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Near infrared spectral imaging of explosives using a tunable OPO laser source

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INTRODUCTION

Increased security measures due to the continuous threat of terrorist activities have placed strong demands on the development of new technologies to detect explosive materials.¹⁻² In addition to airport screening, seaports across the world are increasing their screening of cargo containers for suspicious cargo, and first responders are in constant need of improved technologies may come upon a suspect package or powder. A number of screening technologies are available for detecting explosives. The most prevalent method used at airports is the ion mobility spectrometer (IMS). This method works by swiping the baggage with a filter or some type of collection membrane and thermally desorbing the residue into the IMS. Although this technique is fast and reliable, it requires that a particle be collected on the swipe. Thus, there is a need to develop non-contact standoff methods for explosives detection.

Near infrared (NIR) spectroscopy measures the absorption of light by molecules in the wavelength range from 700-2500 nm with the predominant absorption features being due to the CH, OH, NH vibrational overtone and combination bands. Since many energetic materials contain these functional groups, they will have unique spectra in the NIR. However, in general, spectral resolution of NIR spectrometers is limited and many other non-energetic molecules also contain these groups and could likely have absorption bands in the same locations. Thus, NIR spectroscopy is heavily reliant on using chemometrics to analyze the data for the identification and classification of materials. Using principle component analysis, explosives materials can be readily identified and discriminated from other non-energetic materials.

In this report, we demonstrate the performance potential of NIR spectroscopy for advanced screening with the possibility of identification of materials based comparisons to a predetermined library. Spectra are reported using a conventional dispersive system and advanced laser-based imaging system. The imaging system uses a tunable OPO laser to illuminate the target with a very narrow wavelength light source that is tunable over a wide range of wavelengths without the need for an additional filter. NIR spectra from some explosive materials will be presented and an imaging system describe a hyperspectral imaging system capable of acquiring images of an area and highlight particles or materials that could be suspect materials based on spectral signatures.

EXPERIMENTAL

Explosive materials, 2,4,6-trinitrotoluene (TNT), 1,3,5-trinitro-1,3,5-triazacyclohexane (RDX), and pentaerythritol tetranitrate (PETN) (XM Materials) were placed on on a cellulose based swipe material with no additional preparation. Point source spectra were acquired using a NIR

spectrometer (Analytical Spectral Devices Inc. Labspec Pro) that uses a broad band tungsten halogen light source and 3 detectors covering the spectral range from 350 -2500 nm with an approximate spectral resolution of 10 nm in the NIR range. Fiber optic bundles were used to transmit the light to and collect the reflected light from the sample. The hyperspectral imaging system (HySPEC™, OPOTEK, Carlsbad, CA) incorporates an optical parametric oscillator (OPO) laser as the illumination source and NIR focal plane array detector (AlphaNIR, Indigo System) with a 50mm, $f/1.4$ lens, chromatically corrected between 0.9 μm up to 1.7 μm (Electrophysic). The FPA was an array of 256 x 320 pixels each measuring 30 x 30 μm . The field of view will be determined by the standoff distance and optics, which will also determine the smallest particle detectable. A schematic and photo of the system are shown in **Figure 1**. Laser intensity fluctuations and camera non-linearity are corrected for using 4 calibrated reflectance standards. Software automatically applies the corrections to each image at the different wavelengths.

RESULTS AND DISCUSSION

Explosive materials can come in many different forms including liquids, gels, powders, and solids. For this study, powders of some common explosives, TNT, RDX, and PETN (**Figure 2**), were chosen for analysis. **Figure 3** shows the diffuse reflectance spectra acquired with a dispersive NIR spectrometer with a bifurcated fiber optic bundle for the three different explosive materials. These spectra show unique absorption features for each material with the common peaks at approximately 1650 nm due to C-H vibrational overtone. Although, other materials could have absorption in this range, 1650 nm band could be considered as one of the primary discriminating wavelengths when using NIR imaging as a screening technique. Spectral libraries of energetic materials have been developed and material identification can be achieved using principal component analysis.

Although, using a fiber optic based NIR spectrometer can be a valuable tool for identifying explosives, it requires that the location of the sample is known and is present in 'bulk' quantities. NIR focal plane array cameras enable larger areas to be screened with a spatial resolution that depends on the array dimensions, pixel size, and optics employed. These cameras usually incorporate tunable filters, e.g. LCTF or AOTF, on the front end to provide the spectral resolution. However, the filters greatly diminish the light throughput and have rather large bandpass which limits the spectral resolution. The system used in this study incorporates a tunable OPO laser as the light source and does not require filters. **Figure 4** shows 3 false color images of TNT, PETN, and RDX on filter paper swipe. The total weight of each material was less than 0.5 mg with a field of view approximately 4 cm on a side and the samples dispersed over 2 mm diameter. From these images, it is impossible to determine what the material is or if it is explosive. These are composite images of an image cube and each pixel actually contains a full spectrum from 1000 to 1700 nm.

