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Design Considerations in the Development of an Automated Cartographic System

Robert L. Holden
University of Central Florida

DESIGN CONSIDERATIONS IN THE DEVELOPMENT OF AN AUTOMATED CARTOGRAPHIC SYSTEM

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ROBERT LEW HOLDEN JR.
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ABSTRACT

Cartography, the art of producing maps, is an extremely tedious job which is prone to human error and requires many hours for the completion of maps and their digital data bases. Cartography is a classic example of a job that needs to be automated. Through the new advances in image processing and pattern recognition, the automation of this task is made possible with the cartographer acting as a supervisor. This paper reviews current cartographic techniques, and examines design considerations for a fully automated cartographic system. The benefits of such a system would be improvements in speed, flexibility, and accuracy. The role of the cartographer, with such a system, would change to a process supervisor rather than that of a mass data entry person.

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INTRODUCTION

Historically cartography has been an extremely tedious and time-consuming job because of its repetitious nature of manually producing map data. Beginning with surveyors' notes to the utilization of aerial photography, the cartographer has been responsible for organizing and subjectively interpreting this information. With the introduction of computers, more organized information was kept through the use of digital data bases (DDB). Images produced by multiband scanners became available to the cartographer. Some of this information, such as NASA LANDSAT satellite images, is encoded and stored on magnetic tape or disk mediums. Nevertheless, cartography remains a tedious and repetitious job subject to human error and lengthy updates. The availability of raw digital images, speed and accuracy of computers, the advances in image processing and interpretation techniques, and the nature of cartography are the main reasons for automating cartography.

There are two major categories for map data — culture and terrain. Terrain data, which is called Digital Terrain Elevation Data (DTED) consists of mostly uniform samplings of elevation values for a given area. These samplings are converted to a data file with evenly spaced grid posts over an area of up to one degree by one degree that is usually referred to as a cell. Each cell is placed into an individual file referenced by its southwest coordinates. There may also be partial cells because information over the whole cell may not be known.

Culture data describes the surface features of the land which overlays the terrain data. Culture data contains information on man-made structures such as buildings, bridges, and roads. Culture data also contains information on the natural environment such as forests, rivers, and deserts. This data may be referred to as Digital Feature Analysis Data (DFAD). Culture data is organized on a manuscript basis unlike terrain data. Manuscripts are rectangular areas which are assigned to cartographers to digitize. They may overlap one degree boundaries and they have their own rules governing size, contents, and reference. The main emphasis of this report will deal with culture data unless terrain data is mentioned specifically. This is because image processing and interpretation has more applications dealing with DFAD creation.

CHAPTER I

CARTOGRAPHY

Cartography is the art or practice of producing maps or charts. It began by using landmarks, compasses, and hand-drawn maps. Through the introduction of surveyor tools and printing machines, the accuracy within maps was improved and mass-produced. Cartographers would obtain surveyor reports as they were received and translated them to maps. Aerial photographs brought cartography into a new generation where massive information was contained in a single input. Cartographers would look at the photographs through a stereoscope which gave a 3-D perception and with special rulers, the cartographers obtain coordinate definitions for each feature. They would also collect elevation samplings with these tools. Along with knowledge of the photograph's conditions, the photograph's reference, and the cartographer's experience, a map was created to a standard scale from a set of photographs and any accompanying reports. As technology advanced, aerial photography was improved and the storage of this information was transferred from paper as a storage medium to the computer. Multiband sensors which include infrared and radar information were developed and revealed feature dependent information. The digitized maps became the source for products such as navigational maps for pilots, data bases for simulators, and other map-oriented products. These sources contain a large magnitude of information of which the digitization is at the discretion of the cartographer. Digitized maps are one product produced by the Defense Mapping Agency (DMA), a map source agency for the United States Department of Defense.

The primary source of information for cartography has been aerial photographs. Photographs are classified in three ways [1]:

1) geometric
2) scale
3) spectral

Geometric classification is based upon the camera model and its parameters. The angles of the camera play a major role in the mathematical model of the area. Scale classification adds the concept of distance to this mathematical model. Spectral classification is more subjective. It takes into account the settings of the camera and the environmental conditions within the photograph.

Images within aerial photographs are broken up into point, line, and areal features. Point features are described by a single coordinate and have an associated width/length or radius. They may be strung together under common descriptors. Line features contain at least two coordinates defining a line segment and have an associated width. Areal features are closed polygons with characteristics that can be described by a unique identification code.

The cartographer analyzes the aerial photograph(s) with any corresponding information and attempts to digitize the area with higher priority given to point and line features overlaying the lower priority areal features as they would be viewed from directly above. The cartographer deals with a patch of area called a manuscript. This manuscript is given a background feature of soil (or water in some cases) as the default. The background feature is a rectangle which represents the boundaries of the specific digitization. The cartographer classifies the features within the photograph by:

1) size
2) shape
3) shadow
4) tone
5) texture

6) location

7) relationship to surroundings

Size and shape allows the photographer to separate the feature out into an initial classification based mostly on the mathematical model. Shadows, when referenced with the camera and sun models, yield height. The remaining four classifications are more subjective dependent upon the cartographer's experience, which is a potential source of error in a manual system and would be reduced in an automated system. Tone consists of gray levels, color levels, returns from various types of photographic filters, and residual moisture. Location gives higher probability to the existence of certain features over other features. An example would be that a warehouse is more probable than a barn within a city. City or urban would be the location descriptor in this case. Texture patterns allow the cartographer to identify homogeneous areas such as a pine forest as opposed to a wheat field. Relationship to surroundings is the most subjective. This deals more with a rule-based system, which associates one set of features with another. Two examples of this association would be docks are located on lakes, and railroads crossing a river may yield a bridge.

Variability between photographs may provide information to the cartographer. Different types of films create different results depending upon the features on the surface. For example, in pan-minus-blue film, light images indicate higher permeability in soil than dark images. Each image taken by multispectral sensors of which NASA LANDSAT is a subset exposes different groups of features [2]. These images are taken over the same area and pixel positions between images correspond one to one. Most photographs are taken in sets where there is a 30% overlap in coverage between adjacent exposures [1]. This sampling increases the chances of accurately representing the features within each area of overlap. Stereo photographs add height characteristics. If photographs are taken at different times of the year, seasonal effects may be added such as vegetation growth, glacier movement, water drainage, and soil tone. Contrast within photographs may add information; however, contrast is dependent upon atmospheric factors, season, time of day, sun angle, solar altitude, and soil moisture. These are all factors that the cartographer must take into account.

Additional information may be available to the cartographer for classifying features within the photograph. Specialized information such as radar and infrared images may provide information on significant objects. Some of these objects may have been nonphotogenic because of being too small, having the same reflectivity as the background, or they may have been hidden by shadows or undercover.

The cartographer may also have previous data available prior to a digitizing session. Previously digitized maps are subject to updates fairly frequently. Construction, destruction, and movement have to be reflected as accurately as possible. United States Geological Survey (USGS) maps and maps from other countries may also be another source of input for the cartographer.

Generally, the cartographer has a large number of factors to deal with in feature extraction and identification. The cartographer also has a large source of inputs that provide contrast and help in the decisions that accompany the digitization of features. Using all of this information the cartographer sequentially labels each feature with a certain amount of descriptors and a set of coordinates. One manuscript may contain thousands of features with thousands of coordinates that are the result of an extensive cross-evaluation of a large number of data sources. The added subjectivity of the analysis makes automating the process particularly difficult. The next chapter describes several components and the functions of which they are composed. The majority of the functions that have to be integrated into this type of system are presented in the image analysis section. Several techniques developed by various people are presented to show what may be involved in such a system.

