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Design of A Miniature Near-infrared Laser Range-gated Real-time Video Processing System

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Abstract. The range-gated imaging technique can effectively restrain the backscattering of light and greatly improve the observation distance of photoelectric imaging system in day and night with bad weather. In this paper, a miniature near-infrared laser range-gated imaging system is designed. It is convenient to operate and observe. The system uses four external function buttons to control gating distance, strobe width and clear imaging. FPGA serves as the main control chip to realize the synchronous control of the system. MicroBlaze inside the FPGA is used to configure codec chip for realizing the input/output of PAL video. An image enhancement method is transplanted to FPGA, which greatly enhances the imaging quality of the system and improves the detection distance. Compared to conventional imaging systems, the system improves the observation distance by 3-5 times.

Introduction

In recent years, CCD / CMOS imaging technology using near-infrared laser-assisted illumination has been successfully applied in the areas of night surveillance, security monitoring and vehicle-assisted driving. However, imaging distance of such conventional near-infrared imaging systems are affected by the weather. When the weather conditions are bad, the backscatter of the laser will lead to deterioration of image clarity and significantly reducing of imaging distance. Laser range-gated technique can effectively eliminate or reduce the impact of laser backscatter [1, 2].

Near-infrared laser range-gating imaging technology is an important application [3-5]. In haze, snow and other bad weather conditions, it shows a broader field of vision. The United States, Canada, Sweden and other countries have developed a variety of military and civilian products. Changchun Institute of Optics and Fine Mechanics, Chinese Academy of Sciences Institute of Semiconductors, Changchun University of Science and Technology and Beijing Institute of Technology have also carried out a number of related researches.

Due to large volume and weight, laser range-gated imaging systems are mainly used for in-vehicle or on-board applications. We design a miniaturized near-infrared laser range-gated imaging system which could increases the observation distance in the harsh environment. This paper introduces the system composition and digital image processing technology, and expects to provide reference for the related researches and applications.

The principle of laser range-gated imaging system

In the process of range-gated, the laser emits a narrow pulse with high energy, and the target is fully or partially illuminated by adjusting the divergence angle of the laser beam. The image intensifier acts as a shutter for ICCD. As shown in Fig. 1, when the laser pulse in the round-trip on the way, ICCD is closed, and the system does not imaging. When the reflected light of target arrives at the ICCD, the gate is opened and the tube is working. The reflected light of the target enters the ICCD and is imaged. According to the actual distance of target, ICCD shutter closes for a period of time, which can effectively eliminate the backscatter and enhance the imaging quality [6, 7].

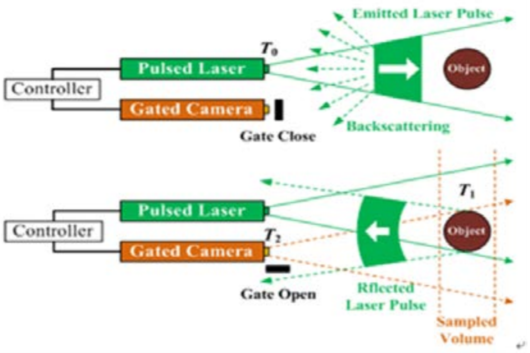


Fig. 1 Working principle of range-gated imaging system

The design of laser distance gating imaging system

The near-infrared laser range-gated system mainly includes ICCD, programmable high-voltage gating power, optical lens, FPGA-based synchronous control system and image processing system. It is shown in Fig. 2.

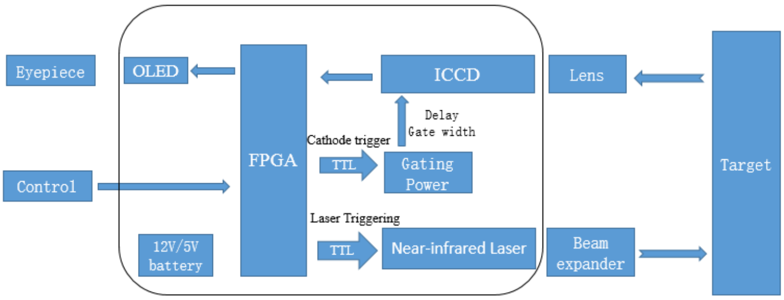


Fig. 2 Block diagram of near-infrared laser range-gated imaging system

The selections of components are shown as follows:

The system uses a super-second generation 18mm diameter close-up microchannel plate image intensifier, shown in Fig. 3, which supports the cathode strobe input, turn on and turn off, and with automatic brightness control, strong light source protection and polarity reversal protection. The cathode pulse width and delay, and MCP gain could be adjusted through the power strobe.

This experiment uses a near-infrared laser, shown in Fig. 4. The laser power is 3W, repetition frequency is 1Hz ~ 1kHz which is adjustable by the external TTL signal, and the width of single pulse is 1400ns. The laser has a beam expander, and the divergence angle could be adjusted manually.