Figure 5 shows spectra of each of the explosive materials obtained from an average of multiple pixels in the image. It should be noted that equivalent spectra can be obtained from a single pixel. The spectral resolution of the tunable OPO laser provides more spectral information than was observed using the dispersive system. For example, the RDX peak at ~1650 nm in Figure 3 is now resolved into several finer absorption bands. This enhanced spectral resolution will enable better discrimination and identification using chemometric analysis. The limit of detection for this imaging

system is now down to the amount of material necessary to obtain an adequate spectrum from a single pixel. Thus, NIR spectroscopy can now be considered a technique for trace analysis.⁴

CONCLUSIONS

We have demonstrated that near infrared spectroscopy can be a valuable tool for screening and potentially identifying explosive particles. Imaging enables larger areas to be screened and with the use of a tunable laser source can improve the spectral resolution. The current limits of detection have not been precisely defined but demonstrate that small particles of explosives can be detected and identify from the NIR spectra. NIR spectroscopic imaging can provide an excellent method of detection of contaminants, be they explosives or other foreign materials.

In addition to the experimental improvements, there are a number of fundamental studies that should be investigated to determine the ultimate limitations of NIR imaging spectroscopy. A broader more fundamental determination of detection limits that relates the minimum particle size (diameter and thickness) and the absorption and scattering properties of the material could be determined. One of the key tests of performance will be to determine how well explosive particles can be discriminated from common background materials. Further evaluations should explore how well explosives can be detected on different materials, e.g. clothes, packaging material, soil, and vegetation. Ideally an explosive detection/screening system will be able to respond in real time. The optical configuration, number of wavelengths interrogated, and signal processing algorithm needed to provide a satisfactory response would have to be redesigned to provide real time information.

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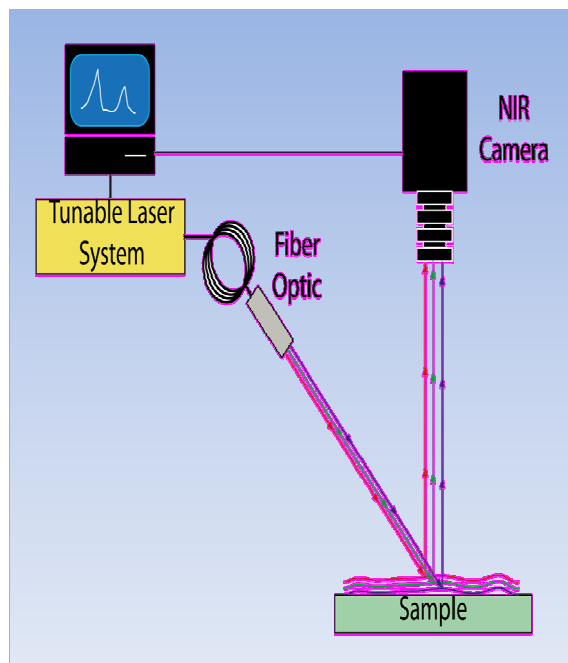


Figure 1. Schematic and photo of the Hyspec illumination and imaging system.

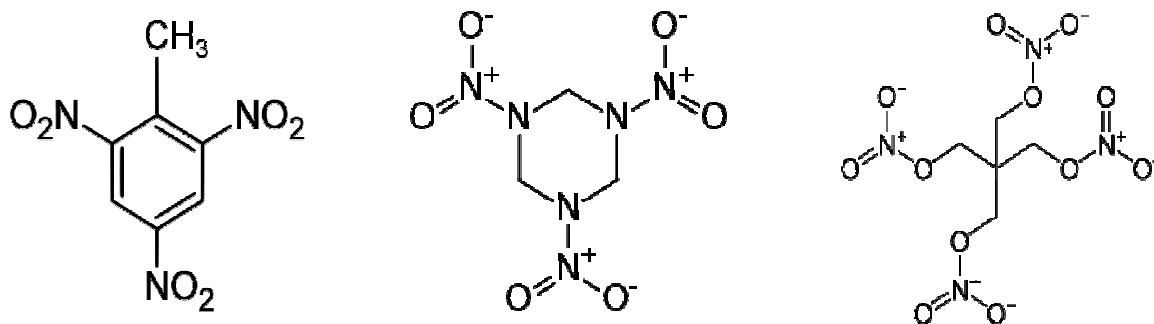


Figure 2. Chemical structures of TNT, RDX, and PETN, respectively.

