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LASER INTERROGATION OF SURFACE AGENTS (LISA) FOR STANDOFF SENSING OF CHEMICAL AGENTS

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Laser Interrogation of Surface Agents (LISA) for standoff sensing of chemical agents

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ABSTRACT

Laser Interrogation of Surface Agents (LISA) is a new technique based on short-range Raman lidar which provides standoff detection and identification of surface-deposited chemical agents. ITT Industries, Advanced Engineering and Sciences Division is currently developing the LISA technology under a cost-sharing arrangement with the U.S. Army Soldier and Biological Chemical Command (SBCCOM) for incorporation on the Army's future reconnaissance vehicles. In this paper, we will discuss the field-engineered prototype LISA-Recon system, designed to demonstrate single-shot on-the-move measurements of chemical contaminants.

1. INTRODUCTION

For the past 4 years, ITT Industries, Advanced Engineering and Sciences Division, has collaborated with Brookhaven National Laboratory (BNL) on the application of Raman scattering from surface-deposited chemicals to military sensing missions. This general measurement technique has been named Laser Interrogation of Surface Agents (LISA). BNL developed a portable proof-of-concept LISA device under DOE sponsorship, the Mini-Raman Lidar System (MRLS), which successfully detected and identified a broad range of chemicals on a variety of surfaces.[1] The experimental sensitivity limit of the MRLS is approximately 2 g/m^2. BNL also has developed and successfully tested a larger system mounted in a van, called the Mobile Raman Lidar Van (MRLV) for detection at ranges over 500 meters.[2]

While LISA technology is based on the architecture of Raman lidar, it is distinct from a classic lidar system because it is specialized for the detection of substances on surfaces at short (<50 m) ranges. Despite the success of Raman lidar in measuring atmospheric constituents at kilometer distances, its ability to remotely measure airborne chemical warfare agents is problematic due to their very small Raman cross-sections.[3] At short standoff ranges, however, the tremendous increase in signal due to the $1/R^2$ effect makes Raman detection practical.

Theoretical analysis and laboratory measurements of Raman scattering from chemical agents and compounds at short ranges have been performed by other researchers.[3,4,5]. The MRLS, however, is the first operational standoff detection system based on the LISA technique which has been successfully demonstrated both in the laboratory and through field trials such as the 1997 New York City Intra-Agency Chemical Exercise.

In September 2000, ITT and BNL cooperatively participated in the Joint Chemical Field Trials (sensor field evaluations for the Restoration of Operations (RestOps) Advanced Concept Technology Demonstration (ACTD)) at Dugway Proving Ground. ITT and BNL deployed the MRLS to Dugway and conducted a series of measurements of chemical agent simulants and actual chemical agents during a 2-week period.[6] The MRLS successfully detected and identified chemical agent simulants at stand-off distances of ~2.5 m on several different surfaces at varying concentration levels, but not down to the 0.5 g/m^2 level required for military reconnaissance systems. This performance limitation of the current MRLS was expected, since it was designed for a broader range of applications and not optimized specifically for these tests.

The potential of the LISA technology for non-contact detection and identification of chemical agents from a rapidly moving reconnaissance vehicle has led to a cost-sharing agreement between ITT and the U.S. Army Soldier and Biological Chemical Command (SBCCOM). The objective of this joint program is to develop and demonstrate a prototype LISA-Recon system optimized to meet the Army's mission requirements. This prototype LISA-Recon system has been designed to provide on-the-move detection and identification of chemical agents at surface concentrations well below the required level for reconnaissance missions.

2. THE LISA CONCEPT

The LISA concept is illustrated in Figure 1. A UV laser transmitter serves as a spectrally narrow light source with high irradiance. It illuminates a chemical agent deposited on a surface. A portion of the incident light is Raman scattered by the chemical compound. This light is scattered both spatially in all directions as well as spectrally into preferred wavelengths corresponding to the unique vibrational energies of the chemical. The Raman scattered light is collected by a telescope and is coupled into a dispersive optical system. In our case, the telescope focuses the collected light onto an optical fiber bundle. At the opposite end of the fiber bundle, individual fibers are oriented linearly to form an entrance slit for a grating-based spectrograph. A focal plane array detector records the optical spectrum of the Raman scattered light. This spectrum serves as a "fingerprint" for the chemical compound. An analysis computer employs pattern-matching algorithms to identify the chemical from its spectral library of known compounds.

