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EVALUATION OF THE ORDNANCE DETECTION EXPERT SUPPORT APPLICATION (ODESA)

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DEPARTMENT OF THE ARMY
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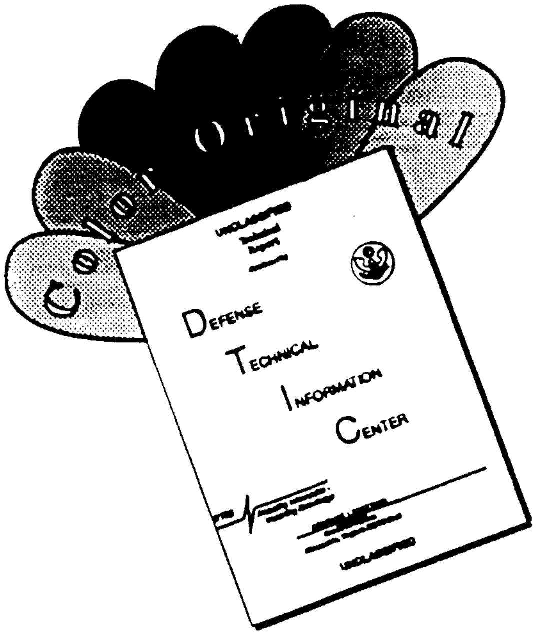

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13. ABSTRACT (Maximum 200 words)

THE ORDNANCE DETECTION EXPERT SUPPORT APPLICATION (ODESA) IS A PROJECT UNDER THE UNEXPLODED ORDNANCE (UXO) CLEARANCE TECHNOLOGY PROGRAM SPONSORED BY THE U.S. ARMY ENVIRONMENTAL CENTER AND MANAGED BY THE NAVAL EXPLOSIVE ORDNANCE DISPOSAL TECHNOLOGY DIVISION. ODESA WAS DEVELOPED TO ADDRESS THE GOVERNMENT'S NEED FOR RELIABLE AND COST-EFFECTIVE UXO CLEARANCE TECHNOLOGY. THIS NEED HAS BECOME A PRIORITY WITHIN THE DEPARTMENT OF DEFENSE BECAUSE OF MILITARY DOWNSIZING, REDUCTIONS AND BASE CONSOLIDATIONS; AND THE NEED TO CLOSE, CLEAN-UP AND RETURN TO THE PUBLIC MILITARY BASES AND RANGES.

ODESA IS A PROTOTYPE DATA FUSION SYSTEM THAT UTILIZES GENETIC ALGORITHMS AND A HEURISTIC RULE BASE TO PROVIDE A MORE ACCURATE AND RELIABLE ACCOUNTING OF THE LOCATION AND IDENTIFICATION OF BURIED UXO. ODESA HAS BEEN DEMONSTRATED TO REDUCE THE AMOUNT OF FALSE ALARMS EXPERIENCED DUE TO SINGLE SENSOR SYSTEMS BY FUSING TOGETHER DATA FROM MULTIPLE SENSORS. SEVERAL PROJECTS UNDER THE UXO CLEARANCE TECHNOLOGY PROGRAM FOCUS ON THE DEMONSTRATION OF ORDNANCE DETECTION TECHNOLOGY. THE OUTPUT DATA PROVIDED BY THESE SENSOR DEMONSTRATION PROJECTS, IN COMBINATION WITH SITE-SPECIFIC INFORMATION ARE FUSED TOGETHER BY ODESA TO PROVIDE A BETTER UNDERSTANDING OF THE LOCATION AND IDENTIFICATION OF BURIED UXO.

THIS REPORT WAS GENERATED TO: (1) DOCUMENT THE WORK PERFORMED UNDER THE ODESA EFFORT, (2) EVALUATE THE PROGRESS AND FEASIBILITY OF ODESA AGAINST OTHER DATA FUSION, KNOWLEDGE BASED AND EXPERT SYSTEMS, AND (3) PROVIDE A TOOL TO U.S. ARMY ENVIRONMENTAL CENTER DECISION MAKERS FOR DETERMINING WHETHER THE USE OF ARTIFICIAL INTELLIGENCE IS FEASIBLE FOR THE DETECTION, IDENTIFICATION AND REMEDIATION OF BURIED UXO.

THIS REPORT EXPLAINS ALL THREE PHASES OF THE ODESA PROJECT, FROM DESIGN STUDIES TO FABRICATION AND TESTING/DEMONSTRATION OF A PROTOTYPE. IT ALSO PRESENTS THE RESULTS OF THE ODESA EVALUATION AND RECOMMENDATIONS FOR FUTURE WORK

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FINAL REPORT

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EXECUTIVE SUMMARY

The Ordnance Detection Expert Support Application (ODESA) is a prototype data fusion system that utilizes genetic algorithms and a heuristic rule base to provide a more accurate and reliable accounting of the location and identification of buried unexploded ordnance (UXO). ODESA is a component of the Unexploded Ordnance Clearance Technology Program (UXO-CTP) sponsored by the U. S. Army Environmental Center and managed by the Naval Explosive Ordnance Disposal Technology Division (NAVEODTECHDIV) located in Indian Head, Maryland. ODESA was developed to address the Government's need for reliable and cost-effective UXO Clearance Technology. This need has become a priority within the Department of Defense (DOD) because of military downsizing, reductions, and consolidations; and the need to close, clean-up and return to the public military bases and ranges. Several projects performed under UXO-CTP center around the demonstration of ordnance detection sensor technology. The output data provided by sensors, in combination with site specific and environmental information, will be fused together by ODESA to provide a better understanding of the location and identification of buried ordnance.

The ODESA Project was started as a multi-phase effort to provide a fusion mechanism for sensor, location, environmental and site specific information. This data fusion process is intended to enhance the effectiveness of a single sensor system in the location, identification and classification of buried unexploded ordnance. As a result, the most efficient and cost effective remediation mechanism can be determined for each survey site. The goals of the ODESA Project are to develop a knowledge based expert system that utilizes state-of-the-art data fusion techniques such as neural networks and fuzzy logic to address the buried UXO problem. ODESA processing replaces much of the manual analysis performed by sensor experts on large amounts of information from different sensors, environments and sites. Used in combination with other processing mechanisms, ODESA can learn how to adapt to new sensors, sites and survey environments. ODESA's processing is modelled after a human's ability to reason, interpret and correlate sensor information obtained from a variety of sources.

The purpose of this report, The Evaluation of ODESA, is to document the work that has been performed to date on the ODESA project, outline the strategy developed to address data fusion aspects of the buried UXO problem, assess the feasibility of the technology to improve the overall characterization of buried UXO and provide recommendations for future efforts in the data fusion arena. The report is divided into several sections which explain the UXO problem and the need that started UXO-CTP and ODESA efforts. The report documents the work performed under each development phase; outlines the documentation, design and fabrication efforts; provides information on the ODESA 1.0 prototype; outlines the criteria used to evaluate the system and provides recommendations for future work.

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LIST OF ILLUSTRATIONS

LIST OF ACRONYMS

AGPR -	Airborne Ground Penetrating Radar
AOE -	Autonomous Ordnance Excavator
ARS -	Automated Research Systems
BRACS-	Base Realignment and Closure Sites
COTS -	Commercial Off-The-Shelf
DOD -	Department of Defense
EOD -	Explosive Ordnance Disposal
FUDS -	Formerly Used Defense Sites
GAM -	Genetic Algorithm Module
GPR -	Ground Penetrating Radar
GPS -	Global Positioning System
GUI -	Graphical User Interface
HPM -	Heuristic Probabilistic Module
IDA -	Institute for Defense Analysis
IRPS -	Installation Restoration Program Sites
JPG -	Jefferson Proving Ground
ManPODS-	Man Portable Ordnance Detection System
ODESA-	Ordnance Detection Expert Support Application
R&D -	Research and Development
SOCS -	Subsurface Ordnance Characterization System
STD -	Standard Target Data
SRD -	Semi-Raw Data

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1.0 INTRODUCTION

The purpose of this report is to: (1) document the work that has been performed under the Ordnance Detection Expert Support Application (ODESA) and the logic behind Government decisions made to date; (2) evaluate the progress and feasibility of the ODESA program in the world of data fusion, knowledge based and expert systems; and (3) provide this report as a tool to Naval Explosive Ordnance Disposal Technology Division (NAVEODTECHDIV) and the U.S. Army Environmental Center (USAEC) decision makers for determining whether the use of artificial intelligence is feasible for the detection, identification and remediation of buried unexploded ordnance (UXO). ODESA is a component of the Unexploded Ordnance Clearance Technology Program (UXO-CTP) sponsored by USAEC and managed by NAVEODTECHDIV. This report, The Evaluation of ODESA, provides background information on work performed under Phase I research efforts and Phase II initial fabrication and prototyping efforts. Phase I consisted of researching commercial off-the-shelf (COTS) software programs and generating the following documentation: System Design Trade Study, Software Design Document, and Software Flow Chart. Phase II consisted of fabrication of the ODESA 1.0 prototype, delivery and set-up of hardware, installation of software, and the generation of the following documents: Final Technical Report, Software User's Manual, and COTS Operations Manual.

This report is organized to provide the reader with an understanding of the UXO problem, the objectives of UXO-CTP, and the use of ODESA to meet some of the program objectives. The report provides the reader with the information used to proceed from concept to prototype, documents the logic behind the prototype design, provides information concerning the basic functions of the ODESA 1.0 prototype, and evaluates the progress of the ODESA effort based on UXO-ATD program goals. The successfulness of the ODESA effort, based on established goals, is discussed and recommendations are provided concerning where future program emphasis should be placed in developing program strategies related to UXO data fusion and analysis.

2.0 BACKGROUND

With the new emphasis on DOD reductions and consolidation, the Federal Government has targeted a number of bases and military ranges for closure, clean-up and eventual reclamation by the public. These military installations include base realignment and closure (BRAC) sites, formerly used defense (FUD) sites and installation restoration program (IRP) sites. Environmental concerns regarding hazardous materials and UXO items at many of these sites has led Congress to mandate actions toward base clean-up operations. As an initial step toward addressing the ordnance and hazardous materials clearance problem, NAVEODTECHDIV and USAEC hosted the 1994 Jefferson Proving Ground (JPG) Phase I Demonstrations in Madison, Indiana. JPG Phase I was open to government, university and private organizations for the purpose of demonstrating technologies designed to detect, identify and remediate buried UXO. JPG I consisted of two controlled test sites: a 40 acre test site for ground vehicular and man-portable detection and remediation systems and an 80 acre site for airborne detection systems. Buried inert ordnance, typical range debris, false targets and simulated hazardous waste containers were buried and surveyed in for accurate location of test items. Public solicitations for demonstrations were advertised in a variety of media encouraging sensor developers, academia, range clearance companies and government agencies to participate in this large scale demonstration. Demonstrators were tasked with surveying either the 40 or 80 acre test site (depending on system configuration), analyzing the sensor information obtained from these tests and generating a target data set of the items found and their locations. Additional controlled-site demonstrations will be performed during JPG Phases II and III and other site specific demonstrations.

The results of the JPG Phase I demonstrations were used as a baseline in determining the performance characteristics of "state-of-the-art" detection systems and where the government should focus its research and development (R&D) efforts in the future. JPG Phase II will be open to demonstrators whose systems were not mature enough to perform during JPG Phase I and to demonstrators that have made significant improvements to their systems since demonstrating during JPG Phase I. The results of the JPG Phases II and III demonstrations will be used to measure the progress made in UXO technology over the past year.

In addition to determining the UXO detection, identification and remediation capabilities of existing systems, NAVEODTECHDIV pursued sensor and data processing technology enhancements under the UXO-CTP, an advanced technology demonstration effort. One purpose of the UXO-CTP is to develop test-bed systems to demonstrate new technologies in the area of UXO detection, identification and remediation technologies whose performance characteristics surpass those of the systems demonstrated at the JPG controlled site tests. Current efforts focus on demonstrating airborne (Airborne Ground Penetrating Radar - AGPR) , ground vehicular (Subsurface Ordnance Characterization System-SOCS) and man-portable systems (Man Portable Ordnance Detection System - ManPODS) using a variety of sensors and sensor types. The sensor data from each of these platforms will be analyzed using sensor specific processing algorithms and formatted in a standard data set (STD). All sensor information acquired from NAVEODTECHDIV's UXO-CTP efforts will be stored a standard format regardless of the sensors or platforms used; this will allow the government to scrutinize data, sensor processing techniques and abilities professed by data analysis companies. Figure 1 is a block diagram that provides information flow between ODESA and other external UXO-CTP external subsystem efforts. This diagram outlines interactions between the simultaneous data collection and processing system (SIDCAPS), explosive ordnance disposal (EOD) personnel, user input files and other UXO-CTP efforts.

