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Title: ARS MUNITION CLASSIFICATION SYSTEM ENHANCEMENTS FINAL REPORT

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Submitted to: Defense Special Weapons Agency Field Command (DOD)

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Los Alamos
NATIONAL LABORATORY

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FINAL REPORT

ACOUSTIC RESONANCE SPECTROSCOPY (ARS) MUNITION CLASSIFICATION SYSTEM ENHANCEMENTS

Los Alamos National Laboratory
Engineering Sciences & Applications Division
Measurement Technology Group
Systems Team, MS J580
Los Alamos, NM 87545

September 18, 1997

FINAL REPORT

ACOUSTIC RESONANCE SPECTROSCOPY (ARS) MUNITION CLASSIFICATION SYSTEM ENHANCEMENTS

Conducted By:
Los Alamos National Laboratory*
Engineering Sciences & Applications Division
Measurement Technology Group
Systems Team, MS J580
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1.0 INTRODUCTION

Acoustic Resonance Spectroscopy (ARS) is a non-destructive evaluation technology developed at the Los Alamos National Laboratory (LANL). This technology has resulted in three generations of instrumentation, funded by the Defense Special Weapons Agency (DSWA), formerly Defense Nuclear Agency (DNA), specifically designed for field identification of chemical weapon (CW) munitions. Each generation of ARS instrumentation was developed with a specific user in mind. The ARS100 was built for use by the U.N. Inspection Teams going into Iraq immediately after the Persian Gulf War. The ARS200 was built for use in the U.S. – Russia Bilateral Chemical Weapons Treaty (the primary users for this system are the U.S. Onsite Inspection Agency (OSIA) and their Russian counterparts). The ARS300 was built with the requirements of the Organization for the Prohibition of Chemical Weapons (OPCW) in mind. Each successive system is an improved version of the previous system based on learning the weaknesses of each and, coincidentally, on the fact that more time was available to do a requirements analysis and the necessary engineering development.

The current system, the ARS300, is the culmination of the development effort and field experience gained over the past several years. This system is at a level of development, except for pre-planned product improvements (P^3I), that warrants transferring the technology to a commercial vendor. The need to transfer the technology is based on the fact that LANL is prohibited by law from competing with private enterprise. Therefore, in order to satisfy the production requirements of the OPCW, the technology must be transferred to a suitable manufacturer. Since LANL will supply the computer software to the selected vendor, it is possible for LANL to continue to improve the decision algorithms, add features where necessary, and adjust the user interface (all in conjunction with DSWA) before the final transfer occurs.

2.0 CURRENT SYSTEM DESCRIPTION

The Acoustic Resonance Spectroscopy Munition Classification System (ARS-MCS) non-invasively identifies fill material in munitions by inducing minute vibrations, or sound waves, into the munition and analyzing the effect the fill material has on these vibrations. It is a fast, nonintrusive technique that uses the natural modes of vibration of an object to determine the object's characteristics, and then classifies that munition based on those characteristics. For filled objects such as munitions, the modes of vibration are affected by the physical properties of the fill material and the amount of fill material present. By sweeping the excitation signal in frequency and measuring the response, an acoustic signature of the object in question can be created. This signature can then be used to classify the munition based on gross characteristics of the spectra, such as average peak width, or by comparing the spectra to other munition scans.

The ARS-MCS has two modes of operation. The first mode is a blind fill discrimination test. This test determines whether the munition in question is filled with liquid or solid material, without any prior knowledge or training by the system. This technique uses the average width of the spectral peaks and the ratio of spectral energy above 10 kHz to the energy below 10 kHz to perform a likelihood ratio test. Data from known solid filled and liquid filled 155 mm munitions was used to generate the set of statistics used in the test. This set of statistics is applicable to any 155mm munition.

The other mode of operation classifies munitions according to the fill type, i.e. GB, VX, H (mustard). This process involves obtaining scans from a known set of munitions. These scans are in turn used to create a template for that munition type. Future scans are compared against these munition templates. The most important aspect of this process is building good templates. A template is considered good if it can correctly classify any spectra not used in the template's creation with 90% reliability at 90% confidence.

The most significant problem for the system operator was knowing when he or she has a "good" template. Version 2.xx of the ARS software requires the operator to scan a random sample of 20 to 32 munitions and then create a template for that munition with no indication as to the quality of the template thus generated. For reasons best explained in Appendix C, "Template Quality in the ARS Munition Classification System, LAUR-96-4604", there was a measurable probability that the template would not be "good". The result would be a munition classification that did not meet the specified 90% reliability at a 90% confidence level.

3.0 ARS SYSTEM ENHANCEMENTS

3.1 Template Metric

The template quality issue has been addressed by the development of a new algorithm that allows the computer, instead of the operator, to determine when a template is "good". The process still requires the operator to scan, at random, a sample of the munitions to be tested. The computer creates a temporary template as each sample munition is scanned and alerts the operator when the template is of sufficient quality to meet the required reliability. For a more thorough description of the basic operation of the template metric, see Appendix B, "ARS300 System Enhancements, LAUR-97-xxxx".

Figure 1 below, illustrates the results of using the template metric algorithm. Notice that the reliability is above 80% after only a few files and stabilizes around 90% after approximately 22 files. These results are achieved automatically, giving the operator confidence that the data evaluations on subsequent munition scans are valid. This chart is taken from the reference cited above.

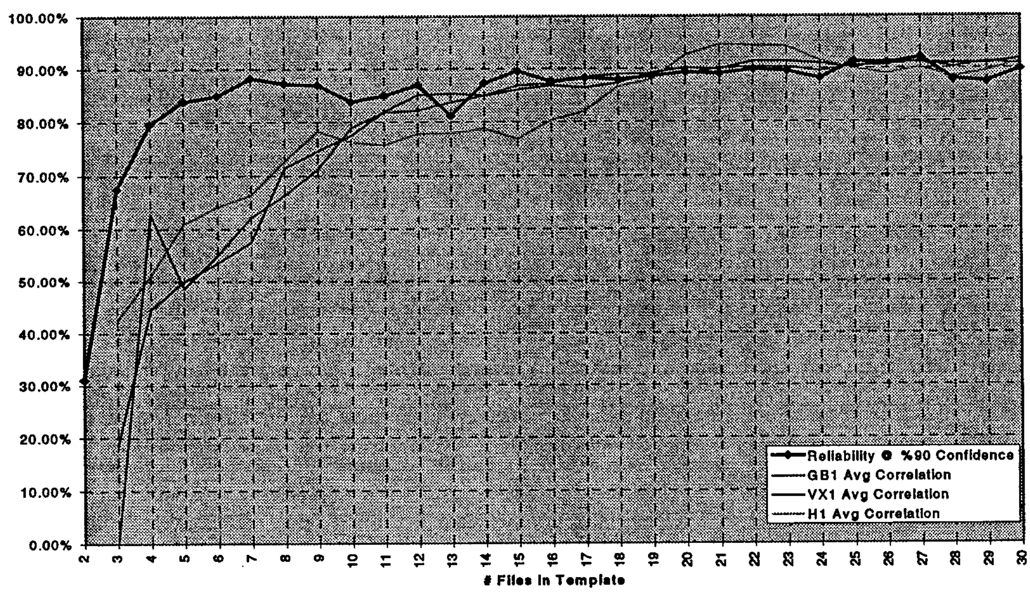

Figure 1. Template Metric Test Results for GB, VX & H

3.2 Liquid/Solid Discrimination Improvements

The availability of field data has always been crucial to the development of the ARS discrimination algorithms. In May, 1997 a new data collection effort was conducted at Tooele Army Depot. This data was used to test the liquid / solid fill discrimination capabilities of the ARS-MCS. The data set consisted of 85 155mm GB files, 47 155mm VX files, 46 155mm H files, 31 155mm HE (Comp-B) files and 25 155mm HE (TNT) files. Currently, the liquid / solid fill discrimination only works on 155mm munitions due to a lack of data on other munition sizes.

Using the additional data, a new set of liquid/solid fill discrimination statistics were generated consisting of all previous munition data and the May, 97 Tooele data. Once these new statistics were generated, they were used to classify the entire data set of available scans. This new set of statistics mis-classified 7 out of 943 munitions, resulting in a 98.76% reliability at 90% confidence. For a thorough explanation of the test results, see Appendix B.

4.0 SOFTWARE ENHANCEMENTS

4.1 Template Build Algorithm

The integration of the "Template Metric" into the template build algorithm necessitated significant software changes. The original template generation was a batch processing scheme in which the user collected many data files from the "Collect Data" section of the program, then selected a group of those files in the "Create Templates" section of the program to create the template. The "Template Metric" is an incremental algorithm, however, that requires that scan files be added one at a time. Therefore, the "Create Templates" section of the program was modified to be an interactive process. The user collects spectral data from this screen, adding each scan to the current template as it is collected. The number of files in the template and the running average of the correlations for the current template are displayed on the screen. Once the running average of the correlations surpasses 90%, a dialog box is displayed informing the user that the template can be considered complete, and asking the user if he/she would like to continue. This allows the user to either terminate the template creation process if an adequate sampling of all the munitions of that type has been made, or to continue to add munitions as necessary.

4.2 User Interface Improvements

Most of the modifications to the user interface centered around either enhancing the usability of the software or streamlining its appearance. Modifications were made to the top level menu screen, the site setup screen, the template creation screen, the data collection screen and the view & analyze screen.

The layout of the menu was rearranged to follow the site inspection scenario; "Site Setup", "Create Templates", "Collect Data" and "View & Analyze", in that order. The name of the currently selected site was also added to the program title bar. An "About" menu item was added to the system menu. This displays a dialog with the current software version, the current DSA version and the names and company logos of the institutions responsible for the development and production of the system. This about dialog is also displayed as the program splash screen when the program first starts.

The site setup interface has been changed significantly. The site creation procedure is still the same, however, the site editing and site selecting functions have been integrated into one dialog box. The previous interface used three dialogs that proved to be confusing for the operator. Therefore, all functionality was maintained while simplifying the data entry procedure for the user.

The data collection screen was modified only slightly. A warning dialog box is displayed if the magnitude of the spectral signal returned from the DSA is less than a preset threshold. Since the program autoscales the spectral graph displayed from the data returned from the DSA, it is sometimes difficult to determine if the data is valid. This warning attempts to warn the user if the program determines that the returned signal is not of sufficient strength. Several interlocks were added to the save routine. The first interlock simply disables the save button if there is no valid scan to save, and re-enables it when there is a valid scan to save. The second interlock helps to prevent the user from inadvertently saving a scan file into the wrong directory. This is accomplished by comparing the evaluation of the current file to the currently selected munition type. If they do not match, a dialog box is displayed with a warning stating this fact. The dialog contains three buttons and a check box. The checkbox is a "Don't warn me again" checkbox which disables the warning dialog box until the program is reopened. The three buttons are on OK button, which accepts the warning and saves the file anyway, a CANCEL button which cancels the save operation, and a COMMENT button, which brings up the comment entry dialog box pre-filled with the comment "This file was not evaluated to match its current type".

The ability to generate a report of all measurements has been added to the view and analyze section of the program. This is accomplished with a checkbox in the "Load" dialog box. When this checkbox is checked, all of the scans for the current munition will be evaluated against all templates, and the liquid / solid fill will be determined. This information is written to an ASCII text file, then automatically loaded into Windows Notepad.

5.0 CONCLUSIONS

The most significant improvement to the ARS-MCS software (release V3.01) is the addition of the template metric. This feature fully automates the process of creating templates and assures the reliability of subsequent scan evaluations.

Additional improvements to the software are designed to increase its useability. With the release of V3.01 of the ARS software, further enhancements are left to the commercial vendor. For specific recommendations regarding the software, please refer to Appendix B, "ARS Munition Classification System Enhancements."

Appendix A

ARS-MCS Operations Manual

(Software Version 3.01)

LAUR Number Pending

Acoustic Resonance Spectroscopy Munition Classification System

ARS-MCS

OPERATIONS MANUAL

Software Version 3.01

August 12, 1997

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Chapter 1: Introduction

1.1 Introduction

Acoustic Resonance Spectroscopy (ARS) is a nondestructive evaluation technology developed at the Los Alamos National Laboratory. The ARS technique is a fast, safe, and nonintrusive technique that is particularly useful when a large number of objects need to be tested.

Any physical object, whether solid, hollow, or fluid filled, has many modes of vibration. These modes of vibration, commonly referred to as the natural resonant modes or resonant frequencies, are determined by the object's shape, size, and physical properties, such as elastic moduli, speed of sound, and density. If the object is mechanically excited at frequencies corresponding to its characteristic natural vibrational modes, a resonance effect can be observed when small excitation energies produce large amplitude vibrations in the object. At other excitation frequencies, i.e., away from resonances, the vibrational response of the object is minimal.

For filled objects, the natural resonances are modified by the physical properties of the fill material and the fill level. Consequently, the resonance spectrum of such an object, or the vibrational characteristics over a band of frequencies, contains relevant information regarding the fill material.

The resonance spectrum, obtained by continuously exciting the object over a wide frequency range (sine-wave frequency sweep) and measuring its response, provides an acoustic signature of the object. The measurements can be made with direct contact transducers such as piezoelectric crystals. Typically, the frequency sweep range used for chemical munitions lies between 3 kHz and 30 kHz and the entire frequency sweep can be carried out in less than 60 seconds. The actual frequency sweep range used depends largely on the size of the object and the type of information desired.

1.2 Purpose for Nondestructive Evaluation

The primary purpose for nondestructive evaluation, as opposed to invasive techniques, is to protect inspection personnel from possible exposure to hazardous materials by minimizing the need for such exposure. Acoustic Resonance Spectroscopy (ARS) is one such technique. ARS can classify chemical weapon munitions by comparing a measured acoustic signature to a known standard or template. An ARS evaluation of an object is fast, taking less than 60 seconds, and requires little or no sample preparation, making ARS very attractive for screening large numbers of munitions

1.3 Basic Concepts

All objects have natural modes of mechanical vibration. Figure 1a, illustrates the one-dimensional vibrational modes of a taut string, such as you would find on a violin or guitar. Each mode can be viewed as a set of standing waves. Figure 1b shows some of the two- dimensional modes of a drum head. In musical terms, each mode corresponds to a tone. Each mode has it own shape and frequency of vibration. Objects vibrate preferentially, or resonate, at these mode frequencies, i.e., a small excitation at these frequencies will produce a large response. If you strike an object, these are the frequencies and patterns at which it will vibrate.

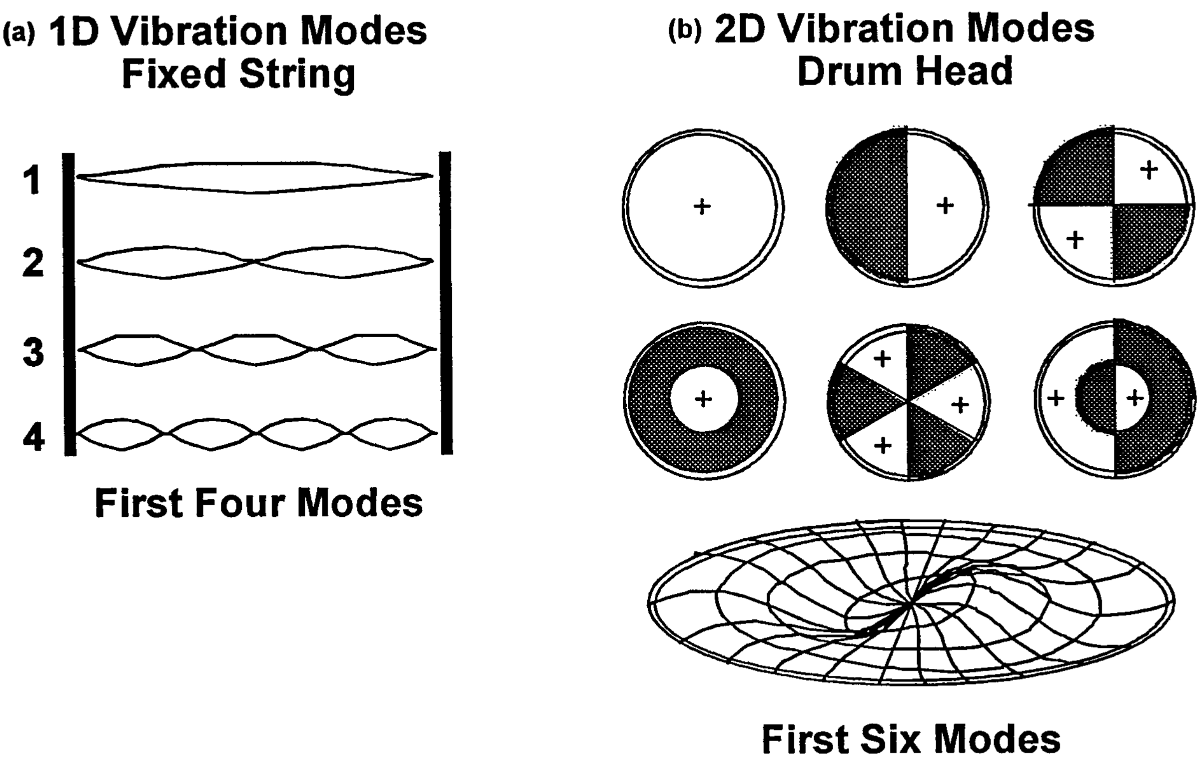


Figure 1. Resonance Modes - String and Drum

The resonant modes of an object are determined by its mechanical properties, including its physical shape, and the material properties of its components. Analytic formulas exist for calculating the modes of simple, idealized objects such as a one-dimensional string, a two-dimensional drumhead, or a simple three-dimensional cylinder. However, for more realistic objects, the complex effects of the various shape and material parameters make the modes impossible to describe analytically. In this case, the vibration modes can only be estimated numerically. Figure 2 illustrates the three-dimensional shapes of three modes of an empty 105mm artillery munition. The figures represent quarter section views of the munition. The vibrational deflections are greatly exaggerated for clarity.

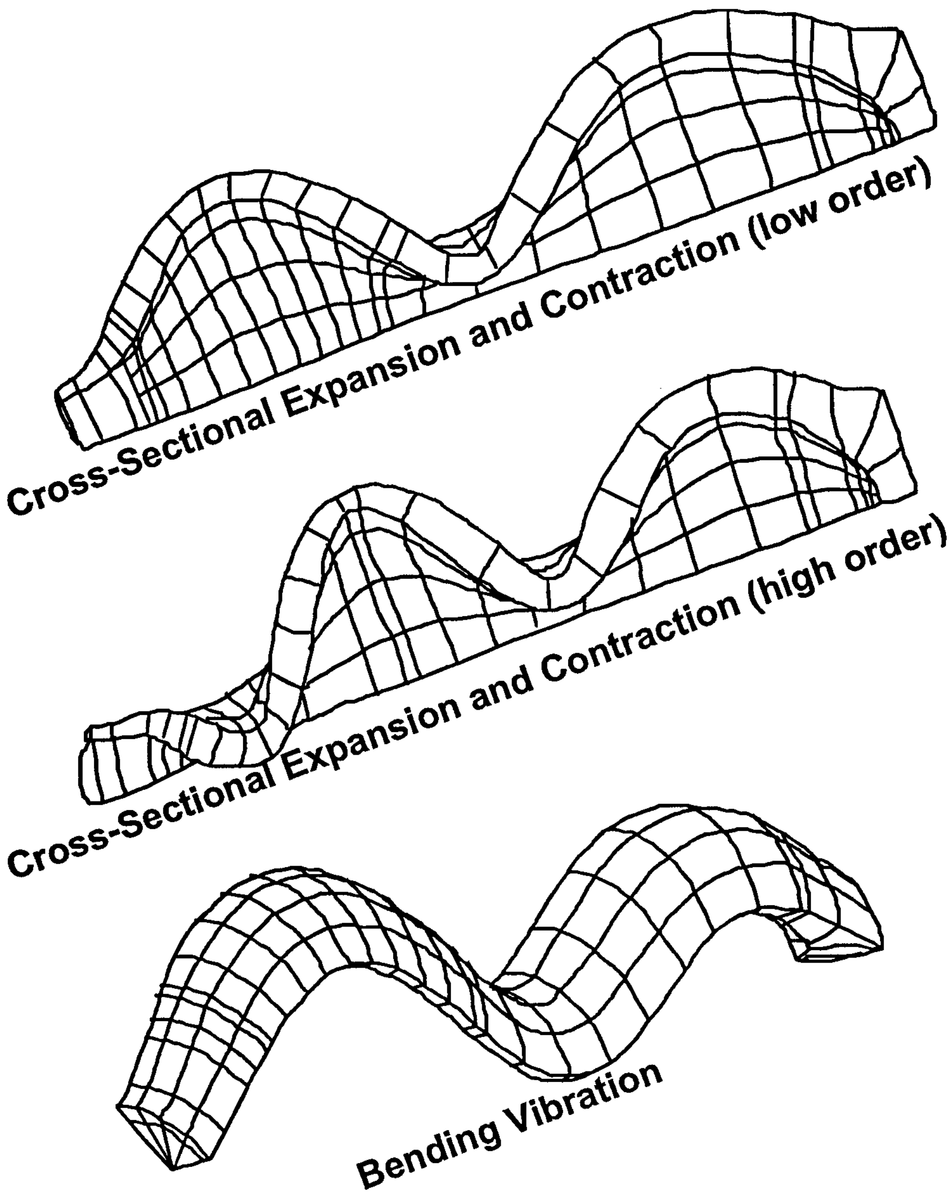


Figure 2. Numerical Modeling of 105mm Munition

The acoustic resonance spectrum of an object is simply the set of its resonant frequencies. For an ideal, lossless elastic object, these will appear as spectral lines, as shown on the left in Figure 3. Real objects, unlike ideal ones, dissipate energy. After you strike a bell, the sound eventually dies away. Energy dissipation causes the spectral line to widen, as shown on the right in Figure 3. A long-lasting mode will have a narrow or sharp resonance peak. A mode that dies away quickly will have a wide resonance peak.

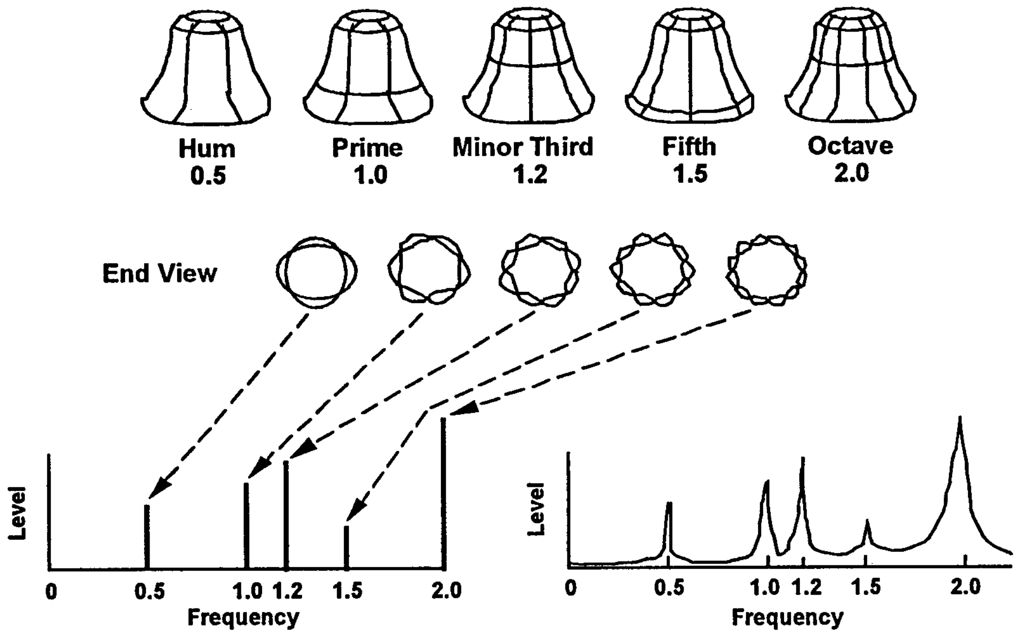


Figure 3. Resonant Spectra for an ideal case versus a real case

Figure 4 shows the correspondence between discrete vibrational modes and the acoustic resonance spectrum. The dotted vertical lines at the top show the frequencies for different vibrational modes of an empty 105mm munition shell, computed numerically using a finite element model. Below the dotted vertical lines is the measured acoustic spectrum of the munition. Each of the peaks in the acoustic spectrum corresponds to one of the computed vibrational modes.

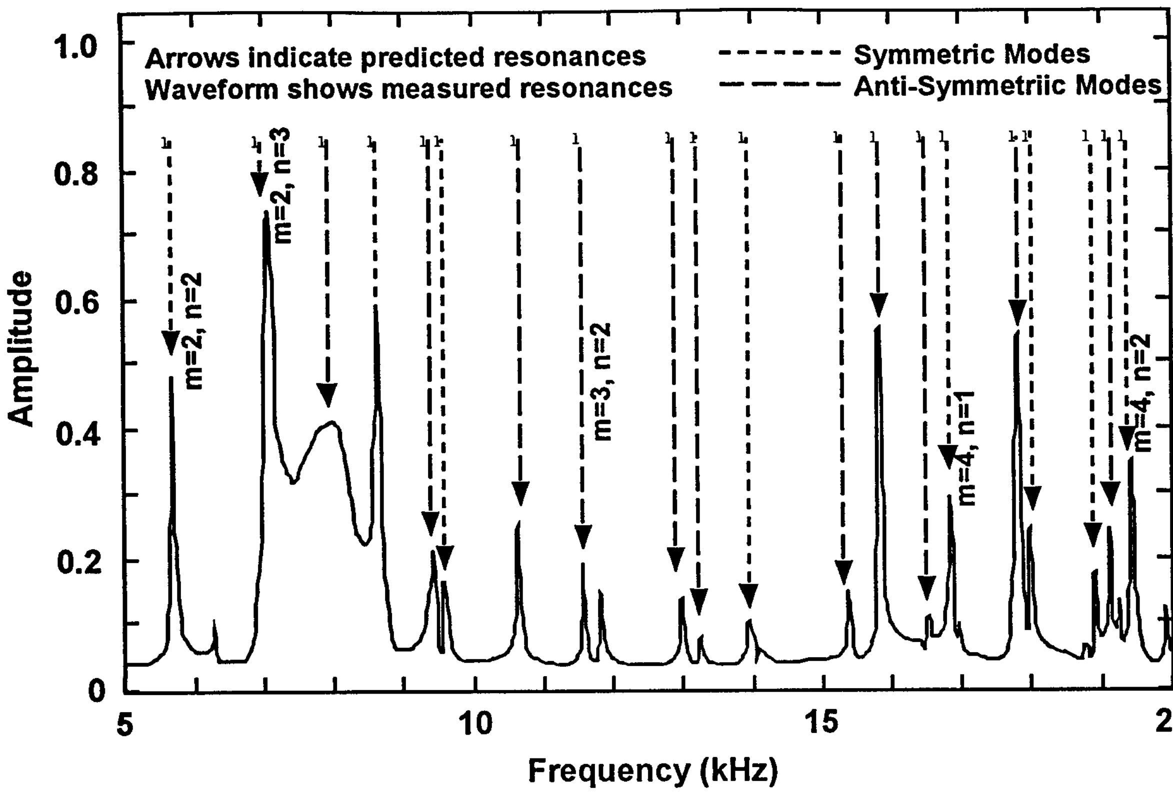


Figure 4. Acoustic Spectrum of 105mm Shell and Resonance Modes

All the mechanical and material parameters of a munition influence its acoustic resonance spectrum. A number of these parameters are illustrated in Figure 5. The spectrum will be affected by the munition size, and smaller munitions will have higher frequency resonances than larger ones. The casing thickness will affect the spectrum, and thinner walls will produce higher resonance frequencies than thick walls. The resonance spectrum is also affected by the physical properties of the munition and its fill materials, such as the density, sound velocity, viscosity, and material stiffness. For example, stiffer material will produce higher frequency resonances than will more flexible material. Viscous, or heavy liquid fills will produce wider resonance peaks than light liquid fills.

