Ferroelectric Liquid Crystal Dammann Grating: for LiDAR Applications

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ABSTRACT

We propose a ferroelectric liquid crystal Dammann grating (FLCDG) based polarization modulated depth-mapping system. Innovatively, FLCDG is used as high-speed shutter in this system. The application of FLCDG enables LiDAR as one-shot capturing system instead of iterative scanning. Moreover, the proposed device shows a fast data-collection time period (50μs) for per 49 points that can be further increased depending on the damman grating, and provide low cost solution to the problem.

1 INTRODUCTION

Light detection and ranging (LiDAR), a laser ranging technology, adopts active laser light source to achieve three-dimensional-imaging (3D-imaging). Compared with other depth-mapping techniques [1-2], LiDAR system which shows strong anti-interference ability, high ranging accuracy, small volume, and light weight has high affinity to aerospace, autonomous vehicles, long-distance nanometer-scale ranging and nondestructive measurement of micro-vibration target [3-5]. For now, variable ranging methods are applied, ranging from geometric optical ranging method, pulse time-of-flight ranging method, phase method, frequency-modulated continuous wave ranging method and polarization modulation ranging method.

Among the approaches mentioned above, polarization-modulated laser ranging technology [6] analyzes and extracts the distance information to be measured by optical effects, reducing the distance error introduced by the photoelectric conversion process and the circuit system. As a result, using electro-optic modulation can effectively 1) reduce the impact of noise, 2) improve the accuracy of ranging, and 3) achieve long-distance high-precision ranging. Apart from that, it shows promising ability in using the area array detector [7] to obtain the target distance in laser 3D-imaging, which is a hot topic recently. However, bottlenecks still exist [8-9], the accuracy, response time and cost performance based on these methods are limited by some factors: laser pulse width, time resolution of time-to-digital conversion chip, detector bandwidth, shot noise and time error generated by electronic circuits.

In this paper, derived from the demands of economical, high-resolution and fast-response three-dimensional-imaging (3D-imaging) for light detection and ranging (LiDAR) applications, we disclose a ferroelectric liquid crystal Dammann grating (FLCDG) [9] based polarization modulated depth-mapping system. The proposed method aims to break the barriers in four aspects, 1) Substitute traditional raster scanning system with one-time projection to whole target 2) Speed up the scanning time by utilizing the diffractive spot array generated by DG and FLC material's electro-optic effects such as fast response 3) Shorten the pulse width based upon the fast switching speed.4) Improve the front of view by using switchable diffraction states of FLCDG. This method is expected to enable LiDAR for a larger scope of applications that require fast response, high resolution with significantly lower cost.

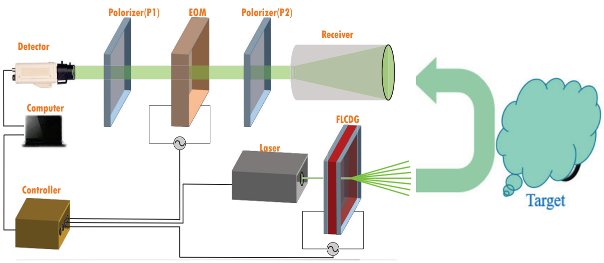


Fig. 1 schematic diagram of ferroelectric Liquid crystals Dammann grating for Light Detection and Ranging Devices

2 EXPERIMENT

This section describes the details about system and experimental principles.

2.1 FLCDG based polarization modulated depth-mapping system

The schematic diagram of the FLCDG based polarization modulated depth-mapping system is shown in Fig. 1. This system includes a transmitter having a laser and one diffracting Damman grating component and a receiver. Specifically, in the part of transmitter, laser is utilized as the illuminator to emit a linear polarized light beam (wavelength=532nm). The cell-superposition structure includes a ESHFLC cell without DG pattern and a FLCDG. This combination works as a high-speed shutter and an optic splitting apparatus to form diffractive spot matrix on a target based on diffract-

