

ETL-0550

AD-A215 154

Bibliography of In-House and Contract Reports, Supplement 16

Annemarie Black
E. James Books
Karen Carroll

October 1989

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U.S. Army Corps of Engineers
Engineer Topographic Laboratories
Fort Belvoir, Virginia 22060-5546

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Form Approved
OMB No. 0704-0188

Public reporting burden for this collection of information is estimated to average 1 hour per response, including the time for reviewing instructions, searching existing data sources, gathering and maintaining the data needed, and completing and reviewing the collection of information. Send comments regarding this burden estimate or any other aspect of this collection of information, including suggestions for reducing this burden, to Washington Headquarters Services, Directorate for Information Operations and Reports, 1215 Jefferson Davis Highway, Suite 1204, Arlington, VA 22202-4302, and to the Office of Management and Budget, Paperwork Reduction Project (0704-0188), Washington, DC 20503

1. AGENCY USE ONLY (Leave blank)		2. REPORT DATE October 1989	3. REPORT TYPE AND DATES COVERED Bibliography: Jan. 88 - Sept. 89	
4. TITLE AND SUBTITLE Bibliography of In-House and Contract, Supplement 16			5. FUNDING NUMBERS	
6. AUTHOR(S) Annemarie Black E. James Books Karen Carroll				
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) U.S. Army Engineer Topographic Laboratories Fort Belvoir, Virginia 22060-5546			8. PERFORMING ORGANIZATION REPORT NUMBER ETL-0550	
9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)			10. SPONSORING/MONITORING AGENCY REPORT NUMBER	
11. SUPPLEMENTARY NOTES				
12a. DISTRIBUTION/AVAILABILITY STATEMENT Approved for public release; distribution is unlimited.			12b. DISTRIBUTION CODE	
13. ABSTRACT (Maximum 200 words) This is Supplement 16 to the (ETL) <i>Bibliography of In-House and Contract Reports</i> . This supplement provides author and title indexes, abstracts, and AD numbers for the 1987, 1988 and 1989 additions to the continuing bibliography. It also contains a complete title index designed to be used in conjunction with the 16 published bibliographies and refers to them by year and number.				
14. SUBJECT TERMS Bibliography Scientific Reports			15. NUMBER OF PAGES 91	
			16. PRICE CODE	
17. SECURITY CLASSIFICATION OF REPORT UNCLASSIFIED	18. SECURITY CLASSIFICATION OF THIS PAGE UNCLASSIFIED	19. SECURITY CLASSIFICATION OF ABSTRACT UNCLASSIFIED	20. LIMITATION OF ABSTRACT UL	

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PREFACE

This is Supplement 16 to the report titled, "Bibliography of In-House and Contract Reports" AD-877 653L; Supplement 1, AD-890 066L; Supplement 2, AD-905 548L; Supplement 3, AD-B005 275L; Supplement 4, AD-B010 642L; Supplement 5, AD-B019 966L; Supplement 6, AD-055 468; Supplement 7, AD-A068 744; Supplement 8, AD-A084 111; Supplement 9, AD-A099 803; Supplement 10, AD-A113 006; Supplement 11, AD-A128 400; Supplement 12, AD-A141 778; Supplement 13, AD-A160 607; Supplement 14, AD-A173 750; and Supplement 15, AD-A195 953. It is a continuing bibliography of reports prepared by and for the U.S. Army Engineer Topographic Laboratories, Fort Belvoir, Virginia. This bibliography includes reports that were published from 1 January 1988 through 30 September 1989.

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Colonel David F. Maune, EN, was Commander and Director, and Mr. Walter E. Boge was Technical Director of the Engineer Topographic Laboratories during the report preparation.

ETL-0478

AD-A203 257

**COMPUTER STRATEGY FOR DETECTING LINE FEATURES ON SIMULATED BINARY
ARRAYS IN SUPPORT OF RADAR FEATURE EXTRACTION
November 1988**

Frederick W. Rohde

Keywords: Radar Image Analysis, Terrain Feature Extraction, Terrain Analysis

Line search techniques for linear features in digital radar images are developed and described. It is shown that the search techniques can be represented by codes. The codes determine the major directions of search and the removal of side branches. The testbed that is necessary to investigate and test the search techniques is described.

ETL-0488

AD-A208 271

**PARALLEL VISION ALGORITHMS
FIRST ANNUAL TECHNICAL REPORT
October 1987**

Hussein A. H. Ibrahim, Editor
John R. Kender
Lisa G. Brown

Columbia University

DACA76-86-C-0024

Keywords: Computer Vision, Artificial Intelligence, Image Understanding, Multi-Resolution, Stereo, Texture, Strategy Computing

The "Parallel Vision Algorithms" annual report covers the project activities during the period from October 1, 1986, through September 30, 1987. The objective of this project is to develop and implement, on highly parallel computers, vision algorithms that combine stereo, texture, and multi-resolution techniques for determining local surface orientation and depth. Such algorithms will immediately serve as front-ends for autonomous land vehicle navigation systems. During the first year of the project, efforts have concentrated on two fronts. First, developing and testing the parallel programming environment that will be used to develop, implement and test our parallel vision algorithms. Second, developing and testing multi-resolution stereo, and texture algorithms. This report describes the status and progress on these two fronts. We describe first the programming environment developed, and mapping scheme that allows efficient use of the connection machine for pyramid (multi-resolution) algorithms. Second, we present algorithms and test results for multi-resolution stereo, and texture algorithms. Also the initial results of the starting efforts of integrating stereo and texture algorithms are presented.

ETL-0489

AD-A190 345

AN EXPERT VISION SYSTEM FOR AUTONOMOUS LAND VEHICLE ROAD FOLLOWING
January 1988

Sven J. Dickinson
Larry S. Davis

University of Maryland

DACA76-84-C-0004

Keywords: Image Understanding, Vision-Based Navigation, Computer Vision Processing, Structured Blackboard

A production system model of problem solving is applied to the design of a vision system by which an autonomous land vehicle (ALV) navigates roads. The ALV vision task consists of hypothesizing objects in a scene model and verifying these hypotheses using the vehicle's sensors. Object hypothesis generation is based on the local navigation task, an *a priori* road map, and the contents of the scene model. Verification of an object hypothesis involves directing the sensors toward the expected location of the object, collecting evidence in support of the object, and reasoning about the evidence. Constructing the scene model consists of building a semantic network of object frames exhibiting component, spatial, and inheritance relationships. The control structure is provided by a set of communicating production systems implementing a structured blackboard; each production system contains rules for defining the attributes of a particular class of object frame. The combination of production system and object oriented programming techniques results in a flexible control structure able to accommodate new object classes, reasoning strategies, vehicle sensors, and image analysis techniques.

ETL-0490

AD-A190 346

BUILDING A 3-D WORLD MODEL FOR A MOBILE ROBOT FROM SENSORY DATA
January 1988

Minoru Asada

University of Maryland

DACA76-84-C-0004

Keywords: Autonomous Land Vehicle, World Model, Sensor Map, Height Map, Global Map, Path Planning, Range Data

This paper presents a method for building a 3-D world model for a mobile robot from sensory data. The 3-D world model consists of three kinds of maps: a sensor map, a local map and a global map. A range image (sensor map) is transformed to a height map (local map) with respect to a mobile robot. First, the height map is segmented into four categories (unexplored, occluded, traversable, and obstacle regions) for obstacle detection and path planning. Next, obstacle regions are classified into artificial objects (buildings, cars, road signs, etc.) or natural objects (trees, bushes, etc.) using both the height image and video image. One drawback of the height map — the recovery of vertical planes — is overcome by the utilization of multiple height maps which include the maximum and minimum height of each point, and the number of points in the range image mapped into one point in the height map. The multiple height map is useful not only for finding vertical planes in the height map but also for segmentation of the video image. Finally, the height maps are integrated into a global map by matching geometrical properties and updating region labels. The method is tested on a model including many objects, such as trees, buildings, cars, and so on.

ETL-0491

AD-A192 139

**PRODUCTION OF DENSE RANGE IMAGES WITH THE CVL
LIGHT-STRIP RANGE SCANNER
January 1988**

Daniel DeMenthon
Tharakesh Siddalingaiah
Larry S. Davis

University of Maryland

DACA76-84-C-0004

Keywords: Range Scanner, Computer Vision, Range Images, Light-Stripe Scanner

This report describes a system able to produce 512 x 512 range images of model scenes in the laboratory. This ranging instrument, which comprises a light-emitting slit, a cylindrical lens, a step-motor controlled mirror and a CCD camera, is compact enough to be mounted on the tool plate of a robot arm. The light source itself is mounted away from this structure, and the light is brought to the slit by a flexible fiberoptic light guide. The robot arm's motion can be controlled by inputs from the range scanner, for simulation of autonomous vehicles equipped with rangefinders. This system is programmed to produce range images which are comparable in many respects to range images produced by laser range scanners. With this similitude of formats, software for edge detection, object recognition, dynamic path planning or data fusion with video images can be developed on range images produced by this laboratory equipment and can be easily ported to laser ranging systems.

ETL-0492

AD-A192 990

**EXPERT SYSTEM FOR MINEFIELD SITE PREDICTION (PHASE I)
FIRST YEAR REPORT
February 1988**

Michael Dillencourt
Jonathan W. Doughty
Anne L. Downs

PAR Government Systems Corporation

DACA72-86-C-0017

Keywords: Expert System, Minefield Site Prediction, Quadtree, Terrain Analysis

The software design of the prototype Minefield Site Prediction Expert Systems (MSPES) is described. The ultimate goal of the system is to emulate the role of a terrain analyst in predicting likely mine sites. The major components of the system are the inference system, the geographic information system, and the user interface. The inference system is driven by a goal-directed backward chaining mechanism. The geographic information system is based on quadtrees. The user interface is menu-driven, and is based on an object-oriented graphics package.

The report describes the implementation of the prototype system. It also contains recommendations for the operational system, based on an evaluation of the prototype system. Descriptions of data format conversion capabilities, a detailed description of the geographic processing algorithms, and a complete listing of the rulebase are included as appendices.

ETL-0493

AD-B120 373L

AN APPROACH TO MODEL FORMATION BASED ON FORMAL GEOMETRIC REASONING
March 1988

Deepak Kapur
Joseph L. Mundy

General Electric Company

DACA76-86-C-0007

Keywords: Model Matching, Image Understanding, Range Sensor, Geometric Reasoning

Methods for model matching and model formation are developed in the context of a model-based image understanding system. A method using a pair of vertices and associated edges for determining the correct match between an object model and an unsupervised segmentation of an image data into two dimensional edges and vertices is outlined.

Two approaches towards generation of models for model matching are discussed. The first approach involves the use of a range sensor which uses triangulation to determine a set of three-dimensional structures of an object. This approach has been successful in generating a polyhedral object which can be used for model matching. Efforts are under way to apply the approach to military vehicles. The second approach involves the use of geometric and algebraic reasoning methods to generate a set of constraints on the geometric and topological structure of an object from its image. These constraints are subsequently used as a model for matching against another image (called the view consistency problem). The effort so far has been to develop and experiment with techniques for reasoning about geometry relationships. A geometric reasoning system, GEometer, has been developed which has been used to prove hundreds of plane geometry theorems. GEometer has also been extended to solve the view consistency problem of ideal polyhedral objects.

