DTIC FILE COPY

Naval Ocean Research and Development Activity
December 1989
Report 233

The NORDA MC&G Map Data Formatting Facility: Development of a Digital Map Data Base

AD-A220 508

DTIC
S ELECTE D
APR 0 4 1990
D

Kevin B. Shaw
James E. Ryan
Maura C. Lohrenz
Mary G. Clawson
Mapping, Charting, and Geodesy Division
Ocean Science Directorate

Lancelot M. Riedlinger
Jesse I. Pollard II
Planning Systems, Incorporated
Slidell, Louisiana 70458

Approved for public release; distribution is unlimited. Naval Ocean Research and Development Activity, Stennis Space Center, Mississippi 39529-5004.

90 04 03 022

Foreword

The Naval Ocean Research and Development Activity (NORDA) is the Navy's leading laboratory for research and development in mapping, charting, and geodesy (MC&G). As such, we are actively involved in applying digital MC&G data to the support of naval weapons systems and in conducting research to improve these data.

This report documents the developments in hardware, application software, and scanned map data bases that are currently providing transformed digital MC&G data for the Digital Moving Map System installed in Navy and Marine Corps AV-8B, F/A-18, and V-22 aircraft. NORDA has developed an advanced computer system, the Map Data Formatting Facility (MDFF), to perform these transformations. The product is the Navy standard scanned map data base. An upgrade to the MDFF application software is planned for January 1, 1990, to increase processing speed.

W. B. Moseley
Technical Director

J. B. Tupaz, Captain, USN
Commanding Officer

Executive Summary

Hardware and software systems have been developed at the Naval Ocean Research and Development Activity (NORDA) to provide digital mapping, charting, and geodesy (MC&G) data bases for Digital Moving Map Systems installed on naval aircraft.

The computer system developed at NORDA is known as the Map Data Formatting Facility (MDFF). The MDFF transforms digital map data bases, distributed by the Defense Mapping Agency (DMA), into a form suitable for actual field use by the AV-8B, F/A-18, V-22, and A-12 naval aircraft and Tactical Aircraft Mission Planning Systems. These data bases include DMA's Equal Arc-Second Raster Chart Digitized Raster Graphic Data, Digital Terrain Elevation Data, and Digital Feature Analysis Data.

In addition to describing the hardware and software components of the MDFF, this report gives an overview of current and proposed MC&G research projects being investigated in conjunction with the MDFF work. This research is primarily intended to improve the digital map display in the cockpit and to investigate new methods of compressing digital image data.

DTIC COPY INSPECTED

Accesion For	
NTIS CRA&I	☑
DTIC TAB	☐
Unannounced	☐
Justification	
By	
Distribution /	
Availability Codes	
Dist	Avail and / or Special
A-1	

Acknowledgments

A number of persons made important contributions to this report and to the development of the Map Data Formatting Facility (MDFF). We would particularly like to thank the U.S. Marine Corps (Lt. Col. George Goodwin) and the Naval Air Systems Command (NAVAIR) 5117F for sponsoring this work, which was funded under Aircraft Procurement, Navy H1CC Subhead AV-8B Harrier, Program Elements 940101 (64262N) and 980101 (APN).

Special thanks are also due McDonnell Douglas Aerospace (St. Louis), Honeywell, Inc. (Albuquerque), and Digital Cartographic Systems, Inc. (Denver), for their efforts related to the development of the Ground Support Station for the AV-8B Digital Moving Map System. This prototype ground station was the forerunner to the MDFF. The Defense Mapping Agency (St. Louis) also contributed to the MDFF by developing the specifications for the Equal Arc-Second Raster Chart Digitized Raster Graphics (the digital scanned map data to be used by NORDA in the MDFF) and by producing and distributing this data base.

Thanks are due to Tulane University's Electrical Engineering Department (Drs. Andrew Martinez and Herb Barad) for the digital map compression research performed under NORDA Contract N00014-88-K-6006.

Finally, we would like to thank Mr. Michael M. Harris, Head of NORDA's Pattern Analysis Branch, for reviewing the text of this report.

Contents

Development of a Digital Map Data Base

Introduction

The Naval Ocean Research and Development Activity (NORDA) has developed the Map Data Formatting Facility (MDFF) to produce a data base of raster chart images, terrain elevation data, and cultural feature data. NORDA is currently distributing transformed, Equal Arc-Second Raster Chart (ARC) Digitized Raster Graphics (ADRG) on magnetic tape to support initial naval aircraft deliveries. Beginning in February 1990, this data base will be distributed as a library of Compact Disk-Read Only Memory (CDROM) optical disks. This report details the hardware and software configuration of the MDFF, provides an overview of the data flow through the system, and describes several research projects completed or being considered in conjunction with this work. Acronyms and abbreviations used throughout the report are defined here for convenience:

ADRG	ARC Digitized Raster Graphics
ARC	Equal Arc-Second Raster Chart projection system
CDROM	Compact Disk-Read Only Memory
CPU	Central Processing Unit
CRT	Cathode Ray Tube (terminal screen)
DELNI	Digital Ethernet Local Network Interconnect
DFAD	Digital Feature Analysis Data
DTED	Digital Terrain Elevation Data
DLMS	Digital Landmass System (DTED/DFAD)
DMA	Defense Mapping Agency
DMC	Digital Map Computer
DMS	Digital Moving Map System
DMU	Digital Memory Unit (an optical disk)
DSS	Digital Storage Set (EEPROM-based)
EEPROM	Electrically Erasable, Programmable, Read-Only Memory
GSS	Ground Support Station
HSC	High Speed Disk Controller
HTI	Horizons Technology, Inc.
JOG	Joint Operations Graphics
LAN	Local Area Network
MACAIR	MacDonnell Douglas Aircraft Corporation
MDFF	Map Data Formatting Facility
MIPS	Million Instructions Per Second
MLRQ	Multilevel Rooted Quadtree
MPS	Mission Planning System
NAVAIR	Naval Air Systems Command
NORDA	Naval Ocean Research and Development Activity
ODI	Optical Disk Image
ONC	Operational Navigation Chart
RGB	Red, Green and Blue
TAMPS	Tactical Aircraft Mission Planning System
TS	Tessellated Spheroid
TPC	Tactical Pilotage Chart
VQ	Vector Quantization

Background

The first Digital Moving Map System (DMS) was developed as part of a Night Attack System for the AV-8B naval aircraft. The DMS displays to a pilot scanned navigational chart images covering the mission area and overlays of threat, route, and target symbols. The scanned map data base distributed by NORDA's MDFF was originally conceived to support the DMS component of the Night Attack System, and is currently providing such support to AV-8B aircraft. F/A-18, V-22, and A-12 naval aircraft have since incorporated their own DMSs and will also be utilizing the MDFF data base.

Digital Moving Map System

The original DMS is located in the cockpit of each aircraft and consists of four main components: a cockpit color cathode ray tube (CRT) display; an onboard digital map computer (DMC); a digital memory unit (DMU), which is an optical disk drive; and a digital storage set (DSS), which is an electrically erasable, programmable, read-only memory (EEPROM) based device (see Fig.1). The scanned navigational chart images displayed by the DMS are stored on optical disk, while the overlays of threat, route, and target symbols are stored in the DSS. The DMS supports scrolling and zooming within these displays.

The chart image data and the threat, route, and target overlay data are mission-specific. Prior to mission performance, these data are selected from a larger data base and loaded onto the memory units via a ground base mission planning system (MPS).

