Measurement for Three Dimensional Surface of Welding Pool in GTAW Welding

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Abstact. Welding pool deformation has a close relationship with the backside bead width, so pool surface shape sensing is used to monitoring and control weld quality, specifically of weld penetration. In this paper, several three-dimensional (3D) reconstruction techniques is analyzed, which were used to reconstruct 3D shape of welding pool. The direct method obtain clear image of pool, so the reconstruction accurate is high. As an indirect method, three SFS algorithms are implemented. Some improved measures are: modeling welding reflection map; new constraint equations; image pretreatment. 3D shape of welding pool was reconstructed and validating results showed this technique can be applied practically.

1 Introduction

During gas tungsten arc welding(GTAW), complicated phenomena occur on the weld pool. However, a skilled operator can estimate and control the welding process based on pool observation. This implies that we can judge whether or not it is good quality if we can detect information about pool parameters. To this end, extensive studies have been done to explore the possibility of indirectly measuring weld pool characteristics based on pool oscillation, infrared radiation, ultrasound, radiography, and so on. Compared with these methods, direction observation of the weld pool may provide more instantaneous and accurate information. For GTAW without filler, pool surface deformation is apparent in the full penetration mode. In the case of partial penetration, three modes of pool deformation can be observed for different current levels. Thus, the deformation of the pool surface is an inherent characteristic of arc welding processes. Furthermore, the observation discovered that the average weld depression depth, which is defined as the cross weld depression area divided by the width, has a close relationship with the backside bead width in the full penetration[1]. Based on this theory, it is possible to control the fusion state of fully penetrated welds in GTAW welding, if we can obtain and control weld depression degree. Presently, three-dimensional image reconstruction techniques are classified into direct and indirect methods. Achievements in these areas have a major impact on computer vision research. In this paper, a major task is the analysis of used methods in three-dimensional shape reconstruction of welding pool, which is important for the monitoring and control of weld quality and consequently the reliability of joint.

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2 Three-Dimension Measurement Technique

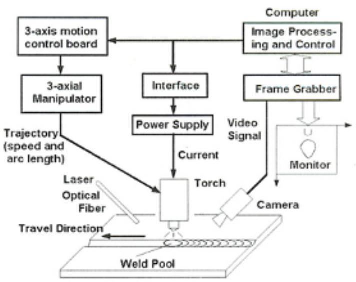
2.1 Direct Methods

Direct or active methods recover depth information directly using a range finder and structured light. Most of these methods use the triangulation principle where a structured light source is directed on to the object's surface.

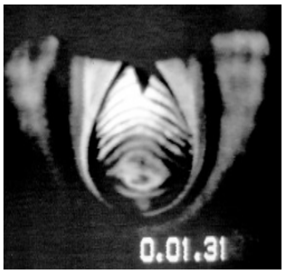
R.Kovacevic and Y.M.Zhang[2] devised a novel mechanism for observing the pool surface shape. Laser stripes projected through a grid are reflected from and deformed by the mirror-like pool surface, as shown in Fig.1a. The shape features of the weld pool surface are clearly shown by the reflection pattern, in Fig.1b.

During the laser pulse, the laser intensity is much stronger than the arc intensity, and the arc influence in weld pool observation is essentially eliminated. When laser is used to illuminate the weld pool surface, the corresponding reflected rays are completely determined by the slope of the weld pool interface and the point where they hit the weld pool. By tracking the reflected rays and computing the slope field of weld pool surface the three-dimensional weld pool shape can be determined.

A apparent advantage of this method is pool image is clear without time delay, because laser light intensity is far greater than arc light. So it is accurate in reconstruction size. Comparing with its advantage, its disadvantage is yet apparent, that is, equipment complexity, volume large and costliness.



(a) System set



(b) weld pool image

Fig. 1. Schematic of sensing of weld pool using structural light system

2.2 Indirect Approaches

Indirect methods determine the relative depth by cues extracted from grey-level images of an observed object. As descried previously, the direct techniques usually involve the complicated installation of various external components, so they may not be suitable for the estimation of real-time variations in shape. Many researchers have focused on indirect methods, shape from different cues as the generalized class of these indirect methods. These cues can be shading, texture, focus, and stereo vision.

