

AD-A170 301

TWO-DIMENSIONAL POLYGONAL REPRESENTATION OF MAPS FOR  
USE WITH AUTONOMOUS VEHICLE ROUTE PLANNING(U) NAVAL  
POSTGRADUATE SCHOOL MONTEREY CA R K DIEHL ET AL.

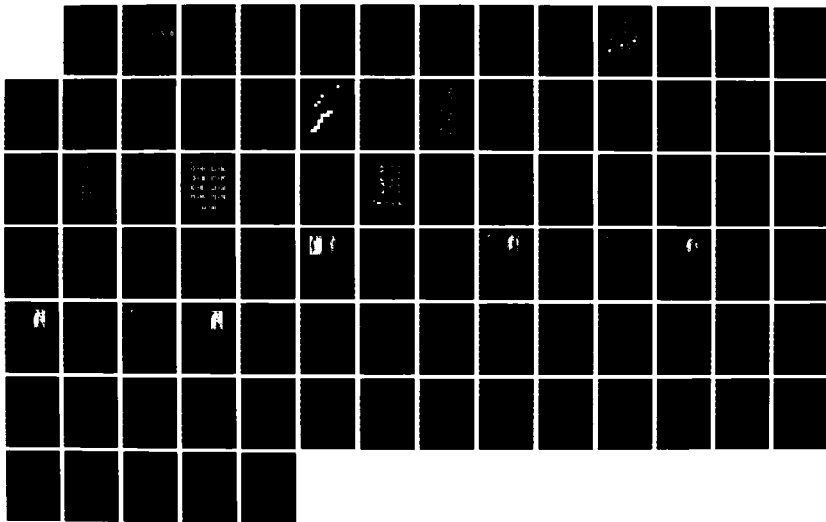
1/1

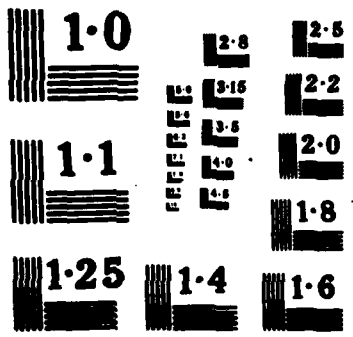
UNCLASSIFIED

JUN 86 NPS52-86-016

F/G 8/2

NL





NPS52-86-016

# NAVAL POSTGRADUATE SCHOOL

Monterey, California

AD-A170 301



DTIC  
ELECTE  
JUL 29 1986  
S D

TWO-DIMENSIONAL POLYGONAL REPRESENTATION OF MAPS  
FOR USE WITH AUTONOMOUS VEHICLE ROUTE PLANNING

ROGER K. DIEHL  
ROBERT B. MCGHEE  
MICHAEL J. ZYDA

June 1986

DTIC FILE COPY

Approved for public release; distribution unlimited

Prepared for:  
Chief of Naval Research  
Arlington, VA 22217

NAVAL POSTGRADUATE SCHOOL  
Monterey, California

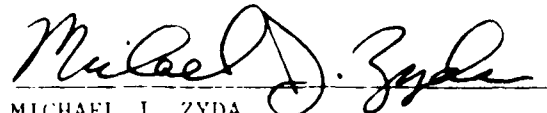
Rear Admiral R. H. Shumaker  
Superintendent

D. A. Schrady  
Provost

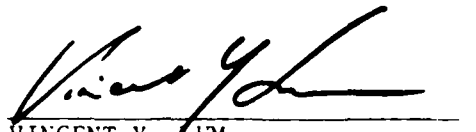
The work reported herein was supported in part by the Foundation Research Program of the Naval Postgraduate School with funds provided by the Chief of Naval Research.

Reproduction of all or part of this report is authorized.

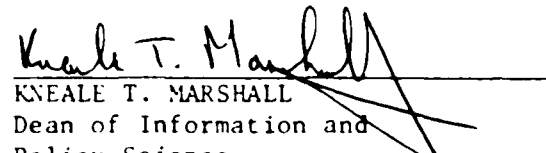
This report was prepared by:

  
MICHAEL J. ZYDA  
Assistant Professor  
Computer Science

Reviewed by:

  
VINCENT Y. LUM  
Chairman  
Department of Computer Science

Released by:

  
KNEALE T. MARSHALL  
Dean of Information and  
Policy Science

UNCLASSIFIED

SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

REPORT DOCUMENTATION PAGE		READ INSTRUCTIONS BEFORE COMPLETING FORM
1. REPORT NUMBER NPS52-86-016	2. GOVT ACCESSION NO. AD A170 301	3. RECIPIENT'S CATALOG NUMBER
4. TITLE (and Subtitle) TWO-DIMENSIONAL POLYGONAL REPRESENTATION OF MAPS FOR USE WITH AUTONOMOUS VEHICLE ROUTE PLANNING	5. TYPE OF REPORT & PERIOD COVERED	
	6. PERFORMING ORG. REPORT NUMBER	
7. AUTHOR(s) Roger K. Diehl Robert B. McGhee Michael J. Zyda	8. CONTRACT OR GRANT NUMBER(s) N0001486WR4B123AC	
9. PERFORMING ORGANIZATION NAME AND ADDRESS Naval Postgraduate School Monterey, CA 93943-5100	10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS	
11. CONTROLLING OFFICE NAME AND ADDRESS  Chief of Naval Research Arlington, VA 22217	12. REPORT DATE June 1986	
	13. NUMBER OF PAGES 86	
14. MONITORING AGENCY NAME & ADDRESS (if different from Controlling Office)	15. SECURITY CLASS. (of this report)	
	15a. DECLASSIFICATION, DOWNGRADING SCHEDULE	
16. DISTRIBUTION STATEMENT (of this Report) Approved for public release; distribution unlimited		
17. DISTRIBUTION STATEMENT (of the abstract entered in Block 20, if different from Report)		
18. SUPPLEMENTARY NOTES		
19. KEY WORDS (Continue on reverse side if necessary and identify by block number) Autonomous vehicle route planning, computer vision, cartography, color discrimination		
20. ABSTRACT (Continue on reverse side if necessary and identify by block number) We present in this study a two-phase approach to the generation and maintenance of a polygonal cartographic database useful for autonomous vehicle route planning. The database is generated non-interactively from available U.S. Geological Survey topographical maps. The database is maintained interactively by a graphics workstation. The focus of this study is on the non-interactive generation of the polygonal database. The non-interactive generation process uses both a set of heuristics derived from the characteristics of paper maps and classical region growing.		