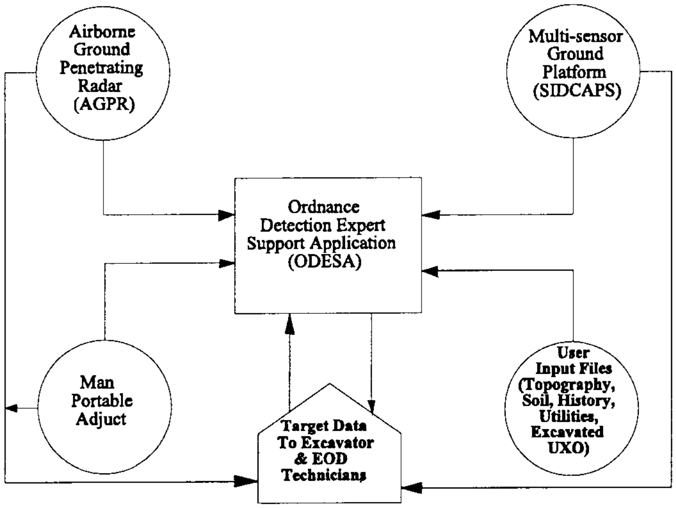

Figure 1. Information Flow Between ODESA and External Subsystems

Sensors currently being investigated for the ground vehicular platform (SOCS) include: ground penetrating radar (GPR), cesium vapor magnetometers, flux gate gradiometers, tensor magnetometers, induction coils and inframetric cameras. The testing performed by SOCS will not be limited to the above sensors, but will evolve with the development of new UXO technologies. The sensor being investigated for the airborne system is a ground penetrating radar and the sensors being investigated for the manportable system are ground penetrating radar and gradiometers. The knowledge acquired from processing sensor information will be used to enhance existing technologies and demonstrate new technologies, and this knowledge will be transferred to the private sector through NAVEODTECHDIV's Technology Transfer Program. It is the Government's intention to further developments in UXO detection, identification and remediation technologies by aiding and encouraging private industry involvment in solving the buried UXO problem.

Existing single-sensor detection systems, many of which are commercially available, are unable to accurately and reliably detect buried UXO. In addition to the actual performance characteristics of detection systems such as sensor accuracy and processing routines, the sensor's ability to detect and identify buried UXO depends upon site specific conditions such as soil type, moisture content, ferrous content, terrain type, etc. No single sensor system has been found that could adequately address the buried UXO problem by providing reliable and accurate buried UXO information. As a result, NAVEODTECHDIV has focussd its efforts on demonstrating multi-sensor, multi-platform systems for the detection of buried UXO and multi-source data fusion for the identification and characterization of buried UXO.

Some commercial companies utilize the multi-sensor approach, but make separate surveys using each sensor type. NAVEODTECHDIV's approach is to simultaneously obtain data from multiple sensors during a single survey operation in order to eliminate the time and money expended from performing multiple surveys. The information acquired from individual sensor surveys is typically analyzed by an individual making comparisons between sensor results; the performance of an individual sensor or system thus depends on the analyst's knowledge of UXO, the performance of the sensor in different environments and the analysts knowledge (or lack of knowledge) of site history and ordnance use. To fill the multi-sensor data fusion need in an automated approach, eliminate the need for an individual's analysis of sensor information, and incorporate topographic, historical and site specific information, NAVEODTECHDIV began the development of ODESA. ODESA's function is to perform data fusion tasks through the use of expert systems, neural networks and fuzzy logic approaches. The more accurate and reliable information on buried UXO identification and location (provided by ODESA) will be provided to range clearance and base clean-up decision makers and to other parties responsible for site remediation processes.

In a concurrent effort to address the UXO remediation need, NAVEODTECHDIV is developing a low cost autonomous ordnance excavator (AOE) for autonomous remediation of buried UXO, through Wright Laboratory at Tyndall Air Force Base. The AOE effort builds upon previous Air Force work performed under the Rapid Runway Repair (RRR) Program. When the cold war ended and there was no need for rapid runway repair mechanisms, RRR technology was transitioned to the UXO-CTP. The information generated by ODESA, target information in a standard data set, will be provided to the AOE for autonomous excavation of selected UXO items at survey sites. The AOE autonomously plans a path from some starting point to the item of interest, navigates to that point and uncovers the item. This same target information can also be supplied to the Explosive Ordnance Disposal (EOD) field troop so that manual remediation efforts can be performed in situations where autonomous or tele-robotic excavation is not feasible.

3.0 PURPOSE OF THE ODESA PROJECT

The development of the ODESA prototype centered around the Government's need to analyze sensor information acquired from different sensor platforms and sensor types along with historical, topographical and user input information to achieve better detection rates and reduce false alarms that directly affect the scope, cost and ultimately the Government's decision to remediate a site. ODESA is a tool to achieve this goal. Sensor data can be acquired at different times, with different systems and with different environmental factors influencing sensor effectiveness and performance. ODESA's processing emphasis was to combine neural networks, fuzzy logic processing, genetic algorithms and heuristic probabilistic analyses in an expert system shell to provide the most accurate, effective and reliable information on the location, identification and classification of buried UXO. ODESA's function/purpose was to provide the data fusion function that would combine all of the information obtained from UXO-CTP sensor test-bed systems into a single more accurate target report. The development of the ODESA prototype version 1.0 was performed by PRC Inc. located in McLean, Virginia under two separate phases: Phase I consisted of researching COTS software that could be integrated together to form ODESA, developing hardware and software designs and design documentation and generating all required planning documents; Phase II consisted of fabricating ODESA 1.0 and preparing associated documentation.

3.1 Phase I - System Design Trade Studies and Initial Investigations

Phase I consisted of investigating COTS products to address the data fusion and analysis, defining the functional requirements of the ODESA system, determining the design drivers of a prototype system, determining the software technical design requirements and developing recommendations for the optimal configuration of the ODESA prototype. Investigations included researching data communication tools, artificial neural network products, fuzzy expert systems, graphical user interfaces (GUI), object database management systems, computer hardware and developing recommendations for the hardware and software architecture of the initial prototype. A System Design Trade Study, Software Development Plan and Software Flow Chart were generated for the development of ODESA; these documents outlined the strategy for prototype development.

Note: *The following information was generated under Phase I efforts and was obtained from the System Design Trade Study, Software Development Plan and Software FlowChart Documents. Specifics on these documents are included in the reference section.*

As a result of ODESA Phase I, the following functional requirements were defined:

3.1.1 Functional Requirements

1. ODESA shall be able to retrieve and use sensor and navigation information from multiple systems, regardless of method of employment, stored in standardized data sets (STDs).

2. ODESA shall use site and environmental information including data stored in historical, geographical and geological databases; data obtained on known anomalies and additional user input to increase the probability of detection and reduce the false alarm rate.

3. ODESA shall make intelligent decisions based on ordnance characteristics such as location, buried depth, classification, orientation and size.

4. ODESA shall be capable of automatically downloading sensor and site information or of manually input by an operator.

5. ODESA shall provide output data in STD format usable by automated, remote or manual remediation methods.

6. ODESA shall provide output in map or tabular format usable by EOD technicians.

7. ODESA users shall be able to modify historical target files after ordnance items have been exposed in order to maintain up-to-date historical files of surveyed areas and provide a feedback loop to improve system performance and predictions.

System design drivers were also generated for ODESA 1.0 during Phase I efforts. These design drivers were used to address the functional requirements specified above and as a basis for developmental work. These drivers are summarized below.

3.1.2 Design Drivers

1. Create Test Bed: ODESA is a test-bed computer system. Its purpose is to explore a variety of processing methods to obtain the optimal configuration for solving the unexploded ordnance detection problem.

2. Apply Advanced Techniques: ODESA will make intelligent decisions with a combination of neural network, fuzzy logic, heuristic probabilistic, and genetic algorithm processing techniques.

3. Add Value: ODESA's performance is based on the value that ODESA processing adds to the UXO location, identification and classification predictions of the individual sensor devices/systems.

4. Utilize Existing Software: ODESA hardware and software architecture will minimize software development times and costs by utilizing COTS products.

5. Comply With Industry Standards: ODESA will comply with industry standards for operating systems, development languages, network computing, peripherals, software and other components.

6. Extendability: A flexible ODESA system design requires a software and hardware architecture that will support system development, product integration, demonstration, and fielding. The architecture should support future and emerging technologies so that the system can learn and evolve over time.

7. Usability: ODESA should take advantage of the superior pattern-matching and classifying capabilities of the sensor experts. All user interface tools should be easy to use and involve the analyst in meaningful ways.

Software Technical Design Requirements for the ODESA software architecture were derived from the functional requirements and design drivers generated under Phase I efforts. The key software architecture technical requirements were determined to be:

3.1.3 Software Technical Design Requirements

1. Performance: No real-time requirements exist for ODESA data processing; however, because of the highly interactive nature of the prototype architecture, ODESA must have a good level of performance.

2. Extendability: ODESA must be able to utilize and process data acquired from new sensor types with minimal changes to the existing system.

3. Open Architecture: The system architecture must minimize the difficulty of interfacing new components. ODESA must be capable of incorporating and trying out new software with minimal changes to the existing system.

4. Usability: The ODESA operator must be able to easily interact with the the ODESA system. Where possible, the user interface for ODESA should not complicate user interaction.

5. Reliability: ODESA must be constructed of mature, technically supportable COTS tools and high quality, fully documented custom software.

6. Compliant: To ensure ease of adding, replacing or modifying hardware or software components, ODESA will be compliant with existing and emerging standards.

3.1.4 Recommendations for ODESA Prototype Version 1.0 Architecture

As a result of Phase I efforts, PRC provided information on a variety of hardware and software design options for the ODESA prototype; a final hardware and software architecture recommendation for the prototype ODESA system was provided in the ODESA System Design Trade Study. Approval of the recommended approach by NAVEODTECHDIV gave PRC authorization to begin Phase II efforts. The following contains recommendations presented by PRC for the ODESA 1.0 prototype:

Input Data Model

Initial input data to the ODESA prototype should consist of target data produced by individual sensor systems and stored in an STD. This will allow the ODESA development to concentrate on data fusion, and let the need for additional data be driven by lessons learned obtained from different processing techniques.

Hardware Architecture

The proposed hardware architecture consists of a homogenous network that will initially contain a single mid-level workstation that will be upgraded to two mid-level workstations for semi-raw data analysis. The initial recommendation is to use a SUN SPARC 20 for the ODESA 1.0 prototype which analyzes target data sets only. A two computer network is recommended for higher versions of ODESA when semi-raw data analysis algorithms are developed and utilized.

The hardware recommendation is based on the selection of an architecture that supports multiple, cooperating hardware platforms. Such platforms will allow the development of a system that:

- Meets the ODESA performance requirements for all stages of the life-cycle.
- Is flexible enough to support integration of COTS components that may be limited to certain platforms. Future specialized components could thus be integrated by adding additional hardware as necessary.
- Serve as a test-bed for emerging processing techniques.

Software Architecture

The major considerations for the software architecture option are data communications, artificial neural network capabilities, fuzzy expert system, GUI and the object database management system. The recommended system utilizes a series of independent applications sharing common information across a distributed computing platform. Figure 3-1 illustrates this software architecture approach. The client/server based approach provides a modular, expandable solution that forsees the incremental inclusion of specialized applications to the system. To facilitate this approach, a COTS distributed object database management system will also be selected to provide the common data storage and data communication tools needed in a client/server environment.

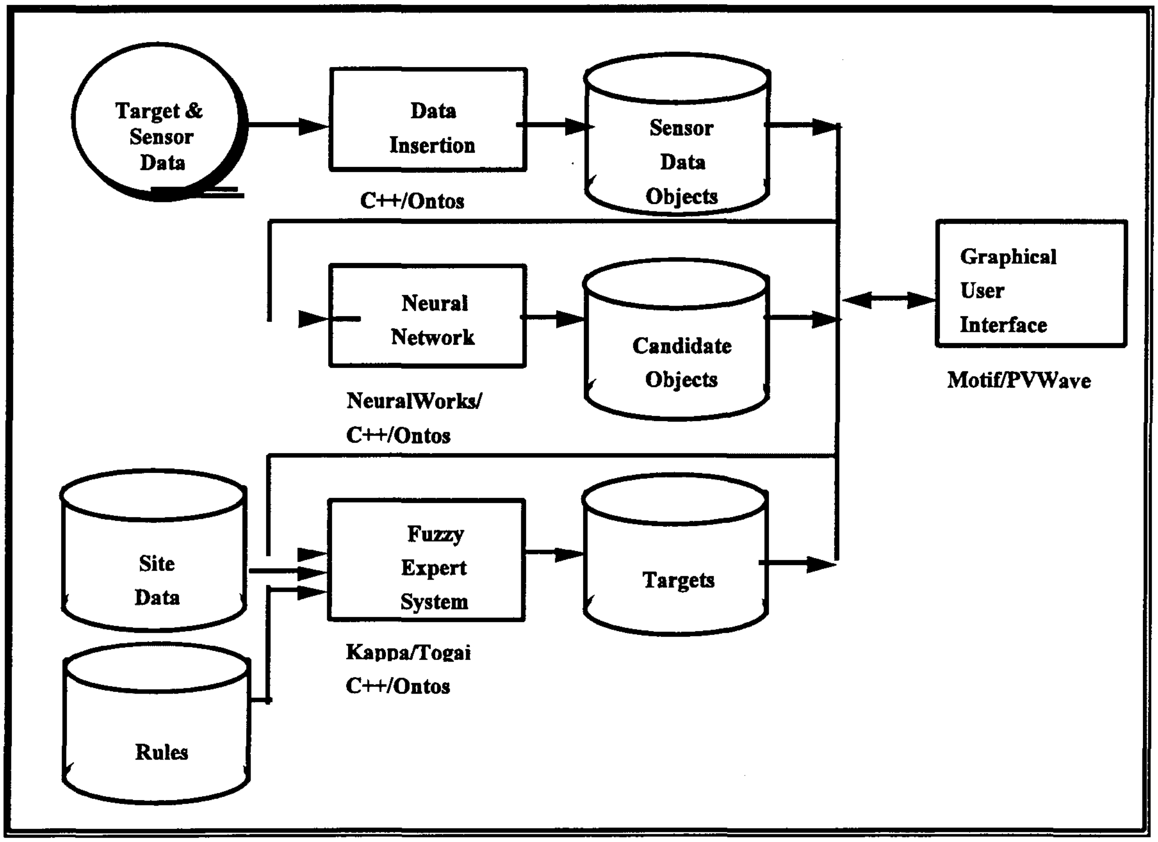

Figure 2. Software Architecture

User Interaction Model:

A mid-level user interaction model is recommended that provides a simple load-and-go mechanism with additional data visualization tools. The key user interface interactions recommended involve the ability to view and manipulate target data, site data and other data in two and three-dimensiona. To ensure that user interface features can be added, the Motif library approach is recommended over the COTS

Data Visualization Tool. Figure 3 depicts a block diagram of the user interaction model recommended under this effort.

