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BOPSCAN Technology:
A methodology and implementation of the billion point optical scanner

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Abstract

Fast microsecond regime beam switching speed, low control power, optical scanner is proposed using thin-film polarization switching devices and passive polarization sensitive beam steering optics.

Introduction

The non-mechanical inertialess optical scanner is a critical building block in numerous optical applications ranging from laser communications, optical storage, and three dimensional (3-D) displays. Perhaps, the ultimate goal of the scanner industry is to realize a low cost 3-D scanner that can rapidly and efficiently scan a volume with 1000 x 1000 x 1000 or a billion points [1]. This also means that such a scanner must have a billion degrees of freedom, a non-trivial task from a device control point of view. So far, approaches for 3-D scan involve mechanical non-inertialess aspects. In this paper, we describe, perhaps for the first time, a solution to achieving this billion points

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scanner [2]. Our approach is to use planar active (electronically programmable) and passive thin-film polarization sensitive optics in a compact LEGO-like stacking or cascaded binary switching architecture to form the desired 3-D scanner. We call our approach BOPSCAN Technology: *Binary Optical Polarization Sensitive Cascaded Architecture Network Technology.* Our non-mechanical optical scanner features include microsecond regime beam reset times, low (e.g., mW levels) control power and low complexity drive electronics, large (several cms) or small (few hundred microns) scan beam active aperture sizes, very large number of scan beams (over a billion), very few control signals (e.g., only 30 signals for a billion point scan), high throughput efficiency (e.g., > 50 %), and most importantly, potential for low cost.

BOPSCAN Technology High-Speed Optical Scanner: Theory

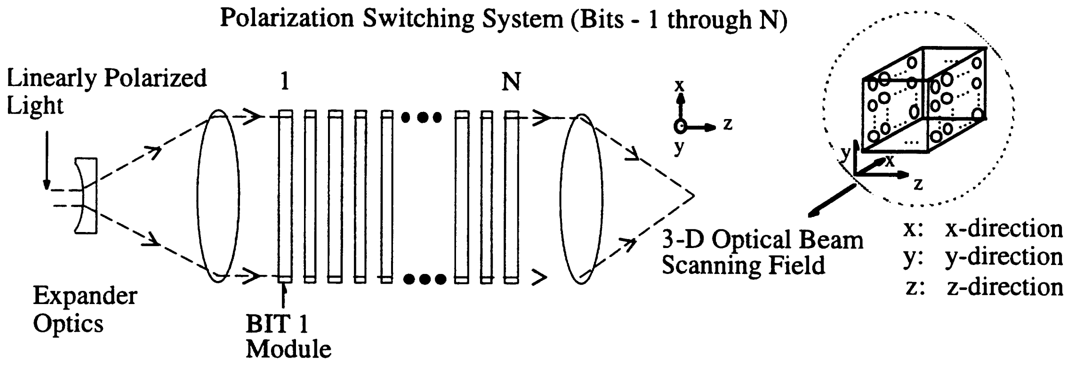


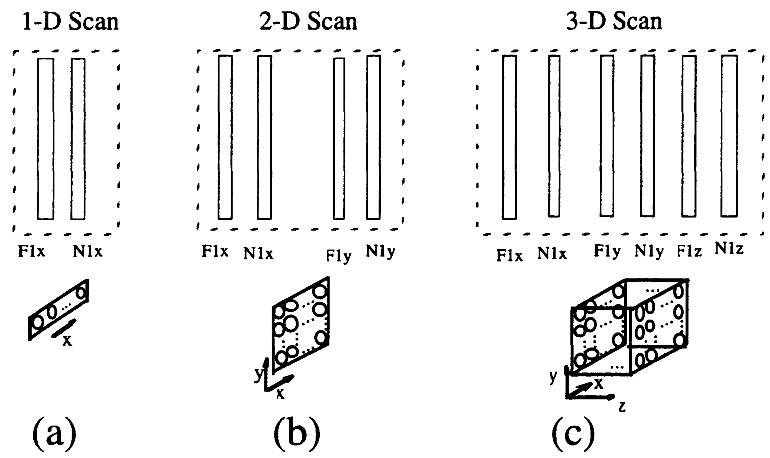
Fig.1 BOPSCAN technology high-speed optical scanner.