The objectives of implementing the DMS and its associated MPS are to provide pilots with in-flight navigation information; increased mission planning and preflight simulation; and the capability to rapidly

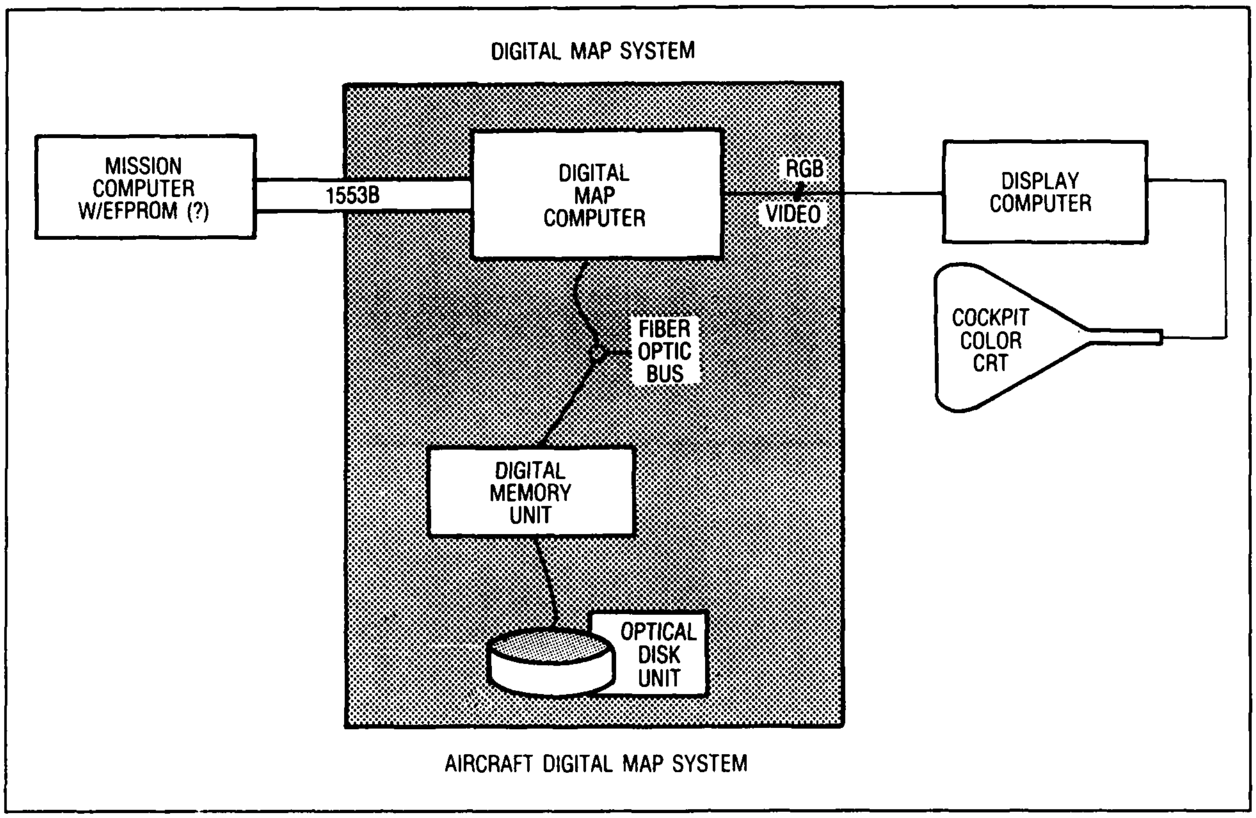

Figure 1. Digital moving map system.

integrate reconnaissance photographs, as well as map and chart updates, into the mission data base. For the AV-8B and V-22, the DMS will almost completely replace paper maps used in the cockpit. For the F/A-18, the DMS will completely replace the filmstrip maps used in the cockpit.

Ground Support Station

The DMS was developed by Sperry Corporation, under contract to McDonnell Douglas Aircraft Corporation (MACAIR). In addition, a prototype MPS, called the Ground Support Station (GSS), was designed by MACAIR. The GSS was used successfully to prepare optical disks and to load DMUs for test flights of the AV-8B in 1987. The GSS combined many functions in one facility: paper map scanning, map image data compression and formatting, and selecting and loading data onto the optical disk and the DMU. Since the completion of the proof-of-concept flight tests, the GSS has been delivered to NORDA, where it has been incorporated into the MDFF.

DMS Support by DMA, NORDA, and NAVAIR

To provide the AV-8B, F/A-18 and V-22 naval aircraft with the data bases needed to support their DMSs, a cooperative effort involving the Defense Mapping Agency (DMA), NORDA, and the Naval Air Systems Command (NAVAIR) has been organized. A flow chart illustrating the arrangement of this effort is shown in Figure 2: DMA provides generic digital map data to NORDA, and NORDA's MDFF processes these data to produce the DMS-specific data base.

The DMS-specific data base must consist of three components: scanned navigational chart image data, terrain elevation data, and cultural feature data. In support of this requirement, DMA is providing NORDA with Equal Arc-Second Raster Chart (ARC) Digitized Raster Graphics (ADRG), Digital Terrain Elevation Data (DTED), and Digital Feature Analysis Data (DFAD). While DTED and DFAD are widely used standard DMA products, ADRG is a newly-designed product that DMA began distributing in May 1989.

ADRG provides a world-wide, seamless data base of scanned chart image data. ADRG was developed specifically to meet the needs of electronic map systems like the DMS. NORDA has worked closely with DMA throughout ADRG's development to ensure that the new data base meets the needs of the DMS program. To produce ADRG, DMA scans standard DMA paper charts, warps the resultant image data into a universal frame of reference (the ARC projection system), and publishes the data on CDROM. The specific ADRG

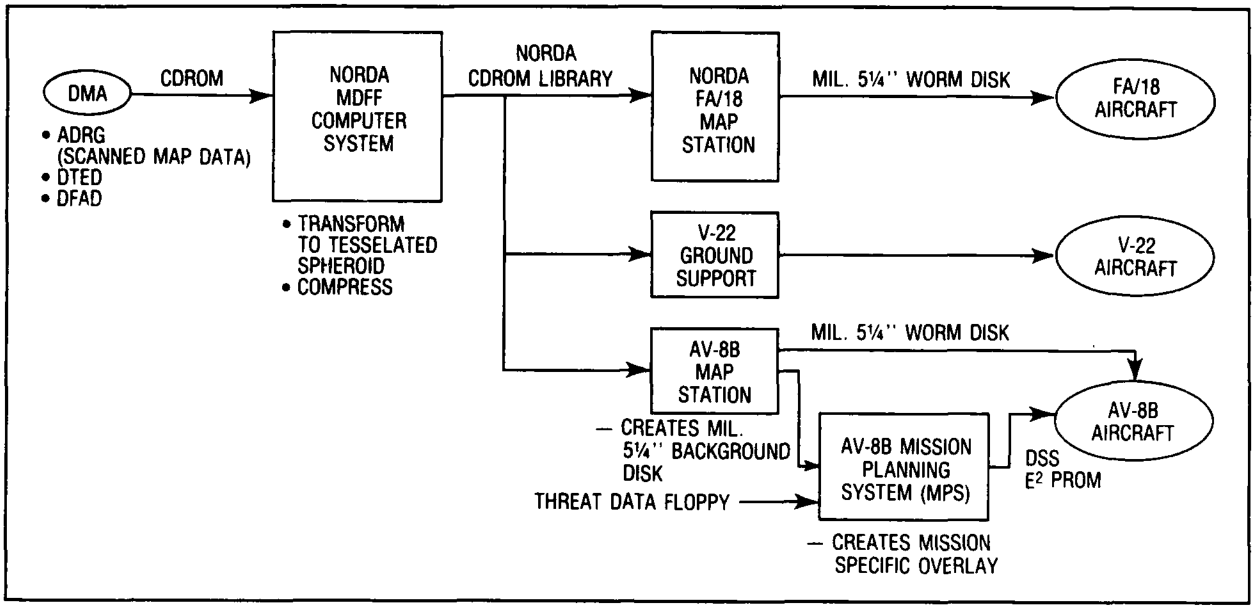

Figure 2. DMS support network.

map image data that NORDA is receiving from DMA is produced from scanned Joint Operations Graphics (JOG), Operational Navigation Charts (ONC), and Tactical Pilotage Charts (TPC).

NORDA's role in supporting the DMS has been to develop the computer system that will transform, compress, and reformat DMA's data and produce the data base required by the aircraft's MPS. Also, NORDA has been monitoring the software upgrade by Honeywell, which provides the operating environment for this computer system. Toward this end, NORDA has designed and implemented the MDFF.

