Journal of Manufacturing Processes 24 (2016) 19–30

Contents lists available at ScienceDirect

Journal of Manufacturing Processes

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

A visual weld edge recognition method based on light and shadow feature construction using directional lighting

Jinle Zeng, Baohua Chang, Dong Du*, Yuxiang Hong, Yirong Zou, Shuhe Chang

Key Laboratory for Advanced Materials Processing Technology, Ministry of Education, Tsinghua University, Beijing, China

ARTICLE INFO

Article history:
Received 20 June 2016
Received in revised form 17 July 2016
Accepted 20 July 2016

Keywords:
Weld recognition
Visual detection
Directional lighting
Light and shadow feature
Image Processing

ABSTRACT

For the efficient and effective detection in automatic non-destructive testing (NDT) of weld defects, the NDT probe must stay aligned with the welds. It is essential to detect the deviation between the seam and the probe by means of weld recognition, in order to adjust the relative position between the workpiece and the probe. The traditional weld recognition method is suitable for real-time seam tracking when the geometric feature of the groove is distinct; however, it may fail when applied to the formed weld recognition. Other methods proposed by researchers are unsatisfactory in the signal-to-noise ratio of imaging, separation degree of visual features and efficiency of the processing algorithm. To solve these problems, this paper proposes a novel visual weld recognition method using two directional lights. The directional lights are projected onto the edges of the seam to produce the distinct man-made "light and shadow" (LS) features. In this paper, we first study the principles and sensing requirements of the LS features; then a stroboscopic circuit is established to lighten the two directional lights alternatively and meanwhile synchronizes the camera to capture images when each light is on. Afterwards, we propose an image processing algorithm based on thresholding and edge extraction to calculate the accurate edges of the seam. Finally, a weld detection platform is established and experiments on weld recognition and deviation correction are conducted. The experiment results show that the proposed detection method can recognize the edges of the seam effectively in 0.023 mm accuracy. The time cost of the image processing algorithm is not more than 13 ms. The proposed method is suitable for weld detection where the reinforcements of the seams are as low as 1 mm. It expected to be applied to the automatic vision-guided NDT of weld defects.

1. Introduction

In non-destructive testing (NDT) of weld defects such as radiographic, ultrasonic and eddy current testing, it is necessary to keep the NDT probe aligned with the detected welds during the whole testing process. For effective and reliable flaw detection, it is important to first achieve accurate positioning and automatic guiding of the probe [1,2]. Fig. 1 shows the ultrasonic testing worksite of natural gas spiral welded pipe. The pipe will rotate and the probe will move along the axis of the pipe at the same time during a continuous testing task. However, due to the movement deviation, dimensional variation, assembling error and thermal deformation of the workpiece, the seam may be out of the detecting range of the probe. The deviation between the seam and the probe has to be corrected manually at present. It is critical in the automatic NDT field to recognize the edges of the seam, calculate the trace and deviation of the seam effectively, adjust the relative position between the workpiece and the probe, and finally always keep the probe aligned with the seam. Automatic weld recognition is significant in improving the efficiency, accuracy and reliability of the testing task [3–5].

Compared to detection methods like mechanical, arc and sound sensing, visual weld recognition has become a research hotspot in automatic weld detection field due to its abundant information, non-contact with the workpiece and high precision. At this time, structured light detection is the most widely used visual recognition method in industry [6–8]. There have been lots of practical structured light sensors developed by companies such as Meta Vision, Servo Robot and Scansonic as shown in Fig. 2. A laser stripe is projected onto the groove and the distortion of the stripe mirrors the geometric difference between the groove and the base metal [9]. This method is applicable in real-time seam tracking during welding, where the geometric feature of the groove is distinguished from the base metal as shown in Fig. 3(a). These structured light

* Corresponding author. Tel.: +86 1062783387.
E-mail address: dudong@tsinghua.edu.cn (D. Du).

http://dx.doi.org/10.1016/j.jmapro.2016.07.002

Fig. 1. Ultrasonic testing of the spiral welded pipe.

sensors have been successfully applied to the seam tracking fields of multiple joint settings, such as butt joint, lap joint, T joint, corner joint, coach joint, etc. However, it may fail in the formed weld detection, where the distortion of the stripe nearly vanishes as shown in Fig. 3(b) since the geometry of the seam is close to that of the base metal. Therefore, the applicability of the structured light method is doubtful in the field of formed weld detection.