Since the effects combine in a complex manner, it is not possible to invert the process. You cannot take an acoustic spectrum of an object and derive its structure or its ingredients. The acoustic spectrum will not provide you with any sort of image of the object's internal construction. In more specific terms, you cannot independently deduce the design parameters of a munition from its acoustic spectrum alone. The acoustic resonance spectrum provides a signature of a munition. This signature can be compared with signatures of other munitions to determine whether they are of the same type or class. Different types of munitions have different acoustic signatures.

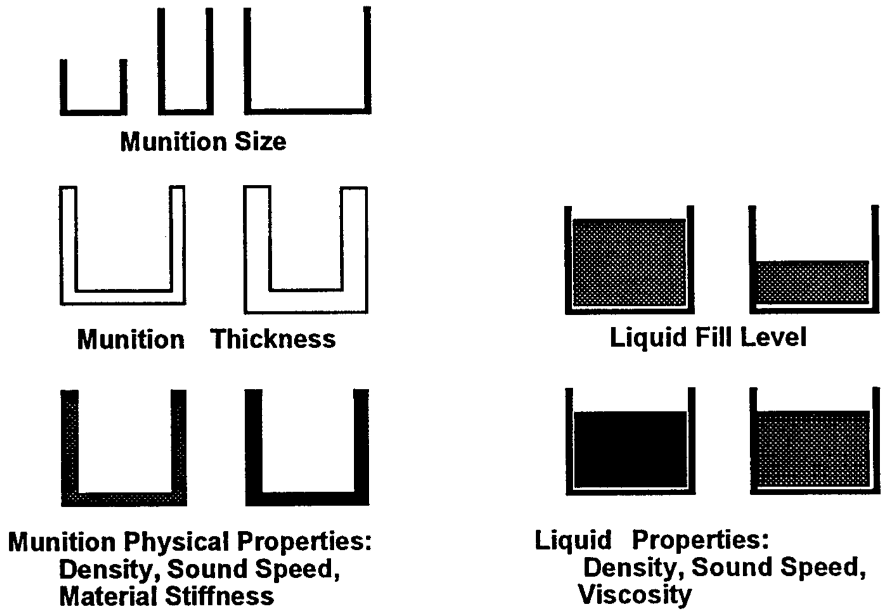


Figure 5. Parameters Affecting the ARS Spectrum

1.4 Basic Measurement Approach

The acoustic resonance spectrum of an object can be measured in various ways. In our instrument, we employ a bistatic swept-frequency technique, as illustrated in Figure 6. A computer-controlled frequency synthesizer generates a sinusoidal signal that drives a transducer. This transducer vibrates the munition at the frequency of the driving signal. A second transducer is used to measure the induced vibrations in the munition. The computer reads this measurement and calculates the amplitude and phase of the munition's response. This provides one point in the spectrum. To measure the portion of the spectrum of interest, we sweep the frequency of the driving signal from the lowest frequency to the highest frequency. In the case of munitions, we generally measure the spectrum in the range of 1 to 30 kHz. The driving power required to measure a munition's acoustic spectra is approximately 1 mW and the vibrations induced are approximately 100 A^{o}, (orders of magnitude below the vibration levels induced by ordinary handling of munitions).

A single ARS measurement will not detect every mode of vibration, because the receiving transducer measures motion in a single direction only. Consequently, the measured acoustic resonances will be a subset of the vibration modes. Furthermore, the amplitudes of the resonance peaks will vary with measurement location. This can be understood by recalling the standing wave interpretation of a mode. If the driving and receiving transducers are located near the tops of waves, a large response will be measured. If they are located between waves, a smaller response will be measured. As a consequence, while the peak locations of an ARS measurement are robust and insensitive to transducer placement, the peak amplitudes are not.

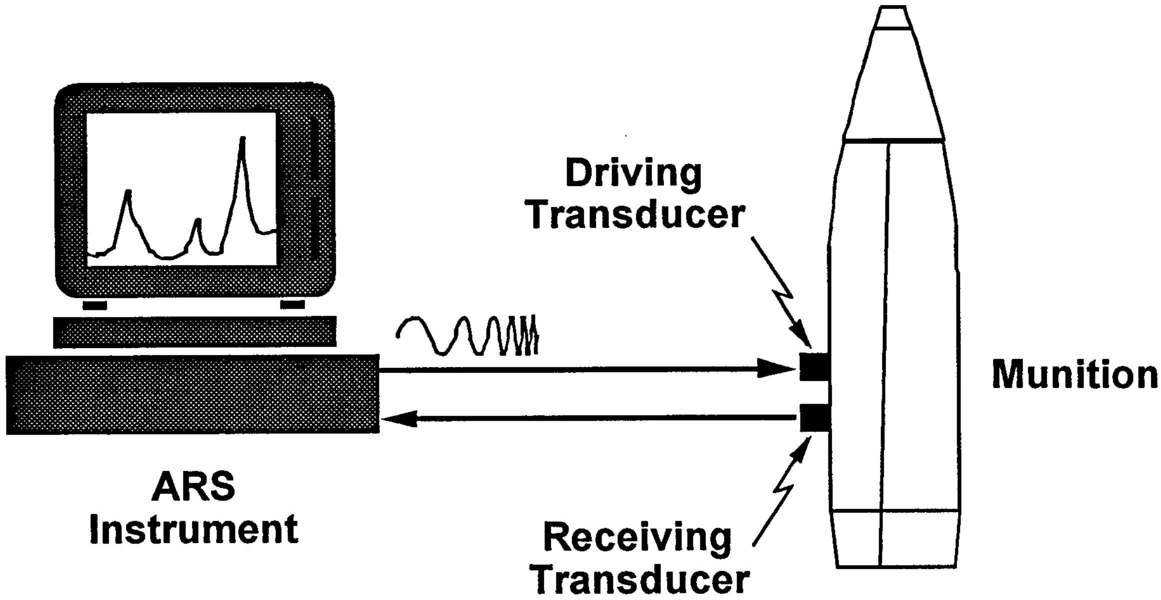


Figure 6. ARS Measurement Setup

1.5 Basics Of ARS Discrimination

Figure 7 illustrates the clear difference between the acoustic spectra of a solid and a liquid filled munition. The upper graph shows the spectrum of an M105 TNT-filled munition. It displays the characteristics of a solid munition, a small number of very wide resonance peaks. If you tap this munition lightly, you hear a thud. In contrast, the spectrum at the bottom is from a GB-filled 155mm munition. It displays the characteristics of a liquid-filled munition, i.e., a large number of very sharp resonance peaks. If you tap this munition lightly, you hear a ringing sound. This example clearly shows the difference in acoustic spectra of two very different items.

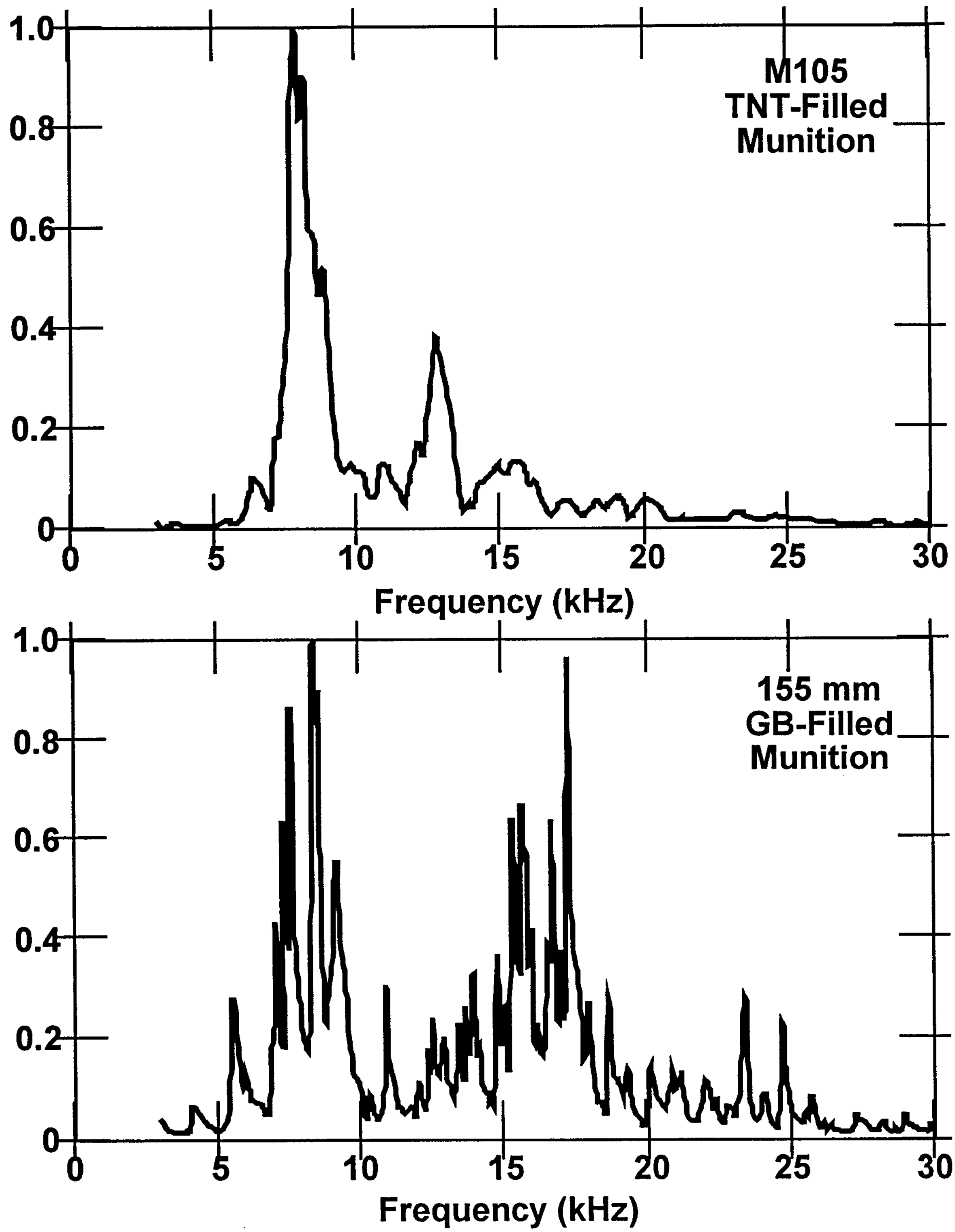


Figure 7. Solid (a) vs. Liquid (b) Filled Munition

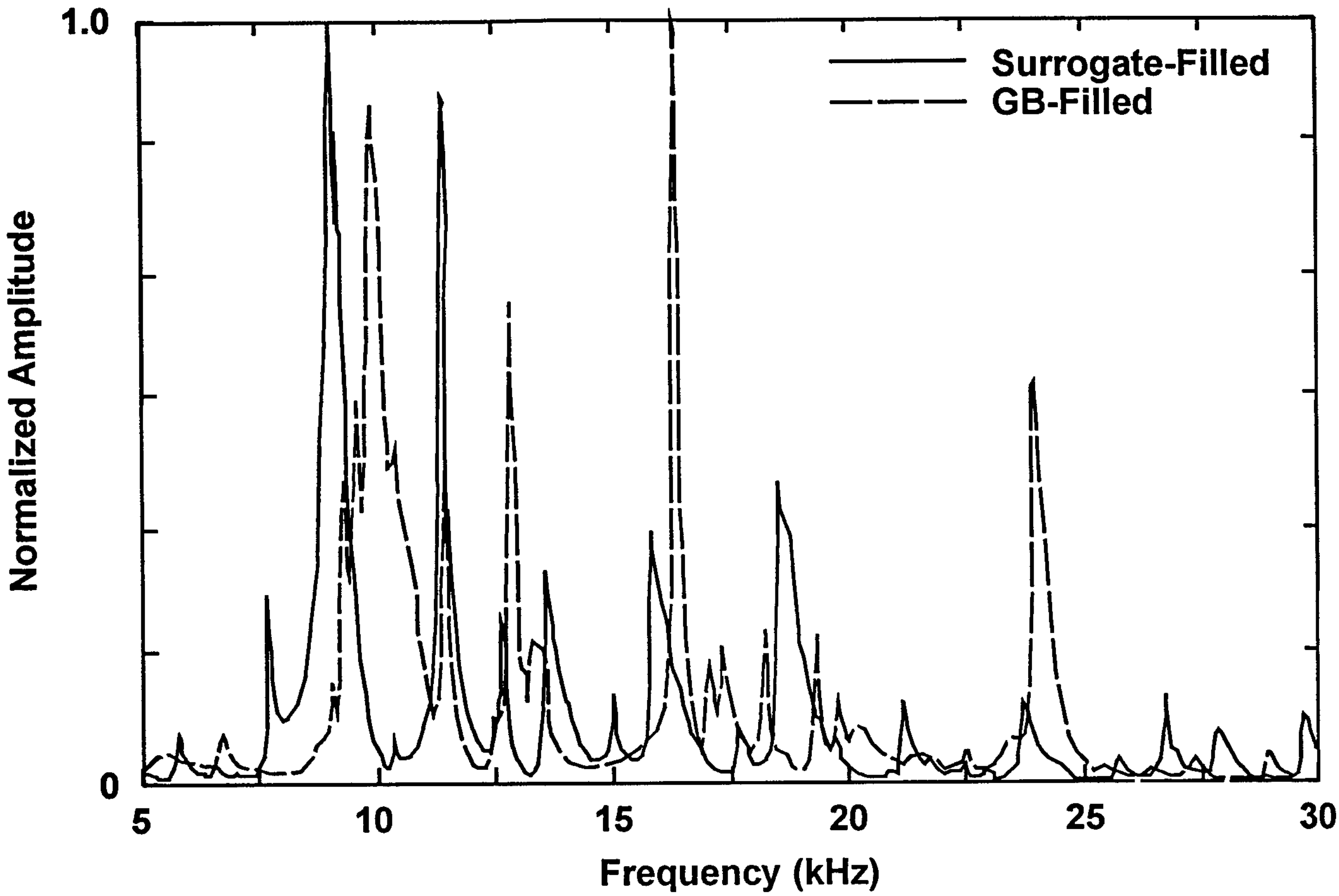


Figure 8. Distinguishability of Fill Types - GB vs. Surrogate

Figure 8 shows the spectra of two items that are more similar, two liquid-filled 155mm munitions. The dotted spectra is from a GB-filled munition, while the solid spectra is from a munition filled with ethylene glycol, a surrogate material. Although both spectra have similar numbers of peaks with similar sharpness, the peak locations are significantly different. The differing locations of these peaks provide a basis for discriminating between these two munitions, even though they differ only in their internal fill material. The shell casings and structure are nominally the same.

Resonance peak locations provide the basis for an acoustic signature of a munition, as shown in Figure 9. A munition is classified by comparing its signature to a prerecorded library of signature templates. In the library, each template corresponds to a different munition type. If a suitable match is found in the library, then the unknown munition has been classified. For example, the signature of a 155mm munition with unknown fill might be compared with library templates of 155mm munitions containing GB, VX, and TNT. If the signature matches one of the templates, then the fill type has been classified. Alternatively, if a number of munitions have been declared to be of a single class, then a sample of the items can be used to generate a template. The template can then be used to verify the similarity of the remainder of the items.

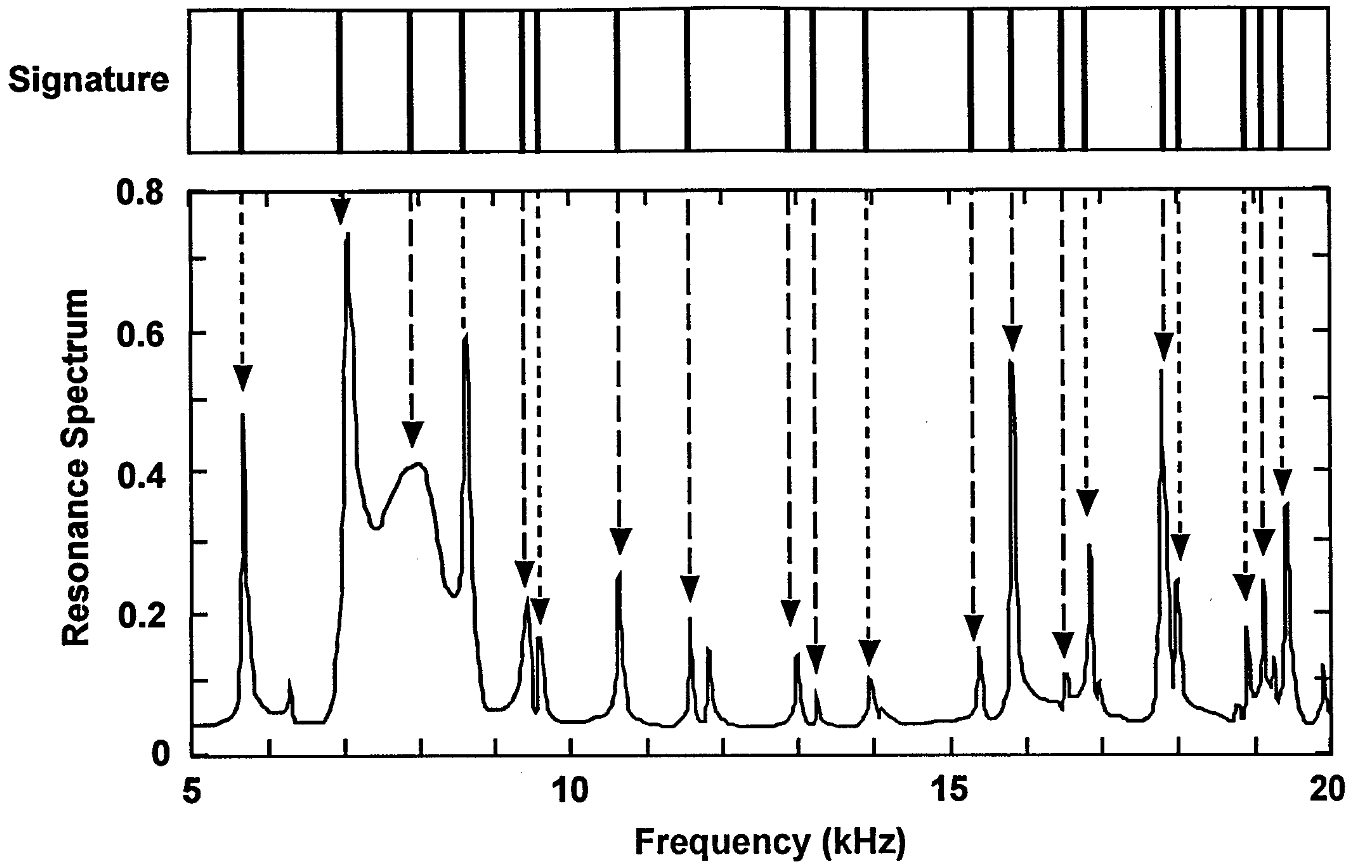


Figure 9. Acoustic Signature

1.6 ARS CW Classification Premise

Figure 10 summarizes the central concept of ARS chemical munition classification. The technique is based on three premises: first, that a given munition possesses a set of well-defined and reproducible resonant frequencies, i.e., its acoustic spectrum; second, that a subset of these resonant frequencies can be excited and detected (the specific subset will depend on the manner of excitation and measurement); and third, that munitions of the same kind and fill type have nominally identical sets of resonant frequencies. Variations will occur only on a finer scale, depending on the type and condition of the munition.

Based on these three premises, unknown munitions are classified by finding the best match of their measured resonant frequencies to a set of reference templates. The basic steps in the ARS classification process are to first build a library of reference templates, then to compare unknown munitions to these templates.

To build a template, we begin with a set of exemplars, generally eight to twelve munitions that adequately represent the munition type. The condition of these munitions should match, as closely as possible, the conditions of the unknown munitions to be identified. For example, they should be of the same age and should have been stored under the same conditions. Likewise, they should be measured in the same manner as the unknown munitions. ARS measurements are taken at several locations on each of the exemplars. This provides a set of spectra that captures the finer scale variability among munitions and among measurement locations. The resonant peaks are extracted from each measurement. The peaks from the different measurements are then grouped or clustered to identify like resonant peaks. From each of these clusters, a feature is identified. In Figure 10, these features are represented by bars, where the center of the bar represents the average resonant frequency, and its width represents the expected variability. A template for a munition type consists of a set of these features, each representing an individual resonance frequency.

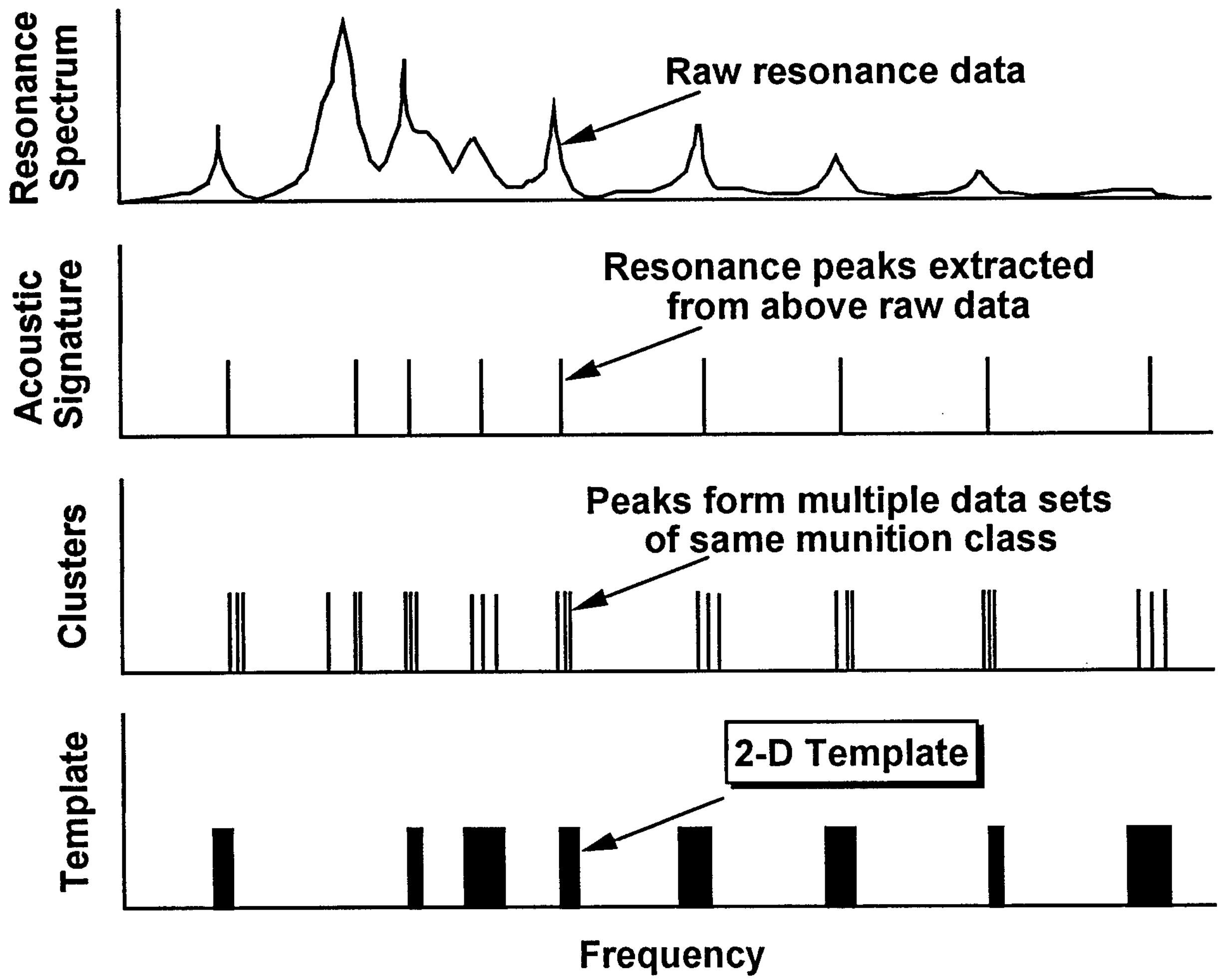


Figure 10. Template Generation

The spectra of unknown munitions are matched to a template by the simple correlation process illustrated in Figure 11. First the peaks are extracted from the spectrum. Then the peak locations are compared with each template. The match is scored by computing the percentage of template bins that contain peaks. The munition is classified by the best matching template, subject to a minimum score requirement. If the munition does not match any of the library templates, then it is labeled as unknown.

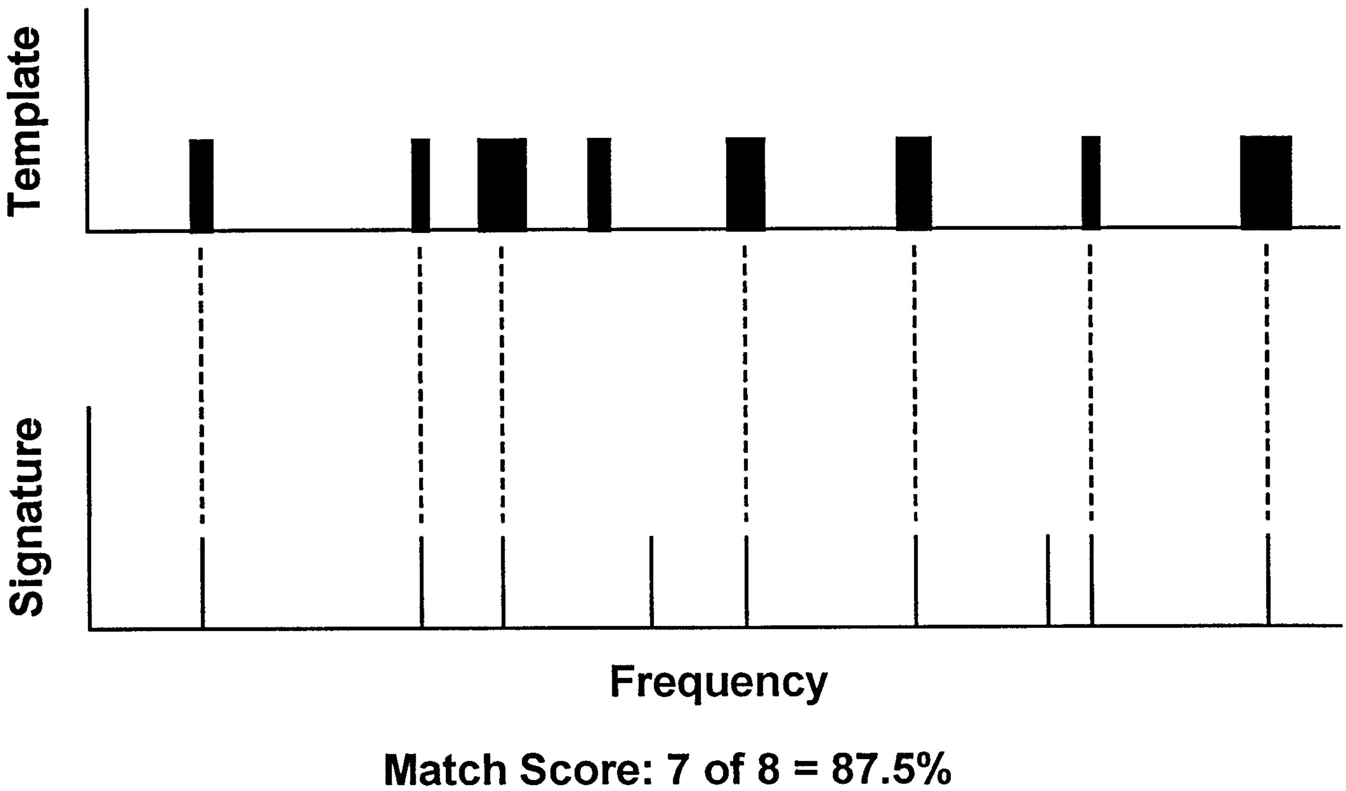


Figure 11. Template Matching

1.7 ARS Field Experience

ARS prototype systems have been field tested on CW munitions in two exercises at the Tooele Army Depot in May 1991 and August 1992. In these exercises the ARS systems were tested on the wide variety of CW munitions and bulk storage containers listed in Figure 12. Although ARS provided valuable information on all classes of items, we found it to be most useful on CW munitions, such as 155mm artillery shells. The smaller size of the munitions makes it easier to excite their body resonances. In addition, the large number of munitions typically found at storage sites makes munitions an attractive candidate for the fast-screening capability of the ARS technique.

