

AD 684337

AD

Research and Development Technical Report  
ECOM-01901-33



# GRAPHICAL-DATA-PROCESSING RESEARCH STUDY AND EXPERIMENTAL INVESTIGATION

## FINAL REPORT

By  
*J. H. Munson*

MAR 17 1969

December 1968

### DISTRIBUTION STATEMENT

This document has been approved for public release and sale; its distribution is unlimited.

# ECOM

UNITED STATES ARMY ELECTRONICS COMMAND • FORT MONMOUTH, N.J. 07703

CONTRACT DA 28-043 AMC-01901(E)

**STANFORD RESEARCH INSTITUTE**

Menlo Park, California 94025

Reproduced by the  
CLEARINGHOUSE  
for Federal Scientific & Technical  
Information Springfield Va. 22151

## NOTICES

### Disclaimers

The findings in this report are not to be construed as an official Department of the Army position, unless so designated by other authorized documents.

The citation of trade names and names of manufacturers in this report is not to be construed as official Government endorsement or approval of commercial products or services referenced herein.

### Disposition

Destroy this report when it is no longer needed.  
Do not return it to the originator.



TECHNICAL REPORT ECOM-01901-33

Reports Control Symbol  
OSD-1366  
DECEMBER 1968

**GRAPHICAL-DATA-PROCESSING RESEARCH STUDY  
AND EXPERIMENTAL INVESTIGATION**

REPORT NO. 33, FINAL REPORT  
1 FEBRUARY 1966 TO 30 NOVEMBER 1968

SRI Project 5864

CONTRACT DA 28-043 AMC-01901(E)  
Continuation of Contract DA 36-039 AMC-03247(E)

Prepared by

J. H. MUNSON

STANFORD RESEARCH INSTITUTE  
MENLO PARK, CALIFORNIA 94025

For

U.S. ARMY ELECTRONICS COMMAND, FORT MONMOUTH, N.J. 07703

**DISTRIBUTION STATEMENT**

This document has been approved for public release and sale; its distribution is unlimited.

## ABSTRACT

---

The complete MINOS III facility has been delivered by SRI to USAECOM at Fort Monmouth, New Jersey, and demonstrated to the sponsor's technical personnel. Operation can be demonstrated under the control of three different computer programs: an operating program, a diagnostic program, and the CALM IV learning-machine program.

Accomplishments during the three years of the project are reviewed. Collected tables of contents are provided to guide the reader to appropriate references among the ten Quarterly Reports of the project.

CONTENTS

---

ABSTRACT

I	ACCOMPLISHMENTS UNDER CONTRACT DA 28-043 AMC-01901 (E) . . . . .	1
II	COLLECTED TABLES OF CONTENTS . . . . .	4
DD	FORM 1473	

## I ACCOMPLISHMENTS UNDER CONTRACT DA 28-043 AMC-01901(E)

### A. Delivery of the MINOS III Facility

The complete MINOS III pattern-recognition facility, including the MINOS II learning machine, the SDS 910 computer, the 1,024-image pre-processor, the computer-controlled TV camera scanning system, and the extensive interface connecting these units, was delivered by SRI to the sponsor (UAECOM) at Fort Monmouth during November 1968. In the period from 2-13 December 1968, Dr. John Munson and Mr. Peter Johanson of Stanford Research Institute checked out the system at Fort Monmouth and demonstrated its operation to the sponsor's technical personnel, Mr. William A. Huber and Mr. Richard Loiselle. The same persons had also witnessed demonstrations of the operation of the equipment at SRI in late October 1968, before the system was shipped.

During both demonstration periods, the MINOS III facility successfully performed the full sequence of activities required for the pattern recognition of graphical data. These activities included scanning under computer control, selective attention and isolation of character images, edge-detecting preprocessing, and adaptive pattern classification. Hardware methods and alternate software methods were demonstrated for both preprocessing and classification.

The system performs under any of three functionally integrated computer programs. The diagnostic program affords a convenient means of checking out, unit by unit, the hardware components of the MINOS III facility. The CALM IV program, the descendant of a number of learning-machine simulation programs, allows extremely flexible control of the entire range of operations of both the hardware and software adaptive pattern classifiers (learning machines). The main demonstration and operating vehicle, the operating program, allows flexible control of any operating sequence involving scanning, hardware and/or software preprocessing, classification with MINOS II, and display of the data at various stages.