ETL-0494

AD-A193 375

A SIMPLE COMPUTER DATABASE SYSTEM FOR UNIX
March 1988

Michael M. McDonnell

Keywords: UNIX, String, Database, Inventory, Rolodex, Computer Program

This is a computer program that allows users to maintain and access a file containing addresses, inventory items, or other units of text information grouped in blocks separated by blank lines. Any string within a file may be used to find and print the block(s) of text containing the string. A file is created, maintained, and accessed by a group of UNIX programs which have been designed for speed and simplicity. Besides being useful in themselves, these programs illustrate cooperative use of C programs and shell command files. A history of the development will also be given since this is of general interest to programmers.

This program uses standard UNIX techniques, except for the Boyer-Moore string matching algorithm. It offers a simple and extensible approach to the type of database represented by the rolodex file found in many offices. This simple flat-file database has proven valuable as a way of maintaining and accessing an inventory file and an address file. The data file is a plain text file containing no control characters aside from new lines. The file is therefore easy to create and maintain using ordinary text editors, though a program is provided to facilitate item entry for users. On an unloaded VAX 780 it takes about 1.5 seconds to search a data file of 150,000 characters. On a system which is about 10 users, this time is about 3 seconds.

**PARALLEL ALGORITHMS FOR COMPUTER VISION
SECOND YEAR REPORT
March 1988**

Tomaso Poggio
James Little

Massachusetts Institute of Technology

DACA76-85-C-0010

Keywords: Computer Vision, Parallel Algorithms & Architectures

Much of our work during the past year has focused on building our Vision Machine system. The Vision Machine is a testbed for our research on parallel vision algorithms and their integration. The system consists of an input device — a movable two camera Eye-Head system with six degrees of freedom — and the 16K Connection Machine (CM-1). We have concentrated on implementing and testing early vision algorithms, and on developing new sophisticated techniques for their integration. The output of the integration stage will be used for navigation and recognition tasks.

From August 31, 1986 to August 31, 1987, we have been using the Connection Machine delivered on July 31, 1986 by Thinking Machines Corporation (TMC). We have developed and tested a substantial body of vision software on the machine. We have also nearly completed, well ahead of schedule, the development of an integrated Vision Machine that includes several early vision algorithms, and the integration stage of middle vision. As outlined in our original proposal, we have begun to explore parallel algorithms at the higher level of recognition. We have also studied the performance of alternative, nonconventional architectures for navigation, and worked on the difficult issue of alternative parallel languages for the Connection Machine, in addition to *LISP and C*. The body of this report gives an overview of the results of our research during the second twelve months of funding. Details can be found in the report.

ETL-0497

AD-A203 688

**LINEAR FEATURE EXTRACTION FROM RADAR IMAGERY: SBIR PHASE II, OPTION I
April 1988**

Gary D. Connor
David L. Milgram
Daryl T. Lawton
Christopher C. McConnell

Advanced Decision Systems

DACA72-86-C-0004

Keywords: SAR, Feature Extraction, Edge Detection, Terrain Analysis, Image Understanding

The goal of this effort is to develop and demonstrate prototype processing capabilities for a knowledge-based system to automatically extract and analyze linear features from synthetic aperture radar (SAR) imagery. This effort constitutes Phase II funding through the Defense Small Business Innovative Research (SBIR) Program. Previous work examined the feasibility of and technology issues involved in the development of an automated linear feature extraction system. This Option I Final Report documents this examination and the technologies involved in automating this image understanding task. In particular, it reports on a major software delivery containing an image processing algorithmic base, a "perceptual structures" manipulation package, a preliminary hypothesis management framework and an enhanced user interface.

**THE IMAGE UNDERSTANDING ARCHITECTURE PROJECT
FIRST ANNUAL REPORT
April 1988**

Charles C. Weems
Steven P. Levitan
Allen R. Hanson
Edward M. Riseman

David B. Shu
J. Gregory Nash
James Burrill
Michael Rudenko

University of Massachusetts

DACA76-86-C-0015

Keywords: Image Understanding Architecture, Knowledge-Based Vision, Real-Time Computer Vision, Software Simulator, Parallel Processor

This report presents the results of the Image Understanding Architecture (IUA) project for the first year of its two-year contract period. The purpose of the IUA project is to design and construct a next-generation parallel processor that specifically addresses the needs of real-time computer vision applications.

The current effort involves the construction of a proof-of-concept, 1/64th scale prototype IUA system (hardware and software) that will serve as the basis of research leading to the design and construction of the next generation IUA system. The work is being performed jointly by the University of Massachusetts at Amherst, and Hughes Research Laboratories in Malibu.

Included in this report are a summary of accomplishments during the first year, an overview of the IUA design, a collection of algorithms, a discussion of a vision processing scenario as it is expected to take place on the IUA, a summary of the performance figures for the IUA on the DARPA IU Benchmark Exercise, a detailed description of the architecture of the bottom level of the IUA, documentation for the IUA software simulators, and a report of the hardware design efforts at Hughes.

**BIBLIOGRAPHY OF IN-HOUSE AND CONTRACT REPORTS,
SUPPLEMENT 15
April 1988**

Annemarie Black
E. James Books
Karen Carroll

Keywords: Bibliography, Scientific Reports

This is Supplement 15 to the ETL *Bibliography of In-House and Contract Reports*. This supplement provides author and title indexes, abstracts, and AD numbers for the 1986 and 1987 additions to the continuing bibliography. It also contains a complete title index designed to be used in conjunction with the 15 published bibliographies and refers to them by year and number. AD-877 653L (1970); AD-890 066L (1971); AD-905 548L (1972); AD-B005 275L (1975); AD-B010 642L (1976); AD-B019 966L (1977); AD-A055 468 (1978); AD-A068 744 (1979); AD-A084 111 (1980); AD-A099 803 (1981); AD-A113 006 (1982); AD-A128 400 (1983); AD-A141 778 (1984); AD-A173 750 (1986).

ETL-0501

AD-B132 062L

**ANALYSIS AND TEST RESULTS OF A GYROCOMPASS WITH REDUCED
SUSCEPTIBILITY TO SHOCK, VIBRATION, AND MOTION**

May 1988

**Barbara S. Gryglaszewski
R. J. Craig**

Incosym, Inc.

DACA72-85-C-0003

Keywords: Earth Rate, North, Gyrocompass, Azimuth, Axis, Angular Rate, Heading, Align, Inclination, Rotate, Milliradian, Time Constant, Bias, Gyro, Accelerometer

Analysis, fabrication, and testing was performed to determine operating performance in severe dynamic environments (angular rotations and translational accelerations) of the North finding system known as the Azimuth and Inclination Measuring System (AIMS). Tests were performed in both the laboratory and a test vehicle. Test data showed that the AIMS system could find North to an accuracy of approximately 2 milliradians under severe dynamic conditions in a period of 60 to 120 seconds over temperature range from -35 degrees Centigrade to 50 degrees Centigrade. The dynamic environments included angular translational vibrations as high as 1 g over frequency range of 1 to 6 Hz.

Additional tests performed in a test van exposed to heavy wind gusts with personnel inside and engine running showed accuracy of 2.5 milliradians with total reaction time equal to 60 seconds.

ETL-0502

AD-A200 291

**IMPROVING CLASSIFICATION ACCURACY OF RADAR IMAGES USING
A MULTIPLE-STAGE CLASSIFIER**

September 1988

**Neil D. Fox
P. F. Chen**

Keywords: Radar Image Feature Extraction, Texture, Histogram, Classification, Pattern Recognition, Edge Operators

A simple method was introduced to classify radar image samples repeatedly for achieving a higher accuracy than by using a single-stage classifier. A Sobel edge operator was applied between the stages of classification to enhance the difference in texture between categories of radar image samples, thus reducing the overlap of image categories.

ETL-0503

AD-A201 023

**AN EMPIRICAL SURFACE TEMPERATURE MODEL
September 1988**

Alan E. Krusinger

Keywords: Surface Temperature, Thermal Infrared, Empirical Model, Backgrounds, Type-Days, Background Clutter, ATR, Automatic Target Recognition, Meteorological Variables, Modeling, Diurnal Temperature, Composite Days, Curve Fitting

Based on long-term radiometric, temperature, and meteorological measurements, made at instrumented test sites, the U.S. Army Engineer Topographic Laboratories (USAETL) has developed an empirical surface temperature prediction model. The model has simple inputs, with no measurements, for use by the field Army. The model uses analogous climates and type-days, or composite days, of relatively unique weather conditions. Model inputs of climate, season, sky cover, and surface soil wetness produce diurnal temperature curves for various backgrounds, for each type-day. The temperate climate, summer season model is presented in this report.

ETL-0504

AD-A201 171

**COMPUTER GENERATION OF FRACTAL TERRAINS
September 1988**

**Eugene A. Margerum
Anne Werkheiser**

Keywords: Fractals, LISP, Terrain, Artificial Landscapes, Simulation, Computer Graphics

The use of fractals for the generation of artificial terrains is presented. An introduction to the relevant basic properties of fractals is given and a method for the generation of artificial fractal landscapes is described. The algorithm has been used to develop a LISP computer program for synthesizing topographic surfaces. Examples of the resulting structures are given in the form of a series of profiled surfaces representing landscapes of varying fractal dimension and varying vertical dilation. The LISP computer programs are also given and described.

ETL-0505

AD-A200 157

**A BIBLIOGRAPHY ON THE CHEMICAL WEATHERING OF GRANITIC ROCKS
September 1988**

**Judy Ehlen, USAETL
A. J. W. Gerrard, School of Geography, University of Birmingham, England**

Keywords: Chemical Weathering, Granitic Rocks, Geomorphology, Soils, Geology

This bibliography lists many of the papers in the international published geological, geomorphological and soils literature that discuss the chemical weathering of rocks often considered "non-soluble." Emphasis is placed on granitic rocks.

ETL-0506

AD-B132 495L

**AUTONOMOUS LAND VEHICLE (ALV) PROGRAM — PHASE I
FINAL REPORT
May 1988**

Rainer Koenig, Editor

Martin Marietta Information and Communications Systems

DACA76-84-C-0005

Keywords: Autonomous Land Vehicle, Unmanned Vehicles, Robotics, Artificial Intelligence, Image Understanding, Computer Vision Processing

During Phase I of the ALV program, we went through three generations of requirements definition, hardware and software design, system integration and testing, culminating in increasingly more difficult system demonstrations. These demonstrations took place in May 1985 (1 km of road following at 3 km/hr); in May 1986 (4 km of road following at speeds up to 10 km/hr) and, in November 1987 (4.2 km of road following at speeds up to 20 km/hr and averaging a speed of 14 km/hr while avoiding obstacles on the road). In addition to these demonstrations, the ALV program has supported the DARPA Strategic Computing (SC) community in the areas of image processing and understanding, advanced parallel processing architectures, reasoning (planning, navigating, piloting), and sensor integration. Technology transfers took place in both directions, involving various corporations such as Hughes, General Dynamics, and FMC, as well as several universities, such as Carnegie-Mellon University (CMU), the University of Maryland, the University of Massachusetts, Stanford University, and the Massachusetts Institute of Technology.

