

Ghost Imaging Lidar via Sparsity Constraints in Real Atmosphere

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ABSTRACT

We present a series of results acquired at a 2-kilometer distance using our lidar system under several weather conditions, clear, cloudy, light rain, moderately foggy, and night. The experimental results show that ghost imaging lidar via sparsity constraints can realize imaging in all these weather conditions.

Keywords: Ghost Imaging; Lidar; Atmosphere; Reconstruction Algorithm

1. Introduction

In recent years, thanks to the development of laser technology and laser detection techniques, several lidar techniques have been developed, such as spot scanning imaging lidar [1], 3D imaging lidar [2-4] and synthetic aperture imaging lidar [5-7]. Ghost imaging lidar via sparsity constraints (GISC lidar) is a newly developed imaging lidar technique based on the ghost imaging principle [8]. It gets target global information with a highly sensitive bucket detector, and the image is reconstructed with some algorithms. At present, most researches about ghost imaging in atmosphere are theoretical [9, 10] or laboratory experiments [11, 12]. We shall present the GISC lidar experimental results under several weather conditions.

2. Experiments

Our experimental setup is shown in **Figure 1**. Pseudo-thermal light is produced by a 532 nm laser pulse passing through a rotating ground glass. The light is split into two paths by a beam splitter, of which the light field intensity of reference and test beam accounts respectively for 95% and 5% of the total energy of the incident light. In our GISC lidar system, the source plane optical field is imaged respectively to the reference plane and the target plane through the lenses L_r and L_t [8, 13]. The target reflects the test beam light back to the receiving system. The aperture of the receiving telescope is 0.42 m with 5.0 m focal length. The photons collected by the receiving system pass through an interference filter with 1nm half bandwidth, then received by a photomultiplier tube (PMT). Reference beam light passes through lens L_r and im-

ages on a CCD detector. The intensity distribution of light field $I(m \times n)$ is reshaped into a row vector $I(1 \times N)$ [14, 15], in which $N = m \times n$. After M observations, we obtain measurement matrix $A(M \times N)$ of M row vectors $I(1 \times N)$, and $Y(M \times 1)$ from the M signals recorded by the PMT. In our experiments, $M = 3000$, $m = n = 200$. The outdoor detection distance is 2km. The scene and target are shown in **Figure 2**. The target with a size of 54 cm * 58 cm is a two-dimensional resolution panel, with two groups of slits (three-slit, and double-slit), whose center-to-center distances between slits is 8 cm, 12 cm, respectively.

Ghost imaging reconstruction algorithm plays an essential role in GISC lidar system. Although the linear reconstruction algorithm was first developed [16], nonlinear algorithms are usually used in a GISC lidar system since they better exploits the information from the collected data [8, 14, 15]. We developed a nonlinear

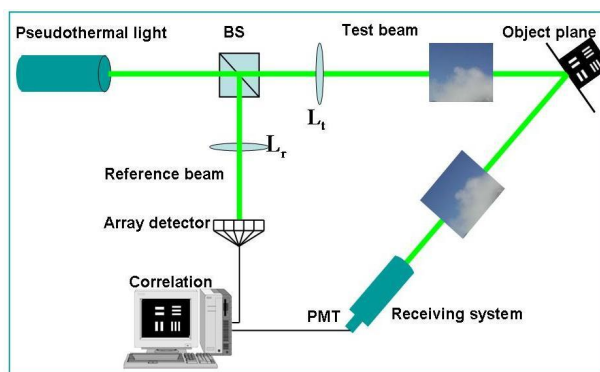


Figure 1. Experimental setup of GIL system.

