ARO 27543.1-EL

(2)

AD-A234 263

Developing a Methodology to Improve the Performance of Smart Weapon Systems in Countermeasure Environments

Final Report

Authors:

Dr. G. M. Flachs
Dr. Ramon Parra
Dr. Gary Hancock
Ms. Juanita Garrison

November 30, 1990

U. S. Army Research Office
Grant: DAAL03-89-K-0169

Department of Electrical and Computer Engineering
New Mexico State University
Las Cruces, New Mexico 88003

The views, opinions, and/or findings contained in this report are those of the authors and should not be construed as an official Department of the Army position, policy, or decision, unless so designated by other documentation.

UNCLASSIFIED MASTER COPY - FOR REPRODUCTION PURPOSES

SECURITY CLASSIFICATION OF THIS PAGE

REPORT DOCUMENTATION PAGE

1a. REPORT SECURITY CLASSIFICATION Unclassified	1b. RESTRICTIVE MARKINGS
2a. SECURITY CLASSIFICATION AUTHORITY 2b. DECLASSIFICATION / DOWNGRADING SCHEDULE	3. DISTRIBUTION / AVAILABILITY OF REPORT Approved for public release; distribution unlimited.
4. PERFORMING ORGANIZATION REPORT NUMBER(S)	5. MONITORING ORGANIZATION REPORT NUMBER(S) DAAL03-89-K-0169
6a. NAME OF PERFORMING ORGANIZATION New Mexico State Univ. 6b. OFFICE SYMBOL (If applicable)	7a. NAME OF MONITORING ORGANIZATION U. S. Army Research Office
6c. ADDRESS (City, State, and ZIP Code) Box 30001, Dept. 3-0 Las Cruces, NM 88003	7b. ADDRESS (City, State, and ZIP Code) P. O. Box 12211 Research Triangle Park, NC 27709-2211
8a. NAME OF FUNDING / SPONSORING ORGANIZATION U. S. Army Research Office 8b. OFFICE SYMBOL (If applicable)	9. PROCUREMENT INSTRUMENT IDENTIFICATION NUMBER DAAL03-89-K-0169
8c. ADDRESS (City, State, and ZIP Code) P. O. Box 12211 Research Triangle Park, NC 27709-2211	10. SOURCE OF FUNDING NUMBERS PROGRAM ELEMENT NO / PROJECT NO. / TASK NO. / WORK UNIT ACCESSION NO.

11. TITLE (Include Security Classification)
Developing a Methodology to Improve the Performance of Smart Weapon Systems in Countermeasure Environments

12. PERSONAL AUTHOR(S)
Drs. G. M. Flachs, Ramon Parra, Gary Hancock, and Ms. Juanita Garrison

13a. TYPE OF REPORT	13b. TIME COVERED	14. DATE OF REPORT (Year, Month, Day)	15. PAGE COUNT
FINAL	FROM 10/1/89 TO 10/1/90	11/30/90	26

16. SUPPLEMENTARY NOTATION
The view, opinions and/or findings contained in this report are those of the author(s) and should not be construed as an official Department of the Army position, policy, or decision, unless so designated by other documentation.

17. COSATI CODES			18. SUBJECT TERMS (Continue on reverse if necessary and identify by block number)
FIELD	GROUP	SUB-GROUP	Sensor Evaluation, Sensor Selection, Complexity Analysis, Countermeasure Analysis

19. ABSTRACT (Continue on reverse if necessary and identify by block number)

The thrust of the research is to initiate the development of a theoretical and empirical basis for incorporating the important environmental and countermeasures variables into the evaluation, selection and processing of multispectral sensors/features for distinguishing target signatures. The research reflects a small but significant effort to develop a methodology for analyzing multispectral sensors and relating their performance to environmental and countermeasure factors under widely varying environmental and countermeasure conditions.

20. DISTRIBUTION / AVAILABILITY OF ABSTRACT ☐ UNCLASSIFIED/UNLIMITED ☐ SAME AS RPT. ☐ DTIC USERS	21. ABSTRACT SECURITY CLASSIFICATION Unclassified
22a. NAME OF RESPONSIBLE INDIVIDUAL	22b. TELEPHONE (Include Area Code) / 22c. OFFICE SYMBOL

DD FORM 1473, 84 MAR 83 APR edition may be used until exhausted. All other editions are obsolete.