DD FORM 1473

1 JAN 73

EDITION OF 1 NOV 65 IS OBSOLETE

S N 0102-LF-014-6601

UNCLASSIFIED

SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

# Two-Dimensional Polygonal Representation of Maps for Use with Autonomous Vehicle Route Planning ‡

Roger K. Diehl, Robert B. McGhee and Michael J. Zyda \*

Naval Postgraduate School,  
Code 52, Dept. of Computer Science,  
Monterey, California 93943

## ABSTRACT

We present in this study a two-phase approach to the generation and maintenance of a polygonal cartographic database useful for autonomous vehicle route planning. The database is generated non-interactively from available U.S. Geological Survey topographical maps. The database is maintained interactively by a graphics workstation. The focus of this study is on the non-interactive generation of the polygonal database. The non-interactive generation process uses both a set of heuristics derived from the characteristics of paper maps and classical region growing.

Categories and Subject Descriptors: I.3.0 [General]: computer vision, image processing; I.3.6 [Methodology and Techniques]: color discrimination; I.3.m [Miscellaneous]: cartography;

General Terms: Techniques:

Additional Key Words and Phrases: autonomous vehicle route planning, computer vision, cartography, color discrimination:

‡ This work has been supported by the Naval Postgraduate School Foundation Research Program and a grant from the Naval Ocean Systems Center, San Diego (Ref # N0001486WR4B123AC)

\* Contact author

For	
&l	<input checked="" type="checkbox"/>
3	<input type="checkbox"/>
ed	<input type="checkbox"/>
Availability Codes	
Dist	Avail and/or Special
A-1	



## TABLE OF CONTENTS

I. INTRODUCTION .....	6
II. BACKGROUND .....	7
A. GENERAL .....	7
B. PAPER MAP SELECTION .....	9
C. COLOR SYSTEMS AND COLOR NAMING .....	11
III. PHASE I MAP PROCESSING .....	14
A. SYSTEM REQUIREMENTS .....	14
B. DIGITIZATION PROCESS .....	15
C. IMAGE PREPROCESSING .....	16
D. PHASE ONE OVERVIEW .....	18
E. INITIAL PIXEL NAMING .....	18
F. REGION GROWING .....	22
1. Growing From Known Pixels .....	22
2. Growing From Unknown Pixels .....	25
G. REMOVAL OF SINGLE KNOWN PIXELS .....	26
H. ASSIGNMENT OF SINGLE UNKNOWN PIXELS .....	28
I. FINAL COLOR NAME ASSIGNMENT .....	28
J. POLYGONAL MAP PRODUCTION .....	30
1. General .....	30

2. Color Group Determination .....	30
3. Polygon Generation .....	31
4. Polygon Map Format .....	33
IV. RESULTS AND RECOMMENDATIONS .....	34
A. INITIAL PIXEL NAMING .....	34
1. Resolution .....	34
2. Filter Alignment .....	35
3. Lens Spherical Aberration .....	35
4. Illumination .....	36
5. Focus .....	36
6. Recommended Digitization Station .....	36
B. REGION GROWING .....	37
C. REMOVAL/ASSIGNMENT OF SINGLE PIXELS .....	38
D. FINAL COLOR NAME ASSIGNMENT .....	39
E. POLYGONAL MAP PRODUCTION .....	40
F. PHASE ONE FINAL RESULTS .....	40
V. CONCLUSIONS .....	60
APPENDIX - PHASE I EXECUTION INSTRUCTIONS .....	62
LIST OF REFERENCES .....	74
INITIAL DISTRIBUTION LIST .....	75



## I. INTRODUCTION

The production of digital representations of available topological maps printed on paper is paramount to the effective production of guidance systems for autonomous vehicles. Although digital representations of some maps are available, these maps are expensive, require extensive human interaction to produce, are slow in production, use extensive amounts of storage, and are often not of high enough resolution. Current systems for digitized map production are, in general, interactive with humans guiding the production. Such human produced maps tend to be fraught with errors. [Ref. 1: p. 137]. With the advances in computer and image processing technology, and the availability of low cost image processing equipment, a computer oriented approach to digital map production is possible.

This study presents a two-phase approach to the digital map production problem. The first phase is a non-interactive phase in which general information is gleaned from a paper topographical map with the use of an image digitizer and computer vision software. The second phase is an interactive one that focuses on the refinement, correction and revision of the map produced in the first phase.

## II. BACKGROUND

### A. GENERAL

The production of map digital databases has been primarily limited to interactive software products where the human user makes all decisions. The system presented here is designed to remove some of the tedium and repetitive nature of those processes by the use of a knowledge based, non-interactive phase. The non-interactive phase is followed by an interactive phase to provide database modification due to topographical changes, as well as database correction and refinement.

The database production system is illustrated in Figure 2.1. A section of the paper map is placed under the video digitizer. The digitizer produces three files corresponding to the red, green and blue filtered images. These three color files are used as the input to the phase one process. This process assigns a color name to each pixel in the map section depending on the red, green and blue values at that pixel. After completion of the color name assignment, the resulting color determined map is processed by a routine that converts the pixel based color determined map into a geometric, polygon based map. The polygon based map consists of areas of uniform color.

