Abstract

The main challenges in modern design of automobile bodies are reduction in weight and maximization of the structural stiffness and passive safety. The “tailored blank” has contributed to achieving a significant weight reduction which is single flat sheets joined by laser welding into the desired configuration without filler wire. Production of laser beam welded tailored blanks requires high speed, high precision and high quality. The welding robots that follow a preprogrammed path are often not able to guarantee a sufficient weld seam quality. Therefore, a seam tracking system is used to improve the reliability of the seam quality prediction. This paper describes the development of the seam tracking system for laser beam welding of tailored blanks. The system consists of DSP based vision camera and stripe-type laser diode. The total system is assembled into a compact module which can be attached ahead of welding torch. The images taken by the camera are analyzed using image processing algorithms. The image processing algorithms for extracting the feature points of weld seam are discussed depending on the characteristics of laser beam welding of tailored blanks. The accuracy of the industrial robots during the laser welding process was guaranteed by the compensation method A prototype sensor system has been developed and experimental results show its effectiveness and good performance.

Introduction

The most famous and spread large-scale laser joining application in automotive industry is the welding of tailored blanks. The benefits of tailored blanks include weight reduction, lower manufacturing/labour costs, reduced design and development time, less material, better utilization of steel, fewer spot welds and improved structural integrity [1]. The production of laser welded tailored blanks involve highly automated laser welding systems. Laser beam welding of tailored blanks requires high speed, high precision and high quality. The accuracy of the industrial robots follow a preprogrammed path is not able to guarantee a sufficient weld seam quality. Therefore, a seam tracking system with a laser-based vision sensor is used to improve the reliability of the seam quality prediction. The laser-based vision sensor is widely used due to its low cost, high resolution, positive performance in real-time and abundance of information and is one of the most promising sensors [2-4]. Although significant achievements have been made in the area of seam tracking [5-9], reliable application techniques for robotic laser welding are still needed.

The seam tracking system presented in this paper consists of DSP based vision camera and stripe-type laser diode. The total system is assembled into a compact module which can be attached ahead of welding torch. This system has ability to obtain an accurate profile of the seam by using the method of triangulation [10] and it has high dynamic performance in guiding the robot arm welder accurately over the seam. The images taken by the camera are analyzed using image processing algorithms. The image processing algorithms for extracting the feature points of weld seam are discussed depending on the characteristics of laser beam welding of tailored blanks.

In this paper, we focus on two respects, image processing and error compensation of industrial robot to increase the robustness of weld seam tracking. The paper is organized as follows: Section 2 describes the structure and principle of the seam tracking system. In section 3, image processing is discussed. And in section 4, tracking process is introduced, followed by
the experimental results shown in section 5. Finally, section 6 concludes the paper.

**System Description**

The overall visual seam tracking system is composed of three modules: a laser stripe sensor module, a motor controller module and a monitor centre module. The laser stripe sensor module consists of a laser diode that operates at a wavelength of 660nm with an adaptive output power, a CMOS camera, an optical filter and an image processing system based on FPGA and DSP. The motor controller module consists of a motion control DSP and a cross slide which has two servo motors. The monitor centre module consists of an industrial computer and a remote control device. All the work of parameters setting and seam tracking monitoring is performed in the industrial computer. Fig.1 shows the structure of this seam tracking system.

![Fig.1 The structure of seam tracking system](image)

In robotic tailored blank welding, the laser stripe sensor is mounted in front of the welding torch, separated by a look-ahead distance between the sensor and the torch where the space is limited to acquire the profile information of the weld seam. So the main design considerations for the laser-based vision sensor are its size, weight, safety, and ability to be configured for different joint types. The seam profiles are captured by the CMOS camera and then they were transferred to the image processing system. After the images are processed, the feature points are extracted. Then the offset between the feature point and the reference point could be calculated before welding and be given to the motor controller module which aligns the torch along the weld seam during the welding process according to the offset.

**Image Processing**

A laser diode projects laser light that falls on the surface of the work piece to form a stripe and a small beam size of the laser diode is required due to the narrow seam of the tailored blanks in the laser welding. The laser light is scattered and collected by the CMOS camera with an adaptive exposure time at an angle of 30 degree. The size of the gray image is 640×480 pixels. Mechanical shielding, optical band pass filter and increased output power of laser diode are used in order to reduce the impacts of the strong laser light, smog and splash in the process of welding. Fig. 2 is the original image of laser strip on butt weld seam during the process of laser welding. The image shows that the efficiency of these physical measures and there is still reflection on the surface of the work piece and the groove of the seam. These give rise to difficulty, error and even failure of the processing of the welding seam image. And the computational time required in the analysis of the laser stripe is the most important problem under our consideration. The procedure of image processing includes image pre-processing, centreline of laser stripe extraction and feature extraction.