However, the object under test may not have sufficient texture information for weld pool, so texture is not suitable for our goal. Focus approach involves the mechanical movements of either the lens or the image plane for each individual point, with a low efficiency and with accuracy limited by the resolution of mechanical movements [3]. Stereo approach need two or more viewpoints (or CCD), restricted it only applying in simply structure; because weld pool shape is dynamic changing, which lead it difficulty to search match elements.

At the present, the researchers mostly could pay a attention to applying SFS in welding, so we should analyze three practical applying algorithms.

3 Shape from Shading

Shape-from-Shading (SFS) is a technique of recovering 3D information from variation of shading on the image, first introduced by Horn in the 1970s. In order to better understand this approach, it is necessary to introduce how the images are formed. A simple model of image formation is the Lambertian model, in which image gray level (or irradiance) at a pixel as a function of the surface orientation of the corresponding scene point is captured in a reflectance map. Thus, for fixed illumination and imaging conditions, and for a surface with known reflectance properties, changes in surface orientation translate into corresponding changes in image gray level. The inverse problem of recovering surface shape from changes in image intensity is known as the shape from shading problem. The relationship is given by

$$I = R(p,q) \tag{1}$$

Where $R(p,q)$ is the reflectance map of the surface point (x,y), $p = p(x,y) = \frac{\partial z}{\partial x}$, $q = q(x,y) = \frac{\partial z}{\partial y}$, z is surface depth, I is the normalize image gray level at corresponding point However, we have a nonlinear equation with two unknowns. Therefore, finding aunique solution to SFS is difficult; it requires additional constraints. Extensive study and approaches were reported to solve this solution. Ruo Zhang [4] divided these approaches into four groups: minimization, propagation, local and linear. Comparison experiments showed that minimization approaches are more robust. So the SFS techniques applying in welding are all based on minimization theory. Following section will discussion them respectively.

3.1 Zhao Dongbin[5]

Zhao Dongbin firstly introduced SFS technique into welding field. The total reflection consisted two parts, that is,

$$f = \beta_d f_d + \beta_s f_s \tag{2}$$

Where, f_d and f_s is diffuse and specular reflection function, β_d and β_s is diffuse and specular reflection coefficient. Reflection model is,

$$R(p,q) = R(i,n,v,r) = \begin{cases} g\dfrac{I_0}{r^2}(v^T n_z)^4(\beta_d(i^T n) + \\ \beta_s \dfrac{\exp\{-k[\cos^{-1}(h^T n)]^2\}}{(i^T n)(v^T n)}) + b, & (\mathrm{i}^{\mathrm{T}}\mathrm{n}) \geq 0 \\ 0, & \text{otherwise} \end{cases} \tag{3}$$

where, $n = (-p, -q, 1)$

A brightness constrain e_b is essential to solve this equation. To improve noise proof, a new constraint e_s is introduced.

$$\begin{aligned} e &= e_b + \lambda e_s \\ &= \iint [(R(p,q) - I(x,y))^2 + \lambda \frac{1}{2}(z_{xx}^2 + 2z_{xy}^2 + z_{yy}^2)]dxdy \end{aligned} \tag{4}$$

The algorithm is implemented using triangular linearization。 Test results show that there are larger errors in the brighter region and smaller errors in the darker region. To overcome this problem, an adjusting factor of brightness is added

$$e_b = \iint w(I)[R(p,q) - I(x,y)]^2 \tag{5}$$

$$e_b = \iint w(I)[R(p,q) - I(x,y)]^2 \tag{6}$$

Where,

$$w(I) = \begin{cases} e^{-(I-150)^2/5000}, & I \geq 150 \\ 1.0 & , otherwise \end{cases} \tag{7}$$

