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Properties of cat-eye modulating retro-reflector and its application with piezoelectric transducer

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ABSTRACT

Piezoelectric cat-eye modulating retro-reflector (MRR) is the core component of an acousto-optic retro-identification system. The influence of the optical parameters (link distance l, lens focal length f and the detector diameter r) to the cat-eye effect was analyzed theoretically and experimentally. A piezoelectric cat-eye retro-identification (PCERI) system was built, and an information transmission ratio of 2 kHz was achieved which can satisfy an access control system.

1. Introduction

MRR has been successfully applied as a core component in free space optical communication system for out space or under marine circumstance since 1990 [1–7]. Corner-cube-based MRR and cat-eye MRR have been developed by coupling with all kinds of modulators such as voice coils, piezoelectric transducer, ferroelectric liquid crystals, microelectromechanical system (MEMS) devices, and multiple-quantum-well electro-absorption modulators. Using multiple-quantum-well MRR, W.S. Rablnovlch et al. built a 1550-nm eye-safe, free space optical communication link over a distance of 2 km with a data rates up to 5 Mbits/s and a bidirectional link across 16 km with the data rate of 2 Mbit/s [1,2]. A MRR-type communication link was built by Linda Mullen for the study of the optical propagation in the underwater environment [3]. Glaser presented some design examples of cat-eye array retro-reflectors applied on optical smart cards for access control identification [4].

Compared to corner-cube-based MRR, cat-eye MRR is more prevail on the view of identification application, due to the relatively larger optical aperture and a wide view field. Optical path theoretical researches of cat-eye MRR have been reported elsewhere [8,9], however the experimental researches about out-of-focus cat-eye MRR, are few and far between, especially the ones with piezoelectric modulators. Piezoelectric devices which can be easily driven are usually employed as a kind of modulator for their abilities of controlling the amplitude, the frequency and the phase of micro-displacement.

This piece of work focused on the modulation efficient of out-of-focus cat-eye MRR by changing the related optical parameters (l, f and r) and introduced a PCERI system that is capable of transmitting data stream.

2. Theory

The integration free space communication link contains two terminals: an interrogator which includes a light source and a detector, a cat-eye MRR which constitutes of a lens and a reflector "R" on its focal plane "F". The light beam illuminating the MRR would be passively reflected back in the original path to the interrogator and collected by the detector which is placed on the same location as the light source. The principle characteristic of cat-eye MRR is that the modulation information can be loaded on the light by periodically changing the position of the reflector. This is due to the dramatic decline of the reflected light intensity when the reflector is forced out-of-focus within a micro-displacement (in dozens of micrometer).

Assuming that the incident light is a geometry parallel light source, the reflected light can be solved with geometrical optics method [9]:

$$\begin{bmatrix} y_2 \\ a_2 \end{bmatrix} = M_0 \begin{bmatrix} y_1 \\ a_1 \end{bmatrix} \quad (1)$$

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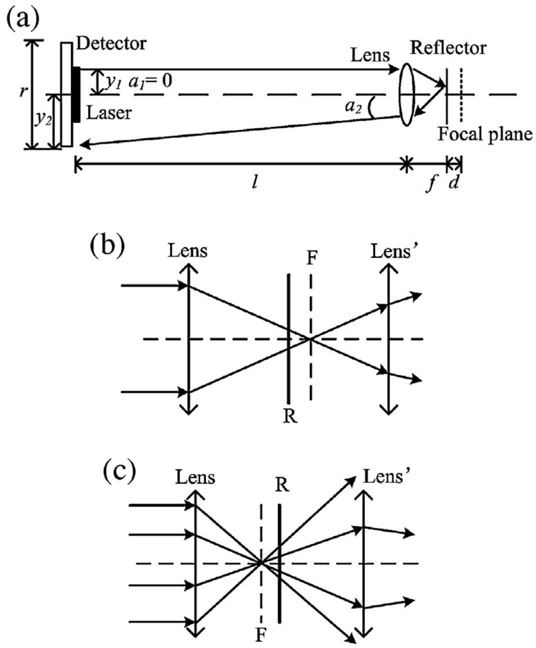

Fig. 1. (a) Equivalent beam path of cat-eye MRR. (b) Forward state. (c) Backward state.

where y_1, a_1 are the off-axis height and angle of the incident light respectively, while y_2, a_2 are the corresponding index of the reflected light, M_0 is the transformation matrix of the out-of-focus cat-eye MRR

$$M_0 = \begin{bmatrix} -1 - \frac{2d}{f} + \frac{2ld}{f^2} & 2\left(f + d - l - \frac{2ld}{f}\right) + \frac{2l^2 d}{f^2} \\ \frac{2d}{f^2} & -1 + \frac{2ld}{f} - \frac{2d}{f} \end{bmatrix} \quad (2)$$

Here l is the distance between the interrogator and the MRR, f is the focal length of the lens, and d stands for the displacement of the reflector out-of-focus.

