Research on the Model of Arc Noise in Welding Seam Tracking

LI KAI
Robot Research Institute
Harbin Institute of Technology
No.92, West Da-Zhi Street, Harbin, Heilongjiang, 150001
The People's Republic of China
YUE HONG, SUN LIXIN, DAI SHIJIE
School of Mechanical Engineering
Hebei University of Technology
No.8 Guangrongdao, Hongqiao District, Tianjin, 300130
The People's Republic of China
CAI HEGAO
Robot Research Institute
Harbin Institute of Technology
No.92, West Da-Zhi Street, Harbin, Heilongjiang, 150001
The People's Republic of China

Abstract: - In the welding seam tracking system，detecting the position and the shape of welding seam is very important. Because the vision sensor with structured light is strongly influenced by the arc light and spatter, the influence of arc noise to laser stripe image is studied. The arc noise model is established. A structured light sensor is set up according to the theory. Experiments show that the sensor can detect welding seam very well in the welding process.

Key-words:- Structured light Sensor Seam tracking Arc Model

1 Introduction

There are many seam detecting methods, such as mechanical sensing, electromagnetic sensing, arc sensing, ultrasonic sensing and optical sensing. Among all of these methods, structure light sensing method can not only detect the center of a seam, but also detect the shape of a seam section [1] [2].

Detecting the position and the shape of the welding seam is very important in the welding seam tracking system. Because the vision sensor with structure light is strongly influenced by the arc light and spatter, it is very useful to establish the model of arc noise for the design of a visual sensor.

2 Establish of the model of arc noise

In the process of arc welding, the main noises are the arc light, the spatter and the molten pool metal radiation. Because the temperature of the spatter is much lower than that of arc light, the wavelength of most radiant energy is higher than 1000nm. As the wavelength of the laser used in the visual sensor is 635nm, arc light noise is the most important factor in the process of the seam detecting.

In the vision aided welding system, the distance (r) from the welding arc to the sensing area of the base metal is greater than 3 cm. While the effective area A of the arc with the temperature higher than 10000K is approximately 0.5mm^2, It is much smaller than the square of the distance between the arc center and the workpiece. Therefore, the assumption of $A/r^2 << 1$ can be successfully adopted in this study, and the arc light can be regarded as a point light source [3]. The irradiance $E(\lambda)$ can be modeled as follows:

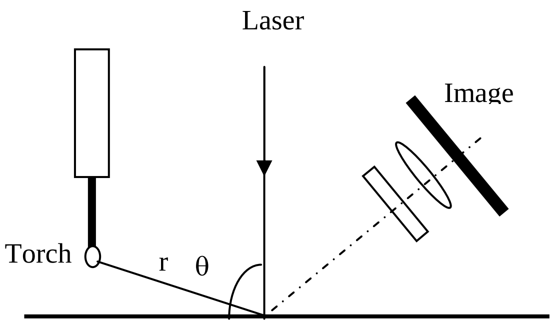

Fig. 1 Diagram of joint detection

$$E(\lambda) = I(\lambda) = \frac{\cos\theta}{r^2}$$

Where $E(\lambda)$ is the irradiance of the arc light, $I(\lambda)$ means the spectral radiant intensity of the arc, which is assumed to be constant in this study, and r is the distance between the arc center and the base metal. The black body spectrum can be expressed by Planck's law:

$$I(\lambda) = AL(\lambda) = A\varepsilon(\lambda)\frac{2hc^2}{\lambda^5\left[e^{\frac{hc}{\lambda kt}} - 1\right]}$$

Where $\varepsilon(\lambda)$ is the radiant coefficient of the arc, h is the Planck constant , c is the velocity of light , k is the Boltzman constant , T is the temperature of arc and A is the effective area of the arc. Therefore the irradiance can be expressed as follows:

$$E(\lambda) = AL_{arc}(\lambda)\frac{\cos\theta}{r^2} = \frac{hA}{r^3}L_{arc}(\lambda)$$

After the arc reached the surface of the workpiece, it was reflected and diffused. Suppose the surface acting coefficient is:

$$f_r = \frac{L_{arc}(\lambda)}{E(\lambda)}$$

Where $f_r = f_{rd} + f_{rs}$, $L_{arc}(\lambda)$ is the radiance of arc, f_r is the surface acting coefficient, f_{rd} is the surface diffuse reflection coefficient, which can be regarded as a constant. f_{rs} is the surface total reflection coefficient. It depends on the surface of the workpiece and the light wavelength. So the arc radiance of the reflection can be expressed as follows:

$$L_r(\lambda) = f_r E(\lambda) = \frac{hA}{r^3} f_r L_{arc}(\lambda)$$

The arc light reflected from the base metal surface is filtrated through an interference filter. The optical characteristic of the interference filter can be expressed in Gaussian distribution function as follows:

