Holographic Line Beam Scanner with Liquid Crystal on Silicon Modulator

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Abstract

A laser scanning device can be used for contour or pattern reconstruction with associated image processing or recognition algorithm. For a better accuracy or accommodating to a high efficiency algorithm, the laser beam often needs reshaping to a specific pattern, such as a line beam, or homogenization so as to reduce the spatial variation of the device performance. In addition, a scanning mechanics is normally inevitable. Both beam shaping and scanning module take quite a volume in the whole system, which could be an issue for the applications in which miniature device is highly desired. In this paper, a holographic scanner has been proposed to perform both laser beam shaping and scanning function. A pure phase modulation liquid crystal on silicon (LCoS) device is used for implementing the dynamic hologram. The LCoS has a pixel size of 3.74μm, and provides 16 phase level with a full phase depth of 2π. A line beam with 20mm and uniformity up to 70% is generated and it is scanned back and forth in the orthogonal direction of the line with a stroke of 20mm. The scanning line pattern is generated based on iterative Fourier transform algorithm (IFTA) and the first diffraction order pattern is exploited with the zero order being blocked and absorbed so that the noise in the scanning line pattern is minimized. The proposed scheme is a compact and versatile solutions for patterned laser beam scanning devices.

Introduction

The market of digital dentistry is growing very fast in recent years, and the technology is moving toward digital process and full automation. Digital CAD/CAM uses intra-oral scanner to get the profile of teeth, which is faster, more efficient and improves the clinic experience to the patients, compared to the traditional approaches. The intra-oral scanner is then the key hardware for taking the digital

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impression. A commonly used approach is to project a line laser beam on the teeth and reconstruct the teeth profile from the distortion of the reflected line beam image [1-2]. For realization, a beam shaper module or component is required to transform the original laser source into a uniformly distributed line beam, and a scanning mechanism, normally a mirror driven by a motor, is required to sweep the line beam over the teeth, as shown in Fig. 1. This combination works quite well and has led to successful products [1-2]. However, the intra-oral scanner is a hand hold device, and compactness is a major concern. Both beam shaper and scanning mechanism take quite a space, and are targets for improvement on form factor. In this paper, dynamic hologram has been proposed as the light modulation device to perform both the functions of beam shaping and beam scanning, which could be a potential solution for future intra-oral scanner. The device for implementing dynamic hologram is phase type liquid crystal on silicon (LCoS)

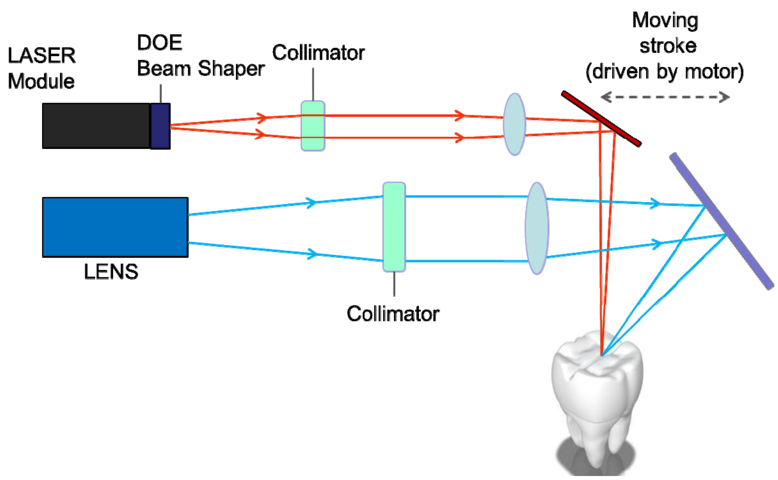

Fig. 1 A laser line scanning scheme for intra-oral scanner

Hologram for beam shaping and scanning

Hologram is a versatile light modulation approach which can perform multi-function of light modulation, such as beam shaping, focus, and image generation etc, with a single component. With the advent of several types of spatial light modulator, computer generated hologram becomes viable and popular. Not only because the realization becomes more convenient than traditional approaches based on recording interference fringe on the film, but also that dynamic and real time modulation becomes possible. One commonly used algorithm for calculating the required phase pattern on hologram for the desired pattern on target plane shown in Fig. 2 is to use the Fourier transform relationship between these two, as indicated in Table 1 for both far field and near field pattern.