ETL-0507

AD-B129 663L

**KNOWLEDGE-BASED VISION TECHNIQUES FOR THE AUTONOMOUS
LAND VEHICLE (ALV) PROGRAM
SECOND ANNUAL REPORT
June 1988**

**Martin A. Fischler
Robert C. Bolles**

SRI International

DACA76-85-C-0004

Keywords: Knowledge Representation, 3-D Descriptions, Mission Planning, Computer Vision

The goal of this research is to develop techniques for automatically acquiring and representing knowledge about complex cultural and natural environments for such purposes as intelligence analysis, planning, navigation, and manipulation. Our research strategy is to (1) develop representations and techniques for storing (or incrementally learning) semantic and geographic information about a specific geographic area to permit both mission planning and knowledge-based interpretation of sensed data, (2) develop representations for natural and man-made objects, (3) develop techniques to predict distinctive features of these objects that can be used to identify them, and (4) develop techniques for building three-dimensional descriptions of an environment from data gathered by range or intensity sensors moving through this environment. In this report we describe our progress and plans in these areas.

ETL-0508

AD-A203 689

**DEVELOPMENT OF AN INTEGRATED MOBILE ROBOT SYSTEM AT CMU
JUNE 1987 ANNUAL REPORT
July 1988**

**Steve Shafer
William Whittaker**

Carnegie-Mellon University

DACA76-86-C-0019

Keywords: Strategic Computing, Machine Vision, Autonomous Land Vehicle

This report describes progress in development of an integrated mobile robot system at the Carnegie-Mellon Robotics Institute from July 1986 to June 1987. This research was sponsored by DARPA as part of the Strategic Computing Vision Program.

Our program includes a broad agenda of research in the development of mobile robot vehicles. In the year covered by this report, we addressed two major areas in vehicle development (NAVLAB vehicle and Robot control system) and two major areas in robot architecture development (CODGER blackboard and Navigation architecture). We built the NAVLAB mobile robot vehicle by outfitting a commercial truck chassis with computer-controlled drive and steering controls and a set of on-board computer workstations. The NAVLAB serves as a mobile navigation laboratory that allows researchers to interact intensively with the system during testing and execution. We also developed a real-time controller system for the NAVLAB using a collection of coordinated processors and software. The CODGER blackboard system incorporates substantial features for geometric reasoning and task synchronization that have not been incorporated in blackboards before. We also developed the Driving Pipeline architecture for coordinating road following, obstacle avoidance, and vehicle motion control. This hardware and software combination is the basis for the New Generation System (NGS) for robot vision and navigation, which will tie together existing and emerging technologies.

ETL-0509

AD-A203 712

**VISION-BASED NAVIGATION FOR AUTONOMOUS GROUND VEHICLES
FIRST ANNUAL REPORT
July 1988**

Larry S. Davis

University of Maryland

DACA76-84-C-0004

Keywords: Autonomous Navigation, Road Following, Computer Vision

This is the first annual report for ETL contract DACA76-84-C-0004. Our activities on the project principally involved building an experimental facility for performing research in vision for autonomous navigation of ground vehicles and developing a computational framework for constructing visual navigation systems.

ETL-0510

AD-A203 309

**A PROGRAMMING ENVIRONMENT FOR PARALLEL VISION ALGORITHMS
Third Annual Report
July 1988**

Christopher Brown

University of Rochester

DACA76-85-C-0001

Keywords: Parallel Processors, Computer Vision, Butterfly Computer

During the third year of the award period, the Computer Science Department of the University of Rochester concentrated on (1) operating systems, debugging support, and performance monitoring for parallel computation, (2) systems utilities for large-scale MIMD (multiple instruction stream, multiple data stream) computation, and (3) applications in active vision. This research produced internal and external reports, as well as some exportable code and several demonstration systems. Implementation of Psyche, a new operating system for large shared-memory non-uniform memory access time computers has begun. The BBN Butterfly Parallel Processor was not applied to low-level vision; instead a parallel-pipelined special-purpose device, the Datacube MaxVideo system, was integrated into the laboratory environment. The vision laboratory was also enhanced by a robot arm that positions and moves the three degree-of-freedom, two-camera robot head. Work was begun on an integrated, heterogeneously parallel system using the Butterfly, the MaxVideo, and other local computers to do complex visuo-motor tasks.

ETL-0511

AD-B129 618L

**AUTONOMOUS LAND VEHICLE (ALV) PLANNING AND NAVIGATION SYSTEM
SECOND ANNUAL REPORT
July 1988**

D. Keirsey, D. Payton, J. Rosenblatt, D. Tseng, V. Wong

Hughes Research Laboratories

DACA76-85-C-0017

Keywords: Autonomous Vehicles, Planning, Navigation, Cross-Country

This report details the history-making cross-country navigation experiments performed on the Autonomous Land Vehicle (ALV) and describe in detail the planning software used in these experiments. An overview of the software architecture and the systems development methodology will be also presented.

ETL-0512

AD-B132 948L

**KNOWLEDGE-BASED VISION TECHNIQUES FOR THE AUTONOMOUS
LAND VEHICLE (ALV) PROGRAM
THIRD ANNUAL REPORT
July 1988**

Martin A. Fischler
Robert C. Bolles

SRI International

DACA76-85-C-0004

Keywords: Knowledge Representation, 3-D Descriptions, Mission Planning, Computer Vision

The goal of this research is to develop techniques for representing knowledge about complex cultural and natural environments so that a computer vision system can successfully recognize key navigational features, such as roads, bushes, cliffs, and buildings. Our research strategy is to (1) develop representations and techniques for storing (or incrementally learning) semantic and geographic information about a specific geographic area to permit both mission planning and knowledge-based interpretation of sensed data, (2) develop representations for natural and man-made objects, (3) develop techniques to predict distinctive features of these objects that can be used to identify them, and (4) develop techniques for building three-dimensional descriptions of an environment from data gathered by range or intensity sensors moving through this environment. In this report we describe our progress and plans in these areas.

ETL-0513

AD-A203 361

**PARALLEL VISION ALGORITHM DESIGN AND IMPLEMENTATION
1987 END OF YEAR REPORT
August 1988**

Takeo Kanade
Jon Adrian Webb

Carnegie-Mellon University

DACA76-85-C-0002

Keywords: Computer Vision, Systolic Processors, Benchmarks, Programming Languages, Parallel Computers, Systolic Warp, Image Processing

Progress on the Parallel Vision project is reported. Three major accomplishments are noted: the development of the Apply language, the WEB library, and benchmarks of Warp for the DARPA image understanding architecture comparisons. The Apply language development included a description of the language and its implementation on warp, the Sun, and the Hughes HBA, together with benchmark comparisons of these very different architectures. The WEB library includes over 100 routines; included in this report are performance numbers of these routines on the CMU Warp machine. Finally, a detailed analysis of the Warp routines implemented for the DARPA Image Understanding benchmarks is given.

ETL-0514

AD-A203 946

**1987 YEAR END REPORT FOR ROAD FOLLOWING AT CARNEGIE-MELLON
August 1988**

Charles E. Thorpe
Takeo Kanade

Carnegie-Mellon University

DACA76-85-C-0003

Keywords: Road Following, Range Data Interpretation, Expert Systems for Image Interpretation, Car Recognition, Geometric Camera Calibration

This report describes progress in vision and navigation for outdoor mobile robots at the Carnegie-Mellon Robotics Institute during 1987. This research was primarily sponsored by the Defense Advanced Research Projects Agency (DARPA) as part of the Strategic Computing Initiative. Portions of this research were also partially supported by the National Science Foundation and Digital Equipment Corporation.

We are pursuing a broad range of perception research for guiding outdoor autonomous vehicles. In 1987 we concentrated on five areas: 1. Road following, 2. Range data interpretation, 3. Expert systems for image interpretation, 4. Car recognition, and 5. Geometric camera calibration.

This report begins with an introduction, chronology, and lists of personnel and publications. It also includes papers describing each of the research areas.

ETL-0516

AD-A204 167

**DYNAMIC IMAGE INTERPRETATION FOR AUTONOMOUS VEHICLE NAVIGATION
1987 END OF YEAR TECHNICAL REPORT
September 1988**

Edward M. Riseman
Allen R. Hanson

University of Massachusetts

DACA76-85-C-0008

Keywords: Scene Interpretation, Sensor Motion, Spatial Reasoning

This report presents the results of the project on Dynamic Image Interpretation for Autonomous Land Vehicle (ALV) Navigation for the time period 2/26/87 — 2/25/88. The purpose of the ALV project is to develop algorithms and tools to enable a vehicle to navigate autonomously through realistic landscapes.

The current effort continues our work on this problem. In the report we summarize the accomplishments of the past year in constructing robust algorithms to be used for vehicle navigation, as well as tools that have been developed to more efficiently utilize these algorithms.

AUTOMATED FEATURE ATTRIBUTE ACCESSING FROM MAP TEXT
November 1988

Stephen F. Hasenfus

Keywords: Bar Codes, Optical Character Recognition, Feature Identifiers, Feature Attributes, Optical Scanning Devices

This report documents an investigation into the feasibility of placing machine-readable symbology (bar codes or OCR text) on map products. The approach to this research included a survey of optical-scanning devices, procurement of suitable devices, and interfacing the equipment to a personal computer for the development of a prototype automated feature attribute access system. This report documents the issues that surfaced during the design and testing of this prototype system.

ETL-0518

AD-A202 831

LASS-II RAPID GEODETIC SURVEY SYSTEM (RGSS)
April 1986

S. Wei, J. Eckenrode, R. Toler, J. Welch

Litton Guidance & Control Systems

DACA72-84-C-0003

Keywords: Position and Azimuth Determining System, Litton Auto Surveyor System, Rapid Geodetic Survey System, Gravity Disturbance Vector, Gravity Anomaly

This final Technical Report presents the progress to date on the conversion of a standard U.S. Army Position and Azimuth Determining System (PADS AN/USQ-70) to a Litton Auto Surveyor System Dash II (LASS-II) to a Rapid Geodetic Survey System (RGSS). Multiple efforts have been initiated for this contract requirement as follows:

1. Perform the non-recurring Engineering design for conversion of a LASS-II to an RGSS.
2. Perform the necessary real-time software mechanization changes to enable an RGSS to attain the following performance goals:
 - a. Interim Goal: Map the gravity disturbance vector to 0.3 sec (RMS) for the deflection components and 0.5 milligal (RMS) for the gravity anomaly.
 - b. Long Term Goal: 0.1 sec (RMS) for the deflection component and 0.1 milligal (RMS) for the gravity anomaly as the ultimate goal.
3. In depth investigation of RGSS real-time software definitions, output parameters expansion, and computer simulations for validation of the on-line software mechanization. Hardware changes, real-time software modifications and definitions are contained herein to attain the interim and ultimate performance goals. This final report discusses the software changes generated along with the hardware changes made to date. Although the hardware changes discussed herein are not necessarily the final configuration, the drawing package submitted under a separate CDRL line item will be definitive for permanent record of all hardware modifications initiated and finalized.