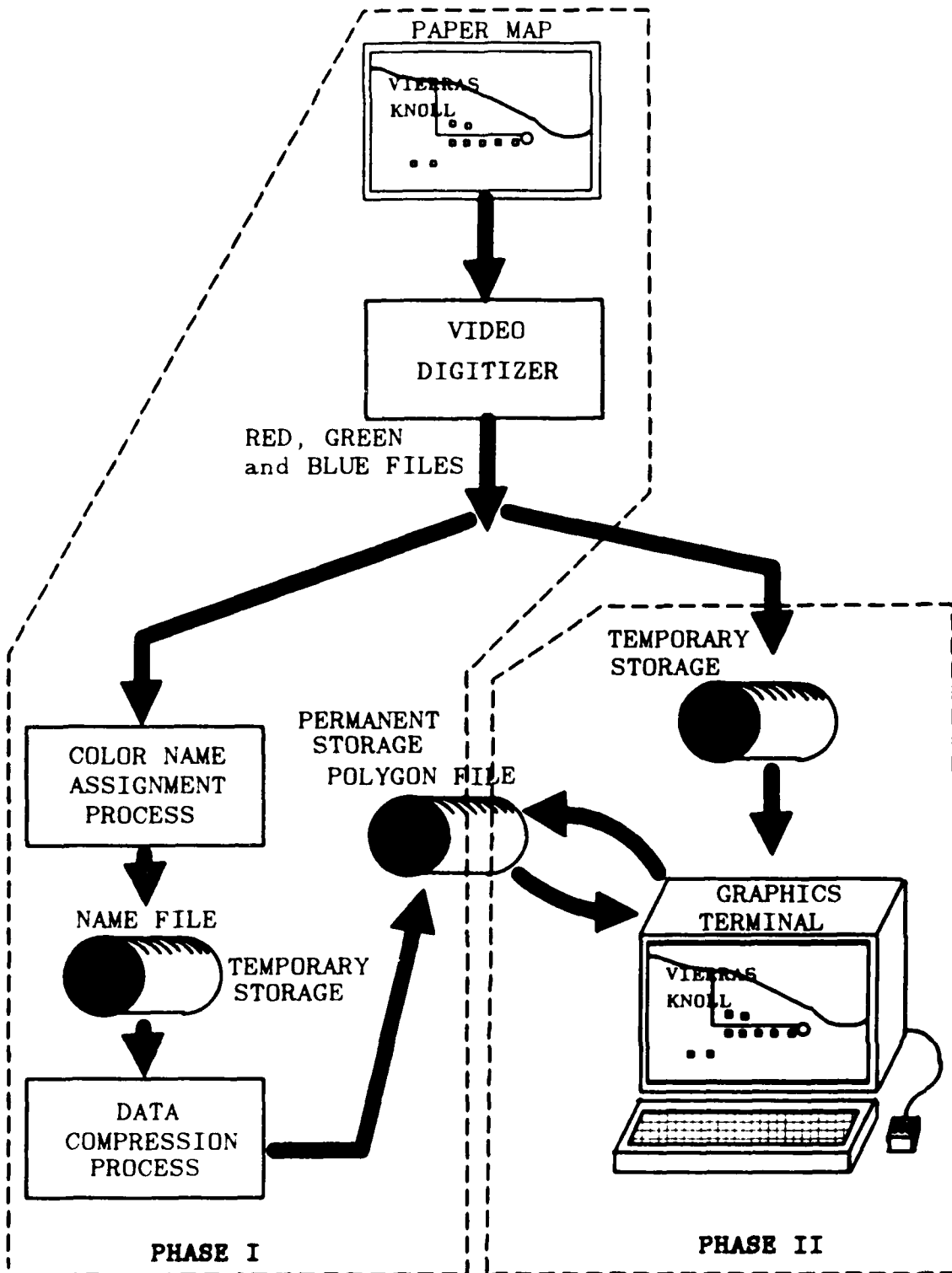


Figure 2.1 - Digital Map Production System Overview

The polygon map file produced provides a significant data reduction when compared to the pixel based map. This reduction in data allows the phase two processes to function at a rapid rate.

This concludes the overview of the non-interactive phase of the system. Phase two of the system provides interactive editing capabilities, such as correction, modification, section joins, and elevation processing [Ref. 2].

## B. PAPER MAP SELECTION

The input for the first phase consists of an available paper topographical map. The selection of a map for use in this system is based on the following considerations:

- Standardization of colors

- Standardization of scale

- Standardization of symbols

- Accuracy of information represented

- Availability

The U.S. Geological Survey, 1:24,000 scale, 7.5 minute quadrangle topographical map series was selected for input into this system. USGS maps are printed in seven standard colors (See Table 2.1). The 1:24,000 scale, 7.5 minute series is one of the standards produced and maintained by the USGS, and is readily available at minimal cost.

This series has a standardized symbol set and the accuracy is maintained sufficiently to produce representations of highly detailed topographical areas. [Ref. 3].

**TABLE 2.1**  
**USGS MAP COLOR STANDARDS**

Color	Description
BLACK	Cultural features such as roads and buildings.
BLUE	Hydrographic features such as lakes and rivers.
BROWN	Hypsographic features shown by contour lines such as slopes and elevations.
GREEN	Surface cover including woodlands, scrub, orchards and vineyards.
PURPLE	Features added from aerial photographs during map revision. The changes are not field checked.
RED	Important roads and public land survey system.
WHITE	Nonvegetative features such as barren waste areas.

### C. COLOR SYSTEMS AND COLOR NAMING

The human visual system is a trichromatic system, meaning that any color can be produced by a linear combination of any three linearly independent basic colors. This observation can not be explained except that the eye contains three types of cones and color perception depends on the output from these cones. The ability of a color television monitor to produce all colors with only three color components is a consequence of this fact. The paper topographical map is intended for human perception and therefore the color systems used to describe human vision are readily usable for the processing of the digital map image. [Ref. 4: pp. 25-26].

Many color systems have been used to describe color, however the different color systems generally have tradeoffs with the amount of information immediately available to the user. Each color system can readily produce all visible colors. Shifting from one color system to another is generally an isomorphic mapping function. [Ref. 4: pp. 85-88].

The color system used for the EyeCom scanner with red, green and blue filters is the Red, Green, Blue (RGB) color system. For each pixel, three values are assigned ranging from 0 to 255. This value corresponds to the intensity that is utilized to display each color of each pixel of the image. [Ref. 5: pp. 19-20].

The actual pixel image produced by the display of the red, green and blue values may not reflect the original color on the paper map. This depends on the accuracy of the color filters used, and the illumination of the paper map during

the digitization process and the zero and range settings of the EyeCom scanner. The digital image produced can be used to determine color name assignments if the RGB pixel values for a color name are consistent for the whole image. If a pixel is known to be black and has a RGB value of (50,0,0) then all pixels with value (50,0,0) should also be assigned the color name black, regardless that the pixel seems to be predominately red.

This characteristic of the system allows a list of heuristics to be compiled for use in the non-interactive phase of the system for a specific setup of the EyeCom scanner. As long as the EyeCom scanner is consistently setup in the specified manner, those heuristic values will correctly identify color names.

Although the RGB color system is sufficient for the determination of the heuristics to be used in the first phase, it is better to be able to assign a color name to a whole range of values than to specific values. The RGB system allows this setting of heuristic ranges, but for some cases the RGB system provides only small ranges for a color name.

Another color system called the YIQ color system more directly represents the human eye's response to differing colors. It can be produced by a linear combination of the RGB values. The YIQ system takes into account the human eye's response to total intensity changes and the eye's greater response to green.

Y is the "Luminance" of the pixel:

$$Y = .299 R + .587 G + .114 B$$

I and Q are "Chrominance" values of the pixel:

$$I = .596 R - .274 G - .322 B$$

$$Q = .211 R - .523 G + .312 B$$

The Y value roughly corresponds to how bright a pixel appears to the human eye. The I value is a measure of the relation of the amount of red to the amount of green and blue (redness). The Q value is a measure of the relation of the amount of green to the amount of red and blue (purpleness). In the RGB system the additive nature of light is linear for brightness. Adding equal amounts of red, green and blue to a color is thought to produce the same color, only brighter. Since the human eye is normally more responsive to green this isn't necessarily true. [Ref. 4: pp. 85] [Ref. 6: pp. 84-90].

The YIQ system better represents this nonlinear response of the human eye and in most cases allows a better setting of heuristic ranges for phase one color determination processing.

The inverse functions for transforming the YIQ system to the RGB system are:

$$R = Y + .948 I + .624 Q$$

$$G = Y - .276 I - .640 Q$$

$$B = Y - 1.105 I + 1.73 Q$$

(Note: the RGB values must be limited to a range of 0 to 255).