Direct support of the aircraft will be provided by the MPSs. An MPS enables its operator to perform the following functions: load the aircraft optical disk with map image data selected from NORDA's data base; display this data on a color CRT display for mission planning; access DTED and DFAD from the NORDA data base for mission planning; load the DMS with threat, route, and target vectors for overlay on the cockpit color CRT; and scan special paper maps or reconnaissance photographs for incorporation into the map image data. NAVAIR currently has a contract with Horizons Technology, Inc. (HTI), to produce several MPSs to perform these functions for the AV-8B.

Summary of the MDFF Effort at NORDA

The current effort of the MDFF program at NORDA has been to design and implement a computer facility to provide maximum efficiency in the production of a DMS-compatible data base. All the hardware for the MDFF has currently been installed, and an operating environment has been established. Upgraded data processing software for the MDFF is being developed by Honeywell, Inc. (Albuquerque) to improve system throughput. Following completion of the software development in early 1990, NORDA will begin producing the data base for its CDROM library. Table 1 shows NORDA's schedule for delivering the map image data portion of the library. Each portion of map image data produced by NORDA will be accompanied by a portion of processed terrain elevation and feature data covering the same geographic area.

NORDA plans to continue producing, updating, and evaluating this library for several years. After the operation has stabilized and NAVAIR's initial needs have been met, another Navy organization may be called upon to take over the production effort from NORDA. While NORDA is performing this function, however, we will also be investigating several related research issues in an effort to improve the quality of map images for the pilots' DMS display.

Table 1. Delivery schedule for MDFF scanned map library.

Fiscal Year	Number of Charts Replaced					Projected MDFF Library No. of CDROMS
	JOG 1:250K	TPC 1:500K	ONC 1:1 M	Total Chart Area (sq. ft.)	Mbytes of ADRG data	
89	71	10	4	437	12,149	3
90	283	60	15	2,004	55,711	4
91	449	60	15	2,606	72,447	4
92-94	2,202	332	83	13,392	372,298	15

Table 2. Primary MDFF processing functions.

Map Image Data Processing
Read in ADRG data from CDROM.
Resample ADRG data into the TS projection system.
Compress the map image data with color and spatial compression techniques.
Format the map data into an Optical Disk Image (ODI) file.
Terrain Elevation and Feature Data Processing
Read in DTED and DFAD data from CDROM or magnetic tape.
Compress DTED elevations from 16 bits per post (i.e., geographical location) to 8 bits.
Associate a coded feature description with each elevation post.
Section the elevation/feature data to correspond with TS segments.
Format the elevation/feature data into an ODI file.

Order of Report

This report describes the hardware and software that compose the MDFF. The next section briefly describes the GSS, which was the prototype to the MDFF, and then describes the configuration of the new MDFF computer system installed at NORDA's Pattern Analysis Branch (Code 351). The fourth section describes the planned MDFF software. NORDA research efforts being conducted in connection with the MDFF program are examined, and the last section summarizes the report.

MDFF Hardware and System Configuration

GSS: The Prototype Configuration for the MDFF

The GSS was used successfully to prepare optical disks and to load DMUs for test flights of the AV-8B in 1987. Nevertheless, the GSS was not suitable for operational use. Production time and the level of user-computer interaction needed to be reduced, and the quality of the scanned map images needed improvement. One of the primary objectives of NORDA's MDFF is to address these needs. Since the 1987 test flights, the hardware and software of the GSS have been turned over to NORDA and incorporated into the MDFF.

MDFF Hardware Overview

The MDFF performs two primary processing functions: map image data processing and terrain elevation/feature data processing. Table 2 presents the main tasks performed by each of these processing functions.

Due to the large quantity of data to be processed, the configuration of the MDFF computer system has been designed to perform these functions as efficiently as possible (Fig. 3). ADRG data is read from CDROM with one of six drives controlled by two MicroVAX II computers. The input ADRG data is transferred via ethernet from the MicroVAXes to a VAX cluster (consisting of a VAX 8800 and a VAX 8200), where it is loaded onto magnetic disk. Resampling of the ADRG into Tesselated Spheroid (TS) is performed by the 8800 Central Processing Unit (CPU) in the VAX cluster. Color and spatial compression, the most computation-intensive of the processing functions, is performed by three VAXstation 3200s that have been dedicated to the compression tasks. The TS map data are transferred from the VAX cluster to the VAXstations via a dedicated ethernet link. After the compression has been performed, the data are transferred back to the cluster and stored on magnetic disk.

Within the VAX cluster's CPU, an ODI is created by combining the compressed TS data with a volume descriptor and a file directory containing pointers to all the files that will be contained in that ODI. The ODI is copied onto magnetic tape for transport to a mastering facility, where the data will be replicated on CDROM.

If DTED and DFAD are received on CDROM, these data are loaded onto magnetic disk in the same fashion as the ADRG data. If received on magnetic tape, they are transferred by the CPU directly from tape drive to magnetic disk. The remaining terrain elevation/feature data processing functions are all performed by the CPU. Finally, as with ADRG, the terrain elevation/feature data ODI is copied onto magnetic tape for transport to a mastering facility where the data will be replicated on CDROM.

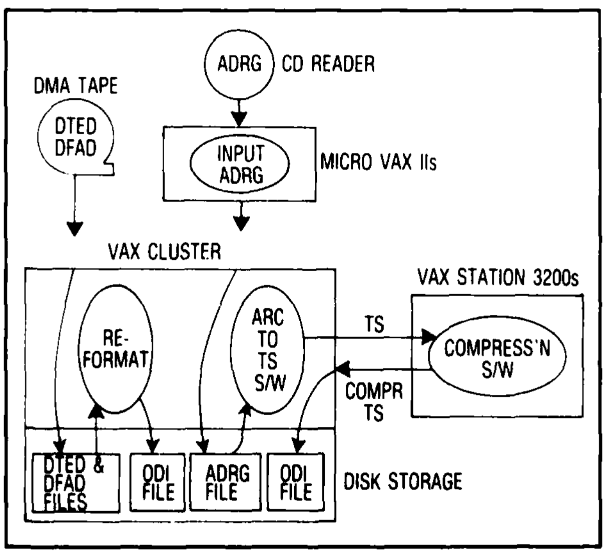

Figure 3. Data flow through the MDFF system.

MDFF Ethernet Configuration

The primary MDFF system components are interconnected by two ethernet systems (Fig. 4). A dedicated ethernet link between the VAX cluster and the three VAXstations provides fast data transfer between these systems. A second ethernet, the main MDFF network, transfers data from the two MicroVAX computers to the VAX cluster for data processing, and provides terminals with access to any MDFF node (i.e., computer attached to the ethernet). Connections to the NORDA-wide computer network, which is external to the MDFF, enables the MDFF nodes to communicate with other NORDA computers. This connection is controlled by a Local Area Network (LAN) bridge, which isolates the MDFF network from the NORDA-wide network. The LANbridge prevents overloading NORDA's network while the MDFF is processing or transferring large amounts of data. In addition, the LANbridge prevents MDFF processes from being slowed down by heavy computer traffic on the NORDA-wide network.

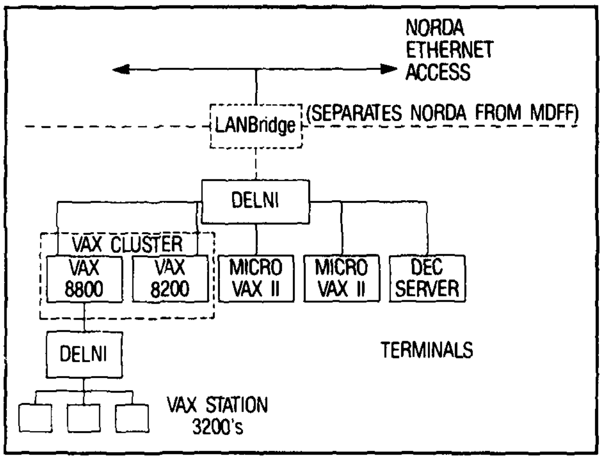

Figure 4. MDFF ethernet configuration.