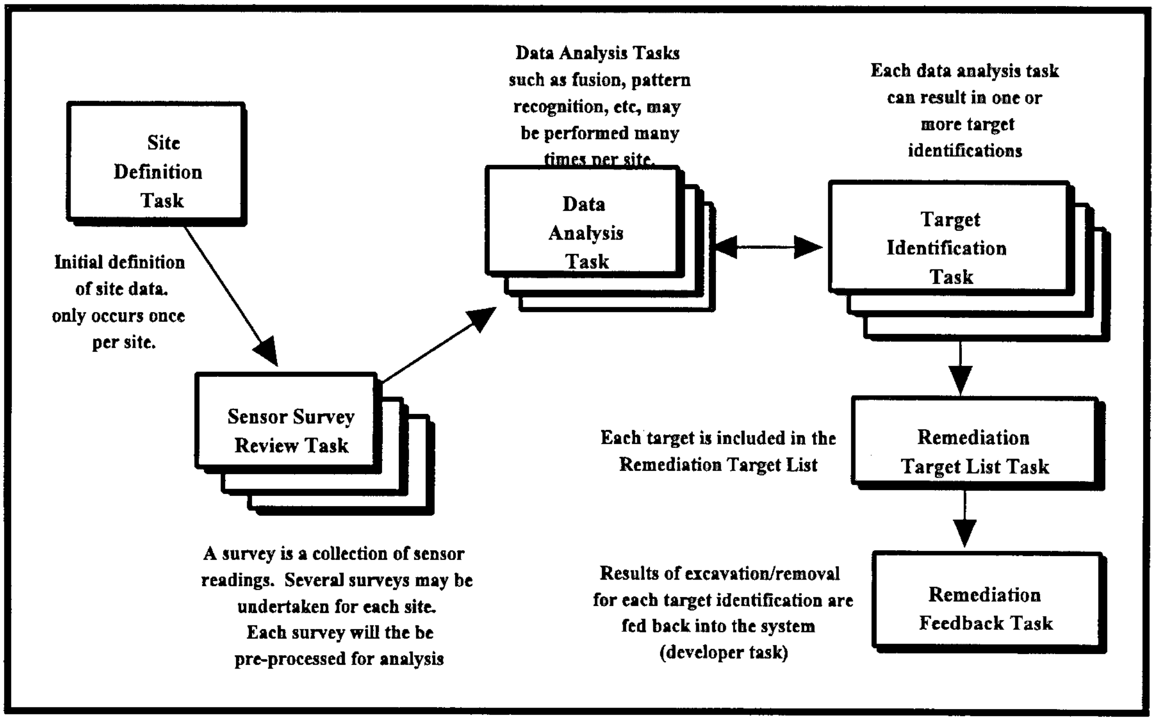

Figure 3. User Interaction Model for ODESA.

Recommended Data Analysis Model:

Figure 4 depicts several of the sensor data analysis approaches discussed in the ODESA System Design Trade Study. The application of intelligent computing to fuse and correlate target data from individual sensors can be implemented in unlimited combinations. Figure 4 provides several different data analysis schemes including: Model 1 - Fuzzy Expert Systems; Model 2 - Single Neural Network System; Model 3 - Conventional Expert Systems; Model 4 - Single neural network for each sensor type that improves the target list and is then applied to the fuzzy expert system; Model 5 - A series of neural networks per sensor, each specializing in a particular type of target identification whose outputs are then fused by a master neural network and then passed onto a fuzzy expert system. Model 4 was the data analysis configuration recommended by PRC.

The recommended data analysis model is a combination of neural networks, fuzzy logic and expert systems. This approach utilizes neural networks to improve the accuracy of the target data produced by individual sensors. This will allow ODESA to learn from collected data signatures. For each sensor type, a neural network will be developed to improve sensor output in the form of an STD. A fuzzy expert system will then fuse the predicted target data from each neural network to identify and locate UXO. The combination of a conventional, rule-based expert system and a fuzzy logic-based expert system is recommended because of the mixed quality of the information that will be embedded in the system. Both heuristics from human experts and patterns learned from data will be available for ODESA utilization, the former represented by the expert system, the latter by the fuzzy component.

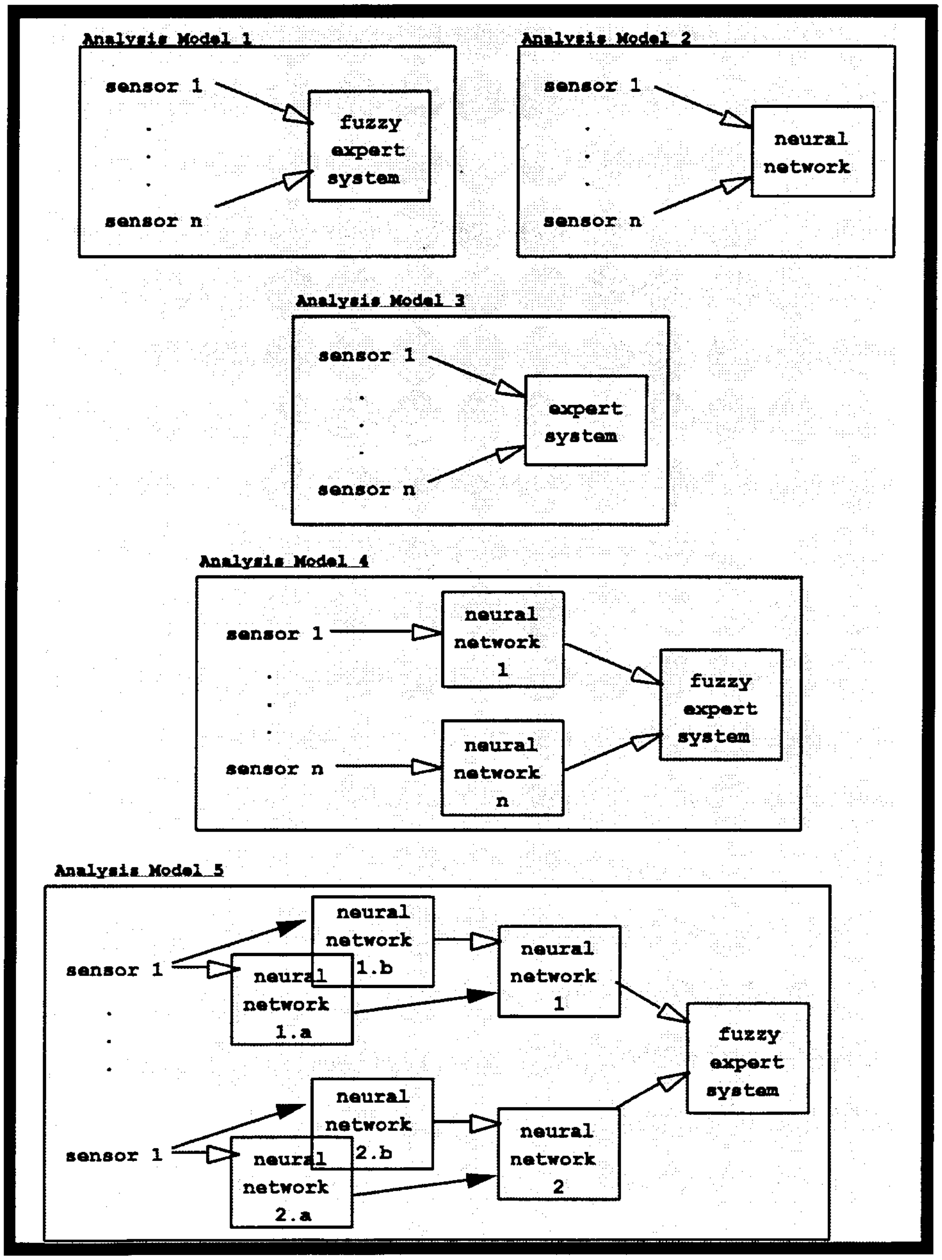

Figure 4.
Data Analysis Models

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3.2 Phase II - Development of ODESA 1.0 - Standard Data Set Analysis

Based on Phase I research, investigations and recommendations NAVEODTECHDIV and USAEC, authorized initial development of ODESA through Phase II efforts. The scope of Phase II consisted of developing an initial prototype using STD processing techniques only Historical, site specific and semi-raw data information will be incorporated into the data fusion approach during later program phases. The purpose of Phase II was to build a limited prototype system, with GUI, utility and analysis capabilities. NAVEODTECHDIV wanted to demonstrate that target information acquired from several different systems could be fused to provide more accurate and reliable information than could be obtained from the analysis of data from any single sensor system. NAVEODTECHDIV's intention was to add additional analysis capabilities like semi-raw data analysis, incorporation of historical, topographical and site specific information and a more enhanced graphical user interface, to ODESA in separate phases based on the success of standard data set analysis.

Phase II efforts consisted of development of data fusion algorithms and a hardware and software architecture that would support the algorithms. Several different analysis techniques were investigated including, genetic algorithms, heuristic and probabilistic methods, neural networks and fuzzy logic applications. For Phase II, the processing of standard data set information only, the two data processing approaches chosen were genetic algorithms and heuristic/probabilistic analysis. The neural network and fuzzy logic approaches were reserved for semi-raw data analysis under Phase III, where the full development of an expert system can take advantage of these higher level processing tools.

The development of the hardware and software to support the data analysis tools consisted of the generating the GUI, limited utility capabilities, the generation of an object oriented software application and the definition of the JPG test site in terms of location, topography and grid orientation. Figure 5 provides a block diagram drawing of the user interface information flow for ODESA; it outlines the interconnectability ODESA software components through the user interface.

The sensor, site and demonstrator information supplied to PRC for Phase II efforts, was drawn from the 1994 JPG Phase I demonstrations. The demonstrator information obtained from the JPG Phase I demonstrations was used as input to ODESA. In addition, approximately half of the target key (information on the actual locations of the buried UXO items) was supplied to ODESA as a training set to teach the expert system how to correctly analyze sensor information. PRC developers performed a test to determine how well ODESA could fuse information from four specific demonstrators (ADI, Coleman, Geo-Centers and UXB) that represented ground penetrating radar and magnetometer technologies. Like the demonstrators at JPG I, ODESA generated target information that was also supplied to the Government's JPG Phase I evaluation mechanism for scoring Automated Research

Systems (ARS) and Institute for Defense Analysis (IDA) algorithms, based on these four demonstrators. This impartial mechanism determined that ODESA could provide a more accurate accounting of buried UXO by reducing the amount of "false alarms" detected, where false alarms is defined as detected anomalies indicated as UXO items that were in actually either non-UXO items or non-existent targets. Since ODESA's detection ability can only be as good as the sensor information it is provided, detection rates of ODESA in comparison to the best JPG I detection system would not be significant; however, it was determined that ODESA could minimize the false alarm rates experienced by individual sensors by utilizing the best performance characteristics of each sensor.

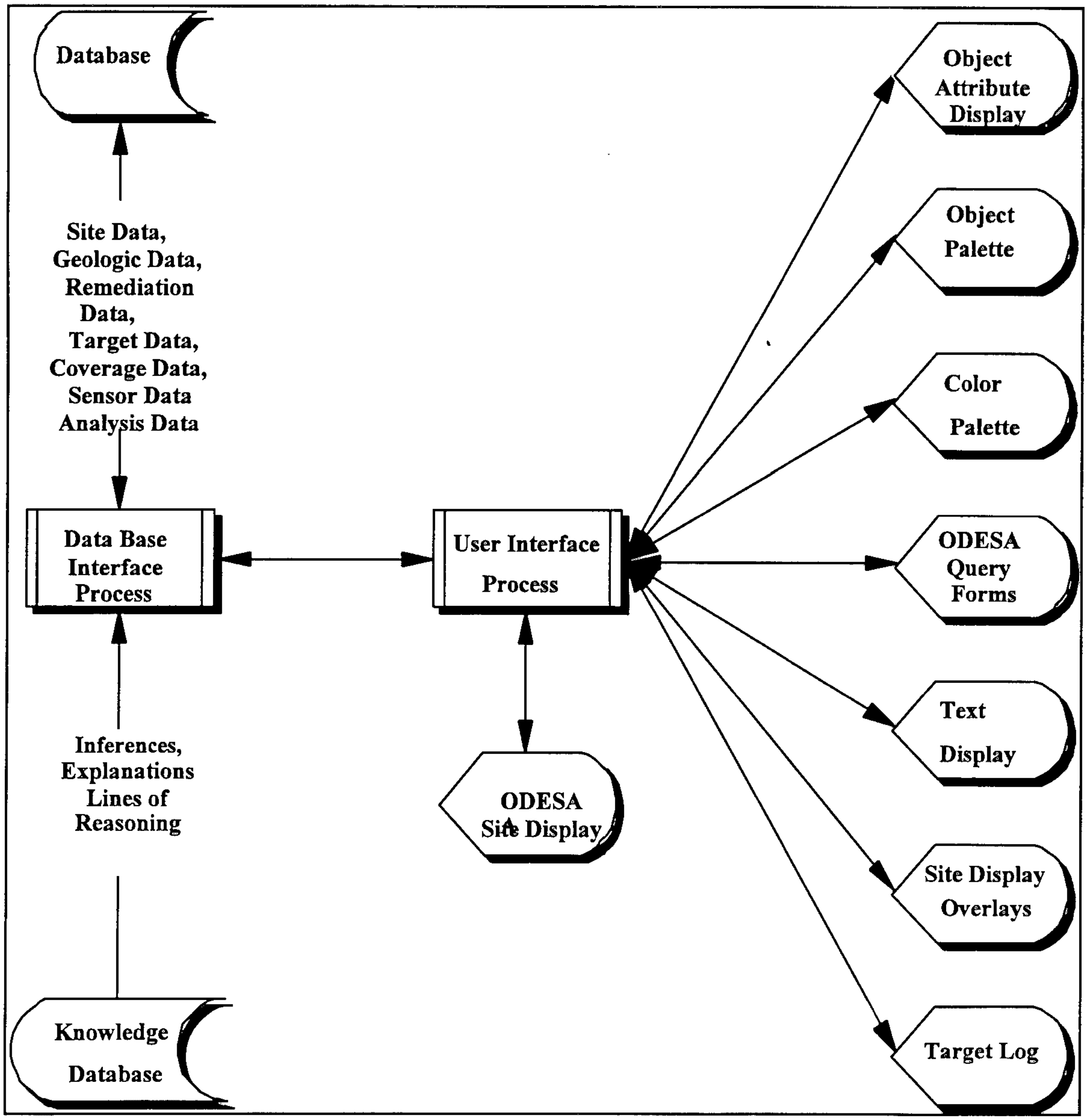

Figure 5. User Interface Information Flow

The first tests performed by ODESA utilized the scoring routine to characterize system and demonstrator performance. Figure 6 below depicts the performance of fifteen target data sets from fifteen separate demonstrators (identified as d1 - d15) using the scoring mechanism and a four foot search radius. The three metrics used for comparison were percentage of targets detected, percentage of false reports and percentage of the area surveyed.