SECURITY CLASSIFICATION OF THIS PAGE
UNCLASSIFIED

TABLE OF CONTENTS

I. STATEMENT OF RESEARCH PROBLEM

Much research and development effort has been devoted to create smart weapon systems capable of detecting air and ground targets in widely varying hostile environments. It is widely accepted that the currently available multispectral sensor technology (infrared, visible, ladar, millimeter wave) has the potential to meet the weapon system requirements. Processing algorithms to distinguish target signatures, however, have not demonstrated the ability to reliably distinguish signatures in widely varying hostile environments. The result has been the development of a large number of algorithms that work only in very limited conditions. Much effort is spent trying to modify these algorithms to work in a larger classes of environments. These efforts have generally been unsuccessful due to the fact that there is no validated theory for adaptively selecting the distinguishing features to terms of the large number of environmental and countermeasure attributes that exist in real battlefield environments. Often these algorithms don't utilize the important physical principles of the atmosphere and countermeasures to select features for distinguishing target and background signatures. The results of these efforts has generally not met the requirements of our modern weapon systems.

The primary objective of this research project is to initiate the development of a theoretical and empirical basis for incorporating the important environmental and countermeasures attributes into the selection and processing of multispectral features to distinguish target signatures. The research described in this report reflects a small but significant effort to develop a methodology to assist in creating, evaluating and selecting sensors/features for widely varying environmental and countermeasure conditions

II. SUMMARY OF RESULTS

The trust of the research is to create a processing environment for evaluating multispectral sensors/features and relating their performance to environmental and countermeasure attributes. Field test data from the SADARM program is used to demonstrate the potential of the multispectral sensor/feature evaluation environment.

A relational database management system is developed to provide an interactive environment for creating multispectral signature databases and interactively evaluating and relating multispectral features to the important environmental and countermeasure attributes. The EOSAEL atmospheric models, developed by the Atmospheric Science Laboratory at WSMR, are used to model the atmospheric effects on sensor signatures. Countermeasure effect models developed by the Electronic Vision Analysis Laboratory at NMSU for the SADARM program are used to model the effect of several countermeasures on signatures. Experience with the SADARM program played a significant role in establishing the structure of the relations and defining the sensor database requirements. Relational operators are developed to partition the information into consistent relations, combine the relations to reduce the uncertainty, and infer relationships.

A new theoretical statistic, called the k-complexity, was developed to measure the complexity of distinguishing signatures in high dimensional feature spaces. The k-complexity statistic is closely related to the minimum probability of error obtained by optimum statistical decision theory. Hence, the complexity relation provides a theoretical measure of the performance of multispectral sensors/features. Field test data from the SADARM program and simulation models for the SADARM processing algorithms provide a basis to verify the theoretical results. By combining the complexity relation with atmospheric and countermeasure relations in a relational database management system, an interactive processing environment is created to evaluate and select sensors/features for widely varying environments. Developing a theoretical basis to relate the performance of high dimensional feature vectors to the important environmental and countermeasure attributes is the major accomplishment of the research project.

2.1 Multispectral Signature Database

The focus of the signature database is on developing a multispectral database to characterize target signatures, background signatures and CM effects. The major results are:

* The development of a relational database structure for target, background and CM signatures.
* The development of a software interface to convert the SADARM sensor database into the relational signature database.
* The development of software modules to convert polarimetric MMW data obtained from Martin Marietta on armored ground vehicles to the relational signature

format.

* The creation of a relational database management interface for selecting signatures by target, background, atmosphere and countermeasure attributes.

A relational multispectral signature database is created using sensor data available from the SADARM field-test program. The signature database is sufficiently general to handle a wide variety of target, background, atmospheric and countermeasure signatures. Using the SADARM multispectral database as a foundation, the structure of the relational signature database is established and a software modules are developed to convert the SADARM sensor data to the new signature format. The signature format was developed to accommodate a large variety of empirical signature data and data derived from theoretical models. The relational structure allows the signatures to be accessed in terms of target, background, sensor and CM attributes. Having a well-defined relational structure provides a user interactive and flexible environment for managing and analyzing the database to establish relations between sensors/features effectiveness and target, background and CM attributes.

Software modules to convert raw polarimetric Millimeter wave (MMW) data onto calibrated target signatures have been completed. The goal is to produce High Resolution Radar (HRR) images of armored vehicles in order to analyze target and CM attributes. The work is primarily Targets 1122 and 1123 of the TABILS 23 database.

