Standoff Raman Hyperspectral Imaging Detection of Explosives

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Abstract - A novel sensor concept for optical standoff detection of explosives that combines Raman hyperspectral imaging and laser induced breakdown spectroscopy (LIBS) is described. Conceptually, the standoff optical sensor trades off the high sensitivity of LIBS elemental analysis with the high specificity of Raman molecular analysis to provide, overall, a high sensitivity, low false alarm rate standoff identification strategy for explosives on surfaces. In this paper, Raman hyperspectral imaging results are presented in an initial assessment of the standoff Raman detection performance.

I. INTRODUCTION

Optical spectroscopy techniques, including Raman spectroscopy and Laser Induced Breakdown Spectroscopy (LIBS) are showing promise for standoff detection of chemical, biological and explosive (CBE) threat agents. LIBS can be used to detect chemical, biological and explosive (CBE) hazardous materials. While Raman or LIBS are suited to evaluate complex hazards, technology approaches that will improve probability of detection (Pd) and reduce false alarms rates (FAR) are desired. Improvements in sensor performance can be accomplished by combining LIBS with Raman spectroscopy, highly complementary spectroscopic techniques, and by employing state-or-the-art sensor data fusion algorithms.

We have developed a concept for combining LIBS and Raman standoff optical sensors into a leap-ahead system for hazardous material detection. The standoff sensor is designed around proven standoff sensor concepts demonstrated by the Army Research Laboratory, Weapons and Materials Research Directorate (ARL, WMRD). The standoff sensor integrates Fiber Array Spectral Translator (FAST) Chemical Imaging technology [1] into the LIBS and Raman standoff sensor designs.

Chemical Imaging combines digital imaging and molecular/elemental spectroscopy for material analysis. Widefield Chemical Imaging is applicable to the problem of detecting trace levels of explosives in the presence of background clutter. In order to demonstrate the FAST Raman hyperspectral imaging concept, we have made LIBS and Raman measurements using a standoff sensor which we have upgraded to use FAST technology.

II. SENSOR CONCEPT

The sensor will employ a hierarchical strategy for standoff optical detection of explosive residues. Specifically, the sensor will operate in two detection modes: (1) Continuous Surveillance Detection Mode; and (2) Presumptive identification mode.

In the Surveillance mode, continuous, large area surveillance using near-infrared (NIR) hyperspectral imaging is performed over a very wide field of view to provide a list of spatial coordinates for potential targets to be confirmed in subsequent identification mode.

In the Identification mode, three detection steps are applied to each target resulting from the Surveillance operation: (ID Step 1): Laser induced breakdown spectroscopy (LIBS) performed on the surface targets from the Surveillance operation; (ID Step 2): Raman hyperspectral imaging spectroscopy performed on the suspected surface targets; and (ID Step 3): Fusion of LIBS and Raman data to support high confidence decision making.

III. RAMAN SIGNATURES OF EXPLOSIVES

The motivation for exploiting Raman detection is to make use of the high degree of specificity provided by Raman sensing. To demonstrate the underlying specificity of Raman detection, we have collected Raman signatures in point detection mode from a variety of explosives reference materials. Specifically, Non-hazardous Explosive for Security Testing and Training (NESTT) powder samples were placed onto an aluminum-coated glass substrate and characterized using a Raman sensor (FALCON, ChemImage Corp.). [2] The NESTT samples contained 8% explosive by weight in a pure silica
matrix. Representative results are shown in Figure 1A-C for KNO₃, PETN, Silica, RDX, KClO₃, and TNT.

Figure 1A shows the mean Raman spectra collected from 5 unique sample locations for each material type. To assess the degree of homogeneity within the samples, a principal component scores scatter plot is shown in Figure 1B, after principal components analysis (PCA) data reduction. Note that most of the spectra are reproducible. However, the potassium nitrate sample was highly heterogeneous and substantial variability is evident within the scatter plot for this class. A Mahalanobis Distance classifier was constructed from the Raman data and each of the six unique classes was evaluated using a confusion matrix, shown in Figure 1C.

When signatures are collected at a high signal to noise ratio (SNR), Raman provides adequate specificity to differentiate these materials.

IV. RAMAN HYPERSONSPECTRAL IMAGING OF EXPLOSIVE MIXTURE

The motivation for using a Raman sensor with a hyperspectral imaging design, rather than a non-imaging design, is to improve the overall sampling statistics of the sensor and to reduce the susceptibility to background clutter. In general, hyperspectral imaging sensors provide improved performance relative to non-imaging sensors when evaluating target analytes in the presence of background interference, when the target is inhomogeneously distributed within a field of regard.

Figure 2A shows an inhomogeneous mixture model system evaluated with the prototype standoff Raman hyperspectral imaging sensor. The Raman sensor is enabled with FAST operating in conjunction with a dispersive imaging spectrometer and intensified charge-coupled device (ICCD) imaging detector.

The mixture sample was comprised of calcium sulfate (CaSO₄), “background”, and sodium nitrate (NaNO₃), a “target” ingredient in explosives. Figure 2B shows Raman spectra for each of the mixture components.

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<th>Confusion Matrix (%)</th>
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<tr>
<td>Chlorate</td>
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<tr>
<td>Chlorate</td>
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<td>Nitrate</td>
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<td>TNT</td>
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Fig. 1C. Confusion matrix demonstrating Raman signature discrimination between explosives classes, including background.
Figure 2C shows the raw Raman focal plane image data collected from the mixture sample. A Raman hyperspectral image is reconstructed from the focal plane image. Raman images specific to CaSO₄ and NaNO₃ are shown in Figure 2D, which is the first demonstration of standoff Raman imaging of a complex mixture. To construct the image, a FAST device was used to collect spatially resolved Raman spectra that were coupled to a dispersive spectrometer. Subsequently, the spatially resolved spectra were reconstructed to produce the Raman images. The FAST image was collected in 50 µsec.

V. CONCLUSIONS

Raman hyperspectral imaging of explosives mixtures has been demonstrated at modest standoff distances. A Raman hyperspectral imaging sensor combined with a LIBS sensor is under development for detection of explosives at standoff distances.

As part of this overall effort, we are exploiting sensor data fusion approaches that have been demonstrated through successful collaborative research efforts between ARL, WMRD and CI. These sensor fusion approaches will be the subject of future publications.

ACKNOWLEDGMENT

The authors wish to acknowledge the important contributions of Professor Martin Richardson, Chris Brown, Matt Fisher, University of Central Florida, and Andrzej Miziolek, Army Research Laboratory.

REFERENCES