VAX Cluster

The MDFF VAX cluster (Fig. 5) is the primary data processing computer. The cluster is formed from two

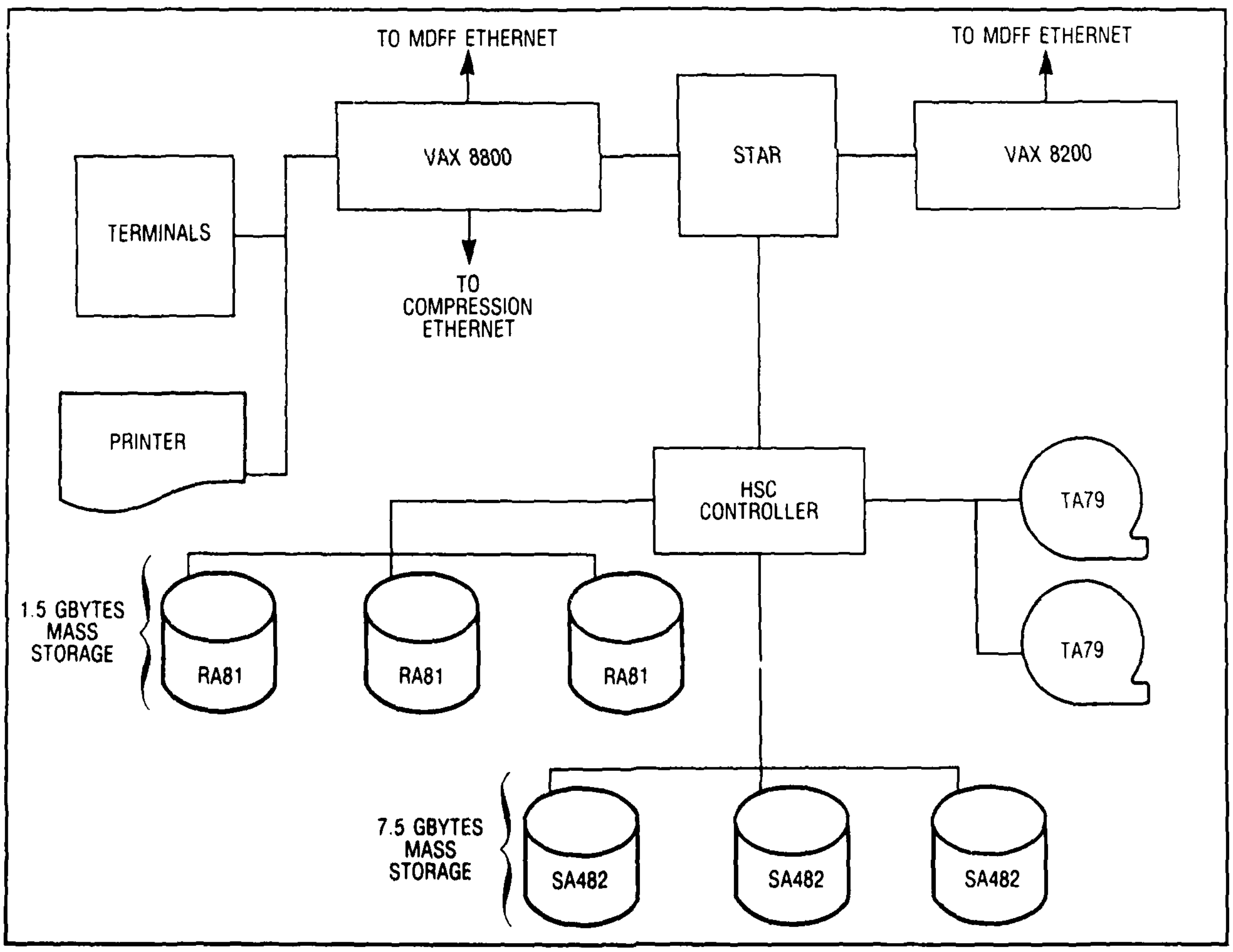

Figure 5. MDFF VAX cluster.

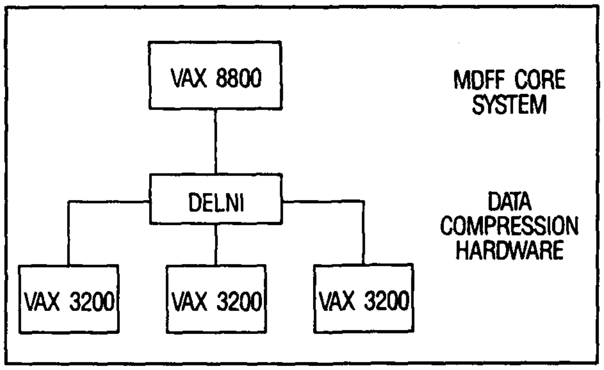

Figure 6. Hardware for accelerated data compression.

CPUs (the VAX 8800 and VAX 8200) linked by a star coupler and a high-speed disk controller (HSC) that allows the CPUs to transfer data to and from the magnetic disk drives (RA81s and SAA82s) and magnetic tape drives (TA79s) without interfering with each other. Due to the slow data transfer rate of CDROM drives (150 kbytes/sec), the only practical way to process large amounts of CDROM-contained data is to first transfer it to a faster-access storage device. To provide this fast access, the MDFF cluster has been equipped with a total of 8.55 Gbytes of magnetic disk storage—enough to hold the contents of up to 12 CDROMs. One advantage of the cluster arrangement is that it allows the VAX 8800 to be dedicated to data processing, while the VAX 8200 can perform all other functions, such as quality control checks and miscellaneous system utility functions.

Hardware for Accelerated Data Compression

The hardware that is dedicated to running the data compression programs is depicted in Figure 6. It is composed of the three VAXstation 3200 computers, which are MicroVAXs with a rated throughput of 3 million instructions per second (MIPS). The VAXstations work in parallel, each performing the same tasks on different sections of data, so that if one VAXstation should fail, data processing can continue uninterrupted on the other two. With the three VAXstations running simultaneously, a combined throughput of 9 MIPS is achieved. The dedicated ethernet link allows for optimum data transfer rates between these computers and the VAX cluster.

MicroVAX Configuration

The MicroVAX computers (Fig. 7) transfer data from CDROM drives to the VAX cluster for storage on magnetic disk. Two MicroVAXes, each controlling three CDROM drives, are configured in the MDFF. Most local data processing on the MicroVAXs is limited to data recovery in case of disk errors.

The MicroVAXes will also be used for research efforts to improve the quality of the output scanned maps and to investigate alternate methods of data compression. A Raster Technologies color monitor is currently connected to one MicroVAX for image display and limited image manipulation. A more advanced image processor is being procured to evaluate techniques of feature extraction, map enhancement, color quantization, and image data compression. This image processor will be functional by October 1989.

MDFF Software

Overview

The upgraded MDFF software presently being developed by Honeywell for NORDA consists of two principal components: application software and performance monitoring software. The former performs all the data processing functions (outlined in Table 2) on the map image data and terrain elevation/feature data, while the latter monitors various aspects of the processing.

Transformation from ARC to TS

ADRG image data is created by scanning source maps and warping the resultant digital data into the ARC projection system. The scanning process, performed at a scan density of 100 microns (254 lines per inch), separates the map image into its red, green, and blue (RGB) components. Each of these components is collected in a separate image file; the data in each image file is warped into the ARC projection, which provides a rectangular coordinate system for the entire earth ellipsoid.

The ARC system divides the earth into 18 bands of latitude, or zones. Each zone is subdivided into sections, called "tiles," the number of which depends on the scale of the source map. Each tile approximately corresponds to a 0.5 by 0.5 inch section of the source map and consists of a 128 by 128 array of pixels.