These two targets are the same vehicle in different configurations. Target 1122 is in a tactical configuration in which 55 gallon drums, hand tools such as shovels, 5 gallon cans, and other items a tanker might take into combat, are tied onto the vehicle. Target 1123 is the same vehicle covered with mud.

The database is fully polarimetric, high resolution capable, but raw, uncalibrated, uncompensated RCS data of an armored vehicle with different countermeasures. These raw RCS data products were taken with a measurement system that was composed of a fully polarimetric millimeter radar operating at Ka band. The radar has two operating modes: Stationary Target Indicator (STI) and Moving Target Indicator (MTI). The STI measurements were high range resolution profiles using a 63-pulse stepped frequency waveform. The MTI measurements were performed using a fixed frequency, 10 KHz Pulse Repetition Frequency (PRF) waveform.

The STI measurements are Martin Marietta mobile tilt-turntable data taken at their outdoor RCS range facility in Orlando, Florida. Full 360-degree counterclockwise target rotations were collected for depression angles of 1, 2, 3, 4, 5, 10, 15, and 20 degrees. In addition, data was collected at select azimuths during elevation sweeps. During an elevation sweep, the tilt-turntable continually increases elevation, sweeping from 0 degrees to 30 degrees in elevation. All tilt-turntable data was collected at a range of 962 meters.

The MTI fixed frequency data was collected as the test vehicles traversed a compass rose. The compass rose consisted of

24 angle markers (0 to 360 degrees) spaced at 15-degree intervals. Typical data measurements were performed on vehicles traveling at 4, 8, and 12 mph. The recorded data is not full polarimetric; it is primarily transmit vertical polarization. The center of the compass rose was at a range of approximately 1,111 meters from the tower.

The work at EVAL was primarily with the azimuthal sweep STI mode data since it can be reduced to create images of the rotating armored vehicle. The measurements are also fully polarimetric, coherent (Inphase (I) and Quadrature (Q) video), and uses an array of dihedrals and a trihedral corner reflectors to continuously record calibration data with the raw target data. A goal of this endeavor was to produce calibrated target images for the four polarization states for both linear (HH, HV, VV, VH) and circular (LL, LR, RR, RL) polarizations. These high resolution images are to be used to determine target attributes as a function of sensor polarization.

All of the data consists of discrete bipolar analog-to-digital outputs. The recorded measurements are raw, uncompensated time series quanta. Each STI azimuthal sweep data file contains one complete rotation of the target vehicle. Each record of a STI file contains one and only one look at the target. Each STI azimuthal sweep data file contains approximately 29,500 records with each record corresponding to a look every .013 degrees of the rotation. The polarimetric data array of the record contains I and Q video for the 63 frequency stepped pulses of the four polarizations or

504 bytes of information for the record. One complete measurement contained in a STI file corresponds to approximately 14.9 MBytes of measurement information that must be read, calibrated, and system instability compensated (the antenna of the instrumentation radar would wander in the azimuth plane during the measurement). This does not include headers, ground truth such as date, IRIG time, aspect angle, or polarimetric calibration array data.

The calibration process involves removing transmitter leakage and receiver distortions from the measured polarization scattering matrix and scaling using the responses from a polarimetric calibration reflector array. The calibration array consist of a trihedral and two dihedrals rotated at 135 degrees and 90 degrees. Using this array, transmitter leakage and receiver distortions can be compensated out, and an absolute RCS conversion constant can be computed from the known RCS of the trihedral.

Calibration is accomplished by representing the measured polarization scattering matrix by the following matrix equation.

$$M = B^T * A * C \qquad (1)$$

where M = Measured scatter matrix

B = Transmit distortion matrix

C = Receiver distortion matrix, and

A = True scatter matrix.

The matrices M, B, C, and A are complex valued 2x2 matrices. The distortion matrices B and C are calculated using the polarimetric calibration array. B and C must be recalculated for each STI file and are given in target signature report for the target [1]. Once

B and C are known, the calibrated polarization scattering matrix can be determined from (1) or

$$A = (B^T)^{-1} * M * C^{-1} . \quad (2)$$

High range resolution processing requires implementing fast Fourier transform (FFT) techniques to the data. The transformation from the frequency to the range domain allows range resolution within the range gate. A FFT in the azimuthal dimension allows for a two dimensional high range resolution image of the target.