CHAPTER II

SYSTEM OVERVIEW

General

The proposed automated cartographic system (ACS) is made up of five major components which handle a unique part of the system and can be related back to the manual system. The initialization component relates to the experience and knowledge of the cartographer about digital data base (DDB) creation. The image analysis component relates to the actual digitization ,subjective feature identification, and data entry. The remaining components relate to the results from the system which are subject to correction, statistics for reports, or may be previous works for other cartographers to review to aid in their decision making.

These components are identified in the structure charts shown in Figure 1.

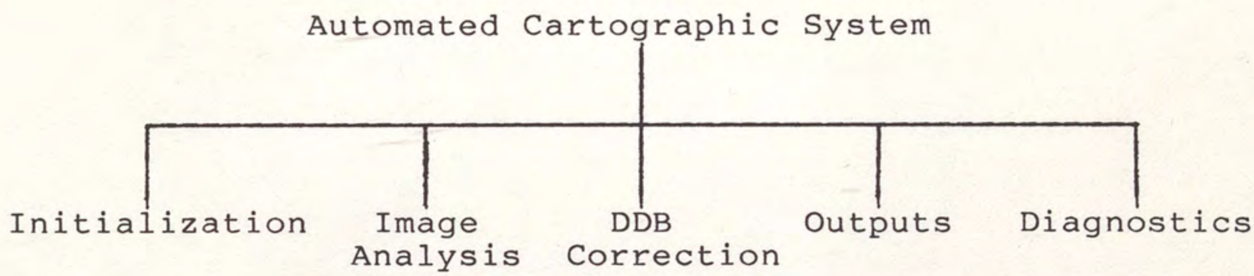

Figure 1. Components of an ACS.

Each component is responsible for a key role in the system and represents a separate task. These components may share several functions. When the ACS is activated, the main menu containing a selection for each component will appear. The cartographer or programmer would select one of the five components or exit.

The initialization component is responsible for creating a representation of the raw image(s) in the computer. This component is also responsible for the mathematical models, which are able to closely approximate the physical placement of features or the elevations of the underlying terrain, and responsible for setting up the rules in the knowledge data bases for feature interpretation. The image analysis component is responsible for feature extraction and interpretation. Image analysis operates at different degrees of interaction specified by the cartographer. The digital data base (DDB) correction component provides the capability for the cartographer to certify and change information in the resulting digital data base. The output component allows the cartographer to acquire different levels of statistics on the final DDB. This component is also responsible for creating a final Digital Feature Analysis Data or Digital Terrain Elevation Data file on disk. The diagnostics component aids in the development of the ACS and the detection of any failures within the system. The following chapters will give more detail on each of the components.

Initialization

The main function of the initialization component is to activate the image processing camera and obtain a digital representation from the aerial photograph or map source. This camera is not to be confused with the camera which takes the original photograph. The initialization function is also responsible for setting up the references of the aircraft's camera or multispectral sensor which created the original image. These references include roll, pitch, heading, and altitude. For map sources, it is necessary to enter latitudes, longitudes, and scales to describe the bounds of the map. A secondary function of this component is to make adjustments in the knowledge rule data bases which contain the subjective information such as texture for feature interpretation. Since photographs are exposed under a variety of conditions, adjustments in the interpretation of these photographs should be made to increase accuracy. These are all functions which are done at the start of a digitization session. The initialization component is also activated at system initialization to enter the default data for the knowledge data bases and any default data for the mathematical models. A structure chart is given in Figure 2 showing the possible inputs of initialization.

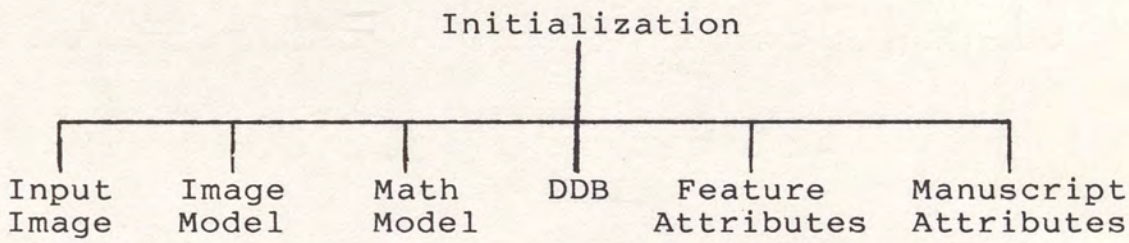

Figure 2. Possible Initialization Inputs.

When initialization is entered, a menu with a selection for each one of these functions is offered. Depending upon the input source, the cartographer chooses the functions that apply. If several sources are to be entered, the cartographer inputs each image separately and enters the corresponding information about the image. The manuscript attributes function ties all of the information into a common analysis.

Input Raw Image And Image Model

The input raw image function activates the image-processing camera and obtains a digital representation of the source image. Source images may be multispectral photographs, ground photographs, or map sources. Normally for aerial photographs and multispectral sensors, the cartographer would only input the raw digital image and enter the characteristics of the source image at the time the image was taken. These characteristics include roll, pitch, heading, altitude, latitude, longitude, aircraft camera settings, multispectral frequencies, film type, and environmental conditions. These characteristics are necessary for determining feature coordinate definitions and accurately defining the feature header attributes. In the case of map sources, an image of the map would be generated by the image processing camera and the cartographer would enter map symbols, color codes, scale, and boundaries. A standard United States Geological Survey map contains red roads, blue waterways, green forest areas, and black railways along with many symbols which could be translated to unique features in the ACS. The cartographer could alter the appearance of the digitized data in several ways. The cartographer could adjoin segmented lineal features, delete features, and massage the data in order to create a better representation.

Math Models

The aircraft or satellite which took the original image provide an initial reference for the image from the its altitude, latitude, and longitude. There are other factors such as drift angle which are calculated by on-board computers. If the cartographer has more accurate information on the positioning of certain features, they may adjust the references accordingly from this information for the entire image. Roll, pitch, and yaw of an aircraft have an effect on the position and scaling of the photograph. Positive roll is defined by the right wing down, positive pitch is with the nose up, and positive yaw is with the nose moving to the right. These factors are used when matching images from multiple photographs.

A standard rotation matrix [2] used by General Electric's Simulation and Controls System Department, Daytona Beach, for its aircraft simulators can be applied. This matrix is given by the equation

$$[D.C.] = [Yaw][Pitch][Roll] \tag{1}$$

where [D.C.] is the direction cosine matrix, [Yaw] is the rotation matrix around the x-axis, [Pitch] is the rotation matrix around the y-axis, and [Roll] is the rotation matrix around the z-axis.

The following equations are used:

$$[Yaw] = \begin{bmatrix} \cos y & -\sin y & 0 \\ \sin y & \cos y & 0 \\ 0 & 0 & 1 \end{bmatrix},$$

$$[Pitch] = \begin{bmatrix} \cos p & 0 & \sin p \\ 0 & 1 & 0 \\ -\sin p & 0 & \cos p \end{bmatrix}, \text{ and} \qquad (2)$$

$$[Roll] = \begin{bmatrix} 1 & 0 & 0 \\ 0 & \cos r & -\sin r \\ 0 & \sin r & \cos r \end{bmatrix}.$$

These equations are combined to produce the D.C. matrix which is given by

$$[D.C.] = \qquad (3)$$

$$\begin{bmatrix} (\cos y)(\cos p) & (\cos y)(\sin p)(\sin r) - (\sin y)(\cos r) & (\cos y)(\sin p)(\cos r) + (\sin y)(\sin r) \\ (\sin y)(\cos p) & (\sin y)(\sin p)(\sin r) + (\cos y)(\cos r) & (\sin y)(\sin p)(\cos r) - (\cos y)(\sin r) \\ -(\sin p) & (\cos p)(\sin r) & (\cos p)(\cos r) \end{bmatrix}$$

The actual positioning of the camera or multispectral scanner mounted on the aircraft or satellite must be adjusted for. This camera could be situated at angles different from the trajectory pattern of the mounted source. The same direction cosine matrix is used as in the plane model where the angles y, p, and r are adjusted by the position of the camera relative to the aircraft. Since both the camera and the aircraft are on the same coordinate system, the angles could be summed first and only one matrix would have to be computed for both models.

