

Paper:

# Image Detection of Seam Line for Laser Welding Robot

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Automating robot laser welding requires that laser irradiation direction and laser focus positioning influencing welding strength be controlled precisely along the seam line. Since the edge of the welded object can be transformed in processing by such as cutting, bending and grinding, direct measurement is necessary to detect the seam line. A robust image detection method of seam lines is proposed for hand-eye laser welding system equipped with an optical microscope, a CMOS camera and two slit lasers for measurement. The seam line is detected indirectly to utilize the difference between local and global distribution of image of measurement lasers. Results of experiments demonstrated the effectiveness of our proposal.

**Keywords:** seam line, vision sensing, laser welding, robot control

## 1. Introduction

Laser welding provides high-density energy, is easy to control, and is low in heat input but deep in depth, enabling it to be used for small-area precision welding. Automating welding using robots has been considered, but laser welding requires accurate alignment along the seam line because of its capability of sensitive welding. We proposed a basic image measurement of position and posture of welded objects for motion control of a laser-welding robot [1–4] and developed a laser head with visual measurement system [5]. However, it is necessary to detect position of seam line as a target of welding laser. The seam line is boundary line of two welded objects. The images of measurement laser appear as bright segments on the welded object. But the image does not appear on a bright segment on the seam line. Hence, the seam line has to be detected indirectly by local change of images of measurement lasers. We propose robust image detection method of a seam line to utilize the difference between local and global distribution of image of measurement lasers.

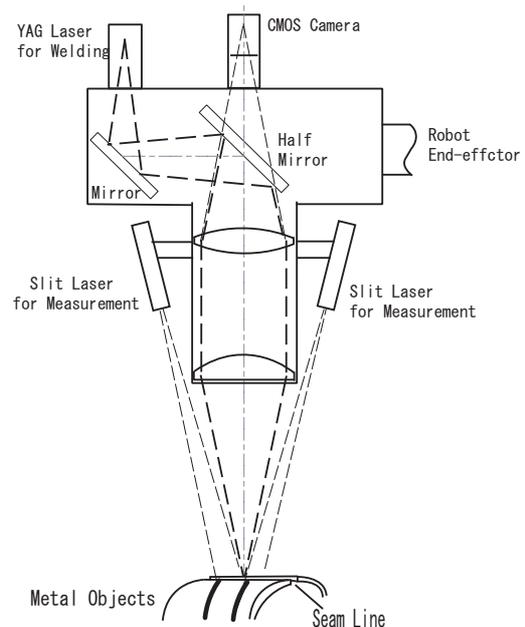


Fig. 1. Laser head.

## 2. Measurement System

The welding head (Fig. 1) has an optical microscope that expands the observed weld target and consists of mirrors refracting an Yttrium-Aluminum-Garnet (YAG) laser so that its optical axis coincides with that of the camera, i.e., visible light goes through the mirrors but the YAG laser is reflected by them. The observation system is shown in Fig. 2. The YAG laser is focused on the seam line between the two objects to be butt-welded. The direction of melting depends on the direction of the optical axis of laser and melting depth depends on the positioning of focus. If the optical axis of laser is not along the seam line on the tangent plane of the metal plates, the direction of melting deviates from the welded seam line as welding progresses, lowering weld strength. In optimal welding, focusing position and the optical axis direction are controlled highly accurately on the seam line. Visual information has been used in monitoring laser-welding conditions [6–8]. However, the measurement is impossible in process because welding vigorously emits light and heat. The off-line measurement is necessary to separate from

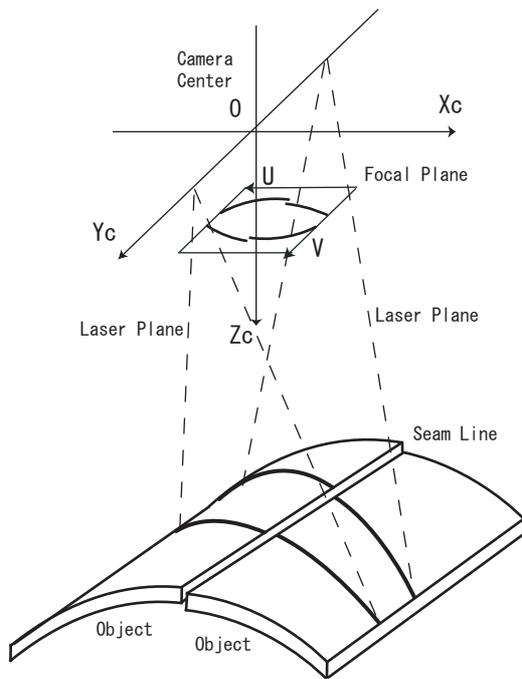


Fig. 2. Observation system.