Initial work with the data was to gain confidence in the methods of reading and manipulating the large amounts of data records. Software was written to read the data records and to calculate the uncalibrated and uncompensated median and average RCS for comparison with reported values. The uncalibrated average and median RCS values calculated in the laboratory are within agreement to two decimal places of that reported by Martin Marietta [1]. Computer codes have been written to access and to correctly compensate and calibrate the data in order to obtain the full polarization RCS matrix as a function of angle for the differing azimuthal and elevation sweeps. Work currently underway is to calibrate, compensate, and Fourier Transform the data in range to bring out the range resolution capabilities of the radar. Work is also underway to use the EVAL graphics capabilities for display and reproduction of the calibrated RCS values.

2.2 K-Complexity Research

Major progress has been achieved in the development of a new analytical measure for evaluating the difficulty associated with distinguishing signatures in high dimensional feature spaces. The new measure, called the k-complexity, combines the complexity measure [2,3,4] and the k-nearest neighborhood concept [5] to provide an effective method to estimate the minimum probability of error associated with distinguishing target signatures. The major advantage of the k-complexity is that it can be computed without estimating the joint probability density functions. This is particularly important for multispectral signature analysis where the number of sensors/features of interest can be quite large. Software modules have been developed to compute the k-complexity and experiments have demonstrated its potential.

The k-complexity measure is defined in terms of the k-nearest neighborhood concept often used for estimating probability density functions. Given two sets of signature measurements

$T = \{ X : X = (x1,x2,...,xN)$ target feature vector $\}$

$B = \{ X : X = (x1,x2,...,xN)$ background .eature vector $\}$

each with NS samples that characterize the target and background signatures, respectively. Considering the T and B samples as points in an N dimensional space, the k-nearest neighborhood set, KNN(X), is defined as the k-nearest points to X in the set $T \cup B$. A discrete random variable Y is defined as the number of points in the intersection of KNN(X) and T, i.e.,

$Y = \text{order}(KNN(X) \cap T) \qquad Y \in \{0,1,...,K\}$.

The conditional probability density functions $f(y:X \in T)$ and $f(y:X \in B)$ are defined as the probability of observing y given that

X came from T or B, respectively. Typical pdf's are shown in Figure 1 where the k-complexity is the overlapping area.

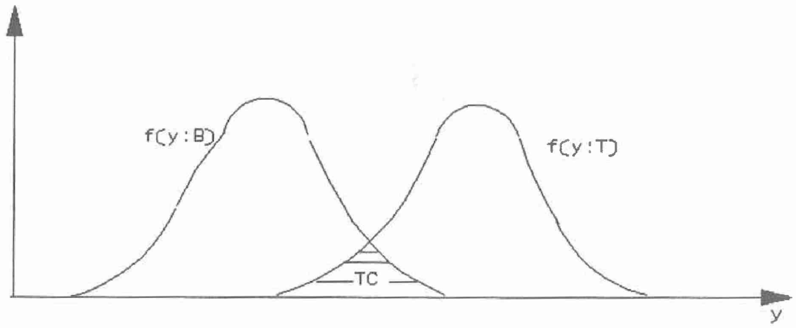

Figure 1. Conditional Probability Density Functions

Letting Pt and Pb define the a priori probabilities of target and backgrounds observations, the KNN-complexity is defined by

$$KC=\frac{1}{(P_t \wedge P_b)}\sum_{y=0}^{K} P_t f(y:X\in T)\wedge P_b f(y:X\in B)\ .$$

where the operator $\wedge$ selects the minimum. It is important to observe that the K-complexity is defined in terms of single dimensional pdf's, making it computationally attractive for estimating the effectiveness of multi-dimensional feature vectors.

The k-complexity varies from 0 to 1 and measures the level of difficulty associated with detecting whether the measurements came from a target or from the background. If the k-complexity is a zero then there is little or no chance of confusing target and background measurements. On the other hand, if k-complexity is one then there is an even chance based on the measured features that the measurements came from a target or background.

Several important theorems [6] have been established to give the K-complexity measure credibility. If the likelihood ratio of the target to background is a constant in the hyperspheres defined by KNN(X), then the k-complexity is directly related to the minimum probability of error (MPE) given by MPE = 0.5*KC. Furthermore, in constant likelihood ratio case, the k-complexity approaches the complexity defined in terms of the joint probability density functions and is independent of k. Experimental results have shown that good estimates of k-complexity are obtained with very reasonable sample sizes. The direct relation between the KC and MPE and the fact that good estimates can be obtained with relatively small samples, motivated the development of the k-complexity to form a basis for measuring the effectiveness of multispectral feature vectors in distinguishing target signatures in CM environments.