Object size and photo scale are two other factors which are included in the camera model. These factors are computed by

$$(F/H) = (P/D) \tag{4}$$

where

F = focal length,
H = altitude,
P = photo image distance, and
D = distance on ground.

The ground resolution is computed by

$$D = S/(304.8*R) \tag{5}$$

where

D = ground object dimensions (feet),
S = RF scale number, and
R = spatial resolution (line pairs/mm).

The ground resolution reveals the size of the smallest detectable object.

Feature height can be obtained by using a sun model. Figure 3 shows the relationship of the sun, a feature, and the shade produced by the feature.

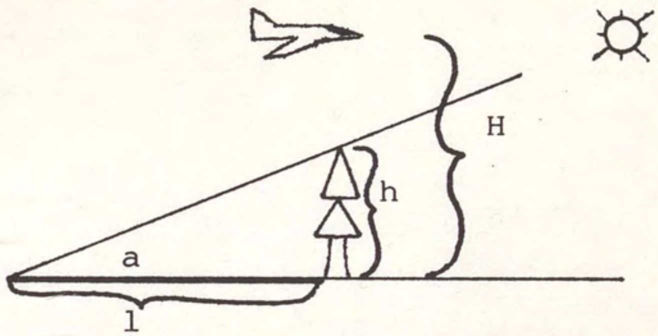

Figure 3. Sun Model.

If the sun is thought of as a point light source and a feature's height is the furthest point from the "level" ground, the length of the shadow cast by the angle of the sun can yield an approximation of the height by the simple equation

$$h = (l)(\tan a) \tag{6}$$

where
tan a = tan solar altitude,
h = height of the object, and
l = length of the shadow (meters).

If an aircraft from directly above takes a picture, the units in the photograph's shadow length changes meters to millimeters and is converted back to by using the focal length. The mathematical equation for the sun model becomes

$$h = (H)(l)(\tan a)/(f) \tag{7}$$

where
H = aircraft altitude,
f = focal length of the camera, and
l = length of the shadow (millimeters).

It is assumed that terrain slope and exposure angles have a negligible affect on the calculations for digitized data bases and this approximation is accurate enough. In addition, features are usually given truncated heights by the time the feature analysis is complete.

Digital Data Bases

Previous digital data bases (DDB) may be subject to updates and therefore may be a source of input. Since the Defense Mapping Agency (DMA) has been producing DDB for many years, the assumption is made that their formats are standard for digitized maps. Culture manuscripts are divided into two levels of detail. Level 1 manuscripts are dimensioned to a minimum of 5 minute x 5 minute. Level 2 manuscripts are dimensioned to a minimum of 2 minute x 2 minute. All features within a manuscript are assigned a unique feature number starting with the background feature which is assigned a one. The background feature is rectangular and describes the boundaries of the manuscript. Its surface material is either soil or water depending on which is more dominant. If one feature overlays another, it is given a higher feature number than the later to denote its priority. Any features which intersect the manuscript bounds will be given a negative latitude value at the point(s) of intersection.

The DMA DDB features [3] are divided into three types: points, lineals, and areals. The highest priority is given to points, followed by lines and then areals. Each feature contains ten header attributes. The attributes are listed below:

1) manuscript number

2) feature number

3) feature type

4) height

5) feature identification

6) surface material

7) PF - orientation
   LF - directivity
   AF - number of structures

8) PF - length
   LF - not applicable
   AF - % tree cover

9) PF - width
   LF - width
   AF - % roof cover

10) number of coordinates

where
PF - point feature
LF - line feature
AF - areal feature

Some examples of feature identification descriptor (FID) codes are:

1) FID 102 - quarry
2) FID 188 - cooling tower
3) FID 222 - railroad station
4) FID 261 - suspension bridge
5) FID 402 - apartments/hotels with flat roofs
6) FID 630 - hospital
7) FID 902 - soil
8) FID 952 - deciduous trees
9) FID 967 - pack ice

There are fourteen defined surface material codes (SMC) which are assigned to features according to which homogeneous surface most predominantly exists within a feature. The fourteen surface material codes are:

1) SMC 1 - metal
2) SMC 2 - part metal
3) SMC 3 - stone/brick
4) SMC 4 - composition
5) SMC 5 - earthen works
6) SMC 6 - water
7) SMC 7 - desert/sand
8) SMC 8 - rock

9) SMC 9 - concrete

10) SMC 10 - soil

11) SMC 11 - marsh

12) SMC 12 - trees

13) SMC 13 - snow/ice

14) SMC 14 - asphalt

Feature Attributes

Presently the DMA has a field in the feature header for a possible 1024 different feature identification descriptor (FID) codes of which about 32% have definitions. Each FID has a set of unique characteristics. In order for an image processor to identify features, these characteristics must exist in some accessible knowledge data base. These knowledge data bases are initialized during system installation or possibly prior to the integration of the software which accesses this information. These data bases contain feature information on tone, texture, location, relationship to surroundings, and restrictions.

The tables for tone and texture contain information for every possible FID/SMC combination. The tables contain statistical information such as mean, variance, moments, entropy, energy, correlation, contrast, homogeneity, cluster shade, and cluster prominence. Formulas for creating these tables are given by Unser [4] for both sum and difference histogram techniques and co-occurrence matrices. The creation of these tables may be done through the use of test images which contain a sample of all possible combinations or through a learning process where the system could retain new information from the digital map generation sessions.

Information for location and contextual relationship to surroundings relates more to the area of artificial intelligence and pattern recognition. McKeown and associates [5] describe the organization of a rule-base system, SPAM, to interpret airport scenes. A system such as SPAM may be set up for agricultural, urban, waterfront, desert, glacier, and other areas that could be grouped under a single domain. The domain-specific knowledge contains different levels of complexity to accommodate the different resolutions of photographs and map sources.

The final area in feature attributes deals with data restrictions. These restrictions are rules which are used by cartographers during manual digitization. The rules give minimum dimensions for certain feature types, FID and SMC combinations. Subsets of these rules [3] are given in Figures 4 and 5. If a rule applies to a feature, the feature may be separated into a different manuscript with a different data resolution or it may become part of a larger feature. If the smaller feature becomes part of a larger feature, it will contribute to the statistics of the larger feature in the areas of tree coverage, number of structures, and roof coverage. The feature may also change types such

	Surface Material Category Size Requirements				SMC Change Requirements*		Height Differential Requirements			Rules
SMC	Min. Length	Min. Width	Min. Height	Min. Roof Cover	Min. Length	Min. Width	Min. Height Diff.	Min. Length	Min. Width	Note
1	150	150	3	6%	90	ANY		NOT REQUIRED		1,5,6,8
2	150	150	3	6%	90	ANY		NOT REQUIRED		2,5,6,8
3	150	150	5	6%	300	300	10	150	ANY	5,8
4	300	300	5	6%	600	600	10	600	ANY	5,8
5	300	300	5	--	--	--	--	--	--	10,13
6	150	150	--	--	--	--	--	--	--	4,5,7
7	1800	300	--	--	--	--	--	--	--	9,12
8	600	600	--	--	--	--	--	--	--	--
9	300	300	--	--	--	--	--	--	--	3,5,10
10	--	--	--	--	--	--	--	--	--	3,5
11	300	300	--	--	--	--	--	--	--	--
12	300	30	8	--	--	--	--	--	--	3,5,11
13	600	600	--	--	--	--	--	--	--	--
14	300	300	--	--	--	--	--	--	--	3,5,10

LEVEL 1 - SURFACE/HEIGHT SPECIFICATIONS
(Dimensions in Meters)

*SMC change within other surface material areas (urban areas) 1-4

Figure 4. Level 1 - Surface/Height Specifications. (Source: [3])

All features will be portrayed as the type shown (areal, linear, point) with the exception of those followed by an asterisk, which may be reassigned as appropriate.