![Fig. 2 The original image of laser stripe](image)

**Image Pre-processing**

A window called ROI (region of interest) is set to be processed instead of the whole image in order to speed up the rate of image processing. This will be operated in the FPGA. The window could be confirmed according to the first captured image because the laser strip has a stable position in these images during linear seam welding. After the first image being captured, add together the gray value of the pixels which are projected on to the same point in both sides of the image. It is given by the equation (1).

\[
\begin{align*}
SW_i &= \sum_{j=1}^{W} I(i, j) \\
SL_j &= \sum_{i=1}^{L} I(i, j)
\end{align*}
\]

(1)

Where \( L \) and \( W \) are the image length and width respectively, \( I(i, j) \) is the gray value of the pixel in coordinate \((i, j)\). The side of ROI window is decided...
by the first derivatives of \( SW_i \) and \( SL_j \). The maximum value point is as the centre point of the ROI window and length and width are chosen according to actual demands.

Subsequently, the efficient median filtering method is adopted for removing random noise mixed in the image and to maintain image sharpness (as shown in Fig. 3). Suppose that the gray value of some pixels and its four-neighbourhood sort in one laser stripe ascending as \( \{p_1, p_2, p_3, p_4, p_5\} \), the gray value of this pixel is given as:

\[
p = \text{median}\{p_1, p_2, p_3, p_4, p_5\}
\]

Fig. 3 The result of median filter process

**Feature Points Extraction**

There are different ways to find the feature points for different weld seams. Butt joints of mono-thickness blanks and bi-thickness blanks usually applied for laser tailored blank welding are taken as examples here. In conventional methods, the turning points of the weld groove are often used as the feature points. In our algorithm, the centre of the weld seam is used as the feature point.

The feature point is determined as follows: threshold \( T_i \) and \( T_j \) are decided by empirical value firstly; then the searching algorithm from both sides is run to find out the edge points and the coordinate \( y_L \) and \( y_R \) are given as equation (4), the coordinate \( x_L \) and \( x_R \) are calculated according to the centre line of the laser stripe; finally, the centre point of the two edge points is as the feature point shown in Fig. 4.

\[
\begin{align*}
y_L &= j \cdot \text{IF}(I(i,j-1) < T_i \& \& I(i,j) > T_i \& \& I(i,j+1) < T_i) \\
y_R &= j + 1 \cdot \text{IF}(I(i,j-1) < T_i \& \& I(i,j) < T_i \& \& I(i,j+1) > T_i)
\end{align*}
\]

Fig. 4 The feature points extraction

**Tracking process**

The motor controller module is used to regulate the position of the weld torch which is the execution part of the system. After the vision sensor is well calibrated, the real distance \( \Delta \) between the reference feature point and the current weld seam feature point is easily to be achieved. This \( \Delta \) is caused by the distortion or poor jig fixing. The tracking process steps are as follows: firstly, \( \Delta \) is obtained by the vision sensor before welding; secondly, the offset caused by industrial robot in TCP (tool centre point) is recorded by the vision sensor under \( \Delta \) having been compensated (offset of industrial robot shown as Fig. 5); finally, the offset will be compensated and the tracking process will be completed.
Experimental Results

Image processing and feature points extraction experiments were conducted in robotic laser beam welding of tailored blanks. The butt weld seam was as the sample using the algorithm described above. The parameters of one experiment are described at table 1. Fig.6 shows the industrial robot for laser beam welding and the situation during welding. It can be seen that there are strong background brightness in the work environment during welding process.

Table 1 The parameters of one experiment

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
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<tbody>
<tr>
<td>Welding speed</td>
<td>64mm/s</td>
</tr>
<tr>
<td>Welding laser power</td>
<td>3000W</td>
</tr>
<tr>
<td>Thickness of blanks (bi-thickness)</td>
<td>1.6mm-2.5mm</td>
</tr>
<tr>
<td>Length of weld seam</td>
<td>1200mm</td>
</tr>
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</table>

Fig.6 The industrial robot for laser beam welding

The experiments show that the speed of image processing is 50 frames ~ 100 frames per second and the system precision depends on the system setup. For the test images discussed in this paper, the camera was looking at an area about 8mm×6mm rectangle. Since the sensor is 640×480 pixels, the system precision is around 0.0125mm per pixel which is accurate enough for laser tailed blank welding.

Conclusions

The concepts and test results of a seam tracking system are presented in this paper. It was designed for real time robotic laser welding of tailored blank applications. Two crucial factors are the speed of processing and the accuracy of results. The high speed image processing is achieved by using FPGA and DSP based image processing system and the appropriate algorithms. In order to reduce these impacts caused by laser and splash disturbance, physical measures including mechanical shielding, optical band pass filters and increased output power of laser diode are used firstly and an image processing algorithm for laser stripe image of welding seam is discussed. A series of image processing and feature extraction experiments are done for butt welding seam of tailored blanks and the algorithm runs online well. The accuracy of the industrial robots during the laser welding process was guaranteed by the compensation method.

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Reference


