

Design of an Optical Emitting System for Scannerless Imaging LIDAR Based on ZEMAX

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Abstract

Optical emitting system is an essential part of scannerless imaging LIDAR. It plays an important role in decreasing the divergence angle and homogenizing the beam spot which have an immense influence on the light signal back from the target. This research work proposes the design of the system using ZEMAX model also determine the includes shaping and zooming features of design model. In the shaping system feature we used two cylindrical lenses whose accurate positions have been solved by using the theories of matrix optics and Gauss optics. The cam curve of a three-group zoom system with (2x-7x) zoom ratios has been drawn. The simulation results verify the availability that the beam from the laser diode meets the requirements after optical emission from system.

Keywords: LIDAR, optical emitting system, optical design, Matlab, ZEMAX

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1. Introduction

Imaging LIDAR are high angular and has range resolution It can get the high resolution 3D image which contains the distance and intensity information. Therefore, it is suitable for the development of the missile guidance, aircraft navigation, terrain survey, underwater detection and related application [1-4]. Imaging LIDAR is divided into two types: scanner and scannerless. Compared to the scan imaging LIDAR, the scannerless imaging LIDAR, which is without scanner mirror, not only is more stable, but also has a higher image update rates and a larger field angle of view [5-8].

However a miniaturized scannerless imaging LIDAR with semiconductor laser unit needs a uniform laser spot as its source. A solution should be found to balance the large beam divergence along with the different angles of two axes of semiconductor laser [9], and for improving the signal-to-noise ratio. When the laser returns back, the LIDAR should take a better use of the source energy. This research work is helpful to the engineering application of imaging laser radar.

Radiation characteristic of laser diode features carries due to its small size, light quality, low threshold, low cost, these properties the laser diode play an important role in the information time, especially in the field of communication LIDAR. The laser diode has unbalanced active region and the beam has the large and different divergence angles along horizontal and vertical axes (the far-field divergence angles in the slow-axis and fast-axis directions are about 10 degrees and 30 degrees, respectively) [10, 11], [18-20]. This effect is shown in Figure 1.

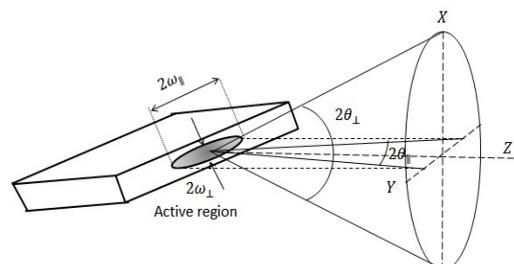


Figure 1. Radiation Pattern of a Semiconductor Diode

Where ω_{\parallel} , ω_{\perp} are the half lengths of the active region in the parallel and perpendicular directions, θ_{\parallel} , θ_{\perp} are the half far-field divergence angles in the parallel and perpendicular directions respectively. For optical design, we just concern the wavelength (905nm) and the far-field divergence angles (25 degrees along X axis and 10 degrees along Y axis) of PGAS1S12H, the laser diode of PerkinElmer Inc, under observation for this work. With our support circuit, the peak power of this diode can be up to 100W, by using the non-sequential mode of ZEMAX to simulate the radiation of the diode. The beam spot radiation pattern as shown in Fig. 2 represents the better view of visibility or observation.

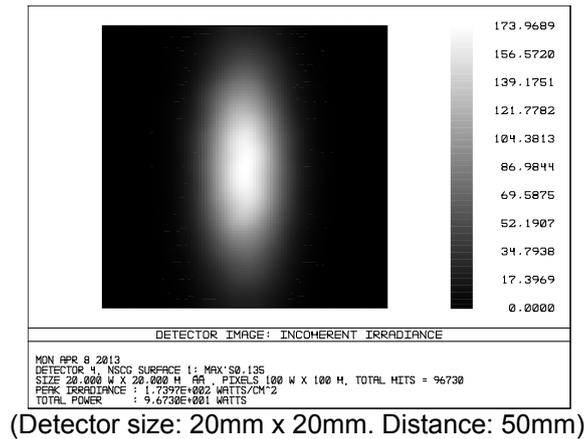


Figure 2. Incoherent Irradiation of the Diode

This research paper is organized as follows. Section 2 presents our proposed shaping system design of LIDAR with theoretical analysis and discussion. The zoom system design and simulation result are presented in section 3. Section 4 concludes the article.