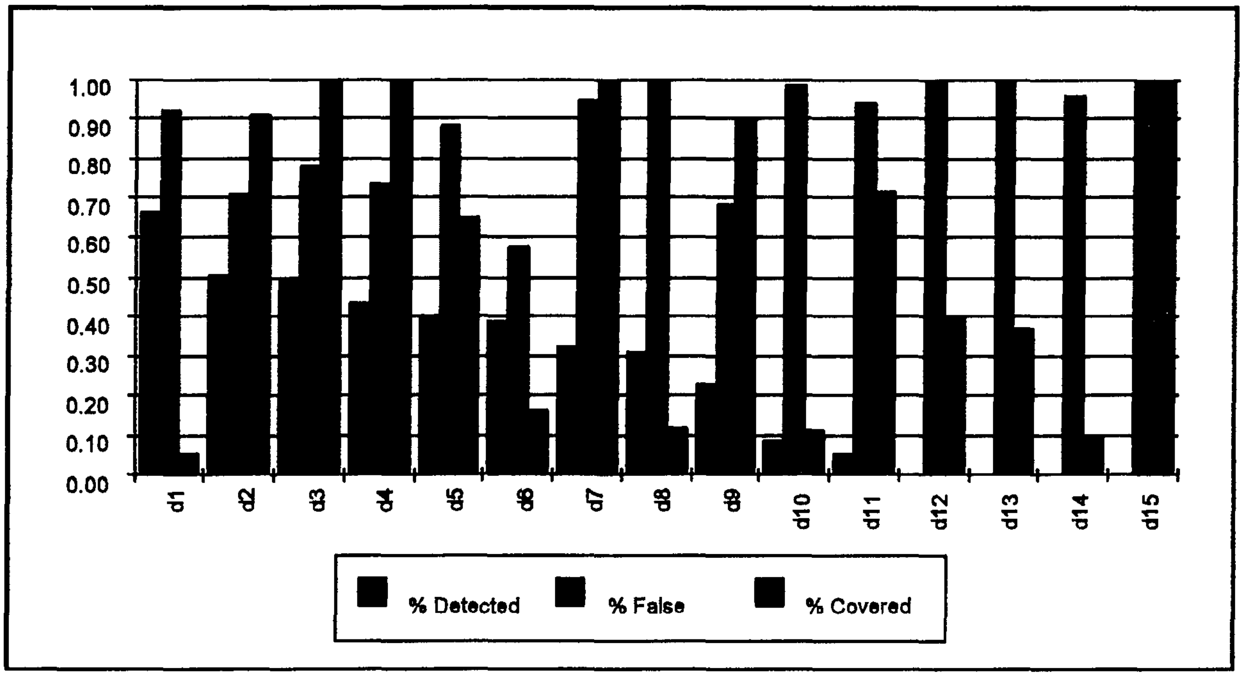

Figure 6. Demonstrator Report Percentage with 4-Foot Search Radius

The percentage of targets detected criteria was calculated by taking the total number of detections obtained by a demonstrator divided by the number of possible targets. The percent of false reports criteria was calculated as the number of false reports divided by the total number of reports. In addition, the total number of detections and false reports for the same target data sets (d1-d15) was calculated and is presented in Figure 7. This figure is provided to give the reader an understanding of the enormous number of reports involved in the fusion process, and the need for efficient data processing and manipulation software.

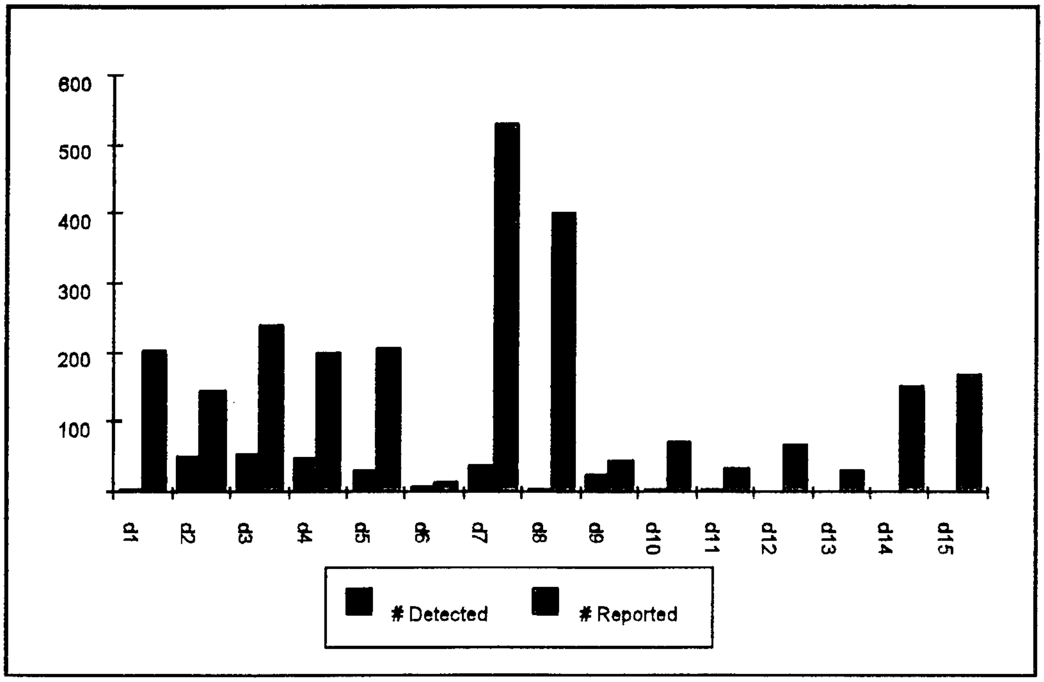

Figure 7. Demonstrator Report Counts with a 4-Foot Search Radius

Based on these scoring techniques, ODESA developers could judge how well the ODESA data fusion techniques were performing in comparison to the data analysis techniques of other demonstrators. This scoring routine is different than the techniques used by ARS and IDA to judge the performance of JPG I demonstrators. Figure 8 depicts the results of several ODESA data fusion attempts.

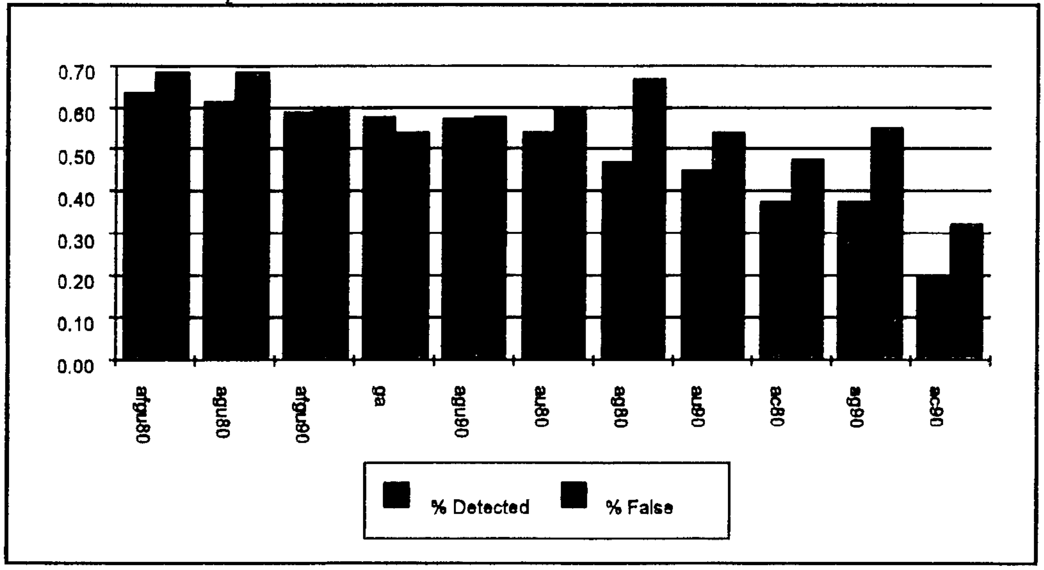

Figure 8. ODESA Percentage Results for Several Different Algorithms

The target data set known as "ga" was produced by the Genetic Algorithm Module (GAM) based on rules created by training the genetic algorithm using four government selected data sets. The remaining data sets depicted in the figure were produce by the Heuristic Probabilistic Module (HPM) by varying the target data sets to fuse and the likelihood threshold. For example, the data set "afgu 80" represents a fusion of data sets "a," "f," "g," and "u" using a likelihood threshold of 80 percent. Demonstrator data sets were given letter descriptors like "a" and "f" to eliminate any bias that could come out of knowing what company that demonstrator data set represented. An examination of the above figure shows that the percentage of detections and false reports increases with a decreasing likelihood threshold.

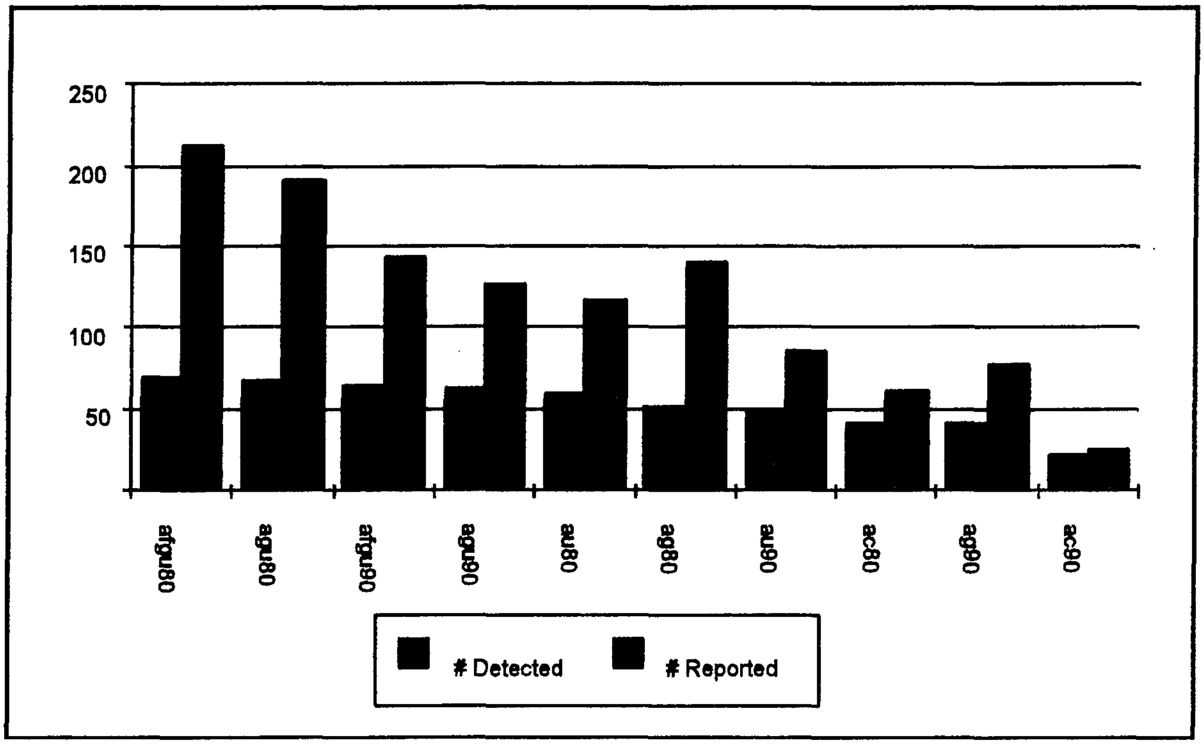

Figure 9. ODESA Counts Results for Varying Algorithms

The same type of chart as shown in Figure 7 for actual number of detected targets and reports for the same set of ODESA target data sets is depicted in Figure 9. As discussed in the ODESA Final Technical Report for Phase II, the report percentages varied according to search radius. Figure 10 shows how well the ODESA processing algorithms described above compared to the demonstrator target reports. The results of the ODESA comparisons are less reported false alarms; the false alarms are minimized during the data fusion process. The best performance characteristics from each sensor system is combined in the ODESA processing.