Item	Type	Qty Tested
1	105-mm GB	51
2	1-ton GB	49
3	155-mm GB (low purity)	22
4	155-mm GB (high purity)	28
5	MC-1 bomb GB	68
6	1-ton mustard	58
7	155-mm mustard	39
8	155-mm HE M483A1 (ICM)	34
9	M107 HE	45
10	155-mm VX	44
11	155-mm WP	61
12	8-inch VX	24
13	M106 TNT	23
14	Spray tank VX+empty	50
15	155-mm empty	8
16	155-mm surrogate GB (property)	15
17	155-mm surrogate H (property)	17
18	155-mm surrogate VX (property)	17
19	155-mm surrogate GB (nuclear)	15
20	155-mm surrogate H (nuclear)	15
21	155-mm surrogate VX (nuclear)	15
22	155-mm surrogate sand	8
23	1-ton surrogate	22
	Total Number of Measurements:	728

Figure 12. Items Tested at Tooele, August 1992

We generally found the ARS measurements to be very repeatable across different munitions of the same type. Figure 13 shows ARS measurements from six different 105mm GB-filled shells. Although the resonance amplitudes vary slightly from shell to shell, the basic resonance frequencies do not. We also found that the ARS measurements were relatively insensitive to storage conditions. This example shows ARS measurements from two different 155mm HE-filled shells, one measured in a pallet of shells and one measured as a stand-alone item.

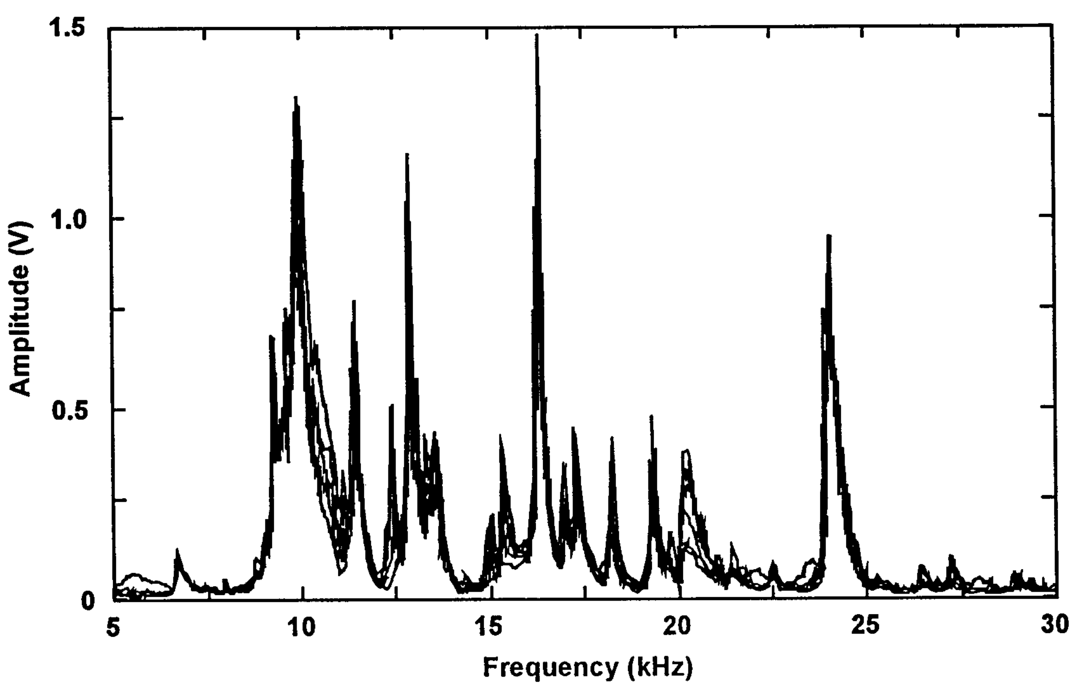


Figure 13. Repeatability Example

There are also detectable difference in the ARS measurements of munitions with different chemical fills. Figure 14 shows the frequency shifts between a 155mm shell filled with VX and a similar one filled with GB.

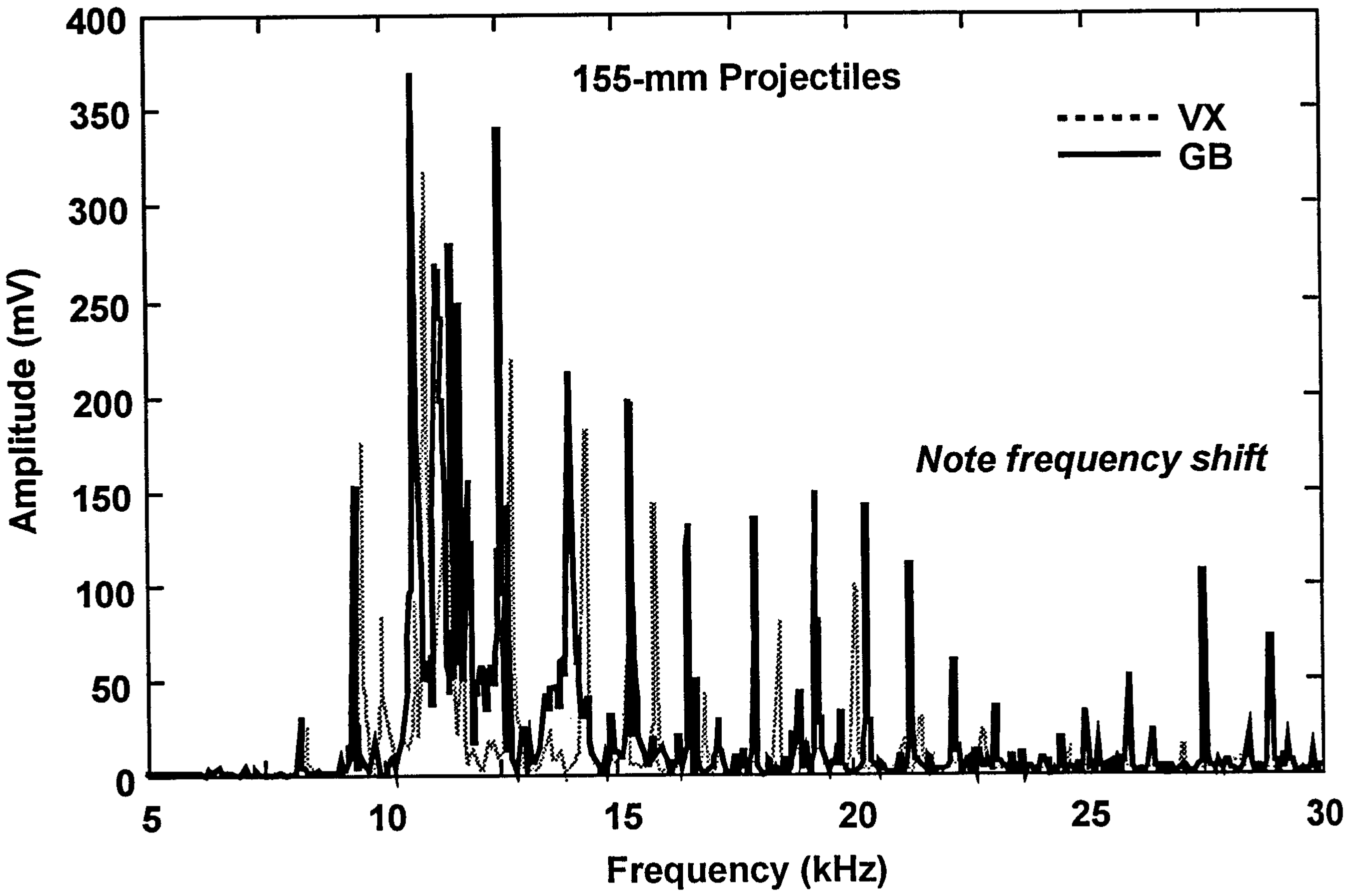


Figure 14. Liquid Fill Example

As a proof-of-principle exercise, we classified the 155mm CW shells (i.e., GB, VX, TNT, and white phosphorus) measured at Tooele. Library templates were developed for each munition type and then each measurement was compared to all of the templates. The results, shown in Figure 15, were consistently good, i.e., correct classification.

Agent Type	Number of Incorrect Categorization	Number of Samples (Tested)
Mustard	0	31
GB	0	46
VX	0	28
TNT	0	15
White Phosphorus	0	23

Figure 15. Tooele Classification Results

Chapter 2: Site Inspection Overview

2.1 Field Operation

A field inspection scenario is based on a two-stage process. The first stage consists of establishing a set of items that will form the "known set" from which a template will be generated. The "known set" can be assembled by randomly selecting items and either:

* Assume all items are as declared, or
* Drill & tap and chemically analyze samples from each item, or
* Use PINS or some other NDE technique to verify the contents.

Once the "known set" has been determined, the ARS hardware can be used to develop a template that the system will then use as a basis for comparison. The second stage consists of scanning unknown items using the ARS hardware to determine if they match the templates created from the "known-set" of munitions.

2.2 Site Inspection Scenario

The ARS software program is based on the following site inspection scenario.

- When an inspection team arrives at a site to be inspected, the team either has, or is provided with the Site Name, ARS Hardware Operators, Munition Types to be inspected, etc. This information is referred to here as "Site Setup Information."

- The first data collection task involves creating templates for all munitions to be encountered. Sample munitions of each type are scanned and used to create a template. If possible, the munitions should be selected at random from the entire population to be tested, and if multiple lots of munitions are present, every lot should be represented in the template set. Once sufficient munitions have been scanned to create a template, the computer will alert the user. This process continues until all munition types have templates created.

- Once the templates exist, the "Collect Data" menu item is designed to simplify data collection on as many munitions as the operator wishes to examine. Each time a data file is collected, the software will provide a comparison against all available templates. In addition, for 155 mm. munitions, the software will automatically differentiate between liquid and solid munitions without prior training.

- The "View and Analyze" menu selection is intended for use as an off-line operation. This menu selection allows the operator to review single data files or entire data sets collected earlier. It also allows comparisons to be made between the data file and the other templates stored within the computer. An additional function of "View and Analyze" is to allow printing of each individual data file to a compatible printer.

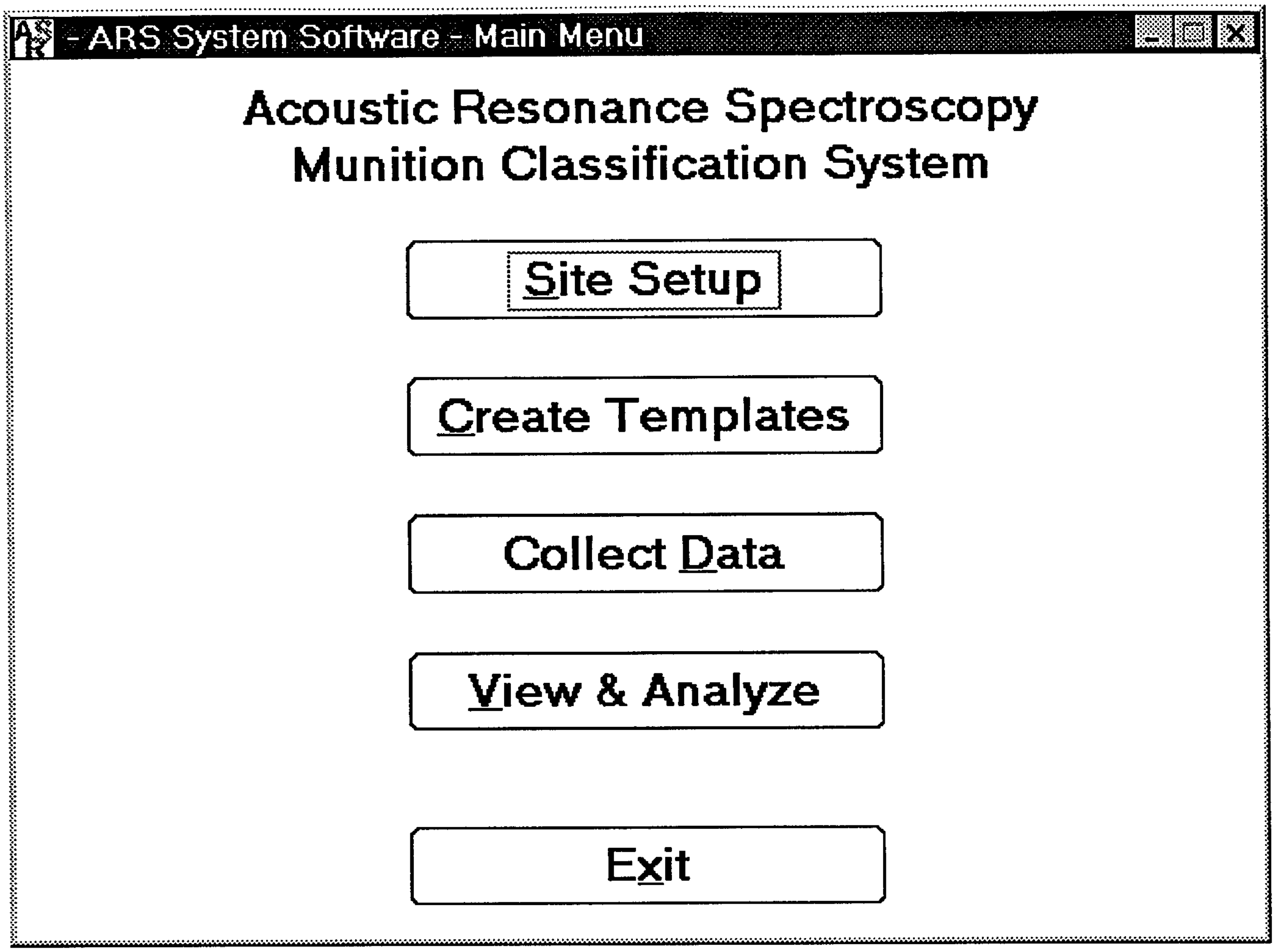


Figure 16. Opening Screen for ARS Program

Figure 16 shows the opening ARS screen. Note that the sequence of events flows from "Site Setup," to "Create Templates," then to "Collect Data." The "View & Analyze" selection is drawn last because it serves an off-line function, as described above. The underscored letters indicate the keyboard selection that will activate that function.

2.3 Software Operation

The ARS version 3.01 system software uses DOS and Windows for Pen Computing with the Win32s extension as its operating environment. In addition, a separate version of the ARS software will run on Windows NT or 95 (the Setup program will install the correct version). The ARS software user interface behaves as a Windows program and conforms to Windows conventions, except that user inputs that could reasonably occur while the user is in full personal protective clothing are designed to operate from a "pen" as opposed to a keyboard. This manual assumes the user has a reasonable knowledge of Windows programs and PC compatible computer operation.

When a sample is acoustically scanned, the algorithm evaluates that scan by comparing it against all available templates instead of against just one template. The result of this evaluation is to indicate which template most closely matches the scan.

If it is enabled, the software will also evaluate the fill material of 155 mm. munitions as either solid or liquid without the need to create templates. If the munition is not clearly either a solid or a liquid, the software will return "indeterminate". When this occurs, it is recommended that the user perform additional scans at different points on the munition to resolve the "indeterminate" reading. Also, if the munition is identified by the user as being a size other than 155 mm., the software will return "indeterminate." The limitation to 155 mm. munitions results from a lack of data on other munition sizes. It is hoped that, in the future, this limitation will be removed.

2.4 System Setup

Remove the DSA300, cables, sensor heads, and Notepad computer from their packing cases and interconnect the cables according to Section 2.3.1 (field configuration) or 2.3.2 (base configuration). Turn computer power on by pressing the power switch and holding it momentarily. Power can be turned off (toggle style) with exactly the same action. The DSA300 power can be switched on now or just before starting the ARS program. While using the ARS software, do not turn off or unplug the DSA300. If the software loses communication with the DSA300, simply exit the ARS software and restart it to reestablish communication.

When the system boots up, it will boot directly into the Windows operating environment. Double click (tap the pen twice) on the ARS icon within the ARS program group in standard Windows fashion. If the DSA300 has not been turned on, an error message "Unable to connect to DSA300, please check wiring" will appear. Click on "OK" (or hit return) to bypass this message. The next screen is the top level ARS program menu.

In all cases, the standard Windows convention is followed (when using a keyboard) except as follows:

- In all cases, the pen works like a mouse in a standard Windows application. This is the recommended way of selecting and activating functions within the ARS program, even when the keyboard is attached.
- In each selection, when a letter in the selection is underlined, the Windows convention is to hold down the "ALT" key and press the underlined letter.

Within the ARS program, this convention works in all cases except in those instances when the operator might be expected to be wearing full personal protection clothing. In those instances pressing the underlined key without the "ALT" key will activate the function.

- In all cases, moving from field to field is done using the Tab key and selecting items within a field is done by using the cursor control keys.

Chapter 3: ARS-MCS System Overview

3.1 ARS-MCS Hardware

The ARS field instrument proposed for use by the OPCW for the CWC consists of the three basic hardware components shown in Figure 17. These components are a transducer assembly and cable, a digital synthesizer and analyzer, and a notepad computer.

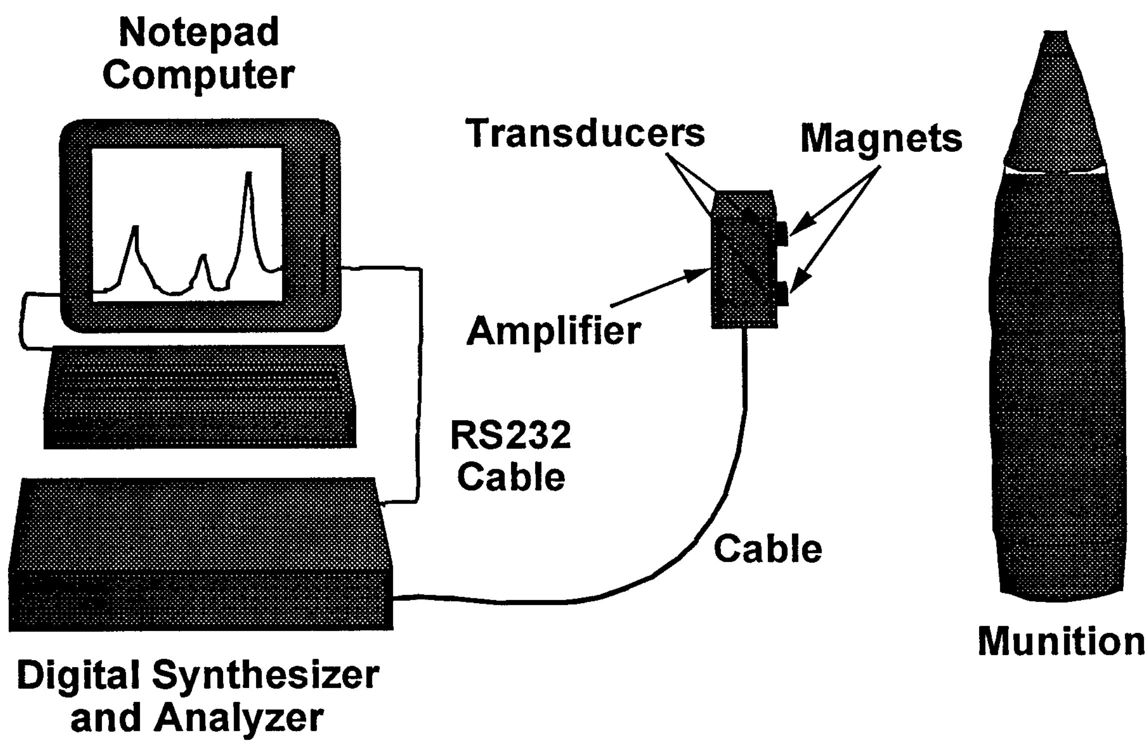


Figure 17. ARS System Hardware Drawing

The three components consist of the following:

- Transducer Assembly
  - Two piezoelectric transducers
  - Magnetic attachments
  - In-line amplifier & 10' or 50' cables
- Digital Synthesizer & Analyzer
  - Digital frequency synthesis
  - Homodyne processing and filtering
  - Small, light, low power instrument

- Internal battery operation

- Notepad Computer
  - 486 based PC or compatible system
  - Operator interface, control, & data analysis
  - Removable data storage (PCMCIA Hard Disk)
  - Small, light, low power PC
  - Internal battery operation
  - Standalone mode

The transducer assembly contains two piezoelectric transducers, one to excite the munition and the other to measure its response. Glued to each transducer are neodymium-iron-boron magnets used to attach the transducers to the munition. The signals from the receiving transducer are amplified by a small in-line amplifier that can drive a 50-ft cable. The components are all housed in a light aluminum frame for ease of handling.

The digital frequency synthesizer and analyzer generates the swept sine wave drive signal and measures the response signal. Homodyne processing is used to eliminate interference outside the measurement band. The response is digitized and sent to the notebook computer. This small, lightweight analyzer runs on an internal rechargeable battery. The battery life is 4 to 6 hours, depending on the number of scans taken. The internal battery can be recharged in about 2 hours.

The final component, the notebook computer, is a commercial portable PC. The computer provides the operator interface, measurement control, data analysis, and data storage. All data is stored on a removable PCMCIA hard disk. The unit is small and lightweight, and runs on internal rechargeable batteries. Each battery provides 4 to 6 hours of operation. The batteries are removable and can be changed in the field provided fully charged batteries are available.

3.2 Hardware Overview

The equipment provided with the Acoustic Resonance Spectroscopy Instrument provides for a number of different configurations in order to provide the maximum flexibility to the field operators. The equipment provided consists of the following items:

A. DSA300 Data Acquisition Module
B. Notepad computer
  B1. Keyboard (Optional)
  B2. PCMCIA Hard Disk
  B3. Stylus (Pen)
  B4. Floppy Disk (External)
  B5. Interfaces for Floppy Disk & Printer
C. Sensor Cables (DSA300 to Sensor Heads)
D. Sensor Heads (SHD300)
E. PC TO DSA Serial Cable (PC-DSA)

F. Soft Pouch (Single Person Data Collection)
G. Spare Battery for DSA300
H. Spare Battery for Notepad Computer
I. Battery Charger for DSA300
J. AC Adapter for Notepad Computer
K. AC Plug Adapters (U.S. to European)
L. Battery Charger for Notepad Computer

In the simplest configuration, only items "A", "B", "C", "D", and "E" are required for data collection. The rest of the items provide flexibility in battery life, battery charging, use of the computer for report writing and other tasks beyond data collection.

The soft pouch (item "F") is intended to simplify single-person operation of the ARS300 system for field data collection. The pouch holds the DSA300, the Notepad Computer, and the cables and sensor head. When the system will be used while wearing gloves and mask, it is advisable to configure the system (i.e. wire up the interconnections) before "suiting up".

The AC adapters for both the notepad computer and DSA300 are 100 - 240 VAC auto-sensing. The AC plug provided is a USA 115VAC, 3-prong standard plug. In order to use these chargers on AC power systems around the world, a "plug converter" is required. While some plug converters are provided with the system, it is recommended that plug converters (Qty 2 per system) specific to the country of intended use be acquired prior to a field inspection.

> Note: With flexibility comes potential confusion, therefore the following sections will attempt to clarify the various hardware configurations that are possible with this set of equipment.

3.3 Hardware Configuration

3.3.1 Field Configuration

The minimum configuration for data collection consists of the DSA300 (Item "A") and the Notepad Computer (Item "B") in addition to the sensor and serial cables (Items "C&E") and sensor heads (Item "D"). The limiting factor in this configuration is the length of time that the Notepad's internal battery will power the computer (4 to 6 hours).

When the computer alerts the operator of a low battery condition, the following procedure should be followed:

* Complete the operation currently under way, i.e., complete a scan, save data, add comments, etc.
* Turn power off after exiting the ARS program
* Remove the laptop's internal battery, and insert a fully charged internal battery.
* Turn computer back on and start the ARS program.
* Continue with the data collection operation.

You can continue in this manner, changing laptop internal batteries (assuming you have fully charged batteries available) until you reach the limit of the DSA300's internal battery (4 to 6 hours of normal operation). Note: You may wish to change out both the DSA300 battery and the Computer battery at the same time to avoid work interruptions.

3.3.2 Base Configuration

The maximum configuration for data collection consists of the DSA300 (Item "A"), the Notepad Computer (Item "B"), the sensor and serial cables (Item "C&E"), the sensor heads (Item "D"), the Computer keyboard (Item "J"), and the Computer External Floppy Disk (Item "K"). This configuration is suitable for entering "Site Specific" information, but not for field use (i.e. when scanning munitions).

3.3.3 Battery Charging Configuration

There are two battery chargers necessary for system operation. One charger (Item "H") provides power for the DSA300. The second charger (Item "I") charges the computer's internal battery. Note that the DSA300 can be charged while operating, but this lengthens the time to reach a full charge. See the computer's operations manual for specific information regarding battery charging.

See Appendix B3 for schematics showing the charging interconnections for both the DSA300 and the notepad computer.

3.4 ARS-MCS Software

A critical part of the ARS system is the custom software that runs on the notepad computer. This software runs under the Microsoft Windows for Pen Computing Environment with the Win32s extension and provides a graphical user interface. Field functions can all be activated using the "pen" without the keyboard or with single keystrokes if the keyboard is attached. This makes it possible to operate the equipment while wearing protective gear. The operator interface is tailored to the anticipated inspection procedures. Measurements and munition types are all organized by inspection site. Prior to the inspection, a site database is set up and logistical information is entered. Munition types are defined, based on the list of declared items for the site.

During the inspection, the system is first used to record signatures from exemplar items for each munition type. From these data, templates are automatically generated and stored. The system is then used to measure and record signatures from munitions at the site. Munitions are classified in real time, as the measurements are made. Questionable items can then be noted and set aside for additional analysis.