### III. PHASE I MAP PROCESSING

#### A. SYSTEM REQUIREMENTS

In order for the system to provide a phased approach to digital cartographic database production, the following system requirements must be met.

The digitizer used to generate the initial digital image of the map must produce color images with sufficient precision to facilitate subsequent processing.

The first phase computer must be efficient in both speed and memory/disc usage. The large volume of data to be processed, it must provide substantial memory and disc storage space.

The second phase computer must be oriented toward graphical displays of complex polygons and must provide sufficient resolution and editing mechanisms to allow the rapid editing of map images. This computer must also be efficient in both speed and memory/disc usage. Substantial memory and disc storage space must be available.

If preprocessing of the color digital image is required prior to the submission to the first phase, an interactive computer system is necessary. The computer system used for second phase image editing is sufficient to provide this service.

## B. DIGITIZATION PROCESS

The digitizing hardware and software used in this system is a Spatial Data Systems, Inc., EyeCom Scanner connected to a Digital Equipment, PDP-11 Minicomputer. The selection of the digitizing system was based solely on availability, rather than any intrinsic values of the EyeCom Scanner.

The EyeCom is a black and white system that produces a 480 by 640 pixel digital image of the source document. The digital image is stored in a 512 by 640 byte file. All processing of the digital image must compensate for the additional 32 bytes appended to each row of the image. [Ref. 5: p. 11].

The creation of a color image using the EyeCom Scanner is accomplished by using red, green and blue filters placed over the lens of the scanner. This produces red, green and blue files of the scanned image. The three files are merged during processing to produce a color image. The filters used for the system are a Cokin A.003 red filter, a Cokin A.004 green filter, and a Cokin A.020 blue filter.

The standard illumination for the EyeCom Scanner is a light table that produces backlighting. This source of illumination proved unreliable for map image production. The illumination for this system consists of overhead desk lamps using 60 Watt incandescent bulbs.

The red, green and blue files output from the EyeCom Scanner are downloaded to tape for processing on either a VAX-11/780 or Motorola MC68020 based workstation. The actual digitization instructions are contained in the Appendix.

### C. IMAGE PREPROCESSING

After digitization of the source map using the EyeCom Scanner, the three files produced using the red, green, and blue filters are merged into a data structure that not only captures the color of the pixel image, but also corrects for the inconsistencies of the independent filter image production.

One of the major problems encountered with the digitization of three separate images using differing filters is that the three digital images produced are usually offset in some manner producing a blurring effect. This is attributed to the manual changing of the filters and the inability to attach the filters to the lens in a consistent manner with the plane of the filter parallel to the source map and normal to the lens-to-source axis. This results in the actual row-column coordinates of a single pixel being shifted left-right and/or up-down from filter image to filter image.

To partially compensate for the offset problem an interactive process is executed on the three filtered files to better align the three digital images as indicated in Figure 3.1. Some error still exists after processing due to the integer-value shifting of the filter images and the actual real-valued offset values.

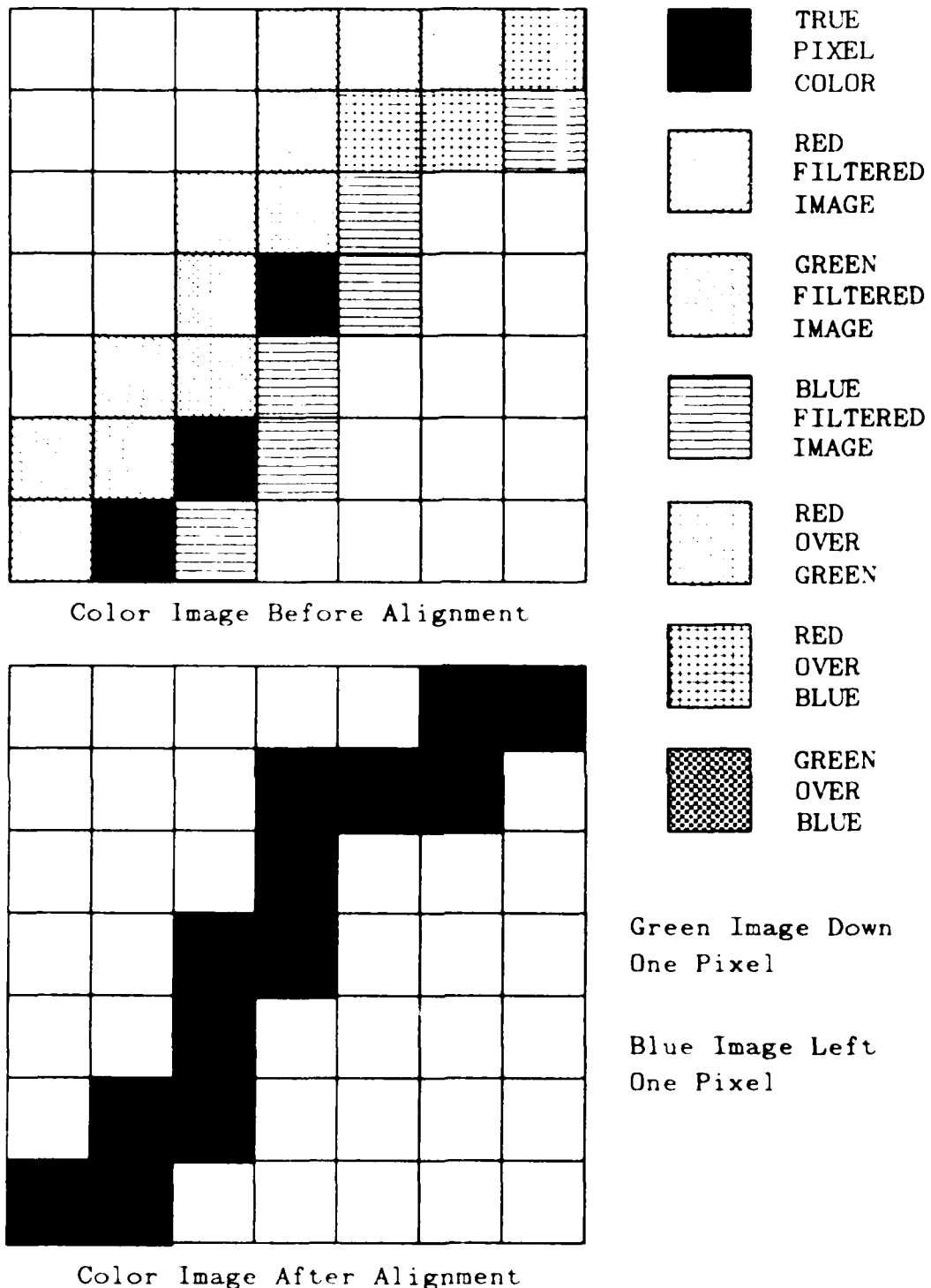


Figure 3.1 - Preprocessing for Filter Image Alignment

For the interactive preprocessing a Silicon Graphics Inc., IRIS Turbo 2400 Graphics Workstation is utilized to display the digital map image, determine the shift values needed to properly align the images, and to accomplish the alignment process.