Specifics concerning the results of the ODESA processing can be obtained by reviewing the

ODESA Final Technical Report for Phase II. Details about this document can be found in the Reference section of this report.

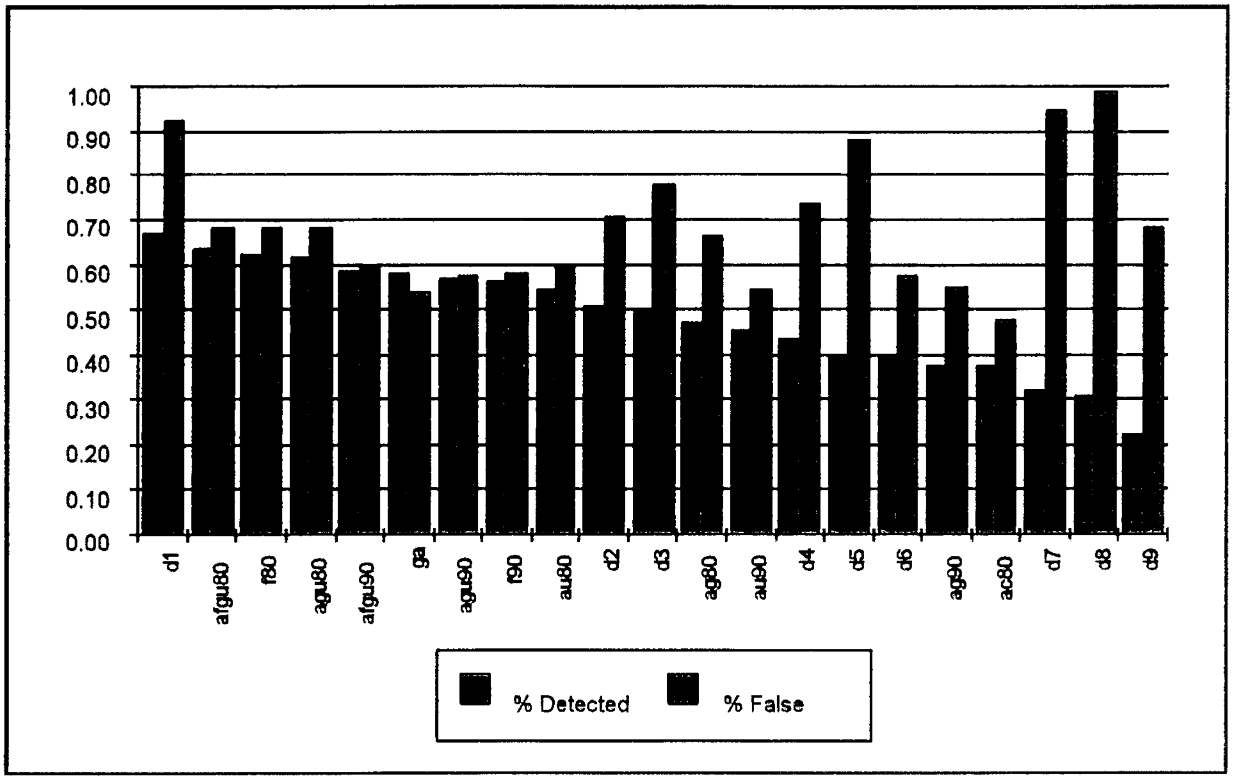

Figure 10. ODESA and Demonstrator Report Percentages Compared

The results obtained from the ARS scoring can not be interpreted in the same way as the results of the ODESA processing. There are several specific differences between the ARS and the ODESA scoring mechanisms. These differences are outlined below:

- The ARS method lowers detection counts since a single demonstrator report can match one and only one baseline target.
- The ODESA Score Utility matches a single demonstrator report with as many baseline targets that are within the critical distance of the report.
- The ARS method raised False Negative Ratios, since only one demonstrator report can match a single baseline report, other reports within the critical distance are counted as false negatives.

- The ODESA False Report percentage will be lower than the ARS False Negative Ratio, since multiple demostrator reports can match a single baseline target or known anomaly and are not considered false.

3.3 Phase III - Enhanced ODESA Development - Semi-Raw Data Analysis

This report is intended to be a stepping stone for further ODESA development. Based on the success of Phase II efforts (standard data set or target data set analysis) and the prospects of further ODESA development, Phase III efforts would center on enhancing ODESA's capabilities in the realm of semi-raw data analysis. NAVEODTECHDIV intended to utilize neural network and fuzzy logic capabilities for the processing of semi-raw data, topographical, historical, site-specific information and performance characteristics of sensors in varying environments early on in the effort. Since program emphasis changed from that of analyzing semi-raw data sets and environmental/site information to that of analyzing standard data sets in Phase II, initial analyses were performed on target data only. It was not feasible to start developing neural network and fuzzy logic processing routines until semi-raw data could be utilized. The semi-raw data and historical information enhancements proposed for Phase III would allow analysis of sensor data from varying test sites, demonstrators and sensor types.

Plans for further ODESA development include utilizing an artificial neural network and expert system approach to analyzing semi-raw sensor data. In Phase I it was determined that analysis of information from variety of sensor types, sensor systems and platforms required an automated approach. ODESA's software design was generated to simulate the processes a human brain performs in analyzing information. One of the goals of the ODESA project was to develop a system that could be used by other UXO-CTP projects that could take advantage of ODESA neural network, fuzzy logic and expert system development for UXO detection. ODESA could then "learn" the effects of soil type, environmental conditions, and site specific information on sensor performance and provide users with a more accurate accounting of buried UXO present at a particular site. In the next version of ODESA, the neural network component would learn to classify input patterns by being trained on examples and classification of input data , much like a human operator does when comparing target reports from different sensors. Neural networks can be used singly or in combination to perform a variety of processing tasks. Individual neural networks might be used to discriminate between ordnance and clutter, classify suspected ordnance into sizes or types, or estimate the depth or orientation of buried objects from the patterns and convergence of signal strengths.

Neural networks are a type of computer architecture modeled after the structure and operations of the human brain. In contrast to conventional computers, neural nets have no separate processors, memory or stored software programs, instead they consist of a large number of simple processors joined together by a complex set of interconnections. These networks are not programmed, but are "taught" by presenting examples of material to be learned. Figure 11 presents an illustration of how the individual nodes are connected.

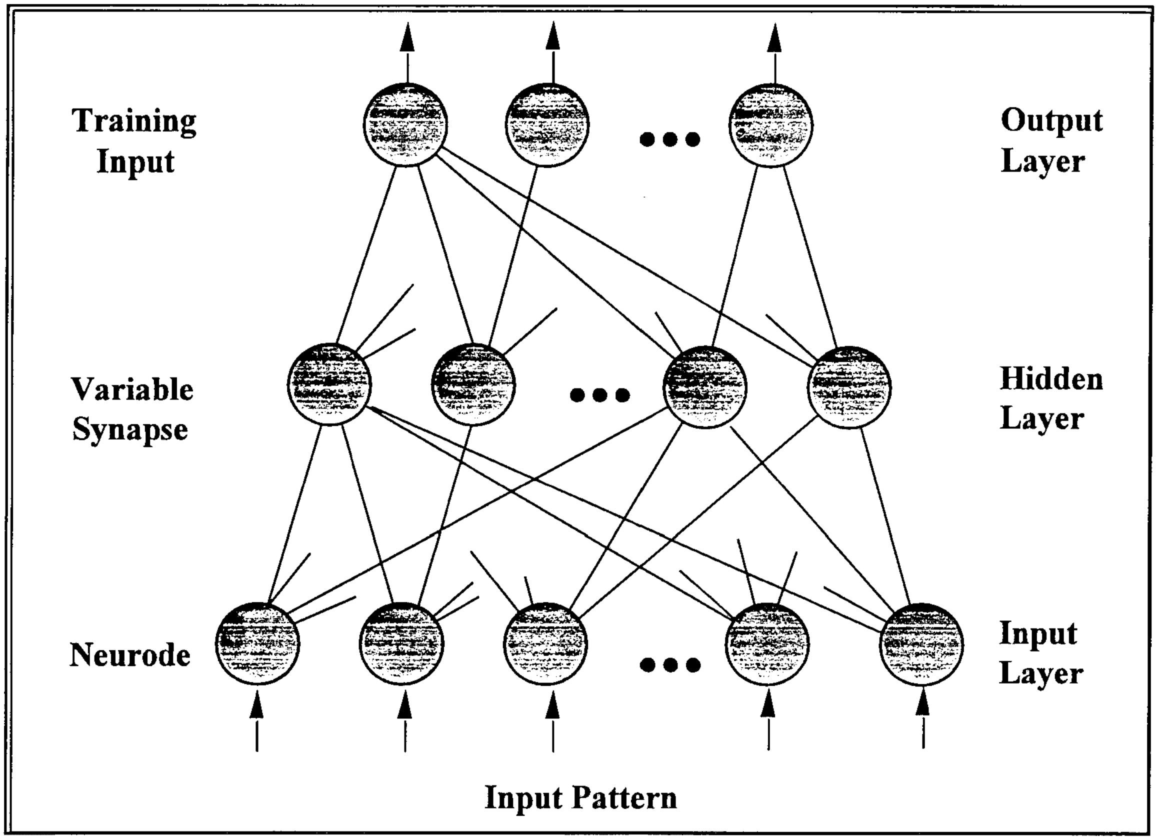

Figure 11. Diagram of Neural Network Design.

An expert system component would be the backbone of the ODESA design structure. It will provide the system with a means of reasoning, an would allow ODESA to correlate, fuse and act upon all types of information made available to the system. Although neural networks can provide valuable assistance in interpreting sensor inputs, they cannot determine the significance of their findings in terms of the total mission of the system. This "interpretation" function must be performed by the rule-based logic of an expert system.

Under Phase III, the expert system component would provide the following functions:

- Grouping raw data points based on factors such as proximity and similarity.
- Classifying the groups into categories relevant to the ODESA mission. This function would assign attributes based on spatial and statistical properties.
- Examining attributes and classifying them as belonging to one or more categories.
- Fusing the results of all the processing applications based on: the area under consideration, sensor readings, buried utilities in the region, history of the site, etc.

NAVEODTECHDIV intends, with approval to continue ODESA development, to enhance the target data processing capabilities of the ODESA 1.0 prototype through the development of neural network and expert system processes for the analysis of semi-raw sensor data. The information on Phase III efforts is provided to allow reader understanding of project strategy, the components of the project selected for demonstration under ODESA 1.0 and the components designated as ODESA 2.0 concepts. The future of the ODESA effort depends on sponsor approval to continue development.

4.0 ODESA, THE SYSTEM (VERSION 1.0)

In this section, information will be provided that documents the current configuration of the ODESA 1.0 prototype. The key components of ODESA 1.0 (the user interaction model, data display and manipulation capabilities, database management tools, analysis algorithms) are explained in detail so that the project status can be evaluated in Section 5.0.

4.1 Background:

The goal for ODESA 1.0 was to intelligently fuse unexploded ordnance target reports from multiple sensors and systems to produce a remediation target list that better identifies the location, orientation and identification of buried ordnance and clutter. This data fusion is accomplished through the use of target reports only, not through direct analysis of raw or semi-raw sensor information. ODESA 1.0 was developed in parallel with the data collection efforts at the JPG Phase I demonstratiolns. Many of the JPG Phase I demonstrator data sets utilized by the ODESA algorithms had to be "fine-tuned" manually for insertion into the prototype system. As a result, ODESA 1.0 is a proof of concept analysis tool for a single site, Jefferson Proving Ground. The main objective for ODESA 1.0 was to maximize the probability of detection and minimize false alarm rates of demonstrator supplied sensor information through fusion techniques. When the NAVEODTECHDIV STD and SRD formats are finalized, ODESA's input processes can be modified to utilize sensor and site specific information obtained from any site and any sensor type. ODESA 1.0 is not a turn-key system and developers assumed that ODESA operators will be familiar with the basics of SUNSPARC 20 operations and the UNIX environment.

The ODESA 1.0 prototype was developed by combining features from several commercially available software packages with custom integration software developed by the ODESA team. These COTS packages were used to develop the GUI, the two-dimensional and three-dimensional graphics tools in the user interface and the object database management system. Initial ODESA development was been accomplished on a SUN SPARC 20, a dual processor UNIX workstation. The SUN SPARC runs under the Solaris 2.3 operating system. The optimum COTS products to be utilized by ODESA were researched in Phase I, and were proposed in the System Design Trade Study.

4.2 User Interaction Model

The ODESA 1.0 user interaction model (UIM) defines how the system should characterize the user's interactions; focus on what the user sees and what he needs to do rather than how the system accomplished the specified tasks. The UIM provides direction for GUI design, the tasks the user must perform, and the flow of information between ODESA and the user interface. Although all aspects of the UIM have not been developed to date, the framework of this model is already in place.

4.2.1 Graphical User Interface

ODESA utilizes an X Window System in combination with the OSF/Motif Window Manager to provide GUI and display ODESA information to the user.

X Windows is a set of subroutines that provide an interface between graphical devices and user applications. OSF/Motif is a standard workstation GUI used in private industry. OSF/Motif provides a Motif Window Manager mechanism that allows the user to manipulate and simultaneously display multiple windows on the screen. User functions include the ability to change keyboard settings, focus themouse pointer and control windows operations.

The ODESA 1.0 GUI allows the users to access all functions necessary to ODESA operations from the main ODESA Window. From the main window, the user can load site data; display target sets; review information about individual targets, target sets, sensor and organizations; view graphical site and target data in two and three dimensions; and perform analyses on the target data. Most of the GUI has already been developed; items that have not been developed have been placed as "markers" in the windows environment so additional modules can be incorporated in the future.