Fig. 3 ICCD

Fig. 4 Near-infrared laser

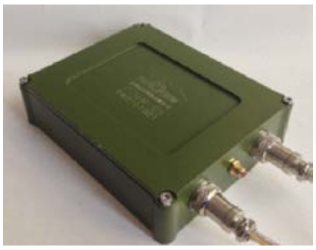
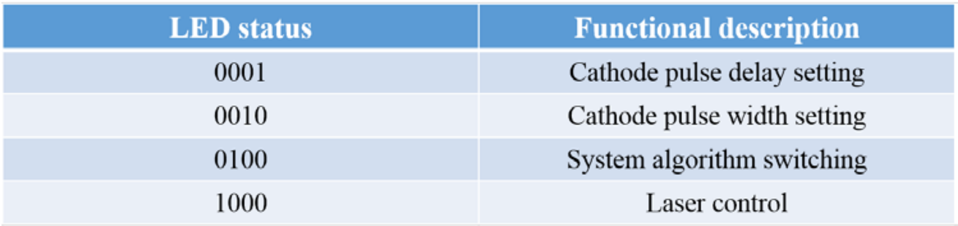


Fig. 5 Programmable power

Programmable power supply is the core components of the system, shown in Fig. 5, which is directly related to whether the system could clear imaging. The laser light signal triggers the programmable power supply, and the programmable power supply generates the gate signal of the image intensifier according to the trigger signal, including the cathode pulse width and delay. The cathode pulse width can be adjusted to a minimum value of 5ns. The adjusting precision is 5ns. The cathode pulse delay is longer than 2us and the adjusting precision is 5ns. In general, we adjust the width to a large value, and according to the detection target distance, adjust the delay until the target is find. Then adjust the width to 5ns first, and adjust the delay until the system clear imaging.

The synchronization of system is controlled by four external keys(shown in Fig. 6). Two of them are function keys, which could switch functions between cathode pulse delay, cathode pulse width, algorithm switching and laser control. The other keys could adjust values, such as increasing or decreasing the cathode delay and cathode pulse width. We use the deburring technology to implement the control of keys within the FPGA.



LED status	Functional description
0001	Cathode pulse delay setting
0010	Cathode pulse width setting
0100	System algorithm switching
1000	Laser control

Fig. 6 System function description

System structure design

According to the system block diagram, a hand-held near-infrared laser range-gated imaging system is designed. As shown in Fig. 7, the system is suitable for single-man operation. The external key design makes the whole system could be flexibly controlled. The gated power supply and FPGA are fixed on the top plate. The imaging system, the laser and the lithium battery are located on the backplane. Lithium battery is connected with the outside through a waterproof connector for charging. The optical lens and the beam expander of the laser are outside of the shell and are manually operated by the personnel. OLED is used for display device. An eyepiece is equipped with OLED, so that it is convenient for personnel to observe. In addition, the system reserves a BNC connector for external video transmission.

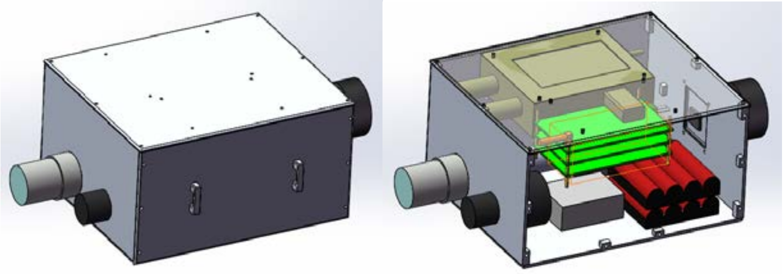


Fig. 7 The shell of near-infrared laser Range-gated imaging system

The whole system is powered by a 12V/5V lithium battery. The laser power supply voltage is 5V, which power is less than 5W, and the rest of the system supply voltage is 12V, which power is less than 10W. System power consumption is smaller, and the battery could work continuously longer than 45 minutes. The size of the system shell is 200×200×120mm, and the total weight of 2.5kg. The system is small and light, therefore it is suitable for single-man operation.

Image processing platform

On the basis of the laser range-gated principle, using effective video enhancement algorithm could enhance the image quality of the system greately. System input / output video signal is PAL signal. The SAA7113H chip is for video capture, and SAA7121 chip is for video output. The two chips are configureed by Microblaze , a soft core in FPGA. The image processing platform is shown in Fig. 8. There are three circuit boards. The top is video capture board. The middle is FPGA. The bottom is control board.

