Feature point extraction based on contour detection and corner detection for weld seam

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Abstract. In an arc welding robot system with vision sensor, the extraction precision of the weld seam position has an important effect on welding quality. However, due to disturbances such as camera resolution, scanning posture, reflections, etc., it is a great challenge to identify weld seam accurately. In this paper, weld seam is considered as a special curve which consists of feature points, based on that, an effective method is proposed to extract the feature points by using contour detection and corner detection. Experiment results show that feature points can be extracted successfully by using this method, so that the robot can weld the work part along the feature points detected. The limitation of this method is that the detected feature points are sometimes inconsistent with the weld center points, which may affect the welding quality.

1. Introduction
Welding is one of the most important parts of industrial automated manufacturing. However, due to the harsh working environment and conditions, manual welding is inefficient and unstable [1-4]. Therefore, improving the automation of welding has become a hot topic. Against this background, welding robots have already started replacing humans.

There are many problems for a welding robot to overcome a welding work. In the past, industrial arc-welding robots were operated by teaching-programing of human operators, which took a great amount of time and expense to program paths and redefined welding parameters for each new workpiece [5-7]. With the developments of sensors technique, information acquisition technique and modern manufacturing, automatic welding is becoming increasingly popular. The detection and identification of weld seams is an important prerequisite of automatic welding process and also the key to improve welding quality. Hence, in order to accurately identify weld seam and extract weld feature point, effectively control the welding process, structured light vision techniques have been widely used in welding automation.

Since the structured light vision sensor is able to provide abundant information of work-piece, such as the profile and shape of a joint, it has become increasingly popular for welding-seam-tracking system [8-10]. Therefore, the fundamental task in welding system based on structured light vision sensors is accurate localization of welding seam in the obtained images. Sicard and Levine developed a string representation and recognition method for classifying three different types of joints detected by laser scanner, i.e., butt joint, lap joint, and V joint [11]. However, this method has low precision of the system if used in the structured-light vision, since it only considers the filter of profile points.
detected by a laser scanner, instead of considering an effective way to avoid the disturbances of noise in the welding image. Then, many researchers extract the weld seam information after a simple denoising process with curve fitting method [12]. Wu et al. extracted the seam of a V groove with its properties and extracted the center line of each segment using Hough transform which improved computational efficiency. However, due to the complexity and uncertainty of welding environment, there are few methods to suit each welding environment.

In this paper, an effective method is presented to extract feature points in consideration of welding part is stainless plane. After the preprocessing of the laser scanning image, several contour detection methods [13-15] can be used to extract the maximal connected domain to determine the contour of the laser stripe. Then, left border of the connected domain can be detected and the right-most pixel on the left border can be determined. After finding the left corner, this corner is taken as a reference point to set a region of interest (ROI). In this ROI, the nearest pixel point from the right border to the left corner can be extracted, define this point as the right corner. The effectiveness of the novel method is tested through experiment. The whole flowchart of the new method is given in figure 1, which will be explained with details in the later sections.

Figure 1. Flowchart of extracting feature point.

The paper is organized as follows: The structured light vision model is given in section II. In section III, the new method was proposed to extract feature point based on contour detection and corner detection. Experiment results are given in section IV. Finally, in section V, conclusion is given.

2. Structured-light vision model
A structured-light vision sensor system is mainly composed of the camera, laser, optical filter, and dimmer glass.

Figure 2. Structured-light vision model.
In figure 2, $W$ is the world coordinate system, $H$ is the welding torch coordinate system, $C$ is the camera coordinate system, and $I$ is the image coordinate system. $P(W_x, W_y, W_z)$ is the intersection of the structured-light plane with the weld seam on welding part, $P(I_u, I_v)$ is the corresponding project point on image. We regard $P(W_x, W_y, W_z)$ as feature point and $P(I_u, I_v)$ is the project point of feature point. The homogeneous transformation $\begin{bmatrix} u \\ v \end{bmatrix} = \begin{bmatrix} A & B & C \\ 0 & 0 & 0 \end{bmatrix} \begin{bmatrix} x \\ y \\ z \end{bmatrix}$ of the camera coordinate system in the welding torch coordinate system can be obtained through eye-hand calibration. The pose of the structured-light plane in the camera coordinate system $C$ is also relative fixed, which may be described as $Ax + By + Cz = 1$, where, $A$, $B$, $C$ are parameters of the structured-light plane. Suppose the intersection point $P(W_x, W_y, W_z)$ in camera coordinate is point $P(C_x, C_y, C_z)$, the coordinate of the project point $P(I_u, I_v)$ can be obtained by obtained image, then, $P(C_x, C_y, C_z)$ can be calculated via the following equation [16]

$$
\begin{align*}
C_x &= \frac{k_y (I_u - I_{u0})}{Ak_y (I_u - I_{u0}) + Bk_y (I_v - I_{v0}) + Ck_y k_y} \\
C_y &= \frac{k_y (I_v - I_{v0})}{Ak_y (I_u - I_{u0}) + Bk_y (I_v - I_{v0}) + Ck_y k_y} \\
C_z &= \frac{k_y k_y}{Ak_y (I_u - I_{u0}) + Bk_y (I_v - I_{v0}) + Ck_y k_y}
\end{align*}
$$