Complete documentation, running to several volumes, was included with the delivered system. The documentation included listings and operating descriptions of the three main computer programs and their myriad component subprograms, drawings of the MINOS II and interface circuitry, descriptions and notes for the facility subsystems, manuals for commercially manufactured equipment included in the facility, etc.

#### B. System Integration

The successful delivery of the MINOS III facility was the culmination of what may be called, from the hardware standpoint, the period of system integration. During the preceding contract,\* emphasis was on equipment-building, and the major elements of the MINOS III facility--the MINOS II learning machine, the 1,024-image preprocessor, the SDS 910 computer, and the TV camera input--were all built or acquired. These units were not tied together, however, in a fully operating system; thus patterns could not be carried through the scanning, preprocessing, and classification operations in a single run. In particular, it was not possible for patterns scanned by the TV camera and isolated in the computer to be presented to the 1,024-image preprocessor.

During the present contract, under the impetus of our experimental needs, this integration of the system components was completed to produce the MINOS III facility. The integration of the facility has yielded a degree of operating convenience in running experiments and demonstrations that far exceeds what was possible in the previous modes of operation.

#### C. Experiments in Hand-Printed Text Recognition

Our major effort in the present contract, aside from system-building, went into experiments aimed at applying the facility to a potentially important problem: the automatic recognition of texts of hand-printed characters on coding sheets. We believe that our research broke new ground in several areas. First, of course, was the use of the particular techniques embodied in the MINOS III facility to perform experiments on a significant body of hand printing. Second, we found a striking

---

DA 36-039 AMC-03247(E). The final report for that project is available as an ASTIA document, AD 632 563.

improvement in performance in going from multiple-coder recognition to single-coder recognition, and an additional improvement when we harnessed multiple-pattern views and multiple preprocessor classifier combinations in parallel. Finally, we performed a pioneering study on the use of context in a specific language to improve recognition performance.

Our work was described and summarized in a pair of technical papers presented at the 1968 Fall Joint Computer Conference, as well as being described throughout the Quarterly Reports of this project. The papers appear in the Conference Proceedings under the common title of "Experiments in the Recognition of Hand-Printed Text," with Part I, "Character Recognition," by J. Munson, and Part II, "Context Analysis," by Richard O. Duda and Peter E. Hart. The support of the USAECOM for this project is acknowledged in both papers. During the session on "Hand-Printed Character Recognition" at the conference, the papers were presented to a standing-room-only audience of over 200 persons.

## II COLLECTED TABLES OF CONTENTS

The work performed during this project has been described in detail in the ten Quarterly Reports issued during the project. As a necessary consequence, the overall arrangement of material is chronological, rather than by subjects. In order that this Final Report constitute a convenient first point of reference for the various subjects--hardware systems, classification experiments, context experiments, etc.--we collect below the Tables of Contents from the ten Quarterly Reports. The reports pertinent to any subject area can be determined by scanning the collected contents.

CONTENTS OF ECOM-01901-23  
(First Quarterly Report)

---

I	INTRODUCTION . . . . .	1
II	EXPERIMENTAL RESOURCES PRESENTLY AVAILABLE . . . . .	3
III	THE SELECTION OF SUBJECT MATTER FOR FURTHER EXPERIMENTS.	5
IV	THE PATTERN INPUT SYSTEM . . . . .	9
	A. The TV Input for Coding Sheets . . . . .	9
	B. Experiments with Writing Instruments . . . . .	10
V	EXPERIMENTS WITH THE INPUT SYSTEM . . . . .	13
VI	A REVIEW OF PREPROCESSOR DESIGNS (PART ONE). . . . .	15
	A. Introduction . . . . .	15
	B. Characteristics of the Present 1024-Image Preprocessor . . . . .	16
	C. Criteria for the Redesign of Existing Equipment . . . . .	18
	D. A Revised Preprocessor Design Based on Multiple Picture Tubes . . . . .	19
	E. A Preprocessor Design Using a High Resolution Cathode-Ray Tube with Fiber-Optic Faceplate . . . . .	20

CONTENTS OF ECOM-01901-24  
(Second Quarterly Report)