On completion of the filter image alignment, the digital image is a very close rendition of the source map except for some blurring of edges.

#### D. PHASE ONE OVERVIEW

After the digital images have been created and aligned the input is ready for the phase one processing program. This program is outlined in Figure 3.2 and is designed to systematically refine the color determined map starting with the use of heuristic parameters to initialize positively identifiable pixels. After the color determined map is completely defined, it is used as input to a subroutine that groups areas of uniformly colored pixels into polygons and subsequently produces the polygonal map representation file.

#### E. INITIAL PIXEL NAMING

Once the three image files have been corrected for alignment, phase one continues with the second part of processing. The second part is the initial name identification using RGB and YIQ heuristic parameters. This process is the primary source of all subsequent processing and as such plays a vital role in the overall performance of the system. The setting of the heuristic parameters is best

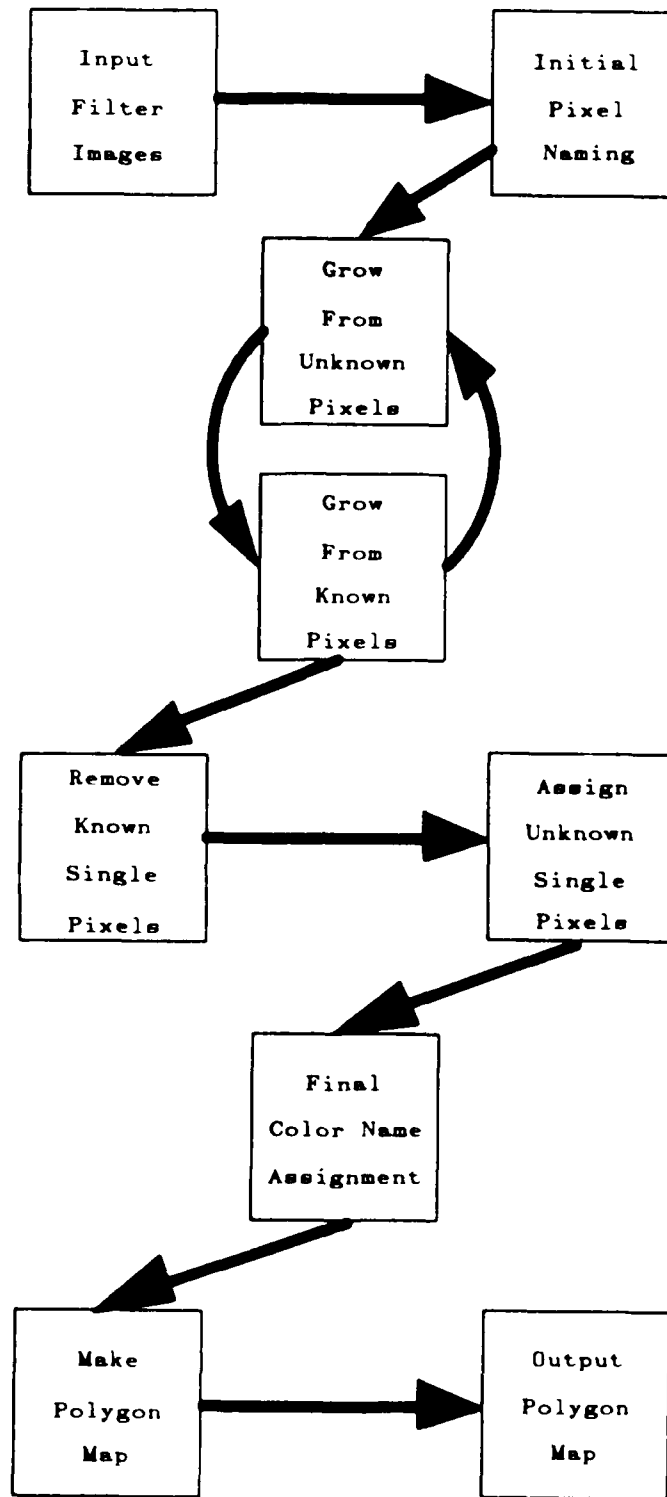


Figure 3.2 - Phase I Processing

accomplished interactively by adjusting the RGB and YIQ parameters to correctly identify pixels, without incorrectly naming any pixels.

The initial determination of heuristic values is accomplished interactively on a Silicon Graphics Inc., IRIS Turbo 2400 Graphics Workstation. Gross parameters are initially selected and the digital map is passed through the sieve to determine the color names, and the color determined map is displayed on the graphics terminal for verification. The parameters are then adjusted to remove any incorrectly named pixels and to name those pixels that can be positively identified. This procedure is repeated until no adjustments are possible to further refine the initial naming process. Depending on the consistency of the illumination used for digitization, the alignment of the three filter images, and the resolution of the video digitizer the color determined map is usually more than 50 percent complete after the completion of this initial process.

Once the heuristic parameters have been identified they remain unchanged for all future processing of images using the same setup of the EyeCom scanner. The heuristic parameters obtained above are used as a sieve in the the initial color naming process:

Example Algorithm:

for each pixel

color is UNKNOWN  
total = R + G + B

determine Y  
determine I  
determine Q

case total of:

0 to 29 ==> color is BLACK

30 to 59 if Y < 25

==> color is BLACK

end if

510 to 539 if Y < 180 and

Y > 160 and

I < -25 and

I > -50 and

Q < 0 and

Q > -35 and

(Q+I) > -5

==> color is BLUE

end if

elseif Y < 185 and

Y > 170 and

I < 50 and

I > 30 and

Q < 10 and

Q > -20

==> color is BROWN

end elseif

elseif Y < 190 and

Y > 175 and

I < 20 and

I > 10 and

Q < -15 and

Q > -30

==> color is GREEN

end elseif



540 to 569 if Y = 190 and

end case  
end\_for

## F. REGION GROWING

The remainder of the first phase processing is non-interactive and is executed on either the Silicon Graphics Inc., IRIS Turbo 2400 Graphics Workstation or on a Digital Equipment Corporation, VAX-11/780.

Once the initial color determined map is produced, phase one continues with a battery of region growing routines to assign colors to pixels remaining undetermined from the initial pixel naming process. Two region growing routines are used. Both routines function similarly but one determines new pixels given a single known pixel, and the other takes a single unknown pixel and determines its color depending on the determined color of the pixels in the immediate vicinity. [Ref. 7; pp. 68-69].

