threshold of switching between fuzzy controller and proportional controller needs to be determined by lots of experiments, and the switch between fuzzy controller and proportion controller will cause dithering. In [22], a neural network was used to establish the nonlinear relationship between the change of the characteristic point of the laser stripe and the adjustment of the cross adjustment axis, and the output of the neural network was used to design the controller directly in the fillet weld seam tracking system. However, the neural network controller needs a lot of data for off-line training before it can be used to control. Luo et al. [23] presented a comprehensive control method to get a high tracking precision in the robotic welding process including predictive control method and iteratively learned feedforward compensation method. However, the algorithm of this controller is complex and has high-computational cost. In order to overcome the above-mentioned challenges, a precise seam tracking method for narrow butt seams based on structured light vision sensor is proposed. Firstly, a structured light vision sensor with optical filters and an extra LED light is designed to filtered out most of noises from strong arc lights and acquire the image including laser stripe and narrow butt seam. Secondly, an image processing method is designed to eliminate disturbances of the noises such as splashes and fumes and extract feature point accurately and robustly. Finally, Fuzzy-PID controllers are designed to achieve seam tracking control based on the welding torch deviations in both horizontal and vertical directions which are obtained by optical triangulation method of structured light.

As is known to all, optical triangulation method based on structure light is conventional method for 3-D measurement, so the 3-D measurement for weld seam based on structure light is not the innovation and focus of this paper. Instead, the main contributions of this paper are two aspects. On the one hand, a structured vision sensor with optical filters and extra LED light is designed to acquire the welding image including laser stripe and narrow butt seam, and achieve narrow butt seam detection, which are hard for traditional structured vision sensors. On the other hand, the developed structured vision sensor can simultaneously realize the seam tracking for narrow butt seams in both horizontal and vertical directions, comparing with the traditional vision-based narrow butt seam tracking systems which can only achieve narrow butt seam tracking in horizontal direction.

The rest of this paper is organized as follows. Section 2 introduces experiment system, vision sensor and vision model. Section 3 describes image processing and feature verification methods. Section 4 proposes the control method to achieve seam tracking. Section 5 presents the experiments to verify the performance of this system. Finally, the conclusion is provided in Section 6.

2. System description and vision model

2.1. Experiment system

The experiment system mainly contains an adjusting mechanism, a vision sensor, a main computer, a PLC and the welding device, as shown in Fig. 2. The adjusting mechanism consists of horizontal axis and vertical axis. They are used to adjust torch position in the horizontal and vertical directions, respectively. The vision sensor mainly contains an industrial camera, a laser emitter, corresponding optical filters and a LED light source. The vision sensor is mounted in front of the torch about 120 mm. The laser emitter projects a laser stripe onto the workpiece. A narrow-band filter and a dimmer glass are installed ahead of the focus lens. The main computer runs feature extraction algorithm and get the deviations. The deviations calculated by main computer are sent to the PLC by using RS232 port. The PLC receives deviations and outputs pulses to rectify torch position. The welding device is composed of welding torch, welding source and wire feeder.

The coordinate frame establishment in our system is shown in Fig. 2.

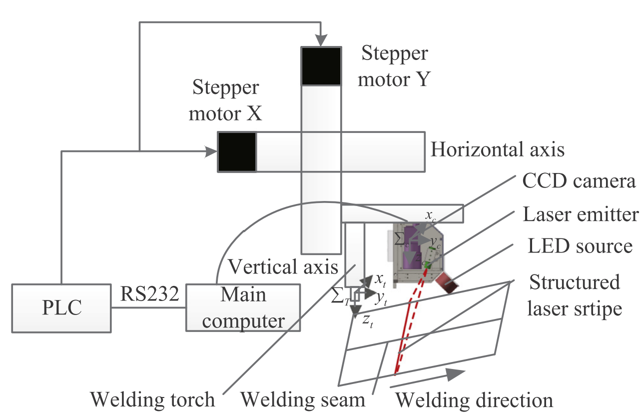

Fig. 2. The schematic diagram of the seam tracking system.