---

I	INTRODUCTION . . . . .	1
II	EXPERIMENTS WITH THE EDGE-DETECTING PREPROCESSOR AND THE PIECEWISE-LINEAR LEARNING MACHINE. . . . .	3
	A. Preprocessing . . . . .	3
	B. Classification . . . . .	4
	C. Experiments . . . . .	5
	D. Discussion of Results in Relation to Future Investigation . . . . .	8
III	EXPERIMENTS USING CLEMENS' TECHNIQUE . . . . .	11
	A. Clemens' Technique . . . . .	11
	B. Experimental Results . . . . .	13
	C. Conclusions . . . . .	16
IV	INITIAL EXPERIMENTS ON CONTEXT . . . . .	17
	A. Introduction . . . . .	17
	B. Experiment in Reading Text with Ambiguous Classifications . . . . .	20
	C. Analysis of FORTRAN Statement Type . . . . .	20
V	EXPERIMENTS ON HUMAN RECOGNITION OF CHARACTERS WITHOUT CONTEXT . . . . .	21
	A. Coding-Sheet Tests . . . . .	21
	B. Quantized-Character Tests . . . . .	23
	C. Conclusions . . . . .	23

CONTENTS OF ECOM-01901-25  
(Third Quarterly Report)

---

I	INTRODUCTION . . . . .	1
II	CONTINUING EXPERIMENTS WITH THE EDGE-DETECTING PREPROCESSOR AND THE PIECEWISE-LINEAR LEARNING MACHINE. . . . .	3
	A. General . . . . .	3
	B. Experiment 5. . . . .	3
	C. Experiment 6. . . . .	4
	D. Experiment 7. . . . .	6
	E. Future Experiments . . . . .	8
III	"AD HOC" PREPROCESSING AND CLASSIFICATION OF CHARACTERS . . . . .	9
IV	A PROGRAM TO DISCRIMINATE BETWEEN "6" AND "G". . . . .	15
	A. General . . . . .	15
	B. Method of Approach . . . . .	15
	C. Description of the Routine . . . . .	16
	D. Performance . . . . .	18
	E. Future Work . . . . .	18
V	PROPOSED METHOD FOR USING THE 1024-IMAGE OPTICAL PREPROCESSOR FOR WAVEFORM RECOGNITION. . . . .	19
	A. General . . . . .	19
	B. Method. . . . .	19
	C. Mask Design . . . . .	20

CONTENTS OF ECOM-01901-26  
(Fourth Quarterly Report)

---

I	INTRODUCTION . . . . .	1
II	EXPERIMENTS, WITH TWO TEMPLATE-MATCHING PREPROCESSORS AND THE PIECEWISE-LINEAR LEARNING MACHINE . . . . .	3
	A. Further Experiments with the Edge-Detecting Preprocessor and the Piecewise-Linear Learning Machine . . . . .	3
	1. PREP-CALM Experiment 8 . . . . .	3
	2. PREP-CALM Experiment 9 . . . . .	7
	B. Experiments with the CALMMASK Preprocessor and the Piecewise-Linear Learning Machine . . . . .	7
	1. The CALMMASK Preprocessing Program . . . . .	7
	2. MASK-CALM Experiment 2 . . . . .	10
	3. MASK-CALM Experiment 3 . . . . .	11
	4. MASK-CALM Experiment 4 . . . . .	11
	5. MASK-CALM Experiment 5 . . . . .	11
	C. Examination of Learning-Machine Statistics During a Test Iteration . . . . .	15
III	TOPOLOGICAL PREPROCESSING OPERATIONS FOR HANDPRINTED CHARACTER RECOGNITION. . . . .	23
	A. Introduction . . . . .	23
	B. Current Status of the Topological Preprocessing and Classification Program. . . . .	24
	C. Discussion of Topological Preprocessing Operations. . . . .	26
	1. Figure Extent and Location. . . . .	28
	2. Connectivity. . . . .	28
	3. Subroutines CONN8 and CONN4 . . . . .	30
	4. Figure Dissection . . . . .	32
	5. Subroutines GROW8 and GROW4 . . . . .	33

CONTENTS OF ECOM-01901-27  
(Fifth Quarterly Report)