$$F_G(\lambda) = t_r e^{-\frac{\lambda^2}{2\sigma^2}}$$

Where $\sigma = 0.2B_w$, B_w is the full width at half-maximum of the band pass filter , and t_r is the peak transmission coefficient. Let the center wavelength of the filter is λ_c. The spectral response of the interference filter can be expressed as follows:

$$F_G(\lambda - \lambda_C) = t_r e^{-\frac{(\lambda-\lambda_c)}{2\sigma^2}}$$

After passing through the interference filter and the lens of camera, the arc light images on the imaging plane. As shown in fig.2. ds is an area cell perpendicular to the light axis. After passing through the optical lens system, the image is *ds′ ,and* P_1P_2、u、$\Delta\Omega$ *are* incident hole, an angle of incidence and the solid angle of incident line respectively. Where $P_1'P_2'$、u'、$\Delta\Omega'$ *are* emission hole, an angle of emission and the solid angle of emission line respectively. L and L' are the radiance of the objective cell *ds* and the image cell *ds'*, respectively. The light flux passing through *ds* at the direction θ and within solid angle $d\Omega$ can be expressed as follows:

$$d^2F = Lds\cos\theta d\Omega$$

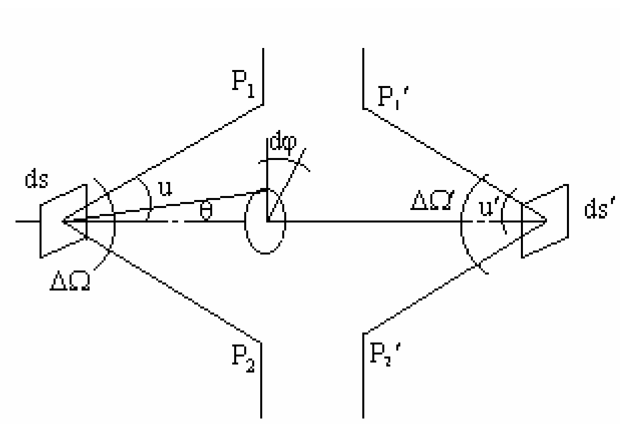

Fig.2 Diagram of camera lens working

Because the area cell *ds* can be regard as a cosine eradiate object and *L* is equal in all the direction, the light flux passing through the camera in the solid angle $\Delta\Omega$ can be expressed as follows:

$$dF = Lds\int_{\Delta\Omega}\cos\theta d\Omega$$

Where

$$d\Omega = \sin\theta d\theta d\varphi \quad (1)$$

So

$$dF = Lds\int_{\theta=0}^{u}\cos\theta\sin\theta d\theta\int_{0}^{2\pi}d\varphi$$
$$= \pi Lds\sin^2 u$$

The irradiance can be expressed as follows:

$$E = \frac{dF}{ds} = \pi L\sin^2 u \quad (2)$$

In the same way, the light flux projecting to the image cell can be expressed as follows:

$$dF' = \pi Lds'\sin^2 u' \quad (3)$$

After absorbed, reflected and refused, the light flux reaching the image plane can be expressed as follows:

$$dF' = k_1 dF$$

Where k_1 is the transmission coefficient of the optical system varying with the wavelength, and it is less than 1. From the equations（1）、（2）and（3）we have

$$L' = k_1\frac{ds}{ds'}\frac{\sin^2 u}{\sin^2 u'}L \quad (4)$$

Suppose the size of the object and the image are *y and* y' respectively ,the refractive indexes of objective space and image space are *n and* n' respectively：

$$ny\sin u = n'y'\sin u' \quad (5)$$

While

$$\frac{ds}{ds'} = \frac{y^2}{y'^2} \quad (6)$$

From the equations（4）、（5）and（6）we know：

$$L' = k_1 L\left(\frac{n'}{n}\right)^2$$

So the irradiance on the image cell ds' can be expressed as follows:

$$E' = \frac{dF'}{ds'} = \pi L'\sin^2 u' = k_1\pi L\left(\frac{n'}{n}\right)^2\sin^2 u'$$

In the camera system, because object distance is much larger than the focus distance，the angle of emission u' can be regarded as a constant, and the optical system of the camera can be regarded as a thin lens. If the diameter of the lens is D，and the focus distance of the image is f'，then

$$\sin u' = \frac{D}{2f'}$$

Therefore

$$E' = \frac{k_1\pi L}{4}\left(\frac{D}{f'}\right)^2\left(\frac{n'}{n}\right)^2$$

