25C7 DEVELOPMENT OF AN IMAGING LASER RADAR FOR LONG-RANGE GAS PLUME VISUALIZATION

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INTRODUCTION

The backscatter absorption gas imaging (BAGI) technique is a laser remote sensing method that fuses the chemical detection attributes of chemical lidar with the visualization capability of imaging laser radar (ladar) to allow real-time television images of invisible gas plumes to be made. BAGI is carried out by actively imaging a scene with laser radiation having a wavelength that can be absorbed by the gas to be visualized. Gas plumes present in the scene become visible in the image when they attenuate a portion of the backscattered radiation. Currently, all BAGI instruments that have been developed operate in the infrared (IR) and image gases via their fundamental vibrational transitions. The laser sources that have been used are the CO_2 and the IR helium neon (HeNe). The former provides tunable radiation at wavelengths in the range between 9 and 11 µm, allowing many organic species to be detected; the latter emits at 3.39 µm and has been used primarily for methane leak location. For further general discussions of the BAGI technique, the reader is referred to earlier publications [1-3].

The target range at which the current BAGI instruments are capable of operating varies between about 6 and 110 m. The imaging device used in those systems is an active raster-scanner that scans the beam of a continuous wave (CW) laser and the instantaneous field-of-view (IFOV) of an infrared detector. Differences in the range performances of the past systems are attributable primarily to differences in their laser power and detector sensitivity. The range performance of the scanned imager has been discussed in a recent paper [1], where the projections of a simple system model have been presented and compared with experimental results.

In this paper, we summarize the design and preliminary performance evaluation of a new raster-scanning BAGI imager that is intended for long-range operation at a target range of 300 m. A system capable of imaging at this range is desired to allow airborne gas imaging from a low-flying airplane or helicopter. The system uses a 20 W CO_2 laser and a redesigned scanner that employs telescopic transmission and receiving optics. Model predictions of the performance of the new system and some recent field testing results will be presented. Issues relating to gas imaging at long ranges will also be discussed.

LONG-RANGE IMAGER DESIGN

In all BAGI imagers, raster scanning is accomplished using a pair of synchronized galvanometrically-driven scan mirrors, operating at 3933 Hz (horizontal, sine wave; 7866 Hz line rate) and 60 Hz (vertical, sawtooth). The concerted motion of the mirrors serves to sweep the IFOV of the IR detector and the beam of the laser source across the target in a raster pattern. The laser backscatter signal that is received is formatted to generate a real-time RS-170 video image.

In considering an extended-range imager operating in the mid-IR, one is confronted with the choice between heterodyne and direct modes of detection. Heterodyne detection offers the possibility of signal shotnoise-limited signal-to-noise ratios, whereas direct detection is background limited. Thus, for the same laser power, much greater ranges can be achieved with heterodyne imaging. There are, however, practical considerations that favor direct detection. Because it is a coherent technique, heterodyne detection requires the collection of a single speckle cell. As a result, images produced in that mode possess strong contrast variations, which is undesirable in a device that will be used to image low contrast features. Furthermore, heterodyne detection requires much stricter alignment tolerances than a direct system. For these latter reasons, and because only a modest imaging range was required, direct detection was chosen for the long-range imaging system.

Improvements to the imager range performance have been defined using a standard lidar signal model in conjunction with the results of past gas imaging field tests. The range performance of the past BAGI imagers was limited primarily by the small size (1.2 cm) of its receiver collection aperture. Thus, the long-range imager was designed to operate with 5X telescopic optics to provide a 5X expansion of the receiver. In order to introduce these optics into the system without generating unwanted scatter crosstalk between the transmitting and receiving paths, a separated-path scanner design was formulated.

The optical design that was fabricated is shown in Figure 1. It employs 5X magnification refractive optics to transmit and collect the radiation. Each telescope is an identical four-element zinc-selenide design (manufactured by II-IV, Inc Saxonburg, PA). To accomplish transmitter-receiver separation, the laser is scanned using a polished surface on the rear of the horizontal scan mirror. From that point, the beam is redirected down to the vertical mirror using a corner cube reflector. The IFOV is scanned, as in the past, from the front surface of the horizontal scan mirror, whereupon it travels directly downward to the vertical mirror. Note that a redesigned beryllium vertical scan mirror is used that is much larger than the corresponding mirror of the original scanner, so that it can accommodate the footprints of the laser and IFOV in two distinctly separated regions. In addition, baffles (not shown in the diagram) are used to optically isolate the laser transmission and receiving path from each other. Upon leaving the vertical mirror, the scanned laser and IFOV paths enter their respective telescopes. The IFOV path is translated perpendicularly to the axis of the scanner using a periscope, in order to make room for the two telescope objective lenses. As seen in Fig. 1, one periscope mirror is used prior to the IFOV telescope, while the other is located between the eyepiece and objective lenses. Overlap of the laser and IFOV raster scans at the target is accomplished by translating the IFOV objective lens perpendicularly to the beam axis to aim the IFOV scan at the appropriate region on the target plane.