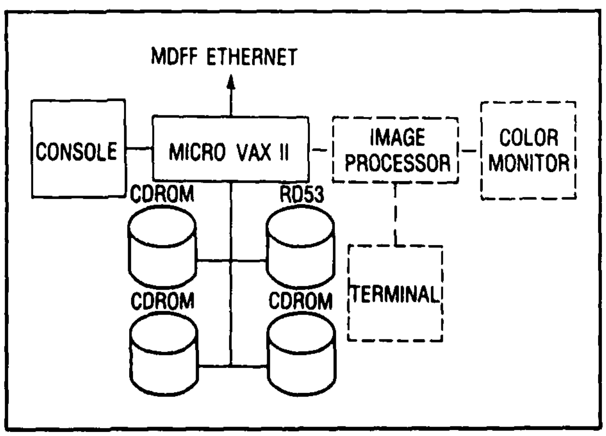

Figure 7. MDFF MicroVAX configuration.

Table 3. Locations and pixel densities of ARC zones for a 1:1,000,000 scale source map.

ARC Zone		Latitude Boundaries	No. Tiles		Pixel Density (pixels / arc-sec)	
No. hemi.	So. hemi.		in N-S direction	in E-W direction	in N-S direction	in E-W direction
1	10	0°—32°	278.0	2888	0.2852	0.3089
2	11	32°—48°	139.0	2364	0.2335	0.3089
3	12	48°—56°	69.5	1920	0.1896	0.3089
4	13	56°—64°	34.8	1556	0.1537	0.3089
5	14	64°—68°	34.8	1276	0.1260	0.3089
6	15	68°—72°	34.8	1072	0.1059	0.3089
7	16	72°—76°	34.8	860	0.0849	0.3089
8	17	76°—80°	34.8	644	0.0636	0.3089
9	18	80°—90°	87*		0.3089*	

*In polar regions, No. tiles and pixel density are measured along the 0°- 180° and 90°E-90°W longitudinal arcs.

Each tile has fixed latitude and longitude boundaries, and each pixel is associated with a fixed latitude and longitude point. A pixel is represented by three bytes that define its RGB intensities. The pixel density of a tile (i.e., the number of pixels per arc-second) is defined by the ARC system specifications and is dependent on the tile's zone and the scale of the source map. Table 3 lists the ARC zones with their boundaries and pixel densities for a 1:1,000,000 scale source map. Figure 8 illustrates this zone layout for the world. The tile image data, along with supplementary data, is distributed by DMA on CDROM.

The TS projection provides a rectangular coordinate system for an entire spheroid model of the earth. Unlike the ARC system, TS has only five zones. Each zone is divided into sections, called "segments," the number of which depends on the scale of the source map. Each segment approximately corresponds to a 2 by 2 inch portion of the source map and consists of a 256 by 256 array of pixels. As in the ARC system, each segment has fixed latitude and longitude boundaries, and each pixel within a segment is associated with a fixed latitude and longitude point. The pixel density of a TS image depends on the zone from which the source map originated and on the map's scale. Table 4 lists the TS zones with their boundaries and pixel densities for a 1:1,000,000 scale source map. Figure 9 illustrates this zone layout for the world, and Figure 10 shows the TS segments distributed over the globe.

Because pixel densities between the ARC and TS systems are different, the transformation from ARC to TS reduces a given amount of image data by a factor of about four.

Color and Spatial Compression

Following the ARC to TS transformation, in which a change in resolution produces a 4:1 data compression, two more compression phases are performed on the map image data (Fig. 11). The first phase consists of a color compression, and the second phase is a virtually lossless spatial compression. *Color compression* replaces 24 bits of color data per pixel (8 bits each of RGB) with a single 8-bit color code, thereby compressing the image data by a factor of 3. Spatial compression further reduces the image data by a factor of 4. The combination of color and spatial compression (12:1) with the initial 4:1 change in resolution (in tranforming from ARC to TS) thereby reduces the image storage size by a final factor of 48.

Several steps are involved in the color compression process. First, a color map is created for a user-defined unit of scanned map data. A least-squares fitting technique is used to select 256 RGB combinations that will best represent that unit of map data. Then, for each pixel, the original 24 bits of RGB are replaced with an 8-bit code that represents one of the 256 RGB combinations. Finally, a decompression color table is generated to convert the 8-bit codes back to the original (or close to the original) RGB values for CRT display. Since the number of possible colors that can be used to represent each pixel in the image has been reduced from 224 (over 16 million) to 28 (256), information is lost in this step, and the compression not lossless. However, this loss of information is merely perceived as a normalization of the map colors.

Following the color compression, a spatial compression process generates a codebook for every user-defined unit of scanned map data. The spatial compression codebook reclassifies the image data using

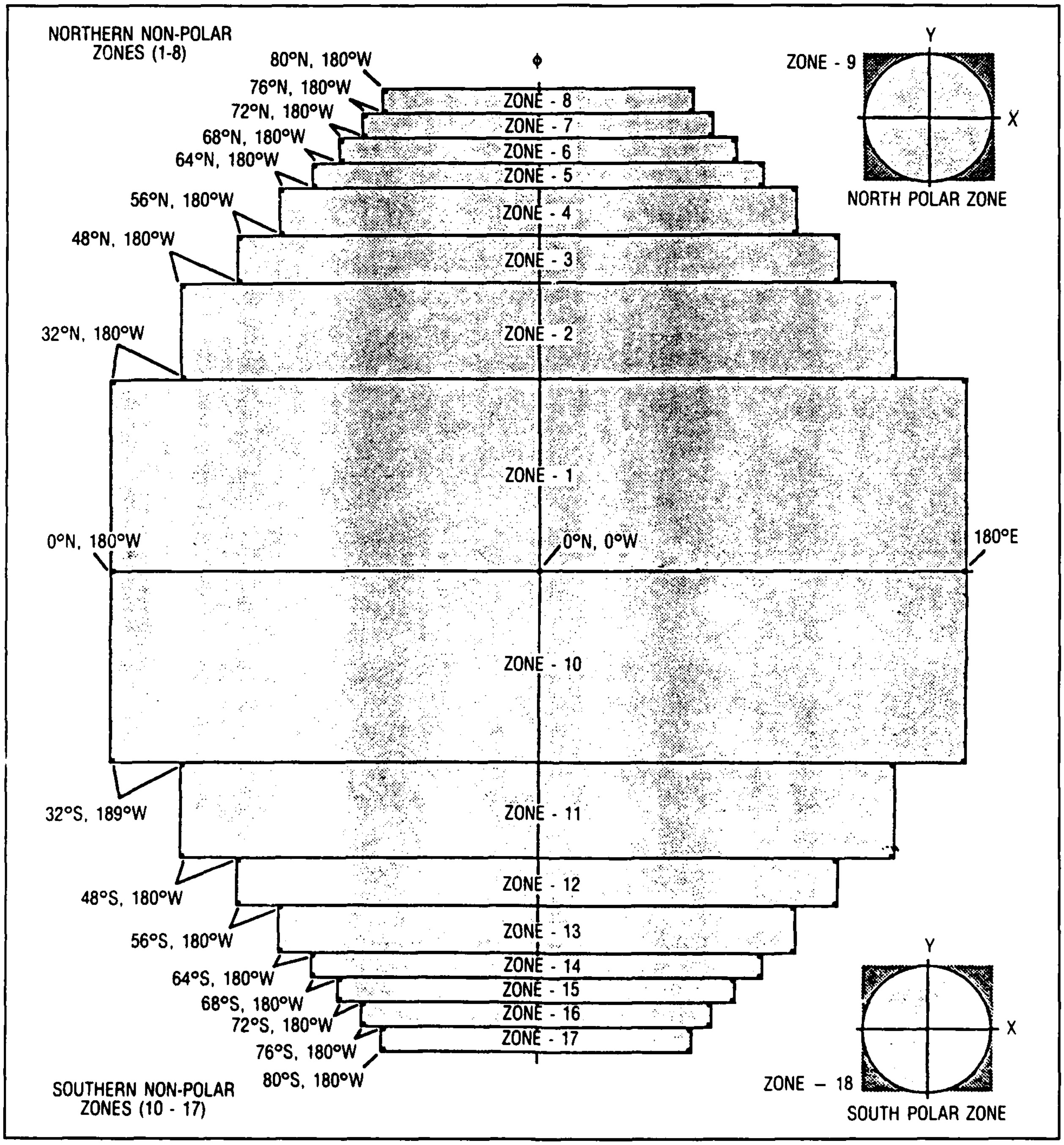

Figure 8. ARC system zone layout.