**VISION-BASED NAVIGATION FOR AUTONOMOUS GROUND VEHICLES
THIRD ANNUAL REPORT
November 1988**

Larry S. Davis

University of Maryland

DACA76-84-C-0004

Keywords: Autonomous Navigation, Road Following, Computer Vision

This is the third annual report for DARPA sponsored ETL contract DACA76-84-C-0004 (DARPA Order 5096), covering the period July 1986 through July 1987. The report describes both new equipment added to our laboratory and the research performed on autonomous vehicle navigation. We describe the design of a structured light range scanner that has been built and mounted on our robot arm. This scanner provides us with the capability of generating range data similar to that obtainable on the Autonomous Land Vehicle (ALV) using the ERIM scanner. The report also describes the following research projects conducted during the past year:

- 1) The design and implementation of a rule-based road following system
- 2) Road obstacle detection in range data
- 3) Theoretical analysis of the accuracy of road recovery using motion stereo
- 4) Parallel vision on the Connection Machine

Finally, the report ends with a discussion of our plans for research during the next three years of our autonomous vehicle navigation research.

ETL-0520

AD-A212 806

**SPATIAL DATA STRUCTURES FOR ROBOTIC VEHICLE ROUTE PLANNING
December 1988**

Michael J. Black
David L. Milgram

Sharon O. Cioffi
Patrice Gelband

Advanced Decision Systems

DACA72-87-C-0015

Keywords: Route Planning, Data Structures, Robotic Vehicles, Terrain Representations

This is the final report for the Phase II Small Business Innovative Research (SBIR) contract, "Spatial Data Structures for Robotic Vehicle Route Planning." The report describes the work completed during Phase II and discusses the directions for future research.

The goal of the Phase II SBIR contract was to investigate techniques and tradeoffs for representing digital terrain information in a computer environment. The long-term goal of this research is to build a Spatial Data Structure Development System (SDSDS) to serve as the infrastructure base for terrain analysis applications.

The Phase II contract addressed the following issues: 1) implementation of common terrain representations, 2) implementation of common spatial operations, 3) design of a methodology for evaluating the performance of spatial operations, 4) evaluation of the implemented representations and operations, and 5) initial design of testbed on which the SDSDS would be built.

ETL-0521

AD-B129 848L

**KNOWLEDGE-BASED VISION TECHNIQUES
THIRD ANNUAL REPORT
December 1988**

M. J. Daily
J. G. Harris
K. E. Olin

K. Reiser
D. Y. Tseng
F. M. Vilnrotter

Hughes Research Laboratories

DACA76-85-C-0007

Keywords: Computer Vision, Virtual Sensors, Obstacle Detection, Obstacle Avoidance, Knowledge Representation

Efforts under the Knowledge-Based Vision Techniques contract have been concentrated on perception needs for autonomous land navigation, in particular obstacle detection and avoidance for off-road maneuvers. Major accomplishments have included: the formal definition of obstacles in terms of clearance, suspension, and slope using a three-dimensional vehicle model; techniques to use laser range and color sensor information; representing the sensed terrain by developing Cartesian Maps of sensed elevation, color information, and the fusion of both information sources; the fusion of information from multiple frames of a single sensor to build a composite map; and the development of an extensive simulation environment. These efforts culminated in the first cross-country map and sensor-based autonomous operation of a robotic vehicle in natural terrain. These experiments satisfied the milestones of the DARPA Technology Status Review for the Autonomous Land Vehicle (ALV) Program approximately one year ahead of schedule.

ETL-0522

AD-A208 546

**RESEARCH IN KNOWLEDGE-BASED VISION TECHNIQUES FOR THE
AUTONOMOUS LAND VEHICLE PROGRAM
THIRD ANNUAL REPORT
December 1988**

**R. Nevatia
K. Price**

University of Southern California

DACA76-85-C-0009

Keywords: Autonomous Land Vehicle, Motion Analysis, Target Detection and Description, Knowledge-Based Vision

This report describes our research in motion analysis and estimation techniques for the period of June 1, 1987 to May 31, 1988. This research is of particular relevance to the DARPA Autonomous Land Vehicle (ALV) program, but should also be of other general utility. Our basic approach to detecting and tracking motion is to extract and match features, such as lines and regions, from a sequence and to generate motion estimates from these. We present one report on matching edge elements in connected line segments (contours) in a sequence of views. This work assumes relatively small motions between views.

We also present a report on an alternative representation for motion and a technique to use occlusion in spatio-temporal analysis. We also present results from a basic integrated system that combines feature extraction, matching and motion estimation.

ETL-0523

AD-A208 806

**A SMART MAPPING, CHARTING AND GEODESY CONTROL GENERATOR
PHASE II
December 1988**

**W. Kober
J. Curlander
M. Karspeck
F. Leberl**

Vexcel Corporation

DACA72-87-C-0011

Keywords: Automated Control Generation, Inertial Navigation System (INS), Image Registration, Global Positioning Satellite System (GPS)

The real-time automated registration of multi-sensor imagery begins with the generation of control information. A specific application may require the registration of newly acquired data to an existing spatial database (absolute registration), or to other images of a series (relative registration). This study examines the feasibility and upper-level design of a system capable of providing the control information required for a range of image registration tasks and image types. In general, the control generator we suggest will be guided by a spatial database maintaining information about the feature content of the area of interest. A rule-based query generator will extract candidate ground control optimized for the particular image type and geometry at hand.

**CONSENSUS THEORY IN EXPERT SYSTEMS: AN ADAPTIVE INFERENCE
FRAMEWORK AND APPLICATION TO IMAGE UNDERSTANDING
December 1988**

Kathryn B. Laskey
Paul K. Black
Marvin S. Cohen

James R. McIntyre
William G. Roman
Russell R. Vane, III

Decision Science Consortium, Inc.

DACA72-86-C-0003

Keywords: Expert Systems, Belief Functions, Non-Monotonic Logic, Assumption-Based Truth Maintenance, Image Understanding

Advances in automated image understanding technology are essential to our ability to exploit today's sophisticated imagery capabilities to support battlefield intelligence requirements. This report describes the application of a unique inference framework, Non-Monotonic Probabilist, to the problem of achieving consensus among modules, each of which supports a different part of the image understanding problem. Non-Monotonic Probabilist combines symbolic default reasoning with numerical uncertainty propagation to support a flexible ability to make and revise assumptions, to examine the degree of conflict associated with the current set of assumptions, and to resolve conflicts by "reaching inside" arguments and adjusting the underlying assumptions. Non-Monotonic Probabilist is a generic inference engine that is domain independent and can be applied to a variety of problems. Non-Monotonic Probabilist has been embedded within COMMiTR, a consensus system intended to be incorporated within the Expert Resolution System at the U.S. Army Engineer Topographic Laboratories.

**KNOWLEDGE-BASED ANALYSIS OF SCENE DYNAMICS FOR TARGET
MOTION DETECTION, RECOGNITION AND TRACKING
SECOND ANNUAL REPORT
January 1989**

Bir Bhanu

Honeywell Systems and Research Center

DACA76-86-C-0017

Keywords: Strategic Computing, Qualitative Reasoning and Modeling, Motion Detection, Tracking, Landmark Recognition, Terrain Interpretation, Dynamic Modeling and Matching, Hierarchical Symbolic Grouping, Autonomous Land Vehicle, Dynamic Scene Understanding, Estimation of Vehicle Motion, Multispectral Images, Machine Learning, Knowledge Acquisition, Computer Vision

This is the Final Report of Honeywell's Contract on Knowledge-Based Analysis of Scene Dynamics for Target Motion Detection, Recognition, and Tracking prepared for the U.S. Army Engineer Topographic Laboratories (ETL) Contract DACA76-86-C-0017 and sponsored by the Defense Advanced Research Projects Agency (DARPA). Our research in Scene Dynamics and Object Recognition presented in this report is directed towards knowledge-based interpretation of scene dynamics and model-based object recognition. The results of our research make a significant technical contribution in vision-controlled navigation/guidance of Autonomous Land Vehicles (ALVs), reconnaissance, surveillance, and other practical military applications such as search and rescue and targeting missions. The topics investigated during the two year period of the contract are:

- 1) *Qualitative Reasoning & Modeling* for motion detection and tracking.
- 2) *Dynamic Model Matching* for landmark recognition.
- 3) *Digital Map Integration* for target tracking and landmark recognition.
- 4) *Automatic Model Acquisition and Refinement* using machine learning.
- 5) *Hierarchical Symbolic Grouping* for interpretation of terrain.

This synopsis of technical achievements in each of these areas is presented in the extended abstract in the report.

**AN APPROACH TO MODEL FORMATION BASED ON FORMAL GEOMETRIC REASONING
SECOND ANNUAL REPORT
February 1989**

Joseph L. Mundy
Nelson R. Corby
Deepak Kapur

General Electric Company

DACA76-86-C-0007

Keywords: Model Matching, Range Sensor, Image Understanding, Geometric Reasoning

Methods for model matching and model formation are developed in the context of polyhedral model-based image understanding. Our basic approach using a vertex-pair as a matchable, efficient polyhedral geometric feature has been extended by considering methods to automate the selection of features and verify hypothesized matches. A method to automatically select the most salient model features is described. The method uses an error metric which is stable and useful for evaluating feature quality.

Progress in automatic construction of matchable models using Boolean Intersection methods on multiple luminance views and in range data-based modeling is described. Geometric and algebraic reasoning methods for model formation and object recognition continues as a key focus. A significant problem was found to be selection of an appropriate symbolic parameterization. The nature of the representation determines the complexity of solution. Work continues on extending the two-dimensional geometric reasoning system, GEOMETER, developed in the past, to a three-dimensional system.

The vertex-pair approach is being applied to photointerpretation problems in PACE (Perceptual Analysis and Control Environment) which seeks to recognize targets from multiple images and produce an integrated representation in a common world frame of reference.

**PARALLEL VISION ALGORITHMS
SECOND ANNUAL TECHNICAL REPORT
January 1989**

Hussein A. H. Ibrahim, Editor
John R. Kender
Lisa G. Brown

Columbia University

DACA76-86-C-0024

Keywords: Computer Vision, Artificial Intelligence, Image Understanding, Multi-Resolution, Stereo, Texture, Strategy Computing

The "Parallel Vision Algorithms" second annual technical report covers the project activities during the period from October 1, 1987, through December 28, 1988. The objective of this project is to develop and implement, on highly parallel computers, vision algorithms that combine stereo, texture, and multi-resolution techniques for determining local surface orientation and depth. Such algorithms will immediately serve as front-ends for autonomous land vehicle navigation systems. During the second year of the project, efforts have concentrated on the following: first, implementing and testing on the Connection Machine the parallel programming environment that will be used to develop, implement and test our parallel vision algorithms. Second, implementing and testing multi-resolution stereo, and texture algorithms in this environment. Also, we continue our efforts for the refinement of techniques used in our texture algorithms. This report describes the status and progress of these efforts. We describe first the programming environment implementation, and how to use it. Then, we present algorithms and test results for multi-resolution stereo, and texture algorithms. More results of the efforts of integrating stereo and texture algorithms are presented.

ETL-0529

AD-A212 489

**PARALLEL ALGORITHMS FOR COMPUTER VISION
THIRD YEAR REPORT
January 1989**

Tomaso Poggio

Massachusetts Institute of Technology

DACA76-85-C-0010

Keywords: Computer Vision, Parallel Algorithms and Architectures

This is the third annual report for Contract DACA76-85-C-0010, entitled "Parallel Algorithms for Computer Vision — Task B," sponsored by the Defense Advanced Research Projects Agency (DARPA), and administered by the U.S. Army Engineer Topographic Laboratories (ETL). The time period covered is the second year that we have had the Connection Machine (CM) available to us. During the same period of time, we successfully demonstrated the Vision Machine system processing images and recognizing objects through the integration of several visual cues. The first version of the Vision Machine system, which is based on the CM and uses an Eye-Head robot as an input device, is now complete and functional. In parallel with the development of the Vision Machine, we have also continued to study the performance of alternative, nonconventional architectures for navigation. The body of this report gives an overview of the results of our research during the third year of funding. Details can be found in the appendices of the report.