The system stores each signature that it measures. These data can be viewed and printed out. Data can also be re-analyzed and compared with different sets of library templates.

The ARS software consists of the following:

Operating system - Microsoft Windows 3.1 with the Win32s extension and DOS, alternately Windows NT or 95.

Windows-based custom user interface

- Pen input of field functions (w/o keyboard)
- Single key operation of field functions (w/ keyboard)

User interface tailored to anticipated inspection procedures

- Measure and record signatures for verified examples of declared items
- Construct templates for each class of declared items
- Measure and record signatures and compare to template of declared class
- Differentiate between solid and liquid munitions without previous training sets

Post-measurement analysis capabilities

- View and print data
- Compare signatures to multiple templates

Data Storage

- Automatic file name generation
- User selectable "write-to-floppy" setting
- Data written only to removable storage media

In the field configuration (without keyboard), some fields, particularly the "Comment" field can be filled-in using the hand-writing recognition software provided by the operating system. Hand-writing recognition is not yet a well-developed technology. It is therefore recommended that hand-written comments be kept very brief. It is also recommended that the operator use block letters instead of script.

For more information, including how to train the hand-writing recognition engine, see the Windows for Pen Computing documentation.

Chapter 4: Software Navigation

4.1 Site Setup

Selecting "Site Setup" by pressing "S" or by clicking with the mouse brings up a dialog box for entering the site parameters (Figure 18). This box shows the directory and current site name, as well as the operators and munitions for the selected site.

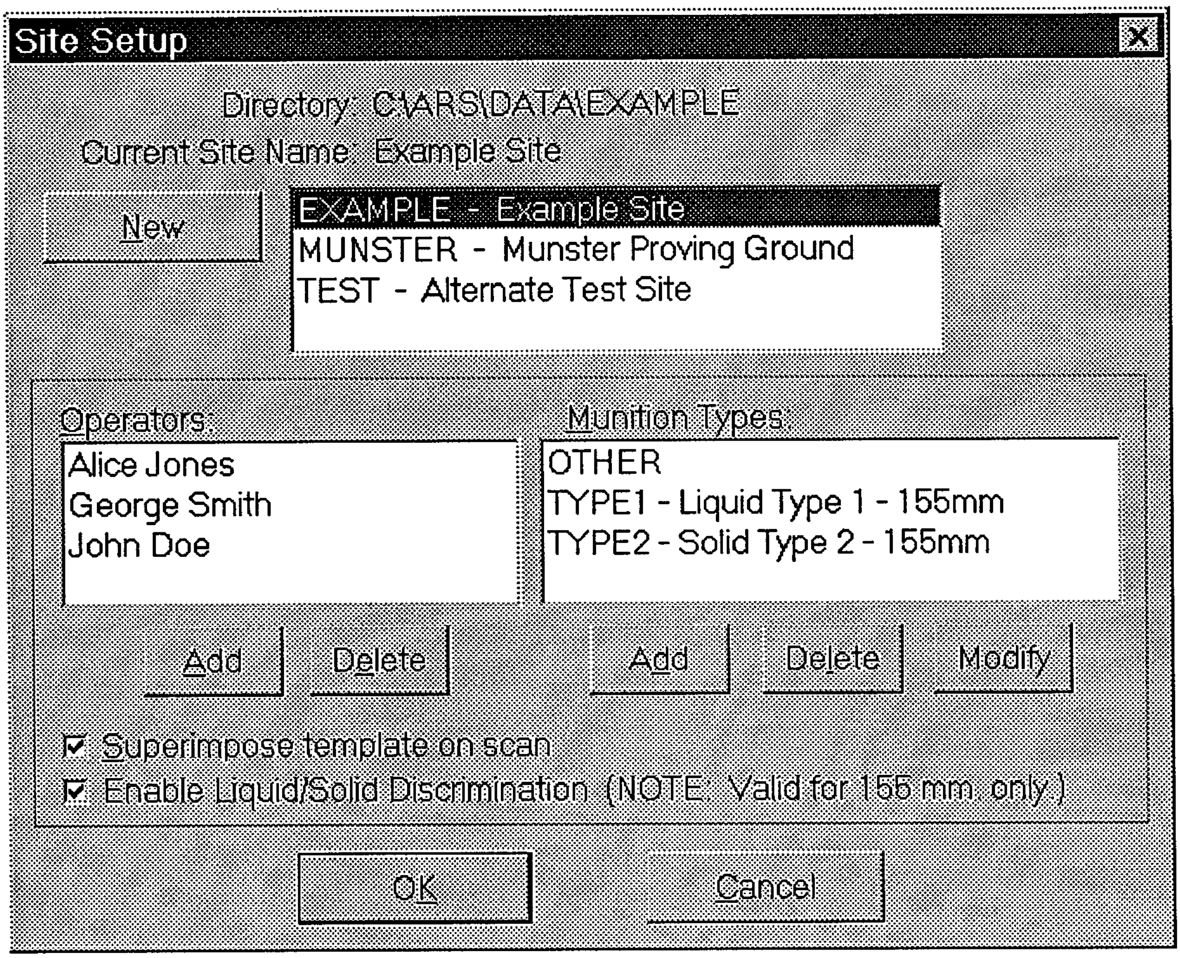


Figure 18. Site Specification Screen

If the directory you wish to select is already listed in the directory box, use the Tab key or the pen to highlight the selection you want.

If the directory you want is not listed (i.e., if this is a new site to be set up), tap the pen on the "New" button. Alternatively, press Tab to move to the button "New," then press Return (Figure 19). This will bring up a "New Directory Name" box and "Site Name" box. As always, the Tab key will move you from one field to the next. Note that the directory name is limited to 8 characters and must conform to standard DOS directory names ('?', '*', spaces, and other punctuation are not allowed). When complete, press the OK key to return to the previous screen.

Note: If you accidentally enter more than 8 characters, the system will truncate the name to create the directory.

Select the new site just entered. Using the Tab key to navigate from field to field, press the Add and Delete buttons (as appropriate) to add information to the Operators and Munition Types boxes. Note that the OTHER munition type is already in the field and cannot be deleted. Add all the munitions that will be scanned at the site.

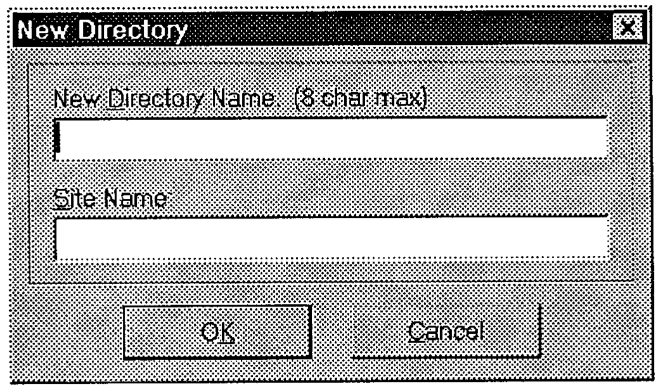


Figure 19. New Directory Dialog Box

Checking the "Superimpose template on scan" box will superimpose the applicable template on the scan response plot after the evaluation has been completed. The template will appear as a "bar code," with the bars matching a number of peaks in the scan response.

Checking the "Enable Liquid/Solid Discrimination" box causes the program to follow the normal template matching algorithm with a Liquid/Solid discrimination algorithm. This is valid only for 155 mm. munitions at the present time.

If the "Add" or "Modify" munition buttons are chosen, the Add Munition dialog box will be shown (Figure 20). This dialog allows each munition to be evaluated to be entered and assigned a directory for data storage. In addition, the munition size can be selected for use in Liquid/Solid discrimination. In the current release, only 155mm. munitions are evaluated by the Liquid/Solid blind (non-template based) algorithm. Other munition sizes can be selected, but will return "Indeterminate" when evaluated. The munition size will be displayed along with the name of the munition throughout the program. When modifying munitions, the user cannot change the directory name.

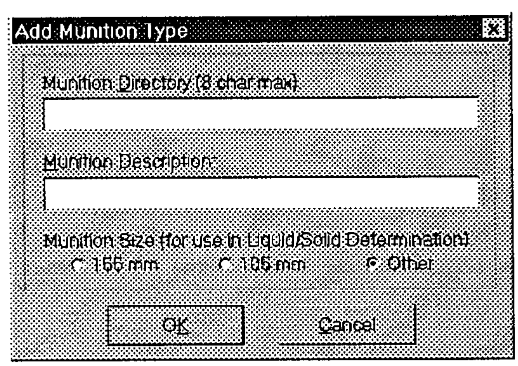


Figure 20. Add Munition Dialog

Note: Previous versions of the ARS software did not include munition size data, so any data files created previously will be evaluated as "Other." This can be corrected by returning to the Site Specification dialog box and modifying the munition types. If no size information is listed after the munition description in the *list box, the data set was created with a previous version of the software and should be modified to include size data.*

When you have filled in the information in the Site Specification screen, select OK to return to the main menu.

4.2 Template Generation

Because no "templates" have been created for munitions at this site, the first data collection activity is performed to create a template. Selecting the "Create Templates" button will bring up the screen necessary for data collection and template creation (Figure 21).

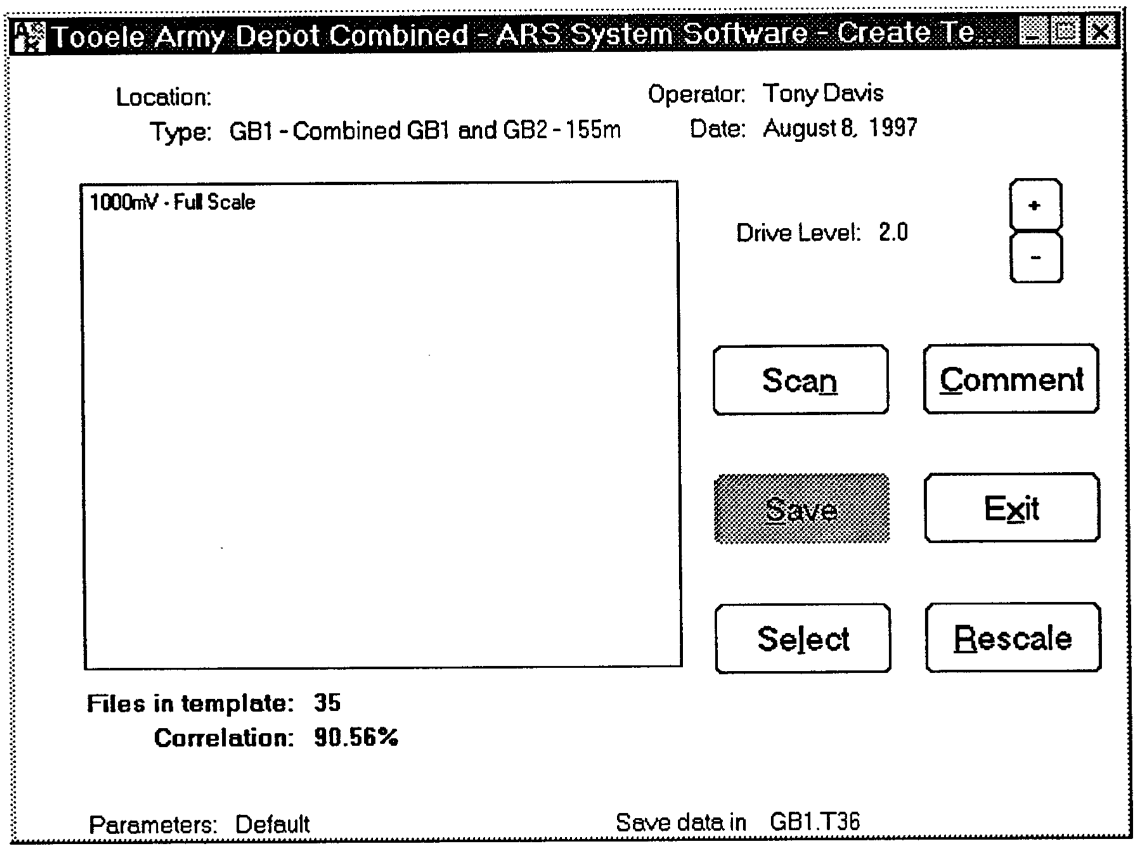


Figure 21. Data Collection Screen

Template creation is an interactive process whereby the user scans known munitions until an accurate template has been created. At this stage, it is necessary to configure the information associated with this particular data collection instance (i.e., name of operator taking data and building name or number). Choose "Select" to bring up the configuration screen (Figure 22).

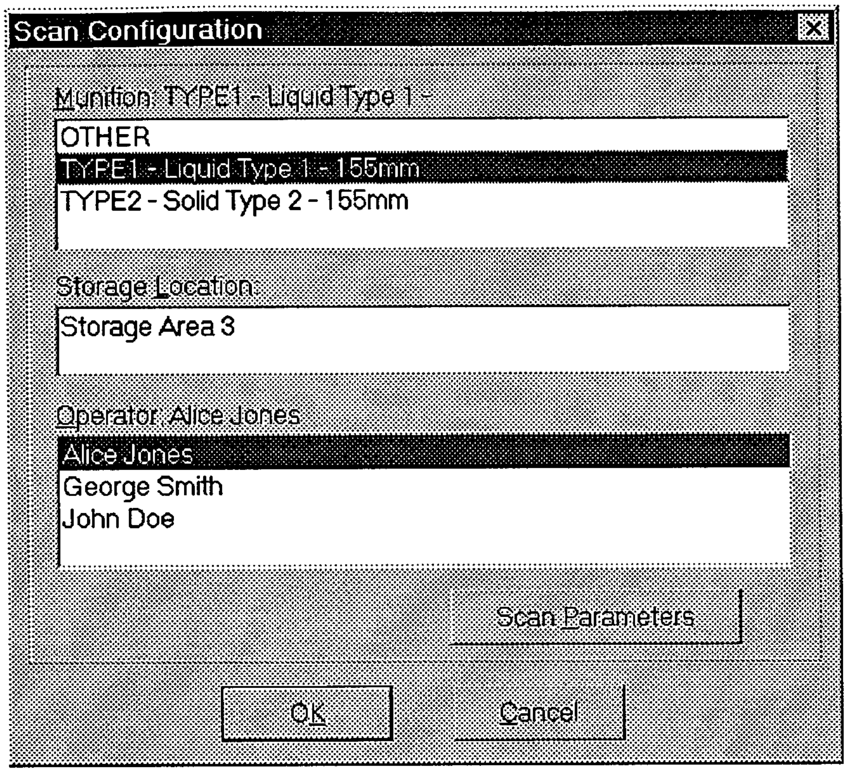


Figure 22. Configuration Screen for Data Collection

Using the "Standard Navigation Keys" (Tab key, Cursor control, Pen) enter the Building Description and select the "Operator Name" and "Munition Type" for this particular data collection session.

Selecting the “Scan Parameters” button will bring up a box that allows you to modify the start frequency, stop frequency, and frequency increment. This box will display the expected length of time for a single scan. It also allows you to reset the scan parameters to their default value (Figure 23).

Note: If you change the scan parameters, a file will result that has different parameters from files created previously. This will result in files that cannot be used together. ***It is recommended that the default values be used,*** *except in special circumstances. At the very least, all munitions of a given size should use the same scan parameters.*

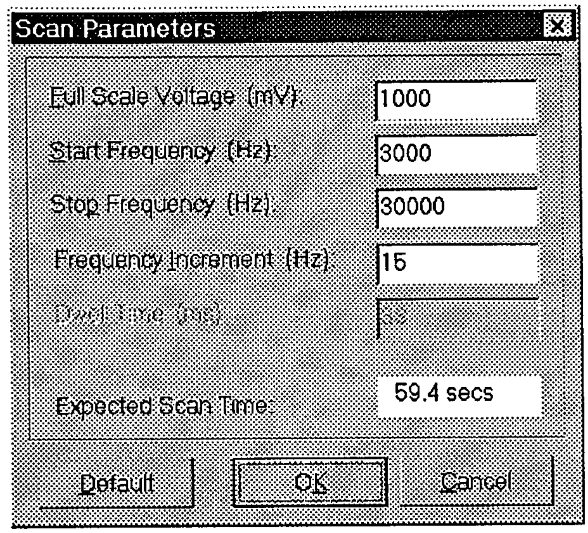


Figure 23. Modifying Scan Parameters

Note: Changing the default values so a new set of values appears as the default requires that the ARS.CFG file in the ARS subdirectory be edited by a knowledgeable individual. If the default values in ARS.CFG are changed, be advised that the product of the frequency increment and the dwell time must be 500. If this is not the case, the ARS program will display a "modified" parameter indication, even though the operator selects the default values.

Selecting OK will return you to the previous menu with the selected values for Building, Operator, and Munition Type displayed at the top of the screen. At the bottom of the screen, you will see the Parameters indicated as default or modified.

Notice the Drive Level indicated as well as boxes with a "+" and a "-". Pressing the "+" or "-" keys will increase or decrease the drive level in 0.5-volt increments, except when the level is below 1.0 volt, at which time the "+" and "-" keys will increase or decrease the drive level in 0.1-volt increments. We recommend that you adjust the drive level until the maximum return signal is between 50% and 75% but does not clip (as evidenced by square topped response peaks). The computer will indicate a signal saturated condition as an aid to the operator in setting the proper drive level.

Note: Collecting data with saturated drive levels results in invalid templates, which will later result in invalid comparisons against the invalid templates.

Once all the preliminary information has been entered, attach the transducer to the first munition and click on the "Scan" button to initiate a munition scan. The system requires approximately one minute to perform the scan. The graph on the left will indicate the resonance spectrum as the frequency is swept. Once the scan is complete, the "Save" button will become available. If the scan appears acceptable (i.e. not clipped and maximum peak approximately 50% to 75% of full scale) click on the

"Save" button. The scan data will be added to the template for that munition type. Move the transducer to the next known munition of the same type and repeat.

At the bottom of the display are two numbers. The first indicates the number of scan files in the template. This number will increment each time a scan is saved. The second number is identified as the "Correlation." The template correlation is used to determine how much a template is changing. A low correlation indicates a template which is changing rapidly as scan files are added. A high correlation indicates a template which is changing very little with the addition of new data. A template with high correlation is considered to be a well formed template. In general, scanning and template creation should continue until the correlation is above 90%. Testing has shown that this may take between 20 and 35 scans to achieve. Once the correlation rises above 90%, the software will give the user the option to discontinue template creation or continue scanning munitions. If a sampling of all munition lots of the same type have been scanned, and the user is satisfied that an adequate sampling of the total munitions has been achieved, then template creation may end. However, if there are additional munitions the user believes the system should add to the template for a particular munition type, then the template build should be continued. Each time the correlation is above 90%, the user will be given the option to stop.

> *Note: Although the system will specifically notify the user at the 90% correlation point, it is possible to stop at any point in the template build operation. The template building process can be resumed at any time without starting over. Additionally, if a template build process is ended before the 90% correlation mark has been achieved, the template will still exist for evaluation in its incomplete form. Templates with between 75% and 90% correlations have been observed to work with only marginal accuracy, and are not recommended for classification. Templates with correlations lower than 75% are considered unusable, and should have additional scan data added to them.*

Once a template is built, the process should be repeated for all other munition types entered. The template being built can be selected using the "Select" button. Templates must be built for all munition types before evaluating unknown munitions, otherwise the evaluations will be limited to the available templates.

Exit from the template generation screen and return to the top-level menu.

4.3 Collect Data

At this point, a template or templates have been created for munitions at that site. For best results, all munition types should have templates created before evaluating unknown munitions. If this cannot be accomplished, it is still possible to collect the data, but the evaluation performed immediately after scanning the munition will not be accurate. The data should be re-evaluated once all templates have been created

(Section 4.5, View and Analyze). Selecting the "Collect Data" button will bring up the screen necessary for data collection (Figure 24).

Note: Since scan evaluations are made against all available templates, having only one template available means that all scans will match that template.

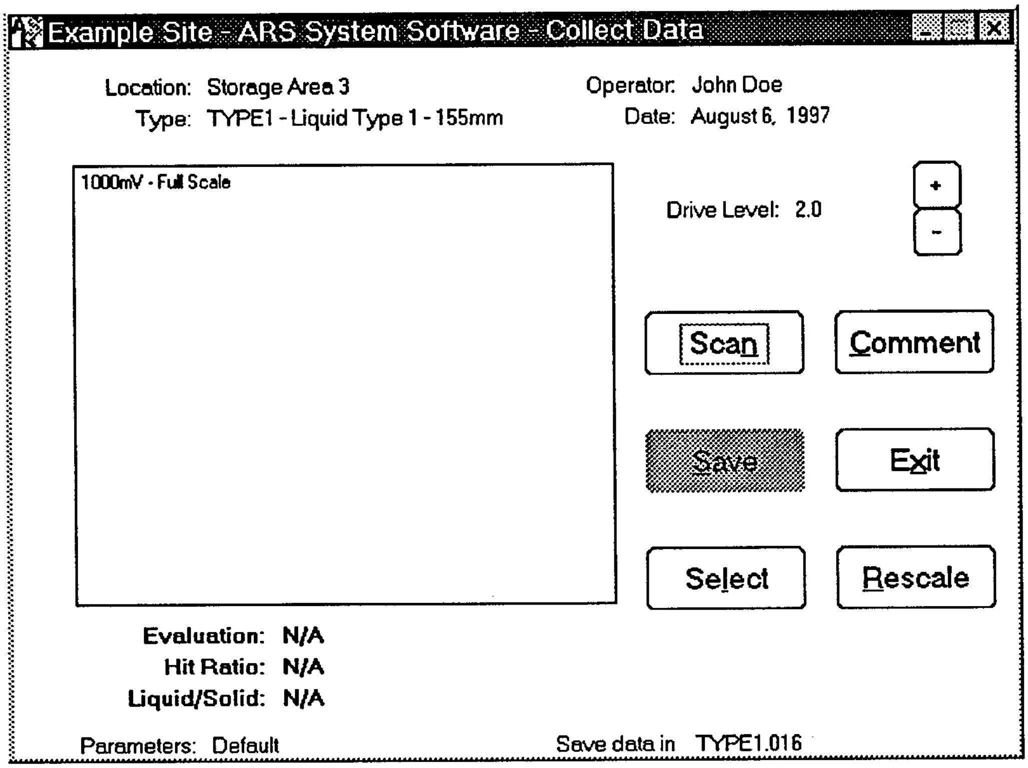


Figure 24. Data Collection Screen

At this stage, it is necessary to configure the information associated with this particular data collection instance (i.e., Operator taking data, building name , and munition type). Choose “Select” to bring up the configuration screen.

Note: If nothing has changed (i.e., building, operator, or munition) from the time the template was created, the default values will be appropriate and you can go directly to the "Collect Data" button. If changes have occurred, configuration will be necessary.

Using the "Standard Navigation Keys" (Tab key, Cursor control, Mouse) enter the Building Description and select the "Operator Name" and "Munition Type" for this particular data collection session.

Note the "Save files to floppy disk" box. If this box is not checked, the files will be saved only to the removable hard disk, not to the floppy disk. If this is the case, transferring files to floppies will have to be done at the DOS prompt level or by using the Windows File Manager as a separate operation outside of the ARS program. If you check the box for "Save files to floppy disk," the saving to floppy operation will occur at the same time that the data is written to the hard disk.

> *Note: Saving data to floppy disk slows down the overall operation and requires that you have a formatted floppy disk in the floppy drive. It also requires that the external floppy be connected to the computer which is not the recommended field configuration.*

Selecting the Scan Parameters button will bring up a box that allows you to modify the start frequency, stop frequency, and frequency increment. This box will display the expected length of time for a single scan. It also allows you to reset the scan parameters to their default value.

> *Note: Changing the scan parameters between the template and the data files to be collected is not advisable. No valid comparison can be made in such a case.*

Selecting OK will return you to the previous menu with the selected values for Building, Operator, and Munition Type displayed at the top of the screen. At the bottom of the screen, you will see the Parameters indicated as default or modified. If the parameters are modified, at the very least the modified values should agree with those used in the template scans.

Notice the Drive Level indicated as well as boxes with a "+" and a "-". Pressing the "+" or "-" keys will increase or decrease the drive level in 0.5-volt increments, except when the level is below 1.0 volt, at which time the "+" and "-" keys will increase or decrease the drive level in 0.1-volt increments. We recommend that you adjust the drive level until the maximum return signal is between 50% and 75% but does not clip (as evidenced by square topped response peaks). The computer will indicate a signal saturated condition as an aid to the operator in setting the proper drive level.

> *Note: If you adjust the drive level for a particular munition, the new drive level will remain in effect for the next munition. It is important that the operator look for an overdrive condition, resulting in signal saturation, on each scan. A saturated signal can result in an erroneous evaluation.*

Once all information on this screen is as desired, run a scan. Assuming the return signal looks "reasonable", save it and repeat the scan acquisition for all the munitions of interest. Exit from this screen and return to the top level menu when finished or when other factors cause you to stop the data acquisition.

If the signal is too low, the system will alert the user to possible wiring or transducer problems. Check the transducer magnets to be sure they are affixed securely, and check the wiring between the DSA and the transducer head.

If the evaluation of the scan data does not match the type selected in the "Select" dialog box, then the computer will warn the user before it saves the file. If the munition type has been incorrectly set, choose cancel and return to the "Select" dialog to change the munition type. If the munition type has been correctly set, and the system classifies it as other than its declared type, move the transducer and re-scan the munition. If the munition still misclassifies, there is an option for adding a comment to the scan. That munition should be set aside for further testing.

If the Notepad computer starts beeping (indicating a low battery condition), follow the instructions given in Section 3.3.1.

When the data collection is complete, exit from the data collection screen and return to the top level menu.

4.4 View & Analyze

The "View & Analyze" menu selection is intended mainly for off-line (no DSA300) processing of data. Selecting this option presents the user with a Load Data File dialog (Figure 25). The available files for each munition type are listed. Production scan files have extensions (the three characters to the right of the period) consisting of three digits, and are listed first. Files used to create templates have extensions with a "T" as the first character and two digits following. Files scanned for template creation but internally discarded to prevent sparse templates are indicated with an asterisk. A single file may be selected for evaluation, or the "Evaluate All Files of Munition" check box can be checked to evaluate all files of that type.

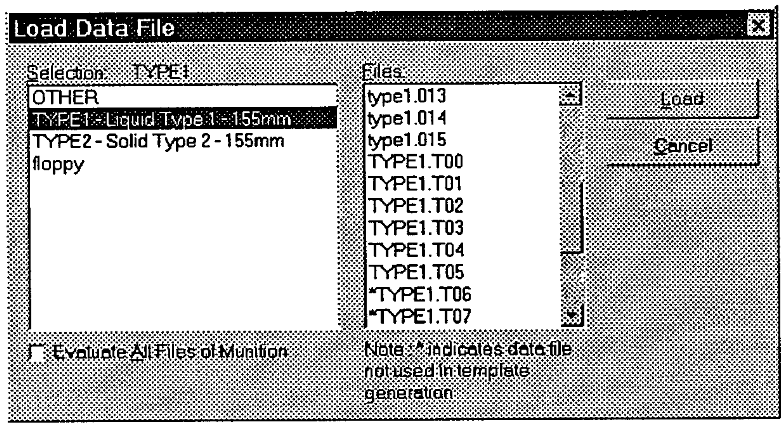


Figure 25. View and Analyze Load Dialog

If a single file is evaluated, a screen looking similar to the collect data display is shown. The primary difference is in the selection of buttons available to the operator (Figure 26).