Table 4. Locations and pixel densities of TS zones for a 1:1,000,000 scale source map.

TS Zone	Latitude Boundaries	No. Segments*		Pixel Density* (pixels / arc-sec)	
		in N-S Direction	in E-W Direction	in N-S Direction	in E-W Direction
North Polar	90.000°N to 48.000°N	179	182	0.1541	0.1501
North Temperate	51.692°N to 29.538°N	48	608	0.1540	0.1201
Equator	33.231°N to 33.231°S	144	760	0.1541	0.1501
South Temperate	29.538°S to 51.692°S	48	608	0.1540	0.1201
South Polar	48.000°S to 90.000°S	179	182	0.1541	0.1501

*Notes on measuring no. segments and pixel densities:

In polar regions:

No. segments and pixel density in the N-S direction are measured along the 0°-180° longitudinal arc;

No. segments and pixel density in the E-W direction are measured along the 90°E-90°W longitudinal arc.

In non-polar regions:

No. segments in N-S direction are measured as the number of rows of segments within the latitude swath for that zone;

No. segments in E-W direction are measured per 360° of longitude.

Pixel density in the N-S direction is measured as the no. pixels/arc-sec latitude.

Pixel density in the E-W direction is measured as the no. pixels/arc-sec longitude.

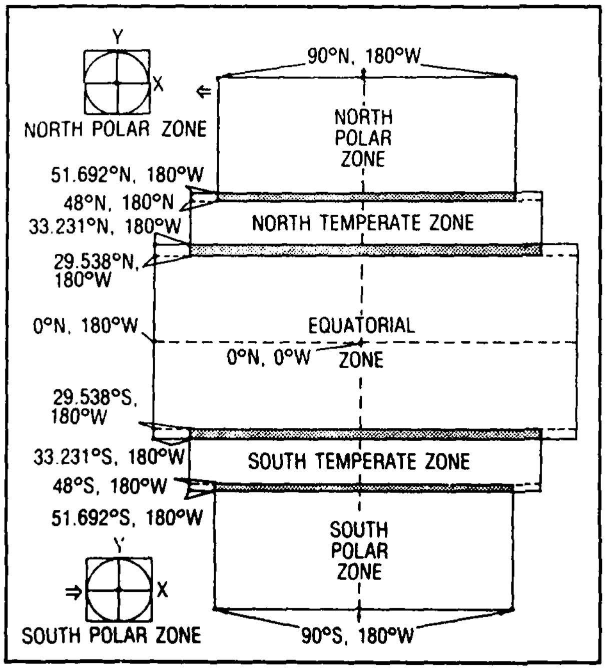

Figure 9. Tesselated spheroid (TS) zone layout.

an average of 2 bits per pixel. A decompression codebook is also generated to convert the compressed pixel data back to the original image. The number of bits of information per pixel is decreased from 28 (256) to 22 (4) in this step. The change in image quality is noticeable, but not significant.

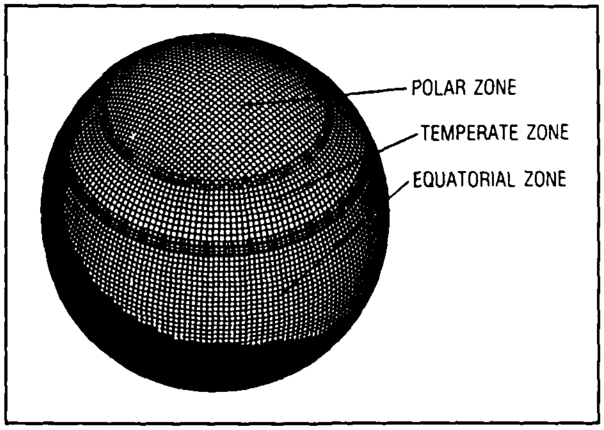

Figure 10. Tesselated spheroid model of the globe.

MDFF Research Plans

NORDA has established a research program that is being executed simultaneously with the MDFF project, which focuses on improving the pilot's moving map display. Four general research areas are being addressed during fiscal years 1989 and 1990: Alternate Methods of ADRG Compression, Base-Map Enhancement and Feature Extraction, Graphic Display Enhancement, and Task Integration.

Alternate Methods of ADRG Compression

The ADRG color and spatial compression methods to be used in the MDFF achieve a data compression

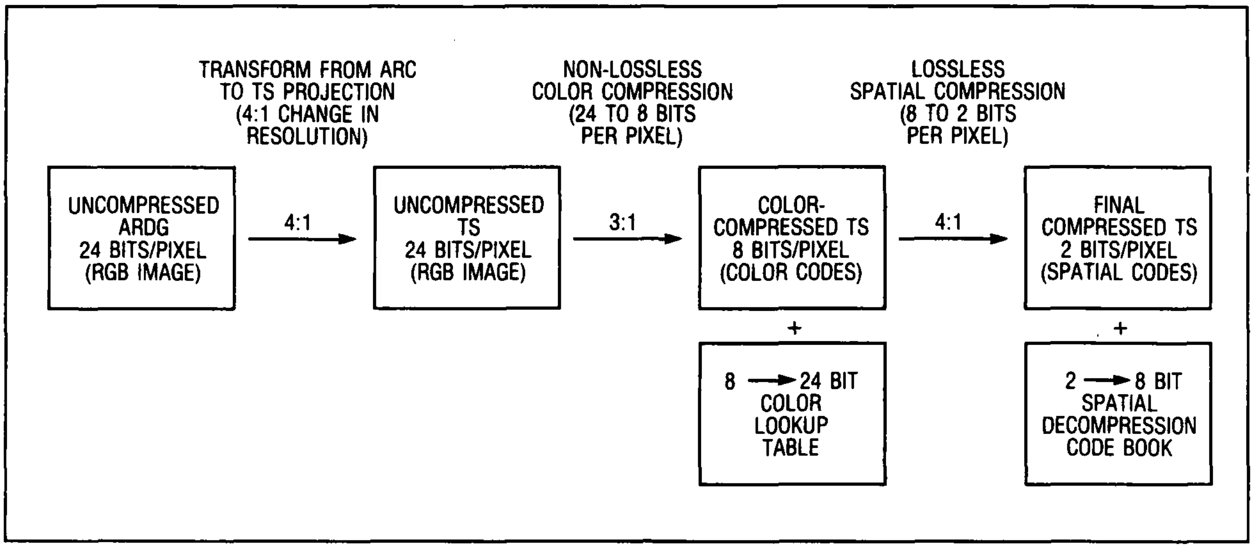

Figure 11. Compressing the digital map image data. Total compression ration is 48:1.

ratio of 12:1, excluding the 4:1 change in resolution from ARC to TS. During fiscal year 1989, NORDA's MDFF team examined alternatives to improve both this compression ratio and the quality of the output, decompressed, images. Methods that were considered include contour encoding, run-length encoding, Huffman compression, and Lempel-Ziv compression. Also investigated were various transform encoding techniques, such as the Fourier transform, that could increase the compression ratio to about 20:1.

This research, which was primarily executed at Tulane University, studied the compression of color cartographic images. As described in Barad and Martinez (1989), an initial investigation of selected scanned maps revealed a small number of color classes and large homogeneous regions. The original 24-bit pixel distribution was examined in several coordinate systems. The best map data compression was achieved using a two-phase process, in which pixel classification was followed by a lossless compression. Two of the most promising classification techniques, K-means and Vector Quantization (VQ), were studied in detail. A neighborhood reclassification algorithm was also applied to eliminate isolated, misclassified pixels. Various high performance, lossless compression techniques were tried.

A new compression scheme, Multi-Level Rooted Quadtree (MLRQ) coding, was developed by sorting binary map images using quadtrees. Traversal, encoding, and decoding algorithms were developed to encode color maps through MLRGs. MLRQ coding was found to give good compression ratios for the color (multi-level) maps under consideration.