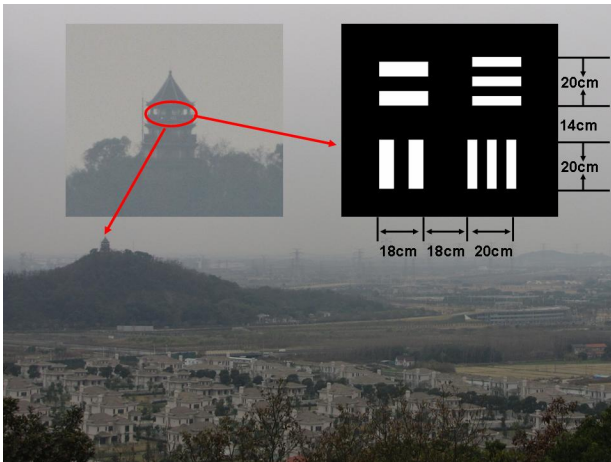


Figure 2. Scene and target of 2km field experiments.

reconstruction algorithm based on TV constraint and Krush-Kuhn-Tucker conditions [17], solving the following optimization program:

$$\begin{aligned} \max & -\|Y - AX\|_2^2 / 2 - \tau \|X\|_{TV} \\ \text{s.t.} & -x_i \leq 0, \end{aligned} \quad (1)$$

where $\|X\|_{TV}$ is the total variation of the image X , x_i the i -th element of X , and τ a constant.

The experimental scene is clearly visible in both clear and cloudy conditions, as shown in the **Figure 3(a1)**, **(b1)**. Under the condition of light rain, as shown in **Figure 3(c1)**, the outline of the 2 km distance mountain, where the target is situated, is still dimly visible. Whereas in a moderate fog as shown in **Figure 3(d1)**, the afore-said mountain is invisible. Though traditional imaging has no problem imaging the target in clear as well as cloudy weather conditions, GISC lidar gets images of a much higher signal-to-noise ratio (SNR), as shown in **Figure 3(a)**, **(b)**. In light rain and moderate fog, affected by low visibility caused by rain drops and fog, traditional imaging cannot see the target, as shown in **Figure 3(c)**, **(d)**. By active illumination, spatial filtering, and highly sensitive signal detection, GISC lidar manages to extract the target's weak signals despite the low visibility and high noises. The results of night experiments are shown in **Figure 3(e)**. Apparently, traditional imaging with equal irradiation energy laser illumination is unable to get the target's image, whereas GISC lidar can. Columns **Figure 3(3)**, **3(4)** compare the images reconstructed by GI linear reconstruction algorithm and TV nonlinear reconstruction algorithm using the same experimental data. Again, apparently, the quality of the images reconstructed by the TV algorithm is better than those reconstructed by the GI algorithm.

3. Conclusions

In conclusion, GISC lidar's ability of imaging in real

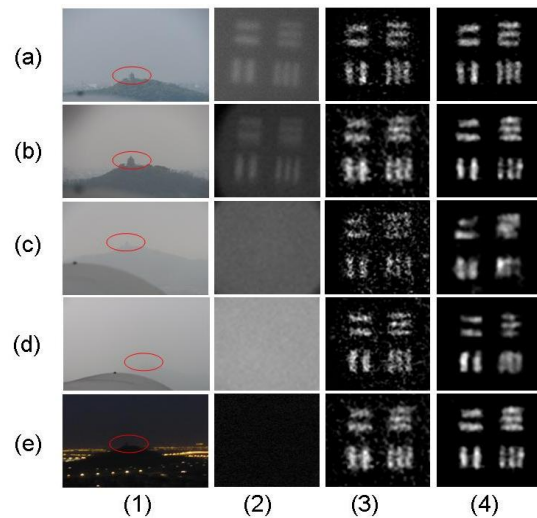


Figure 3. GIL experimental results. Weather and atmosphere conditions: (a) clear, (b) cloudy, (c) light rain, (d) moderately foggy, (e) night. (1) Scenes of Field Experimental, (2) the results of traditional imaging, (3) images reconstructed by GI, (4) images reconstructed by TV.

atmosphere is demonstrated. It features in its quality imaging in rainy, misty and foggy, and night conditions. It is a new type of imaging lidar that can work in some weather conditions where traditional imaging methods can't work. The unique superiority of GISC lidar will point to the development of its potential application value in various areas.

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