4.2.2 User Defined Tasks

The UIM outlines the tasks a user must perform and the sources of knowledge that must be utilized to perform the tasks. The UIM also includes information on the relationships between tasks and the expected frequency of the given task. Since ODESA 1.0 was a proof-of-concept prototype to demonstrate that better target information can be acquired through data fusion, the ODESA framework was built around the JPG Phase I site information and its demonstrators. NAVEODTECHDIV plans to make the analysis routines more open in the next phase of development by allowing new sites, new demonstrators and new sensor information to be incorporated as inputs to the system. The following is a list of user tasks that will be incorporated into future versions of ODESA:

- Site Definition Task - produces the basic definition of a site including geography, topography, roads, utilities, soil types, ordnance types, etc.
- Sensor Survey Review Task - defines the information concerning sensors employed, area surveyed, hot spots, missed areas, etc.
- Data Analysis Task - occupies the bulk of the user's time. The main goal is to examine sensor information and refine target lists. The user will use data visualization software in conjunction with the expert system and neural network components to perform this task.
- Target Identification List - provides a detailed listing of pertinent information about the target, evidence supporting its identification and the user's categorization of the target.
- Remediation Target List - the primary output of ODESA is a predicted target list (STD) that can be used by remediation resources to excavate the UXO identified by ODESA.
- Remediation Feedback/Results Task - Once a target is excavated, the results of that remediation effort are provided to ODESA via a (STD) input from the remediation source. The information can then be fed back into ODESA so that the system can improve its performance as experience is gained in the remediation cycle.

4.3 Data Display and Manipulation:

ODESA utilizes a graphical display program called PV-WAVE that provides a versatile set of commands for manipulating and displaying data in a graphical format. This information is stored in libraries that can be utilized to manipulate display information in several ways including two-dimensional and three-dimensional displays, data filtering, rotation of data and slicing of data. PV-WAVE can accomodate the manipulation of large amounts of data.

Some of the capabilities of the PV-WAVE software package are illustrated in Figure 12, a screen capture image of ODESA. This figure depicts an image of a test area in the three- dimensional mode. The user is free to rotate the image, zoom in on a particular area of interest, overlay topographical and contour lines and change the colors of the three dimensional image to allow for easier viewing of suspected targets.

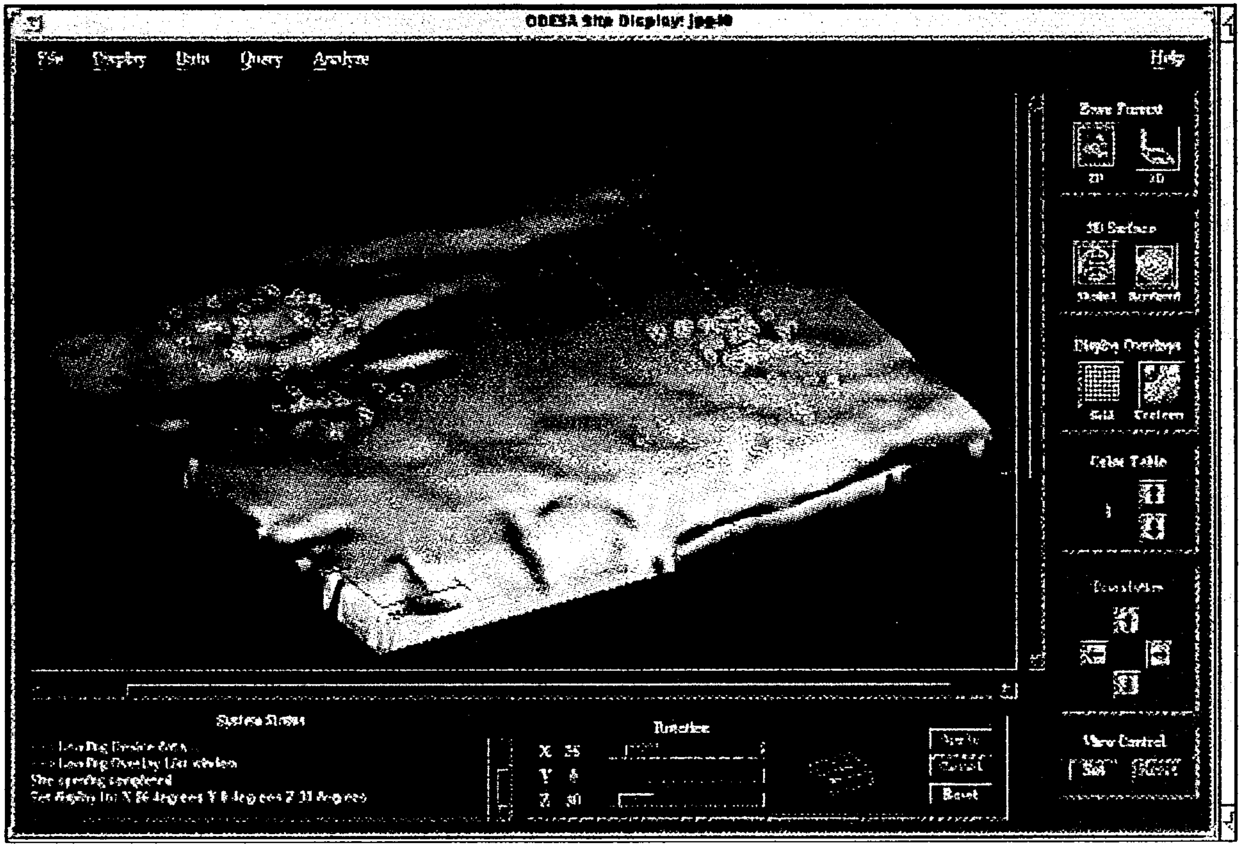

Figure 12. ODESA Site Display Window

test area and Figure 14 depicts the associated three-dimensional representation. These grid areas provide the user with some frame of reference as to where actual surveys were performed in relation to the test site as a whole. The user can easily toggle back and forth between two and three dimensional site displays.

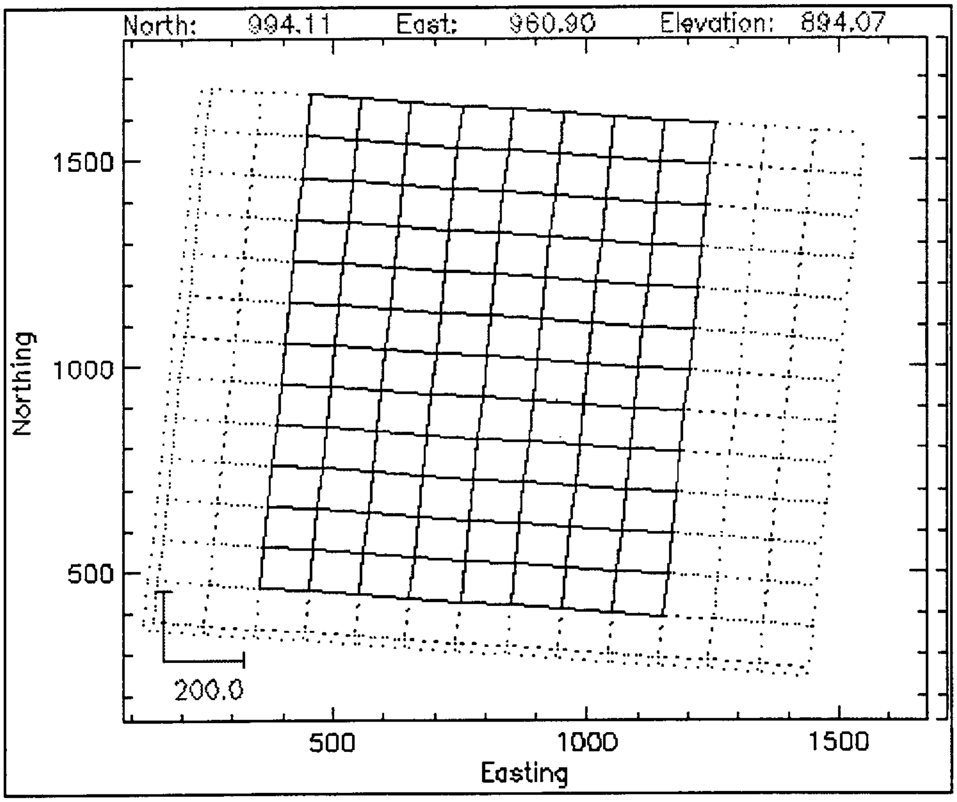

Figure 13. Two Dimensional Site Representation

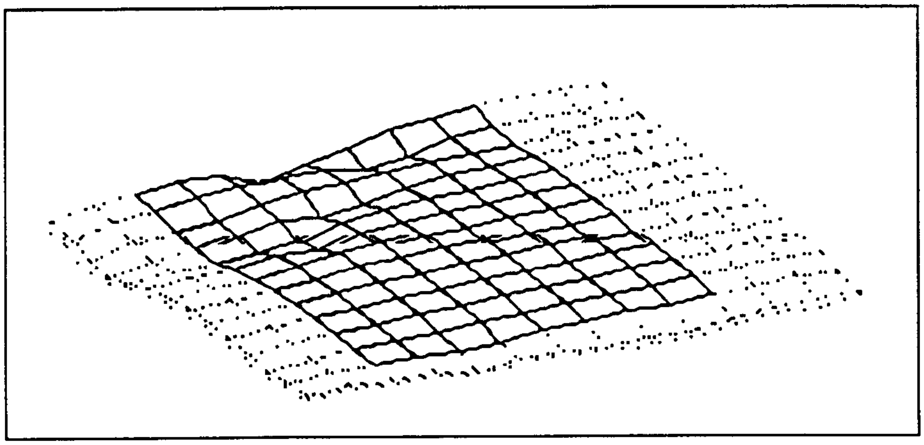

Figure 14. Three Dimensional Site Representation

Additional functions can be performed using ODESA such as overlaying a contour plot of the survey site (Figure 15); rotating, shading and rendering surfaces; translating; and zooming the display in and out.

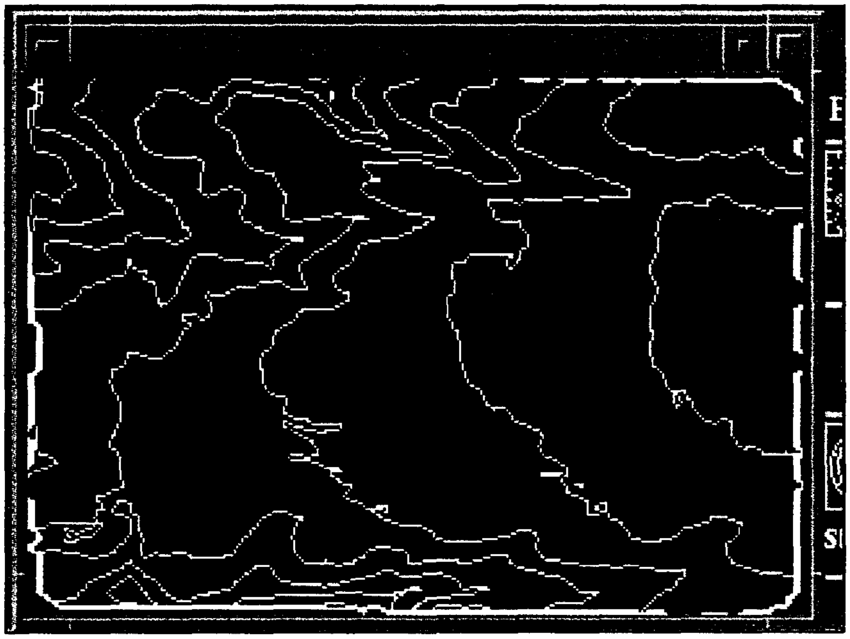

Figure 15. Contour Overlay for ODESA Site Display

4.4 Database Management:

ODESA uses the capabilities of an object-oriented database management system known as ONTOS. ONTOS supports multiple clients distributed across a network. ODESA uses the ONTOS database management system feature to store and retrieve data. ONTOS provides ODESA with a mechanism for reporting target information on the screen, revealing information about demonstrators or retrieving any of the information or data sets ODESA uses for display and processing algorithms.

The following information is used by the ODESA database:

Site Definition
Target Reports and Targets
Detection Rig and Sensor
Performance Weights
Genetic Rules
Heuristic Rules

1. Site Information: Site information includes: site name, boudary information and usage history. It also includes the names of files that contain elevation, magnetic and dielectric constant data.

2. Target Reports and Targets: Target reports are a form of standard data sets used by the JPG Phase I data analysis team. Target report information includes data submitted by JPG Phase I demonstrators in ARS format. A target report lists the company name, date, report number, environmental conditions, and target file name. The target file is an ASCII text representation of an Excel spread sheet.

3. Detection Rig and Sensor: Detection rig and sensor data provide information on the physical configuration of the detection systems used. The Detection Rig Data Set includes navigation, number of sensors, detection technology, data processing type and towing mechanism information. The Sensor Data Set describes the sensor technology and capabilities.

4. Performance Weights: Performance Weights are derived and used by ODESA to characterize the performance of a detection system in correctly identifying the existence of buried objects. The weights describe the performance of a detection system in several categories corresponding to depth, class, type and size of UXO. These weights are used by the Analysis component to analyze and fuse results. Weights are derived automatically by Target Reports analysis, but can be input into ODESA as well.

5. Genetic Rules: Genetic Rules are a means of processing information using a "dominant trait" survival approach, much like the way in which dominant characteristics are passed on from generation to generation in humans and recessive traits are not. Genetic rules were written for four demonstrator data sets that were used for ODESA testing and verification. These rules cannot be applied to user specified data sets,but they serve to demonstrate the viability of using this approach. Further development of genetic algorithms is planned for Phase III.

