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Research on Laser Warning Receiver Based on Sinusoidal Transmission Grating and High Speed DSPs

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Abstract: - A measurement method for the wavelength and incident angle of narrow pulsed laser based on sinusoidal Transmission Grating and Digital Signal Processor has been proposed in this paper, and the corresponding principle prototype fof laser warning receiver has been designed, this instrument consists of a sinusoidal transmission amplitude grating, a plant-convex cylinder lens, a linear CCD with 50MHz driving frequency made by ATMEL Company, a High speed DSP TMS320VC5509 and a liquid Crystal Screen. our experiment results show that this instrument has the following technical characteristics : measurement wavelength range(span) is from 500 to 1100nm, wavelength resolution is less than or equal to 10nm, the Field of View is 22.5^{o} in latitude or longitude, the incident angle resolution is about 1, the responding time to laser threat is less than 0.1s, the detecting sensitivity is less than $10mW/cm^2$.

Keywords: sinusoidal Transmission Grating, Laser warning, wavelength, Incident direction Digital Signal Processor

1 Introduction

Optoelectronic reconnaissance and warning technology is an important part in optoelectronic countermeasure, plays the more and more role in modern electronic war.

Optoelectronic reconnaissance and warning technology are used to get the information such as the tactical and technical characteristics of hostile optoelectronic equipments, distinguish the Power, wavelength, modulation mode ,the width and frequency of pulse, coding type and so on of arriving laser, The aim of getting these information is to provide foundation for making optoelectronic countermeasure.

Laser warning receiver is passive Optoelectronic reconnaissance device Its functions is to detect incoming laser siginal, to discriminate true and fale sigaland to locate the positon of laser soure. Laser warning Receiver always operates Under the sun, or in the environment wiyh glareand fire light, the intensity of solar ray is always larger than that of hostile laser , in order to discriminate non-laser, the coherent detecting technology has ususaly been used, acording to the difference among coherent etalon, we can classify Laser warning receivers as Fabro-perot type, Michelson, Grating diffraction, Fizeau and Fourier Transform Spectrometer, Their disadvantage and dvantages has been compared in paper [1]. In this paper we will report the relative technology of laser warning receiver based on sinosoidal transmission grating and High speed Digital signal Processors, which can give the wavelength and incoming angle of short pulse laser.

2 The measurement principle of wavelength and incident angle based on sinusoidal grating

There exist many measurement methods for wavelength [2], the advantage of using diffraction grating is simultaneous measurement of wavelength and incident angle. In order to conquer the overlap among different wavelengths and different diffraction orders, and to simplify abstraction algorithm of wavelength and incoming angle , we hope there are only the first and zero order diffraction ,hence ,a Sinusoidal transmission grating is selected as coherent detecting element.

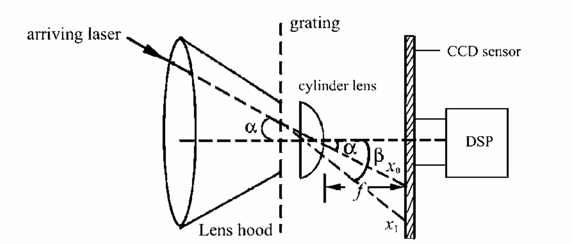


Fig.1 The principle of Sinusoidal Grating laser warning receiver

Fig.1 depicts the principle of laser warning receiver based Sinusoidal Transmission Grating, the receiver consites of linear CCD, plane-convex cylinder lens, Sinusoidal grating . As showed in this figure□a beam of laser with wavelength λ and incident angle α impinges on the Grating, after being diffracted by the grating and being focused by the Lens. Two diffraction stripes have been formed, this diffraction pattern is transformed into electronic signal by CCD, Then, the electric signal is processed by DSP, finally, the information about wavelength and incident angle are displayed and delivered to main control Unit. The measurement principle is as follows.