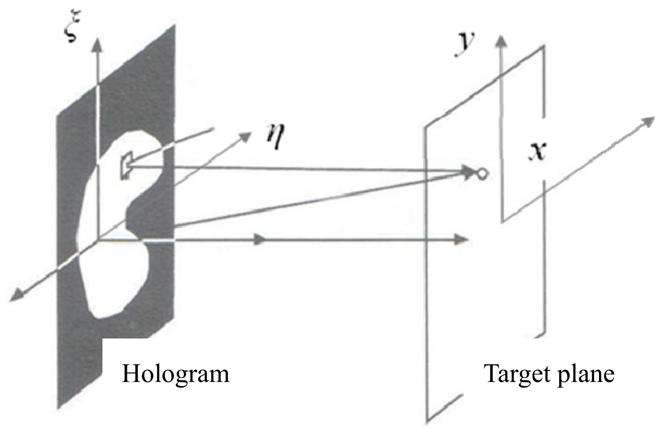

Fig. 2 Denotation of coordinate on hologram and target plane [3]

Table 1. Relationship of the complex amplitude on hologram and target plane [3]

	formula
Fresnel Diffraction	$U(x,y)=\frac{e^{jkz}}{j\lambda z}e^{j\frac{k}{2z}(x^2+y^2)}\int\int_{-\infty}^{\infty}\{U(\xi,\eta)e^{j\frac{k}{2z}(\xi^2+\eta^2)}\}\times e^{-j\frac{2\pi}{\lambda z}(x\xi+y\eta)}d\xi d\eta$
Fraunhofer Diffraction	$U(x,y)=\frac{e^{jkz}}{j\lambda z}e^{j\frac{k}{2z}(x^2+y^2)}\int\int_{-\infty}^{\infty}U(\xi,\eta)\times e^{-j\frac{2\pi}{\lambda z}(x\xi+y\eta)}d\xi d\eta$

The required pattern on the target plane (teeth) is a uniformly distributed line pattern which can be shifted to different position at different time, as illustrated in Fig. 3. The distance between the hologram and the target plane is 100 mm, and therefore near field relationship in Table 1 will be used in the case.

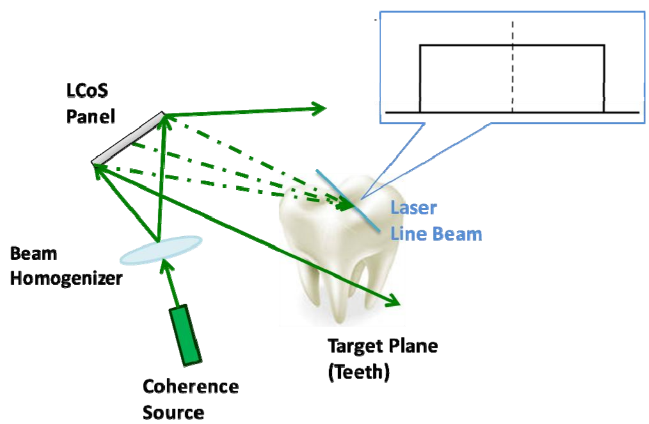

Fig. 3 Illustration of required pattern on the target plane (teeth)

Phase type liquid crystal on silicon for dynamic hologram

The spatial light modulator used for implementing the dynamic hologram is a phase type liquid crystal on silicon provided by Jasper Display, as shown in Fig. 4, and its specification is listed in Table 2.

