Two-Wavelength Digital Holography

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Abstract: With two-wavelength digital holography, 3D images of diffuse objects are generated by computing the phase difference between coherent images recorded at two wavelengths. Results are presented that show robust, fine resolution 3D imaging.

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1.0 Introduction

Advances in coherent laser technology and multi-pixel detector arrays have enabled a new class of image-based laser radar (LADAR) systems that operate by flood illuminating a scene and recording coherent data with an array receiver [1-3]. Such sensors eliminate the need for raster scanning that is employed in conventional, scanning-spot LADAR sensors. Due to limitations in the pixel rates of large format detector arrays, fine-resolution, image-based LADAR systems typically operate in an FM mode (for example step-frequency) rather than a pulsed mode [2]. In fact, researchers have demonstrated FM LADAR systems with sub-micron range resolution [3].

One difficulty in producing image-based LADAR sensors for 3D imaging of large outdoor scenes, or living objects, is that the coherence of the received signal is degraded by object motion. For this reason, one is driven to an FM system with a high-chirp rate and a high-speed array receiver. One way to alleviate the pressing frame-rate requirements on the high-speed camera is to reduce the frequency content of the illumination. For example, instead of transmitting a waveform with 32 discrete laser frequencies and recording 32 frames of data, one can transmit just two frequencies and record two frames of data. While the two-wavelength system can have the same overall bandwidth, and therefore range-resolution, as a more filled waveform, two-wavelengths result in reduced sampling in the range dimension which gives reduced capability when, for example, an object has more than one range-bin occupied within each pixel.

2.0 Method

As stated above, the coherent images used in these experiments were recorded using digital holography. The experimental setup is shown in Figure 1. Light from a tunable laser source is split into two components, an object beam and a reference beam. The object beam illuminates the diffuse object and

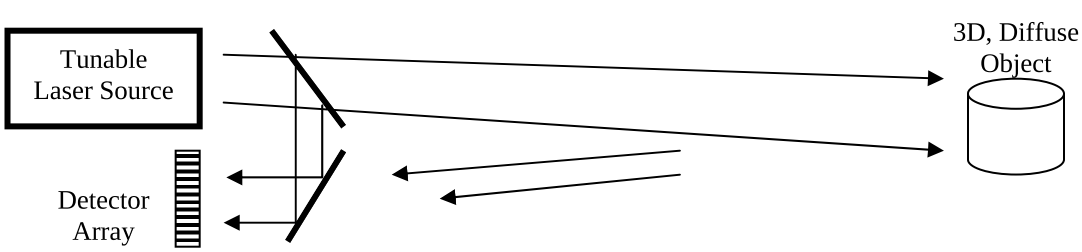

Fig. 1. Experimental setup used for data collection.

backscattered light is incident on the detector array. This light is interfered coherently with the reference beam and complex-valued data is then derived from the interference pattern recorded by the detector array.

Before computing the 3D image, aberrations were removed from the component images. While the primary aberration was defocus, other higher-order aberrations were also removed. To accomplish this we used a method based on maximizing image sharpness [4]. Coherent images before and after focusing are shown in Figure 2. Notice that before focusing, features of the image are not recognizable. Also note that convergence of the focusing algorithm and image appearance are enhanced by using multiple speckle realizations.

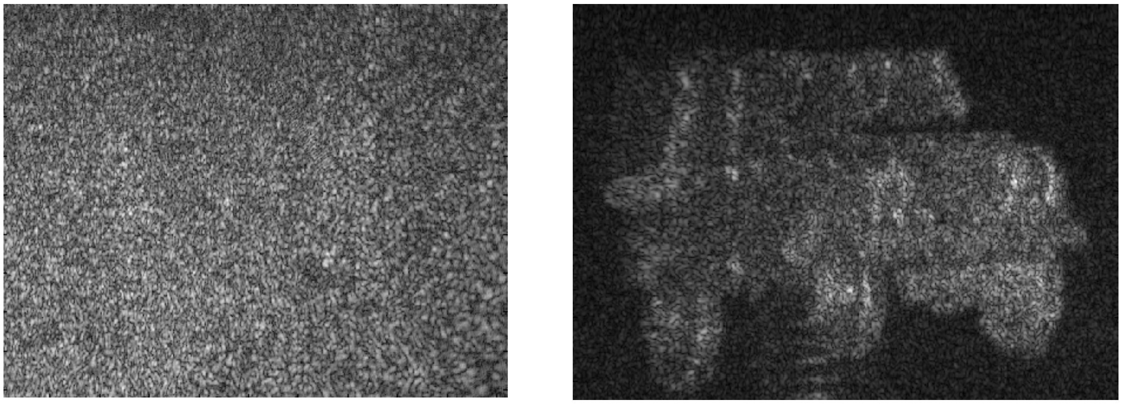

Fig. 2. Image examples before (left) and after (right) focusing.