Fast algorithms [7] have been developed to locate the k_nearest neighbors in large dimensional feature spaces. The number of comparisons required to locate the k_nearest neighbors is linear with the n^{th} root of the number of samples in the database where n is the dimension of the feature space. Hence, the search algorithm becomes more efficient in larger dimensional feature spaces. The algorithm gains its speed by partitioning the database into a balanced tree structure and then using a "best-first-search" algorithm to locate the k_nearest neighbors.

2.3 Relational Signature Analyzer

A relational signature analyzer has been developed for EVAL's Weapon System Analyzer to provide an interactive environment for analyzing the performance of multispectral sensor/features. The signature analyzer is operational with the ability to access target and background signatures from the signature database, to perform target signal suppression countermeasures and to create atmospheric disturbance effects. An interactive user interface allows the user to select signature data, simulate atmospheric and countermeasure disturbances, compute the complexity of detecting the target signatures from the background signatures and store the information in a relational performance database for analysis. The relational performance database provides an interactive environment for establishing important relationships for sensor performance in terms of countermeasure and atmospheric effects for different environmental conditions.

The performance database is created using the VAX Rdb/VMS environment. The relations in the database can be accessed and analyzed using user-defined interface programs or the Standard Query Language. The relations currently implemented in the relational performance database are given in Table I.

Table I Performance Database Relations.

AIMPOINT	Defines location of targets.
BACKGROUND	Defines characteristics of background clutter.
COMPLEXITY	Defines the complexity of distinguishing target and background signatures.
DATA_SOURCE	Defines source of data.
ENCOUNTER	Provides a detailed description of target encounter information.
ENCOUNTER_TGT	Provides a detailed description of targets in encounter.
ENVIRONMENT	Describes environmental conditions for the encounter.
MISSION	Contains general information about a mission that create the target encounter.
MODIFICATIONS	Defines CM and atmospheric modifications of data.
SENSORS	Defines the sensors/features used in the encounter.
TARGETS	Describes mission specific information associated with the targets.

The relations in the database provide a well-defined structure for describing the interrelationships between sensors/features performance and the important characteristics of the target signature, background clutter, atmospheric disturbances and countermeasure effects. Each relation has a well-defined set of attributes that key the relations together and define the important characteristics associated with the relation. The attributes of the complexity relation are given in Table II.

While the database is relational for flexibility and ease of maintenance, it is designed using a hierarchical (one to many) basis. Constraints have been placed on the relations to allow this design to be maintained. Provision has been made for information not currently available to be added without affecting the structure of the database. As more data is gathered, the database will be available to support research and modeling in the areas of sensors, environmental factors, countermeasures, and various target characteristics.

The relational database is currently in an infant state of development, containing signatures obtained from the SADARM field-test program. Much more effort is required to expand the database and analysis capability to a large class of sensors/features with a wide variety of target and background signatures that reflect important countermeasure and atmospheric disturbances. The relational structure developed, however, provides a foundation for research directed at understanding how countermeasure and atmospheric disturbances affect the complexity of detecting targets in widely varying environmental conditions.

Table II Attributes for the Complexity Relation.

SITE_CODE	Identifies the mission site.
MISSION_NR	Unique mission number.
SOURCE_CODE	Identifies the data source.
ENCOUNTER_NR	Unique target encounter number within the mission.
TGT_SEQ_NR	Sequence number of the target signature for which the complexity was computed.
SENSOR_CODE	Defines the sensors/features used for the complexity computation.
MODIFY_CODE	Defines signature modifications (CM or atmospheric) made prior to complexity calculation.
SCAN_NR	The aimpoint scan for the target.
SENSOR_BEG	The beginning sensor of the target signature.
SENSOR_END	The last sensor of the target signature.
PIXEL_BEG	The first pixel of the target signature.
PIXEL_END	The last pixel of the target signature.
N_FEATURES	Number of features used to compute the k-complexity.
K_VALUE	The value of k used to compute the k-complexity.
TGT_POINTS	Number of samples in the target signature.
BKGND_POINTS	The number of samples in the background signature.
K_COMPLX	The complexity of detecting the target signature in the background signature.