The transmittance of plane sinusoidal grating is.

$$T(x,y) = T_0 + T_1 \cos(2\pi x/d + \phi_0) \qquad (1)$$

The angle spectrum of a beam of incoming laser with wavelength λand incident angle α can be expressed

$$U_1(\lambda, x) = A\exp(j2\pi x \frac{\sin(\alpha)}{\lambda}) \qquad (2)$$

the transmitted wave by grating can be wrote as

$$\begin{aligned} U_2(x,y) &= U_1(x,y)T(x,y) \\ &= T_0U_1 + \frac{1}{2}T_1A\{\exp[j2\pi x(\frac{\sin(\alpha)}{\lambda} + \frac{1}{d} + \varphi_0)] + \\ &\quad \exp[j2\pi x(\frac{\sin(\alpha)}{\lambda} - \frac{1}{d} - \varphi_0)]\} \\ &= U_0(x,y) + U_{+1}(x,y) + U_{-1}(x,y) \qquad (3) \end{aligned}$$

there

$$\begin{aligned} U_0(x,y) &= U_1(x,y)T_0 \\ &= AT_0\exp(j2\pi x\frac{\sin(\alpha)}{\lambda}) \qquad (4) \end{aligned}$$

$$U_{+1}(x,y) = \frac{1}{2}T_1A\exp[j2\pi x(\frac{\sin(\alpha)}{\lambda} + \frac{1}{d}) + \varphi_0] \qquad (5)$$

$$U_{-1}(x,y)=\frac{1}{2}T_1 A\exp[j2\pi x(\frac{\sin(\alpha)}{\lambda}-\frac{1}{d})-\varphi_0] \quad (6)$$

obviously the output from the grating includes three trains of waves with different diffraction angle, from them one is $U_0(x,y)$ which propagates along the original incident direction of incident laser beam, the second part and third is $U_{+1}(x,y), U_{-1}(x,y)$ respectively, they are a pair of conjugated waves, their diffraction angle is β_+, β_- separately which meets the following equations

$$\sin(\beta_+)=\sin(\alpha)+\frac{\lambda}{d} \quad (7)$$

$$\sin(\beta_-)=\sin(\alpha)-\frac{\lambda}{d} \quad (8)$$

after being focused by the cylinder lens with focus length f on CCD, the positions coordinates of the zero order, the positiver and the negative first order can be calculated by

$$\begin{cases} x_0 = f\tan\alpha \\ x_+ = f\tan\beta_+ \\ x_- = f\tan\beta_- \end{cases} \quad (9)$$

from above expressions, we can get the formula of wavelength

$$\lambda = d[\sin(\arctan(\frac{x_0}{f}))+\sin(\arctan(\frac{x_1}{f}))] \quad (10)$$

From above deduction, we can see, the fact that there is no higher orders diffraction except the zero and first orders in the diffraction pattern of sinusoidal grating is benefit to simplifying the algorithm for wavelength and angle discrimination and because the diffraction energy of laser is distributes among the zero and first order, it is helpful for the ratio improvement of signal to noise of optical system.

3 The parameters choice of optical elements

According to the technical demand the wavelength span is from 500nm to 1100nm the wavelength resolution is less than or equal to 10nm and the filed of view is 22.5^o, we can build the following equation

$$f\tan(11.5^\circ)\le Nd/2;$$

$$\Delta\alpha=\frac{\Delta x_0}{f}\cos^2(\alpha)\le 1^\circ(0.0174 radian);$$

$$d(\sin(\beta_+)-\sin(\alpha))=\Delta\lambda<10\text{ nm} \quad (11)$$

At the end, we choose f=25 mm, grating density $d=1/300$ grating size 2.5×2.5 cm^2.

4 The selection of driving frequency of CCD

The sensitivity of the laser warning receiver has to reach 10mW/cm^2, and Laser warning receiver always works in harsh circumstance, in the spectrum span between 500nm and 1100nm the background noise from the sun is very great , which may lead the CCD to be saturated, therefore the effective extraction of laser signal from background is the foundation of the selection of Driving frequency of CCD. because the duration of laser pulse is short for example ,$\tau\approx$10ns the peak power is great, but the integration time of liner CCD is millisecond level, during the integration time the useful integration for the laser signal is just several nanoseconds,other time mainly is used to integrate the background noise, the effective way to improve the ratio of signal to noise is to increase the driving frequency of CCD, to decrease integration time .