ETL-0530

AD-A205 195

**LINEAR FEATURE EXTRACTION FROM RADAR IMAGERY:
SBIR PHASE II, OPTION II
December 1988**

**David L. Milgram
Philip Kahn
Gary D. Conner
Daryl T. Lawton**

Advanced Decision Systems

DACA72-86-C-0004

Keywords: SAR, Feature Extraction, Edge Detection, Terrain Analysis, Image Understanding

The goal of this effort is to develop and demonstrate prototype processing capabilities for a knowledge-based system to automatically extract and analyze linear features from Synthetic Aperture Radar (SAR) imagery. This effort constitutes Phase II funding through the Defense Small Business Innovative Research (SBIR) Program. Previous work examined the feasibility of and technology issues involved in the development of an automated linear feature extraction system. This final report documents this examination and the technologies involved in automating this image understanding task. In particular, it reports on a major software delivery containing an image processing algorithmic base, a "perceptual structures" manipulation package, a preliminary hypothesis management framework, and an enhanced user interface.

ETL-0531

AD-A206 696

**TARGET LOCATION ERRORS DERIVED FROM A HYPOTHETICAL
TARGET TRACKING SYSTEM
February 1989**

Michael A. Crombie

Keywords: Real-Time Attitude, Real-Time Positioning, Real-Time Targeting

An error analysis of a hypothetical target tracking system developed around an ongoing real-time attitude (RTA) project at the Space Programs Laboratory was performed at the U.S. Army Engineer Topographic Laboratories. An extensive set of tables of target errors was developed as a function of a variety of collection geometries and system component random errors. The target tracking system includes RTA, a real-time positioning capability, an automatic target sensor, and a slant range measuring device. The system components were characterized in the study by their expected random errors. For example, the real-time positioning capability in this study reflects the expected range of GPS errors.

**SPATIAL TARGET LOCATION ERRORS DERIVED FROM MEASUREMENTS
COLLECTED FROM SIXTEEN SATELLITE CONSTELLATIONS
March 1989**

Michael A. Crombie

Keywords: Satellite Constellations, Minimum PDOP Values, Shortest Distance to Target

In this report, tables of sample cumulative probability distributions of minimum PDOP (Position Dilution of Precision) values and shortest distances between target and target trackers were developed, where the target is a spatial one and where the target trackers are constrained to any one of 16 satellite constellations. Shortest distance was used as a parameter in this work because target location errors involving direction to target increase as distance to target increases. The tables pertain to the first, second, and third shortest distances and to minimum PDOP's computed from slant range observations taken from 3, 4, or 5 target trackers. Tables of expected values of minimum PDOP's and shortest distances are also provided. Values in the tables of shortest distances are also provided. Values in the tables of shortest distances can be combined with a prior error analysis to determine 99 percent confidence sphere radii about estimated target locations. Values in the tables of minimum PDOP's can be used to determine 99 percent confidence sphere radii about target locations estimated from 3, 4, or 5 slant range observations.

**AUTOMATIC RADAR FEATURE EXTRACTION SYSTEM USING DESCRIPTORS
March 1989**

Daniel K. Gordon
Paul W. Mueller

Autometric, Incorporated

DACA76-88-C-0005

Keywords: Computer Vision, SAR Imagery, Descriptor Sets, Automatic Feature Extraction, Expert Systems

The research investigation described in this interim report identified and developed image processing and computer vision techniques used for suppressing noise and for enhancing and automatically identifying features of interest in SAR imagery. This project built upon computer vision software already developed during the previous phase. Under the previous phase, software was developed that automatically identified line drawings of SAR feature descriptor sets that were identified during the initial phases of the investigation.

**EXPERT SYSTEM FOR MINEFIELD SITE PREDICTION
PHASE II FINAL REPORT
May 1989**

Jonathan W. Doughty
Anne L. Downs

PAR Government Systems Corporation

DACA72-86-C-0017

Keywords: Expert System, Minefield Site Prediction, GIS (Geographic Information System), Quadtree, Window System, Terrain Analysis, Minefield Doctrine

This report reviews the major system components of the MSPES and discusses modifications made to the system under Phase II of this contract. Phase II development grew out of the prototype system developed under Phase I. A high-level description of the software architecture was presented in an earlier document (Barth et al., 1987), with a more detailed description presented in the Phase I Final Report (Dillencourt et al., 1988). The scope of Phase II was the development of a "complete expert system for minefield site prediction." Phase II MSPES development continued on the Sun 3/160 at the request of ETL. The transporting of the system to the target computer, a VAXStation II GPX, was scheduled for Phase III. Phase II effort was concentrated in two areas: first, the implementation of the user interface using the X Window System graphics package, and secondly, in expanding the knowledge base of minefield doctrine.

**KNOWLEDGE-BASED VISION TECHNIQUES TASK B:
TERRAIN AND OBJECT MODELING RECOGNITION
THIRD ANNUAL REPORT
April 1989**

Advanced Decision Systems:

Daryl T. Lawton
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Christopher C. McConnell
Daniel J. Edelson
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Advanced Decision Systems

DACA76-85-C-0005

Keywords: Model-Based Vision System, Terrain Modeling, Schema-Based Reasoning, Perceptual Processing, Image Understanding Tools, Spatial Representation, Hypothesis Management, Navigation, Image-To-Map Matching

This report describes the development and critical components of a model-based vision system for an autonomous vehicle operating in complex, outdoor, dynamic environments using optical, laser, motion, and position sensors. The critical technologies are organized with respect to Object and Event Modeling, Perceptual Processing, Spatial Representation and Reasoning, and the Integration of work in these research areas into modular and transferable components. Key results included the following: (Editor's note: results can be seen on original DD Form 1473 in the published report).

**KNOWLEDGE-BASED VISION TECHNIQUES: OBSTACLE DETECTION AND AVOIDANCE
FOURTH ANNUAL REPORT
May 1989**

K. E. Olin
M. J. Daily
M. D. Howard

F. M. Vilnrotter
D. Y. Tseng

Hughes Research Laboratories

DACA76-85-C-0007

Keywords: Computer Vision, Obstacle Detection, Knowledge Representation, Virtual Sensors, Obstacle Avoidance, Cross Country Navigation

Efforts under the Knowledge-Based Vision Techniques contract have been concentrated on perception needs for autonomous land navigation, in particular obstacle detection and avoidance for off-road maneuvers. Major accomplishments have included: the formal definition of obstacles in terms of clearance, suspension, and slope using a three-dimensional vehicle model; techniques to use laser range and color sensor information; representation of sensed terrain by developing Cartesian maps of elevation, color, data fused from both sensors, and data representing traversability weights; the fusion of information from sequences of laser range data to both build a composite map of a vehicle path and to compare sensed data with data obtained from digital maps; and the development of an extensive simulation environment. These efforts demonstrated the first cross-country map and sensor-based autonomous operation of a robotic vehicle in complex natural terrain. These experiments, on-board the Martin Marietta Autonomous Land Vehicle (ALV), satisfied the DARPA Technology Status Review (TSR) milestone for cross-country navigation approximately one year ahead of schedule.

**1988 YEAR END REPORT FOR ROAD FOLLOWING AT CARNEGIE-MELLON
May 1989**

Charles E. Thorpe
Takeo Kanade

Carnegie-Mellon University

DACA76-85-C-0003

Keywords: Road Following, Range Data Interpretation, Expert Systems for Image Interpretation, Car Recognition, Geometric Camera Calibration

This report describes progress in vision and navigation for outdoor mobile robots at the Carnegie-Mellon Robotics Institute from January 1988 through March 1989. This research was primarily sponsored by the Defense Advanced Research Projects Agency (DARPA) as part of the Strategic Computing Initiative. Portions of this research were also partially supported by the National Science Foundation and Digital Equipment Corporation. In the four years of the project, we have built perception modules for following roads, detecting obstacles, mapping terrain, and recognizing objects. Together with our sister contract, "Development of an Integrated ALV (Autonomous Land Vehicle) System," we have built systems that drive mobile robots along roads and cross country, and have gained valuable insights into viable approaches for outdoor mobile robot research. This work is briefly summarized in Chapter 1 of this report. Specifically in 1988 and the first three months of 1989, we have completed one color vision system for finding roads, begun two others that handle difficult lighting and structured public roads and highways, and built a road-following system that uses active scanning with a laser rangefinder. We have used 3-D information to build elevation maps for cross-country path planning, and have used maps to retrace a route. Progress on these projects is described briefly in Chapter 1, and in more detail in the remaining chapters.

**GROUND TARGET LOCATION ERRORS DERIVED FROM MEASUREMENTS
COLLECTED FROM A VARIETY OF HYPOTHETICAL SATELLITE SENTINEL SYSTEMS
June 1989**

Michael A. Crombie

Keywords: Satellite Constellations, Target Location, Stellar Camera, Real Time Attitude

A large number of symmetric circular orbit satellite constellations were tested for their worth in providing continuous surveillance of five selected corps-sized regions over various parts of the world. The results of this work when combined with results from a previous report can be used to evaluate the target location mensuration capability of a variety of target mensuration systems located on satellite platforms defined by the constellations.

ETL-0539

AD-B135 161L

**AUTONOMOUS LAND VEHICLE (ALV) PLANNING AND NAVIGATION SYSTEM
FINAL ANNUAL REPORT
May 1989**

**D. Keirse
D. Payton
J. Rosenblatt
D. Y. Tseng**

Hughes Research Laboratories

DACA76-85-C-0017

Keywords: Mobile Robots, Autonomous Vehicles, Planning, Navigation

This report summarizes some of the first cross-country navigation experiments performed on the Defense Advanced Research Projects Agency (DARPA) Autonomous Land Vehicle (ALV) and describes in detail the planning software architecture that has been developed as a result of experience gained from these experiments. We present a set of architectural concepts which address the needs for integrating high-level planning activities with lower-level reactive or participatory behaviors. Based on lessons learned from experience with our hierarchical architecture for autonomous cross-country navigation, we have adopted a new approach which emphasizes the minimization of information loss both within and between system layers. The resulting change in perspective has allowed us to greatly enhance the overall capabilities and performance of our system.

ETL-0540

AD-A212 622

**AN ANALYSIS OF AIR PHOTO AND RADAR IMAGERY OF
BARRO COLORADO ISLAND, PANAMA
July 1989**

**J. N. Rinker
P. A. Corl**

Keywords: Air Photo Analysis, Radar Analysis, Closed Tree Canopy, Tropical Landforms

Imagery of terrain that is covered with a closed canopy of tall trees does not show the ground surface, and any information about surface characteristics, such as rock and soil types, structure, drainageways, etc., must come from an examination of the tree canopy surface. An evaluation of stereo aerial photography showed that inferences could be made about general terrain characteristics such as landform, probable structure and rock types, and major drainageways, but it requires experienced and skilled analysts, and stereo imagery. Surface roughness, obstacles, and minor drainageways could not be determined. Lack of vegetation penetration by radar severely limits the quantity and quality of information that can be derived.