The laser that was selected to be used in the prototype imager is a 20 W tunable waveguide CO_2 system manufactured by Laser Photonics (Orlando, FL). Given its nominal 7 mrad divergence, the beam of the laser is passed through a 3X beam expander prior to being injected into the scanner. Tests described here were done prior to the use of the waveguide source, instead employing a 20 W glass tube laser that was used in the earlier CO_2 laser-based system [3].

The 5X magnification increases the collection aperture of the system by a factor of 5. It also reduces the maximum field-of-view of the scanner and the laser and IFOV divergences by the same factor. Thus, the maximum working field-of-view is reduced from 18° to 3.6° and the IFOV and laser divergences are reduced to about 0.8 mrad. Obviously, the reduced field-of-view is a tradeoff that must be considered in expanding the system collection aperture using a telescope.

IMAGER FIELD TESTING

The first evaluation of the breadboard imager was carried out during the fall of 1992 at LLNL. As in earlier field tests [3], images were made of sulfur hexafluoride releases against target panels having known IR reflectivities. Video images were collected on an ordinary VHS videocassette recorder.

During the tests, gas imaging was attempted at ranges up to 300 m (1000 ft). Images of visually acceptable signal-to-noise ratio were obtained at ranges up to about 227 m (750 ft). Beyond 227 m, there was a notable deterioration in the image quality, caused by a combination of the reduced return signal and by increased intensity modulations caused by atmospheric turbulence effects on laser speckle. The intensity modulations were especially troublesome at long ranges because they exhibited a motion that was very similar in appearance to that of the gas plume. It is likely that this effect was observed at its worst case because, at a height of about 2 m from the ground and with site temperatures of ~90°F, the imaging path traveled the distance to and from the target through a strong thermal gradient. If a BAGI system was deployed in a downlooking mode (such as from a helicopter), in which only a small portion of the optical path traveled through the turbulent zone at the surface, it is conceivable that this problem would not be as severe.

In comparing the measured performance to the model predicted performance, it was clear that, although 75% of the 300 m target range was achieved, performance fell somewhat short of expectations. Possible explanations for this include losses unrepresented in the model due to atmospheric turbulence (i.e. defocusing of the laser beam), and other losses that were unaccounted for in the optical system. Work is currently being done to correct these problems. The breadboard system is being converted to a standalone prototype. In doing so, an acousto-optic deflector is being incorporated into the imager to correct for time-of-flight mismatches between the laser and IFOV and a complete throughput analysis of the system is being carried out. Final field evaluations of the prototype will be carried out following its completion.

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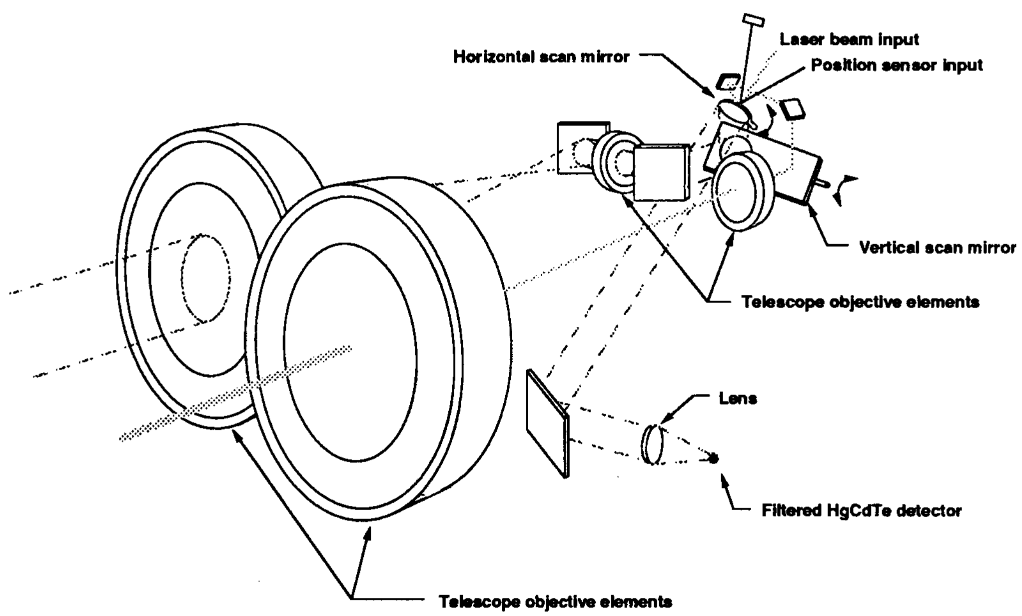

Figure 1 - Schematic of the long-range BAGI imager.