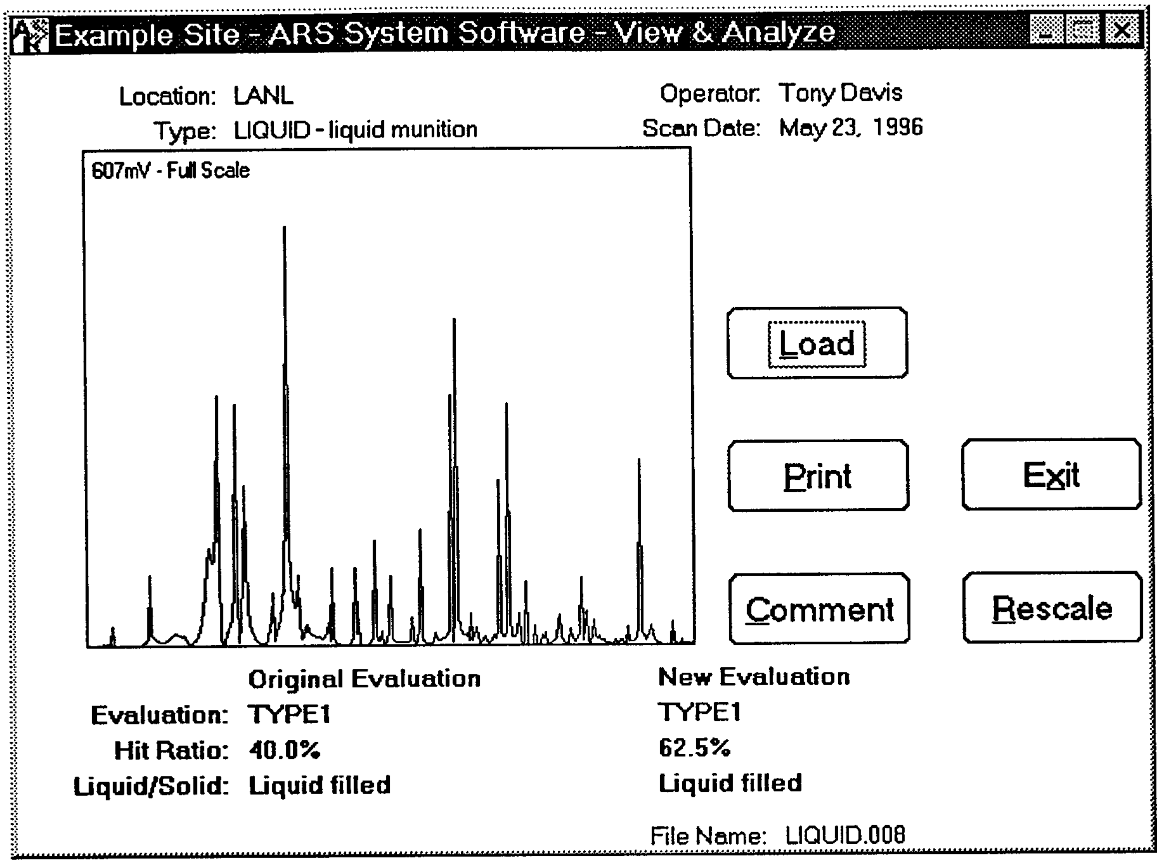


Figure 26. Viewing and Analyzing Files Off-Line

All of the relevant information saved in that file is displayed including the scan. Additionally, the scan is reevaluated with any templates currently present. The display shows the evaluation made at the time of the scan as well as this new evaluation. To see any comments that may have been entered at the time of the scan, select the "Comment" button. The "Rescale" button shows a more detailed view of the plot, but it hides all the other information except an "Exit" button.

The "Print" button will print a copy of the plot, in addition to all the pertinent information associated with that particular file. The print function prints to the default Windows printer.

If the "Evaluate All Files of Munition" check box is checked in the load box, all scan files of that munition are evaluated and a report is generated and displayed in Notepad (Figure 27). From notepad, this file can be saved, printed, or copied to the clipboard. Closing Notepad will return the user to the single evaluation screen, where the "Load" button can be selected to open another file.

Site : Example Site

Operators : Alice Jones
George Smith
John Doe

Date : August 6, 1997

Filename	Date	Orig. Classification	New Classification	Hit Ratio	Liquid/Solid	Comments
type1.001	May 22, 1996	No template avail	TYPE1	87.5%	Indeterminate	
type1.002	May 22, 1996	No template avail	TYPE1	87.5%	Indeterminate	
type1.003	May 23, 1996	No template avail	TYPE1	37.5%	Indeterminate	
type1.004	May 23, 1996	TYPE1	TYPE1	62.5%	Indeterminate	
type1.005	May 23, 1996	TYPE1	TYPE1	37.5%	Indeterminate	
type1.006	May 23, 1996	TYPE1	TYPE1	87.5%	Indeterminate	
type1.007	May 23, 1996	TYPE1	TYPE1	87.5%	Indeterminate	
type1.008	May 23, 1996	TYPE1	TYPE1	62.5%	Indeterminate	
type1.009	May 23, 1996	TYPE1	TYPE1	75.0%	Indeterminate	
type1.010	May 23, 1996	TYPE1	TYPE1	50.0%	Indeterminate	
type1.011	May 23, 1996	TYPE1	TYPE1	87.5%	Indeterminate	
type1.012	May 23, 1996	TYPE1	TYPE1	100.0%	Indeterminate	
type1.013	May 23, 1996	TYPE1	TYPE1	100.0%	Indeterminate	
type1.014	May 23, 1996	TYPE1	TYPE1	100.0%	Indeterminate	
type1.015	May 23, 1996	TYPE1	TYPE1	62.5%	Indeterminate	
TYPE1.T01	May 22, 1996	No template avail	TYPE1	87.5%	Indeterminate	
TYPE1.T02	May 22, 1996	No template avail	TYPE1	87.5%	Indeterminate	
TYPE1.T04	May 23, 1996	TYPE1	TYPE1	62.5%	Indeterminate	
TYPE1.T06	May 23, 1996	TYPE1	TYPE1	87.5%	Indeterminate	
TYPE1.T14	May 23, 1996	TYPE1	TYPE1	100.0%	Indeterminate	
*TYPE1.T03	May 23, 1996	No template avail	TYPE1	37.5%	Indeterminate	
*TYPE1.T05	May 23, 1996	TYPE1	TYPE1	37.5%	Indeterminate	
*TYPE1.T07	May 23, 1996	TYPE1	TYPE1	87.5%	Indeterminate	
*TYPE1.T08	May 23, 1996	TYPE1	TYPE1	62.5%	Indeterminate	
*TYPE1.T09	May 23, 1996	TYPE1	TYPE1	75.0%	Indeterminate	
*TYPE1.T10	May 23, 1996	TYPE1	TYPE1	50.0%	Indeterminate	
*TYPE1.T11	May 23, 1996	TYPE1	TYPE1	87.5%	Indeterminate	
*TYPE1.T12	May 23, 1996	TYPE1	TYPE1	100.0%	Indeterminate	
*TYPE1.T13	May 23, 1996	TYPE1	TYPE1	100.0%	Indeterminate	
*TYPE1.T15	May 23, 1996	TYPE1	TYPE1	62.5%	Indeterminate	

Figure 27. Output from Evaluate All Files

4.5 Exiting The ARS Program

Once you are finished with the ARS program, exit the program by tapping the "Exit" button at the top level menu. This will bring you back to the Windows Program Manager screen. To exit Windows, double tap the control bar or press "ALT" + "F" then "X" to exit Windows. When the message prompt asks if you want to exit Windows, press "Return".

> *Note: Wait until the screen returns to the DOS prompt before turning power off. The power to the DSA300 can be turned off at any time after exiting the ARS program.*

Appendix A: Configuration File and Command Switches

A.1 ARS Program Configuration File

The configuration file (ARS.CFG) resides in the ARS subdirectory of the computer's hard disk. This file is used to set all the default parameters used by the ARS program. The most common parameters to change are the start and stop frequency and the frequency increment. There are several other parameters such as drive level, full scale voltage, etc that can be changed. It is ***strongly recommended*** that only start and stop frequency, frequency increment, and drive level be changed for field use (and then only by knowledgeable operators). Changing other parameters could result in severe degradation of the function of the ARS program.

ARS Configuration File Listing

Directive	Default Value	Description
ROOT=D:\ARS\DATA	D:\ARS\DATA	Default data root directory (required)
STARTF;3000	3000	Sweep start frequency (Hz)
STOPF;30000	30000	Sweep stop frequency (Hz)
INCR;15	15	Sweep step frequency increment (Hz)
DWELL;33	33	Sweep frequency dwell time (ms)
DRIVE;20	20	Sweep drive voltage (2.0 volts)
PORT;COM1	COM1	Serial port for DSA300
FLOPPY;A:	A:	Floppy drive port

Note: None of the values listed below should be changed except under direction from the software developer.

GRAPH;32767	32767	Graph plot range
FLTCLST;30	30	NFLATCLUSTER
MAXCLST;100	100	MAXCLUSTER
VCUTOFF;4	4	VARCUTOFF
VFACTOR;3	3	VARFACTOR
WINFRAC;150	150	WINFRAC
WININC;0.1	0.1	WININC
WINSIZ;8	8	MAXWINDOW
WSCL;1.6	1.6	WSCALE
NQSELECT;100	100	NQSELECT
#DEBUG;1	1	Debug mode switch
NEELC;1	1	Down scale constant
FSCALE;1000	1000	Full scale voltage (mv)
MATCH;0	0	Minimum match level (MATCH / 1000)
FEATFRAC;0.80	0.80	Minimum attendance level for cluster
TB_START	5	Number of files in template build before sparsity check imposed.

Note: If you change the scan parameters, a message will indicate that an incompatible file will result. This is true if you attempt to compare two files (i.e., a file against a template) scanned with different parameter settings. We recommend that the default values be used, except in *special circumstances. At the very least, all munitions of a given size should use the same scan parameters.*

Note: Changing the default values so a new set of values appears as the default requires that the ARS.CFG file in the ARS subdirectory be edited by a knowledgeable individual. If the default values in ARS.CFG are changed, be advised that the product of the frequency increment and the dwell time must be 500. If this is not the case, the ARS program will display a "modified" parameter indication, even though the operator selects the default values.

A series of config file directives allow the internal statistics for the liquid/solid discrimination algorithm to be altered. When the directives are not present in the config file, the default values are used. Each set of statistics consists of two covariant matrices, four mean values, and an error factor arranged as follows:

Small munitions (used for 105mm. and Other settings):

Solid covariant matrix:

SS00=2187.41	SS01=-3.9361
SS10=-3.9361	SS11=0.2268

SSAW=663.731 Small solid average width
SSAR=1.47126 Small solid average ratio

Liquid covariant matrix:

SL00=440.43	SL01=-2.613
SL10=-2.613	SL11=0.6438

SLAW=485.619 Small liquid average width
SLAR=1.586 Small liquid average ratio

SERR=-1 Small munition error factor (negative number causes "Indeterminate" result for all data.)

Large munitions (used for 155mm.):

Solid covariant matrix:

LS00=8248.9	LS01=-0.7042
LS10=-0.7042	LS11=0.0271

LSAW=520.9663 Large solid average width
LSAR=0.5042 Large solid average ratio

Liquid covariant matrix:

LL00=579.7723	LL01=-2.2310
LL10=-2.2310	LL11=0.0948

LLAW=314.5357 Large liquid average width
LLAR=0.7904 Large liquid average ratio

LERR=4.0 Large munition error factor (negative number causes "Indeterminate" result for all data.)

A.2 Command Switches

The ARS program behavior can be altered for special situations by using command switches when executing the program. These switches can cause dramatic program changes and should not be adjusted by the user. The switches are listed here for reference, and, with the exception of '-n,' are not supported and may yield unexpected results. The switches are not case sensitive.

Switch	Function
-n	Disables the DSA check on startup. This is used to allow processing of data on a desktop computer without receiving the "Cannot connect to DSA" message on startup. Also disables tactile beep when buttons are pressed in main program. This switch is automatically set by the setup program if requested.
-a	Sets the DSA into autoscale mode.
-e	Expert mode switch. Allows dwell time to be modified and enables manual template build feature (Section A.3).
-s	Disables splash screen at startup.
-q	Quiet mode. Disables tactile beep when buttons are pressed.
-p	Displays lines where the program has identified a peak.
-o	Set for support of old DSA300 scan boxes (use only if problems encountered).

A.3 Manual Template Build

Template building is typically accomplished through the interactive scanning process in "Create Templates." Data files which significantly disturb template creation are automatically removed from consideration by the automated process. In rare cases, however, it may be desired to manually control the template building process. This may be accomplished by adding the '-e' switch to the program at startup, which enables an extra button in the "Create Templates" screen for manually building templates. Manually building templates can only be accomplished after all scans to be included in the template have been taken using the "Create Templates" process.

> *Note: The automated template build system is designed to eliminate errors in the template building process introduced by spurious data files. Manually building templates bypasses this automatic check, and can produce templates which will degrade system performance dramatically. This should only be done by experienced users.*

From the top-level menu, select "Create Templates" and then choose “Manual Build” to manually process the template generation. In this screen, you will see a "Selection" box with the current selection shown above the box and a list of available scans appropriate to that selection (Figure 28).

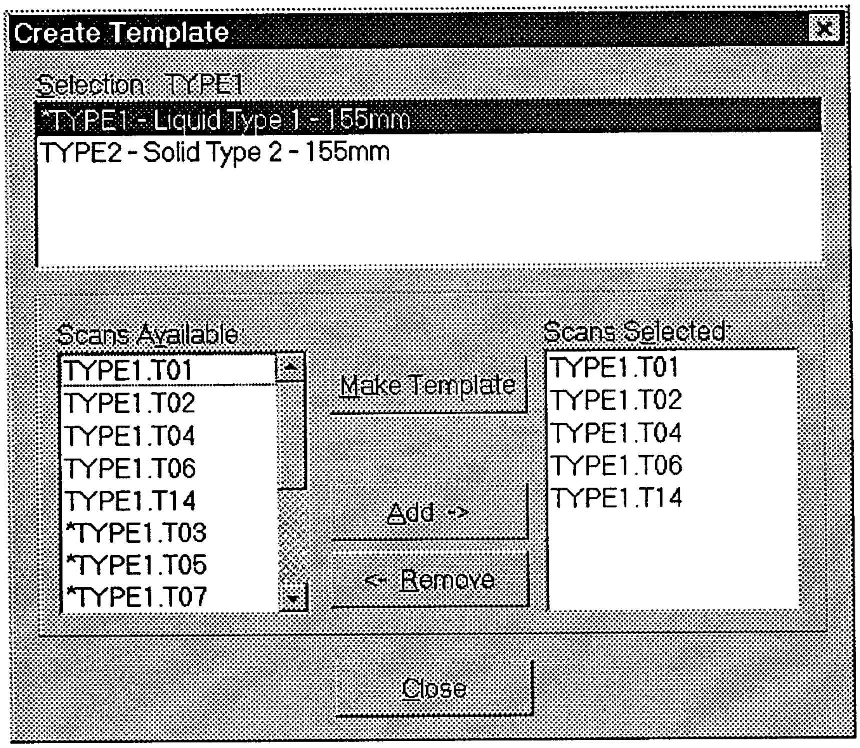


Figure 28. Template Creation Screen

Use the pen to select the desired item or alternatively use the *Tab* key to move to the desired field and use the cursor control keys to highlight the desired selection from the list. Use the *Tab* key to move to the "ADD" button, then press *Return* (or double-tap the scan file). This adds the individual file to the list of "Scans Selected." Scans can be deleted from this list by following a similar procedure using the "Scans Selected" list and the "Remove" button.

Once you have selected all the files to be included in that template, move to the "Make Template" button and activate it. An "Abort" box is available that allows you to abort the operation. The "Abort" box also informs the operator of the file name being processed.

> *Note: An error message appears if one or more of the selected files has incompatible parameters. If this happens, the template creation is aborted. Delete the incompatible file from the list of "Selected Files" and press the "Create Template" button again.*

If no errors occur, a message will indicate that a template has been created and what type of munition the template applies to. At this point, the user can leave the manual build dialog and begin production scans in the "Collect Data" screen, or the user can refine the templates further using the "Create Templates" screen.

A.4 Directory Structure

The ARS-MCS program internally uses the DOS/Windows directory structure to separate different data file sets. Under normal circumstances, the user should not be aware of the full extent of the directory structure. However, should special circumstances arise, the user may wish to move files into and out of the directory structure.

The ARS.CFG file specifies the data directory used. The setup program defaults this directory to \ARS\DATA. Figure 29 shows the subdirectories in the \ARS\DATA directory. The first subdirectories are the site directories, in this case "Example", "Munster", and "Test". The "Example" site has two munition types entered, "type1" and "type2". Production scan data is stored in these directories with the names followed by an extension of three digits (e.g. "type1.001", "type2.005", etc.) Additionally, the "Template" directory contains the template files for all munitions. The template files are named with the munition name followed by the extension ".tpl". These files can be moved from computer to computer to provide premade templates for other systems, however *templates must be made onsite, and are not valid from one inspection to the next.*

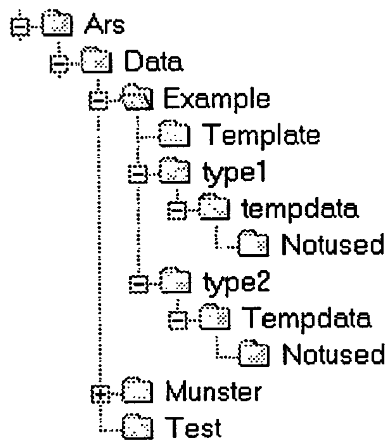


Figure 29. ARS Directory Structure Example

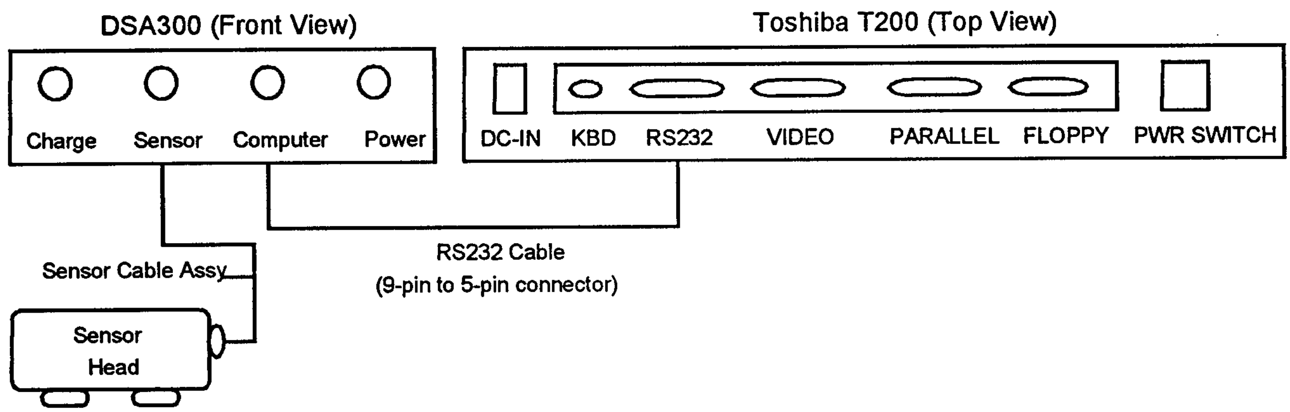
Inside each munition directory is a subdirectory named "tempdata". The "tempdata" directory contains the scan data files used to create the template for that munition. These files are named with the munition name followed by an extension of "T" and two digits (e.g. "type1.t03", "type2.t12"). Inside the tempdata directory is a "notused" directory which contains template scan data files which were discarded by the template build algorithm. They have the same naming convention as the files in the "tempdata" directory, and are numbered consecutively in the same sequence as the files in the "tempdata" directory. The files in the "notused" directory can be included in the template using the Manual Template Build option (Section A.3).

Appendix B: Interconnection Wiring Diagrams

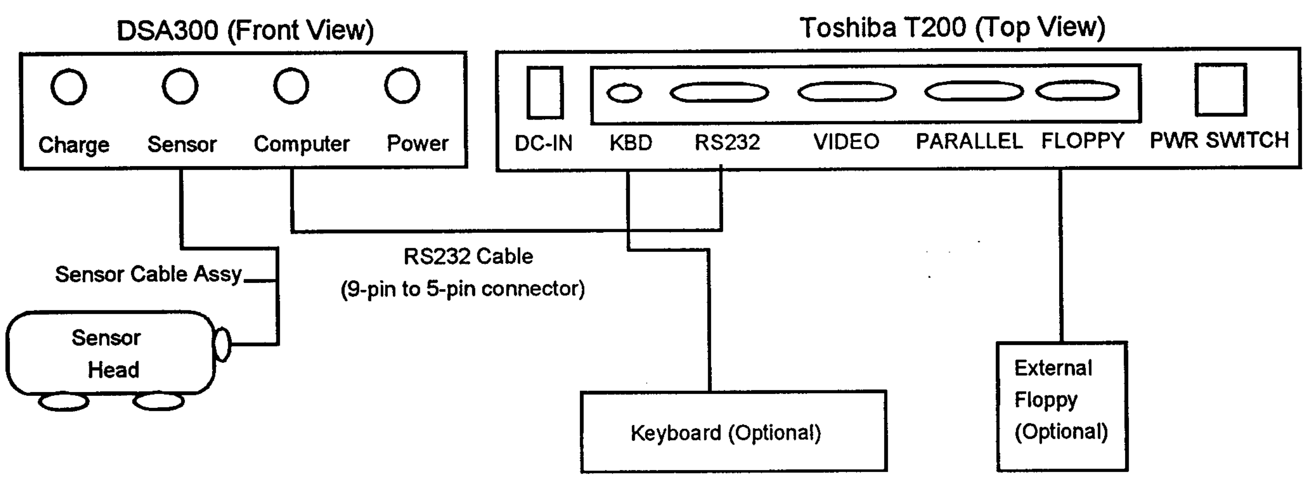
INTERCONNECTION WIRING

Note: The computer shown in these diagrams is a Toshiba T200. Minor differences exist between the T200 and the fielded equipment. Check the user manual of the specific notepad computer used for port location.

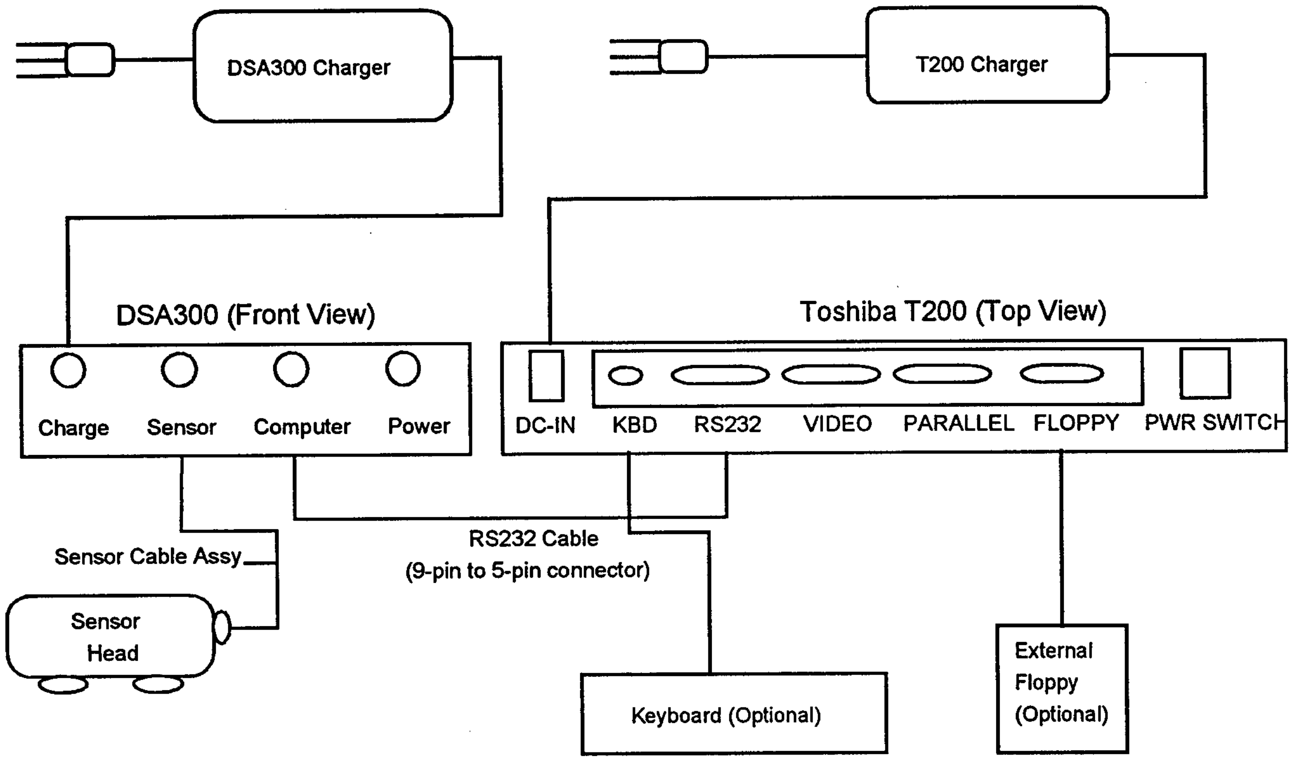
B.1 Field Configuration



B.2 Base Configuration



B.3 Charging Interconnection Wiring



Note: (1) Both the DSA300 and the Toshiba T200 can be operated while charging. The front panel "charge" light on the DSA300 will turn off when fully charged and the T200 charge light will turn green when fully charged.