**PARALLEL VISION ALGORITHM DESIGN AND IMPLEMENTATION
1988 END OF YEAR REPORT
August 1989**

Carnegie-Mellon University

DACA76-85-C-0002

Takeo Kanade
Jon Adrian Webb

Keywords: Computer Vision, Systolic Processors, Benchmarks, Programming Languages, Parallel Computers, Warp, Image Processing

The Apply programming language has been extended to allow variable-sized image computations, and also to allow border mirroring, in which pixels accessed outside the borders are produced by copying pixels from the interior of the image. Implementation and design decisions are discussed. Apply and the WARP programming language W2 were used to implement the second DARPA image understanding benchmark. The results of this implementation are reported. Experience with this benchmark suggests a method for performing global image computations in a machine independent manner, using the divide and conquer model. Implications of this model for algorithms in the image understanding benchmark are discussed. It is shown that this model is capable of computing any algorithm in which data is accessed in a fixed order, regardless of the data values, and in which the final computation is reversible: that is, it produces the same results if the data values are reversed in order.

**THE IMAGE UNDERSTANDING ARCHITECTURE PROJECT
SECOND ANNUAL REPORT
March 1989**

Charles C. Weems
Steven P. Levitan
Allen R. Hanson
Edward M. Riseman

David B. Shu
J. Gregory Nash
James Burrill
Michael Rudenko

University of Massachusetts

DACA76-86-C-0015

Keywords: Image Understanding Architecture, Knowledge-Based Vision, Real-Time Computer Vision, Software Simulator, Parallel Processor

The primary goal of the Image Understanding Architecture (IUA) project is to build a proof-of-concept prototype of a 1/64th slice of a next generation vision architecture, and develop the software support environment that will be needed to utilize the hardware. The majority of the hardware effort is taking place at Hughes Research Laboratories, Malibu, California, although UMass has principal responsibility for the design of the IUA architecture. UMass has also undertaken some smaller portions of the hardware development (the feedback concentrator for the low and intermediate level arrays, and the communications router for the intermediate level array). The majority of the software effort is taking place at UMass, although Hughes is also involved in some software development, both in support of their hardware efforts, and in the form of algorithm development for specific applications on the IUA. During the second year of this program, we have focussed on extensions to the IUA software simulator programming environment, the development of library routines and demonstration software for the IUA, construction of the custom chips for the architecture, circuit board design, and the design and implementation of an integrated image understanding benchmark for DARPA. This report presents the results of the IUA project for the second year of its original two-year contract period. The purpose of the IUA project is to design and construct a next-generation parallel processor that specifically addresses the needs of real-time computer vision applications. Included in this report is a summary of accomplishments during the second year, an overview of the IUA design, a description of the new DARPA Integrated IU Benchmark Exercise, a summary of the performance figures for the IUA on the exercise, and test reports and photos of chips developed through MOSIS under this program in an appendix.

ETL-0543

AD-A211 584

**VISION-BASED NAVIGATION FOR AUTONOMOUS GROUND VEHICLES
SUMMARY REPORT
August 1989**

Larry S. Davis

University of Maryland

DACA76-84-C-0004

Keywords: Autonomous Navigation, Road Following, Computer Vision

This is a summary report for contract DACA76-84-C-0004, "Vision-Based Navigation for Autonomous Ground Vehicles." Our research has resulted in seventeen technical reports (list appended to this report, with abstracts), many of which have been subsequently published in journals, conferences and workshops. Additionally, our project involved close collaboration with the Martin Marietta Corporation, Denver, Colorado, in the development and testing of vision algorithms for navigation of roads and road networks. Several experiments were run on the Martin Marietta Autonomous Land Vehicle using programs developed at the University of Maryland, and some critical components of Martin Marietta's visual navigation system were based on fundamental research conducted at the University of Maryland under support of this contract — specifically, the overall framework of a focus-of-attention vision system, in which detailed analyses are performed on selected windows of images of roads, and the shape-from-contour algorithms (e.g., the zero-bank algorithm) that allowed the vehicle software to recover an accurate three-dimensional road model from monocular imagery, thus saving the autonomous land vehicle (ALV) from having to perform costly, and less reliable, analyses based on either stereo or motion.

ETL-0544

AD-A211 876

**SENTINEL SATELLITE POSITIONAL PRECISION DERIVED
FROM THE NAVSTAR GLOBAL POSITIONING SYSTEM
August 1989**

Michael A. Crombie

Keywords: Global Positioning System (GPS), Position Dilution of Precision (PDOP), Satellite Position Precision

Error estimates of position are presented for a variety of symmetric circular satellite constellations when four or five observations are made on NAVSTAR GPS satellites. Results are calculated in terms of minimum PDOP and expected outages.

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Application of Artificial Intelligence to Radar Image Understanding	ETL-0387	1985
Application of Biorthogonal Filter Functions to Pattern Recognition and Feature Extraction	ETL-0222	1980
Application of Coriolis Force to Geodetic Measurements	AD 477 136	1965
Application of Hierarchical Data Structures to Geographical Information Systems	ETL-0301	1982
Application of Hierarchical Data Structures to Geographical Information Systems (Phase II)	ETL-0337	1983
Application of Hierarchical Data Structures to Geographical Information Systems (Phase III)	ETL-0376	1984
Application of Hierarchical Data Structures to Geographical Information Systems (Phase IV)	ETL-0411	1985
Application of Inertial Techniques to Surveying	AD 805 156	1966
Application of Image Sensing Arrays to Metrology, Detection and Instrumentation	ETL-CR-71-6	1970
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Application of LORAC to Precision Terrestrial Line-Length Measurement and Position Fixing	AD 232 015	no date
Application of Scalar Renormalization to the Scattering of Electromagnetic Waves from a Three-Dimensionally Inhomogeneous Medium with Strong Dielectric Fluctuations	ETL-0020	1975
Applications of Advanced Accelerometers to Surveying and Geodesy I	AD 429 324L	1963
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Approach to the Evaluation of Strategies in Insurgency, An	AD 722 787	1968
APPS-IV Civil Works Data Extraction/Data Base Application Study (Phase I)	ETL-0310	1982
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APPS-IV Remote Sensing Applications Guide	ETL-0333	1983
ARK-1 Gyro Aiming Circle (Wild Heerbrugg Instruments, Inc.)	49-TR	1969
ARMIDOP/ZERO-DOP Positioning Technique	ETL-RN-71-2	1971
Army Tactical Terrain Data Requirements Forecast (FY87-FY93)	ETL-SR-1	1987
Army Terrain Information System	ETL-0050	1976
Artifact Removal in Frequency Domain Compressed Imagery	ETL-0233	1980
Artillery Survey System, Phase I — Study of Methods	AD 883 288L	1958
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Associative Array Processing of Raster Scanned Data for Automated Cartography	ETL-0046	1976
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Associative Array Processing for Topographic Data Reduction	ETL-CR-74-1	1974
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Astrogeodetic-Inertial Methods for Vertical Deflection Determination	ETL-0414	1985
Astronomical Attachment Azimuth Determination, Reflecting, for Transit or Theodolite	1374-TR	1954
ATF-Hadego Photocompositor Photolettering Machine	1414-TR	1955
Atmospheric Refraction	TR-61-505	no date
Atmospheric Refraction for Satellite Photography	56-8B-1	1962
Autocorrelation of Control Points on 11-Band Multispectral Imagery	ETL-0473	1987
Automated Industrial Feature Extraction from Synthetic Aperture Radar Imagery	ETL-0459	1987
Automated Processing of Geographic Information in Image Data Forms	ETL-0114	1977
Automated Route Finder for Multiple Tank Columns	ETL-0480	1987
Automated Technique for Measuring Built-Up Urban Areas from Map Graphics through Analog Image Processing	ETL-0012	1975
Automatic Contour Digitizer (ACD)	ETL-ETR-71-2	1971
Automatic Contouring Instrumentation	1488-TR	1957
Automatic Control of Digital Stereo Correlation Methods	ETL-0356	1984
Automatic Correlation of USGS Digital Line Graph Geographic Features to GNIS Names Data	ETL-0426	1986
Automatic-electro Optical Satellite Triangulation System	RN-23	1967
Automatic Feature Extraction/Algorithm Testing	ETL-0410	1985
Automatic Feature Extraction: An Annotated Bibliography	ETL-0189	1979
Automatic Map Compilation System	AD 277 456	1962
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Automatic Point Transfer Instrument	AD 834 230L	1968
Automatic Reseau Measuring Equipment (ARME)	ETL-0099	1976
Automatic Stereo Perception of Aerial Photography by Means of Optical Correlation	AD 406 363	1962
Automatic Type/Symbol-Placement Developments	ETL-TR-74-9	1975
Automation of Airborne Profile Recorder Data Reduction (Interim)	AD 805 562L	1966
Automation of Airborne Profile Recorder Data Reduction (Final)	AD 825 545L	1967
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Autonomous Land Vehicle 1st Quarterly Report, The	ETL-0430	1986
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Background Study and Selection Criteria Analysis of MIL-STD-810C: Environmental Test Methods	ETL-0154	1978
Backscattering of Electromagnetic Waves from a Slightly Rough Surface with a Lossy Layer	ETL-TR-74-10	1974
Backscattering of Electromagnetic Waves from a Surface Composed of Two Types of Surface Roughness	ETL-TR-71-4	1971
Backscattering of Radar Waves by Vegetated Terrain	ETL-0105	1977
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Basic Factors Limiting the Accuracy of Mapping and Aerotriangulation by Photogrammetric Procedures	AD 77 390	1955
Bayesian Approach to Identification of a Remotely Sensed Environment	AD 860 060	1969
Bibliographic Literature Search Concerning the Relationship Between Soils and Plants in Arid and Semi-Arid Regions in North America	ETL-0171	1978
Bibliography and Abstracts of Analytical Photogrammetry	1487-TR	1957
Bibliography of In-House and Contract Reports	ETL-SR-70-1	1970
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Bibliography of In-House and Contract Reports, Supplement 9	ETL-0255	1981
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Bimodal Display	ETL-0110	1977
Blue Laser	ETL-0412	1985
Broad-Spectrum Electromagnetic Spectrum Backscatter	AD 878 341L	1970
Brush Surfaced Lithographic Press Plates	1452-TR	1956
Camera Calibration Study		no date
Capabilities of Remote Sensors to Determine Environmental Information for Combat	ETL-0081	1976
Cartographic Application of Conflex I	AD 882 789L	1964
Cartographic Design Standards — A Preliminary Investigation		1967
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Second Interim Report		
Cartographic Electron Beam Recorder (EBR) System	ETL-0111	1977
Cartographic Electron Beam Scanner Design Study	ETL-0257	1981
Cartographic Scanner Plotter	ETL-CR-72-12	1972
Change Detector Maintenance Instructions		1966
Change Detector Operation Manual		1965
Change Detector Studies		1961
Characterization and Optimization of an Electro-Optic Imaging Device for Real-Time Map Profiling	ETL-CR-74-18	1974
Characterization of the PROM for Coherent Optical Processing Applications	ETL-0053	1976
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Chemical Array Studies	ETL-0130	1977
Circularly Polarized Measurements of Radar Backscatter from Terrain	ETL-0199	1980
Circularly Polarized Measurements of Radar Backscatter from Terrain and Snow Covered Terrain	ETL-0234	1980
Circumpolar Method for Determining Azimuth	ETL-0317	1983
Classification and World Distribution of Vegetation Relative to V/STOL Aircraft Operations	ETL-SR-74-4	1973
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Coated Paper and Developer for Continuous Tone Electrophotography	AD 674 241	1968
Cold Weather Testing of 10-Second Direction Theodolite, 1-Minute Direction Theodolite (Foreign Model), Astronomical Attachment, and Winterization Kit	1288-TR	1953
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Color Ink-Jet Demonstration Program	ETL-0196	1979
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Combination Map Reproduction Van Body	1536-TR	1958
Combined Engineering and Service Tests of the Copy and Supply Van Section of the Motorized Photomapping Train	1444-TR	1956
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Comparative Study of Photography for Soils and Terrain Data	38-TR	1968
Comprehensive Summary of Project Trend	ETL-0041	1975
Computer-Assisted Likely Minesite Prediction Model and Estimated Electromagnetic and Thermal Soil Properties	ETL-0391	1985
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Concept Development of Automated Image Analysis	ETL-0194	1979