Table 1. Experimental apparatus parameters.

CMOS Camera (SXGA)	1024 × 1280 pixels
Focal Length of Laser Head	200 mm
Wave Length of Measurement Laser	640 nm
Power of Measurement Laser	4.4 mW

welding process. We irradiate only the two measurement lasers onto the metal pieces without initiating welding and observe the two-segmented laser images on the butt area filmed from above. The robot keeps the welding head at positioning optimal on points at equal distance for welding while moving the initial start point to just above the end as robot movement is recorded. In welding, the robot initiates the welding laser, playing back movements, from the start point to the end point.

Two slit lasers for measurement are illuminated at 30° to the optical axis of the welding laser from both sides of the laser head (Table 1). For the two welded objects that are flat plates, where two straight lines of measurement laser are parallel, the distance is 2–3 mm, the seam line is located on the center of the image, and the position of the focus of the welded laser is the most proper condition. By the images of two measurement lasers, the position and posture of the seam line and welded objects are given simultaneously. Since the range of the extended photographed image is about 5 mm × 6 mm, the seam line is considered to be a straight line in the range. Two slit lasers are necessary to measure the position and posture of straight line. If the butt angle is concave to the camera, since the welded objects have the mirror surface of metal, the image of reflected laser must be removed from the image by any method.

The measurement is carried out in point to point, and robot movement between points is manually manipulated by the operators. The proposed seam line detection and measurement of position and posture [1–4] are carried out in each point, and the robot is automatically controlled by the measurement results. By repeating measurements and control, the robot becomes adjusted into proper welding position and posture automatically. Since the range of the extended photographed image is relatively small, the seam line is considered to be a straight line in the range. The purposes of seam line detection are that the welding laser is just on the seam line and to distinguish the measurement laser images on the welded objects having different posture and position as the seam line is a boundary. Measurement precision of position and posture of the welded objects becomes better by distinguishing a measurement laser image.

### 3. Seam Line Detection by Vision Sensing

To weld two objects strongly, the welding laser has to irradiate precisely along the seam line between the edges of objects from regular position and angles. The position and angles are conventionally adjusted manually by human vision [5]. For automation by a robot, seam line detection is necessary. The aspect of the image has some variations depending on the difference of heights and gap distance of welded objects. The seam line appears as breaks or constriction of two laser images (Fig. 3). Where two objects are placed together in contact, the images of the laser slits are constricted on line width (Fig. 3(a)). Where interval of the objects becomes larger, images have breaks on the seam line (Fig. 3(b)). As the objects become higher, the width between slit images becomes wider. Then, where objects have the height difference, slit images have position gap on the seam line (Fig. 3(c)). By both of width and height of objects, the different condition appears on the seam line (Fig. 3(d)). Furthermore, the edge of objects has various conditions depending cutting ways, shape processing and grinding. Seam line detection is required to have robustness against these.

Our proposed method utilizes the difference between global and local distribution of the image. From original image  $\{a_{i,j}\}$  as an example (Fig. 4(a)), moving average image  $\{b_{i,j}\}$  between short distance  $(2P_S + 1) \times (Q_S + 1)$  pixels from left to horizontal direction is given. Moving average image  $\{c_{i,j}\}$  between long distances  $(2P_L + 1) \times (Q_L + 1)$  pixels from left to horizontal direction is derived where  $Q_S \ll Q_L$  and  $P_S = P_L$ . The example images of  $\{b_{i,j}\}$  and  $\{c_{i,j}\}$  are shown in Figs. 4(b) and (c) ( $Q_S = 5$  pixels,  $Q_L = 50$  pixels and  $P_S = P_L = 1$  pixel). The moving average filter is shown in Fig. 5. The speckle pattern appears on the laser image on the metal plate. The parameters  $P_{S,L}$  to the vertical axis are the minimum 1 pixel needed to remove the speckle pattern. The parameters ( $Q_S = 5$  pixels,  $Q_L = 50$  pixels) are decided by trial and error.