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Feasibility of a method to identify targets that are likely to contain conventional explosives

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Abstract

A method to remotely identify vehicles or other targets that might be harboring conventional explosives is described. The method utilizes multiple responses from a target that is interrogated by gamma-ray and neutron pulses and employs a template-matching procedure that reduces the collected information into a figure-of-merit. The template-matching procedure seeks to identify suspect targets based on deviations between a response vector obtained from a target under scrutiny and templates from a library; the templates are characteristic of targets with known cargoes. The methodology is illustrated with simulated data and the results of preliminary experiments on simplified targets are presented.

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1. Introduction

Recent terrorism tactics involve the use of vehicles and other targets that contain explosives, which are detonated either remotely or by a participant acting as a suicide bomber. An ability to identify whether or not a given target contains conventional explosives without personnel having to inspect the target, and thus be put at-risk, would be invaluable in areas where car bombs and other explosive packages are used or suspected. The capability to quickly and accurately detect small amounts of explosive at large stand-off distances inside any type of target is beyond current technology, but it may be possible to detect a mass of explosive of several kg within a target using system components that are more than a meter from the target.

In essence, the problem we address can be stated as follows. Assume that from a large population, N, of targets a small number, n, of them contain conventional explosive packages; the percentage of such "bad" targets is thus $p = 100\frac{n}{N}$. We seek to identify a number, m, of suspect targets that has the properties that all or most of the n bad targets are among the m suspect targets and the percentage $q = 100\frac{m}{N}$ of suspect targets is relatively close to p. Thus, we are willing to tolerate some false positives in order to minimize false negatives.

2. Physical basis

It is well known, e.g. [1], that most conventional explosives (such as RDX, TNT, Comp B, Comp A5, Comp C4 and PETN) contain similar proportions of hydrogen (H), carbon (C), nitrogen (N) and oxygen (O), and that these proportions differ from those for inert HCNO materials. Also, the mass densities of conventional explosives are typically higher than those of the common inert HCNO substances [2]. Most other materials, such as metals, contain elements of higher atomic number (Z) and have higher densities than either explosives or the light inert HCNO materials.

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Numerous authors have discussed the use of neutron techniques for explosive and contraband detection, e.g. see [3–8]. Neutron thermalization is a measure of hydrogen content, because neutrons lose more energy in interactions with hydrogen than with any other element. Once thermalized, neutrons also produce prompt neutron capture gamma rays in hydrogen, at 2.223 MeV, and nitrogen, at 10.38 MeV. Fast neutrons also scatter inelastically from carbon (4.43 MeV), nitrogen (1.64, 2.31, 5.11 MeV) and oxygen (6.128 MeV), giving rise to additional potential signatures (if the neutron energy is sufficiently high to excite these). The elastic scattering of fast neutrons is subject to strong resonances in carbon, nitrogen and oxygen [2]. In fact, the cross-sections for elastic scatter are generally higher than the capture or inelastic scatter cross-sections. Thus, fast neutron scatter responses also should depend on stoichiometry of the contents of a target. Recently, other techniques, such as nuclear quadrupole resonance [9], have also been investigated for the purpose of detecting hidden explosives.

Gamma-ray transmission and back-scattering have long been used to measure mass density and liquid level. If the target contains a fuel tank, a pulse of gamma rays incident on the fuel tank can be used to estimate the amount of fuel on board. Two different responses from backscattered gamma rays can be used to estimate average density and, crudely, composition.

We are investigating a technique to quickly identify suspect targets by employing a variety of neutron and gamma-ray signatures in order to generate a collection of responses that are dependent on the stoichiometry and density of the contents of a target. A collection of material that is characterized by smaller fractions of H, C and heavy elements, higher fractions of N and O, and mid-density values is a strong candidate to be an explosive.

3. Template-matching procedure

We suggest a template-matching procedure that compares a vector of detector responses, **R**, from an unknown target with a "template," **S**, which is a vector of detector responses typical of a similar target with known contents. By creating a database of templates – characteristic of, for instance, different vehicle types, different cargoes and different fuel levels – one can in principle detect the presence of an explosive package from the way **R** differs from all of the relevant templates for that target type.

For generality we consider an arbitrary number K of individual responses. We assume that the total number of possible responses has been reduced to the K responses that are sensitive to the presence of explosives and further that we know the "direction" of the deviation from the template for each response, i.e. if an explosive package is on-board we presume we know whether a given response will be greater or less than the corresponding template response. Let $\mathbf{S}_\ell$ be a vector of responses for a target that contains a known cargo, where the subscript ℓ indicates a particular target configuration, i.e.

$$\mathbf{S}_\ell = (S_{\ell 1} S_{\ell 2} \ldots S_{\ell K}), \tag{1}$$

and let **R** be a vector of responses for a test target,

$$\mathbf{R} = (R_1 R_2 \ldots R_K). \tag{2}$$

Further, suppose that the K responses are ordered such that for the first I of them, we expect $R > S$ and for the remaining J of them the opposite is true; thus $K = I + J$.

We suggest a template-matching procedure that utilizes the figure-of-merit defined by

$$\zeta = \sum_{i=1}^{I} \alpha_i \frac{R_i - S_{\ell i}}{[\sigma^2(R_i) + \sigma^2(S_{\ell i})]^{1/2}} + \sum_{j=1}^{J} \beta_j \frac{S_{\ell j} - R_j}{[\sigma^2(R_j) + \sigma^2(S_{\ell j})]^{1/2}}, \tag{3}$$

where σ^2 is variance and α_i and β_j and weight factors. This figure-of-merit will increase as deviations from the templates grow in the expected directions and will decrease, perhaps even becoming negative, as deviations from the templates grow in the unexpected directions. The specific signatures can be weighted as desired, allowing the strongest signatures to dominate.

In principle, judicious use of this figure-of-merit should allow one to identify suspect vehicles. If we use templates typical of inert cargoes, we can say that any target for which $|\zeta| \geqslant \zeta_0$, where ζ_0 is a positive cut-off value, becomes a suspect target. For templates typical of targets containing explosives, $|\zeta| < \zeta_0$ identifies a suspect target. The value chosen for the figure-of-merit cut-off is a measure of how certain one wishes to be that a target contains explosives. A low value of ζ_0 reduces the false negative rate but increases the false positive rate whereas high values have the opposite effect.

This process can possibly protect against counter-measures. For instance, a bomb hidden within a target and covered by lead, in order to reduce the prompt and inelastic gamma-ray signatures, would lead to a response vector that should be very different from all templates. The template-matching approach obviously allows inclusion of non-nuclear signatures, such as target weight, as well as nuclear signatures.

4. Results

The MCNP code [10] was used to simulate a 2 m diameter by 2 m long cylindrical target whose long axis is along the direction of an incident beam and which is surrounded by 50 detector surfaces that cover a solid angle of 4π sr. The target contained a cylindrical package of one of sixteen generic materials – H, C, N, O, Al, Si, Cu, Fe, water, petroleum, wood/paper, glass, plastic, clothing, explosive and ammonium nitrate (as an explosive surrogate). Table 1 gives the assumed weight fractions for the HCNO compounds. We simulated monoenergetic neutron beams