TITLE	REPORT NO.	YEAR
Concept Development of Automatic Instrumentation for Monitoring Movement of Dams	ETL-0187	1979
Concept for an Ultraprecise Geodetic Baseline	RN-24	1967
CONPLOT I — A Contour Generating Program	ETL-CR-70-2	1970
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Continuous-Tone Electrophotography	AD 673 881	1968
Contour Digitizing and Tagging Software (CONTAGRID)	ETL-0228	1980
Contour-to-Grid Interpolation with Nonlinear Finite Elements: A Feasibility Study	ETL-0472	1987
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Corona Study Relevant to Electrostatic Printing Process	ETL-CR-71-22	1971
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Correlation of Noisy Images	ETL-0230	1980
Cultural Data Base Implementation Study and Computer-Aided Scene Modeling System Users Manual	ETL-0380	1984
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Data Base Sizing Methodology Applied to the Army Terrain Information System (ARTINS)	ETL-0150	1978
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Derivation and Potential of New Filter Equations for Numerical Weather Prediction	ETL-RN-71-3	1971
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Design and Analysis of a High-Production Mini-Computer System for Regridding Digital Terrain Elevation Matrices	ETL-0240	1980
Design and Development of a Position and Azimuth Determining System (PADS)	ETL-CR-71-18	1971
Design and Development of an Advanced Electron Beam Control System	ETL-0032	1975
Design and Development of Power Package for Surveying Instrument: Azimuth, Gyro, Lightweight	ETL-CR-71-5A	1971
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Design and Fabrication of a 70 Millimeter Interference Imaging System	ETL-CR-71-8	1971
Design and Fabrication of an Experimental Multiband Camera	ETL-CR-71-28	1971
Design and Feasibility Study of an Off-Line Digital Orthoprinter for Field Use	ETL-0149	1978
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Design Study of a Large Format Printer (LFP)	ETL-0368	1984
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TITLE	REPORT NO.	YEAR
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Determination of the Geometrical Quality of Comparators for Image Coordinate Measurements	RN-3	1962
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Developing a Data Base for Predicting Soviet Tactical Behavior	ETL-0015	1975
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Development of a Prototype Family of Military Geographic Intelligence Products to Support Airmobile Operations	ETL-ETR-70-7	1970
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Development of a Variscale Stereo Point Marking Instrument	AD 643 722	1966
Development of an Evaluation Model-Change Detector		1965
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Development of Computer Vision Techniques for Automatic Feature Extraction	ETL-0451	1987
Development of Descriptor Sets for the Unambiguous Characterization of Geographic Features on SAR Imagery	ETL-0369	1984
Development of Electronic Control of a Superconducting Gravity Gradiometer	ETL-0397	1985
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Development of Height Finder Oblique, Topographic	1383-TR	1954
Development of High Speed CRT Print Head Systems for Cartographic Applications	ETL-0213	1980
Development of Improved Area Correlation Techniques	ETL-CR-73-19	1973
Development of Lightweight Long-Range Survey System (LRSS)	AD 477 042	1965
Development of Spherical Map Sections and Transparent Conforming Overlays	1440-TR	1956
Development, Service Tests, and Production Model Tests, Autofocusing Rectifier	1307-TR	1953
Development, Test, Preparation, Delivery, and Installation of Algorithms for Optimal Adjustment of Inertial Survey Data	ETL-1307	1982
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Digital Cartographic Study and Benchmark	ETL-0168	1978
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Digital Computer Program for the Solution of a Photogrammetric Net (Preparation of Maps from Aerial Photographs)	AD 711 858	1961
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Digital Mapping System Concepts Study	ETL-CR-71-26	1971
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Discrete Scattering Approach to Vegetation Modeling	ETL-0215	1980
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Electrofax Specifications for Army Five-Color Map Reproducing Equipment	AD 841 828L	1968
Electron Beam Recorder Applications Study	ETL-0120	1970
Electronic Angle-Measuring Device	ETL-TR-72-1	1972
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Electrostatic Paper and Toner Development		1969
Elevation Data Compaction by Polynomial Modeling	ETL-0140	1978
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TITLE	REPORT NO.	YEAR
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End of Year Report for Parallel Vision Algorithm Design and Implementation	ETL-0467	1987
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Engineer Design Test and Evaluation of a Planimetric Compiler	35-TR	1966
Engineer Design Tests and Evaluation of a Multipower Army Stereoscope	12-TR	1963
Engineer Route Reconnaissance Feasibility Study	AD 486 337L	1966
Engineer Test and Evaluation of the Command- Retrieval Information System/Direct Input (CRIS/DI)	42-TR	1968
Engineer Tests of 2.5x Reduction Printer	ETL-ETR-74-7	1975
Engineering Design Test Report: Inertial Surveying Equipment (ISE)	16-TR	1963
Engineering Evaluation of Pulsed Xenon Light Sources for Graphic Arts Use	2-TR	1961
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Engineering Tests and Evaluation of Multiplex Reduction Printer for Metrogon and Distortion-Free Photography	1431-TR	1955
Engineering Tests and Evaluation of Printers for the Preparation of 9½- by 9½-inch Diapositives for the Precision Stereoplotter	1538-TR	1958
Engineering Tests and Evaluation of the Photo- grammetric Transforming Printer for 20° Convergent Photograph	1497-TR	1957
Engineering Tests of a Temperature-controlled Processing Unit, Deep-tank, for Photomechanical Film	1599-TR	1959
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Engineering Tests of Interim Target Location Systems for Use in Controlled Areas	1498-TR	1957
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Engineering Tests of Opaque Cartographic Bases	1290-TR	1953
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Engineering Tests of the PPI Radar Presentation Restitutor	1629-TR	1960

TITLE	REPORT NO.	YEAR
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Engineering Tests of Two Printer-Developers, Ammonia Process, 24 Inch	1292-TR	1953
Enhanced Photomap Evaluation Study	AD 651 396	1967
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Environmental Conditions Experienced by Rockets and Missiles in Storage, Transit, and Operations	ETL-CR-74-3	1973
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Environmental Conditions in a Tropical Forest Region in Thailand	ETL-0129	1974
Environmental Position Errors of the GPS — Army User Equipment	ETL-0055	1976
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Equipment and Techniques for the Utilization of Convergent Photography in Mapping	1583-TR	1959
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Error Statistics for Astrogeodetic Positions for an RGSS Test Course	ETL-0267	1981
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ETL 211-OD Gravitational Model, A Union Solution of Optical and Doppler Satellite Determinations	AD 502 044L	1968
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Evaluation and Comparison of Terrain Classification Methods (Type III)	AD 845 338L	1968
Evaluation and Test of a Five-Color Electrostatic Printing Machine for the Reproduction of Topographic Maps and Charts	25-TR	1965
Evaluation and Test of a Modified Plate Process Section, a Proposed New Photomechanical Process and a Redesigned Brush-Surfacing Machine	1560-TR	1959
Evaluation and Test of a Self-Contained Vehicle Land Navigation System	ETL-0167	1979
Evaluation and Test of a Single-Color Electrostatic Printing Machine for the Reproduction of Topographic Maps and Charts	19-TR	1964
Evaluation of a New Electrostatic Recording Medium	ETL-0102	1977
Evaluation of a Xerographic Process for Preparing Zinc Oxide-Silicone, Binder-Type Lithographic Plates	1545-TR	1958

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Evaluation of Coherent Radar Photography	18-TR	1963
Evaluation of Color Recognition Devices for Making Color-Separations from Multicolor Maps and Charts	1401-TR	1955
Evaluation of Color Test Photography for Military Geographic Analysis: A Literature Review	ETL-TR-70-6	1970
Evaluation of Components for Some Elevation-Determining Systems	AD 407 297L	1963
Evaluation of Conventional Correlation Methods When Matching Infrared Imagery to Panchromatic Imagery	ETL-0195	1979
Evaluation of Experimental Xerographic Process for Lithographic Platemaking	1417-TR	1955
Evaluation of High Precision SHORAN-Controlled Photography	1484-TR	1957
Evaluation of Land Use Techniques for Processing MGI	AD 817 124L	1967
Evaluation of Multiband and Color Aerial Photography for Selected Military Geographic Intelligence in a Subtropical Desert Environment	54-TR	1970
Evaluation of Offset Collotype Printing for the Field Reproduction of Aerial Photographs	1465-TR	1956
Evaluation of Pointing to a Sharp Edge	AD 668 260	1968
Evaluation of Published Criteria for Identifying Metamorphic Rocks on Air Photos: Two Case Studies in the Northeastern United States	ETL-0326	1983
Evaluation of Registering Image Gradients When Matching Infrared Imagery to Panchromatic Imagery	ETL-0250	1981
Evaluation of Single and Multicolor Map and Chart Reproduction Equipment	ETL-0080	1976
Evaluation of the Method of Determining Parallax from Measured Phase Difference	ETL-0145	1977
Evaluation of the Prototype, Natural-Image Computer	48-TR	1969
Evaluation of the Stellar-Moon Camera System	AD 673270	1968
Evaluation Tests of Royal Zenith, 29 Press	1490-TR	1957
Evidential Reasoning in Expert Systems for Image Analysis	ETL-0381	1985
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Experimental Correlator Studies	AD 374 450L	1966
Experimental Determinations of Fringe Counting Errors Associated with Rotation of a Corner Cube Forming an Arm of a Laser Interferometer	RN-26	1967
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Extraction of Mapping Detail from Radar Photography	AD 328 257	1961
Extreme 24-Hour Snowfalls in the United States: Accumulation, Distribution, and Frequency	ETL-SR-73-4	1973
Feasibility of Using Optical Power Spectrum Analysis Techniques for Automatic Feature Classification from High Resolution Thermal, Radar, and Panchromatic Imagery	ETL-0186	1979
Feasibility Study for an All-Weather Surveying Signal Light	37-TR	1968
Feasibility Study for Field Generation of Input for Radar Scene Generation from DLMS Terrain and Elevation Data	ETL-0203	1978
Feasibility Study of a Quick Response Multicolor Printer (QRMP)	ETL-0242	1980
Feasibility Test of a Proposed 3-D Radar System	AD 349 882L	1964
Feasibility Test Program for Measurement of Gravity Anomaly Changes Using 2 MICRO-g Accelerometer in the Inertial Platform	ETL-CR-74-16	1974
Feature Analysis and Reduction of Laws Texture Measure	ETL-0343	1983
Feature Component Reduction Through Divergence Analysis	ETL-0305	1982
Feature Extraction Assessment Study, Final Report	ETL-0377	1984
Feature Extraction of the Illiac IV	ETL-0191	1979
Feature Tagging	ETL-0227	1980
FEED Evaluation	ETL-0322	1983
FEED Software Documentation	ETL-0335	1983
Fictitious Data Generator for Analytical Aerotriangulation	AD 640 799	1965
Field Artillery Plotting Equipment	1421-TR	1955
Final Report, Development of Mirror Stereoscope	1382-TR	1954
Final Report on Stable Cartographic Bases	1542-TR	1958
Final Report, Study of Digital Matching of Dissimilar Images	ETL-0244	1980
Finite Element Models of the Earth's Gravity Field Phase IV	ETL-0198	1979
Five-Color Separation Investigation	AD 662 725	1967
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Floodplain Tree Species: A Bibliographic Literature Search with Abstracts	ETL-0193	1979
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TITLE	REPORT NO.	YEAR
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Fourier Transform Autocorrelation	ETL-0184	1979
Frequency Dependence of Backscatter from Rough Surfaces (An Experiment with Broad-Spectrum Acoustic Waves)	AD 847 275	1968
Full View Holograms	ETL-CR-70-1	1970
Further Investigation of an Electronic Angle-Measuring Device	ETL-TR-74-1	1973
Further Study of Digital Matching of Dissimilar Images	ETL-0385	1985
Gamma-Ray Spectrometer Study	ETL-0008	1975
GEISHA Computer Theory of Operation	AD 883 289L	no date
General Climatological Guide to Daily Freezing Conditions: Frost Days, Ice Days, and Freeze-Thaw Days, A	ETL-0287	1982
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Geocentric Position and/or Orbital Parameters with Star Satellite Photography from a Single Camera Station	CR-102-1	1963
Geodetic Control by Means of Astronomic and Torsion Balance Observations and the Gravimetric Reduction of Levelling	AD 672 491	1967
Geodetic Control without Triangulation, Trilateration, or Gravity Data and Gravimetric Reduction of Levelling		
1st Interim Report	AD 447 994L	1964
2nd Interim Report	AD 461 100L	1965
3rd Interim Report	AD 477 474L	1965
Geodetic SECOR	AD 721 648	1962
Geodetic SECOR Ground Equipment	AD 721 649	1964
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Geographic Modelling of Insurgency Resources	AD 848 723L	1969
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Geoid Representation from Satellite-Determined Coefficients	AD 634 541	1966
Geologic Evaluation of Radar Imagery from Darien Province, Panama	AD 853 884	1969
Geometric Simultaneous Multistation Determination, with Constraints, Using Data from Geodetic Satellites	RN-22	1967