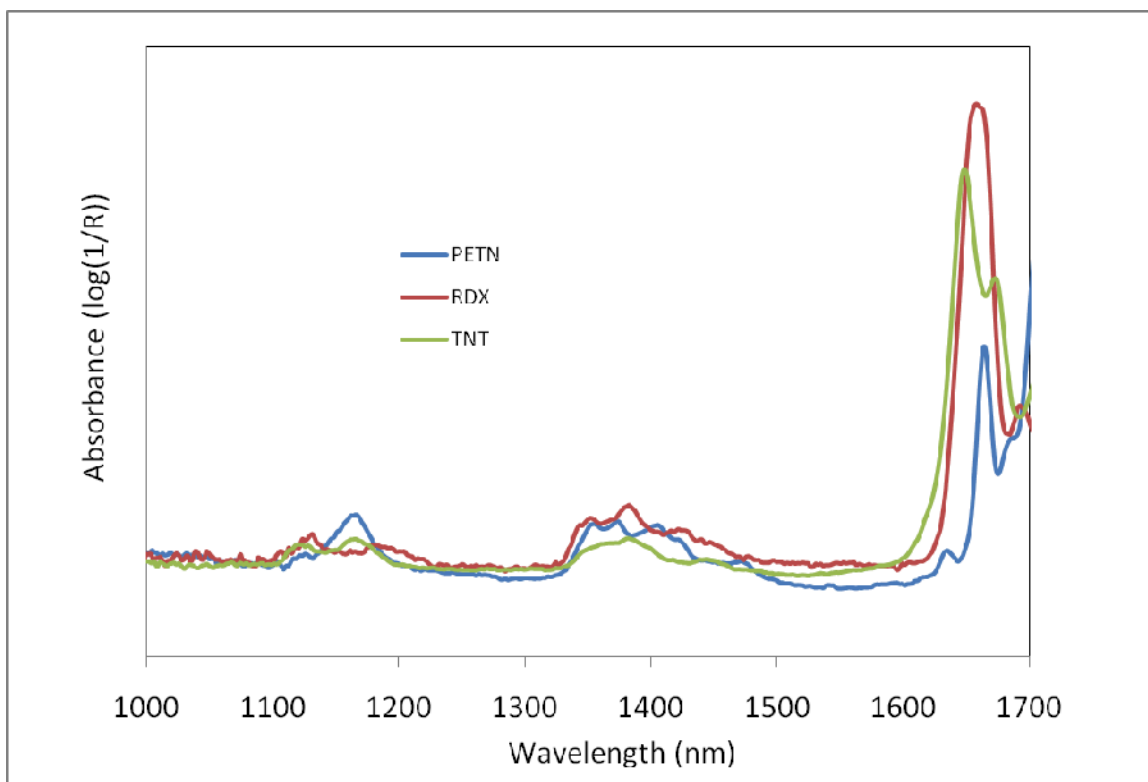


Figure 3. NIR spectra of TNT, RDX and PETN acquired with broadband light source and dispersive instrument (spectral resolution ~ 10 nm).