Appendix C: Component List

Acoustic Resonance Spectroscopy (ARS300 System)

ITEM	QTY	DESCRIPTION
DSA300	1	Data Acquisition System (Modified per LANL specifications) Mfg: Neel Electronics Inc. 12 Silent Knoll Laguna Niquel, CA (714) 495-3216
Sensor Heads (SHD300)	2	Transducer Heads for DSA300 (Built to LANL specifications) Mfg: Neel Electronics Inc. 12 Silent Knoll Laguna Niquel, CA (714) 495-3216 Components: Panametrics Transducers 221 Crescent St. Waltham, MA 02254 (617) 899-2740 Model: Videoscan V103-RM; 1.0 MHz; 0.5" Transducer Magnets Edmund Scientific Co. 101 E. Gloucester Pike Barrington, NJ 08007 (609) 547-8880 Model: Nd-Fe-B; 1/2" dia.; 1/8" thick; Stk. # F35,105 In-line Amplifier (Built to LANL Specifications) Neel Electronics Inc. 12 Silent Knoll Laguna Niquel, CA (714) 495-3216 Sensor Housing (Custom Built to LANL Specification)
Sensor Cable (SC300-50)	1	Cables (50' Length) for DSA300 to Sensor Heads (Custom Built to LANL Specifications)
Sensor Cable (SC300-10)	1	Cables (10' Length) for DSA300 to Sensor Heads (Custom Built to LANL Specifications)

PC-DSA Cable	1	Serial Cable from PC to DSA300 Custom Built by LANL Components: LEMO Connector (P/N: FGG.1B.305.CLAD-72Z) Serial AT Style 9-pin Cable (Radio Shack or Equivalent)
Computer	1	Laptop Computers for Data Processing Example computer: Mfg: Toshiba Corp. DynaPad T200 Pen (Monochrome) Laptop Add-On & Accessories Memory Module (8M) Extra Battery AC Charger
DSA300 Charger	1	Charger for DSA300 Mfg: Custom Built by LANL Components: LEMO Connector (P/N: FFA.1S.302.CLAC52) International Power Sources, Inc. (Model #: PUP30-12-B2) AC Power Cord (Detachable)
DSA300 Case	1	Soft Carrying Case for DSA300, Computer, Sensors, & Cables Mfg: HER Electronics 6201 Copper NE Albuquerque, NM (505) 265-7843 P/N: ARS300 Carrying Case
Transport Case	1	Transport Case for Complete ARS300 System Mfg: HER Electronics 6201 Copper NE Albuquerque, NM (505) 265-7843 P/N: ST1714-10F-LP Size: 17 3/4 x 14 1/2 x 10

Appendix B

ARS Munition Classification System Enhancements

Acoustic Resonance Spectroscopy Munition Classification System Enhancements

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Introduction

The Acoustic Resonance Spectroscopy Munition Classification System (ARS-MCS) is a nondestructive munition evaluation system. It is a fast, nonintrusive technique which uses the modes of vibration an object to determine the object's characteristics, then classify that munition based on those characteristics. For filled objects such as munitions, the modes of vibration are affected by the physical properties of the fill material and the amount of fill material present. By sweeping the excitation signal in frequency and measuring the response, an acoustic signature of the object in question can be created. This signature can then be used to classify the munition based on gross characteristics of the spectra, such as average peak width, or by comparing the spectra to other munition scans.

The ASR-MCS has two uses. The first use is a blind fill discrimination test. This test can determine whether the munition in question is filled with liquid or solid material, without any prior knowledge or training by the system. This technique uses the average width of the spectral peaks and the ratio of spectral energy above 10 kHz to the energy below 10 kHz to perform a likelihood ratio test. Data from known solid filled and liquid filled 155 mm munitions was used to generate the set of statistics used in the test. This set of statistics is applicable to any 155mm munition. The other use of the software is in classifying munitions as a particular fill type, such as high explosive or mustard gas. This process involves obtaining scans from a known set of munitions which are in turn used to create a template for that munition. Future scans are compared against these munition templates. The scan is classified as the type of the template which it mostly closely matched. The important aspect of this process is building good templates. A template is considered good if it can correctly classify any spectra not used in the template's creation with 90% reliability at 90% confidence. To consistently ensure the creation of good templates, Anthony Davis and Randy S. Roberts developed the Template Metric algorithm[1].

Several problems were addressed by this work. The liquid / solid blind fill discrimination statistics needed to be updated with more data. The Template Metric required further testing with new data. Assuming the Template Metric successfully passed the new tests, it would then need to be integrated into the ARS-MCS software. Finally, several software user interface enhancements were necessary.

Analysis of Tooele Data

In an effort to further test and refine the ARS-MCS, new data was collected from Tooele Army Depot in May of 1997. This data was used to test the liquid / solid fill discrimination capabilities of the ARS-MCS, and the Template Metric.

For the liquid / solid fill discrimination test, five munition types were used. This set consisted of 85 155mm GB files, 47 155mm VX files, 46 155mm H files, 31 155mm HE files and 25 155mm TNT files. Currently, the liquid / solid fill discrimination only works on 155mm munitions due to a lack of data on other size munitions.

The Template Metric test centered around three munition types. The test set was comprised of 85 155mm GB files, 47 155mm VX files and 46 155mm H files, for a total of 178 scan files.

Liquid Solid Discrimination

The five munitions from the May, 97 Tooele data were classified using the original ARS-MCS liquid/solid fill discrimination statistics. These statistics were generated from all previously collected 155mm munition data. Out of 187 total munitions classified, 12 were classified incorrectly, resulting in a reliability of 90.69% at 90% confidence. Figure 1 shows the decision boundary generated by the original fill statistics and the specific points representing the new data collected from the Tooele munitions..

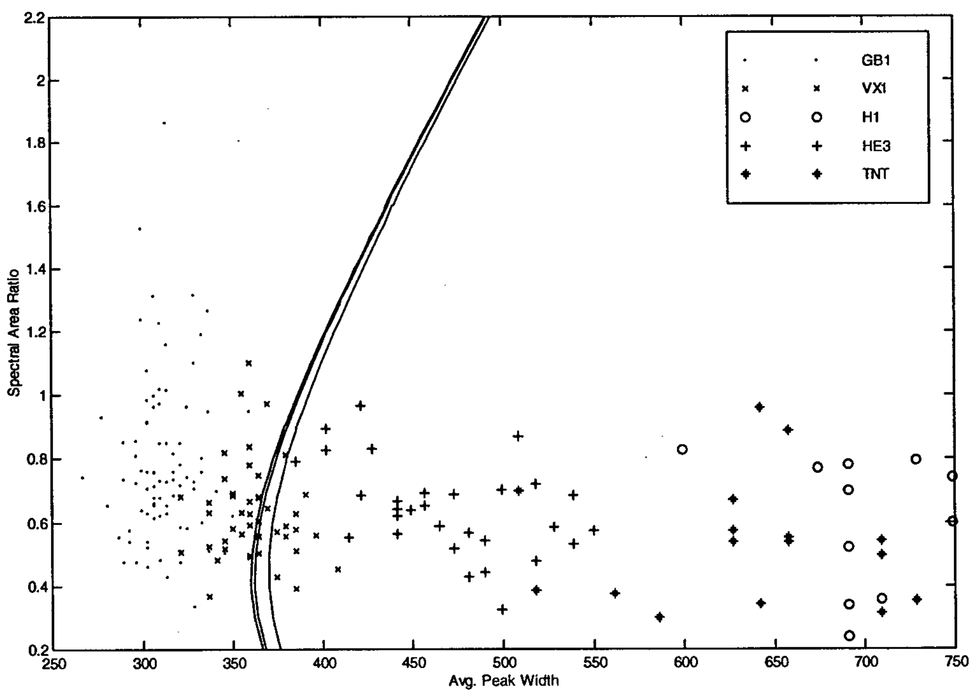

Figure 1. May, 97 Tooele Data with Original Fill Statistics

As can be seen from this plot, the majority of incorrect classifications come from VX munitions falling on the wrong side of the decision boundary. This analysis lead to the realization that new fill statistics which took into account this new data were needed. Therefore, a new set of liquid/solid fill discrimination statistics were generated consisting of all previous munition data used to generate the original fill statistics and the May, 97 Tooele data. Once these new statistics were generated, they were used to classify the entire data set with which they were created. This new set of statistics misclassified 7 out of 943 munitions, resulting in a 98.76% reliability at 90% confidence. Figure 2 shows the new decision boundary and the distribution of data for all munitions

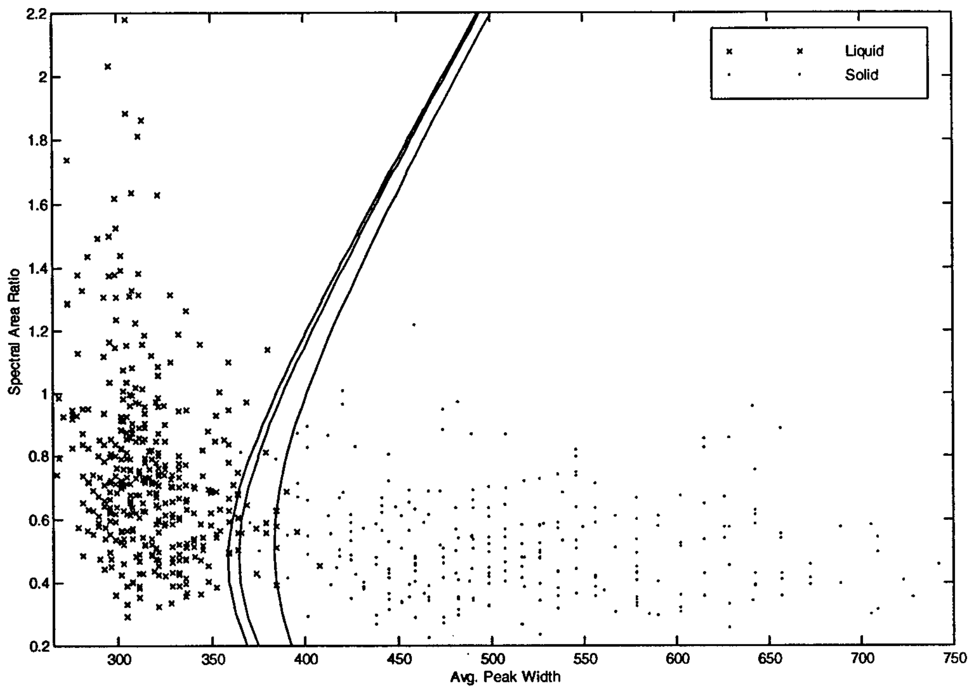

Figure 2. All Current Data with New Fill Statistics

Munition Classification

The new data collected from Tooele was also used to further test the Template Metric. The Template Metric is an algorithm that attempts to guarantee the reliability of the templates created by the ARS-MCS. It is an incremental approach to building templates. Scan files are taken one at a time and added to the current template. After each file addition, the current template is compared to its predecessor. The first comparison determines the new template's sparsity, or total number of features compared to the previous template. A template is considered sparse if its number of features is less than two thirds of the number of features of the previous template. If the template is determined to be sparse, the template and the most recently added scan file (the one which caused the sparse condition) are discarded, and the process resumes with the previous template. If the new template is not sparse, the zero-shift cross correlation is calculated between the new and old templates. This correlation is a measure of how the features in successive templates are changing. It is used to indicate when the templates have settled on a solid feature set and can be considered complete. When the running average of the last five correlations for a given template exceed 90%, the template is considered complete, and the build process is stopped.

Three munitions were used in the evaluation of the Template Metric; GB, VX and Mustard (H). As described previously, sequential scans were incrementally added to the three templates. After each new set of templates were generated, they were used to classify the remaining scans. The results of these classifications were used to determine the reliability at 90% confidence for the given template sets. The reliability and the running average of the template correlations are plotted as a function of the number of files in each template of the set in Figure 3.

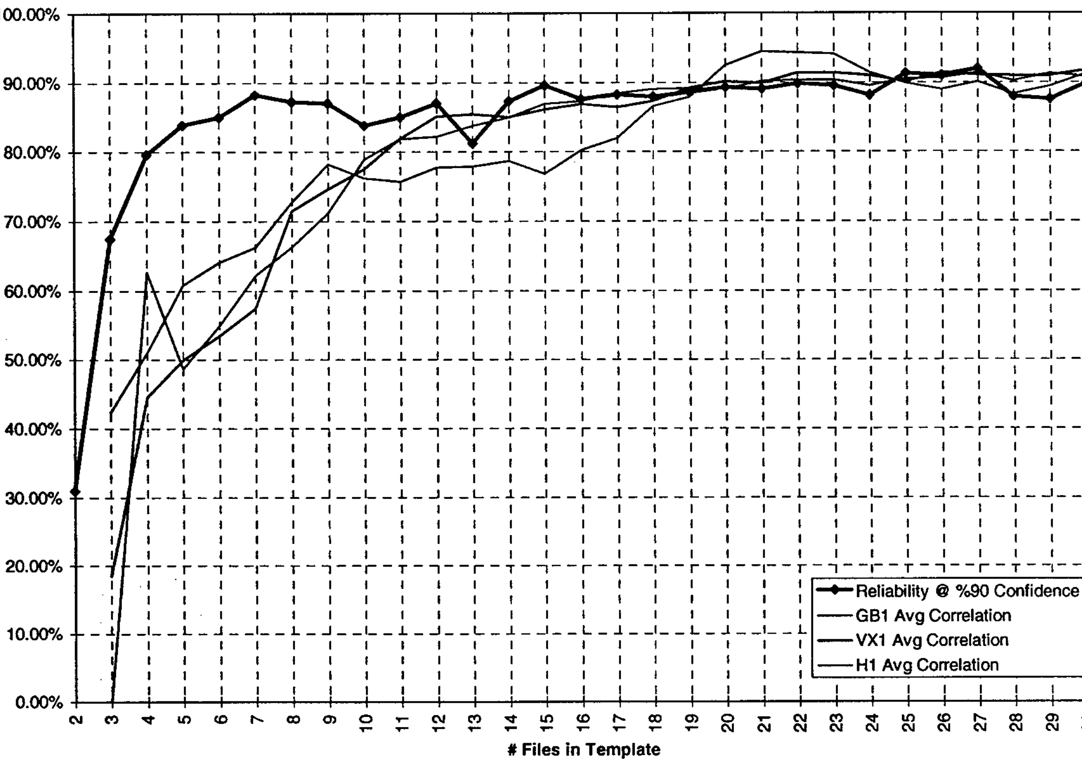

Figure 3. Template Metric Test Results for GB, VX & H

As mentioned earlier, a template is considered complete when the running average of its last five correlations exceed 90%. This happened at 21 files in the template for GB, 20 files in the template for VX and 20 files in the template for H. These three templates were used to classify the remaining data scans which had not been used in the templates. Out of 117 scans, 8 were classified incorrectly, resulting in an 89.22% reliability at 90% confidence. It is interesting to note that the 90/90 mark was met when comparing three munitions. Most tests to this point focused on comparing two munitions, namely GB and VX. To test against this benchmark, just the GB and VX templates were used to classify the remaining GB and VX scans. In this instance, out of 91 scans, 0 were misclassified, leading to a 97.53% reliability at 90% confidence, well exceeding the desired the 90% reliability at 90% confidence mark.

Previous to the Template Metric, template generation was a batch operation. Several scan files were selected at once and used to create a template. This was the method the ARS-MCS employed for template generation. As such, the three munitions were classified using this approach. Templates with 8, 10, 12, 14 and 16 files were generated and used to classify the remaining spectra. The results of this test are shown in Figure 4.

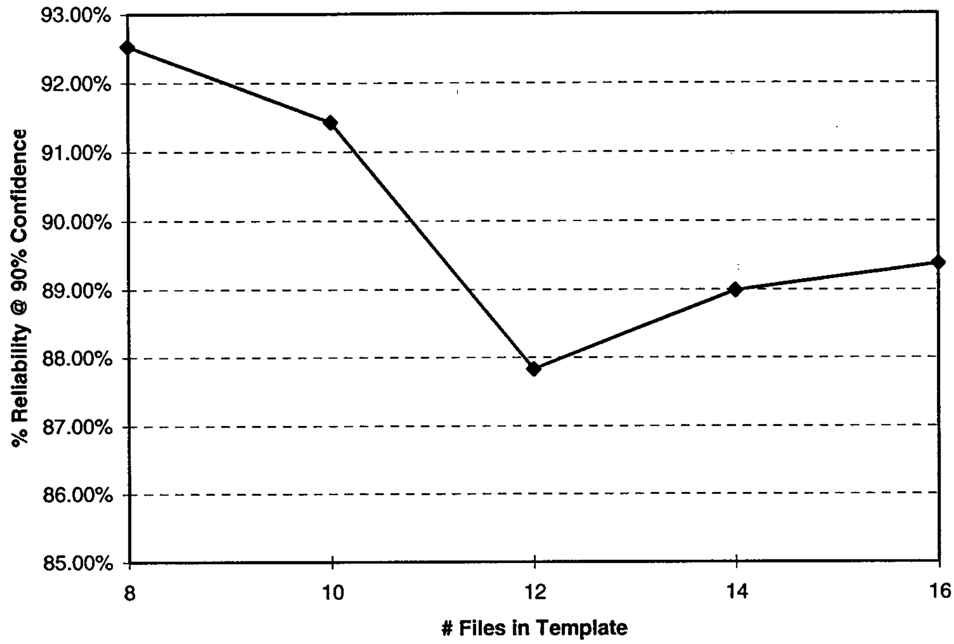

Figure 4. % Reliability at 90% Confidence for Templates Generated With Out Using the Template Metric

By comparison, the Template Metric performed very well. The 90/90 mark was exceeded for the GB versus VX test, and was almost met for the GB, VX, and H test. In the three munition test, H proved to be the problem. Figure 5 illustrates the templates used in the three munition Template Metric test. The templates are plotted over the munition frequency scan range, 0 to 30 kHz, with bars representing clusters. Many things can be seen from this plot.

First, the H templates posses very few clusters in general. Such templates are referred to as "sparse" templates, and generally cause problems when used for classification. They can either poorly represent the spectra of their own munitions, and thus have difficulty correctly classifying their own munitions, or they can be overly generalized, thus classifying to all munitions. For this particular test, GB generally classified 100% correctly, as did H. However, the majority of misclassifications came from VX classifying as H. It is apparent that the sparse H templates confused the classification of the VX munitions. When H was excluded from the test, no misclassifications occurred, again pointing to the sparse H templates as the culprit of the problems in the three munition test.

Second, the clusters of the H templates are very broad, normally a characteristic of solid filled munitions. This trend of H simulating a solid can also be seen in Figure 1, as the cluster of H munitions fall far to the solid side of the decision boundary. This can be explained by the fact that the H data was collected when the temperature inside the storage bunker was very cold. The mustard must have solidified.

Figure 5. Illustration of Templates Used In the Three Munition Test. The Red Templates Were Produced From GB munitions, the Blue From VX and the Green From H.

Software Improvements

Many enhancements were made to the current ARS-MCS software. These enhancements included integrating the Template Metric into the template build algorithm and numerous user interface improvements.

Template Build Algorithm

The integration of the Template Metric into the template build algorithm necessitated drastic software changes. The original template generation was a batch processing scheme in which the user collected many data files from the "Collect Data" section of the program, then selected a group of those files in the "Create Templates" section of the program to create the template. The Template Metric is an incremental algorithm, however. Scan files must be added one at a time. Therefore, the "Create Templates" section of the program was modified to be an interactive process. The user collects spectral data from this screen, adding each scan to the current template as it is collected. The number of files in the template and the running average of the correlations for the current template are displayed on the screen, as demonstrated in Figure 6. Once the running average of the correlations surpasses 90%, a dialog box is displayed informing the user that the template can be considered complete, and asking them if they would like to continue. This allows the user to either complete the template creation process if they feel an adequate sampling of all the munitions of that type have been made, or to continue to add munitions as they deem necessary.

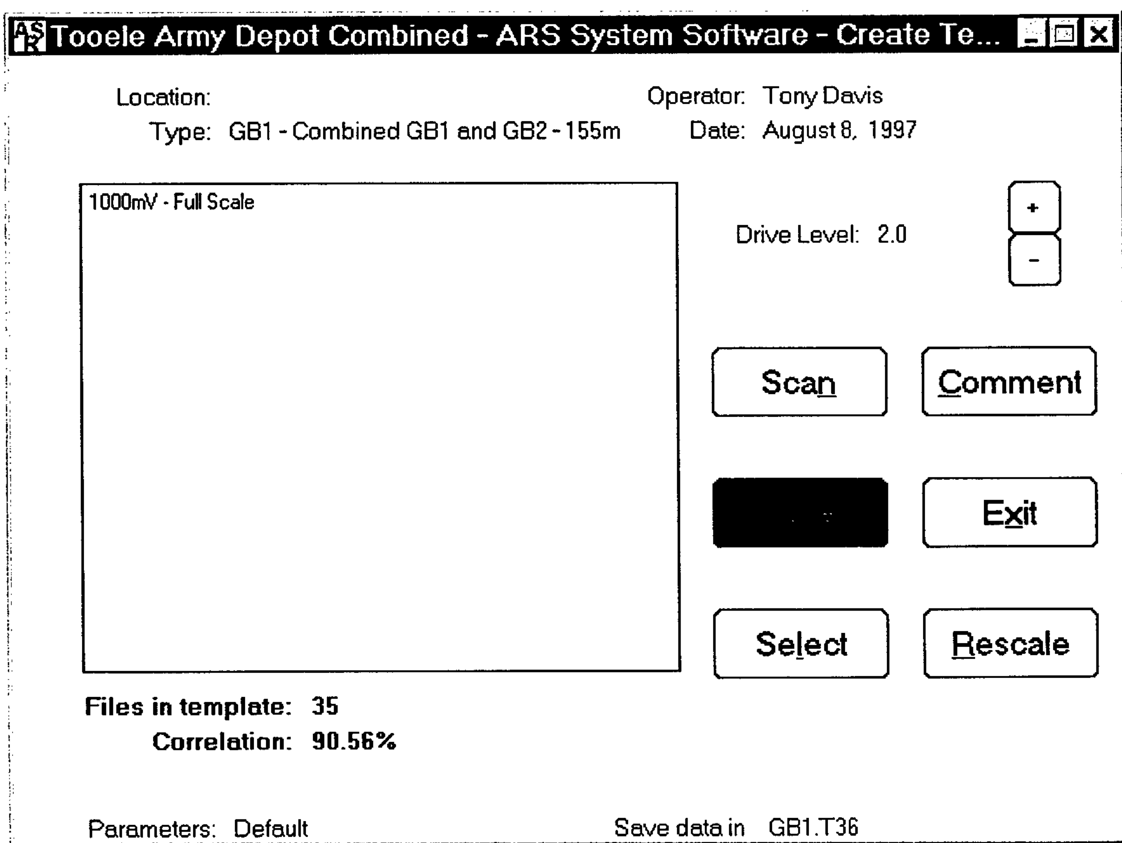

Figure 6. "Create Templates" Screen of ARS-MCS Software

The first step of the new template build process is to collect a spectral sample to add to the current template. This is done by pressing the scan button, as is done in the "Collect Data" screen. Once the scan is completed, the user can add it to the template by pressing the save button. This begins the template build process.

The first step of the template creation process involves saving the current data scan to disk. Given the fact that template scan files should be kept separate from data scan files, and that some template scan files may be "discarded" from the template file set, slight modifications to the current software directory structure were required. A new subdirectory, "TEMPDATA", was added to all munition subdirectories. This directory contains the scan files collected from the "Create Templates" screen which are actually used in the template (that is, that did not make the template sparse). This subdirectory contains another subdirectory, "NOTUSED", that contains the template scan files which were determined to make the template sparse, and therefore discarded from the template. All scans are first saved to the "TEMPDATA" directory, where they are added to the template and their corresponding effect on the template determined.

Once the scan file has been saved, the program checks to see if a template already exists for the current munition. The Template Metric requires both the current template in question and the previous template for comparison. Therefore, if a template already exists, it is copied into a backup file in the same subdirectory with the extension ".OLD" and the hidden attribute set., overwriting any previous backup template. The hidden attribute is set because the backup template is meant to be used only by the program. It was feared that the existence of two templates for a munition might confuse the user, or that the backup template might be mistakenly used for classifications. After the previous template is backed up, the current template is saved as usual.

Next, the program attempts to determine if the current template is sparse. This check is only performed if there are more than five scan files already in the template. If less than five files exist in the template, the current scan is added. If more than five files exist in the template, the total number of features in the current template are compared against the total number of features in the previous template. If the current template contains less than 2/3 the number of features of the previous template, the current scan file is not added to the template permanently. It is instead moved to the "NOTUSED" subdirectory, and the current template is discarded. If the current template contains at least 2/3 the number of features of the previous template, or the previous template does not exist, the current scan is added to the template permanently and the correlation between this new template and the previous template is calculated. The new correlation is then added to the list of correlations maintained to calculate the running average. The list of correlations is stored in a "FILEID.CFG" file in the "TEMPDATA" directory. This file contains the last five correlations calculated and the number of the next file to be scanned. All previous correlations are shuffled down as new correlations are added to the list. By storing the recent correlations and the current template scan file number, the template build process can be interrupted and resumed at a later time. This also allows the template to be further refined if the user decides to add new munition scans. Finally, the new average correlation is calculated. If this number is greater than 90%, the user is presented with a dialog box. This dialog informs the user that the template is considered complete by the software, and asks if template creation should continue. If they user responds 'no', then the software exists to the main menu. If they answer 'yes', the dialog is dismissed and the template creation process can continue.

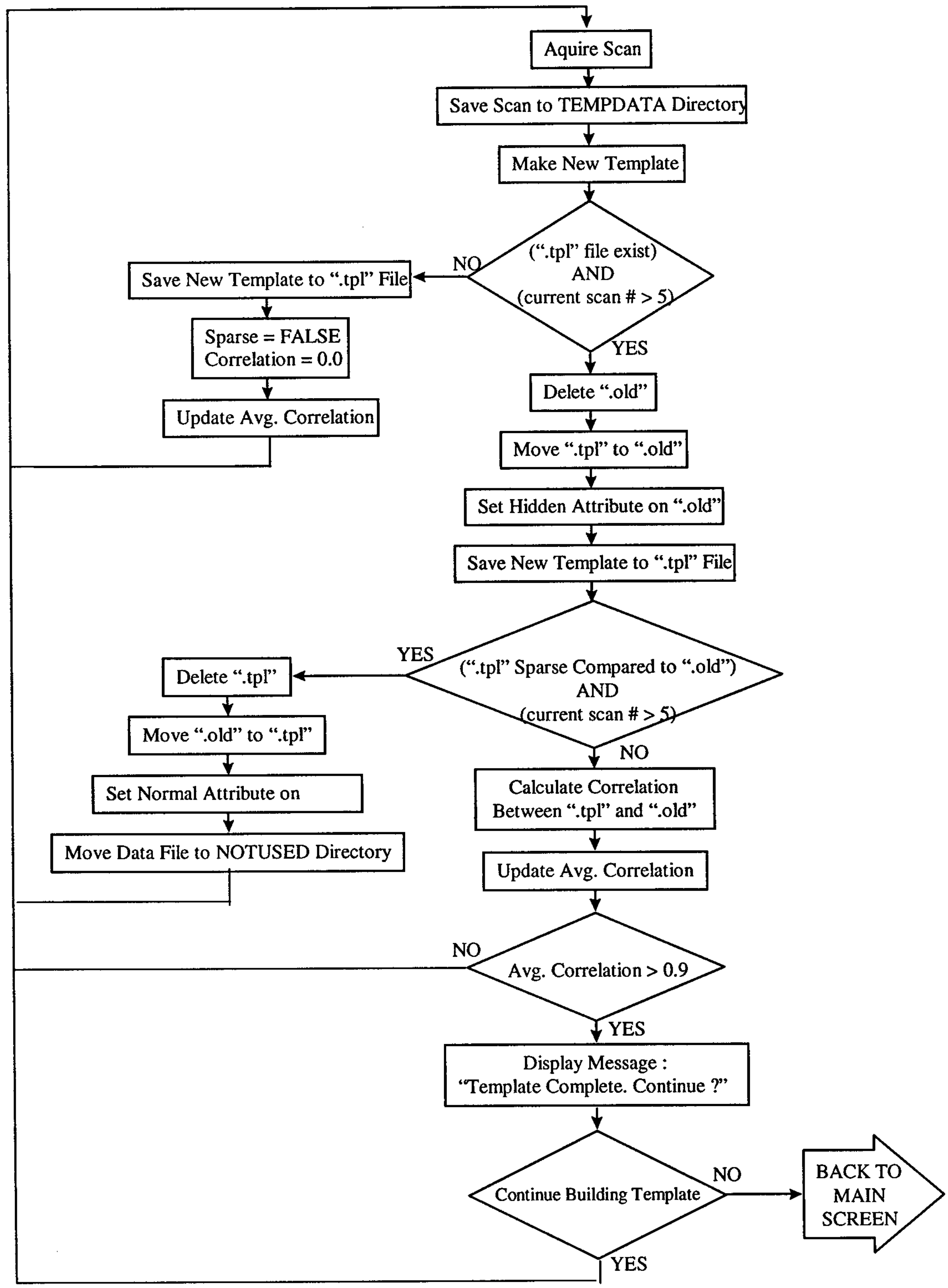

Figure 7. Flowchart of the ARS-MCS Template Build Algorithm

User Interface Improvements

Several user interface enhancements were also made to the software. Most of the modifications centered around either enhancing the usability of the software or streamlining its appearance. Modifications were made to the top level menu screen, the site setup screen, the template creation screen (as previously mentioned), the data collection screen and the view & analyze screen.