Experiment and reconstruction images is showed in Fig.2

(a) welding pool (b) reconstruction image

Fig. 2. Welding pool and its reconstruction

3.2 Li Laiping[6]

By analysis of the distribution of arc light intensity, Li Laiping found that the arc shape is close to the sphere when the current is in background during pulse welding. So he establish a sphere extended light source model, the irradiance of the object surface is,

$$E = \int_0^{\alpha} \int_0^{2\pi} E d\theta d\phi = C(I_c, \lambda, r, r_s) \cos\theta_n \tag{8}$$

Where $C(I_c, \lambda, r, r_s)$ is a function of welding current, material, arc shape, arc length. Due interreflection exist in pool concave, the total irradiation is,

$$L = \beta_d L_d + \beta_s L_s + \beta_{\text{int}\, er} L_{\text{int}\, er} \tag{9}$$

The first term is diffuse, the second term is specular, and the final term is interreflection. The reflection model is,

$$R(p,q) = g\left(\frac{d}{f}\right)^2 (v^T n_z)^4 L + b \tag{10}$$

The constraint e_s of Zhao Dongbin need second derivative existence, however, common surface just guarantee successive character. Thus, Li Laiping introduce a new constraint,

$$e_v = \iint (z_x^2 + z_y^2) dxdy \tag{11}$$

Final, the total constraint is,

$$e = e_b + \lambda e_s + \mu e_v \tag{12}$$

The algorithm is implemented using pretreatment conjugate gradient based on Lee Kuo's[7].

3.3 Du Quanying[8]

Du Quanying first test several SFS approach, and find that Horn and LeeKuo' both need too much runtime to apply in real-time inspecting; and that Zheng's[9] algorithm is balance accuracy and runtime. So Du take this algorithm and improved it. Reflection model consist both diffuse and specular parts. In constraint equation, an adjusting factor ω of brightness is added, and the intensity gradient constraint is applied instead of a smoothness constraint.

$$e = \iint F dxdy \tag{13}$$

where

where

$$F = \omega[R-I]^2 + [R_p p_x + R_q q_x - I_x]^2 + [R_p p_y + R_q q_y - I_y]^2 + \mu[(p-Z_x)^2 + (q-Z_y)^2]$$

The algorithm is implemented using a hierarchical structure in order to speed up the computation.

To validate, he apply this improved SFS algorithm to the detection of the weld bead shape, as shown in Fig.3. The comparison between the measured points and their reconstructed is shown in Fig.4.

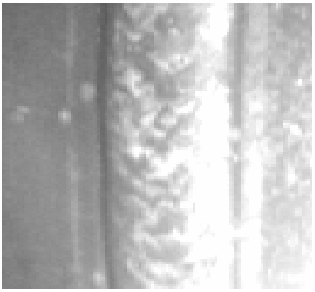


Fig. 3. Image of weld

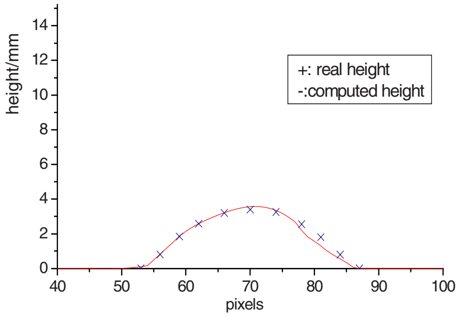


Fig. 4. Compared between reconstructed and measured

4 Conclusion

Several reconstruction techniques recover the 3D description of an object from a single view of the welding pool.

The direct technique used structure lighting to illuminate welding pool, so the image of the welding pool is clearly and the interference from the arc light could be ignored. But this technique usually involve the complicated installation of various external components, they may not be suitable for the estimation of real-time variations in shape.

SFS technique only used one CCD without any external equipment. Three algorithms were improved, and all performed good results in 3D reconstruction of welding pool. And Du Quanying' method was carried out in real-time controlling. However, there are a lot of difficulties when applying SFS technique in welding field. Due to the illuminating is arc light, pool image is interfered even though fixing filter system. These light interference caused the image gray level is not absolutely according with the SFS model, which could bring with error in 3D reconstruction size. In addition, it is difficult to determine illuminant direction and surface albedo. Thus, there are still many factors need to be researched, if we want to take SFS technique to recover accurate 3D welding pool shape.

Acknowledgements

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