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System for Debris Cloud Tracking and Characterization

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A Self-Directing Elastic Backscatter Lidar System for Debris Cloud Tracking and Characterization

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Abstract. An elastic backscatter lidar that utilizes the lidar signal itself to direct the system towards fast moving isolated aerosol clouds has been developed. System capabilities include tracking clouds as well as measuring their volume and density distribution. Results of the first system tests are given.

1 Introduction

The advent of lidar (laser radar) has facilitated the study of atmospheric composition and dynamics. Lidar has been employed in monitoring the continuous flow of effluent gases and aerosols emanating from industrial stacks. However, detecting and tracking invisible transient effluents from unknown locations, though conceptually straightforward, has still remained experimentally challenging. We present here the first results from a newly designed elastic backscatter lidar system that is capable of detecting and tracking transient visible or subvisible aerosol plumes. Accurate cloud volume, cloud density distribution, and track information have been obtained on small, fast moving, subvisible debris clouds resulting from above ground tests in which conventional explosives were detonated.

Measurement of respirable fractions (fraction of specific materials released to the atmosphere as particulate matter having diameters less than 10 microns) has been challenging in the past. Early experiments that employed photographic techniques [1] and ground-based particle sampling systems to measure cloud volume and constituents were subject to obvious drawbacks. The cloud volume measurements would be crude due to difficulty in measuring all the cloud convolutions, and the triangulation advantage diminished as the clouds moved away from the cameras. Clearly, volume measurements were impossible for invisible clouds. Furthermore, the clouds often missed the effective range of ground-based particle sensors.

To overcome these and other difficulties, a new lidar control system that utilizes the backscatter signal itself to direct the lidar toward the cloud, while minimizing the scan dimensions, was developed. We anticipate integrating this lidar system with air sampling instrumentation mounted to a remotely piloted vehicle (RPV) [2] that is directed by the lidar. Data from the RPV will be combined with lidar information to yield comprehensive cloud analyses.

2 System Description

Automatic cloud tracking software was added to an existing elastic lidar system having the following characteristics: Laser: Nd:YAG, 1064nm wavelength, 50 Hz, 500 mJ/pulse maximum; Telescope: 42 cm diameter f/8 Cassegrain; Detector: 3 mm diameter silicon avalanche photodiode; Computer: 486/DX, 60 MHz PC; Digitizer: LeCroy 8818, 8-bit, 8 kbyte memory, 100 MHz maximum sample rate.

System operation is conceptually simple. In anticipation of the sudden appearance of a debris cloud, the lidar is set to a raster scan mode that covers a large volume of space over the expected release location. Low resolution (large angular step) scans are made repeatedly over the same volume. Digitized data from each laser shot are processed to look for a signal that is statistically significant when compared to signal from ambient aerosols. Data are not stored while ambient signals only are present. When signals above ambient are detected, their positions are used to resize the scan volume (window) to cover the area of interest. Considering existing wind conditions and expected lofting rate, parameters that are entered by the operator before operation begins, the window is automatically sized to encompass the region of interest and allow room for cloud motion. After the new window is set, another raster scan is taken. Then, again, the locations of significant signals are used to resize the scan window, data are stored, and another scan begins. These self-perpetuating sequences are repeated until the cloud either moves out of range, out of the preset, fixed, safety envelope, or operation is terminated by the operator. Thus, operation of the system is completely autonomous from the time the operator starts scanning the original large volume.

Real time calculations are done to direct the lidar, but, at present, detailed data analysis is performed offline. In post-processing, data points are identified either as "cloud data" or "not-cloud data". The logic is very similar to that used for signal extraction during data acquisition but is more sophisticated in order to extract weaker cloud signals. Cloud edges are carefully determined with a signal processing technique that compares each point with its nearest neighbors. Cloud volume is then computed. Analysis shows that the expected error in volume is 5 percent or less [3,4]. Also, cloud density is calculated and expressed relative to the scattering strength of ambient aerosols.

3 Experiments

For the two experiments described herein, the lidar system was set up on a hillside overlooking the sites where explosives were to be tested. The terrain was characterized by deep canyons and evergreen forests on mesa tops. One site was at a distance of about 6.5 km and the other was at about 5 km. Neither of the test sites could be seen from the lidar as they were obscured by trees and slopes. A level line of sight from the lidar was one to two hundred meters above the explosions.

The first experiment was conducted at the 6.5 km distant site on a sunny afternoon day. About 1 kg of high explosives was detonated. The resulting explosion was so feeble and so distant that it was neither audible nor visible to

the lidar operators. However, after the debris cloud had lofted into the lidar field of view, the system automatically locked onto the invisible cloud and proceeded to acquire data. Figure 1 shows scan windows 1 and 8. One can see that the cloud is entirely encompassed within each scan. For clarity, the intermediate six scan windows are not shown. Cloud volumes ranged from $0.394 \times 10^6 \text{ m}^3$ to $2.83 \times 10^6 \text{ m}^3$.

Fig. 1. The outlined boxes define the dimensions of scan windows 1 and 8 as set by the lidar control mechanism. Time between the scans is approximately three minutes.

The second experiment had a larger charge of explosives and was detonated after dark at the site 5 km away. A flash was seen by the lidar operators but the debris cloud was not visible. Figures 2 (a) and (b) are cross-sectional views depicting the density of the cloud during its evolution.

4 Summary and Future Development

An automatic cloud tracking and mapping elastic lidar has been developed and tested. Two experiments were performed in which the system successfully tracked and obtained data on invisible clouds. Applications of a cloud tracking lidar system are numerous, from environmental monitoring to defensive military applications such as detection of chemical aerosols and biological warfare agents.

For upcoming series of experiments, we anticipate having a more intelligent tracking control system. The lidar cloud track information will direct a RPV

through invisible clouds. Incidentally, volumetric wind field measurements can be acquired with the *same* lidar system [5] before and after the experiments to provide input to the system.

The next major scientific upgrade to the present system shall be the addition of adaptive processing capabilities to achieve real-time 3D visualization of transient clouds. To this end, efforts are currently underway to implement adaptive algorithms, including neural networks, on massively parallel machines to characterize the backscattered signal.

In the future, this cloud tracking lidar can direct other remote sensing devices, such as DIAL or Raman lidar, for species identification. Such devices, which often require long integration times, would then be free to interrogate a specific part, eg. the centroid, of the cloud without having to scan the cloud or its surroundings.

Fig. 2. (a) and (b) represent temporal cross-sectional views of the plume resulting from the second detonation. Note the decreasing density as the cloud disperses.

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