Several modifications were made to the top level menu screen. The layout of the menu was rearranged to follow the site inspection scenario; "Site Setup", "Create Templates", "Collect Data" and "View & Analyze", in that order. The name of the currently selected site was also added to the program title bar. An "About" menu item was added to the system menu. This displays a dialog with the current software version, the current DSA version and the names and company logos of the institutions responsible for the development and production of the system. This about dialog is also displayed as the program splash screen when the program first starts.

The site setup interface was changed significantly. The site creation procedure is still the same. However, the site editing and site selecting functions were integrated into one dialog box, as shown in Figure 8. The previous interface used three dialogs. This proved to be very confusing for the operator. Therefore, all functionality was maintained while simplifying the data entry procedure for the user.

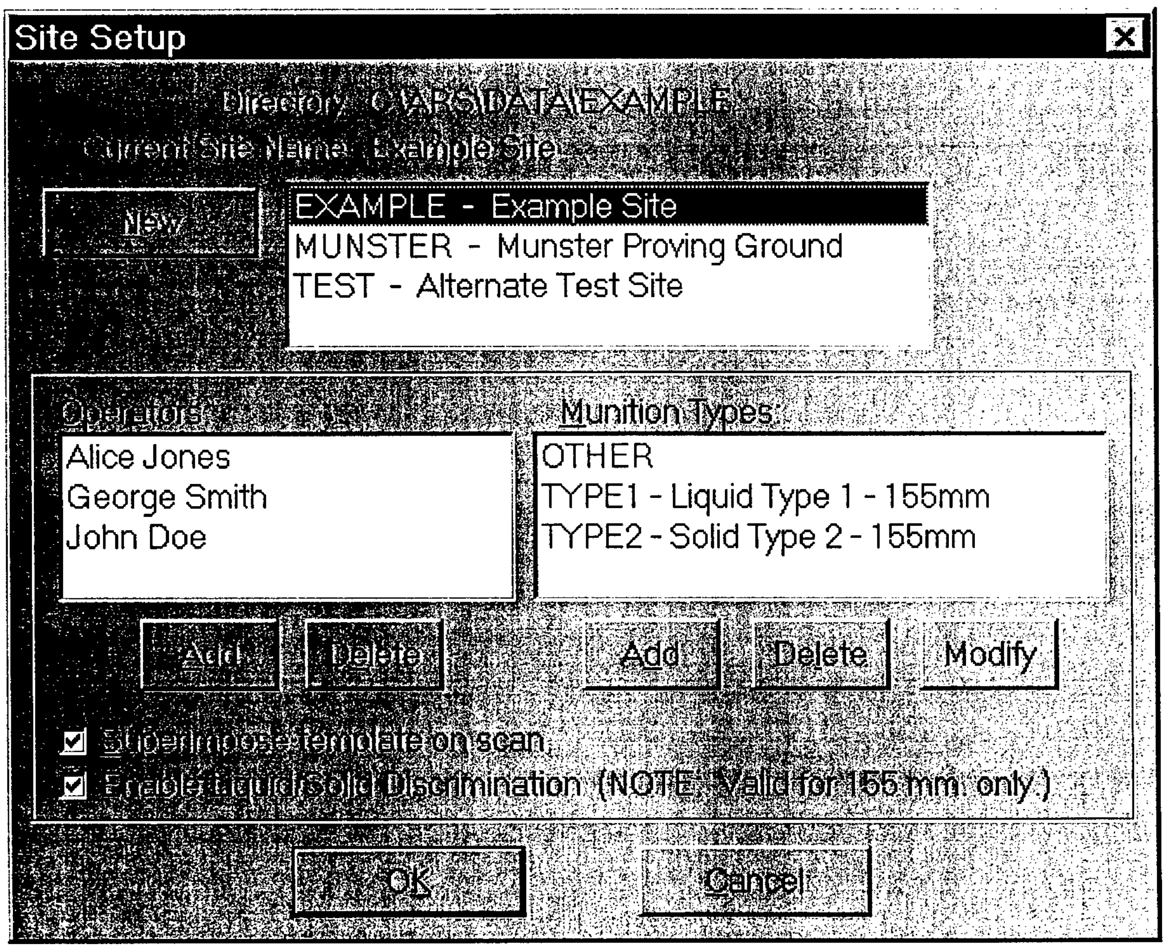

Figure 8. Site Setup Dialog Box

The data collection screen was modified only slightly. A warning dialog box is displayed if the magnitude of the spectral signal returned from the DSA is less than a preset threshold. Since the program autoscales the spectral graph displayed from the data returned from the DSA, it is sometimes difficult to determine if the data is valid. This warning attempts to warn the user if the program determines that the returned signal is not of sufficient strength. Several interlocks were added to the save routine. The first interlock simply disables the save button there is no valid scan to save, and re-enables it when there is a valid scan to save. The second interlock helps to prevent the user from inadvertently saving a scan file into the wrong directory. This is accomplished by comparing the evaluation of the current file to the currently selected munition. If they do not match, a dialog box is displayed with a warning stating this fact. The dialog contains three buttons and a check box. The checkbox is a "Don't warn me again" checkbox which disables the warning dialog box until the program is reopened. The three buttons are on OK button, which accepts the warning and saves the file anyway, a CANCEL button which cancels the save operation, and a COMMENT button, which brings up the comment entry dialog box prefilled with the comment "This file was not evaluated to match its current type".

The ability to generate a report of all measurements was added to the view and analyze section of the program. This is accomplished with a checkbox in the "Load" dialog box. When this checkbox is checked, all of the scans for the current munition will be evaluated against all templates, and the liquid / solid fill will be determined. This information is written to an ASCII text file, then automatically loaded into Windows Notepad.

Discussion

Many improvements have been made to the ARS-MCS software to increase its usability. However, the current code base seems to be nearing the end of its life. The entire program could stand to be rewritten to take advantage of many standard Windows components and other improvements. Additionally, support for Win32s should be dropped, with a complete migration to Windows 95 implemented. Windows 95 has greatly enhanced user interface, resource handling and communications abilities that would simplify program maintenance and increase the system's speed, reliability and efficiency.

References

[1] Roberts, R. and A. Davis, "Template Quality in the ARS Munition Classification System", LA-UR-96-4604, August, 1996

Appendix C

Template Quality in the ARS Munition Classification System

Template Quality in the ARS Munition Classification System

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Abstract

Acoustic Resonant Spectroscopy (ARS) has been successfully used for the noninvasive classification of chemical munitions. Classification is performed by comparing spectral features of unknown munitions to templates created from spectral features of known munitions. Template quality is central to the ARS munition classification technique. This report describes an investigation into several aspects of template quality. It begins by describing template creation and object classification. Next, results are presented from a study on the performance of templates in classifying munitions. Finally, a new template creation algorithm is proposed that can potentially produce high quality templates using a minimum number of measurements.

1.0 Overview

The application of Acoustic Resonance Spectroscopy (ARS) to the noninvasive classification of chemical munitions is an area of active research (see references [1]-[6]). The technique consists of measuring the acoustic resonant spectrum of an unknown munition, extracting features from the spectrum, and comparing the extracted features with templates in a template library [3], [4]. The unknown munition is classified as the type of munition associated with the closest matching template. A key component of the classification system is the templates used to perform the classification. Templates are created from features extracted from the acoustic spectra of known munitions. These features are grouped into clusters, and the clusters are combined to form templates. Although the ARS munition classification technique has proven quite successful, there remain fundamental questions concerning the classification algorithms.

The ARS munition classification technique has been implemented in a portable inspection instrument, referred to here as the ARS Munition Classification System (ARS-MCS). In field use of the ARS-MCS, it is occasionally noted that templates may produce results less accurate than the normal performance. The general solution to this problem has been to use more measurements when creating the templates. This solution results in a longer algorithm training time, and can still produce poor templates. To add to the problem, there was no easy way to identify a poor template. A significant improvement to the ARS-MCS would be to detect poor templates as they are created, and suggest corrective action to the operator.

This report addresses the issue of template quality in the ARS-MCS. Specifically, questions involving the quality of a template, and the number of measurements required to create a high quality template are addressed. The report begins by describing the template creation and object classification algorithms. (Feature extraction has been reported elsewhere and will not be repeated here [3], [4].) Although the template creation and object classification algorithms have been described elsewhere (see [3] and [4] for example), the description presented here is much more detailed. In addition, a new approach to feature clustering is described. The results of a study on the number of measurements required to create high quality templates is presented next. This study is based on measured spectra collected at the Tooele Army Depot in December, 1994 [2]. A new template creation algorithm, based on the results of the template quality study, is proposed. Results of applying the proposed template creation algorithm to the Tooele data set is presented. Finally, ramifications of incorporating the proposed template creation algorithm into the ARS-MCS are discussed.

2.0 Template Creation and Object Classification

Consider a set of feature measurements from a class of similar objects, and let the i^{th} feature measurement be denoted as X_i. The feature measurement is modeled as a sequence of impulses so that the *features* in measurement X_i are represented by the *locations* of the impulses f_{ij}:

$$X_i = \sum_{j=0}^{N_i - 1} \delta(f - f_{ij}). \qquad \text{(EQ 1)}$$

To generalize the feature model (and thereby allow the model to reflect a large number of physical situations), allow that:

1. The number of features in different measurements need not be identical, i.e., it is not required that $N_i = N_j$ for $i \neq j$.
2. The locations of features in different measurements are not identical, but vary randomly about common points in the feature space.
3. Features might be missing from some measurements.

Using this model, feature measurements consist of impulses spread over the feature space. The features in an ensemble of N feature measurements can be written as

$$
\begin{aligned}
X(f, i) &= \sum_{i=0}^{N-1} X_i \\
&= \sum_{i=0}^{N-1} \sum_{j=0}^{N_i-1} \delta(f - f_{ij})
\end{aligned}
\qquad \text{(EQ 2)}
$$

The ensemble of features $X(f, i)$ is seen to be continuous in feature space parameter f, and discrete in ensemble index i.

Features f_{ij} in $X(f, i)$, when viewed along lines of constant f over all i, form localized groupings, or clusters, around common locations in the feature space. Indeed, these clusters are presumed to distinguish measurements associated with one class of objects from measurements associated with other classes of objects. (This underlying assumption forms the basis of the pattern classification technique described here.) The commonality of features amongst the measurements X_i is described by a template T. A template is a function that characterizes the locations of feature clusters and the degree of spread of features within the clusters. Each cluster in the template is represented by a unity amplitude pulse and has two parameters: the cluster location, and the cluster width. A template is thus expressed as:

$$
T(f) = \sum_k a_{\Delta f_k}(f - f_k) \qquad \text{(EQ 3)}
$$

where the k^{th} cluster is centered at f_k with width Δf_k. The unity amplitude pulse $a_{\Delta f_k}$ in (EQ 3) is defined as

$$
a_{\Delta f_k}(f) = \begin{cases} 1 & -\Delta f_k/2 \le f \le \Delta f_k/2 \\ 0 & \text{elsewhere} \end{cases} \qquad \text{(EQ 4)}
$$

Templates quantify the similarities between features in the measurements. They are central to the pattern classification technique described here.

Template creation consists of finding clusters of features (in f) in the ensemble of feature measurements $X(f, i)$, and then selecting those clusters that meet acceptability criteria. In the ARS-MCS, two acceptance criteria are used: for localized selection, choose the minimum variance cluster; for global selection, choose a set of clusters with minimal variances. The first criterion is used to distinguish clusters in a localized region. A set of data often generates many potential clusters, and hence, a criterion is required for choosing between clusters. A reasonable criterion for selecting clusters is that of minimum variance: given two clusters C_1 and C_2, select the cluster with the smaller variance $\min(\text{var}\{C_1\}, \text{var}\{C_2\})$, where the variance estimate is over the feature space parameter f. Using the minimum variance criterion, the cluster parameters that we seek, namely cluster location and cluster width, are apparent. The cluster location is the mean value of the features in the grouping, and the cluster width is the variance of the features in the grouping. The second criterion provides for cluster selection in a global sense. Even though the minimum variance criterion provides a means of choosing between two localized clusters, it is not evident that the rejected cluster is globally unacceptable. Over all possible clusters in the ensemble of features, it might be acceptable. Thus, in addition to the minimum variance criterion, a threshold on cluster variance is required to ensure globally minimal variance clusters. In the ARS munition classification technique, the cluster variance threshold was determined through an empirical study. As a result of that study, the ARS munition classification algorithm accepts, at the most, the one hundred clusters with the smallest variances. Experience with the ARS-MCS indicates that on the order of seventy clusters are typically formed during template creation.

One approach to finding minimum variance clusters is to form all possible combinations of features (one feature per measurement per combination of features), estimate the variance of all combinations, and accept those combinations with variances below the cluster variance threshold. This approach, while conceptually simple, has a major drawback. The number of combinations of features is the product of the number of features in each measurement: $N_1 N_2 \ldots N_N$. An exhaustive search for minimum variance clusters can easily become computationally intensive even for moderate values of N and N_i. Moreover, this approach is computationally inefficient, as features that are widely separated are considered as viable clusters. A practical approach to generating clusters is described next.

2.1 Window-based Data Clustering

One approach that reduces the computational complexity of an exhaustive search is to window the data in feature space, and form clusters from those features within the window. After the clusters are formed, the window is shifted and the clustering process repeated. Several design issues emerge when window-based approaches to feature clustering are considered. Foremost amongst the design issues is window size. If the window size is chosen too large, the computational advantages of window-based clustering disappear. If the window size is chosen too small, too few features are present within the window to warrant a cluster. Ideally, the window size is selected so that only one cluster is present within the window. Unfortunately, this condition is difficult to achieve in practice. A second design consideration is the distance the window is shifted after a cluster has been formed. The window shift can be as great as the window width, but then features that fall on the window's edge might not be included in a cluster. Too small of a window shift might not introduce enough new features into the window to warrant a new cluster.

The window size and window shift in the ARS munition classification application were determined through a series of empirical studies. For ARS munition data, the study revealed that the window size should be large enough so that, on the average, two to three features per measurement are within the window. It was found that such a window size tends to produce one cluster per window, so the clustering algorithm was designed to find the minimum variance cluster within the window. The study also showed that a window shift equal to one-tenth the window size produces an acceptable compromise between missing clusters and not acquiring enough data to form new clusters. With these guidelines for window size and window shift in place, three problems were observed in feature clustering. The problems are listed below:

Problem 1: Say that a cluster is formed in a window that contains many features, and that the next increment of the window does not add any new features. Since a new cluster is formed on each shift of the window, a new cluster will be formed with the remaining features. Depending on the arrangement of features, it is possible for the new cluster to straddle the old cluster. To prevent this occurrence, discard all features in the window after the cluster is formed.

Problem 2: Consider that the leading edge of the window bisects a group of features that constitute a cluster. Say that due to the bisection, not enough features are present in the window to form a cluster, and that the features are discarded as recommended in Problem 1. As a result, a viable cluster is eliminated. To prevent this occurrence, features between the leading edge of the window and the leading edge of the cluster need to be retained. Features behind the leading edge of the cluster can be discarded without harm.

Problem 3: Say that a minimum variance cluster is formed within the window, but that the cluster is not acceptable due to a globally large variance. Say that the reason for the large variance is the inclusion of features near the leading edge of the window into the cluster. These features, even though they were used to build the present cluster, might be better used in the cluster built in the next window. However, these features will be eliminated as a solution to Problem 2. To prevent this occurrence, allow the features to be available for a cluster in the next window. The fact that they are used in two clusters is not a problem. The cluster with the larger variance will be eliminated by the cluster variance threshold.

Problems 1 through 3 can be mitigated by incorporating a unit step function into the feature windowing operation. The step function is positioned so that the transition of the step function occurs at the center of the last cluster. The step function thus divides the feature space into features that have been used for clustering, and those that have not. The details of the windowing operation are presented next.

Consider a unity height window $a_{\Delta w}(f)$ of width Δw. Recall that the window is defined as:

$$a_{\Delta w}(f) = \begin{cases} 1 & -\Delta w/2 \le f \le \Delta w/2 \\ 0 & \text{elsewhere} \end{cases} \quad \text{(EQ 5)}$$

In the munition classification application, the width of the window is based on the maximum and minimum locations of the features. Thus,

$$\Delta w = \frac{\max_{i,j}(f_{ij}) - \min_{i,j}(f_{ij})}{W_f} \quad \text{(EQ 6)}$$

where W_f is the fractional span of the window. In the munition classification application, this value is set to $W_f = 150$. Next, consider a step function $u(f)$ defined by

$$u(f) = \begin{cases} 1 & f \geq 0 \\ 0 & f < 0 \end{cases} \quad \text{(EQ 7)}$$

As noted above, the step function is used to mitigate Problems 1 through 3. The window and step function are applied to $X(f, i)$ thereby producing a subset of localized features. Call the new subset of features $G(f, i)$, where $G(f, i)$ is given by

$$G(f, i) = a_{\Delta w}(f - f_0 - n\Delta w W_i)u(f - f'_k)X(f, i) \quad \text{(EQ 8)}$$

The window parameter in the above equation, W_i, is a window shift increment, and is set to 0.1 in the munition classification application. The parameter f_0 in the window is an offset factor, and is given by $f_0 = \min_{i,j}(f_{ij}) + \Delta w$. The factor f'_k in the unit step function is the mean value of the most recently created cluster. It is given as $f'_k = \max(f_k)$.

The objective of the window is to select impulses from the measurements over a restricted region. On each window shift a new $G(f, i)$ is formed. Before clusters are formed from the features in $G(f, i)$, a certain inclusivity criterion must be met. We require that most of the measurements (but not necessarily all) provide at most one feature per cluster. If enough measurements contribute features to $G(f, i)$, clustering proceeds. If not, the clustering operation is abandoned and the window is shifted. Define an indicator function $I(i)$

$$I(i) = \begin{cases} 1 & \text{if} \quad \int_{-\infty}^{\infty} G(f, i)df > 0 \\ 0 & \text{elsewhere} \end{cases} \quad \text{(EQ 9)}$$

The integral in the indicator function simply counts the number of impulses (features) in the i^{th} measurement within the region of support of $G(f, i)$. If this number is nonzero, the indicator function is unity, else it is zero. Let N' be the number of measurements that contribute features to $G(f, i)$ so that

$$N' = \sum_i I(i) \quad \text{(EQ 10)}$$

Form the ratio of the number of measurements contributing features to the total number of measurements, N'/N. If the inequality $N'/N \leq I_f$, where I_f is an inclusivity factor, holds, then clustering proceeds with the features in $G(f, i)$. If not, the window is shifted to the next position, and the inclusivity criterion is again applied. The inclusivity factor for the ARS munition classification application is $I_f = 0.8$.

Once the data has been partitioned by the windowing functions and the inclusivity criterion has been met, the mean and variance of the minimum variance cluster in $G(f, i)$ is found. Put another way, we seek the value f_k that minimizes the squared distance between f_k and the f_{ij}, at most one j for every i containing features (i.e., at most one feature from every measurement containing features). This value can be expressed as

$$f_k = \min_f \left[\sum_i \min_j (f - f_{ij})^2\right] \quad \text{(EQ 11)}$$

where the summation index is over all measurements that contain at least one feature. The spread of the features about the mean is then

$$\Delta f_k = \frac{1}{N'}\sum_i \min_j (f_k - f_{ij})^2 \quad \text{(EQ 12)}$$

where N' is the number of measurements that contain features. Two approaches for computing f_k and Δf_k are described next. Both approaches exhaustively search for the minimum variance cluster in $G(f, i)$. One approach recursively generates and tests sets of clusters, while the other vectorizes the features in $G(f, i)$ and searches for minimums. We begin with the recursive approach since it is used in the ARS-MCS. The second approach is well suited for implementations with matrix-based systems such as Matlab.

2.1.1 Recursive approach to data clustering [1]

The method used in the ARS-MCS to locate and parameterize clusters recursively searches feature sets in $G(f, i)$ to find the cluster with minimum variance. Feature indices for the recursive search are generated by a ripple counter where each register in the ripple counter has been generalized to perform a modulo addition on its contents and the incoming carry. The operation of the generalized ripple counter is described next, followed by the cluster generation algorithm used in the ARS-MCS.

Consider a ripple counter consisting of N registers (stages) where each register is associated with an arbitrary base. Denote the contents of the counter as $A = [a_1 a_2 \ldots a_N]$

1. For clarity of presentation, allow that the number of measurements contributing features is equal to the total number of measurements, i.e., $N' = N$. Extensions to the case where $N' \neq N$ are obvious: simply discard the non-contributing measurement(s) and reindex the remaining measurements. For clarity of notation, let $f_{ij} \rightarrow f_{i,j}$.

where the a_i are integers and $a_i \geq 0$, and the associated bases of the counter as $\boldsymbol{B} = [b_1 b_2 \ldots b_N]$ where the b_i are integers and $b_i > 0$. The counter is represented symbolically by:

$$\left|[a_1]_{b_1}\right|[a_2]_{b_2}\left|[a_3]_{b_3}\right| \cdots \left|[a_N]_{b_N}\right| \qquad \text{(EQ 13)}$$

Each register in the counter accepts the carry generated by its neighbor to the right, performs a modular addition of the carry to its contents, and propagates the generated carry to the neighbor on its left. The modular addition base b of a register's contents, a and the input carry, c, is given by

$$[a+c]_b = a - \left\lfloor \frac{a+c}{b} \right\rfloor b \qquad \text{(EQ 14)}$$

Carries are generated by a register whenever $a + c = nb$, where n is an integer. In this case the carry generated by the addition is n.

In order to use the generalized ripple counter to find minimum variance clusters, it is necessary to first find an index offset vector. The index offset vector is used to reindex the indices of features in $G(f, i)$ so that the index of the first feature of each measurement in $G(f, i)$ is zero. Thus, if the first feature in each measurement in $G(f, i)$ is $[f_{\theta_1, 1} f_{\theta_2, 2} f_{\theta_3, 3} \cdots f_{\theta_N, N}]$, then the index offset vector is given by $\theta = [\theta_1 \theta_2 \theta_3 \ldots \theta_N]$. The following steps are used by the generalized ripple counter to find the attributes of the minimum variance cluster:

Step 0: Initialize the process by determining the index offset vector θ, initializing an N register generalized ripple counter to $\boldsymbol{A} = [0, 0, \ldots 0]$, and loading the counter base vector with the number of features in each measurement $\boldsymbol{B} = [n_1 n_2 n_3 \ldots n_N]$. Set the initial variance to $\mathrm{var}\{F_{-1}\} = 10^{10}$, or some other large number.

Step 1: Form the index vector $\alpha = \theta + \boldsymbol{A}$, and associated feature vector $\boldsymbol{F} = [f_{\alpha_1, 1} f_{\alpha_2, 2} f_{\alpha_3, 3} \cdots f_{\alpha_N, N}]$.

Step 2: Compute $\mathrm{var}\{\boldsymbol{F}_i\}$. If $\mathrm{var}\{\boldsymbol{F}_i\} < \mathrm{var}\{\boldsymbol{F}_{i-1}\}$, set $\Delta f_k = \mathrm{var}\{\boldsymbol{F}_i\}$ and $f_k = \mathrm{mean}\{\boldsymbol{F}_i\}$.

Step 3: Increment the generalized ripple counter by one:

$$\left|[a_1]_{b_1}\right|[a_2]_{b_2}\left|[a_3]_{b_3}\right| \cdots \left|[a_N]_{b_N}\right| \leftarrow 1 \qquad \text{(EQ 15)}$$

Step 4: When $\boldsymbol{A} = [0, 0, \ldots 0]$, stop. Else, repeat **Step 1**.

As previously mentioned, this approach is used to find the clusters in the ARS Munition Classification System.

2.1.2 Vector approach to data clustering[1]

Consider a matrix $\boldsymbol{G}$ where the rows of the matrix list all possible combinations of the features contained within $G(f, i)$. Since there are N measurements in $G(f, i)$, there will be N columns in $\boldsymbol{G}$. If there are n_i features in the i^{th} measurement of $G(f, i)$, then there are $M = n_1 n_2 \ldots n_N$ possible combinations of features. Thus, $\boldsymbol{G}$ will contain M rows. Form the last column of $\boldsymbol{G}$ thus:

$$g_N = [g'_N \; g'_N \; \ldots \; g'_N]^T \quad \text{(EQ 16)}$$

where $g'_N = [f_{N,1} f_{N,2} \ldots f_{N,n_N}]$, and is repeated M/n_N times. (Note that the prime symbol in g'_N does not imply transposition, but rather that g'_N is a constituent element of g_N. The symbol T as a superscript is used to denote transposition.) The $(N-1)^{th}$ column is formed as:

$$g_{N-1} = [g'_{N-1} \; g'_{N-1} \; \ldots g'_{N-1}]^T \quad \text{(EQ 17)}$$

where $g'_{N-1} = [f_{N-1,1} \ldots f_{N-1,2} \ldots f_{N-1,n_{N-1}} \ldots]$ and is repeated $M/(n_N n_{N-1})$ times. (Each element within g'_{N-1} repeated n_N times.) In general, the k^{th} column is formed as:

$$g_k = [g'_k \; g'_k \; \ldots g'_k]^T \quad \text{(EQ 18)}$$

where $g'_k = [f_{k,1} \ldots f_{k,2} \ldots f_{k,n_k} \ldots]$ and is repeated $M/(n_N n_{N-1} \ldots n_k)$ times. (Each element within g'_k repeated $n_N n_{N-1} \ldots n_k$ times.) The feature matrix is formed by combining the columns: $\boldsymbol{G} = [g_1 g_2 \ldots g_N]$.

Now that the feature matrix has been formed, the mean and variance of each row of features is estimated. The mean information is stored in the vector g_m

$$g_m = \text{mean}\{G\} \quad \text{(EQ 19)}$$

and the variance information is stored in the vector g_σ,

1. The same clarifications used in Section 2.1.1 apply here. Likewise, the indices of the features are offset so that the index of the first feature in a measurement starts at unity.

$$g_\sigma = \text{var}\{G\} \qquad \text{(EQ 20)}$$

The width of the cluster is then given as $\Delta f_k = \min(g_\sigma)$, and the center of the cluster is the mean of the features in the row of G associated with Δf_k.