A modified Classified VQ was also tested to compress the maps. Combined component coding was performed with little loss of information. High compression with reasonable error was achieved with as few as 256 codewords. Tables 5 and 6 present a summary of the final compression results.

Base-map Enhancement and Feature Extraction

This proposed effort will investigate techniques to extract such features as roads, water, urban areas, and text from the scanned ADRG product, based on

Table 5. Compression ratios for MLRQ coding (Barad and Martinex, 1989) includes 3:1 compression due to classification.

	Compression Ratios			
	Unpacked Bytes	Lempel Ziv Coding on Unpacked Bytes	Packed Bytes	Lempel Ziv Coding on Packed Bytes
Map 1	6.12:1	21.45:1	12.24:1	21.00.1
Map 2	3.27:1	10.14:1	6.54:1	9.90:1
Map 3	4.71:1	15.30:1	9.42:1	15.00:1

Table 6. Compression ratios for VQ classification followed by Lempel Ziv compression (Barad and Martinez, 1989) includes 3:1 compression due to classification.

	Compression Ratios			
	6 Code Words	8 Code Words	10 Code Words	12 Code Words
Map 1	21.2:1	23.1:1	16.0:1	15.1:1
Map 2	15.0:1	13.1:1	12.6:1	11.7:1
Map 3	22.2:1	19.7:1		

feature colors and patterns. The value of such a technique would be the resultant flexibility and control in displaying the data. For example, eliminating unneeded features would declutter the display, enabling the pilot to focus on mission-essential elements of the map and not be distracted by unnecessary information. Automated "decluttering" would also support further data compression.

Using feature extraction techniques, maps could be represented as a set of overlays that would be combined to produce a truly mission-specific composite map. The overlays could also be constructed from the original map's color separates at DMA, but these are not readily available. Instead, NORDA has proposed to use feature extraction methods to classify objects in a map image and relate them to particular overlays.

Graphic Display Enhancement

The DMS will support two types of graphic displays: ground station displays used for flight planning, and cockpit displays used for en route navigation. The current configuration allows minimal display flexibility because base-map designs are fixed. Assuming, however, that ADRG data can be digitally decomposed into color or feature separates, base-map displays could be decluttered and enhanced. This work will identify display design possibilities for ADRG, and will consider the integration of other data products (e.g., Vertical Obstruction Data, World Vector Shoreline data, DTED, DFAD, and multispectral imagery) to generate more informative, mission-specific cockpit displays.

Task Integration

The Task Integration project is intended to transition all relevant research into the NORDA MDFF, so these new developments will be more rapidly integrated into the operational data base for the aircraft's DMS. Task Integration is crucial to the success of this NORDA research program, which will be reflected by the improvement to the DMS data base in AV-8B, F/A-18, and V-22 aircraft by the end of fiscal year 1990.

Summary and Conclusions

NORDA has designed and developed the MDFF computer system and initial software that is currently providing transformed ADRG digital map imagery to operational AV-8B aircraft. This product is the Navy standard air-scanned map data base. Other naval aircraft, including F/A-18, V-22, A-12, and the Navy's standard Tactical Aircraft Mission Planning System (TAMPS) plan to be utilizing this library of data within fiscal year 1990. The initial delivery of the library to AV-8B (on magnetic tape) is scheduled for the summer of 1989. Deliveries of transformed data on CDROM will begin in early 1990.

The MDFF has overcome the technical difficulties of providing naval users with transformed, Navy-standard, scanned map data for cockpit and mission planning applications. The MDFF is the link between DMA and the Fleet for Navy-specialized, digital MC&G data, as demonstrated by NORDA's delivery of transformed ADRG to the first operational AV-8B aircraft in August 1989. The MDFF applications software will be upgraded in February 1990 to dramatically accelerate the transformation processes.

As part of the MDFF project, NORDA has established a joint research program with Tulane University's Electrical Engineering Department to investigate alternate methods of scanned map compression. While exploring new processing techniques, researchers this year yielded several promising new compression schemes. In particular, the MLRQ coding technique was shown to be very effective in compressing digital map images. It was also shown that a two-stage compression scheme was most effective, in which large, nearly homogeneous areas were first classified and made to be totally homogeneous, and then a lossless compression technique was applied. The two most promising classification techniques were shown to be K-means and VQ. Finally, it was shown that high compression ratios could be obtained with as few as 256 code words. NORDA is presently using a proprietary method of spatial VQ developed by Honeywell. NORDA's research has established the feasibility of replacing the Honeywell method with a government-owned method, which would give the government full rights to all applications software in the MDFF.

Recommendations

The MDFF is a first-generation scanned map transformation system. As digital MC&G and computer technology develop, the MDFF must adapt and expand to meet the growing requirements for digital MC&G data. Since supercomputing resources are potentially available to NORDA, and may dramatically improve the speed and efficiency of the MDFF, we recommend that the possibility of transitioning the processing load to such a computer be investigated.

NORDA's MDFF program has investigated future alternatives to transition the production effort to another activity. We recommend that the MDFF be transitioned to DMA when the transformation processing reaches steady-state. As the Navy standard developed by NORDA, becomes more widely used, DMA will be the logical choice for running a fully developed and tested MDFF system. The point at which

MDFF processing will reach steady-state depends on the following:

(1) DMA may soon be compressing ADRG, DTED, and DFAD before distributing them to NORDA. This compression will require a modification to the MDFF front-end processing software.

(2) Pilots for such aircraft as the A-12 desire a variant type of display that will emphasize three-dimensional perspectives of DTED integrated with the scanned map data. Therefore, NORDA may have to modify the transformed DLMS format to accommodate the A-12 requirements.

(3) DMA may remove the ISO-8211 layer from ADRG, an action that NORDA recommends. This removal would require additional modification to the MDFF processing.

(4) CDROM mastering technology is rapidly becoming more affordable. It may soon be more cost effective to master CDROMs on-site instead of at a remote mastering facility.

(5) The distribution medium for DTED and DFAD may change from 1/2 inch, 9-track magnetic tape to CDROM.

(6) In the short term, NORDA CDROMs will contain legend images compressed by a factor of 12:1. In order to minimize CDROM storage requirements, NORDA intends to identify and implement a more efficient compression scheme for these images.

Finally, it is recommended that NORDA produce the output CDROM data base for the first few years in order to incorporate feedback from Fleet users into the MDFF before transitioning the facility to DMA or other future designated operator.

References

Barad, Herb and Andrew B. Martinez (1989). Final Report: *Digital map research*. Electrical Engineering Department, School of Engineering, Tulane University, New Orleans, LA.

Defense Mapping Agency (1987). *Product specifications for ARC digitized raster graphics (ADRG)*. DMA Systems Center/West Group, St. Louis, MO., 15 December.

Defense Mapping Agency (1984). *Product specifications for digital landmass system (DLMS) data base*, Second Edition. DMA Systems Center/West Group, St. Louis, MO.

Goodwin, Lt. Col. George G. and Kevin Shaw (1987). *AV-8B digital map system night attack program*. Proceedings of the Naval Digital Mapping, Charting and Geodesy Data Testbed Interest Group Meeting, Washington, D.C., 22-23 June.

Miller, R. K. (1987). *User's guide for the ground support station*. Digital Cartographic Systems, Inc.

Schiller, Paul J. (1987). *System design description document for the ground support station*, Vol. 1. Digital Cartographic Systems, Inc.