2.4 Relational Database Management Research

A major problem in multisensor smart weapon systems is the limited ability to manage and process large volumes of incoming measurement sensor data to distinguish target from non-target signatures. In addition, smart weapon systems also are often required to incorporate prior knowledge of the environment and sensor performance characteristics. A Relational Data Base Management Structure (RDBMS) is not only suitable for managing and organizing large volumes of related information but also provides a means to infer and incorporate important environmental and sensor relationships. Because of these characteristics, a RDBMS was developed for analyzing and improving the performance of smart weapon systems in hostile environments.

A relational data base is a set of relations along with a well-defined set of operators for managing and analyzing relations. A relation R is defined as a set of n-tuples with k-attributes

$$R = \{ a_{i1}, a_{i2}, \ldots\ldots, a_{ik} \} \quad \text{for } i=1,n$$

that describe the observed behavior of the attributes. A typical relation definition is shown below.

Sensor Type	Scan No.	X Position	Y Position	Object Type	Degree of support

This relation represents the attribute arrangement for a sensor detection relation. RDB operators operating over these attributes and composite environmental relations can describe relevant information about a sensor's performance in varied environmental conditions.

Although, RDBMS technology has been extensively developed and used in other fields, the standard RDBMS operators are not available for the sensor signature characterization problem. There is a large amount of uncertainty associated with the measurement of signatures due to sensor characteristics, target characteristics, background clutter, atmospheric effects and countermeasure effects. All these relations have an inherent uncertainty associated with them; therefore, operators dealing with uncertainty, information fusion, and inference are developed to complement the standard operators. The result of this effort is an iterative RDBMS for developing adaptive multispectral features selection and processing algorithms to distinguish target signatures for a large class of hostile environments.

The research has produced two major contributions. The first contribution is the development of clustering operators to partition input measurement relations into consistent measurement subrelations [8,9]. The second contribution deals with the implementation of information fusion operators to reduce the uncertainty associated with deciding the target signatures in the consistent clusters [8,10].

Several data clustering operators are developed to associate consistent relation measurements. These range in complexity from a simple minimal Euclidian distance assignment [11] to a more robust statistical assignment [12]. A clustering algorithm based on a modification of the K-Means approach was developed for multiple target tracking environments. In this approach a non-iterative procedure operating over the spatial coordinates of the input measurement relation partitions the relation into spatially related (clusters) measurement subrelations. A drawback to this simple approach is that no information about the sensor is used in the clustering process. Ren Luo and Min Lin [12] have shown how sensors' characteristics can be described by probability density functions $p_i(x)$ which can be used to develop an statistical distance d_{ij} among sensor measurements X_i and X_j. Considering two sensors with different probability distributions $p_i(x)$ and $p_j(x)$, the distance measures d_{ij} and d_{ji} are be defined as

$$d_{ij} = 2\int_{X_i}^{x_j} p_i(x)\,dx \qquad \text{and} \qquad d_{ji} = 2\int_{X_j}^{x_i} p_j(x)\,dx$$

Using these statistical distances a relational matrix can be created. Within this context, clusters corresponds to partitions (equivalent classes) of the relational matrix.

When cluster relations are created, there is a need for an operators to combine the information contained in the cluster to determine the target type. The Dempster-Shafer theory of evidence [13] is used to develop operators to reduce uncertainty in the cluster relations. Sensor confidence factors (CF) are used as evidence to develop a belief function that is used to determine the target signature prevailing in the cluster. This operation reduces the uncertainty by combining the evidence from all sensors into a final belief for decision making.

In summary, RDBMS research approached two problems associated with multisensor multitarget systems: data clustering and data fusion. Operators to perform these tasks were developed to complement the standard set of relational operators. Currently, operators to determine sensor performance and sensor selection are under development.

2.5 References

[1] "Target Signature Report No. 5, Target 1122," CDRL AOOT, Martin Marietta Orlando Aerospace and Westinghouse Electric Corporation, Contract Number DAAJ09-86-C-A335, March 27,1987.

[2] Carlson, Jeffrey J., "Decision-Making Complexity with Applications in Electronic Vision," Ph.D. dissertation from New Mexico State University, Sept. 1988.

[3] Beer, Cynthia, "The Tie Statistic and Texture Recognition," Ph.D. dissertation from New Mexico State University, Dec. 1989.

[4] Flachs, G. M., Cynthia L. Beer and David R. Scott, "A Well-Ordered Feature Space Mapping for Sensor Fusion," Proceedings of the SPIE 2nd International Conference on Sensor Fusion, vol. 1100, March 1989.