2. Shaping System Design

The shaping systems of semiconductor laser are often taken into cylindrical lens, aspherical lens and micro-prism stack [12-14]. The best choice which meets the actual requirement of our research is the orthogonal cylindrical lenses system. In order to get a rotational symmetry beam, the ratio of the focal length of two cylindrical lenses should be larger than the ratio of the two far-field divergence angles (which is set to be the ratio of 2.5). The parameters of two cylindrical lenses, which are used for our simulation, are shown in Table 1.

Table 1. The Parameters of Two Cylindrical Lenses /mm

Aperture	Object Focal Length	Radius of Curvature	Back Focal Length	Center Thickness
25.4	25	12.92	17.09	12
25.4	75	38.76	72.89	3.2

The two cylindrical lenses collimate the slow-axis and fast-axis, respectively. This is shown in Figure 3, where θ_{\parallel} , θ_{\perp} are the half far-field divergence angles in the parallel (Y axis) and perpendicular (X axis) directions respectively d_1, d_3 are the first and the second lens distances from diode and d_2, d_4 are the specific distances from the two lenses. If we consider the two directions have the same spot size and divergence angles on the dotted line, the laser spot should be circle.

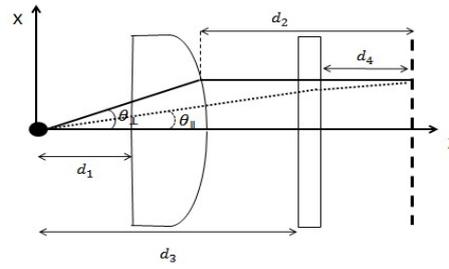


Figure 3. Schematic of Shaping System

To determine the positions of two lenses, a single geometrical optics cannot get the strict results, however the method with matrix optics and Gauss optics will get the better results. With combinations of q parameter of Gauss beam, it is easy for the matrix optics to describe the transmitting procedure of the beam in the air and optical systems [15].

The q parameter is defined as:

$$\frac{1}{q(z)} = \frac{1}{R(z)} - i \frac{\lambda}{\pi \omega^2(z)} \tag{1}$$

Where λ , $R(z)$, $\omega(z)$ are the wavelength of the laser beam, the radius of curvature of equiphase surface at a specific distance and the spot size at a specific distance respectively. The transmission matrix T of a beam, which is from the source to the target through the entire medium, is defined as:

$$T = \begin{vmatrix} A & B \\ C & D \end{vmatrix} \tag{2}$$

So as we know that:

$$q_{2(x,y)} = \frac{Aq_{1(x,y)} + B}{Cq_{1(x,y)} + D} \tag{3}$$

Where $q_{1(x,y)}$, $q_{2(x,y)}$ are the q parameters of the beam at the beginning and the q parameter of the beam at the target respectively. The index (x, y) represents the different direction. Substituting Equation (1) in Equation (3) then we can get an equation:

$$\begin{cases} \omega_{2(x,y)}^2 = \frac{(A + B/R_{1(x,y)})^2 \omega_{1(x,y)}^4 + (\lambda B)^2}{n(A D - B C) \omega_{1(x,y)}^2} \\ R_{2(x,y)} = \frac{(A + B/R_{1(x,y)})^2 \omega_{1(x,y)}^4 + (\lambda B)^2}{(A + B/R_{1(x,y)})(C + D/R_{1(x,y)}) \omega_{1(x,y)}^4 + \lambda^2 B D} \end{cases} \tag{4}$$

Where (1, 2) represent the laser beam at the beginning and the end, respectively. n is refractive index of the medium (in the air). The process is computed by Matlab. It is required to draw the transmission curves of Gauss beam in the two directions, X (fast-axis) and Y (slow-axis). The computation process has two parts:

- a) Determine the positions where the sizes of beam lost of the two directions are the biggest, so the divergence angles are the smallest respectively.
- b) Fine adjust the positions to make the transmission curves in two directions should be nearly parallel, so the beam spot will be nearly circle in a large range.