TYPE	SURFACE MATERIAL CATEGORY	MIN. LENGTH	MIN. WIDTH	MIN. HEIGHT	NOTES
Areal					
Parking Aprons, Areas, Squares	9, 14	300	300	ANY	2
Metal Ore Slag Dumps	2	150	150	3	
Islands*	10,3	ANY	ANY	ANY	2,5
Storage Areas	1-5	150	150	ANY	8,19
Mud/Tidal Flats	7	1800	300	ANY	2
Wastepiles	5	600	600	5	
Stripmines	5	600	600	-10	
Quarries*	3	300	300	-10	9
Linear					
Canals/Rivers/Streams*	6	3000	ANY	ANY	13,16
Railroads	2	300	ANY	ANY	16
Railroad Yards, Spurs, Sidings	2	300	5 TRACK	ANY	3,16
Roads	5,9,14	300	ANY	ANY	16
Bridges	1-4	150	ANY	ANY	1,14,15
Bridge Superstructures	1-4	150	ANY	4	17
Road/Railroad Viaducts	1-4	150	ANY	5	1
Causeways	1-5	150	ANY	ANY	1
Cleared Ways	9,10,14	150	ANY	ANY	9,12
Cleared Ways (e.g., Firebreaks)	10	3000	30	ANY	9,12
Embankments/Cuttings	5	300	ANY	±5	1
Fences	NOT REQUIRED				
Walls	1-3	300	ANY	3	1
Dams/Weirs	3	150	ANY	5	1
	5	300	ANY	5	1
Airfield Runways/Taxiways	9,14	1000	ANY	ANY	2
Wharves/Piers	1-4	150	ANY	3	1
Breakwaters/Jetties	3	150	ANY	ANY	1
Cliffs/Waterfalls	3	300	ANY	30	2,3
Locks*	3	150	ANY	3	1
Regional Features	5,12	600	ANY	ANY	2,3
Pipelines	2	600	ANY	ANY	1
Aqueducts	3	300	ANY	5	1
Point					
Obstructions	1-4	ANY	ANY	15	1,10
Special Tall Buildings*	1-4	30	ANY	15	1,4,10
Bridge Towers	1-4	ANY	ANY	46	
Bridges	1-4	30	ANY	ANY	1,14
Bridge Superstructures	1-4	30	ANY	4	17
Interchanges*	9,14	150	ANY	ANY	
Tunnel Entrance/Exits	3	ANY	ANY	ANY	1,2,3,18
Isolated Structures*	1-3	30	ANY	3	1,7,11
Radar Reflectors	1	ANY	ANY	ANY	1,6
Airfield Navigation Aids	NOT REQUIRED				
Transformer Yards*	1	30	ANY	5	1

LEVEL 1 UNIQUE FEATURE SPECIFICATIONS
(Dimensions in Meters)

Figure 5. Level 1 Unique Feature Specifications. (Source: [3])

as an areal to a lineal depending on size and resolution. The majority of the product specifications for digitize data contain rules for feature analysis. The remaining parts of the specifications describe the data base formats.

Manuscript Attributes

Manuscript attributes provide information for the manuscript header and the image analysis. The cartographer enters the level type, latitude, longitude, and other specialized header information. Level type describes the capture criteria of the feature. In other words, level type describes the resolution of the resulting DDB. Each level has its own rules for capture criteria and formats. If a low-resolution manuscript were specified and some high-resolution features were detected and identified, the system will convert them to point or lineal features. The system will also set up another manuscript with a different level type corresponding to a higher resolution and place these features in this manuscript in order to prevent some redundant processing. It would be at the discretion of the cartographer to retain this extra manuscript at the end of a session. Perhaps not enough higher resolution features were produced for retainment. Additional information such as the manuscript size and bounds is entered because it is necessary that adjacent manuscripts line up at the boundaries. This function is used to guarantee this result. The cartographer also enters location information such as if an area of the manuscript will be city, lakes, agriculture, etc. This information provides insight to feature interpretation when dealing with location and relationship to surroundings analysis.

Image Analysis

The core of an automated cartographic system would be the image analysis component. This component is responsible for feature extraction and interpretation. The degree of automation is controlled by the cartographer. This component may be totally interactive, totally automated, or some degree in between and is specified upon entering the image analysis component. A structure chart for this component is given in Figure 6.

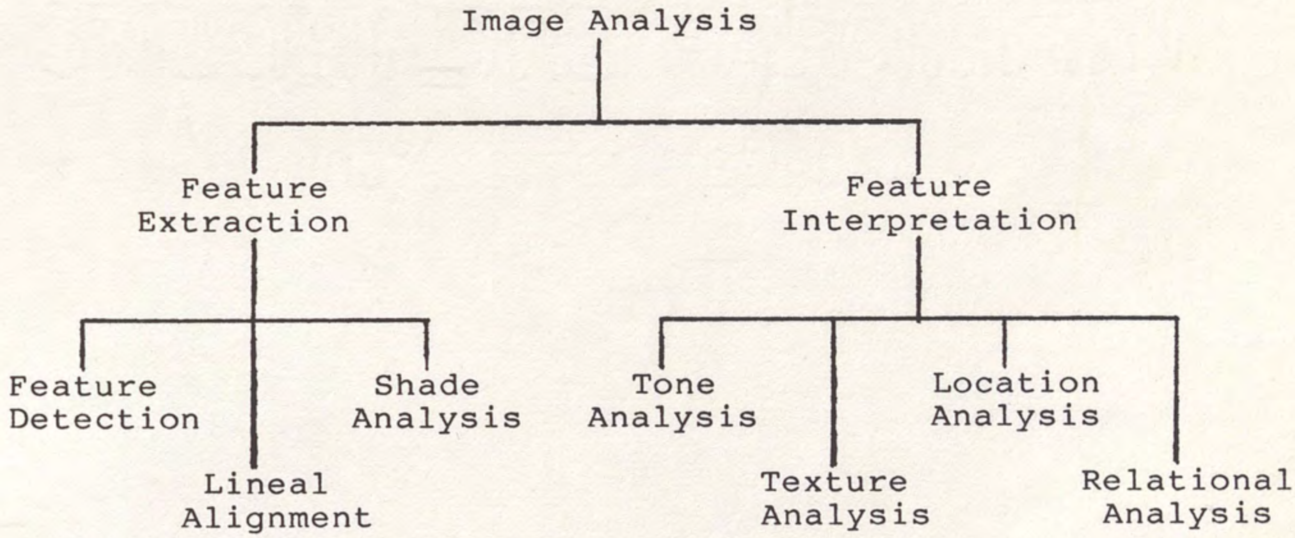

Figure 6. Image Analysis Breakdown Structure.