6. Heuristic Rules: Heuristic Rules fuse demonstrator target data sets into a final target data set that more accurately describes the location of a buried object. This fusion process is accomplished by combining performance measures, a likelihood calculus, probabilities and a merging algorithm.

4.5 ODESA Analysis Algorithms

The knowledge base for ODESA's data fusion modules is derived from processed data collected from 20 demonstrators who participated at the JPG Phase I demonstrations held at the 40-acre test site. To assist in the design of ODESA reasoning components, half of the answer key for the emplaced objects was supplied to generate the rule-base. The target key information supplied to developers consisted of half of the number of targets emplaced in an area approximately half the size of the survey site. The answer key provided a "training window" in which it was possible to develop and test concepts for the fusion components of ODESA. As an initial step, ODESA developers had to determine which aspects of the demonstrator's detection system affected performance. Developers had to answer questions such as which sensor technology could detect deeper targets and which systems utilized GPS or more accurate navigation systems. ODESA analysis algorithms include a scoring utility, heurisitic probabilistic processing, and genetic algorithm techniques.

4.5.1 Scoring Utility:

To provide insight into system and sensor performance, and to have a means of gauging data fusion algorithm effectiveness, ODESA developers generated a scoring utility that analyzes the target data against the baseline data in the training area. The scoring utility counts the number of targets detected, the number of targets missed and the number of false reports inside the training area. It summarizes performance based on categories such as target type, target class, target size, target depth and target material. The scoring utility provides information on ordnance type detected and accuracy of the demonstrators target reports . Developers discovered that many of the systems that did poorly at identifying targets, provided useful information in attempting to classify those same objects. It was determined that the classification categories reported by demonstrators often correlated with detection performance. The scoring utility generated output reports similar to the table that appears in Figure 16.

	Target	**Found**	**Rate**	**Report**	**False**	**Rate**	**Anom**	**Found**	**Rate**
Total	109	54	0.50	238	185	0.78	47	13	0.28
Depth									
Shallow	54	21	0.39	129	117	0.91	-1	0	-1
Medium	16	12	0.75	64	43	0.67	-1	0	-1
Deep	25	14	0.56	21	9	0.43	-1	0	-1
Very Deep	12	7	0.58	15	7	0.47	-1	0	-1
Unknown	12	0	0	9	9	1	-1	13	-1
Size Summary									
Small	54	18	0.33	197	165	0.84	-1	8	-1
Medium	24	15	0.63	20	12	0.60	-1	3	-1
Large	30	21	0.70	21	8	0.38	-1	2	-1
Unknown	1	0	0	0	0	-1	-1	0	-1
Material									
Ferric	86	52	0.60	238	185	0.78	-1	0	-1
Non Ferric	1	1	1	0	0	-1	-1	0	-1
Non Metal	22	1	0.05	0	0	-1	-1	0	-1
Unknown	0	0	-1	0	0	-1	-1	0	-1
Class									
Bomb	8	5	0.63	17	5	0.29	-1	0	-1
Mortar	27	14	0.52	0	0	-1	-1	0	-1
Projectile	28	18	0.64	141	101	0.72	-1	0	-1
Mine	21	0	0	0	0	-1	-1	0	-1
Cluster	4	3	0.75	1	1	1	-1	0	-1
Others	21	14	0.67	0	0	-1	-1	0	-1
Unknown	0	0	-1	79	78	0.99	-1	0	
Type									
Single	84	37	0.44	158	106	0.67	-1	0	-1
Multiple	4	3	0.75	1	1	1	-1	0	-1
Non Ordnance	21	14	0.67	79	78	0.99	-1	0	-1
Unknown	0	0	-1	0	0	-1	-1	0	-1

Figure 16. Summary Data for Sample Target Report Score

The target score sheets summarized the correlation of target data sets with baseline data set information for detection and reporting accuracy. The "-1" value shown in the figure represents that no data was collected in this category. The ODESA scoring methodology does not penalize target data sets that make multiple reports of the same object with slightly varying location data. A possible disadvantage to this approach may be that a large number of reports over a small area may or may not be due to the same real target, but the scoring algorithms scores them as correct if they are within the search radius. This same scoring utility is then used to interpret if the data analysis performed by the ODESA advanced processing (heuristic and genetic algorithm approaches) yielded better results.

4.5.2 ODESA Heuristic Probability Module (HPM)

ODESA utilizes heuristic probabilistic processing in an analysis step known as the HPM. HPM theoretically fuses any number of demonstrator target data sets into an analysis target data set that more accurately describes the location of buried objects. The current HPM fuses data by combining performance measures, a likelihood calculus, probability theory and a merging algorithm.

The ODESA 1.0 prototype was developed with a closed HPM architecture simply for the purposes of proving that HPM processing is valuable in fusing sensor information from a variety of demonstrators. Plans to make the architecture more open in order to allow the user to select data sets for input into the HPM is scheduled for Phase III. Future HPM processing could provide answers to depth, class, size, type and orientation questions.

The HPM assigns a detection likelihood to every detected target in every target data set to be fused; in the future the user would be allowed to select which sensor information he would like to fuse. Using a heuristic approach, a detection likelihood is calculated that combines reporting accuracy probabilities. The decision to use a heuristic method rather that a conventional probability method was made to allow for the development of non-probabilistic rules.

After assigning detection likelihoods, the HPM merges all demonstrator target reports within the specified fusion distance parameter. The merging algorithm is a minimum-cover algorithm designed to produce the minimum number of clusters (groupings of several detected anomalies within the given input radius) with a fixed radius that can contain all target reports; this approach minimizes the number of holes that a remediation team would have to dig. Once the minimum number of clusters is found, data is merged using a simple average of the positions (x, y, and z).

Lastly, the HPM process stores all merged targets that surpass the detection likelihood threshold. This module creates an analysis target data set that can be manipulated via the ODESA GUI and other tools such as the data visualization mechanism and database management tools.

4.5.3 ODESA Genetic Algorithm Module (GAM)

The second fusion mechanism to be utilized by ODESA is referred to as the GAM. The GAM is modeled on the way dominant and recessive traits in humans are passed down from generation to generation. The GAM consists of five major processing components: clustering, fact itemization, rule-set generating, optimizing, and ordnance prediction. The first four components deal with the process of developing a set of rules to drive the data fusion mechanism in the Ordnance Prediction Component. The last component uses the developed rule-set to predict the presence or absence of buried ordnance at a particular location.

GAM Clustering Component

The GAM Clustering Component compiles individual contractor/sensor target reports into groups based upon the proximity of one detected anomaly to another; these groups are called clusters. This component requires an input search radius for processing and examines each target report, comparing it to others nearby, to determine if any of the neighboring reports lie within the circle defined by the cluster center. A cluster list is then generated for further GAM processing.

GAM Fact Itemizer

The GAM Fact Itemizer compiles a set of facts concerning each cluster. These factors are simple statements which summarize the major attributes of each cluster. Ideally, each fact would provide evidence relevant to the determination of whether the cluster contained any real ordnance. Facts can include: class of ordnance, sensor type reporting detection, size of ordnance, depth of ordnance, type, etc.

GAM Rule-Set Generator

The GAM Rule-Set Generator generates the set of rules upon which the fusion module can operate. The rule-base was developed in a purely heuristic manner. The basic approach used is to create many different rule-sets and see how well each rule-set performs. The rule sets with the best performance would be retained for future use on the ODESA prototype system. The mechanism used in the creation of a particular candidate rule-set is a mixture of deterministic and random processes. Initially single-condition rules are generated, and then multi-conditions rules are added. The final rule-set demonstrated in ODESA 1.0 is a combination of 47-single-condition rules, 46-two condition rules, 7-three condition rules totalling 100 rules.

GAM Rule-Set Optimizer:

The Rule-Set Optimizer determines a set of weights for the rules in the rule-set which effectively predicts the presence or absence of ordnance in clusters. Although there is no guarantee that such a set of weights exists, the Rule-Set Optimizer tries to provide the best set of weights. First, the optimizer creates an integer array (a x b), where "a" represents the number of array columns (the size of the population to be used by the genetic algorithm) and " b" represents the number of rules in the set. The optimizer then randomly assigns weights to the cells of the array, ranging from -50 to +50. The optimizer scores each column against the entire set based on true negatives, false negatives, false positives and true positives, where the definitions of these terms follows:

- True Negative: No object was predicted and no object present.
- False Negative: No object waspredicted, but an object was present.
- False Positive: An object was predicted, but no object was present.
- True Positive: An object was predicted, but no object was present.

When all columns have been scored, they are then ranked in terms of overall performance. The columns with the most detections, the fewest misses and fewest false reports are scored the highest. The results of all the columns are then weighted, the results are scored, and divided into two groups consisting of the best and worst performers. The weights of the best performers are kept and are mated to generate a new set of weights to score. The mating of the best performers is repeated until the optimizer determines that it is not feasible to continue; this is usually determined when continuing iterations yield the same or worse performance than previous attempts. At the moment this process is time-consuming, time dependence based on the size of the matrix, the number of rules and the complexity of the rules.

Ordnance Prediction Component:

The Ordnance Prediction Component uses the rule-set developed by the four previous components (GAM Clustering Component, GAM Fact Itemizer, GAM Rule-Set Generator, GAM Rule-Set Optimizer) to predict the presence or absence of buried objects at a particular location. For each cluster the component makes a prediction by running the entire rule-set against that cluster and summing the weights for all the rules found to be true. This process determines whether a target is present.

5.0 EVALUATION OF THE ODESA PROTOTYPE

The purpose of this section of the report is to evaluate the progress of the ODESA 1.0 prototype towards meeting the goals established for the prototype and the goals established for finished product. This section will reiterate prototype and final product ODESA goals, and evaluate ODESA 1.0 against those goals

5.1 Goals of ODESA - The Final Product:

The goals of the ODESA program were developed when the program was initially started. The UXO-CTP program required a mechanism to perform data fusion processing on sensor and environmental data being acquired from UXO detection systems like the Subsurface Ordnance Characterization System (SOCS), the Airborne Ground Penetrating Radar (AGPR), and the Man Portable Ordnance Detection System (ManPODS) projects in a addition to a variety of other data processing efforts utilizing sensor data in the standard data set format such as JPG Phase II and Live Site Demonstrations.

Goals of the ODESA System (Final Product) include:

- Provide more accurate and reliable information on buried UXO, by maximizing the probability of detection and minimizing the false alarm rate
- Establish an open system architecture that would allow flexibility in the utilization of historical, geographical, geological, sensor, known anomaly and user input information
- Provide a platform (hardware and software mechanism) that would fuse sensor, location, environmental and site specific information presented in STD and SRD formats.

- Make intelligent decisions on ordnance characteristics such as location, buried depth, classification, orientation and size
- Provide output information in a format useable by the remote excavator (STD) and EOD technicians (maps and tables)
- Modify historical target files after ordnance items have been remediated to maintain up-to-date historical files of surveyed areas
- Provide user friendly operations

5.2 Goals of ODESA 1.0 Prototype

Early on in the ODESA Phase II effort, the goal of the ODESA system was to design, develop and demonstrate a system that could be used to analyze sensor and site specific information. NAVEODTECHDIV intended to develop the "final product" that need only minimal refinements to make the system operational. After initial discussions between NAVEODTECHDIV and USAEC personnel, it was determined that ODESA development should be based upon the successful completion of several smaller integral steps. The initial effort was chosen to be development of STD data analysis techniques. NAVEODTECHDIV and PRC established the following goals for the ODESA 1.0 prototype, a subset of the goals stated in Section 5.1:

- Develop and demonstrate an interactive graphical user interface for ODESA manipulation. This process allows the user to easily perform operations and data manipulation.
- Analyze sensor information (using genetic algorithms and heuristic analyses) from four different JPG I demonstrators and provide a more accurate accounting of buried UXO detection and location than could be acquired from any single sensor.
- Develop software mechanisms for incorporating future analysis processes.
- Design, develop, and deliver a prototype system that demonstrates data manipulation and data fusion capabilities.
- Develop a system with open, flexible and easily modified software to incorporate enhancements planned for the later development phases.
- Provide output target information in a format acceptable for remediation mechanisms.

5.3 ODESA Evaluation:

This section evaluates the ODESA 1.0 prototype against the parameters outlined in Section 5.2. Each parameter is addressed separately and supporting information is provided to reinforce conclusions made.

5.3.1 **Graphical User Interface** - *Develop and demonstrate an interactive graphical user interface for ODESA manipulation. This process allows the user to easily perform operations and data manipulation.*

The ODESA 1.0 prototype allows operations to be easily performed through a windows (Motif or Open Look) environment. In addition to the developed ODESA capabilities, the prototype allows the operator to utilize Motif, Open Look and Solaris capabilities already available under the SUN SPARC 20 environment.

ODESA commands are easily initiated through a menu and icon driven approach. Commands are accessed through pull-down menus and a software users manual provides easy to understand information for inexperienced operators. The prototype allows the JPG Phase I 40 acre site to be plotted and manipulated on the screen, in two and three dimensional formats. Additional data manipulation capabilities include overlaying grid, contour and sensor data information, zooming in and out capabilities and modification of the color palette to enhance background to target differences. The survey area can be three dimensionally rendered and colors changed to allow the user more visibility in observing target detections.