---

I	INTRODUCTION . . . . .	1
II	TOPOLOGICAL PREPROCESSING OPERATIONS FOR RECOGNITION OF HAND-PRINTED CHARACTERS . . . . .	3
	A. Introduction . . . . .	3
	B. Contour Following (The Perimeter and the Shell) . . . . .	4
	1. Finding the Perimeter of a Figure . . . . .	5
	2. Finding the Shell of a Figure . . . . .	8
	C. The Convex Hull . . . . .	8
	D. Concavities and Enclosures. . . . .	13
	E. Spurs . . . . .	14
III	STATUS OF THE TOPOLOGICAL PREPROCESSING AND CLASSIFICATION PROGRAM (TOPO 2). . . . .	17
	A. Preprocessing . . . . .	17
	B. Intermediate Steps. . . . .	18
	C. Classification. . . . .	20
	D. Classification by a Learning Machine from Topological Features . . . . .	22
	E. Experimental Results. . . . .	23
	1. Authors 1-20. . . . .	23
	2. Authors 21-40 . . . . .	25
	3. Authors 41-49 . . . . .	27
	4. Casey's Data: Letters and Numerals. . . . .	27
	5. The Backroom Data . . . . .	29
	F. Plans for the Near Future . . . . .	31
IV	DESCRIPTION OF PROGRAMS FOR SYNTAX ANALYSIS. . . . .	33
	A. Introduction. . . . .	33
	B. Assumptions . . . . .	33
	C. General Program Structure . . . . .	35

CONTENTS OF ECOM-01901-28  
(Sixth Quarterly Report)

---

I	INTRODUCTION . . . . .	1
II	LEARNING-MACHINE AND NEAREST-NEIGHBOR EXPERIMENTS ON THE TOPOLOGICAL FEATURES FROM <u>TOPO 2</u> . . . . .	2
	A. Introduction. . . . .	2
	B. TOPO-CALM Experiment 3. . . . .	3
	C. TOPO-Nearest Neighbor Experiment 1. . . . .	3
	D. Comparison of Results . . . . .	5
	E. Discussion. . . . .	6
III	INTRA-AUTHOR EXPERIMENTS . . . . .	10
	A. Introduction. . . . .	10
	B. Intra-Author TOPO-CALM Experiments. . . . .	11
IV	AN EXPERIMENT INCLUDING PREPROCESSING, CLASSIFICATION, AND SYNTAX ANALYSIS. . . . .	17
V	STATUS OF THE SYNTAX ANALYSIS PROGRAM. . . . .	24
	A. Introduction. . . . .	24
	B. Dynamic Programming Approach. . . . .	24
	C. Compression of Characters . . . . .	25
	D. Heuristic Partitioning. . . . .	27
	E. Improvements in Dynamic Programming . . . . .	29
	F. Table of Variables. . . . .	29

CONTENTS OF ECOM-01901-29  
(Seventh Quarterly Report)

---

I	INTRODUCTION . . . . .	1
II	INTRA-AUTHOR EXPERIMENTS ON THE JM DATA FILE . . . . .	2
	A. Introduction. . . . .	2
	B. The JM Data File. . . . .	2
	C. Legibility of the JM Text . . . . .	3
	D. TOPO 3-CALM Experiment 1. . . . .	4
	E. PREP-CALM Experiment 11 . . . . .	6
	F. PREP-CALM Experiment 12 . . . . .	6
	G. PREP-CALM Experiment 12A. . . . .	8
	H. PREP-CALM Experiment 13 . . . . .	8
III	EXPERIMENTS ON THE JM DATA FILE WITH COMBINED CLASSIFIERS. . . . .	10
	A. Introduction. . . . .	10
	B. TOPO 3-CALM Experiment 1 and PREP-CALM Experiment 11 Combined. . . . .	10
	C. TOPO 3-CALM Experiment 1 and PREP-CALM Experiment 12A Combined . . . . .	11
	D. Summary . . . . .	12
IV	EXPERIMENTS WITH HIGHLEYMAN'S DATA . . . . .	13
	A. Introduction. . . . .	13
	B. Nearest-Neighbor Classification . . . . .	14
	C. Edge-Detecting Preprocessing and Piecewise-Linear Classification . . . . .	15
	D. Human Performance . . . . .	16
	E. Conclusions . . . . .	17

CONTENTS OF ECOM-01901-30  
(Eighth Quarterly Report)