The transmission curve has drawn the two parts, the result shown in Figure 4 corresponding to Table 2. The divergence angles of the fast-axis and slow-axis are 0.0635 mrad and 0.0622 mrad. These results are based on an ideal situation.

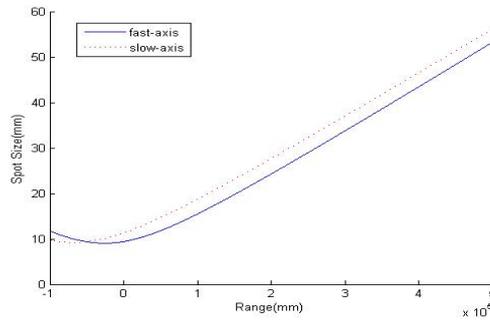


Figure 4. The Transmission Curves of Different Axis

Table 2. The Beam in Two Directions Parameters

Direction	position of lens (mm)	size of waist (mm)	position of waist (m)	Divergence angle (mrad)
fast (X)	17.429	9.067	-25.065	0.0635
slow (Y)	74.010	9.259	-65.998	0.0622

The parameters passed to the system and the positions of two cylindrical lenses are process into ZEMAX. The model and the simulation of beam spot are shown in Figure 5 and Figure 6 respectively.

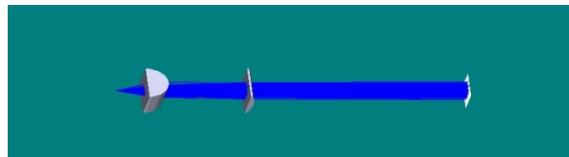


Figure 5. The Model of Shaping System

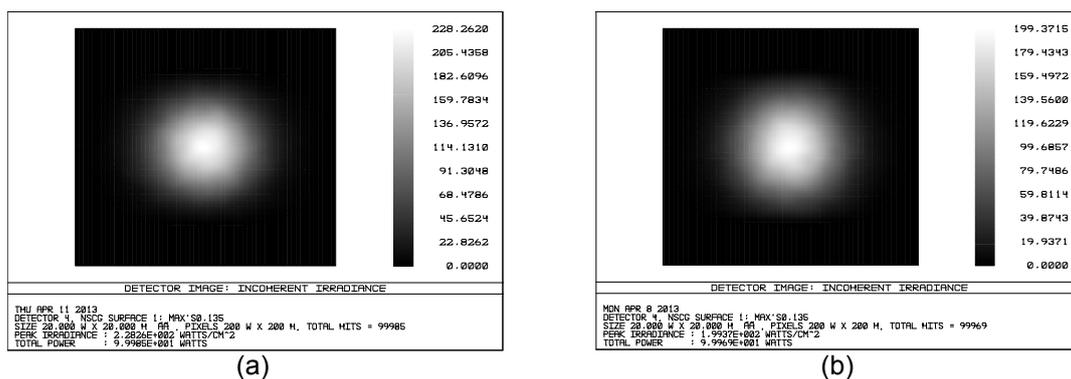


Figure 6. Incoherent Irradiation of the Diode after Shaping (Detector size: 20mm x 20mm); (a) 100mm distance, (b) 200mm distance

3. Zoom System Design

Usually the emission from optical system of the scannerless imaging LIDAR cannot cover the targets uniformly, if it has a single shaping system. The beam should be increased and it adjusted for the adapting of different situations e.g. the same target is at the different distances or two targets are the same distance but the carry different sizes. Three groups are

chosen as the structure of zoom system such that fixed group, zoom group and compensation group [16-17]. As shown in Figure 7, where d_1 is the distance between zoom group and fixed group before zooming, d_1' after zooming, d_2 are the distances between compensating group and fixed group before and after respectively. Zoom ratio depends on the movements of the zoom group and the compensation group to realize beam zoom.