An automated mode gives complete control to the computer's software in the image analysis. The system begins by performing feature extraction on the entire image. Feature extraction attempts to identify features in the order of points, lineals, and then areals from smallest to largest. All features may initially be described as areals due to the resolution but the intent of the system would be to extract the smaller features first so that they may be ignored when extracting the larger underlying areals which may fall below several smaller features. As features are extracted, the system stores their coordinates and any information from a shade analysis off into a temporary file. The feature is deleted from the original image by performing a local smoothing using surrounding intensities or identifying those positions as "don't cares". Once the system has finished by extracting the background feature, the system proceeds to feature interpretation where the system will identify the feature and its attributes. After all analysis have been performed, the system will start off with the largest feature and through recursive logic and a tree structure work its way down to the smallest feature and decide which features overlay others and what the final attributes of these features will be. That is, the features will be set up in a tree structure according to priority.

Figure 7 shows a sample where Feature Analysis Code (FAC) represents the sequential order of feature extraction. A lower branch extending from a feature shows the features that overlay the higher node.

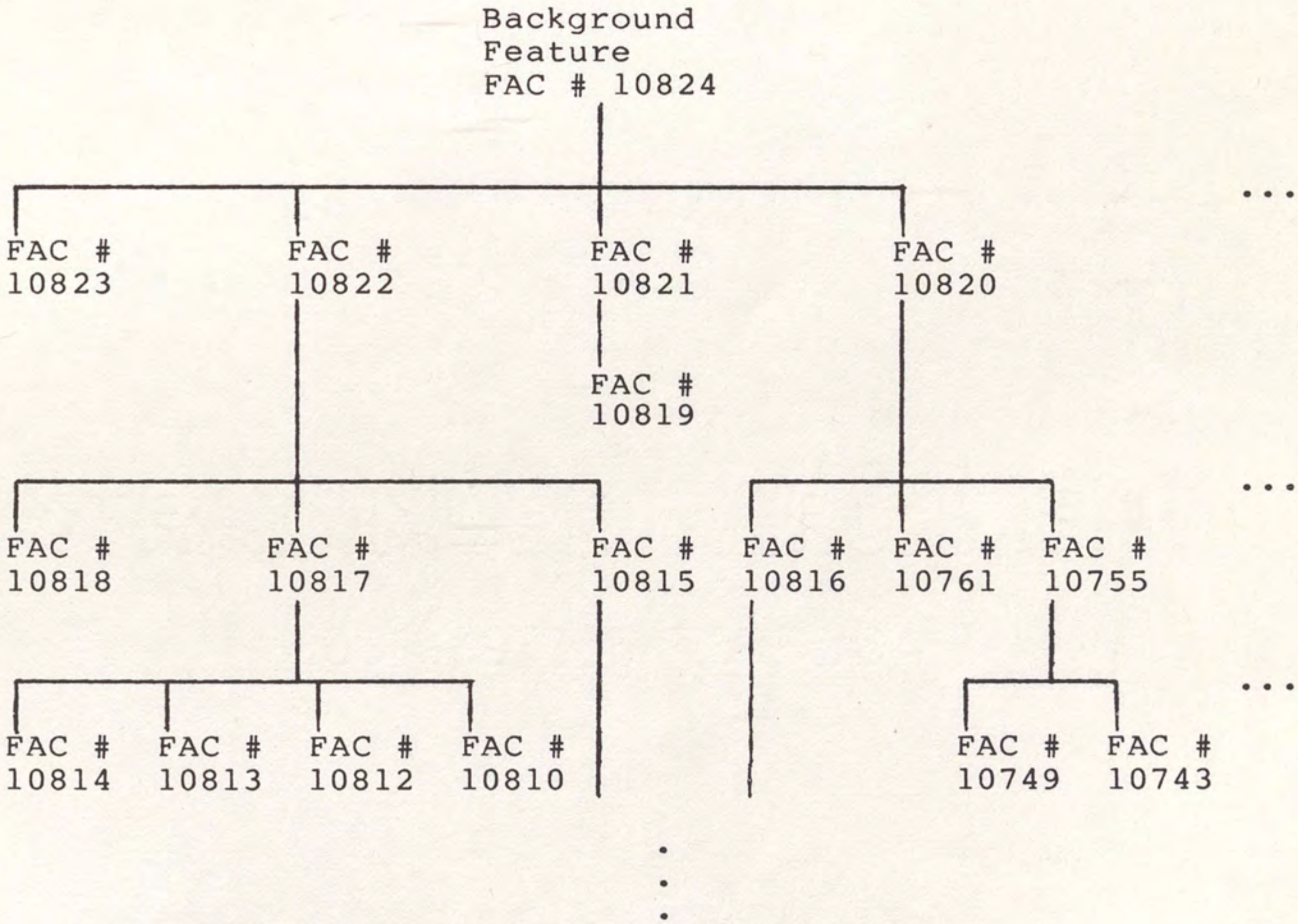

Figure 7. A Sample Tree Structure.

Due to resolution and the rules from the product specification for digital analysis, several things may happen. The feature may become statistics for a larger underlying areal and be deleted. The feature may become statistics for a larger underlying areal in a manuscript with a lower resolution and the feature may be placed in another manuscript with high resolution features. The feature may be converted to a point feature with a single coordinate or a lineal feature with several coordinates depending upon the resolution. The interactive mode is used if the cartographer wants to digitize an area by previous methods such as a digitization tablet and mouse. Feature interpretation could be turned off and the system would perform all extractions and control would be transferred to the cartographer for feature interpretation. The system could control the order of interpretation. The cartographer chooses whether to retain the feature or not. If the feature is retained, the cartographer proceeds on to entering the feature attributes into the feature header. Upon completion of the attributes, the computer rechecks this information and renders an opinion of the cartographer's accuracy. Automatic feature extraction could be turned off allowing the cartographer to digitize the feature and the software to identify the feature intermediate attributes. Upon completion of the attributes, the cartographer could change this information and the computer would render an opinion. After each feature has been completed, the computer would run through the rule checking or capture criteria and organize the output manuscripts. An analysis inhibit function is supplied and possibly executed prior to the image analysis if any of the algorithms did not apply to the image. The status menu may include linear alignment, shade analysis, shade analysis, tone analysis, texture analysis, location analysis, relational analysis, or more generally feature extraction and interpretation.

Feature Extraction

Prior to any feature detection or interpretation, it is desired to have as much initial knowledge about the area of interest as possible and to use any previous data. This desire includes operations for matching two or more images within a common area, an image and a map, an image and a previously digitized data base (DDB), or a map and a DDB. The operation for matching two or more images is done to align features and take advantage of the variability between them such as angle, season, time of day, multispectral frequency, type of film, etc. The variability would add information about the area and the matching would allow the system to compare corresponding feature positions.

Matching maps and images allows the system to take advantage of the information already presented in the map. Feature detection and extraction are simplified by those features already identified on the map. The map in this case serves as a starting point and basis for this particular combination.

Finally matching maps or images to a previously digitized data base prevents the system from reanalyzing the entire area and speeds up the operation of updating. The DDB is the basis for any combination in which this source of information is available. The result may be an updated DDB and possibly an additional manuscript with high resolution features.

Medioni and Nevatia [6] describe a software system for matching two images or an image and a map. The system uses line-based descriptions, and matching is accomplished by a relaxation operation which computes the most similar geometric structure. The authors also describe a more efficient variation. Although the software system was not totally integrated, it produced excellent results with complex aerial images which contain many image differences due to nature and man. This method applies easily to DDB updates because some of the features are already identified. It also reveals details on construction, destruction, and movement.