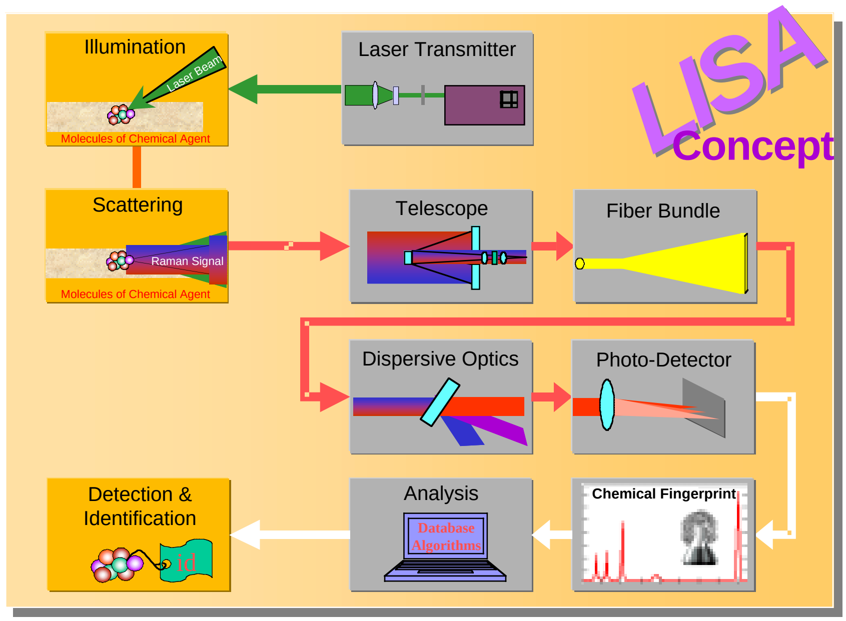

Figure 1. The LISA concept

3. LISA-RECON PROTOTYPE DESIGN

The LISA-Recon prototype has been designed specifically to meet the need of the Army for on-the-move detection of chemical warfare agents. The LISA-Recon system consists of a sensor module which will be mounted to the rear of the Nuclear Biological Chemical Reconnaissance Vehicle (NBCRV) and stare at a fixed pointing direction at the ground. The sensor module will be connected by umbilical to an operator's console interior to the vehicle. The control and analysis computer has the capability to analyze a complicated measured spectrum for the presence of chemical agents in real-time for each individual laser shot.

An exploded view of the prototype sensor module is shown in Figure 2. The sensor module housing provides environmental protection and a rigid mounting surface for the sensor subsystems. A line-narrowed excimer laser serves as the laser transmitter. This laser is very compact and can produce 20 mJ pulses at 248 nm with a pulse repetition rate of 25 Hz. This laser is an improvement over the MRLS laser transmitter both due to its increased energy and reduced wavelength (248 nm vs. 266

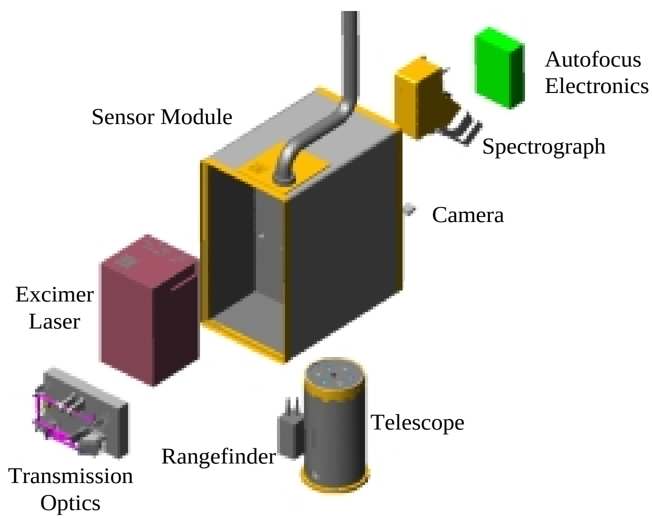

Figure 2. LISA-Recon sensor module design.

nm). This shorter wavelength has two major advantages: increased scattering cross-section and greatly reduced interference due to background fluorescence.