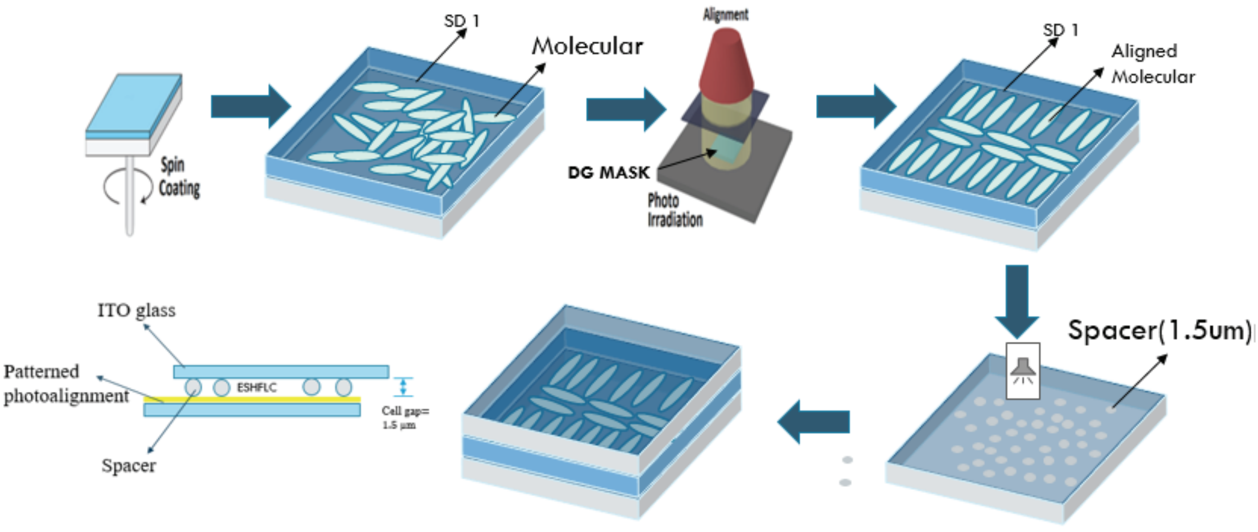


Fig. 2 Fabrication process of FLCDG

tion order of Dammann grating. As shown in Fig. 2 the Dammann grating liquid crystal cell includes two transparent substrates coated with the current conducting layer, one patterned alignment layer coated on SD1(dissolved in dimethylformamid (2 wt %)), wherein the alignment layer is patterned to satisfy the Dammann grating phase profile. Moreover, an electric suppressed helix ferroelectric liquid crystal layer sandwiched between the said two transparent substrates. In the part of receiver, the polarization state of electro-optic provides time-resolution image returned from the target. Then the CCD camera detects the light intensity of the received spots. The traditional raster scanning can be divided into two categorie:1) point-by-point scanning based on single point detector.2) line-by-line scanning based on array detector [3]. Whereas, the DG based Lidar system, because of the diffraction profile of DG having eqal intensity points of the first order diffraction, and the fast response of FLC material, enables one-shot capture, which is significantly faster than the conventional system. Thus, the additional time required for raster scanning is no longer needed.The total scamming time can be reduced to 50μs for 49 spots (DG size:7x7). The total speed for data-collection is expected to reach 58 million points per second. The commercial device can acquire the data at 2.4 million points per second. It is obvious that the data-collection speed is 24 times faster than the commercial system. In sum, the FLCDG based LiDAR system shows promising ability of one-shot capturing with wide FOV and short response time.

2.2 Principle

For polarization-modulated approach, as shown in Fig. 1, when the voltage is applied across the EOM, the polarized light's phase retardation of the LC cell (EOM) is proportional to the applied voltage, which can be expressed as [5]

$$\Gamma = \frac{2\pi n_0^3 r}{\lambda} V(t) \qquad (1)$$

In this expression, n_0 is the ordinary refractive index of the LC cell, λ is the laser light wavelength, V(t) is the voltage applied on EOM and r is electro-optic index. Since the triangular AC voltage is applied on the EOM, the relationship can be simplified as:

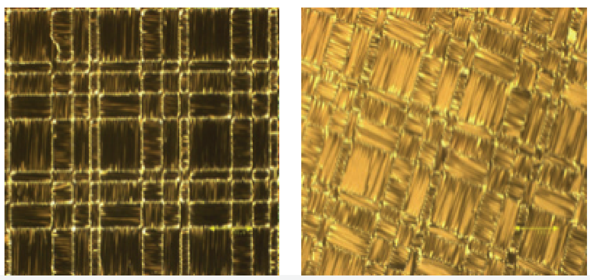
$$\Gamma = \frac{\pi}{T_r}(t - t_0) \qquad (2)$$

Where T_r is the rise-time of applied voltage, t_0 is the delay time.