There are primarily four types of source images which require feature extraction techniques. These are multispectral images, aerial photographs, maps, and ground photographs. Multispectral or sometimes called multiband images are the products of satellite or aircraft multispectral sensors. These images are taken through several different bands of the light spectrum and may be encoded and sent to a magnetic storage medium or a film. Some of the bands may be in the nonvisible portion of the spectrum as is the case with LANDSAT [7,8]. LANDSAT is taken through four bands, one of which is infrared. Other multispectral sensors can produce images over a range of twenty different bands. One method for feature detection using multispectral images is given in Gonzalez and Wintz [8].

Gonzalez and Wintz begin by stating that methods associated with encoding techniques may be used for feature extraction. One method employs the Hotelling transform and variance properties between adjacent bands. An example of an area covering 0.9 by 0.7 miles taken by a six-band multispectral scanner is provided. The six images contain 384 by 239 pixels each. The corresponding pixels between all of the images form a vector dimensioned by the number of bands which in this example is six. Each element of the vector represents the respective gray level from each band. The average within each vector along with the correlation between all adjacent vectors over the entire range is taken next. The result shows that the vectors have different means and are highly correlated. The components are normalized about their means. Through a property of the Hotelling transform, the correlation of the components is eliminated.

The Hotelling transform is given by:

$$\bar{y} = \bar{A}(\bar{x}-\bar{m}) \tag{8}$$

where
$\bar{x}$ is the vector of elements,
$\bar{m}$ is the mean vector population, and
$\bar{A}$ is the normalized eigenvectors of the covariance matrix C.

The correlation property is described using the covariance matrices of x and y along with their expected values. The Hotelling transform reveals the orthogonal components with the greatest variance. The main principal behind this technique is to find significant variances between the first several images with monotonically decreasing effects in the later. A coordinate definition of under 8190 coordinates is the result of this function.

Nonmultispectral ground and aerial photographs require different techniques for feature extraction. Since these photographs usually have a thirty percent overlap at different angles, the images must be adjusted through a rotation matrix so that feature boundaries can be aligned within a certain tolerance. The common overall areas have to be identified at initialization when the image model is initialized. Different thresholds are applied to each image. The results produced by one threshold are then compared between images and reveal certain features.

The same threshold technique applies to map sources except that only one map is analyzed at a time. There may be other sources but they act as a comparison during this process. Lubkowitz and Groch [9] suggest a method for automating the digitization of map sources. Lubkowitz and Groch mainly give examples of their linear extraction algorithm which starts off with significant features such as intersections and follows them to "dead ends". Aerial photography was used to support and verify the results. The end result of any methods used in feature extraction must be a coordinate definition for each possible feature.

Feature Interpretation

Once the coordinates of a feature have been determined, the attributes other than the manuscript number, feature analysis code (FAC) number and number of coordinates must be identified. The attributes are stored in the feature header and may be changed as more information is determined in the process.

The type of feature, point, line, or areal should be obtained from the feature detection function. Due to ground resolution calculations, a width and length is associated with point features and a width is associated to lineal features. Height is another scalar attribute that is determined by the use of mathematical modeling. In ground photography, the height of a feature may be easily calculated directly from the focal length and distance to the object. A more complex method that is used in low altitude aerial photography and possibly in ground photography is a modified version of the local shading method.

Pentland's local shading method [10] obtains estimates for surface orientation, 3-D surface shape, and the illuminate direction on a constrained regional basis. The analysis uses image intensity and its derivatives to produce these results. The model in Figure 8 reveals three major components which can be applied to a feature.

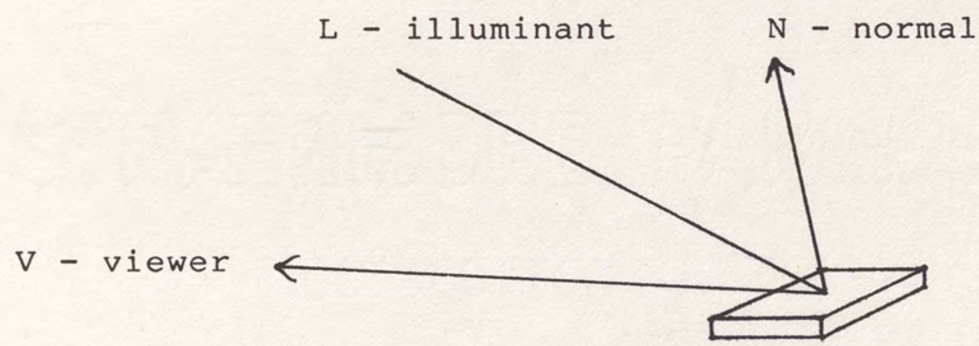

Figure 8. Three Components of Local Shading Method.

The image intensity is given by:

$$I = p(q)(N \cdot L) \tag{9}$$

where

p is the albedo of the surface,
q is the intensity of the illuminant, and
L is the direction of the illuminant.

The first derivative is given by:

$$dI = p(q)(dN \cdot L) \tag{10}$$

assuming that there is negligible change in illumination and albedo of the surface and therefore treating L, p, and q as constants. The second derivative is given by:

$$d^2 I = p(q)(d^2 N \cdot L). \tag{11}$$

Pentland states that many surfaces produce similar results with these equations and limits the analysis to planar, cylinder, convex, concave, and saddle surface. In the case of culture, this method mainly applies to man-made features which usually fall mainly under these surface shapes. Pentland also gives an example of using this method on natural scenes and producing topographic information which leads to the creation of terrain data. This method is improved by assuming that most of the man-made features (e.g. buildings, smokestacks, bridges) are planar or cylinder surfaces. The sun model presented in an earlier section is used in conjunction with this method. The shadow area is approximated based on the feature position and orientation. This shadow area is isolated by an local intensity analysis. The information from this method yields height, orientation of point features, directivity of lineals and tone. Tone is a factor which contributes to information about FID and SMC but is not enough to accurately determine identify these attributes. Tone is a result from the local shading method or it may simply be the overall intensity descriptor of the feature if the local shading method were inhibited.

The final attributes are the most subjective which include Feature Identification Descriptors (FID) and Surface Material Codes (SMC) for all types of features. In the case of areals, extra attributes include percentage of tree coverage, percentage of roof coverage, and number of structures per square nautical mile. These attributes are determined through a combination of techniques in image processing and artificial intelligence. The techniques involve analysis in texture, location, and relative surroundings.

Many articles have been written on different techniques developed for texture analysis. Texture analyses ranged from machine recognition of an object to complete aerial images. Separate research would be done to identify which techniques are the best for aerial images. Vilnrotter and associates [11] explain that textures can be described structurally by individual textural elements and their spatial relationships. The authors describe a system and algorithm to generate useful descriptors. Unser [4] presents a simplification to an existing method for texture analysis. Sum and difference histograms are given as an alternative to co-occurrence matrices. He presents equations for mean, variance, energy, correlation, entropy, contrast, homogeneity, cluster shade, and cluster prominence using both methods. The equations stated by Unser are shown in Figure 9.

The sum and difference histograms prove to be almost as accurate as co-occurrence matrices for texture identification. The advantage of sum and difference histograms is that they require less computation time and memory storage than the co-occurrence matrices. Jerigan and D'Astous [12] analyzed only the entropy factor of textures. The authors give an approach which measures entropy in the spatial frequency domain in a regional basis. The spread of the frequency components from this method yield a higher accuracy than those of summed energies or co-occurrence matrices. The analysis is independent of size. Nothing is mentioned about speed and memory usage. All of the texture analysis methods use probabilities and statistics. If comparisons were performed on each of the techniques, it would have to be shown how feature attributes such as size affect computations. Speed, memory usage and limitations must be analyzed to see which methods are acceptable for use by the ACS.