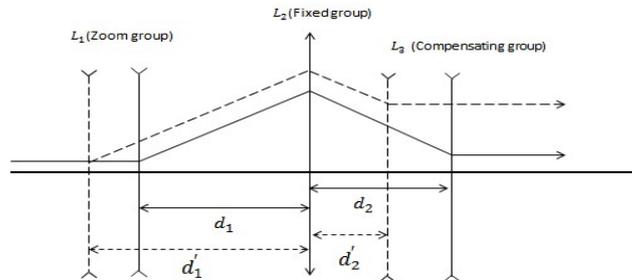


Figure 7. The Structure Chart of Three Groups Zoom System

To draw the cam curves it is critical to keep the optical system during the design process. The cam curves, however it is determined by the focal length of the three groups. In order to make the system realized. The focal lengths should consider for the following rules:

- a) Longer than 15mm. It will be difficult to process the lens, if its focal lengths are too short.
- b) The space between two groups which is affected by the focal lengths should be longer than 5mm or the groups can't be installed together.

These rules are implemented by the aided design using Matlab. It is required the focal lengths of fixed group, zoom group and compensation group as 89mm, -29mm, -120mm, respectively and determine the zoom ratio is 2x-7x as needed then the resultant cam curves are shown in Figure 8, the related data are shown in Table 3.

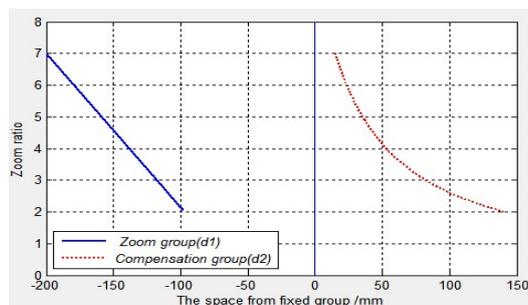


Figure 8. The Cam Curves of the Zoom System

Table 3. The Space from Fixed Group at Different Zoom Ratio

Zoom ratio	2x	3x	4x	5x	6X	7x
d_1 /mm	103.01	124.52	146.03	167.54	189.05	210.55
d_2 /mm	153.13	91.75	61.60	42.65	30.37	21.69

It is required the models for three different zoom ratios as shown in Figure 9. An ideal parallel beam is expanded by the zoom system by getting the different widths value.

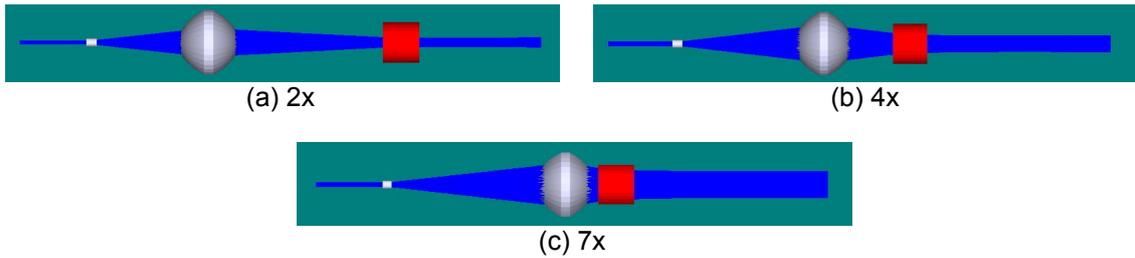


Figure 9. The Zoom System with Different Ratios

4. Results of Overall System

The two parts of the emission optical system have been designed and assembled as it is shown in Figure 10. The whole length of the system is shorter than 300mm.

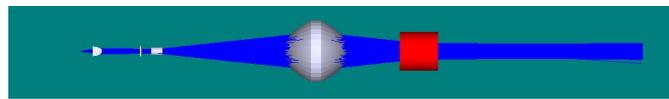


Figure 10. The Emission Optical System

Simulation is performed by using ZEMAX and a series of results of incoherent irradiation are presented in Figure 11. The Figure 11(a) is the laser beam without being expanded by the zoom system and it gives more uniform and expended beam after 2x, 4x, 7x zoom. The irradiation uniformity is calculated after importing the beam data into Matlab and then the ratio of specified minimum illuminance to average illuminance called uniformity of laser diode without any optical systems, the beam after shaping system and the beam after the overall system are 3.1816, 3.2583 and 4.9390 respectively. So one can see that the beam spot at the target becomes more uniform, which has a great benefit for the signal processing.