Since different targets with different location would have different time for round trip. Then the relationship of distance and phase retardation can be deduced based on the relationship between time and phase retardation:

$$\Gamma = \frac{\pi}{D}(L - L_0) \qquad (3)$$

Where D is the initial distance induced by the gate opening. L_0 is the base range corresponding to the start point? L is the distance between target and object.



(a) (b)

Fig. 3 Micro-graph of (a)non-diffractive state (b)diffractive state

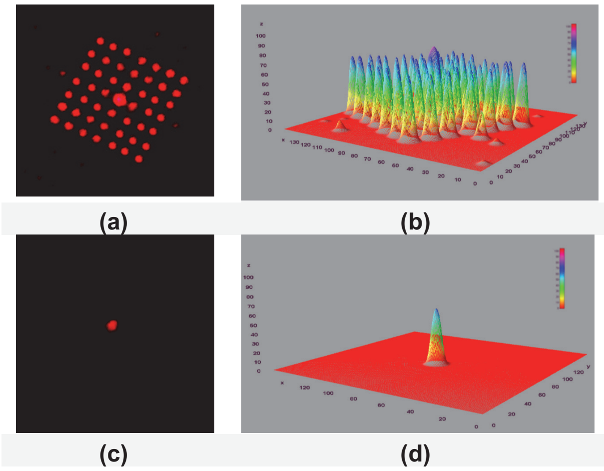


Fig. 4 Diffractive pattern for (a)diffractive state (b)non-diffractive state and (c) (d) corresponding intensity graphs

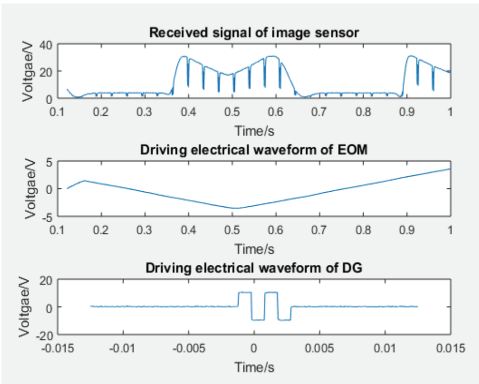


Fig. 5 The received signal (top) and the driving electric waveform of EOM (middle) and DG (bottom) of one point

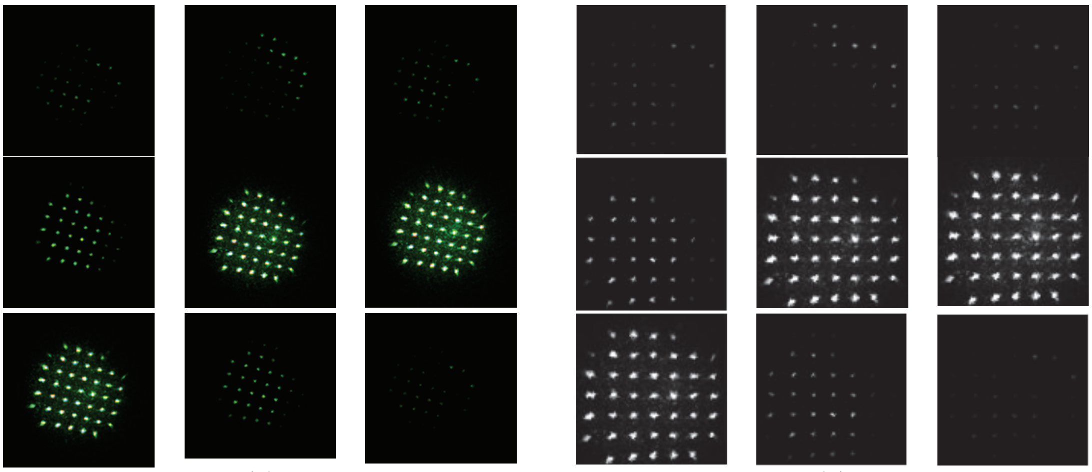
3 RESULTS

The results of the FLCDG and the verification of the method are introduced in this section.

The switchable states of FLCDG are shown in Fig. 3, (a) and (b) are the micro-graph of non-diffractive state and diffractive states, respectively. The corresponding diffractive patterns are demonstrated in Fig. 3(a) and (b). The corresponding intensity graph of non-diffractive state and diffractive state are shown in Fig. 4.