We can take sun as a blackbody radiant source with 5900K. Its radiance is

$$M(\lambda,T)=\frac{2\pi hc^2}{\lambda^5(e^{\frac{hc}{\lambda kT}}-1)}=\frac{c_1}{\lambda^5(e^{\frac{c_2}{\lambda T}}-1)}(w\cdot m^2\cdot\mu m^{-1}) \tag{12}$$

where λ is wavelength, h Planck constant, T absolute temperature, c velocity of light, $k=1.38\times10^{-23}W\cdot m^2$. Bolzman constant, $c_1=2\pi hc^2$, $c_2=\frac{ch}{k}$. The stretch solid angle of the earth to the sun is about $\Omega=6.8\times10^{-5}sr$, the illumination Of the surface of the earth from the sun is

$$E_{sun}=\frac{M(\lambda,T)\Omega}{2\pi}(W\cdot m^{-2}\cdot\mu m^{-1}) \tag{13}$$

In order to further decrease background light, a lens-hood with 24°plane angle , equivalent to solid angle, Ω_2=0.1372sr is used before the Grating, so the illumination entering into the surface of grating is

$$E_{grating}=\frac{E_{sun}\Omega_2}{2\pi}=\frac{M_\lambda(T)\Omega_1}{2\pi}\frac{\Omega_2}{2\pi} \tag{14}$$

supposing the spectral response function of The CCD is $\Psi(\lambda)$, then during the spectral range CCD, the effective optical power is

$$E_{eff}=\int_{0.5}^{1.1}E_{grating}\cdot\Psi(\lambda)d\lambda(W\cdot m^{-2}) \tag{15}$$

referring to the typical spectrum response, from equation (13) using digital integration , we can get $E_{eff}=5W/m^2$.

If the least laser power which the laser warning receiver can detect is P_M=10mW/cm^2, the length of the CCD pixel is 14μm, the size of sinusoidal grating is 2cm×2cm, whose diffraction efficiency is 25% , the focus occupied 5 pixels, the illumination from laser is

$$E_{laser}=10mw/cm^2\cdot25\%\cdot2cm/(14um\times5) \tag{16}$$

in the spectral range from 500nm to 1100nm, when the wavelength is larger than 1000nm, the sensitivity of CCD decreased by 20% or more, for example, for the wavelength of CO_2 laser , 1.06μm, $\psi(\lambda)$ decreased by 15%, no loss representative, taking the duration time τ= 10ns, then the lowest ration of signal to noise is

$$SNR=\frac{E_{laser}\times15\%\times\tau}{E_{ef}\Delta t} \tag{17}$$

there Δt is the integration time of the CCD, if $SNR=1$, we obtain $\Delta t=178us$ .If output of CCD is separated into two parts, each part includes the output of 1024 pixels, we can make the conclusion that the Driving frequency of CCD is no less than 6MHz.

5 The circuit design of the laser warning Receiver

Based on the measurement principle and parameters choice of the Laser Warning Receiver, combining with the requirement of response time (less than 0.1ms),we finished the design of electronic circuit of optoeletronic system. A TMS320VC5509 and AviiVA™M2 CL CameraLink™ Line scan Camera from ATMElT company and a Single Chip Computer 89C2051 have been used, as showed in Fig.2, the electronic circuit is composed of Signal Sampling Module, Signal Processing Module, Information Exchange communication Module, and Information Display Module, the circuit module fulfills the opeoelectronc information sampling of diffraction pattern, thecalculation of wavelength and incident angle, and Information Display and so on.