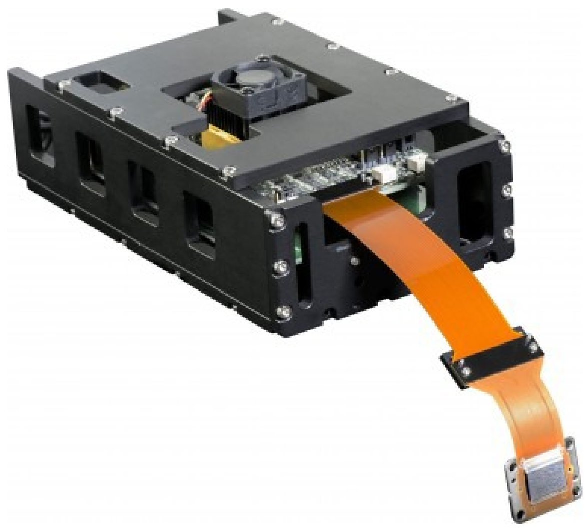

Fig. 4 Phase type LCoS [4]

Table 2. Specification of phase LCoS [4]

ITEM #	JD8554 SDK 1080P
Microdisplay Type	0.55" / 1080P / LCoS / 1-Channel
Power Supply	Input: 100-240VAC 50/60Hz Output: 12VDC/3A, 12VDC/0.5A
Video Input/Output	1080p / 60Hz

LCoS is a reflective element and therefore only phase of the incident light will be modulated. In addition, if the incident polarization align with the principal plane of liquid crystal molecule, the incident light will experience pure phase retardation without changing polarization direction and state, which is the referred to phase type modulation. Consequently, the complex amplitude to be calculated on the hologram based on iterative Fourier transform algorithm (IFTA) leaves only phase term, which is implemented on the LCoS with corresponding driving voltage or gray scale. There are certain amount of gray scale of LCoS panel, which makes itself behave as a dynamic binary optical element. In this study, only two phase levels are used for proving the feasibility.

Prototype and experiment result

Fig. 5 shows the schematic diagram of the whole structure for the holographic line beam scanner, and Fig. 6 shows the experiment setup. The wavelength of the laser beam is 405nm. Laser beam is firstly expanded and collimated before shining on the LCoS panel to make sure the condition matches with that in CGH calculation. Off-axis structure has been used so as to match with the optomechatronic layout in intra-oral scanner.