Location attributes are initialized when the the manuscript attributes are defined. The cartographer

TABLE I
EXAMPLES OF GLOBAL HISTOGRAM FEATURES

FEATURE	FORMULA
mean	$\mu = \sum_i i \cdot \hat{P}(i)$
variance	$\sigma^2 = \sum_i (i-\mu)^2 \cdot \hat{P}(i)$
q^{th} moment about the mean	$m_q = \sum_i (i-\mu)^q \cdot \hat{P}(i)$
entropy	$H = \sum_i -\hat{P}(i) \cdot \log(\hat{P}(i))$

TABLE II
EXAMPLES OF THE MOST COMMONLY USED TEXTURE FEATURES COMPUTED FROM THE CO-OCCURRENCE MATRICES AND THEIR EQUIVALENT FORM COMPUTED FROM THE SUM AND DIFFERENCE HISTOGRAMS

TEXTURE FEATURE	CO-OCCURRENCE MATRIX	SUM AND DIFFERENCE HISTOGRAMS
mean	$f_1 = \sum_i \sum_j i \cdot \hat{P}(i,j)$	$= \frac{1}{2} \sum_i i \cdot \hat{P}_s(i) = \mu$
variance	$f_2 = \sum_i \sum_j (i-\mu)^2 \cdot \hat{P}(i,j)$	$= \frac{1}{2}\left(\sum_i (i-2\mu)^2 \cdot \hat{P}_s(i) + \sum_j j^2 \cdot \hat{P}_d(j) \right)$
energy	$f_3 = \sum_i \sum_j \hat{P}(i,j)^2$	$= \sum_i \hat{P}_s(i)^2 \cdot \sum_j \hat{P}_d(j)^2$
correlation	$f_4 = \sum_i \sum_j (i-\mu) \cdot (j-\mu) \cdot \hat{P}(i,j)$	$= \frac{1}{2}\left(\sum_i (i-2\mu)^2 \cdot \hat{P}_s(i) - \sum_j j^2 \cdot \hat{P}_d(j) \right)$
entropy	$f_5 = \sum_i \sum_j -\hat{P}(i,j) \cdot \log(\hat{P}(i,j))$	$= -\sum_i \hat{P}_s(i) \cdot \log(\hat{P}_s(i)) - \sum_j \hat{P}_d(j) \cdot \log(\hat{P}_d(j))$
contrast	$f_6 = \sum_i \sum_j (i-j)^2 \cdot \hat{P}(i,j)$	$= \sum_j j^2 \cdot \hat{P}_d(j)$
homogeneity	$f_7 = \sum_i \sum_j \frac{1}{1+(i-j)^2} \cdot \hat{P}(i,j)$	$= \sum_j \frac{1}{1+j^2} \cdot \hat{P}_d(j)$
cluster shade	$f_8 = \sum_i \sum_j (i+j-2\mu)^3 \cdot \hat{P}(i,j)$	$= \sum_i (i-2\mu)^3 \cdot \hat{P}_s(i)$
cluster prominence	$f_9 = \sum_i \sum_j (i+j-2\mu)^4 \cdot \hat{P}(i,j)$	$= \sum_i (i-2\mu)^4 \cdot \hat{P}_s(i)$

Figure 9. Texture Equations.
(Source: [4])

visually inspects the image(s) and decide what characteristics best describe the area or areas within the image. Some examples or general descriptors are suburban, urban, rural, agricultural, forest, lakes, ocean, desert, military, glacial, and mountainous. The cartographer would digitize a rectangular area and give it a descriptor. When feature interpretation performs the location analysis, probabilities for the likelihood of a feature are assigned to all FID/SMC combinations. Location analysis provides another factor for the system to use when it finally identifies the feature.

Relationship to surroundings is a much larger and more complicated subject than location. McKeown and associates [5] describe a rule-based system, SPAM, that uses map and domain-specific knowledge to interpret airport scenes. The system used image segmentation performed by a human and a region-based image segmentation program. The input was a high-resolution airport. The system categorized major groupings within the airport. Interpretations were performed based on spatial and structural consistency. The article describes SPAM components, primitives, main processes, rules, and gives some performance statistics. Some of the problems that existed were related to errors in image segmentation and the recognition strategies used in the rule-based approach. Added texture information improved results. The authors mentioned that with an increase in subclass fragment interpretation, there is a significant increase in processing time. McKeown also references other work done in this area involving multispectral images.

A similar effort would have to be done with rule-based systems as with texture. Once the system was designed and implemented, it would have to be integrated with the other components of the ACS. The rule-based system would be the main component of feature interpretation because it would use the results from the other analysis and perform the feature identification.

Digital Data Base Correction

After the completion of a manuscript, the cartographer may wish to manually alter or check features within the manuscript. This component provides the cartographer with the capability of displaying, adding, deleting, and changing features and terrain elevation grid posts. Another function of this component is to certify the culture and terrain information to verify that the data is in adherence to the specification that it was digitized under.

Under the displaying function, the software should have the capability of visually displaying an area within the culture manuscript, zooming in and out, listing feature headers/coordinates, and isolating a feature with a cursor position. Fishnet and contour plots are available for terrain. An example of these are shown in Figures 10 and 11. The alteration functions allows the cartographer to change feature header and coordinate definitions for culture data. This function has the capability of adding and deleting entire features and their definitions.

Outputs

A separate handles the outputs of this system which include the final manuscript on disk and any output reports on the digitization session. The reports contain statistics and information about the digital data base generation. The difference in reports is the detail. Output reports range from simple summaries to complex reports used for debugging, analyzing the details behind the digitization of certain features and analyzing software efficiency. The more complex reports may be hidden from the cartographer and made available only to the system maintenance programmer through a password system.

Diagnostics

The area of diagnostics overlaps with the output reports component. Diagnostics are used to detect hardware and software problems. Special test images are the source input to this function. These test images must be created ahead of time. These images contain cases that include shadow, tone, and/or texture. There may be different geometric shapes within the test image to test out feature