### 1. Growing From Known Pixels

The first region growing routine (grow from known) grows from already determined pixels. Each invocation of this subroutine includes a parameter list that are region growing heuristics for the color of the pixels to be grown (see below). A comparison is made between the known pixel and each adjacent

unknown pixel. If the comparison is within the parameters assigned by the routine, then the unknown pixel is changed to the color of the unknown pixel.

Comparison parameters passed as arguments to this routine are:

- |   |   |
|---|---|
| Color:                                  | The color of the known pixel from which region growing is to proceed.   |
| Maximum Red Difference:                 | If the difference between the red value of the known pixel and the red value of the unknown pixel being tested is less than the Maximum Red Difference then the unknown pixel may be the same color as the known pixel.       |
| Maximum Green Difference:               | If the difference between the green value of the known pixel and the green value of the unknown pixel being tested is less than the Maximum Green Difference then the unknown pixel may be the same color as the known pixel. |
| Maximum Blue Difference:                | If the difference between the blue value of the known pixel and the blue value of the unknown pixel being tested is less than the Maximum Blue Difference then the unknown pixel may be the same color as the known pixel.    |
| Maximum Intensity of the Unknown Pixel: | If the unknown pixel's intensity is less than the Maximum Intensity of the Unknown Pixel the unknown pixel may be the same color as the known pixel. (intensity = $R + G + B$ )   |
| Minimum Intensity of the Unknown Pixel: | If the unknown pixel's intensity is greater than the Minimum Intensity of the Unknown Pixel the unknown pixel may be the same color as the known pixel. (intensity = $R + G + B$ )  |

After execution of this routine a "scratch pad" copy of the color determined map is made with "1"s for those pixels that are known to be the desired color and "0"s for those pixels that are either unknown or not the desired color. The scratch pad copy is maintained to ensure that every previously named pixel is investigated and indicates when all named pixels have been investigated, terminating the routine.

Using the above scratch pad copy and the color determined map the following occurs:

1. Each pixel of the color determined map is queried sequentially to determine if a "1" exists in the scratch pad (a named pixel).
2. If a "1" exists in the scratch pad, the scratch pad value is changed to "0", and the pixel is submitted to a recursive subroutine for region growing.
3. The recursive subroutine checks each adjacent pixel to determine if it has been previously named.
4. If the adjacent pixel has not been named, the named pixel and adjacent pixel are compared to determine if the adjacent pixel is within the prescribed parameters.
5. If the adjacent pixel is within the prescribed parameters, the color of the adjacent pixel is set to that of the named pixel, a "1" is inserted in the scratch pad for the adjacent pixel, and a recursive call to the subroutine is made using the newly determined pixel as the previously named pixel.
6. If the adjacent pixel is not within the prescribed parameters, it remains unknown and the next adjacent pixel to the previously named pixel is tested.

7. If the adjacent pixel is found to be previously named, the scratch pad copy is tested for a "1" at the corresponding pixel. If there is a "1" in the scratch pad a recursive call is made using that adjacent pixel as the previously named pixel.
8. When all adjacent pixels of a previously named pixel are tested step #1 is continued.
9. When the last pixel in the scratch pad has been tested, the process either terminates, if the scratch pad is all "0"'s, or step #1 is restarted, if there exists "1"'s in the scratch pad. (a scratch pad counter is maintained for this purpose).

## 2. Growing From Unknown Pixels

The second region growing routine attempts to determine an unnamed pixel's color by comparing it to the pixels in its immediate vicinity. The immediate vicinity is defined by a radius passed to the routine as a parameter. The pixel comparison is similar to that used in the grow from known routine. However, the unnamed pixel's color is determined by the pixel in the immediate vicinity that has the red, green and blue values closest to the unnamed pixel's red, green and blue values.

The routine functions as follows:

1. Each pixel of the color determined map is queried sequentially to determine if it is unnamed.
2. If a pixel is unnamed (target pixel), each pixel within the specified radius is compared to the target pixel starting from the furthest pixels within the radius and proceeding to the closest neighboring pixels. The furthest pixels within the radius are compared first because if two pixels of differing color name generate identical comparison values then the closest named pixel's color is the preferred color and therefore must be assigned to the target pixel.

3. If the neighboring pixel is named and it differs from the target pixel by a value less than or equal to those pixels previously compared, then the target pixel is tentatively assigned the color of the named pixel.
4. If the neighboring pixel is also unnamed and it differs from the target pixel by a value less than or equal to those pixels previously compared, then the target pixel is tentatively assigned a color name of unknown. This prevents the target pixel from being assigned an inaccurate color name when other unnamed pixels within the radius may later be assigned accurate color names.
5. When all pixels within the radius have been compared, the target pixel is permanently assigned the tentative color name if it is not unknown.
6. When all unnamed pixels within the color determined map have been processed the process starts over at step #1 if any unnamed pixel has been named during the cycle. If no pixel has been named during the cycle, then the process terminates.

#### G. REMOVAL OF SINGLE KNOWN PIXELS

Due to the high resolution used for map digitization and the relative small ground area represented by a single pixel (about 2 ft by 2 ft), pixel area orientations that represent a single pixel object or a linear object of only one pixel width are useless for autonomous vehicle route planning. A routine to remove these single named pixel areas is used as exemplified in Figure 3.3. On invocation, the color determined map is repeatedly scanned to determine if a named pixel is a single pixel case. This routine continues as long as changes occur and terminates after scanning the whole map without change.

- Any Known Pixel
- ▨ Any Known Pixel  
Other Than Color  
of ■
- ▩ Any Pixel
- Unknown Pixel

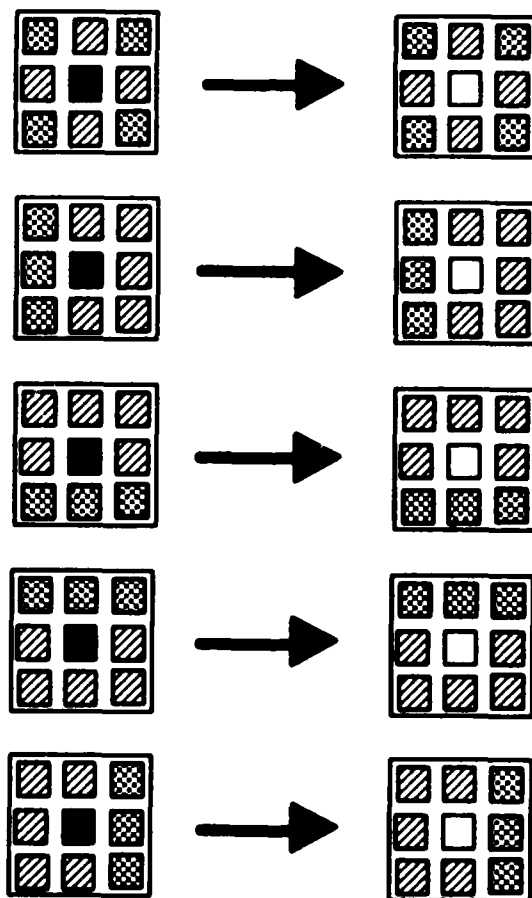


Fig. 3.3 - Removal of Single Known Pixels

## H. ASSIGNMENT OF SINGLE UNKNOWN PIXELS

As explained above, the occurrence of a single pixel object or single pixel wide linear object is neither necessary nor desired. In those cases where a single pixel is unnamed and its orientation (see Figure 3.4) leads to only two possible cases, either a single pixel known, discussed above, or it being assigned the same color as its immediate neighboring pixels, it is assigned the color of its neighbors. A routine to assign color names to those pixels identified as single unknown pixels is utilized to further enhance the color determined map. This routine repeatedly scans the color determined map to identify those unknown pixels that fall within the identified cases. This routine continues as long as changes occur and terminates when no unnamed pixel is assigned a color name during a pass through the map.