First we describe the basic philosophy we use to solve this billion point scanner problem. As we need to scan in 3-D space, e.g., (x,y, z) cartesian coordinate space, we separate the 3-D beam control problem into three independent scanner control signal dimensions. In otherwords, we will independently control three separate scanners, one for the x, one for the y, and one for the z-scan direction. For the simple case where we need K scan points per cartesian dimension, or K^3 total scan points (voxels), we need a control structure per dimension that efficiently produces K scanned beam points. Our approach is to use the well known binary switched cascaded N-bit control structure where switching the N binary optical control modules results in 2^N optical states for the scanner. As there are three independent optical control structures for the x, y, and z scan directions, this results in a total $2^N \times 2^N \times 2^N$ optical states for our scanner. Hence, as our goal is a billion point scanner, N=10 bits achieves this goal. In effect, we control only 3N or 30 binary optical switching modules to get a billion degrees of control, a far cry from other optical scan control methods.

As we have solved the billion degrees of freedom control problem, the next question is what optical implementation fits the key scanner specifications such as a binary cascaded structure, low control power consumption, and fast microsecond domain switching speed. Our approach is to utilize the high speed binary switching nature of thin-film active polarization optics (hence, the binary control structure) in cascade with passive or slowly programmable polarization sensitive optics such as birefringent plates. Fig.1 shows a cartesian coordinate scan domain optical implementation of our proposed BOPSCAN technology optical scanner. Linearly polarized light is expanded and collimated for entry into the scanner. N planar optical modules are sandwiched together to form the heart of our N-bit scanner. Each single bit module contains active polarization switches and passive polarization sensitive beam steering optics.

Scanner Implementational Issues

Fig.2 shows the basic options for the BIT 1 modules for this 1-D, 2-D, and 3-D scanner. The F1's are the BIT 1 fast 90 degree polarization rotators, such as thin-film cells made from high speed microsecond regime binary ferroelectric liquid crystal (FLC) device technology. Each FLC cell is a single pixel device that requires a single



F1: Single Pixel 90° Polarization Switch : N1: Birefringent Plate

Fig.2 shows the basic options for the BIT 1 modules for the (a) 1-D, (b) 2-D, and (c) 3-D scanner.

binary square wave voltage drive signal. The component labels with the x, y, z subscripts relate to their specific scan directions. The N1's are BIT 1 module polarization sensitive passive or slowly programmable phase masks. For instance, the N1's could deflect light for one input linear polarization while not deflecting light for the orthogonal input linear polarization. There are several options for the N1 cells. For instance, if no N1 device programmability is required, N1 can be passive birefringent pre-patterned plates made from a variety of phase mask fabrication technologies such as diffractive optics, nano-optics, photorefractive optics, thin-film optics, polymer dispersed optics, and plastic optics to name a few. The basic idea is to create thin (e.g., < 2 mm) and planar structure birefringent plates for beam deflection and focusing/defocusing functions. For instance, sub-wavelength 1-D gratings can exhibit anisotropic behavior and synthesized effective form birefringence can be implemented. Also, general birefringent phase distributions can be made in polymer dispersed liquid crystal (PDLC) technology or photo-thermal refractive (PTR) glasses. One key feature of using these ultra-thin passive birefringent optics plates is the simplified scanner assembly and lower power scanner drive requirements that lead to overall lower scanner cost. Because of the cascaded nature of our scanner design, all antireflection (AR) coated optical devices, both active and passive, must be used to keep total losses to < 50%. Also, since all optical devices, both active and passive, are thin, e.g., a few mm thick, our scanner can be realized as an ultra-compact (e.g., < 3 cm thickness) optical beam steerer. Substrate reuse can be cleverly employed to reduce overall scanner size.