Where *f/D* is called *F* number. Both the objective space and the image space have the same medium，that is to say n'/n=1，so：

$$E' = \frac{k_1\pi L}{4}\left(\frac{D}{f'}\right)^2$$

Suppose the points on the image plane are full of the emission holes，the angle between the optical axis and the line connecting the center of lens and the reflecting point on the base metal is ω，then practical irradiance E_ω' can be expressed as follows:

$$E_\omega' = E'\cos^4\omega$$

But in the practical optical system, there is a coefficient k_2 ,and the irradiance E_ω' can be expressed as follows:

$$E_\omega' = k_2\cos^4\omega E'$$

So the practical irradiance reaching the image plane can be expressed as follows:

$$E_\omega' = k_2\cos^4\omega\cdot\frac{k_1\pi L(\lambda)}{4}\cdot\left(\frac{D}{f}\right)^2$$
$$= \frac{k_0\pi hA}{4r^3}\cos^4\omega\left(\frac{D}{f}\right)^2 f_r L(\lambda)$$

Where $k_0=k_1k_2$. After passing through the lens and the filter, practical irradiance reaching the image plane can be expressed as follows

$$E''(\lambda)=\frac{k_0\pi hA}{4r^3}\left(\frac{D}{f}\right)^2\cdot \cos^4\omega\int_0^{\infty} f_r L(\lambda)F_G(\lambda-\lambda_c)d\lambda \tag{7}$$

After passing through the imaging sensing element, the irradiance E can be converted in to the gray level G :

$$G(\lambda) = pE''(\lambda)^{\gamma} \tag{8}$$

Where p *is a* constant , and Υ *is a* characteristic coefficient of the camera.

From equations (7) and (8) we know :

$$G(\lambda_c)=p\left[\frac{k_0\pi hA}{4r^3}\left(\frac{D}{f}\right)^2\cos^4\omega\right]^{\gamma}\cdot \left[\int_0^{\infty} f_r L(\lambda)F_G(\lambda-\lambda_c)d\lambda\right]^{\gamma} \tag{9}$$

The curve between the relative gray level and the distance r is shown in fig. 3, and the curve between the relative gray level and the angle ω is shown in fig.4.

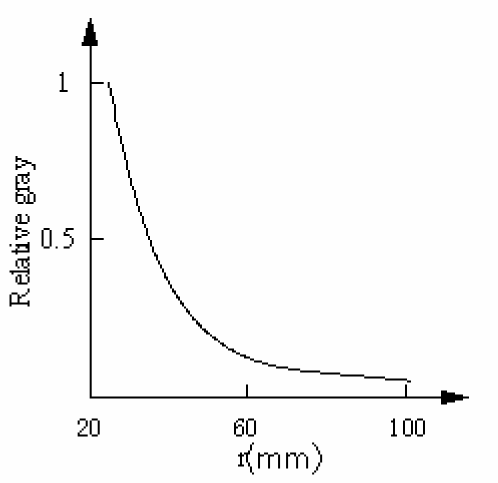

Fig.3 The curve of relative gray level *vs.* r

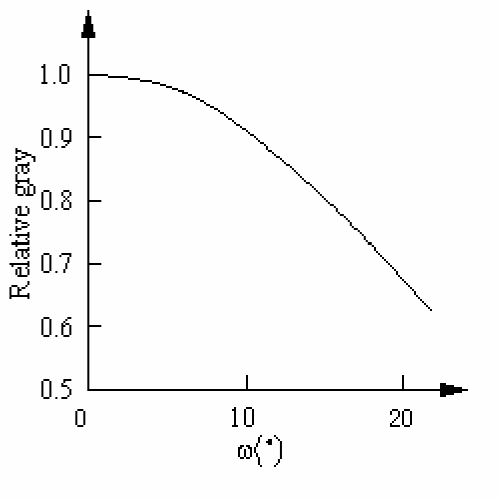

Fig.4 The curve of relative gray level *vs.* ω

3 Conclusion

A structure light sensor is set up according to the theory. The camera is WAT-902H, laser diode is with wavelength 635nm and power 20mW, the wavelength of the interference filter is 635nm, and band width is ±10nm. The configuration parameters are r=40mm, ω=7°. Experiments show that the sensor can detect welding seam very well in the welding process.

Acknowledgements

The authors gratefully acknowledge the financial support provided by the Tianjin Natural Science Foundation of China (No.033803111).

References

[1] M.Dufour and P.Cielo. Optical Inspection for Adaptive Welding. *Applied Optics*. 1984, 23(8): 1132-1134

[2] C.W.Lee and S.J.Na. A Study on the Influence of Reflected Arc Light on Vision Sensors for Welding Automation. *Welding Journal*. 1996, 75(12): 379-387

[3] J.-Y. YU, J.-I. KIM, AND S.-J. NA. Influence of Reflected Arc Light on Vision Sensors for Automatic GTAW Systems. *Welding Journal*. 2003, 82(2): 36-42

[4] Yan, Z. H.; Zhang, G. J.; Gao, H. M.; Wu, L.. Determining penetration from topside weld bead and weld pool geometry in PGMAW. Science & Technology of Welding & Joining, 2005, 10(6),

744-749