AN OPTICAL HETERODYNE RADAR SYSTEM FOR POSITION AND VELOCITY DETECTION

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Abstract

An optical heterodyne system for the determination of the position of the light source and also the velocity distribution of the moving target is proposed, theoretically analyzed and experimentally verified.

1. Theory.

Assuming the two light sources have the different optical frequency ω_S and ω_L, the resultant wave front at the photodetector with large aperture generates the beat frequency $|\omega_L-\omega_S|$ component from the output of the photodetector. By using the cylindrical coordinate which originates at the center of the aperture of the photodetector, the beat component is given by

$$i_{beat} \propto \int_0^1 \int_0^{2\pi} \exp(-jur^2/2)\ \exp(-jvr\ \cos(\theta-\alpha))\, d\theta \cdot r \cdot dr \qquad (1)$$

where u and v are given by

$$u=-(2\pi a^2/\lambda)(1/z_S - 1/z_L) \qquad (2)$$

$$v=(2\pi a/\lambda)[(\rho_S/z_S - \rho_L\cos(\theta_S-\theta_L)/z_L)^2+(\rho_L\sin(\theta_S-\theta_L)/z_L)^2]^{1/2}, \qquad (3)$$

ρ, θ and z are the coordinate components of the light source, λ is the optical wavelength. and a is the aperture of the photodetector.

The equation (1) can be solved by the Lommel functions[1] U and V as

$$i_{beat}^2 \propto (2/u)^2[U_1^2(u,v)+U_2^2(u,v)] \quad \text{for } |u/v| \leq 1 \qquad (4)$$

or

$$i^2_{beat} \propto (2/u)^2[1+V_0^2+V_1^2 - 2V_0\cos\Theta - 2V_1\sin\Theta] \quad \text{for} \quad |u/v| \geqq 1 \qquad (5)$$

where

$$\Theta = (u + v^2/u)/2 \; . \qquad (6)$$

This solution is illustrated as in Fig. 1 which is equivalent to the intensity distribution of the ordinary simple focusing lens.

So it can be concluded that the optical heterodyne system is equivalent to the lens, but has the sharper dispersion (depending on the bandwidth of the receiver) and no aberration. By using this system, the position of the light source is determined by the scanning of the one source ω_L, and also the velocity of the source is detected by the Doppler frequency shift.

2. Experiment of the transversal and longitudinal resolution

The output light of the He-Ne laser (633nm) is split into two, one of which is fed through the optical frequency translator by $LiNbO_3$ crystal where the optical frequency is shifted by 10.7 MHz, and illuminate the two pinholes, which simulate the point sources.

Changing the aperture of the photomultiplier, the resolution is measured scanning the position of one pinhole. The transversal resolution at 6 mm aperture is 50 μm, and longitudinal resolution is 12 mm, which agree well with the theory, and correspond to the conventional optical system with same aperture.

3. Measurement of the velocity distribution

A reflecting mirror is stuck on a vibrating speaker cone. The light in focused onto the mirror. The reflected light is mixed with the scanning local light. The beat component from the photomultiplier is detected by the frequency discriminator. This output corresponds to the vibrating velocity. In fig.2, the two vibrating mirrors at different frequency (250 and 500 Hz), discriminated spatially.

4. Conclusion

Because the disturbance of the wavefront spoils the optical heterodyne, this method is applied within a relatively smaller area than the conventional laser radar. However, this method can be applied when the distances for the transversal and longitudinal directions are necessary, or when the velocity distribution should be measured.

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References

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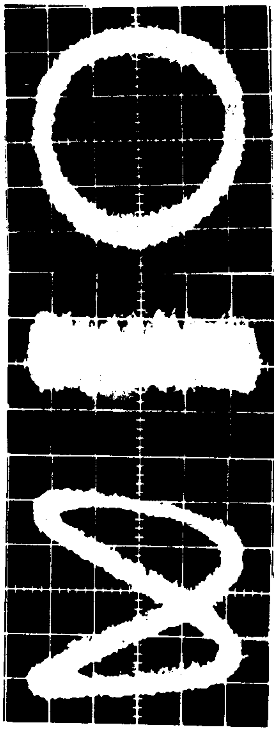

Fig.2
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a)results of the detection of the position and velocity.
(a) A light source moving at 500 Hz,
(b) position between sources (a) and (b) separated by 800μm,
(c) another light source moving at 250 Hz.

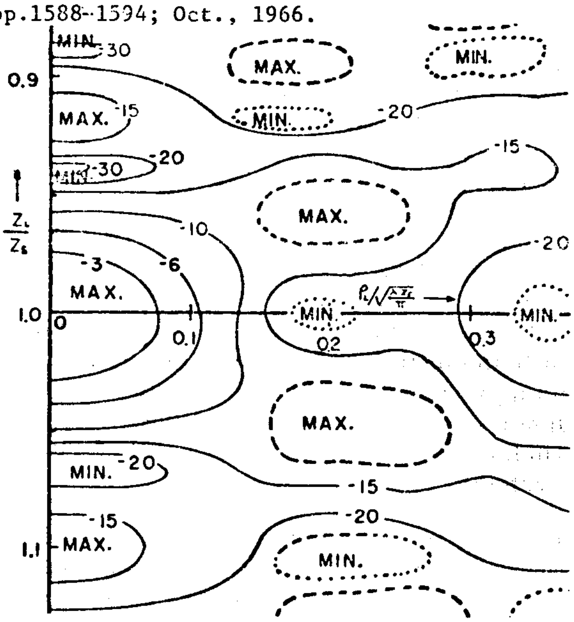

Fig. 1. Intensity distribution by the optical heterodyne (equations (4) and (5)). Numbers by contour are in dB. $\rho_s = 0$.