Evaluation of UXO Discrimination Using PELAN

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Abstract--*PELAN (Pulsed ELemental Analysis with Neutrons) is a man-portable system for the detection of explosives and chemical warfare agents, weighing less than 45 kg. It is based on the principle that explosives and other contraband contain various chemical elements such as H, C, N, O, etc. in quantities and ratios that differentiate them from other innocuous substances. The pulsed neutrons are produced with a pulsed 14 MeV (d-T) sealed tube neutron generator. Separate gamma-ray spectra from fast neutron, thermal neutron and activation reactions are accumulated and analyzed to determine elemental content.*

Unexploded ordnance (UXO) is a risk to the environment and communities. Due to age and condition, unknown items must be treated as if they contained high explosive and are often "blown in place" which leads to increased remediation costs.

In the last year, PELAN's ability to discriminate UXO has been tested and evaluated by the Environmental Security Technology Certification Program and the U.S. Navy EOD Technology Center. False alarm rates, false negative rates, minimum detection limits, and other critical information have been measured under these programs. In field trials performed in May 2002, PELAN had a false alarm rate of ~20% for UXO larger than 90 mm and a false negative rate of 3% for these sizes. For smaller UXO, minimum detection limits were encountered and the results are decidedly worse. In this paper, we will present the results on PELAN's ability to discriminate UXO.

I. INTRODUCTION

The elemental composition of explosives has been shown[1,2] to be quite different from other innocuous materials and contraband. Neutrons are excellent probes for the nondestructive analysis of elemental content. In particular, 14 MeV neutrons can be used to produce three types of reactions in materials: inelastic scattering, thermal neutron capture, and activation.

The Pulsed Fast/Thermal Neutron Analysis (PFTNA) technique is a method for producing these three reactions in a single system. In PFTNA, a pulsing deuterium-tritium (d-T) neutron generator is utilized to create pulses of neutrons with a duration of a few microseconds and a frequency of several thousand Hertz.

During the neutron pulse, the 14 MeV neutrons produce gamma rays primarily through inelastic scattering (n,n'γ). Both carbon and oxygen have relatively large cross-sections for this reaction (about 200 mb and 100 mb, respectively). Also nitrogen has an appreciable cross-section (~20 mb).

Between pulses, the fast neutrons are moderated by materials in the environment and the elements in the explosive. These neutrons are moderated to thermal energies and thus thermal capture reactions (n,γ) are initiated. Elements such as H, S, Cl, and N have substantial cross-sections for this type of reaction.

Finally, neutron activation reactions from (n,p), (n,α), etc. are also possible with 14 MeV neutrons. Since neutrons are created from a nuclear reaction that requires an accelerating potential, the beam can be turned off to measure gamma rays from the short half-life activation reactions without interference from the beam.

In PFTNA, a single data acquisition system that can switch between memory groups is used to collect and store these spectra at different memory locations. For example, the gamma rays produced during the neutron pulse are stored at one location, the spectrum of gamma rays produced between pulses at another memory location, and the activation at a third location. A wide variety of applications including landmine detection and bulk chemical analysis using PFTNA is given in Reference 3.

II. THE UXO PROBLEM

As the ability to detect sub-surface metallic objects increases, the organizations which must remediate sites designated for base realignment and closure (BRAC) and at Formerly Used Defense Sites (FUDS) face an increasing problem. The problem is to differentiate between unexploded ordnance (UXO) and other metallic clutter. The problem is exacerbated at former firing ranges where ordnance filled with inert materials was fired to test ballistic characteristics. At the Jefferson Proving Ground in Indiana it is estimated that for every six shells found only two contain high explosives[4]. To treat every piece of ordnance found as "live" increases cost and time required for the remediation process.

Recently, the Environmental Security Technology Certification Program in conjunction with the U.S. Navy EOD Technology Division has been testing a PFTNA-based system that our group developed called Pulsed ELemental Analysis with Neutrons (PELAN) for non-intrusive filler identification of unexploded ordnance.

The PELAN consists of a pulsing d-T neutron generator and a bismuth germanate (BGO) gamma-ray detector. PELAN is a small man-portable device composed of two units which interlock to form the shape shown in Figure 1. In one unit are housed the neutron generator along with the computer and the various power supplies. Housed in the second unit are the BGO γ-ray detector and the necessary material to shield the detector from the neutrons. The total mass of PELAN is less than 45 kg.