## I. FINAL COLOR NAME ASSIGNMENT

On completion of all region growing, single known pixel removal and single unknown pixel name assignment, the color determined map is predominately complete. However, some pixels are still unknown primarily due to the "fuzzy edge" effect produced during the digitization process. The final routine executed on the map is identical to region growing from unknown pixels discussed above, except that other unnamed pixels within the radius of the target unnamed pixel are ignored. This results in every unnamed pixel being assigned a color name depending on the named pixels surrounding it.

Known Pixel Color  
  Any Pixel  
  Unknown Pixel

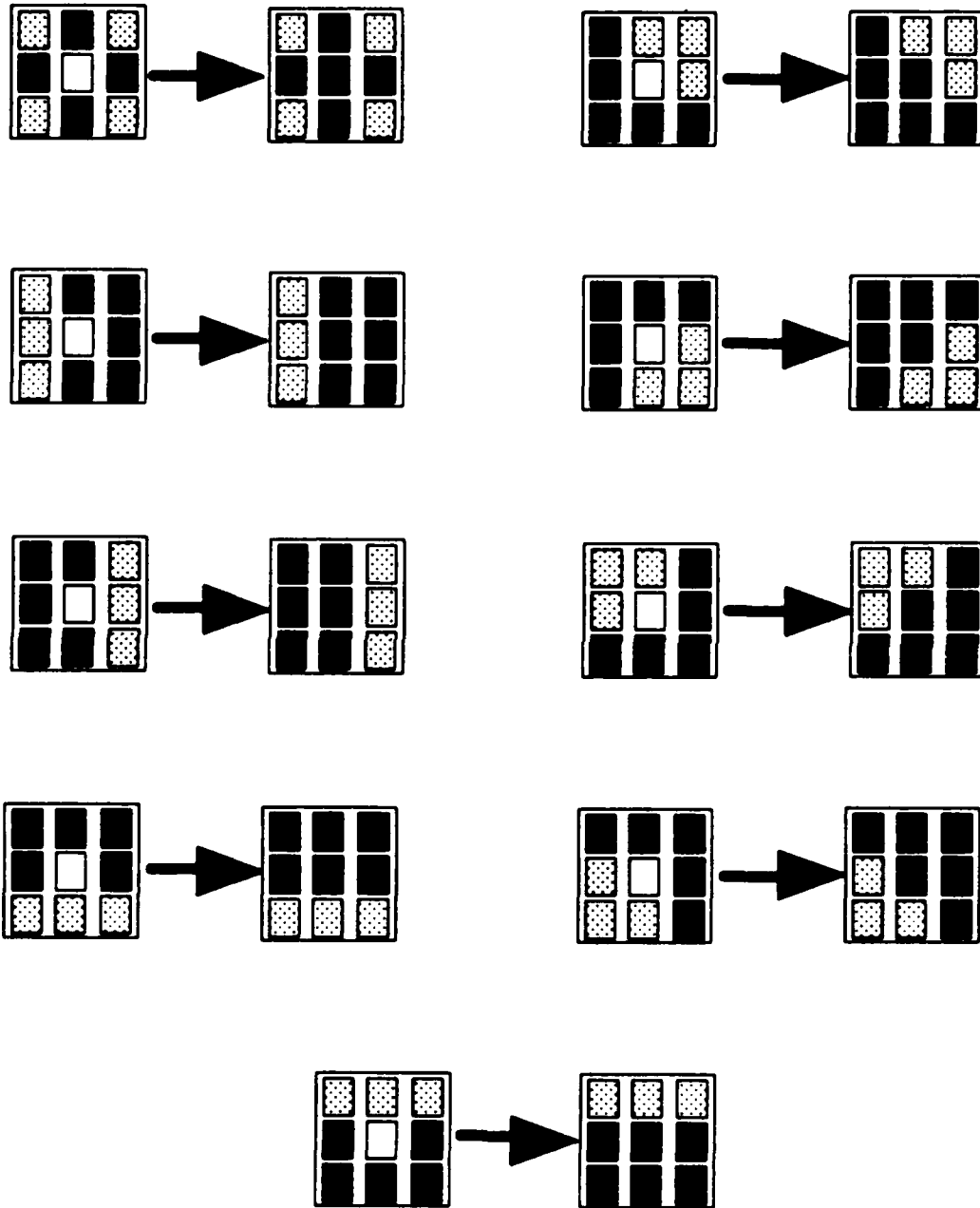


Fig. 3.4 - Assignment of Single Unknown Pixel



## J. POLYGONAL MAP PRODUCTION

### 1. General

Once every pixel has been assigned a color name, the color determined map is processed to generate a polygonal map representation. For this process a simplistic approach is taken to decrease execution time and to ensure that every polygon produced is convex.

After subroutine execution at the start of the polygonization subroutine, a duplicate pixel array, hereafter referred to as a "scratch pad", is created consisting of all "0"'s. This scratch pad copy is utilized to store the image of a single group of equally named pixels during processing.

The color determined map is scanned sequentially to find a named pixel that has not been used previously in a group. When an unused pixel is found, it is marked as used, the corresponding element of the scratch pad is set to "1" and the pixel is submitted to another subroutine, described below, for group determination.

Once the group has been determined and a copy of it is stored in the scratch pad, the scratch pad group is submitted to a subroutine, described below, for division into non-intersecting, triangles, lines and points and subsequent inclusion in the polygonal map file.

### 2. Color Group Determination

A color group is an area of pixels with the same name that have at least one vertex in common with any other pixel in the group. The color determined

map is divided into color groups by a subroutine that sequentially scans the color determined map for a pixel that is not already in a group. Once a pixel has been found, it becomes the first member of a new group, the pixel is marked as used, and then a call to a recursive subroutine is made on all immediate neighbors with the same color name that have not been used in a group. As a neighbor is found to be the same color and not part of a previous group, it becomes a member of the new group, the pixel is set to used, a "1" is placed in the corresponding scratch pad element, and the subroutine recurses on that pixel's immediate neighbors. This process continues until no other elements of the group are identified.