TITLE	REPORT NO.	YEAR
Geometrical Quality of Lunar Mapping by Photogrammetric Methods	RN-9	1962
Geomorphic Evaluation of Radar Imagery of Southeastern Panama and Northwestern Columbia	ETL-CR-71-2	1971
Geopotential Determination from Satellite to Satellite Tracking and Satellite Altimetry	ETL-CR-74-21	1975
Geopotential Determination from Satellite to Satellite Tracking and Satellite Altimetry, Supplement I	ETL-CR-74-21-S	1975
GEOPS	RN-25	1967
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Geo-Spin Precision Inertial Survey	ETL-0135	1978
Gigas-Zeiss Digital Control Unit	ETL-ETR-73-1	1973
Gradiometer-Aided Rapid Gravity Survey System	ETL-0112	1977
Graphic Arts Symbol Generating Hardware for a Gerber Plotting System	ETL-CR-74-14	1974
Graphic Data Handling Techniques	AD 659 807	1967
Gravimetric Geodesy Free of Density Estimates through Analysis of Discrete Gravity Data	RN-12	1963
Gravity Anomalies as Indicators of Groundwater Reserves in Glacial Deposits	ETL-CR-73-16	1973
Gravity Correlation Studies for Determination of the Gravity Field of the Earth	AD 866 798L	1970
Gravity Study Program, Final Report	ETL-0262	1981
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Hail and Its Distribution	ETL-SR-73-3	1973
Hexagonal Data Base Study	ETL-0338	1983
Hexagonal Data Base Study, Phase II	ETL-0360	1984
High Resolution Optical Power Spectrum Analyzer	ETL-0127	1978
High Resolution Orthophoto Output Table (HIROOT)	AD 856 731L	1969
High Resolution Orthophoto Output Table	ETL-ETR-72-3	1972
High Speed Disc Memory and a Color Image Display for a Small Computer	AD 878 975L	1970
High-Speed, Large-Format Film Writer Methodologies and Design Study	ETL-0389	1985
High Speed Parallel Sensing Scheme	ETL-0119	1977
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Holographic Compensation of Wavefront Aberrations	ETL-RN-74-11	1975
Holographic Optical Elements With Low Q-Factors	ETL-0123	1977
Holographic Ray Tracing and Spot Diagrams	ETL-0052	1975
Holographic Stereogram Display Techniques for the Viewing and Mensuration of Stereo Photogrammetric Imagery	ETL-CR-74-2	1973
Holographic Terrain Displays	ETL-0083	1976
Holography and Stereoscopy	ETL-CR-72-2	1972
Horizontal Gradients of Gravity in Geodesy	AD 672 492	1964
Horizontal Gradients of Gravity in S.W. Ohio	AD 672 489	1967

TITLE	REPORT NO.	YEAR
Hot Weather Testing of 10-Second Direction Theodolite with Universal Tribrach and Universal Tripod, Astronomical Attachment, Universal Sun Compass, Lensatic Compass, and Wrist Compass Air Photo Patterns	1289-TR	1953
Hough Transform on the Butterfly and the NCUBE, The	ETL-0438	1986
IBIS Query — Software to Support the Image Based Information System (IBIS) Expansion for Mapping, Charting, and Geodesy	ETL-0422	1986
Image Alignment and Correlation System	ETL-0237	1980
Image-Based Approach to Mapping, Charting, and Geodesy	ETL-0366	1982
Image Correlation on a Parallel Processor	ETL-0061	1976
Image Enhancement by Chemical Intensification	ETL-0014	1975
Image Processing for Visual Navigation of Roadways	ETL-0406	1985
Image-Processing Precision and Affecting Relative Orientation	ETL-RN-71-6	1971
Image Scanner Technology Study	ETL-0137	1978
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Implications of Symbol Usage on U.S. Army Maps for an Automated Cartographic System	AD 667 979	1968
Implications of Symbol Usage on U.S. Army Maps for an Automated Cartographic System, Appendix	AD 667 986	1968
Improvement Program Automatic Map Compilation System	AD 442 522	1964
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Inertial Positioning System Test Data Summary Report	ETL-0028	1975
Inertial Survey Applications to Civil Works	ETL-0309	1983
Inertial Survey Equipment (GEISHA)	AD 814 051	1963
Inferential Techniques for Soil Depth Determinations, Part I: Coleogyne ramossissima Torr. (Black-Brush)	ETL-0036	1975
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Instrumentation for Color Aerial Photography	ETL-RN-70-1	1970
Integration of Artificial Intelligence Concepts into the Methods for Extracting Line Objects from Monochromatic Aerial Imagery	ETL-0425	1986
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TITLE	REPORT NO.	YEAR
Interactive Digital Correlation Techniques for Automatic Compilation of Elevation Data	ETL-0272	1981
Interactive Digital Image Processing for Terrain Data Extraction	ETL-0241	1980
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Interactive Digital Image Processing for Terrain Data Extraction, Phase 3	ETL-0294	1982
Interactive Digital Image Processing for Terrain Data Extraction, Phase 4	ETL-0348	1983
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Interactive Digital Image Processing Investigation	ETL-0172	1978
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Interactive Image Analysis System Design	ETL-0312	1982
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Interpretation of Radar Imagery for Terrain Analysis in Tropical Environments		1968
Introduction to the Terrain Effects on the Intelligence Preparation of the Battlefield (IPB)	ETL-0481	1987
Inverse Perspective of a Road from a Single Image	ETL-0429	1986
Inverse Scattering Applications in Determining Terrain Feature Parameters	ETL-0279	1981
Investigation and Evaluation of Planigon Lens Distortion Characteristics	1472-TR	1957
Investigation, Experiments, and Study of Electron Beam Recorder (EBR) Techniques for Map Production	ETL-CR-73-15	1973
Investigation of Bjerhammar's New Gravity Reduction Method	AD 460 404	1964
Investigation of Cartographic Pressplate Recording from Digital Data	ETL-0043	1976
Investigation of Continuous Photoconductive Layer Arrays	ETL-0011	1975
Investigation of Discrete Function Technology for Topographic Sciences	ETL-0162	1978
Investigation of Electro-Acoustic Technology for Topographic Application	ETL-0160	1978
Investigation of Extrema in Digital Images for Texture Analysis	ETL-0210	1979

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Investigation of Linear Transformations for Automatic Cartographic Analysis	ETL-0181	1979
Investigation of Multiband Photographic Techniques, Vol. I	AD 479 300L	1965
Investigation of Photographic Mapping Detail and Data Encoding	AD 286 715	1962
Investigation of Techniques to Generate Contours from Stereo Pairs	ETL-0029	1975
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Investigation of the Electronic Distance Measuring Equipment Electrotape	AD 460 401L	1964
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Investigations of the Use of Conventional Films in the ETL Cartographic EBR	ETL-0177	1979
Investigations Related to the Establishment of a World Geodetic System	AD 697 163	1969
IRS: A Simulator for Autonomous Land Vehicle Navigation	ETL-0455	1987
Joint Analyses in Glen Canyon National Recreational Area	ETL-0073	1976
Kalman Filtering and Smoothing in Fotonap for Orbit Determination using GPS Measurements	ETL-0162	1978
KANDIDATS	ETL-CR-71-3	1971
Knowledge-Based Analysis of Scene Dynamics for Target Motion Detection, Recognition, and Tracking	ETL-0486	1987
Knowledge-Based Images Analysis	ETL-0258	1981
Knowledge-Based Vision Techniques (March 1985 - March 1986)	ETL-0431	1986
Knowledge-Based Vision Techniques (March 1986 - March 1987)	ETL-0487	1987
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TITLE	REPORT NO.	YEAR
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Mathematics of Geodetic SECOR Data Processing	AD 721 837	1964
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TITLE	REPORT NO.	YEAR
MATS Performance with the SECOR System	AD 721 635	no date
MATS Transponder	AD 721 634	1966
Measurement of the Change in the Deflection of of the Vertical with a Schuler-Tuned North- Slaved Inertial System	ETL-0138	1977
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TITLE	REPORT NO.	YEAR
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Multi-Parametric Figures of Equilibrium: Curvature of the Plumb Line	AD 603 073	1964
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Multisensor Approaches for Determining Deflections of the Vertical	ETL-0314	1983
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TITLE	REPORT NO.	YEAR
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New Formulas Useful When Changing Ellipsoidal Parameters or Orientation	RN-2	1962
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TITLE	REPORT NO.	YEAR
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Performance Evaluation of the Position and Azimuth Determining System (PADS) with an Improved Vertical Accelerometer	ETL-0166	1978
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