PELAN automatically analyzes the three spectra derived from inelastic scattering, thermal capture, and neutron activation to determine whether a threat is present.

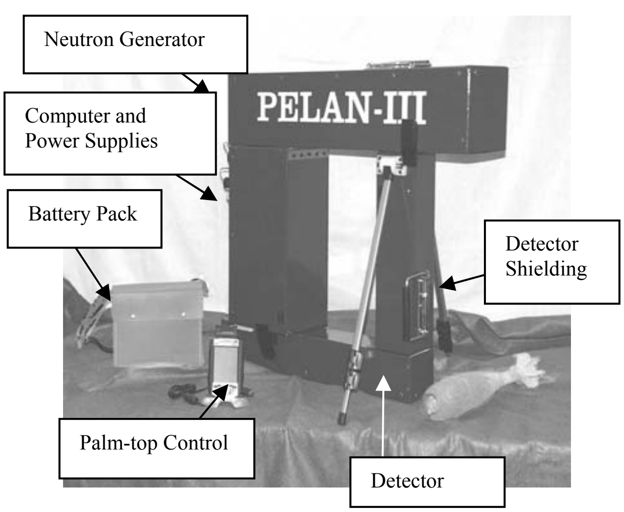

Figure 1. The PELAN system.

III. FIELD TRIAL, MAY 2002

During a two-week period in May 2002 (May 13-24) at the U.S. Navy Explosive Ordnance Disposal Technology Center at Indian Head, Maryland, an extensive validation test of PELAN was conducted. Purpose of the test was a) to examine PELAN's stability over a long time period, different types of soil, etc. and b) to collect data on different fill materials for shells (both explosive and non-explosive) and other explosives not found in UXO.

The demonstration was performed using:

- Five different types of PELAN placement: one on a table and four on different types of soil (gravel, sand, wet soil in 3'x3'x1' boxes and regular soil)
- Select shells of size 60, 76, 81, 82, 90, 105, 122, and 155 mm.
- Three landmines designed for both anti personnel and anti tank warfare
- The following explosives: TNT, RDX, COMPB, ANFO, PBX-108, PETN, Octal, Semtex, smokeless powder, and mixtures of TNT and RDX
- Shells of inert types: sand, wax, epoxy, plaster of Paris, and empty

A total of 164 cases were examined. All the data were automatically analyzed at the end of each run and recorded in the PELAN computer and on a spreadsheet. Each run was 5 minutes in duration. The data were used to establish such parameters as the validity of decision-trees built on the 164 cases, repeatability of measurements, critical analysis of spectral analysis software, etc.

In this paper, we will concentrate on the results of the validity of the decision trees. In the case of PELAN, a decision tree is a chain of logic statements (Boolean or otherwise) which makes a determination of the type of material it is analyzing. In the case of UXO, not only was the presence of a threat returned ("threat" or "no threat") but type of filler material was also determined (e.g. RDX, wax, etc.).

IV. DECISION TREE RESULTS

In creating a decision tree, the items under scrutiny are segregated by threat type and then separated according to material type (RDX, wax, TNT, etc.). In this way, patterns, such as wax having a high C and high H content with no O or N content, could be discerned. A set of Boolean logic was then created from these patterns. From this logic an automated decision-making code was created.

Three decision trees were written. The first decision tree was created from the data from only the UXO items (shells and mortars). The second decision tree was created from all of the explosives and inert items in the field trials (including landmines and raw explosive). In these decisions, the required inputs were the H, C, O, and N elemental content.

The third decision tree, unlike the others, required the user to input the size of the UXO before a decision could be made and was based only on the UXO items. The data set from Indian Head is flawed in that there is not enough variety in the fills for certain sizes e.g. the 76 mm shells have only explosive fills.

In Table I, we show the results of these decision trees. In Table I, FN denotes a false negative i.e. returning a value of "no threat" when a threat is present. FP denotes false positives or false alarms. The shell environment (depending on whether the shell is placed on a table or partially buried) will vary these results.

As shell size decreases, the PELAN's FN rate increases. This is due to the fact that signal from the small explosive size (300 g) is overwhelmed by that from the environment. In other words, if the shell is on the soil and the shell is much smaller than the mass of the soil, then the PELAN returns a value of "no threat".

Another trend in Table I is that the more information that we give the decision tree, the better the results. The additional information of the size significantly reduces the FN rate for the smaller shell since the decision tree can be made specifically for that particular size. It is logical to assume that information on the environment (such as soil type) may have a further beneficial result.

