Optics and Laser Technology 99 (2018) 39–51

Contents lists available at ScienceDirect

Optics and Laser Technology

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

A novel weld seam detection method for space weld seam of narrow butt joint in laser welding

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ARTICLE INFO

Article history:
Received 12 May 2017
Received in revised form 1 September 2017
Accepted 20 September 2017
Available online 7 October 2017

Keywords:
Structure light
Vision sensor
Seam detection
Butt joint
Laser welding

ABSTRACT

Structured light measurement is widely used for weld seam detection owing to its high measurement precision and robust. However, there is nearly no geometrical deformation of the stripe projected onto weld face, whose seam width is less than 0.1 mm and without misalignment. So, it's very difficult to ensure an exact retrieval of the seam feature. This issue is raised as laser welding for butt joint of thin metal plate is widely applied. Moreover, measurement for the seam width, seam center and the normal vector of the weld face at the same time during welding process is of great importance to the welding quality but rarely reported. Consequently, a seam measurement method based on vision sensor for space weld seam of narrow butt joint is proposed in this article. Three laser stripes with different wave length are project on the weldment, in which two red laser stripes are designed and used to measure the three dimensional profile of the weld face by the principle of optical triangulation, and the third green laser stripe is used as light source to measure the edge and the centerline of the seam by the principle of passive vision sensor. The corresponding image process algorithm is proposed to extract the centerline of the red laser stripes as well as the seam feature. All these three laser stripes are captured and processed in a single image so that the three dimensional position of the space weld seam can be obtained simultaneously. Finally, the result of experiment reveals that the proposed method can meet the precision demand of space narrow butt joint.

1. Introduction

Laser welding is a very promising welding method in terms of high energy density, narrow HAZ, low shape distortion of components, and high welding speed, which is one of the most important implementation of laser technology. As a result of the development of high power lasers as well as the improvement of the optical fiber transmission technology for laser beam, recent years have seen a tremendous growing of laser welding in automotive industry, shipping industry, and aircraft industry.

It is difficult for traditional welding method to weld materials with high hardness, high melting point, or high brittleness. On the contrary, laser welding has the characteristics of non-contact, deep penetration, high precision, flexible, and compatible with complex shapes of all sizes that it is especially suitable for materials such as TC4 in aircraft industry. As a result, the increase of laser welding for rocket motor nozzle, skin structure and inlet structure in aircraft industrial is especially noticeable. However, as compared to traditional welding methods, laser welding demands stricter assembly quality. Moreover, aircraft industry gives top priority to the weight that many of its structures are made of titanium alloy sheet with thickness less than 2 mm. That means the seam of the butt joint is very narrow and without misalignment that the seam feature is difficult to be extracted by an ordinary vision sensor based on optical triangular principle.

As for butt joint formed by metal sheets with thickness of 0.2 mm, both gap and misalignment of its seam should be less than 0.1 mm at the assembling stage [1]. To ensure welding quality, the laser beam focus should follow the seam center exactly and there should be appropriate defocus amount during laser welding process. At the same time, welding speed and welding power should be adjusted according to the seam width. Especially, as the diameter of the laser beam focus is about 0.3 mm, the offset between the laser focus center and the weld seam center should be less than 0.1 mm. Otherwise, it may cause asymmetric heat source along the weld seam center line, which may result in poor welding quality or even welding failure. Meanwhile, to obtain a better welding quality, there should be appropriate angle between the laser optical axis and the normal vector of the weld face [2–4]. In a word, the weld seam center, seam width and the normal vector

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https://doi.org/10.1016/j.optlastec.2017.09.037
0030-3992/

of its local weld face should be precisely measured before we can get satisfactory welding result.

Generally, there are apparent imaging features in the weld joint when laser structure light is projected on weld face. In addition, much of the noise light caused by welding could be eliminated by optical filter, which makes this measurement very precise and robust. This is the reason that laser structure light has been widely used in seam measurement for laser welding [5]. In literature, there are numerous researches on weld seam measurement by using structure light. Among them, the detection of the butt joint with V-shaped groove or T-shaped groove by structure light are very success because the projected structure light get bended in the weld joint. The bended structure light forms very apparent imaging features, which can be easily detected, makes the vision measurement very effective.

As for V-groove butt joint, a new image process algorithm consisting of particle filtering and self-adapting dynamic window was proposed by Tao et al. for this kind of joint, which was very robust in very hostile welding environments [6]. Wu et al. introduced a modified Hough algorithm for image process in weld seam tracking for V-groove butt joint [7]. He et al. proposed a seam extraction algorithm based on orientation saliency for V-groove butt joint [8]. Prasarn Kiddee et al. used cross mark structured light to detect V-groove butt joint [9]. A modified template matching method was used to detect the edges of V-shaped groove, which greatly reduced computational cost in image process.