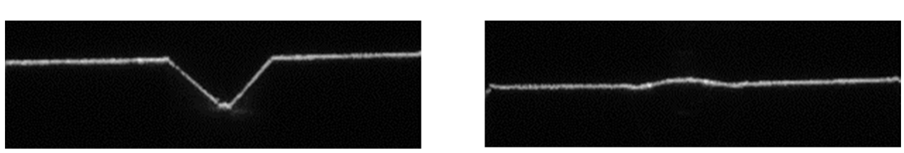
Besides the structured light detection method, researchers have proposed many other recognition methods based on various visual features: Shao et al. [10] used the quadratic curve fitting method and analyzed the multi-order differences of the intensity profile to extract the weld region in X-ray radiographic testing; Sun et al. [11] proposed a color image processing method to distinguish the seam and the base metal based on morphological gradient, eliminating the interference from arc light and spatters in GMAW weld images; Zou et al. [12] applied the color space conversion to the RGB image of the weld to produce a high-contrast image, achieving a reliable recognition of milled welds with zero reinforcement; Zhang [13] combined the grayscale gradient operators and genetic algorithm to calculate the edge positions of the seam in low signal-to-noise ratio images; Dang [14] developed a thresholding method using OTSU and improved genetic algorithm, realizing a fast and effective segmentation of the weld images; Zeng et al. [15] characterized the seam and the base metal with invariant moments and used an adaptive thresholding method to detect the accurate edges of the seam; Deng et al. [16] proposed a weld detection method using Beamlet transform to obtain the edges of the seam; Zou et al. [17] created a textural feature template to match the edges between the seam and the base metal; Zou et al. [18] developed the textural template matching method with Isomap algorithm to create a more reliable seam template; Kramer et al. [19] analyzed the textural differences between the two-sided base metal in laser welding and then proposed a weld recognition method based on texture gradient; Zou et al. [20,21] applied Haralick texture method to weld detection and found that the Haralick texture features (such as textural energy, entropy and contrast) are distinct between the seam and the base metal.

The recognition method above often requires a grayscale or color weld image captured in uniform lighting conditions. Certain features are calculated to highlight the grayscale/color distribution differences between the seam and the base metal or a thresholding method is applied to image segmentation. Fig. 4 shows a typical grayscale image of the SAW weld. The grayscale distribution of the seam and the base metal is very close. Those methods are not suitable for weld detection when the grayscale/color distribution differences between the seam and the base metal are not clear. Moreover, many methods are unsatisfactory in signal-to-noise ratio of imaging and separation degree of visual features, which may subsequently lead to a complex and time-consuming image processing procedure. It is critical to develop a proper sensing method to distinguish the seam and the base metal based on their differences in reflection characteristics and grayscale distributions. This paper will focus on a sensing and weld detection method, in which a man-made clear visual feature is constructed to highlight the edges between the seam and base metal.

The rest of the paper is organized as follows. Section 2 will propose a novel detection method based on "light and shadow" feature construction using directional lighting. The principles and procedures of the detection method will be explained in detail. Section 3 will introduce a real-time algorithm to detect the edges of the seam in the images captured by our method. In Section 4, experiments will be carried out on the established weld detection platform. The software flow and controller design of the established platform will be illustrated before the experiments. The efficiency and accurateness of the proposed method will be evaluated by experiment results. Finally, conclusions are given in Section 5.

(a) Meta Vision sensor (b) Servo Robot sensor (c) Scansonic sensor

Fig. 2. The structured light detection sensors developed by companies.



(a)Before welding (b)After welding

Fig. 3. Evolution of the laser stripe distortion.