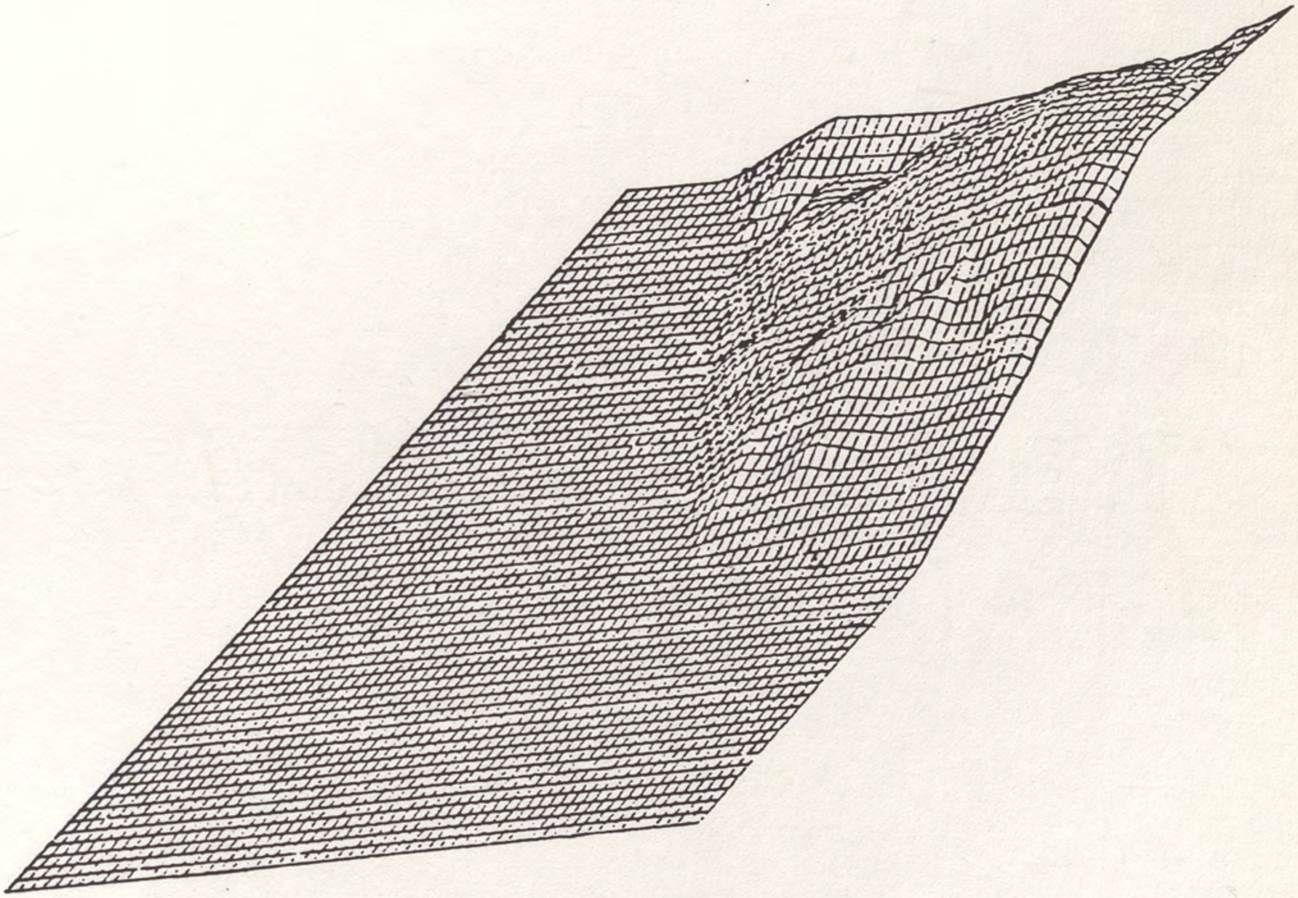

Figure 10. Terrain Fishnet Plot.

Figure 11. Terrain Contour Plot.

detection. An artificial situation such as an airport may be modeled for a test image. Another test image may be composed of a highly complex aerial photograph which could be used as a standard in testing new components added to the ACS. Each function should have at least one test image associated with it.

CHAPTER III

LIMITATIONS

The automated cartographic system has some limitations and concerns associated with its development. The limitations of such a system are controlled by the characteristics of the input images. Resolution of the input image is one factor. It is not beneficial to input an image with an extremely high resolution containing only a few features over a small area. Manual digitization, if desired, is more effective for this case. On the other extreme, LANDSAT images may cover over 10,000 square nautical miles. Since terrain cells only cover 3600 square nautical miles or less, this limit should be applied to culture manuscripts also. In addition to this limit, manuscripts can only contain a maximum of 16383 features.

There may be features within the image that are not defined as a legitimate features in the initialization tables. These undefined features may have similar characteristics such as a large jet and a small warehouse with a metallic roof. Features such as the jet need additional processing to keep them from being added to the digital data base or even contributing to the statistics.

Other considerations should be taken into the design and must be handled. The first is variability due to atmospheric factors, season, time of day, sun angle, solar altitude, soil moisture, and vegetation growth. What extremes should the system go to handle these factors? What happens if the area is to be updated some time in the future? The system should be able to identify preexistent features along with ones that were removed. Features may be nonphotogenic because they are too small (e.g., pylons), the same reflectivity as the underlying area, and hidden by shadows or undercover. A software consideration which is vital to feature coordinate definition is how are missing edge points, failure to localize edge points and classifying noise pulses as edge points eliminated from the system. There will also be bounds put on the system by the product specifications for the digitized data. These specifications will define the range of values for all attributes and the special case rules on how these attributes are arrived at. These tables that initialize the system must be expandable to handle new features and attributes. The expansion of these tables could be handled by an artificial intelligence process. When a new feature is introduced to the system, the cartographer could let the system acquire statistics about this feature by identifying other features with similar statistics. The information would be collected and a new entry would be made when the cartographer inputs a new feature identification descriptor and the surface material code. The same method would apply when new surface material codes are defined. At the same time, the rest of the features in the area would have to be analyzed to obtain relationship to surroundings attributes. Location attributes would be defined by the initial location attributes that were assigned to the area. This method would be complex because it deals with all of the subjective attributes. The level of detail for some of these attributes would have to be managed with caution by the software. Too much detail would slow the interpretation process down considerably and too little would produce indecision.

CHAPTER IV

IMPLEMENTATION PLAN AND CONCLUSION

Initial System

The proposed cartographic system would be so large that the development and installation would have to be done in several stages. The first stage would contain the necessary software and hardware to manually create digitized data bases. This software would also be able to perform DDB correction. The corresponding output reports and diagnostics would be provided.

The next stage would be to set up the feature extraction function and the part of the initialization component which it depends on. Once feature extraction is complete, productivity would increase because the job of manually tracing a feature's perimeter with a digitization tool is eliminated or the effort is reduced considerably. At this point the system would undergo extensive testing by the cartographers and technical support should be provided. Statistics would be kept during the digitization sessions to reveal the efficiency, reliability, and accuracy of the initial system. Problems would be identified and improvements possibly would be made with new methods. Special case situations would reveal the extent to which the system would provide accurate feature coordinate definitions.

Final System

Concurrently the remainder of the system could be developed. This development would include finishing the initialization component by defining all possible feature attributes along with the rules that govern feature analysis. Lineal alignment, shade analysis, and feature interpretation functions would be integrated into the system along with the respective output reports and diagnostics.

Statistics would be kept on efficiency, reliability, and accuracy on each of the functional areas. Problem areas would be isolated and corrected. Once the statistics reach a certain point of acceptance, the job of the cartographer transitions to that of a supervisor. The cartographer would set up the image processing devices, activate the automated system, and review the results. The cartographer may also choose to edit portions of the manuscript from information acquired from intelligence sources.

The subjectivity involved in cartography makes automating it difficult. The benefits of automation along with the advances in image processing and artificial intelligence make it possible. More information would be produced in far less time with greater accuracy. Improvements would be made as technology advances further and algorithms improve. The limits of an automated system far supersede the extents of a manual system.

Software Engineering Considerations

There are three major considerations that deal with different aspects of software engineering. These are in the areas of code, users, and the production environment. Since the system would be enormous and the installation would take years, the system would be subject to change due to improvements in technology. Therefore the code must be modular and well documented. Current algorithms may be replaced by more accurate and faster ones. Well structured interfaces must be well defined. The replacement and addition of new algorithms must be made as easy as possible. Since the government is a possible customer for such a system, it may be necessary to set up a configuration management system that is in adherence to their rigid standards. User manuals must explain every step needed to produce data. Test procedures must be well defined revealing the accuracy, efficiency, reliability, and the size of every part of the cartographic system. The system must be user-friendly where different levels of experienced people are only exposed to certain levels of complexities. Diagnostics and output reports should also be separated into these different levels. The combination of the documentation and any help functions must be sufficient to create digitized data for the most inexperienced person. There are additional considerations because this system would most likely be used in a production environment where there are many users. A batch option should be added to handle either automated feature extraction or interpretation or both. A restart capability should be added so that the system could pick up where it left off in case of a system crash or if the cartographer decided to split the digitization up into several sessions. Read-only files should be accessible by all users at one time and should not be exclusively assigned. The system should also be expandable to handle new features, surface material codes, capture criteria, and formats. This is an immense system and the majority of the time should go into design.

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