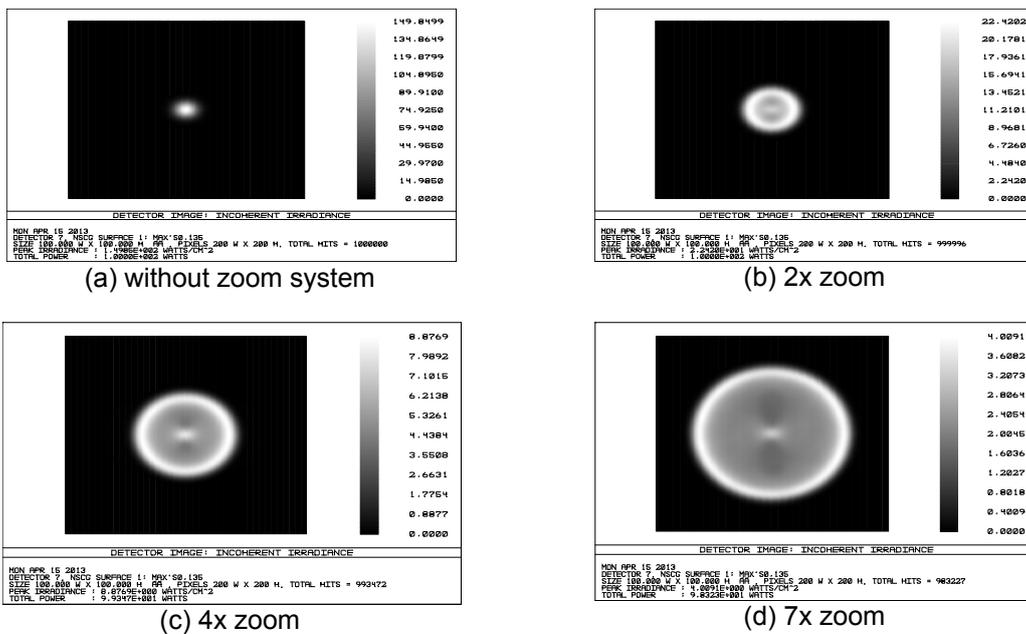


Figure 11. Incoherent Irradiation of Laser Beam (Detector size: 100mm x 100mm. Distance: 500mm)

In order to get the actual divergence angle, when the zoom ratio is 4x, the beam spot at 3m distance are presented in Figure 12. The spot sizes at 0.5m and 3m distance are about 40mm and 70mm so the divergence angle is about 6 mrad then the beam size will cover the targets uniformly at hundreds of meters distance.

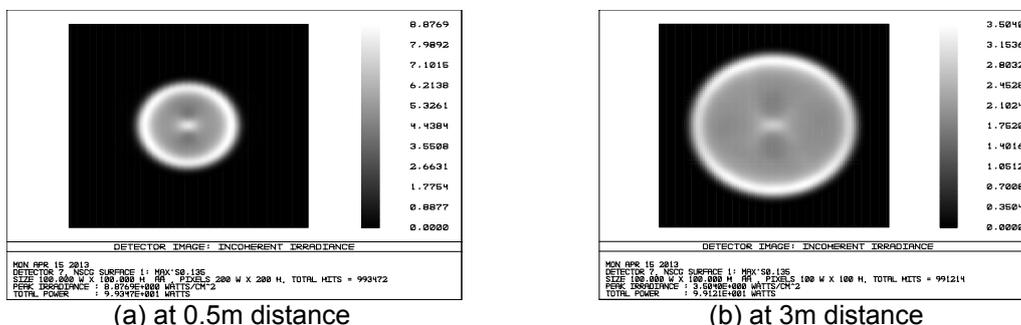


Figure 12. Incoherent Irradiation of Beam at 4x (Detector size: 100mm x 100mm.)

5. Conclusion

This paper presents an optical emitting system for scannerless imaging LIDAR. It deploys the shaping system from the matrix optics and Gauss optics. Furthermore the uniform laser beam and adjustable zoom system has been determined. The simulation results have verified the practical values in various crucial situations. We have presented the theoretical specification of optical design, which provides a possibility for widely used scannerless fields system design.