(1)

where the parameters $k_x = f \cdot m_x$, $k_y = f \cdot m_y$ represents the focal length in terms of pixels, $m_x$ and $m_y$ are the scale factors relating pixels to distance and $f$ is the focal length in terms of distance. $I_{u0}$ and $I_{v0}$ represent the principal point of image coordinate. Hence, the coordinate of $P(I_u, I_v)$ in welding torch coordinate system can be obtained through $\begin{bmatrix} u \\ v \end{bmatrix} = \begin{bmatrix} A & B & C \\ 0 & 0 & 0 \end{bmatrix} \begin{bmatrix} x \\ y \\ z \end{bmatrix}$, so that, a feature point on weld image can be expressed by welding torch coordinate to carry out welding works.

3. Feature point extracting

Many disturbances affect the quality of the welding image, such as, reflections, splashes, etc. It is difficult to extract the feature point accurately. Therefore, it is necessary to avoid disturbances by reducing the search range of the laser stripe in the real welding image. A simple method is proposed in this to avoid reflections influenced the extraction of the feature point.

3.1. Image preprocessing and max connected domain

Due to the fact that the weld part is stainless steel plate, the welding image is mixed with some reflection. A preprocessing step to extract maximal connected domain is carried out for the original image to reduce its effects as far as possible.

First, Gaussian filter is used to preprocess the original images in this paper. Second, convert the original image to binary image by using automatic threshold segmentation. Third, find out all connected domain, and then, calculate and compare the area of all connected domains to determine the max connected domain. It purposes to reduce the disturbance as far as possible. The result of image preprocessing is shown in figure 3.

3.2. Extracting the left border and left corner

In section 3.1, the max connected domain has been extracted. This part is aim to extract the left border of max connected domain and its left corner. Since the connected domain consists of pixel points, and every image with $640 \times 480$ pixels, the coordinate of pixel points can be determined. Hence, the extraction of the left border can be sought by seeking the leftmost pixel point of all pixel point in same $I_u$. 

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Figure 3. (a) is the original image; (b) is the binary image; (c) is the maximal connected domain image.

Figure 4. The left border and left corner.

The left border consists of these leftmost pixels, left corner is the right-most pixel point of left border. Thus, extract the left corner by compare $I_v$ coordinate of all leftmost pixels. The left border and left corner are show in figure 4.

3.3. Determine ROI and extracting right corner
In section B, the left corner is extracted. This part aims to extract the right corner.

In order to extract the right corner, near the left corner, set a region of interest (ROI), as shown in figure 5. ROI is a rectangle that contains the right border. Then, extract the right corner of all corners by comparing the Euclidean distance of these corners to left corner.

Figure 5. Region of interest (ROI).

3.4. Extracting the feature point
As mentioned above, the left corner and right corner are extracted. We define feature point is the centre point of the left corner and the right corner. It can be calculated through equation (2).

$$
\begin{align*}
I_u &= (L_u + R_u) / 2 \\
I_v &= (L_v + R_v) / 2
\end{align*}
$$

(2)

where are the image coordinate of feature point, are the image coordinate of left corner and are the image coordinate of right corner.
4. Experiments
In this experiment, the structured-light sensor is composed with lasers, monochrome CMOS camera with USB 2.0 interface, as shown in figure 6. The novelty method is tested on angle welding (welding work-pieces are composed of a 1150-mm-long, 3-mm-thick stainless steel and a 860-mm-long, 3-mm-thick stainless steel). The obtained image including 486 pieces images are shown in figure 7.

![Figure 6. The vision sensor system.](image)

![Figure 7. Parts of obtained images.](image)

![Figure 8. Illustration of feature point extracting.](image)
First, the max connected domain of all images can be searched. Second, all left borders and left corners are extracted. Then, right corners can be sought out by setting ROI. Finally, all feature points are calculated by left corners and right corners as shown in figure 8.

There are 486 images in this experiment. Feature points of 480 images are extracted successfully while others failed to extract. So, the accuracy of extraction is up to 98.77%.

There are some extracted feature points deviated from the expected position apparently, as shown in figure 9.

5. Conclusions
With the aim to identify the weld seam successfully, extracting the feature point accurately and to improve the welding quality, a simple and effective feature point extraction method for stainless steel plate was proposed in this paper. Procedures of this method include: First, utilize the contour detection to filter out disturbances caused by environment factors and extract the max connected domain. Second, seek out the left border of extracted max connected domain and its left corner. Third, set a ROI near the left corner, then, utilize corner detection to extract the right corner. Finally, feature point can be determined. The experiment result show that there are 480 feature points extract accurately of 486 feature points, the accuracy of extraction is up to 98.77%. It is thus shown that this method can extract the weld feature points, so that the robot can weld the work part along the feature points detected and the operation of welding is guaranteed effectively. The limitation of this method is that the detected feature points are sometimes inconsistent with the weld center points, which may affect the welding quality.

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