Fig. 8 Image processing platform

We transplante the super-horizon real-time image enhancement method to FPGA. The method was proposed by Li Li in 2010 and based on TI DSP and Xilinx FPGA chips [8]. The enhancement effect of the image is remarkable, and the image enhancement could be done in real-time. The algorithm improves the overall contrast of the image greatly, and keeps the details of the image very well. The local enhancement effect is obvious.The algorithm (shown in Fig. 9) divides the image into M×N sub-blocks, and each sub-block having a size of m×n. In each sub-block, upper-left corner is set to (0,0) and lower right corner is set to (m-1, n-1). Assume that the current sub-block is the sub-block named a, then its adjacent sub-block is set to b, c, d. Next, the pixel gray scale and the gray probability density of four subblocks are respectively calculated. The gray probability density function is given below.

$$P_j(r_k) = \frac{n_k}{m \times n}, \; j = a, b, c, d \tag{1}$$

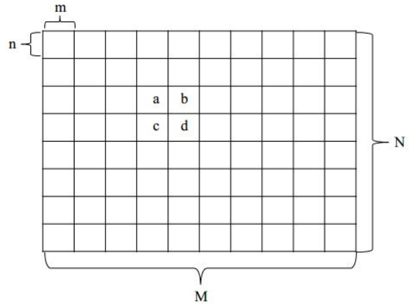
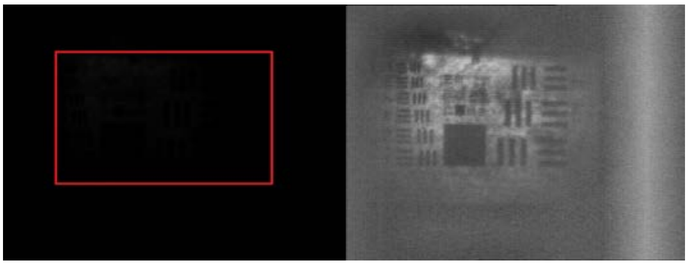


Fig. 9 The super-horizon real-time image enhancement method

According to the gray probability density of the four sub-blocks, the pixels in the a sub-block are sequentially gray-transformed using the histogram equalized gray scale transformation function. Then the pixels after transformation are multiplied by different weights to obtain the gray value after transformation. The transformation function is given below.

$$\begin{aligned} s(x,y) = \frac{1}{mn}\{ & T_a\left[f_a(\mathrm{x},\mathrm{y})\right](m-x)(n-y) + T_b\left[f_a(\mathrm{x},\mathrm{y})\right]x(\mathrm{n}-\mathrm{y}) \\ & + \mathrm{T}_c\left[f_a(\mathrm{x},\mathrm{y})\right](m-x)y + T_d\left[f_a(x,y)\right]xy\} \end{aligned} \tag{2}$$

In underwater range-gated experiment, the enhancement effect of the algorithm is obvious when the 532nm laser is used as illumination source. Fig. 10 shows the enhancement effect on the underwater image when the cathode strobe width is 5ns.

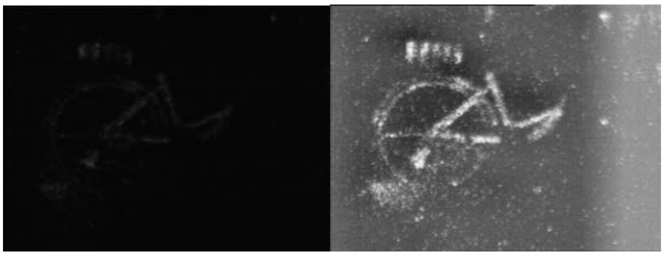


a) Before enhancement b) After enhancement

Fig. 10 Images of the target in underwater

Experimental results

The results of near-infrared laser range-gated experiment, which is in the low-light environment, are shown in Fig. 11. In the experiment, the system is used to image a bicycle and video enhancement algorithm is applied. The near-infrared laser spot is rectangular, and the illumination is uneven. The pulse width of the laser is large, and the backscattering is not well filtered, therefore the imaging effect is not clear. Better results could be achieved after the replacement of a better laser in applications.



a) Before enhancement b) After enhancement

Fig. 11 Images of the bicycle on land

Conclusions

In this paper, a miniature near-infrared laser range-gated imaging system is designed. The system uses Xilinx FPGA chip Virtex-5 as the main control chip, and the synchronously of the system is controlled through four external keys. At the same time, the super-horizon real-time image enhancement algorithm is applied on FPGA platform. The imaging effect and observation distance of the system are improved greatly.

Near-infrared laser range-gated system could effectively eliminate the impact of light backscattering, which is suitable for long-range observation during night and bad weather conditions. Compared with the traditional near-infrared imaging system, our system could improve the observation distance by 3-5 times. The system is hand-held, therefore it is easy to carry and operate. For bad weather in day and night, the system has good prospects. Also for some closed space, such as indoor and inside the car, the system could eliminate the impact of light reflection by glass and other transparent obstacles.

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