Efficient Weld Seam Detection for Robotic Welding from a Single Image

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Abstract. The weld seam recognition is a key technology in robotic welding. This paper presents an efficient algorithm of weld seam detection for butt joint welding from a single image. The basic idea of our approach is to find a pair of weld seam edges in the local area first. Then, starting from the two endpoints of each edge, search for the remnant edge by iterative edge detection and edge linking. This method is insensitive to the variance of the background image and can apply to most type of weld seams in butt joint welding. Experimental results on several type of weld seam images are shown.

1 Introduction

With the development of robotized welding, improving intelligence and autonomy of arc welding robots is becoming one of the main research directions in the area of industrial robots [1]. To this aim, one should solve the problems of functional sensors and effective information acquisition methods. As a result, weld seam detection with high precision gained increasing importance in automated plants and has made many achievements.

In early period, Estochen et. al.[2] used ultrasonic sensor for weld seam detection. However, there exist many difficulties when ultrasonic sensor worked in real application. Arc sensor has good recognition ability for weld seam [3], but it hard to detect the weld seam when the groove is not so big. Vision sensor technology has been widely applied in welding industry due to plentiful information. Some approaches, such as laser scanning [4], structured light [5] or infrared technology [6], need active lighting device. Recent decade, some researches focus on the vision system for weld seam recognition and tracking in natural lighting conditions [7-8], but the arc disturbance and surface noise still have great influence during this process. To solve this problem, one can make trajectory preplanning of the weld seam before welding.

Zhang et. al. [7] proposed a recognition method of weld seam trajectory based on image pattern feature. The algorithm divides the weld seam into many sections and describes each section with a feature vector. It recognizes the weld seam by comparing the similarity between the current feature vector and former feature vector iteratively. This method has the advantage of fast speed and can perform exact tracking, however, it assumes that the initial position of the seam was given in advance. Ref. [8] implemented weld seam detection at sub-pixel precision by using Zernike moments, but it can only deal with those weld seam with parametric shape. Other ways of weld seam detection include Wavelet, Kalman Filtering [9] etc.

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In this paper, we address the problem of weld seam trajectory preplanning from a single image and propose an autonomous recognition algorithm. The basic idea of our approach is to find a pair of parallel weld seam edges in local area first. Then, starting from the two endpoints of each edge, search the remnant edge by iterative edge detection and edge linking in a shift window.

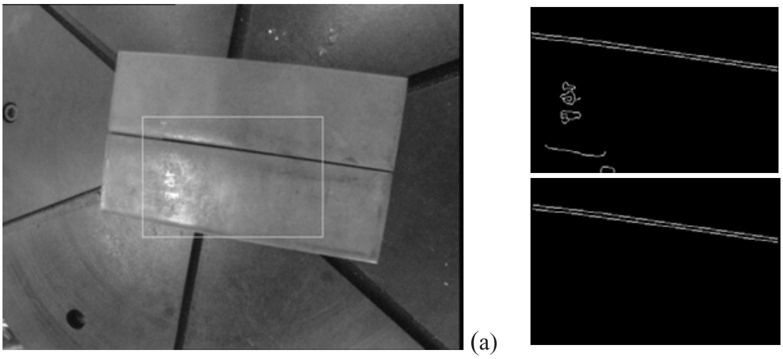
2 Algorithm of Welding Seam Detection from an Image

In the image of work-piece for butt-welding, the weld seam shows as a low gray strip with two parallel edges. The basic steps of our approach include: (1) find a pair of parallel weld seam edges in local area; (2) starting from the two endpoints of each edge, iteratively search the remnant edge by a shift window; (3) refine the seam endpoint by corner detection. More specifically, our approach proceeds as follows:

2.1 Edge Detection of Weld Seam in Local Area

The first step of our approach is to find a pair of parallel weld seam edges locally. Without loss of generality, we suppose that the weld seam pass by a predefined rectangular area in the central image, which is easy to fulfill in practice. See Fig. 1, 1a is the whole image of a line weld seam and the rectangular area.