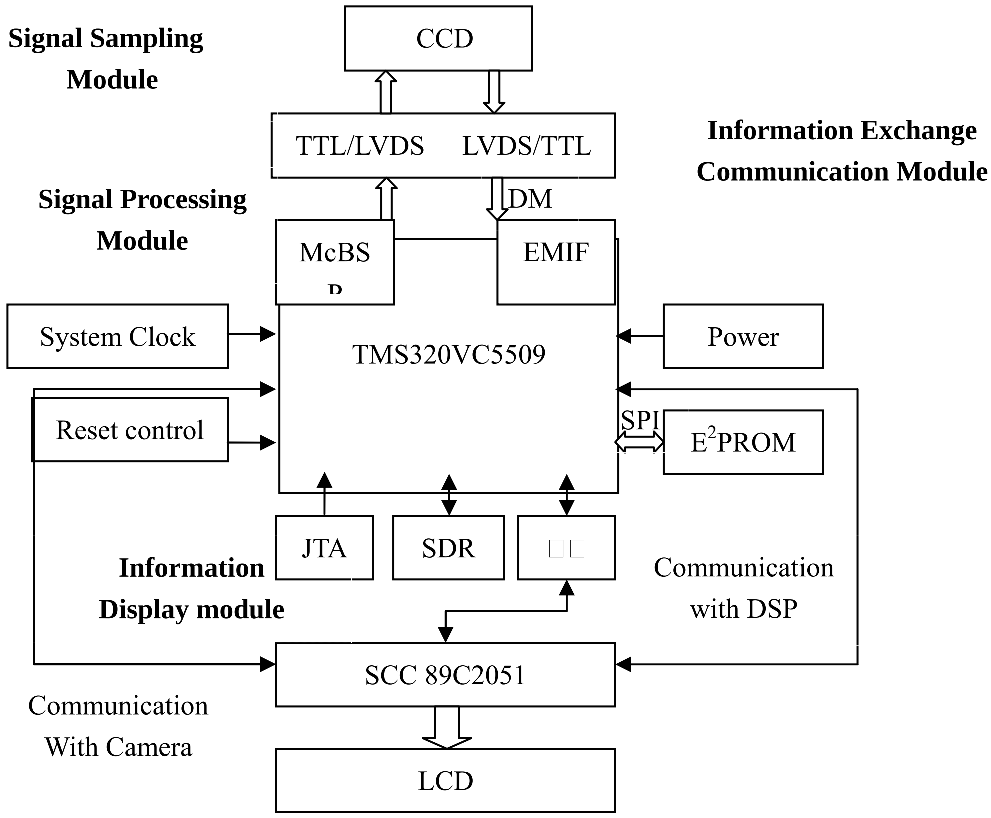


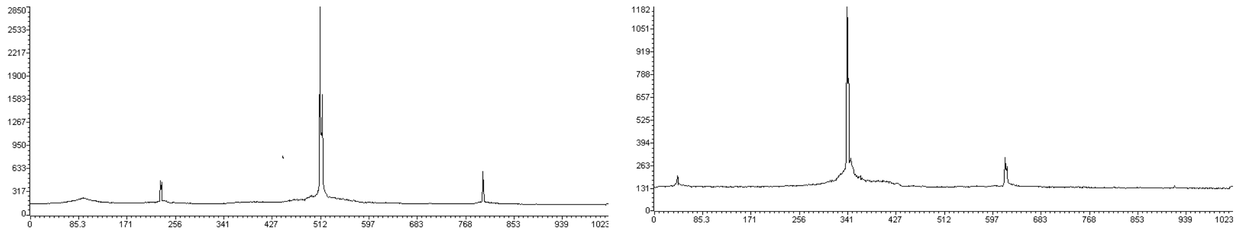
Fig.2 Optoelectronic detecting system of laser warning receiver

6 The prototype of laser warning receiver and actual measurement results and conclusion

The theory analysis and the development of prototype indicated that Using Sinusoidal transmission Grating, CCD and High speed DSPs, we can measure the wavelength and incident angle of pulse laser, the prototype can meet the following performance:

Optical Spectral range is 500-1100nm, the resolution of wavelength is 10nm, the duration time of pulse laser is no less than 10ns, the peak power of being measured laser is no less than 10mw/cm^2, the Field of view is 22.5^o and the angle resolution is less than 1^o.

Fig.3 The prototype of laser warning receiver and display results



(a) (b)

Fig.4 The laser diffraction graphs collected by CCD, when wavelength is 532nm and incident angle is zero(a), and 11^{o}(b)respectively

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