Beam shaping and steering optics in front of the laser insure that the laser spot on the ground has the optimal size and is centered in the telescope field of view. The beam is transmitted coaxially with the telescope.

The collecting telescope has an 8-inch primary mirror and has been designed for a stand-off distance of 1.5 m. A thorough optical analysis has revealed that the optical throughput of the telescope is very sensitive to changes in the standoff distance, as shown in figure 3. Since the reconnaissance vehicle will travel over rough terrain, a fixed focus telescope is not the optimal configuration. We have designed a “lookahead” autofocus telescope system which utilizes a rangefinder to measure the distance to ground, computes the focus position to optimize the optical throughput for the next laser pulse, and holds the telescope focus at this position. It is capable of performing this task for each laser pulse, ie. 25 times a second.

A Raman edge filter assembly is integrated at the rear of the telescope to reduce the 248-nm elastic scattering energy into the system. This assembly is fiber coupled to the analyzing spectrograph. This feature enables the subsystems to be located based upon packaging or mechanical considerations without sacrificing optical alignment tolerances. The spectrograph contains a fiber bundle which acts as a circle-to-line converter, a flat grating, and associated focusing optics. The dispersed spectrum is recorded by an intensified CCD array and is read out to the computer after every laser shot. A diagnostic video camera is mounted on the LISA sensor in order to provide further documentation of the interrogated surfaces during field testing.

Increased optical throughput is the key improvement over the MRLS required to enable single-shot detection at the required sensitivity level of 0.5 g/m^2. The major modifications incorporated into the LISA-Recon system are: (i) reduced wavelength—improves scattering efficiency and reduces fluorescence background, (ii) higher laser energy (20 mJ/pulse), (iii) increased telescope diameter, (iv) increased spectrometer input coupling, and (v) improved detector quantum efficiency.

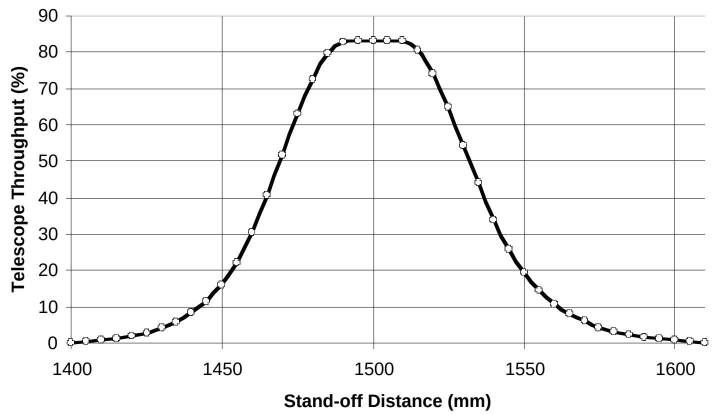

Figure 3. Optical throughput vs. standoff distance for a fixed focus telescope

4. CONCLUSION

The application of Raman lidar to short-range detection of surface chemicals has given rise to a new technique known as Laser Interrogation of Surface Agents (LISA). LISA provides the capability for safe, rapid, standoff detection and identification of hazardous chemicals. In the LISA approach, a high energy laser transmitter operating in the ultraviolet illuminates the chemical. The Raman-scattered return signal is collected by a telescope, spectrally dispersed and imaged onto a focal plane array detector. The unique optical fingerprint contained in the spectrally dispersed return signal is compared to a library of Raman optical fingerprints of chemical compounds. A positive chemical agent identification is obtained using pattern matching algorithms optimized for this purpose. This technique has been successfully demonstrated by BNL’s MRLS in both the laboratory and in the field.

A joint SBCCOM-ITT development project is underway to design and test a prototype LISA-Recon system which is optimized to make measurements of chemical agents from a moving reconnaissance vehicle. A preliminary performance analysis of the LISA-Recon instrument has been made based upon the actual field performance of the MRLS and a careful evaluation of the system improvements incorporated into the LISA-Recon instrument. This analysis indicates that the sensor’s sensitivity will exceed the Army’s requirements by over an order of magnitude. Field testing of the LISA-Recon system will occur during 2002. Results of these tests will be reported in the conference paper.

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