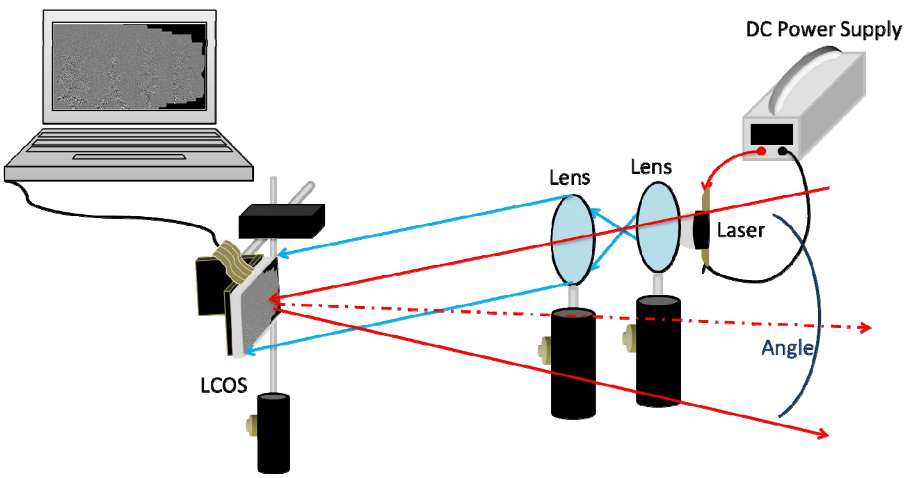

Fig. 5 Schematic diagram of the holographic line beam scanner

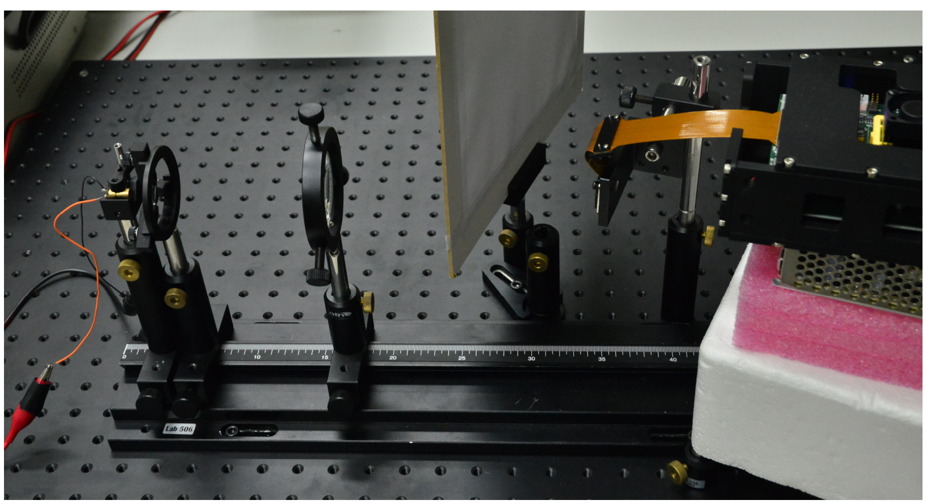

Fig. 6 Experiment setup of the LCoS scanner

Fig. 7 shows the line beam at different scanning position. Due to only two phase level is used in calculating the phase pattern, the diffraction efficiency is not sufficiently high so that several diffraction orders were also generated and disturb the required pattern. Those unwanted diffraction order had been blocked away before the picture was taken. The efficiency can be improved with using higher number of phase level, and putting efficiency as one criteria in the optimization algorithm [5].

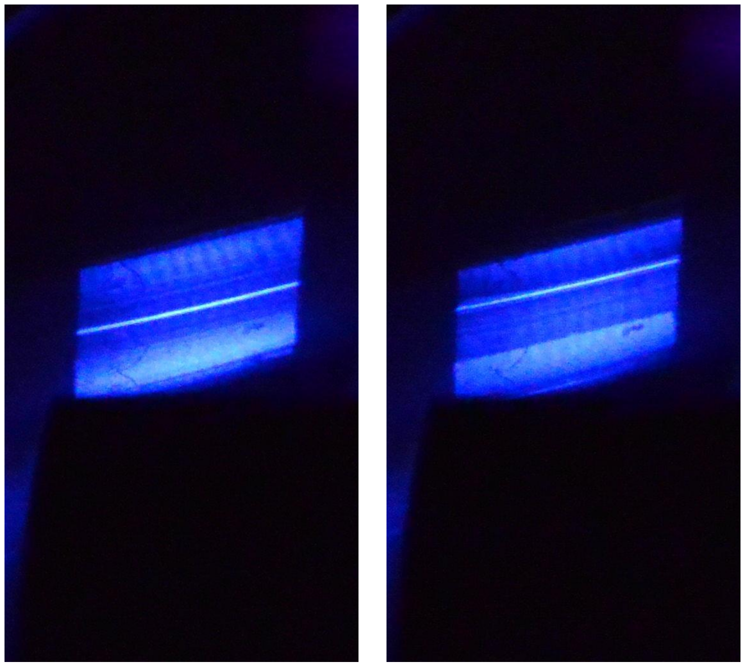

Fig. 7 Line beam from the LCoS dynamic hologram

Conclusion

A line beam shaper and scanner based on dynamic hologram has been proposed and implemented with a phase type LCoS panel. The prototype and experiment shows the feasibility and its potential application to intra-oral scanner for improving the form factor. The expanded application is to generate different patterns so as to accommodation to different or more efficient pattern recognition algorithm.

References

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