References

- [1] Molebny, Vasyly, Gary Kamermanb, OveSteinvallic. *Laser radar: from early history to new trends*. Proc. of SPIE. 2010; 7835: 783502-1.
- [2] Marino RM, Stephens T, Hatch RE, et al. *A compact 3D imaging laser radar system using Geiger-mode APD arrays: system and measurements*. AeroSense 2003. International Society for Optics and Photonics. 2003; 1-15.
- [3] Richmond, Richard D, Stephen C Cain. *Direct-detection LADAR systems*. SPIE Press, Bellingham. 2010. ISBN: 9780819480736
- [4] Gleckler, Anthony D. *Multiple-slit streak tube imaging LIDAR (MS-STIL) applications*. AeroSense 2000. International Society for Optics and Photonics. 2000; 266-278.
- [5] Gelbart A, Redman BC, Light RS, et al. *Flash LIDAR based on multiple-slit streak tube imaging LIDAR*. AeroSense 2002. International Society for Optics and Photonics. 2002; 9-18.
- [6] Ailisto, Heikki, et al. Scannerless imaging pulsed-laser range finding. *Journal of Optics A: Pure and Applied Optics*. 2002; 4(6): S337.
- [7] Guang, Deng, Liu Qingwang, Li Zengyuan, Zhang Xu, and Huang Zhenchun. A Kind of Lidar Application Grid Based on eScience's View. *TELKOMNIKA Indonesian Journal of Electrical Engineering*. 2012; 10(5): 1147-1150.
- [8] Ji, Zhongxiao. Adaptive Cancellation of Light Relative Intensity Noise for Fiber Optic Gyroscope. *TELKOMNIKA Indonesian Journal of Electrical Engineering*. 2013; 11(12): 7490-7499.
- [9] Heming Chen, Xinyan Zhao. *The principle and application of the laser*. Publishing House of Electronics Industry, Beijing. 2009. ISBN: 9787121085055.
- [10] Pflibsen, Kent P, Albert N Stuppi. Laser light beam homogenizer and imaging LIDAR system incorporating same. U.S. Patent No. 5,303,084. 12Apr. 1994.
- [11] WANG, De, XQ Li. New progress in semiconductor lasers and their applications. *Optics and Precision Engineering*. 2001; 9(3): 279-283.
- [12] Clarkson WA, DC Hanna. Two-mirror beam-shaping technique for high- power diode bars. *Optics letters*. 1996; 21(6): 375-377.
- [13] Serkan, Mert, HulyaKirkici. Optical beam-shaping design based on aspherical lenses for circularization, collimation, and expansion of elliptical laser beams. *Applied optics*. 2008; 47(2): 230-241
- [14] Shi, Peng, et al. Micro-prism stack beam shaper for high power laser diode array. *Actaopticasinica*. 2000; 20(11): 1544-1547.

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- [15] Peng, Wu, et al. Study on Collimating of Semiconductor Diode Laser. *Semiconductor Technology*. 2009; 5: 012.
- [16] Tao Chun-kan. Zoom optical system design. National defense industry press, Beijing, 1988. ISBN: 7118000124.
- [17] ZEMAX Optical Design program, User's Guide ZEMAX Development Corporation. 2005.
- [18] Moosa A Dida, MR Anjum, F Manzoor. Comparative Analysis of Orthogonal Frequency Division Multiplexing and Single Carrier Cyclic Prefix Modulation Schemes in Powerline Communication Systems. *IJERT Journal*. ISSN # 2278-0181. 2013; 2(12).
- [19] Shi Pengfei, MR Anjum, Zhao Yue. Tone-Reservation based on fractional Fourier Transform for Chirp-based OFDM. *International Journal of Scientific & Engineering (IJSER)*. ISSN # 2229-5518. 2013; 4(7).
- [20] MR Anjum, yinbei Li, shifeng fei. Improved calibration method of amplitude and phase errors based on diagonal loading. *International journal of Advanced Materials Research*. Switzerland. 2013; 717: 359-364. ISSN: 1662-8985.