5.3.2 **Sensor Analysis** - *Analyze sensor information (using genetic algorithms and heuristic analyses) from four different JPG I demonstrators and provide a more accurate accounting of buried UXO detection and location than could be acquired from any single sensor.*

ODESA developers demonstrated the use of genetic algorithms and heuristic probabilistic techniques to analyze demonstrator data sets. This ability was demonstrated through data analysis and system demonstration. Through the data analysis portion, ODESA generated a target data set based on four JPG Phase I demonstrators. The goal was to determine if ODESA's processing ability was better at determining the presence of buried targets than four individual sensors systems. ARS analyzed the ODESA data using the same JPG Phase I demonstrator data processing routines. It was determined that ODESA minimized the false alarm rates incurred by individual sensors. The system's GUI and user friendly operations were demonstrated to NAVEODTECHDIV and AEC personnel at a system demonstration in December 1994 at McLean, Virginia and at Indian Head, Maryland.

5.3.3 **<u>Modifiable Software and Hardware</u>** - *Develop software mechanisms for incorporating future analysis processes.*

This evaluation criteria can be separated into two categories: user interface mechanisms and data analysis processes. ODESA developers have incorporated several mechanisms to allow additional capabilities to be added to the system. In the windows environment, menu options for planned enhanced features have already been incorporated, even though the features themselves have not been developed.

Since the prototype system was designed to analyze JPG Phase I demonstrator data, the genetic algorithm uses four specific demonstrator data sets. ODESA 1.0 does not allow the input of new site or sensor information, the genetic algorithm cannot be performed on any other demonstrators than the four specified, the operating system cannot be upgraded without destroying the prototype. According to system developers, since the software architecture and GUI have mechanisms in place to make the architecture more open, minimal effort will be needed to convert the demonstrator specific and site specific environment into a more open architecture.

The processing capabilities planned for ODESA 2.0, include utilizing semi-raw data information. Because of the complexity and size of this effort, no mechanisms have been put in place to address semi-raw data analysis. This effort will be time-consuming and will involve state-of-the-art data fusion techniques to address the buried UXO problem.

5.3.4 **<u>Prototype Development (Hardware and Software)</u>** - *Design, develop, and deliver a prototype system that demonstrates data manipulation and data fusion capabilities*

ODESA developers designed a prototype system based on the results of Phase I investigations and with the approval of the government. The prototype was initially developed using Phase I information and was used to demonstrate genetic algorithm and heuristic probabilistic analysis methods could provide more accurate information on buried targets. The system was delivered to NAVEODTECHDIV, and Navy personnel were trained on the system.

One problem with the hardware configuration as it exists is that no external disk drive or CD ROM drive was purchased for this system, even though CDs including system software information were delivered with the prototype. An external tape drive was purchased because initial data acquisition studies indicated that a tape unit would be the most likely candidate for SOCS data storage.

Also, there might be a problem when data analysis proceeds to the SRD processing point. Originally two workstations were proposed for Phase II efforts. It was planned that these two workstations would be networked to provide the processing ability needed to manipulate and process data simultaneously. ODESA 2.0 might have to be "ganged" with another workstation to provide the needed speed and processing ability.

The software tools used to develop ODESA were a combination of COTS products and custom-made algorithms (written in C). Because of cost, time and schedule considerations, the contractor purchased the development software and used this software to build ODESA. As a result, the government does not own the development tools, cannot modify any of the analysis routines developed, and owns only a license to "run" the executible files. The Navy intends to purchase the development tools used under Phase II as well as those tools to be used under Phase III. This will give the Government the ability to modify analysis processes without the aid of any specific contractor.

Several "glitches" were found to exist in the prototype system. One problem occurred when the user attempted to leave the ODESA program using the Motif environment: the system's configuration would change to produce white letters on a white screen. ODESA developers investigated the problem, determined that it was a Solaris-generated problem and provided new code to correct the error. Problems were also encountered in the laboratory, when the prototype was networked to other computers. Systems competing for memory space sometimes caused ODESA to crash. Although NAVEODTECHDIV has not been able to recreate this problem, the software user's manual explains how to address this issue and software is provided on tape to reinstall the program.

5.3.5 **Output Mechanisms** - *Provide output target information in a format acceptable to remediation mechanisms.*

Because the data fusion function is required by a variety of remediation mechanisms, the ODESA prototype must be able to provide output files in tabular form, STD files on disk or tape and hard copy printouts for EOD personnel in the field. ODESA 1.0 allows output of target information to a printer in a tabular format. The current system does not have the printer function activated, and while the ODESA program save a file to the hard disk, the operator must exit the ODESA program and utilize UNIX commands to save that file to other media. The print command will have to be made easier to use, and the commands used to save data in different formats should be made transparent to the operator. The output data is in a format compatible with ARS processing required for Phase II development and was used to judge the performance of ODESA. Under Phase III, NAVEODTECHDIV will require the system to save the ODESA output information in ARS and STD format to disk/tape. Regarding requirements for ODESA to send files to a printer and provide hardcopy maps to users, the developers believe that incorporation of these capabilities involves a relatively minor effort and that these capabilities can be added to the prototype utility functions.

6.0 RECOMMENDATIONS

The following section provides recommendations for future enhancements of the ODESA 1.0 prototype. These recommendations were obtained from system developers and NAVEODTECHDIV personnel through system interaction and design experience. Both enhancements to current system capabilities and ideas for new development efforts are discussed below.

6.1 Development of a Fieldable System

Transitioning the ODESA prototype into a deployable system will require the developer to: resolve software problems, fine-tune system performance, enhance existing capabilities, provide general maintenanceand upgrades, and repair the system. After extensive evaluation of the ODESA system by users, a prioritized list of performance enhancements should be generated for the Phase II system. With USAEC approval, this list of enhancements will be generated after formal review of this report, and Phase III enhancements will then begin.

6.2 Genetic Algorithm Module Enhancements

The GAM performed well during Phase II demonstrations. The GAM was optimized for an initial set of conditions specific to the four JPG Phase I demonstrators and will be modified as the ODESA prototype evolves. Because of limitations in funding, time and schedule a simple genetic algorithm was developed to demonstrate feasibility. It is recommended that for Phase III analysis of semi-raw data information, a more advanced genetic algorithm package be used for the GAM. The contractor recommends using a software tool known as the Splicer Genetic Algorithm Tool. This software package was developed by NASA's Software Technology Branch and is currently available for use on government contracts at no cost. ODESA developers have obtained a distribution copy of this software and are ready to integrate this package into the prototype.

The genetic algorithm rule-base provides currently provides no flexibility in selecting new data for fusion or for adaptively changing the GAM rule-base, and ODESA has no capability to store the rules as persistent objects in its database. This limitation in rule-base flexibility can be overcome by integrating the rule-set structures into the ODESA ONTOS database.

The GAM rule base was developed and optimized using the data reported by four JPG Phase I demonstrators. It has no adaptive ability to develop new rule-sets in response to system changes incurred by new demonstrators or sensor devices. It is recommended that an adaptive or learning mechanism be incorporated into the prototype so that the system can "automatically" adjust to changes in the input data stream.

6.3 Heuristic Probabilistic Module Enhancements:

The HPM can be modified to incorporate sensor, site, and target information obtained during the remediation process. The modification process could be accomplished through the use of fuzzy expert system rules as they are acquired. Changes to the HPM can then be made to improve system performance based on specific site, sensor and environmental considerations. Several types of HPM enhancements are suggested:

- Intelligent Clustering Approach - Methods for combining multiple reports in the same survey area should be investigated, and identification and classification characterstics should be exploited when generating fuzzy rule-set information.

- Utilization of Target Report Characteristics -Target report information should be expanded to include target size and mass characteristics. This information can then be utilized and compared to a recognized ordnance reference.

- Enhanced Heuristic Rules - Additional heuristic rules should be added to the rule-base when new information on sensor technology and performance is acquired.

- Alternative Probabilistic Model - Methods for determining the likelihood values used in HPM processing should be investigated.

6.4 Graphical User Interface Enhancements

Several enhancements to the exisiting GUI component are recommended by both ODESA developers and ODESA users. These enhancements revolve around the addition and modification of GUI functions to make the user's data manipulation job much easier. The recommended enhancements are as follows:

- Query Function: The user should have the ability to choose and retrieve information from any file in the database and to display that information in either a textual or graphical format as required. The current query function is limited and prevents the user from performing very broad queries.

- New Survey Site feature: The current system does not have the ability to add new site information. JPG Phase I information was entered manually by the ODESA developers; the input process was not automated. By defining a standard site description format for the input file, a new site could be created dynamically.

- Object Editor: Currently, the user cannot edit objects displayed by the system, create new objects or delete unwanted ones. While it is necessary to retain a copy of the actual raw data for archival purposes, the user may have a need to alter the information when generating new processing strategies. In a flexible system, the object editor should allow the user to perform the follow tasks:

  1. Select which objects should be included in the remediation data set

  2. Incorporate comments with objects inside the ODESA window

  3. Create new analysis targets based on the user's processing experience

  4. Alter the nomenclature used in the input data for incorporation into specific analysis processes.

  5. Include and specify confidence factors to predictions made.

- Graphical Display of Target Data: The ODESA display separates analysis targets from other types of targets by plotting different colors and symbols on the screen to represent different targets. The user should have the option to display special information such as the demonstrator or system that detected the target, the search radius, and so on.

- Display of Semi-Raw Data: Current ODESA processing does not accommodate analysis of semi-raw data. When this new processing capability is incorporated into the prototype, there will be a need to display the data in patterns that can be analyzed. The data manipulation capabilities demonstrated for the target data (2-dimensional and 3-dimensional plotting, rotating the survey area, and slicing vieww will have to be incorporated into the semi-raw data visualization displays.

- GAM Control Capability - The user should be able to modify the GAM module in order to change analysis parameters such as search radius, number of hits and misses, false reports, number of rules in the rule-set, and the number of generations to run the GAM.

- On-line help: The prototype provides no on-line help assistance to the user. If the system is to be field deployed, it should have a on-line help capability.

- Display Additional Site Data: The user should be able display addition site information such as: soil types, bedrock structures, vegetation, lakes, rivers, man-made structures, utilities, site usage, and history data.

- Neural Network Interface: The prototype system does not currently utilize neural network processing. This feature will be incorporated after semi-raw data processing is developed.

- Work Session Preservation: The current system does not permit the user to save an active work session for retrieval at a later time. To minimize the number of redundant processes performed by the user, the system should allow the user to save the particular work session and all accompanying processes for use at a later time.

6.5 Extended Data Collection

In addition to specifying a standard format for semi-raw data information (SRD) and target information (STD), a standard format for a site definition should be generated . The site definition should be easily generated and interpreted. With standardization, little to no manual manipulation of input data to ODESA.

7.0 Future Development Strategy and Conclusions

Future ODESA development encompasses three general areas: enhancement of standard data set analysis, generation of semi-raw data set processing, and development of a fieldable system. Some of the specific development efforts related to these three components can be addressed concurrently, while others require a more serial approach.

7.1 Enhancements of STD Analysis

To maximize the performance of ODESA 1.0 and the Government's investment in data fusion techniques, the next ODESA development emphasis should be making components more flexible and open. Because ODESA 1.0 was tested based on its ability to analyze specific demonstrator information JPG Phase I, the site and demonstrator information was manually entered into the system. An open architecture prototype would allow new site and demonstrator information to be incorporated. Displaying of targets should be refined; currently it is difficult for ODESA operators to visually distinguish between targets detected by different demonstrators. The output of ODESA processing should be made simpler and icon driven. A printer should be incorporated as part of the ODESA system to generate color output plots and remediation tables.

7.2 SRD Processing

From processing target information, ODESA developers learned that manufacturer specific processing of sensor data greatly influences the performance of sensor systems. Companies that demonstrated at JPG Phase I and utilized the same sensor technology had performance level that varied enormously. For a knowledge-based expert system to provide more accurate and reliable UXO information, more sensor processing information would have to be incorporated into ODESA processing. NAVEODTECHDIV intends to pursue development of semi-raw data processing. ODESA could then process target information on SRD and STD information. SRD analysis is a perfect application for developing neural network algorithms and fuzzy logic processing routines. ODESA could "learn" from past experiences with different sensor systems and different survey environments. This would allow the development of a system that acquires new knowledge and insight with changes in sensor technology and environmental conditions. The SRD processing could be performed with or without STD analyses. The results of both STD and SRD processing mechanisms could be compared to determine if manufacturer specific sensor analyses deteriorated the performance capabilities of the sensors themselves. This comparison of analyses can also determine whether manufacturer specific algorithms are really necessary in determining the location, orientation and classification of buried unexploded ordnance or raw sensor data alone is all that is needed.

7.3 Fielding a system

In order to field ODESA, several enhancements would have to be made to the prototype system: provide a help capability, incorporate software checks to insure that the operator is not choosing a feature or a function outside the system's abilities, test the software and debug as necessary, document input and output data in a specific format, and develop error messages.

7.4 Concluding Remarks

The information provided in Sections 7.1 through 7.3 outline the recommended future strategy for the ODESA data fusion project. Enhancements of STD analysis routines and the generation of SRD analysis routines could be performed concurrently, if funding and schedule allow. Fielding an ODESA system would either have to be performed for STD processing only, or for SRD and STD analysis.

A great deal of knowledge was gained from the work performed during Phases I and II of ODESA development. Contractor and government personnel learned that manufacturer specific sensor processing is as much a part of sensor system performance as the characteristics of the sensor being used. Heuristic probabilistic and genetic algorithm data fusion techniques were proven as a means for reducing the false alarm rates inherent in the performance of single sensor based systems. Flexibility in software and hardware architecture is a must, and a large portion of the ODESA prototype was developed without this flexibility. Although the prototype validated the use of data fusion mechanisms to provide more accurate and reliable information on buried UXO, the input and output architecture was built in a closed environment. As a result, the prototype does not allow an operator to process information acquired from any other test site or from any other sensor manufacturer or system. NAVEODTECHDIV concludes that additional effort should be expended to make the configuration open, provide semi-raw data analysis and if these tasks are successful, modify the prototype to a fieldable system.

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