Example: Consider a $G(f, i)$ that consists of $N = 3$ measurements, where the first measurement contains $n_1 = 2$ features $\{f_{11}, f_{12}\}$; the second measurement contains $n_2 = 2$ features $\{f_{21}, f_{22}\}$; and the third measurement contains $n_3 = 3$ features $\{f_{31}, f_{32}, f_{33}\}$. The feature matrix G thus has $N = 3$ columns and $M = 12$ rows. The columns of G are formed as follows. The primed component of the last column of G, namely g'_3, is the set of features from the third measurement:

$$g'_3 = [f_{31} f_{32} f_{33}] \qquad \text{(EQ 21)}$$

The last column of G is formed by repeating g'_3 $M/n_3 = 12/3 = 4$ times:

$$g_3 = [f_{31} f_{32} f_{33} f_{31} f_{32} f_{33} f_{31} f_{32} f_{33} f_{31} f_{32} f_{33}]^T \qquad \text{(EQ 22)}$$

The primed component of the next to last column, g'_2, is formed by repeating each feature $n_3 = 3$ times:

$$g'_2 = [f_{21} f_{21} f_{21} f_{22} f_{22} f_{22}] \qquad \text{(EQ 23)}$$

The next to last column is built by repeating the primed component $M/n_3 n_2 = 12/6 = 2$ times:

$$g_2 = [f_{21} f_{21} f_{21} f_{22} f_{22} f_{22} f_{21} f_{21} f_{21} f_{22} f_{22} f_{22}]^T \qquad \text{(EQ 24)}$$

Finally, the primed component of the first column is found by repeating each feature in the first measurement $n_3 n_2 = 3 \times 2 = 6$ times:

$$g'_1 = [f_{11} f_{11} f_{11} f_{11} f_{11} f_{11} f_{12} f_{12} f_{12} f_{12} f_{12} f_{12}] \qquad \text{(EQ 25)}$$

The primed component of the first column is repeated $M/(n_3 n_2 n_1) = 1$ times so that $g_1 = (g'_1)^T$. Assembling the columns into the feature matrix yields

$$G = \begin{bmatrix} f_{11} f_{11} f_{11} f_{11} f_{11} f_{11} f_{12} f_{12} f_{12} f_{12} f_{12} f_{12} \\ f_{21} f_{21} f_{21} f_{22} f_{22} f_{22} f_{21} f_{21} f_{21} f_{22} f_{22} f_{22} \\ f_{31} f_{32} f_{33} f_{31} f_{32} f_{33} f_{31} f_{32} f_{33} f_{31} f_{32} f_{33} \end{bmatrix}^T \qquad \text{(EQ 26)}$$

At this point, the variance of the features in each row in G is estimated, and the mean of the features in the row with the smallest variance becomes the cluster center.

2.2 Object Classification

Classification of a feature measurement from an unknown object is performed by comparing the unknown pattern against all templates in the system library. Consider an unknown measurement X, where X consists of N features:

$$X = \sum_{j=0}^{N-1} \delta(f - f_j) \qquad \text{(EQ 27)}$$

Say that the template library consists of N_T templates, T_i, $i = 1, 2, \ldots, N_T$. The integral of the product of each template is the library and the unknown measurement is computed:

$$S_i = \int_{-\infty}^{\infty} X(f) T_i(f) df \qquad \text{(EQ 28)}$$

Individual values of S_i, when divided by the number of clusters in the i^{th} template are referred to as the hitratio on a the i^{th} template. The measurement is classified as belonging to the class of objects associated with the template that has the largest hitratio.

In the munition classification application, it was necessary to make minor modifications to the templates used in the classification. Specifically, consider a template modified by dilating the clusters:

$$T(f, \sigma) = \sum_k a_{\sigma \Delta f_k}(f - f_k) \qquad \text{(EQ 29)}$$

and modify (EQ 28) to account for possible shifts in the measurement features

$$S_i(k) = \int_{-\infty}^{\infty} X(f) T_i(f - k, \sigma) df \qquad \text{(EQ 30)}$$

In this approach, the maximum value of $S_i(k)$ is found for each i over several shift values of k. For the munition classification application, the range of the shift value is set to $-3 \le k \le 3$. The template dilation factor is set to $\sigma = 1.6$. The hitratio is defined as previously described, and the measurement is again classified as belonging to the class of objects associated with the template that has the largest hitratio.

3.0 Template construction for munition classification

The pattern classification technique described in Section 2 has been successfully used to classify acoustic resonant spectra from unknown munitions using templates built from acoustic resonant spectra of known munitions. However, fundamental questions arise when applying the technique to munition classification. In particular:

1. How many measurements are required to create a good template?
2. What is meant by a "good" template?

To answer these questions, an investigation into the nature of template creation for the munition classification application was conducted. Before the investigation began, it was necessary to answer the second question regarding a quality criterion. The quality criterion used in this investigation is based on the ability of a template to classify spectra. Specifically, if a template can classify spectra not used to create the template with 90% reliability at 90% confidence, the template is considered a good template.

The investigation began by focusing on sampling strategies. A sampling strategy guides the selection of spectra used to construct a template. Several sampling strategies were considered, and the reliability of templates constructed with these strategies determined. From the sampling study it became apparent that some spectra have a corrosive affect on a template. Introduction of these spectra into the template creation process tends to produce template that are sparsely populated with clusters. Munition classification using sparse templates tends to produce unacceptable results. It is conjectured that by properly identifying spectra that produce sparse templates, and removing those spectra from template creation, good templates can be constructed using a minimum number of measurements. To test this conjecture, an experimental template construction algorithm was developed. Classification results from the experimental algorithm are presented at the end of this section.

Before describing the nature and outcome of the investigation, a description of the measurements used in the investigation is in order. The acoustic resonant spectra used in this investigation were collected in December of 1994 at the Tooele Army Depot. Two primary types of munitions were used: 155 millimeter GB and VX shells. These were broken down into two sets each, for a total of four file sets with 64 files in each set. Within each set, eight munition lots were sampled, for a total of 16 lots of GB and 16 lots of VX.

3.1 Measurement sampling strategies

The selection of files for creating templates plays an important role in the performance of the ARS Munition Classification System. Three sampling strategies were employed for this investigation: sequential sampling, sampling by lots, and random sampling. Six template sets were created using these three methods, and representative results for each sampling method are discussed here.

The simplest sampling method is sequential. In this strategy, the grouping of munitions into lots is irrelevant. Spectra used in template creation are simply selected by increasing file number (e.g., the template created from five spectra contains file numbers 001, 002, 003, 004, and 005.) Since 2 to 48 files were used to create the templates in this study, a maximum of 6 of the 16 lots of GB or VX are represented in the templates. Figure 1a illustrates the percentage reliability (at 90% confidence) as a function of number of files used to construct the template. From Figure 1a, it is evident that this sampling strategy incurs wide swings in reliability, and only approaches a desirable condition in excess of 35 measurements. This result is not surprising, since templates created from larger numbers of files contain spectra from more lots.

The second method selects files from all available lots. This method is currently recommended for the ARS-MCS. In this case there were 8 files in each lot, so every fourth file was selected, two from each lot (e.g., 004, 008, 012, 016.) At 32 files, every lot was represented in the template with two files. An additional file from each lot was selected sequentially up to 48 files in the template, so three of the eight files from each lot were present in the template. This is the sampling strategy used in the Tooele field test in December 1994. (See Figure 1b for the performance of the template used during that field test.) The reliability curve for this sampling strategy does not have the wide swings observed in the sequential strategy. It also rises sharper than the sequential reliability curve, first reaching 90% reliability at 20 files.

Both of the previous methods simply add one file to each template to create the next template, so that every template is created from the same files as the template before, plus one additional file. In the random sampling method, a unique set of random file numbers was generated for each template. The objective was to randomly select files for template creation from all lots. Figure 1c illustrates a typical outcome of this sampling strategy. The reliability curve for this approach is reminiscent of the reliability curve for sampling by lot.

In summary, the resulting plots indicate that 90% reliability at 90% confidence (90/90) was reached after 20 to 32 spectra per template were used, depending on the sampling technique. When files were sampled from all of the available lots, as in Figure 1b and Figure 1c, the general trend toward the 90/90 goal was steeper. However, the problem of poor results intermixed with good results is apparent in these graphs. Even after the 90/90 goal is reached, a file may be introduced which causes an invalid template to be produced, and the overall reliability dramatically reduced until more files were added. Although single files appear to cause the invalid templates, the probability of generating an invalid template is reduced when more files are used. To satisfy the goal of efficiently producing quality templates, some characteristic of the invalid templates had to be identified.

3.2 Identification of sparse templates

Insight into the reliability curves generated from the sampling strategies can be obtained by plotting the sequence of templates used to perform the classification. Figure 2a and 2b illustrate the first sixteen templates used in the sequential sampling and sample by lot cases. The templates are plotted over the frequency range of 0 to 30 kHz, and each bar in a template represents a cluster. In the ARS-MCS, templates are limited to 100 such clusters,

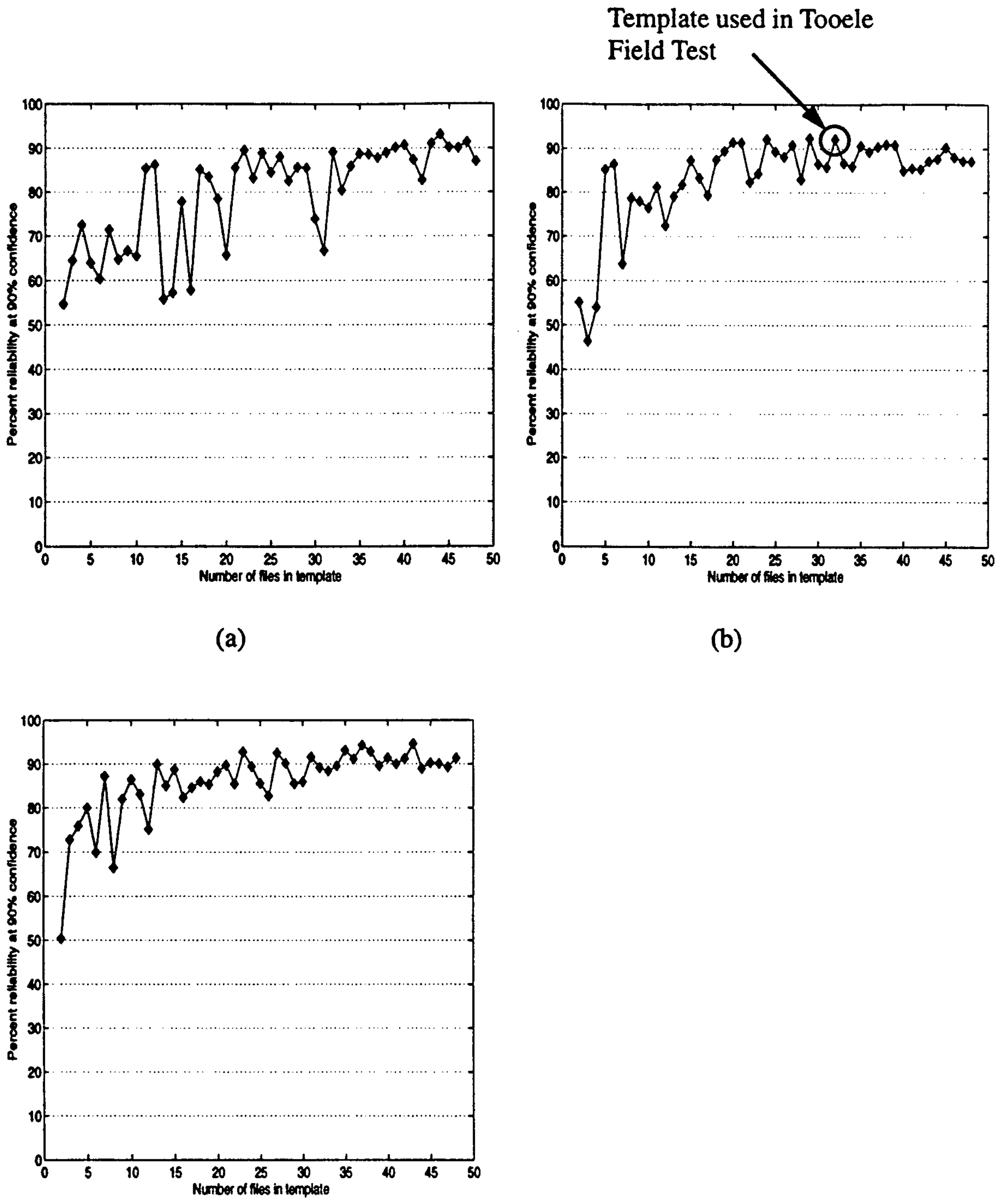


Figure 1: Percent reliability at 90% confidence as a function of number of files used to create a template. Results from three sampling strategies are illustrated (a) sequential sampling, (b) sampling by lot, and (c) random sampling over all lots.

but may have fewer. The most prominent feature of the poorly performing template pairs was that one (or both) of them had very few clusters. Such templates are referred to as "sparse" templates, and the introduction of particular spectra can cause them to appear, regardless of the order in which the spectra are added. The correlation between sparse templates and poor performance is illustrated in Figures 3a through 3c, where reliability figures generated with templates having fewer than 40 clusters are marked in red.

While not every poorly performing template pair included a sparse template, the removal of files producing sparse templates would certainly produce templates with a much greater probability of high reliability. At a minimum, the goal of template quality could be largely met simply by alerting the user when a sparse template was created. Optimally, however, the system could guide a user through the template creation process and, with the addition of each file, decide if that file is fit for the template or not.

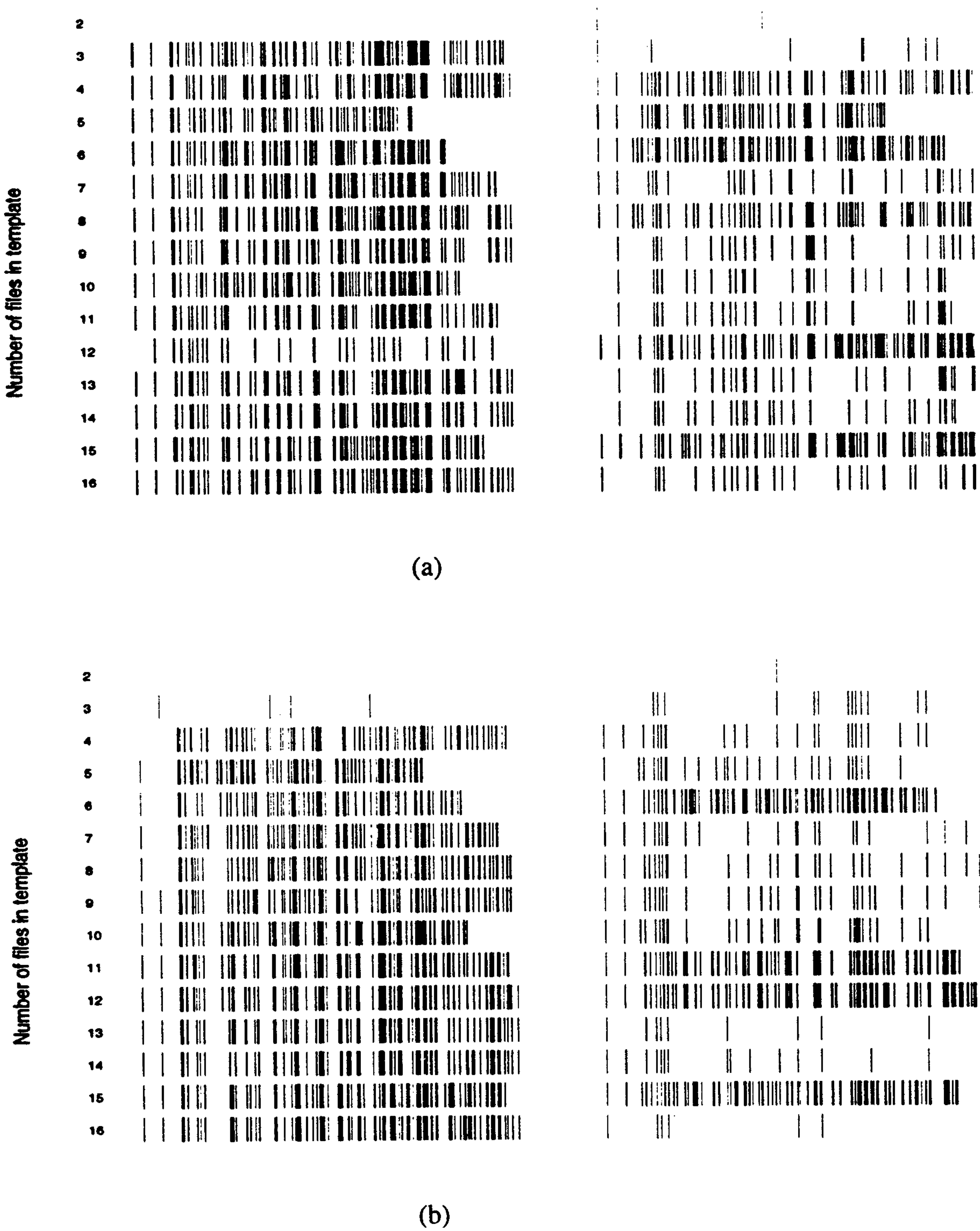
3.3 A new template creation algorithm

The present method for creating templates is a batch process—a group of spectra is processed together to form a template. Unfortunately, the only way to detect a file that causes a sparse template is to create a template without the file and verify that by adding the file, the template changes from full to sparse. As an experiment, a new template creation algorithm was developed. The new algorithm compares templates before and after a new measurement is added to the template set. The disadvantage of this method is the time required to create the templates. For example, if 32 files are used to create a template, a minimum of 31 templates must be created before the final template.

Two measurements of template files were developed to aid in the template creation process: cluster count and correlation. These two measurements were used together to create a prototype algorithm for filtering the files used for template creation. The cluster count measurement is simply the total number of clusters in the template and is the primary indicator of sparse templates. A zero-lag cross-correlation is used to measure how different two templates are from each other. It is defined as

$$R_{TU}(0) = \frac{\int_{-\infty}^{\infty} T(f)U(f)df}{\int_{-\infty}^{\infty} T(f)df \int_{-\infty}^{\infty} U(f)df} \qquad \text{(EQ 31)}$$

where the zero-shift cross-correlation is calculated between templates T and U. If the templates are identical, the cross-correlation is unity; if there are no common clusters between the two templates, the cross-correlation would be zero. The correlation between the n^{th} template and the $(n-1)^{th}$ template in a series is a measurement of how quickly the templates are changing in the series, a potentially useful tool to determine when sufficient files have been used to create a template.



(a)

(b)

Figure 2: Illustration of sparse templates. The red templates (on the left) were produced from GB munitions, while the blue templates were produced from VX munitions. Two sampling strategies are shown (a) sequential sampling, and (b) sampling by lot.

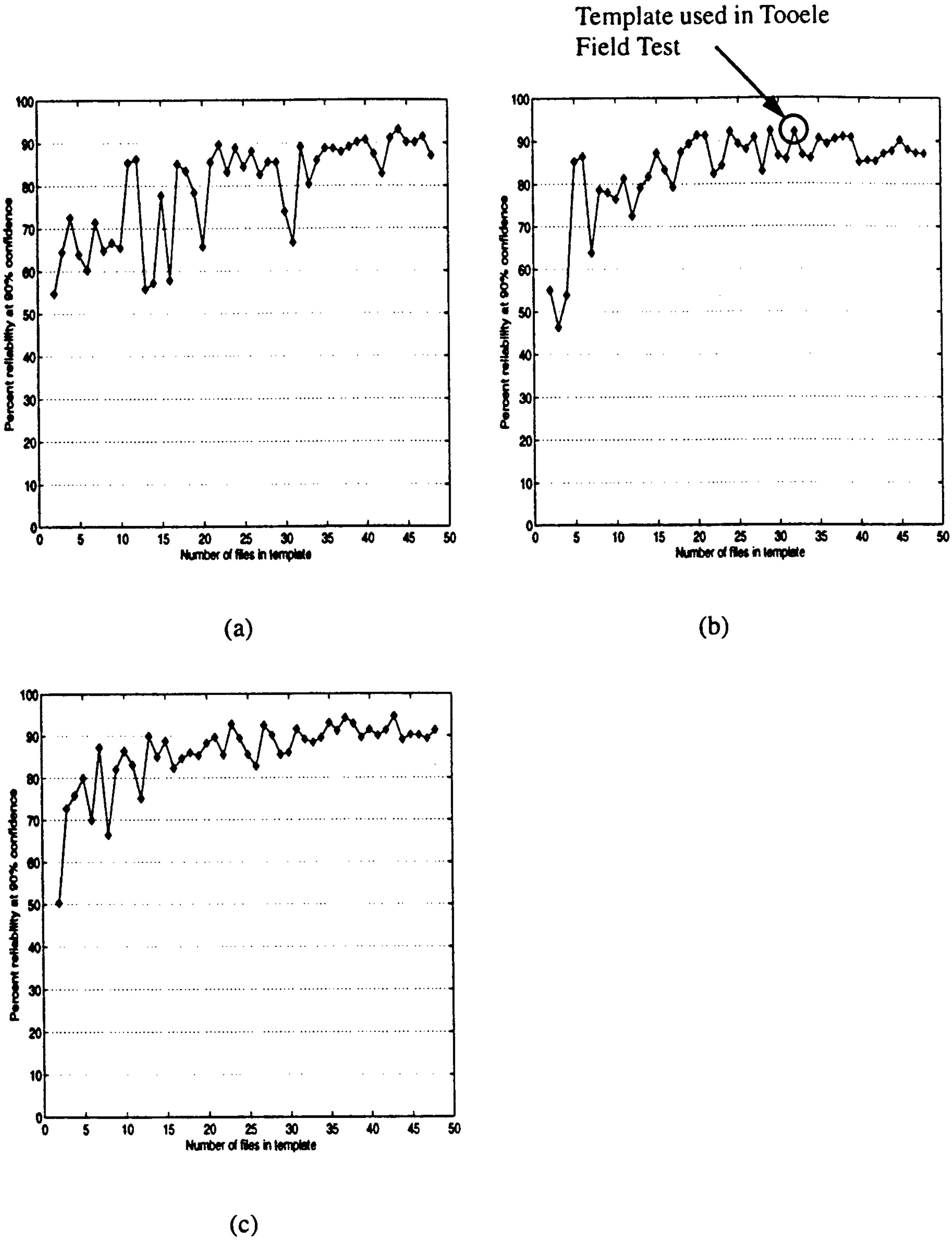


Figure 3: Percent reliability at 90% confidence as a function of number of files used to create a template. Results from three sampling strategies are illustrated (a) sequential sampling, (b) sampling by lot, and (c) random sampling over all lots. The blue markers indicate full templates while the red markers indicate sparse templates.

The prototype algorithm used for this experiment follows:

Step 0: Start with the first two files in the template set and create a template.

Step 1: Add the next file to the template set and create the template.

Step 2: If the correlation between the n^{th} template and the $(n-1)^{th}$ template is undefined (one of the templates has zero bandwidth in the clusters), keep the n^{th} data file in the template and go to Step 2. (This case happens for the first three or four templates.)

Step 3: Although not implemented in this experiment, if the correlation is sufficiently high (around 0.90), the template creation process could be concluded as long as all the munition lots had been sampled.

Step 4: If the number of clusters in the n^{th} template is less than 66% of the number in the $(n-1)^{th}$ template, the template is sparse; throw out the n^{th} file as well as the n^{th} template.

Step 5: Continue at Step 1.

This algorithm was applied to the GB and VX data sets. The files were selected by first selecting the first file from each munition lot. If a file created a sparse template, the file was removed and another file from the same lot was substituted. When all 16 lots were represented, the 17th file was taken from the first lot, and the process was repeated up to 48 files in both GB and VX. The results were evaluated and plotted in the same manner as the previous data sets, with reliability at 90% confidence as a function of the number of files in the templates. As Figure 4 shows, the 90/90 goal was reached after only 6 files were used in the templates, and only 12 of the 47 template pairs resulted in reliabilities less than 90%. Further, only the first two template pairs were below 85% reliability. After the running average of the cross-correlation rose above 90%, no templates were produced which fell below the 90/90 goal. Unfortunately, no further conclusions can be made about this process without additional tests on different data sets.

3.4 Comments on the template creation algorithm

Implementing the template metric discussed here requires a major redesign of the ARS software user interface to be useful. Instead of collecting data, creating the template, and then returning to collect the rest of the data, the system might integrate these activities into a single step, where the user would take data, and after each scan, a new template would be built and evaluated automatically. Using the correlation number, the system could then decide when enough data files have been processed to create a valid template. As the user continued to create data files, the system would begin to classify the incoming data. This solves two major problems of the current system, the most major being the creation of invalid templates, the second being the uncertainty about how many files are required to

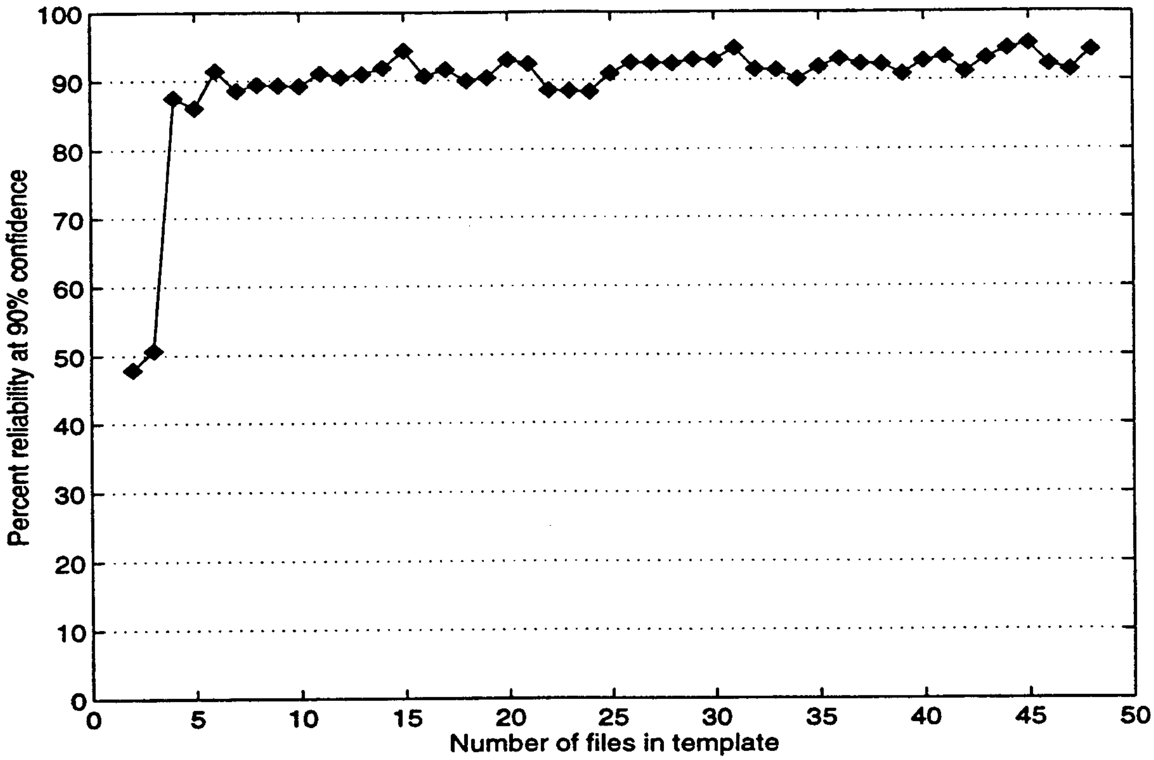


Figure 4: Percent reliability at 90% confidence as a function of number of files used to create a template for the proposed template creation algorithm.

make a good (not simply adequate) template. Streamlining the interface could reduce training times and decrease the likelihood of user error.

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