For one spot, the relationship between intensity of polarized light and depth of the extracted information is shown in Fig. 5. To be specific, 10 Hz triangular wave and 500 Hz square wave are applied on EOM and FLCDG, respectively. The corresponding modulated signal with time-resolution information is received. After calibrating the normalized intensity map of the received real images with periodic variation(Fig, 6). As shown in Fig. 7, the feasibility of the system is verified by comparing the intensity of polarized light and depth of the extracted information.

Based on the results, to the best of our knowledge, our application of FLCDG enables LiDAR as one-shot capturing system based on continuous-wave laser instead of iterative scanning for the first time. Compared with previous work, it shows promising potential for three reasons. Firstly, the scanning speed for fastest commercial LiDAR system is 2.4 million points per second [11]. The proposed method potentially has 50μs response time for 7×7 array of DG. Secondly, 360-degree front of view is achieved. Thirdly, the switchable state of FLCDG can produce more flexible viewing angle for different targets and in different environment.



(a) (b)

Fig. 6. (a). The real images with periodic variation (9 images from left to right, top to the bottom at left hand side belong to one period) captured by CCD at 1400fps. (b). The corresponding normalized intensity maps after calibration.

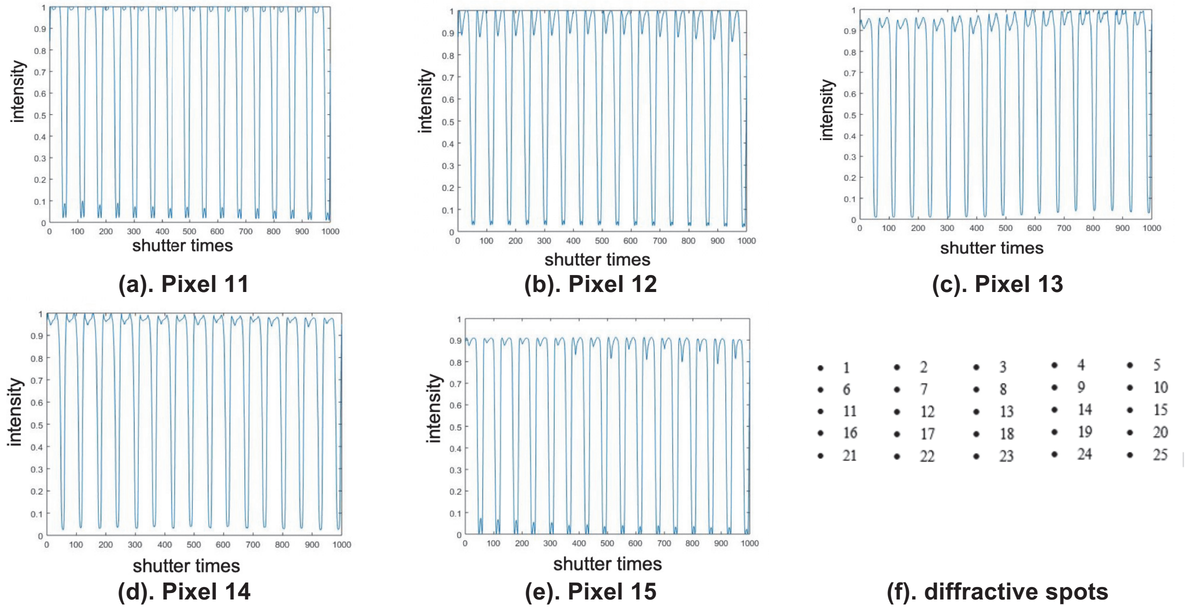


Fig. 7 (a-e). The received intensity versus shutter times of the pixels at the third row.
(f). The schematic graph for corresponding number sequential of the spot array generated by DG.

4 CONCLUSIONS

Innovatively, FLCDG is used as the high-speed shutter in our system. It has two benefits, firstly, the data collection procedure can be speeded up (50μs) by replacing the raster scanning system with one-time projection for whole target and cell-superposition structure. Specifically, DG can generate diffractive spots matrix, which is wide enough to capture the whole front view in only one shot, thus, the scanning time can be avoid by one-shot capturing. Secondly, the cost of LiDAR can be reduced significantly by using fast switching FLC. For summary, the one-shot capturing system based on FLCDG is a promising option for LiDAR and 3D imaging applications.

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