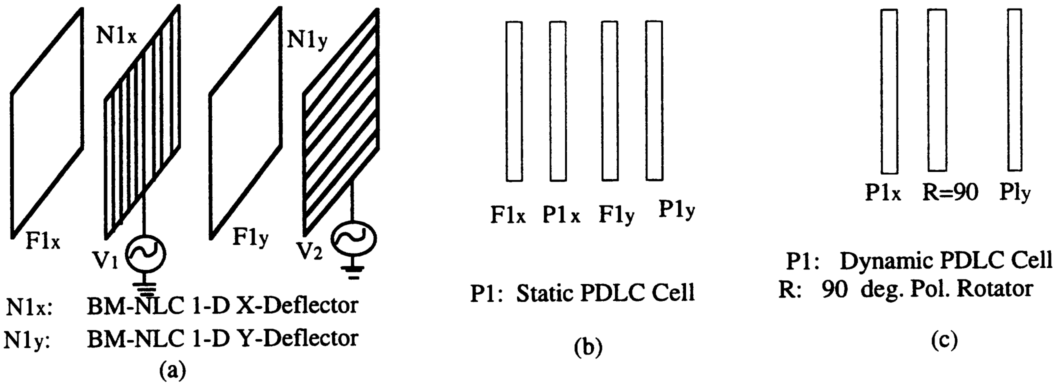


Fig.3 Electronically programmable fine and coarse tuning options for a 2-D scan single bit module. (a) On-chip control electronics single voltage drive BM-NLC device option, (b) passive PDLC device option, and (c) active PDLC device option.

As shown in Fig.3, if some degree of programmability is required for the N's, a good option is to use our recently demonstrated milliseconds domain speed, single voltage control signal BM-NLC devices [3]. Each BM-NLC device has hard-wired on-chip control circuitry that leads to a 1-5 V single drive requirement. In each 2-D scan bit structure of the scanner, one NLC device acts as the variable x-deflector while the other

NLC device acts as the variable y-deflector. The NLC devices have orthogonal molecular directors. F1x selects whether the light must acquire an x-deflection or not. F1y selects whether the light must acquire a y-deflection or not. Hence, by selecting the voltage levels of the FLC and NLC devices, any beam deflection within the 2-D scan zone can be selected with fine and coarse tuning capabilities. For 3-D scan, two single voltage drive NLC cylindrical lens devices are added alongwith one F1z polarization switch. Fig. 3 also shows another option for the single bit structure where three and not four components are required. Here, instead of FLC devices, moderately fast speed (e.g., < 0.5 ms) binary, high-diffraction efficiency, Bragg-matched, PDLC devices are used. In each bit, only the binary electrically controlled PDLC Bragg grating devices are electrically active, with a passive 90 degree polarization rotator between the two PDLC devices. These PDLC devices are orthogonally oriented, with one PDLC device acting as the x-deflector and the other PDLC device acting as the y-deflector to give the 2-D scan. At present, with the application of high voltages (e.g., 80 Vpeak), the PDLC Bragg grating can be essentially erased with a Bragg efficiency drop of 95 %. The key benefits of these electrooptically activated Bragg gratings in PDLCs is their large active areas and wide range of optical beam deflection angles.

Conclusion

Note that because of the LEGO style cascaded nature of our scanner, we have the liberty to insert spatial filter plates at various stages in our scanner so as to clean the light to be transmitted via the output port. Also note that if the spatially coherent light input to our scanners is not linearly polarized, the two input orthogonal polarizations can be separately processed by two parallel structures. Another option is to convert input light to one linear polarization and then process by one structure. Applications for our 3-D (also 2-D and 1-D) BOPSCAN technology optical scanners are diverse and plenty and include 3-D storage, volumetric imaging, 3-D industrial inspection and reconstruction, laser damage-based systems, beam steering in optical/laser communications, 3-D and 2-D displays, Bar code scanners, computer peripherals, and more. Future work relates to the design and experimental demonstrations of these BOPSCAN technology scanners for various system applications.

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