V. CONCLUSIONS

Currently, a 3" x 2" BGO detector is incorporated into the design of the PELAN. However, the high γ-ray efficiency of this detector has a drawback in that it detects γ rays from the environment surrounding the object under interrogation. These γ rays from the environment are essentially noise that must be filtered from the signal from the object under interrogation. Since there is no practical way to focus neutrons, the signal-to-noise ratio (SNR) of the detector must be modified. In the past three years, we have tried several approaches to solve this problem[5].

Another approach is a more sophisticated decision-making logic. Neural networks may have some potential but the task of data gathering for the initial training set is daunting. In the past, our group has performed some initial work in the area of fuzzy logic. Our results indicated a much higher potential for false alarms for fuzzy logic.

Recently, we have examined linear discriminant analysis (LDA). In LDA, a linear transform of the input data is made. The linear transformed data is plotted on some 2-D or 3-D axis and a line or plane is derived which segregates the threat data from the innocuous data. In Figure 2, we show such a transform and potential that it holds.

In conclusion, we have shown the PELAN has an excellent FN rate if there is sufficient material present. However, the ultimate solution to increase PELAN's sensitivity is to change the SNR

TABLE I. Results of decision trees for the field trial. FN denotes false negative and FP denotes false alarm.

				Decision Tree 1		Decision Tree 2		Decision Tree 3	
Size	Approximate Explosive Mass (g)	Number of Inerts	Number of Explosives	FP %	FN %	FP %	FN %	FP %	FN %
90 mm-155mm	> 900	36	36	22	3	22	0	0	3
76 mm -82 mm	700	28	40	29	20	29	15	18	3
60 mm	300	12	10	8	70	8	70	42	0
TOTAL		76	86	22	19	22	8	20	1.3

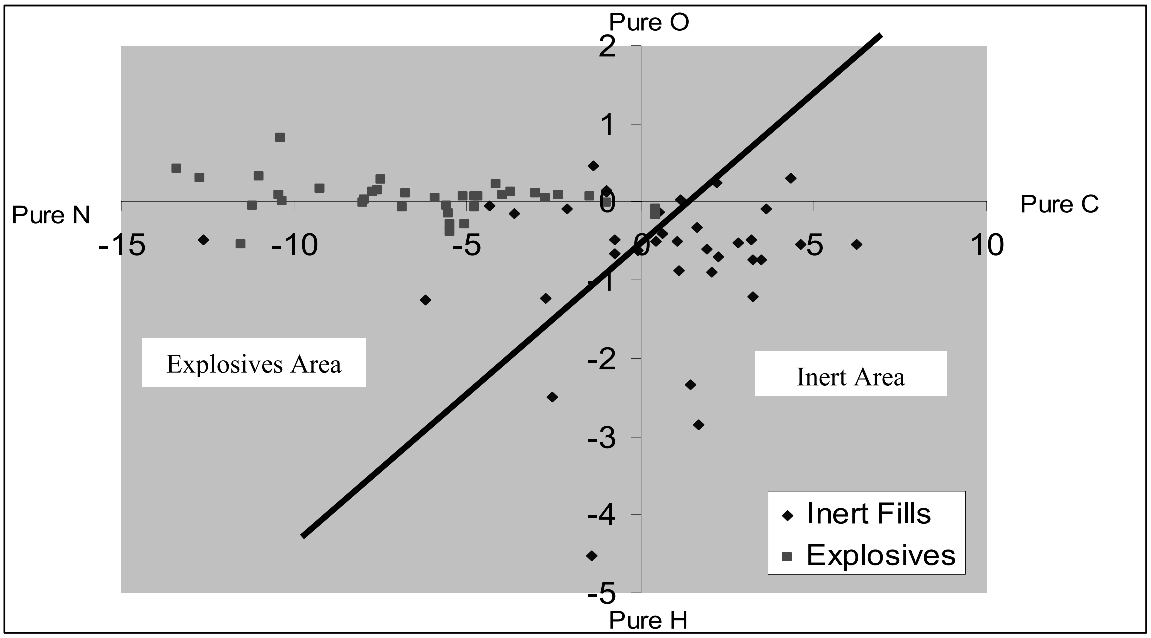

Figure 2. Graphical discriminant analysis of fills from 90 mm-155 mm UXO. By using a linear transform and mapping the results into a two dimensional graph, discrimination between inert fills and explosives can be shown. A boundary line has been added to aid the eye.

ACKNOWLEDGMENTS

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