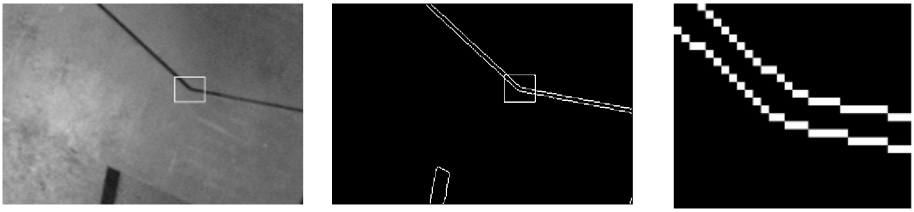
Firstly, we use edge detection method to extract the edge information of the local image. Numerous edge detection techniques have been proposed (see [10][11] to cite a few). Among them, Canny operator [10] and its variations are the most popular edge detection approaches. In this paper, we use Canny operator to get the edge image I_0, see Fig. 1(b). Note that this process only deals with a local image. Although Canny is a little more complex than many other edge detection operators, it is still efficient relative to the whole image and the computation cost can be ignored here if the window is small enough.



(a) (b) (c)

Fig. 1. Welding seam edge detection in the central image area. (a) the whole weld seam image with a white rectangular frame which denotes the predefined window; (b) edge image in the rectangular area; (c) weld seam edge, which is extracted from (b).

Then, we concentrate on the post-processing of the edge image I_0, which aims to extract the weld seam edge and remove the non-interest edges. To reach this aim, we should make clear the characteristics of the weld seam image first. As we know, any weld seam has two parallel edges with limited gap in butt-welding, even for kink line weld seam whose edges also parallel to each other locally, see Fig.2. In addition, the mean gray-level of the weld seam area is lower than those pixels on the edge. This leads to the following algorithm for extracting weld seam edge from the acquired edge image.



(a) (b) (c)

Fig. 2. Kink line welding seam. (a) original image; (b) edge image of (a); (c) local details about the edge of kink mark in (b).

Algorithm 1 (Extracting weld seam edge from binary edge image)

1. Remove the edge pixels on the borderline area of the image;
2. Do { If (current pixel is labeled or equal to 0) , go to next pixel;
If (no 8-neighbor pixel equal to 1)
Then, reset this pixel to 0 and go to next pixel;
If (current edge pixel satisfy that: (1) there exist edge pixel(s) lies within the given range in the normal direction of the current edge; (2) the mean gray-level of the pixels within the above two edge pixels is lower than the edge pixels)
Then, label current edge pixel as weld seam edge pixel and continue to search along the current edge
Else, reset current edge pixel to 0;
Go to next pixel;
}Untill (end of image)
3. Count the length of each connected edge; the two edges with maximal length are taken as the weld seam;
4. Trim the data of weld seam to remove the redundant edge pixels.

Fig.1(c) is the result of Fig.1(b) by using Algorithm 1. We may also apply the above process to the later iterative procedure to find the remnant weld seam edge.

2.2 Extract the Remnant Weld Seam Edge

Once a pair of weld seam edges is obtained, we can try to extract the remnant weld seam edge starting from each endpoint of the acquired edge respectively. We use a shift window to carry this operation. The window moves along the direction of the seam edge. In each position, we use Canny operator to get the edge image of the window and Algorithm 1 to extract the weld seam edge from the local edge image. Finally, link the obtained edge segment to the former weld seam edge. Iteratively perform the above steps until the window reaches the end of the weld seam. More specifically, this process can be described as the following algorithm:

Algorithm 2 (Extracting remnant weld seam edge by using a shift window)

1. *Compute the edge direction of the obtained weld seam at the endpoint, which is used as the moving direction of the shift window;*
2. *Compute the future position of the shift window;*
3. *Make edge detection by Canny operator in the shift window;*
4. *Extract the weld seam edge segment from the edge image by Algorithm 1;*
5. *Link the edge segment to the former weld seam;*
6. *Judge whether the searching is finished according to the distance between the segment endpoint and window boundary. If not finished, then go to step 1.*

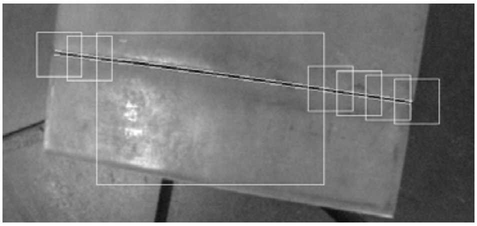


Fig. 3. An illustration of shift windows for edge detection and linking

The above process need to be carried at the two endpoint of the weld seam respectively, thus we can get the whole weld seam edge. Fig. 3. illustrates the shift windows for edge detecting and edge linking.