Distribution List

Asst Secretary of the Navy
(Research, Engineering & Systems)
Navy Department
Washington DC 20350-1000

Chief of Naval Operations
Navy Department
Washington DC 20350-1000
Attn: OP-02
OP-71
OP-0962X, R. Feden
OP-987

Oceanographer of the Navy
Chief of Naval Operations
U.S. Naval Observatory
34th & Mass Ave., NW
Washington DC 20390-1800
Attn: OP-96
OP-961E, R.F. Williams

Commander
Naval Air Development Center
Warminster PA 18974-5000

Commanding Officer
Naval Coastal Systems Center
Panama City FL 32407-5000

Commander
Space & Naval Warfare Sys Com
Washington DC 20363-5100

Commanding Officer
Naval Environmental Prediction
Research Facility
Monterey CA 93943-5006

Commander
Naval Facilities Eng Command
Naval Facilities Eng Command HQ
200 Stovall St.
Alexandria VA 22332-2300

Commanding Officer
Naval Ocean R&D Activity
Stennis Space Center MS 39529-5004
Attn: Code 100
Code 105
Code 115
Code 117, J. Hammack
Code 125EX
Code 125L (13)
Code 125P (1)
Code 200
Code 300
Code 350, D. Hickman
Code 351, J. Byrnes
Code 351, J. Braud
Code 351, M. Lohrenz

Brooke Farquhar
NORDA Liaison Office
Crystal Plaza #5, Room 802
2211 Jefferson Davis Hwy.
Arlington VA 22202-5000

Commanding Officer
Naval Research Laboratory
Washington DC 20375

Commander
Naval Oceanography Command
Stennis Space Center MS 39529-5000

Commanding Officer
Fleet Numerical Oceanography Center
Monterey CA 93943-5005

Commanding Officer
Naval Oceanographic Office
Stennis Space Center MS 39522-5001
Attn: Code GGAP, B. Mullen
Code A, J. Depner

Commander
Naval Ocean Systems Center
San Diego CA 92152-5000

Commanding Officer
ONR Branch Office
Box 39
FPO New York NY 09510-0700

Commander
David W. Taylor Naval Research Center
Bethesda MD 20084-5000

Commander
Naval Surface Weapons Center
Dahlgren VA 22448-5000

Commanding Officer
Naval Underwater Systems Center
Newport RI 02841-5047

Superintendent
Naval Postgraduate School
Monterey CA 93943

Director of Navy Laboratories
Rm 1062, Crystal Plaza Bldg 5
Department of the Navy
Washington DC 20360

Officer in Charge
New London Laboratory
Naval Underwater Sys Cen Det
New London CT 06320

Director
National Ocean Data Center
WSC1 Room 103
6001 Executive Blvd.
Rockville MD 20852
Attn: G. W. Withee

Director
Woods Hole Oceanographic Inst
P.O. Box 32
Woods Hole MA 02543

University of California
Scripps Institute of Oceanography
P.O. Box 6049
San Diego CA 92106

Officer in Charge
Naval Surface Weapons Center Det
White Oak Laboratory
10901 New Hampshire Ave.
Silver Spring MD 20903-5000
Attn: Library

Commanding Officer
Fleet Anti-Sub Warfare Training Center,
Atlantic
Naval Station
Norfolk VA 23511-6495

Defense Mapping Agency Sys Cen
12100 Sunset Hill Rd. #200
Reston VA 22090-3207
Attn: SGWN
Code 10D/10P, Dr. E. Silva
Mel Wagner
Ed Danford

Defense Mapping Agency Sys Cen
8301 Greensboro Dr., Suite 800
McLean VA 22102-3692
Attn: William Alford

Defense Mapping Agency
Naval Observatory, Bldg. 56
Washington DC 20305-3000
Attn: Benny L. Klock (RES)

DMA Systems Center, West Group
3200 S. Second St.
St. Louis MO 63118-3399
Attn: Mark Shelburg

DMA Hydrographic Topographic Cntr
Mapping & Charting Department
Washington DC 20315-0030
Attn: Mel Wagner (MCT)

Defense Mapping Agency HQ
U.S. Naval Observatory, Bldg. 56
Washington DC 20305-3000
Attn: LCDR Vernon Hutton
(DMA-PRR)

US Army Engineering Topographic Labs
Ft. Belvoir VA 22060-5546
Attn: Rick Joy

Office of Naval Technology
800 N. Quincy St.
Arlington VA 22217-5000
Attn: Code 20, Dr. P. Selwyn
Code 228, Dr. M. Briscoe
Code 234, Dr. C. V. Votaw

Office of Naval Research
800 N. Quincy St.
Arlington VA 22217-5000
Attn: Code 10
Code 10D/10P, Dr. E. Silva
Code 12
Code 112, Dr. E. Hartwig

Commander
Naval Sea Systems Command HQ
Washington DC 20362-5101

Commanding Officer
Naval Civil Engineering Laboratory
Port Hueneme CA 93043

Commander
Naval Air Systems Command HQ
Washington DC 20361-0001

Commander
Naval Air Systems Command
Jefferson Plaza 2, Rm. 1202
1421 Jefferson Davis Hwy.
Washington DC 20361-5110
Attn: Lt.Col. Prendergast

Commander
Naval Air Systems Command
Washington DC 20361-8030
Attn: (AIR-5115X) CDR R. Vehorn

Naval Air Systems Command
Jefferson Plaza 2
1421 Jefferson Davis Hwy.
Washington DC 20361-5110
Attn: AIR-5117F Lt.Col. R. Currer
AIR-5116F CDR B. Welch
AIR-5116F CDR Englehart

Pennsylvania State University
Applied Research Laboratory
P.O. Box 30
State College PA 16801

University of Texas at Austin
Applied Research Laboratories
P.O. Box 8029
Austin TX 78713-8029

Johns Hopkins University
Applied Physics Laboratory
Johns Hopkins Rd.
Laurel MD 20707

University of Washington
Applied Physics Laboratory
1013 Northeast 40th St.
Seattle WA 98105

REPORT DOCUMENTATION PAGE

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. December 1989

3. Report Type and Dates Covered. Final

4. Title and Subtitle.
The NORDA MC&G Map Data Formatting Facility:
Development of a Digital Map Data Base

5. Funding Numbers.
Program Element No. 980101 (APN) 940101 (64262N)
Project No.
Task No. 107
Accession No. DN257017

6. Author(s).
Kevin B. Shaw, James E. Ryan, Maura C. Lohrenz, Mary G. Clawson,
Lancelot M. Riedlinger*, Jesse I. Pollard II*

7. Performing Organization Name(s) and Address(es).
Ocean Science Directorate
Naval Ocean Research and Development Activity
Stennis Space Center, Mississippi 39529-5004

8. Performing Organization Report Number.
NORDA Report 233

9. Sponsoring/Monitoring Agency Name(s) and Address(es).
Naval Air Systems Command
Washington, DC 20361-5110

10. Sponsoring/Monitoring Agency Report Number.

11. Supplementary Notes.
*Planning Systems, Inc., Slidell, Louisiana 70458

12a. Distribution/Availability Statement.
Approved for public release; distribution is unlimited. Naval Ocean Research and Development Activity, Stennis Space Center, Mississippi 39529-5004.

12b. Distribution Code.

13. Abstract *(Maximum 200 words).*

Hardware and software systems have been developed at the Naval Ocean Research and Development Activity (NORDA) to provide digital mapping, charting, and geodesy (MC&G) data bases for Digital Moving Map Systems installed on naval aircraft.

The computer system developed at NORDA is known as the Map Data Formatting Facility (MDFF). The MDFF transforms digital map data bases, distributed by the Defense Mapping Agency (DMA), into a form suitable for actual field use by the AV-8B, F/A-18, V-22, and A-12 naval aircraft and Tactical Aircraft Mission Planning Systems. These data bases include DMA's Equal Arc-Second Raster Chart Digitized Raster Graphic Data, Digital Terrain Elevation Data, and Digital Feature Analysis Data.

In addition to describing the hardware and software components of the MDFF, this report gives an overview of current and proposed MC&G research projects being investigated in conjunction with the MDFF work. This research is primarily intended to improve the digital map display in the cockpit and to investigate new methods of compressing digital image data.

14. Subject Terms.
cartography, digital moving map, database, CDROM, aircraft, computer systems, digital mapping, mapping, charting, and geodesy

15. Number of Pages. 16

16. Price Code.

17. Security Classification of Report.	18. Security Classification of This Page.	19. Security Classification of Abstract.	20. Limitation of Abstract.
Unclassified	Unclassified	Unclassified	None