[5] Fukunaga, Keinosuke, "Statistical Pattern Classification," <u>Handbook of Pattern Recognition and Image Processing</u>, Tzay Y. Young and King-Sun Fu (EDS), Academic Press, New York, 1986.

[6] Scott, D. R., "The K-Nearest Neighbor Statistic With Applications to Electronic Vision Systems," Ph.D. dissertation from New Mexico State University, Dec. 1990.

[7] Scott, D. R., G. M. Flachs and P. T. Gaughan, "Sensor Fusion Using K-nearest Neighbor Concepts," Proceedings of the SPIE Symposium on Advances in Intelligent Systems, Sensor Fusion III, Boston, November 1990.

[8] H. Rasoulian, W.E. Thompson, L.F. Kazda and R. Parra, "A Multisensor Data Fusion Model for Multitarget Tracking," Proceedings of the 90 SPIE OE/Aerospace Sensing Symposium, Orlando FL, April 1990.

[9] W.E. Thompson, R. Parra and C. Tao, "A Pseudo K-Means approach to the Multisensor Multitarget tracking Problem," To appear on the Proc. of the SPIE Orlando '91 Conference on Aerospace Sensing.

[10] R. Parra, W.E. Thompson, G.M. Flachs and A.P. Salvi, "Control Structure for Intelligent Controllers," Proceeding of the 21th. Annual Pittsburgh Conference on Modeling and Simulation, Pittsburgh PA, May 1990.

[11] J.T. Tou and R.C Gonzalez, <u>Pattern Recognition Principles</u>. Boston MA, Addison-Wesley Publishing Co., 1974.

[12] R.C. Luo, M. Lin and R.S. Scherp, "The Issues and Approaches of a Robot Multi-sensor Integration," Proceedings IEEE International Conference on Robotics and Automation, Raleigh, NC, Mar. 1987, pp. 1941-1946.

[13] G. Shafer, A Mathematical Theory of Evidence. Princeton, NJ, Princeton Univ. Press, 1976.

III. PUBLICATIONS AND REPORTS

[1] Scott, D. R., "The K-Nearest Neighbor Statistic With Applications to Electronic Vision Systems," Ph.D. dissertation from New Mexico State University, Dec. 1990.

[2] Scott, D. R., G. M. Flachs and P. T. Gaughan, "Sensor Fusion Using K-nearest Neighbor Concepts," Proceedings of the SPIE Symposium on Advances in Intelligent Systems, Sensor Fusion III, Boston, November 1990.

[3] H. Rasoulian, W.E. Thompson, L.F. Kazda and R. Parra, "A Multisensor Data Fusion Model for Multitarget Tracking," Proceedings of the 90 SPIE OE/Aerospace Sensing Symposium, Orlando FL, April 1990.

[4] W.E. Thompson, R. Parra and C. Tao, "A Pseudo K-Means approach to the Multisensor Multitarget tracking Problem," To appear on the Proc. of the SPIE Orlando '91 Conference on Aerospace Sensing.

[5] R. Parra, W.E. Thompson, G.M. Flachs and A.P. Salvi, "Control Structure for Intelligent Controllers," Proceeding of the 21th. Annual Pittsburgh Conference on Modeling and Simulation, Pittsburgh PA, May 1990.

IV. PERSONNEL SUPPORTED AND DEGREES GRANTED

Principal Investigators		Research
Flachs, G. M.	(3.6 wks Summer)	KNN Concepts
Parra, R.	(1/8 ay)	Relational Database
Garrison, J. S.	(5 wks PSL)	Signature Analyzer

Students Supported		Research
Chung Ng	(GRA)	Signature Models
Ewa Antosik	(GRA)	Relational Database
Natalie Clark	(GRA)	KNN Search Algorithms

V. GOVERNMENT/INDUSTRIAL CONTACTS

An important goal of the research project is to transfer new concepts and techniques to the Army laboratories and industry. Often this requires the investigators to present seminars and assist the laboratories implement the concepts in their applications. The feedback, however, is important in evaluating and motivating the basic research.

* A seminar was presented on the signature analysis research at NMSU to ARDEC in February 1990. The seminar was presented to staff members of several weapon system programs. About twenty research scientists attended the seminar.

* The signature analyzer will be incorporated into EVAL's weapon system analyzer and delivered to ARDEC in the next software update.

* The signature analyzer has been presented and demonstrated to several government and industrial scientist interested in signature analysis.