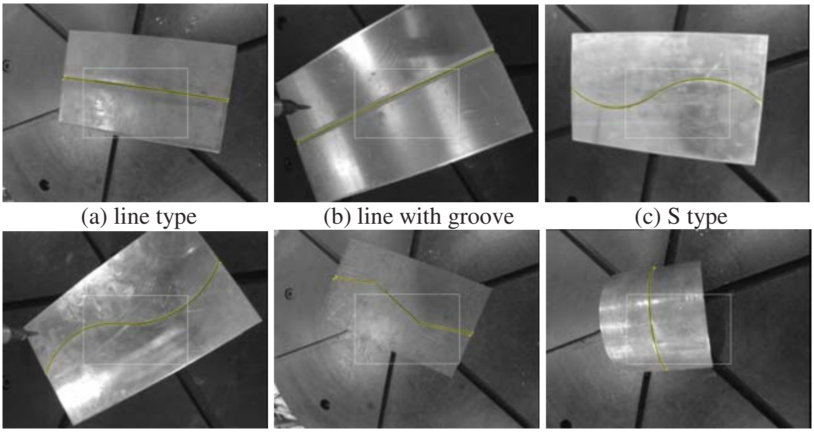
2.3 Refine the Endpoint of Weld Seam

Since the whole weld seam edge is extracted, the endpoints of the weld seam are known. However, these endpoints are extracted by edge detector, thus they may not be the accurate corner position. In this paper, we use the classical Harris corner detector [12] to find the accurate weld seam endpoint.

The corner detection is only performed in the last shift window in Algorithm 2. There maybe exist several corners in the detection results. We chose two corners, which are closest to the pre-acquired endpoints, as the object endpoints. Once the endpoints of the weld seam are located, we can directly link the endpoints to the obtained weld seam edge.

3 Experimental Results and Discussion

We test the algorithm on several type of weld seam to evaluate its practical performance. We adopt CCD camera (Watec-902H) in the experimental system and the image size is 768*576. We set the size of predefined window to be 300*200 and the shift window 60*60. Fig. 4 shows the results of applying our algorithm on different type of weld seam. In the result images, yellow curves represent the extracted weld seam, and the yellow mark "+" represent the detected seam endpoints by corner detection. From the result we can see that the proposed method is suitable for most type of weld seam in butt-welding. However in some cases, there is only one corner detected near the endpoint of the weld seam, and some detected endpoints are not so accurate in terms of human experience. On one hand, it is due to the limitation of the corner detection algorithm; on the other hand, the angle of view or blurry image quality affects the detection to some extent. Anyway, we can take the detected seam endpoints as a reference to adjust the angle of view of the robot, so as to locate the initial welding position accurately.



(a) line type (b) line with groove (c) S type

(d) S type with coarse surface (e) kink line type (f) space curve

Fig. 4. Experimental result of different type of welding seam, the welding seam edge and endpoint are labeled with yellow line and yellow mark "+" respectively

Note that, the size of predefined window will affect the working efficiency in real application. Larger the window is, more convenient the worker feel in operation, however, more risk for seam edge detection. So, there must be a trade off consideration between the convenience and the risk of image processing.

Although it is effective in most cases, the proposed method can not work when the reflection of the work-piece is strong enough to submerge the weld seam in the image. Therefore, more robust algorithm is in need to be developed.

4 Conclusion

This paper presents an efficient and practical algorithm of weld seam detection for butt joint welding. Given a single image, one can find a pair of weld seam edges in the local area first. Then, starting from the two endpoints of each edge, search for the remnant edge by iterative edge detection and edge linking. This new approach offers three important technical advantages over previously known solutions to weld seam detection: a). It can detect both the weld seam and the endpoint from a single image automatically; b). It applies to most type of weld seam in butt joint welding, including any shape of planar curve and space curve; c). As all the steps operate locally, the algorithm is insensitive to the variance of the background image, and decreases the computation cost greatly. Experimental results show that it can apply to most type of weld seams in butt joint welding.

Acknowledgements

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