Eq. (1) describes the beam prosperities of the reflected light according to the position of the reflector, as shown in Fig. 1(a). Two states for the reflector: the forward state and backward state are shown in Fig. 1(b) and (c) where equivalent beam path is adopted.

Simulations evaluating the ratio of the reflected light intensity to the incident intensity with d were developed by setting l, f and the diameter of the detector r as parameters. Assuming that the incident spot diameter is 3 mm, the reflected ratio changes to d with different values of l (f = 25 mm, r = 3 mm) are shown in Fig. 2(a). It reflects three aspects: (1) increasing displacement leads to pronounced decrease of the reflected intensity because of that the reflected light is unparallel and diverging when the reflector is out-of-focus; (2) in the case of forward state (the displacement value has a negative sign), the reflected ratio is 100% within a small forward displacement, unlike the immediate decreasing response in the backward case as the reflector moved out-of-focus, this is due to that as the reflector moves forward generally, though the reflected light beam becomes diverging, its spot size is smaller than the incident one when the two terminals are close, Fig. 1(b); and (3) the reflected ratio declines faster in longer link within a same out-of-focus displacement because of the divergence of the reflected light leading to fewer proportion of light collected by the detector, as shown in Fig. 1(b) and (c). The corresponding simulation results for various f (l = 3 m, r = 3 mm) and r (l = 3 m, f = 25 mm) are shown in Fig. 2(b) and (c), which suggest that the reflected ratio declines faster with smaller f and r.

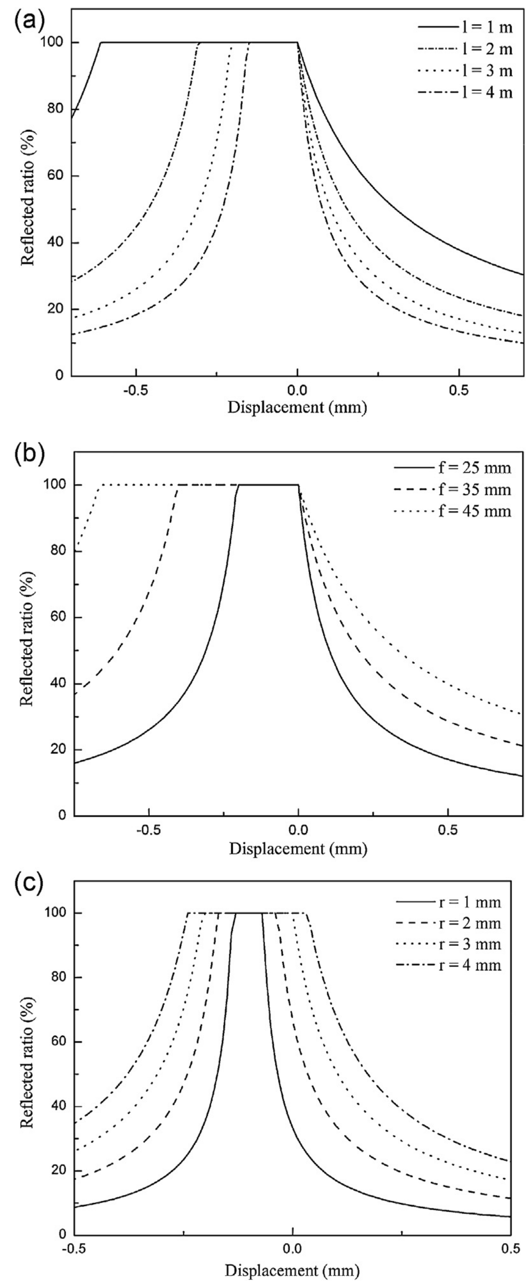

Fig. 2. Influence of the optical parameters on the reflected ratio. (a) The displacement scan of reflected ratio with various l. (b) The displacement scan of reflected ratio with various f. (c) The displacement scan of reflected ratio with various r.

Refer to the application of signal identification, in order to get high resolution signal, large decreasing of reflected light intensity within small displacement of the reflector is preferred. By the analysis above, it is obviously that strong cat-eye effect could be achieved by increasing l and decreasing f or r. In these ways, the reflected ratio of the incident light will dramatically decline, and the incident intensity could be modulated effectively within a small displacement of the reflector.

3. Experiments results and discussion

3.1. Cat-eye effect

The schematic diagram of the cat-eye effect experimental set-up as shown in Fig. 3 contains two parts: the interrogator and the