With the complex-valued data recorded at the two wavelengths, 3D images are found by taking the phase difference of the two images on a pixel-by-pixel basis. The relationship between distance and phase difference is

$$D = \frac{c\Delta\phi}{4\pi(\nu_1 - \nu_2)}, \tag{1}$$

where c is the speed of light, $\Delta\phi$ is the measured phase difference and ν_1 and ν_2 are the two transmitted frequencies. Note that distance determination with this method is subject to ambiguity interval limitation with the ambiguity interval given by $c/2(\nu_1-\nu_2)$.

3.0 Results

Image results of data collected using this two-wavelength method are shown in Figs. 3 and 4. Figure 3 contains the reflectivity image of a scale model truck and Fig. 4 shows the corresponding gray-scale encoded 3D image. These images resulted from averaging 8 pairs of two-wavelength data.

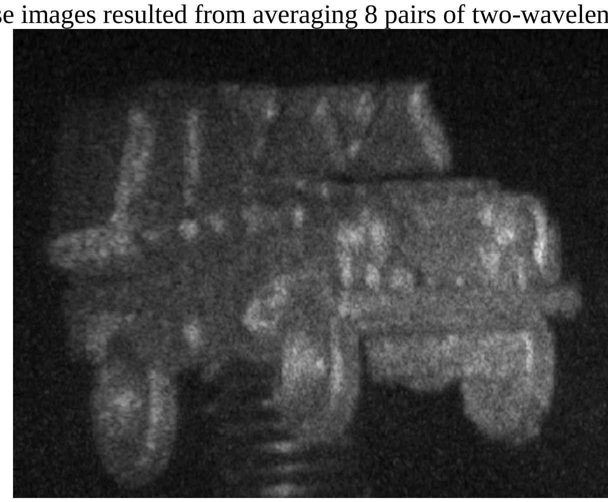

Fig. 3. Intensity image produced from two-wavelength LADAR data. Eight speckle realizations were used.

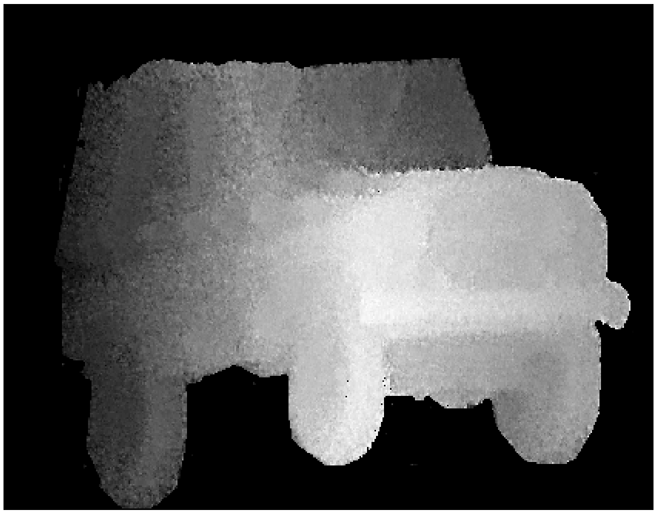

Fig. 4. Three dimensional image produced from two-wavelength LADAR. Range is encoded as gray-scale. Eight speckle realizations were used to form this image.

For these experiments the frequency separation of the laser wavelengths was set so that the imaging ambiguity interval was greater than the depth of the object. By doing this we avoided the need for unwrapping the image.

4.0 Conclusion

In this paper we have demonstrated the capability of two-wavelength LADAR. This method shows promise for being robust and it results in relaxed requirements for the transmitted laser waveform and detector array.

5.0 References

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