---

I	INTRODUCTION AND SUMMARY . . . . .	1
II	LEARNING-MACHINE EXPERIMENTS ON AN INTER-AUTHOR FILE OF HAND-PRINTED CHARACTERS . . . . .	2
A.	Introduction. . . . .	2
B.	PREP-CALM Experiment 20 . . . . .	3
C.	PREP-CALM Experiment 20A. . . . .	3
D.	TOPO 3-CALM Experiment 20 . . . . .	3
E.	TOPO 3-CALM Experiment 20 and PREP-CALM Experiment 20A Combined . . . . .	4
F.	Summary . . . . .	6
III	CONTROL OF MINOS II FROM THE SDS 910 COMPUTER. . . . .	7
A.	Introduction and Background . . . . .	7
B.	Review of Learning-Machine Structure, and Operation . . . . .	9
C.	Operating MINOS II. . . . .	16
D.	Units of Measurement and Sources of Inaccuracy. . . . .	19
E.	The CALM Learning-Machine Program, Mark IV. . . . .	22

CONTENTS OF ECOM-01901-31

(Ninth Quarterly Report)

---

I	INTRODUCTION AND SUMMARY. . . . .	1
II	STATUS OF CONTEXT-ANALYSIS PROGRAM. . . . .	2
	A. Background . . . . .	2
	B. Past Approaches. . . . .	3
	C. Formal Solution. . . . .	4
	D. Structure of Context-Directed Analyzer . . . . .	7
	1. Statement Identification . . . . .	8
	2. Statement Analysis . . . . .	9
	3. Identifier Table . . . . .	11
	4. Resolution of Arithmetic Expressions . . . . .	13
	5. Summary of Analyzer Structure. . . . .	16
	E. Examples . . . . .	17
	F. Discussion . . . . .	23

CONTENTS OF ECOM-01901-32  
(Tenth Quarterly Report)

---

I	INTRODUCTION AND SUMMARY . . . . .	1
II	COMPUTER OUTPUT OF QUANTIZED IMAGES TO THE 1024-IMAGE PREPROCESSOR. . . . .	3
A.	Introduction. . . . .	3
B.	Description of the Method . . . . .	5
C.	Details of Operation. . . . .	9
D.	Connection to the Preprocessor. . . . .	14

UNCLASSIFIED

Security Classification

DOCUMENT CONTROL DATA - R & D		
<i>Security classification of title, body of abstract and indexing annotation must be entered when the overall report is classified.</i>		
1. ORIGINATING ACTIVITY (Corporate author) Stanford Research Institute 333 Ravenswood Avenue Menlo Park, California 94025		2a. REPORT SECURITY CLASSIFICATION UNCLASSIFIED
		2b. GROUP N/A
3. REPORT TITLE  GRAPHICAL-DATA-PROCESSING RESEARCH STUDY AND EXPERIMENTAL INVESTIGATION		
4. DESCRIPTIVE NOTES (Type of report and inclusive dates) Final Report, 1 February 1966 to 30 November 1968		
5. AUTHOR(S) (First name, middle initial, last name)  John H. Munson		
6. REPORT DATE December 1968	7a. TOTAL NO. OF PAGES 22	7b. NO. OF REFS 0
8a. CONTRACT OR GRANT NO. DA 28-043 AMC-01901(E)	9a. ORIGINATOR'S REPORT NUMBER(S) Final Report SRI Project 5864	
b. PROJECT NO.	9b. OTHER REPORT NUMBERS (Any other numbers that may be assigned this report)	
10. DISTRIBUTION STATEMENT  This document has been approved for public release and sale; its distribution is unlimited.		
11. SUPPLEMENTARY NOTES		12. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES) U.S. Army Electronics Command Fort Monmouth, New Jersey 07703
13. ABSTRACT  The complete MINOS III facility has been delivered by SRI to USAECOM at Fort Monmouth, New Jersey, and demonstrated to the sponsor's technical personnel. Operation can be demonstrated under the control of three different computer programs: an operating program, a diagnostic program, and the CALM IV learning-machine program.  Accomplishments during the three years of the project are reviewed. Collected tables of contents are provided to guide the reader to appropriate references among the ten Quarterly Reports of the project.		

DD FORM 1473

(PAGE 1)

5 NOV 66 0101-807-6801

UNCLASSIFIED

Security Classification

14 KEY WORDS	LINK A		LINK B		LINK C	
	ROLE	WT	ROLE	WT	ROLE	WT
Pattern Recognition Handprinting Recognition Learning Machines Graphical Data Processing Visual Image Processing						