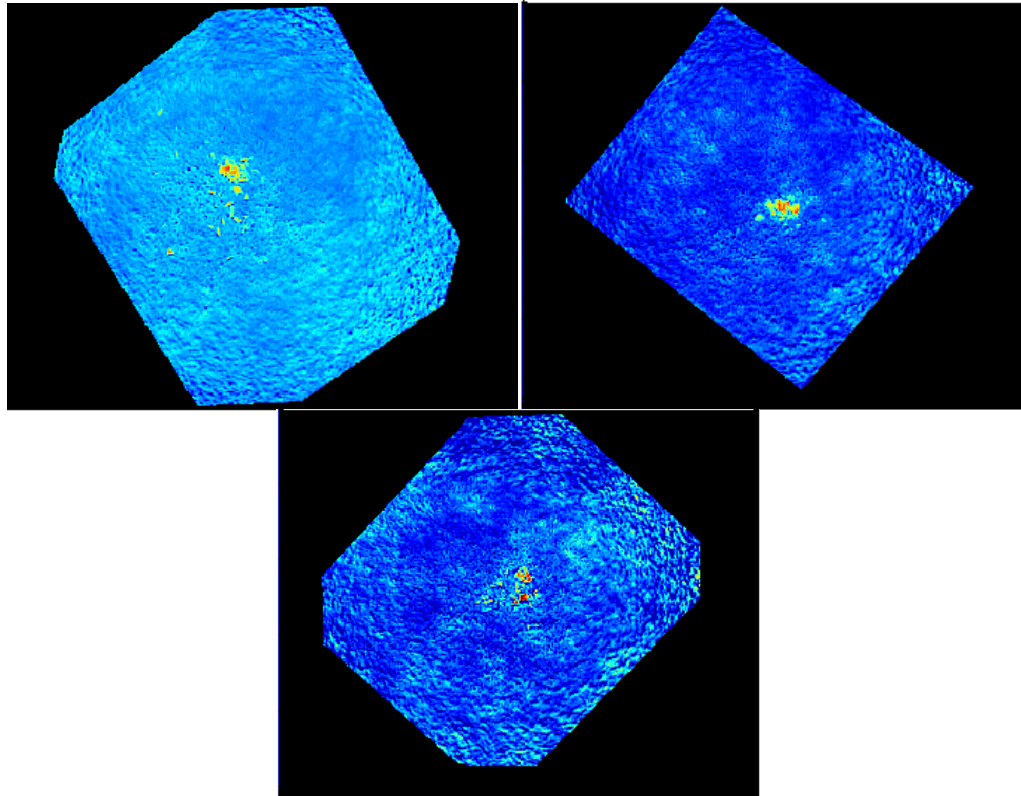


Figure 4. False color images of TNT, PETN, and RDX on filter paper .

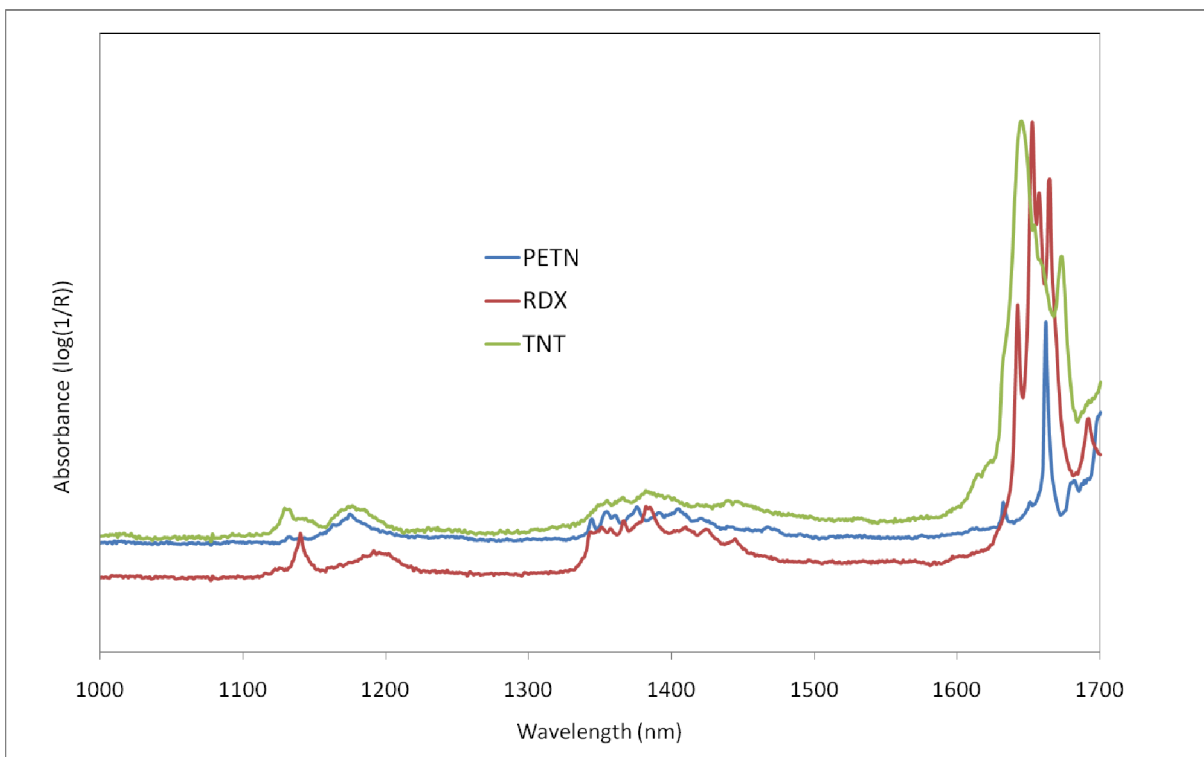


Figure 5. NIR spectra of PETN, RDX, and TNT acquired with tunable laser source (spectral resolution = 1 nm).