As for T-shape weld joint, Huang et al. used structure light based vision sensor to detect weld seam in a dual laser welding system for T-joint in aircraft industry [10].

Not only that, laser structure light based measurement was very suitable for butt joint, whose gap is larger than 0.1 mm. Zhang et al. reported a novel laser vision sensor based on structure light for weld seam detection on wall-climbing robot, which can capture 3D information of the weldment with very low measurement error [11].

However, some noteworthy researches [14,15] indicated that laser structure light was ineffective for narrow butt joint, especially those whose gap is smaller than 0.1 mm.

In order to tackle this problem, passive light vision technology was adopted instead of structure light based vision sensor, in which images were captured by using arc light or auxiliary light source. Xu et al. tried to solve the seam tracking problem for butt joint arc welding of metal sheet by using passive vision system [12]. To avoid processing images with too much noise, an image selecting method was investigated. The seam position precision range was controlled to be within ±0.3 mm, which was obtained by an improved Canny edge detection algorithm. Fang et al. developed a visual seam tracking system for butt weld of thin plate [13]. The seam was too narrow to be detected by the structure light that the seam position in horizontal direction was extracted from images captured on natural lighting. The Structure light was only used to detect the seam position in vertical position. The seam tracking accuracy of the system in horizontal and vertical directions were 0.2 mm and 0.1 mm, respectively. Due to the same reason, Chen et al. did not used structure light to detect narrow seam [14]. Instead, they presented a vision sensor system consisting of a CCD camera and a white light-emitting diode (LED) light source, which is mainly used to detect narrow seam whose width is generally less than 0.2 mm. Since there were sparks and fuming during welding process, the captured images in this way contained too much noise. So, a set of feature extraction algorithms, such as profile extraction, Hough transform, and least-square fitting, were employed to extract weld seam. Gao et al. aimed at detecting narrow butt weld by using a magneto-optical sensor [15]. It was also argued that this kind of weld joint was too narrow to measure by structure light. However, his method was only applicable to magnetic materials.

Most recently, Wang et al. developed a set of seam measurement system, which used multiple optical magnifier to detect narrow weld seam [16]. Measurement accuracy for the seam width and seam position were 6 μm and 8 μm, respectively. But, the field of view was 1.3 mm^2, which made its application very limited. Particularly, weld seam detecting sensors produced by companies, such as Meta Vision Systems Ltd, were widely used in industry field. Nonetheless, as for butt joint, these vision sensors were ineffective when seam gap was less than 0.1 mm.

On the one hand, vision system based on passive light sensor can obtain more seam feature, which is beneficial for the measurement of narrow butt joint. On the other hand, it's very sensitive to light noise during welding process. On the contrary, vision system based on active light sensor can eliminate much of the light noise by adopting optical filter and it's more suitable for three-dimensional measurement such as normal vector measurement of the weld face. But, as the weld gap is less than 0.1 mm, the projected structure light deforms slightly around the joint that it is hard to extract the seam position.

Therefore, a novel seam measurement system, which effectively combines the superiority of passive light sensor and active light sensor, is designed in this article. Three laser stripes are used to detect the weld seam in this measurement system. Two of them are for three-dimensional measurement purpose, which are used to get normal vector of local weld face by measuring the profile of the weld face; one of them is used for two-dimensional measurement purpose, which is used as light source to extract weld seam edge.

It's well known that optical triangulation method based on structure light is very applicable for three-dimensional measurement. In addition, it's very feasible to extract weld seam edge according to difference in gray value by two-dimensional image measurement. Applying structure light based three-dimensional measurement or two-dimensional image measurement for weld seam detection is not new idea and not the focus of this article. Instead, the contribution of this article is the combination of the two methods, in which the proposed vision sensor can detect narrow butt joint with seam gap less than 0.1 mm. The contribution of our system lies in the following two aspects:

1. It provides an effective vision sensor to measure butt joint with no misalignment and width less than 0.1 mm by combining traditional methods.
2. Weld seam width, seam center and normal vector can be obtained in a single image by one measurement.

As the popularization of laser welding technology, and the harsh assembling precision requirements and strict weld torch position control demands, the demand for high precision weld seam detection technology grows daily. The proposed method is not only applicable for butt joint in aircraft industrial but also can meet butt joint detection requirements in other industrial applications.

2. Experiment setup

2.1. Task analysis

The seam measurement principle of traditional optical triangulation by structure light is shown in Fig. 1. The shape, position and gray value of the laser stripe would be changed when projected on the groove or gap of the weld face. Then, the seam width and seam