### 3. Polygon Generation

Each group is submitted to a subroutine that divides the group into a series of non-intersecting equilateral right triangles, lines and points as depicted in Figure 3.5. This is accomplished by scanning the group from left-to-right and from top-to-bottom. In this way, there are only five categories of equilateral right triangles, four categories of lines and one category of points. Each successive pixel in the group and its immediate neighbors are tested against the ten possible pixel configurations. Each configuration identifies the type of triangle, line or point that is to be generated. For each configuration, a subroutine is called that determines the maximum size of the triangle, line or point allowable for the group.

■ Specified Pixel Color

□ Other Pixel Colors

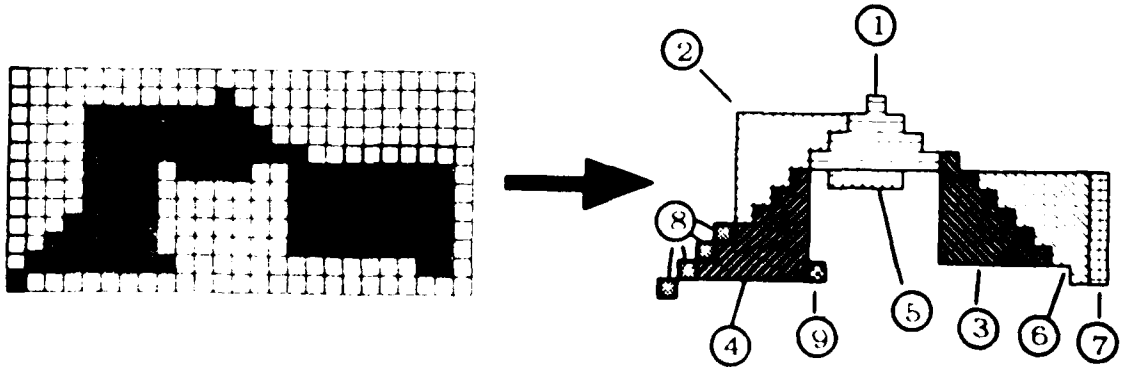
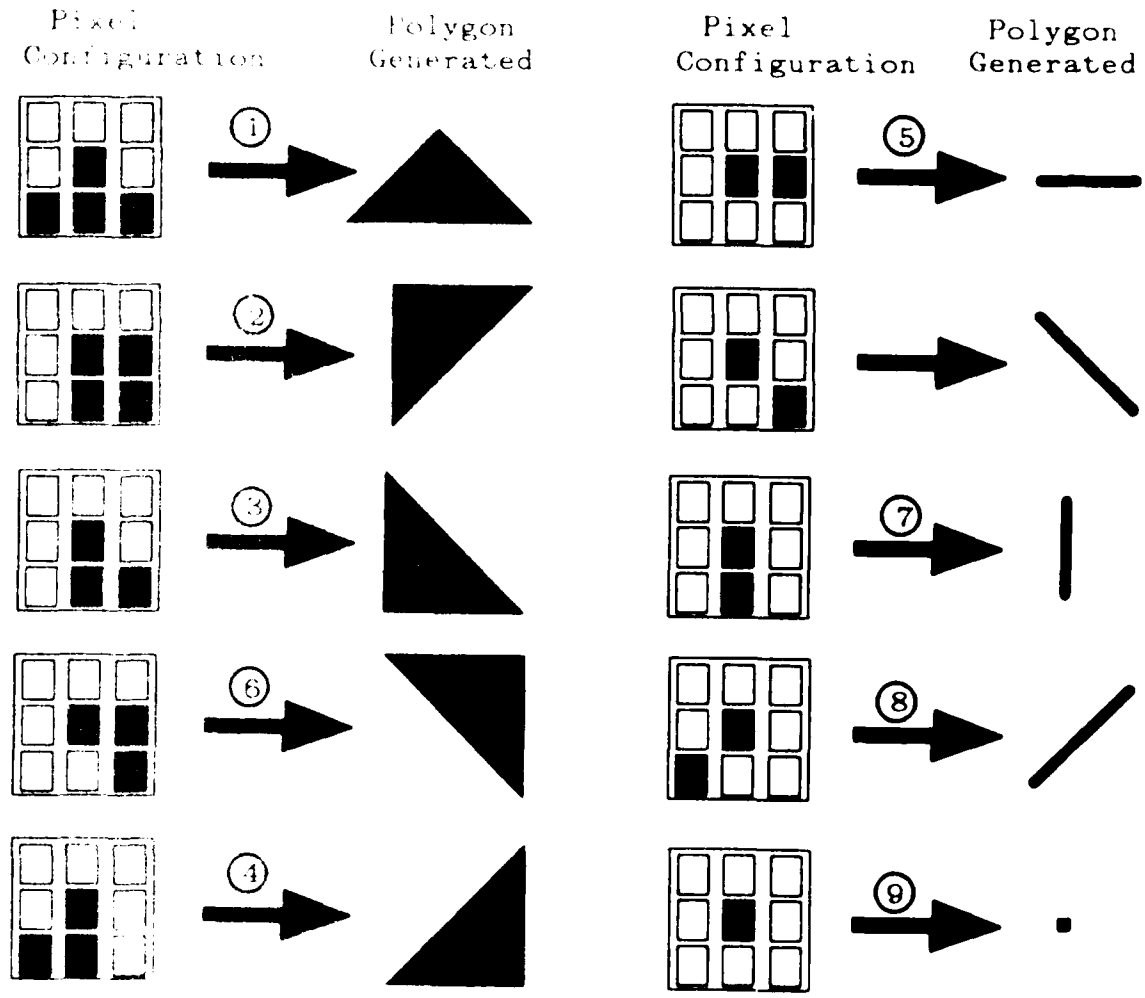


Fig. 3. Polygonal Map Generation

On completion, the triangle, line or point is added to the polygon map file and those elements in the scratch pad that are defined by the polygon, line or point are set to "0" and removed from the group.

4. Polygon Map Format

The polygon information generated is appended to the polygon map file for use in phase two processing. This file is designed to be not only useful for editing purposes but also useful in autonomous vehicle route planning. The format for the polygon map file is:

1. Group Color Code
2. Group Description Code
3. Group Speed Value
4. Type (polygon, line, point). Vertices (coordinate pairs)  
    . (as many type-vertex entries as need for the group)  
    .  
    .
5. End of Group Marker

## IV. RESULTS AND RECOMMENDATIONS

### A. INITIAL PIXEL NAMING

The use of heuristic values to initially determine a sufficient number of pixel names adequately provides a basis for region growing. The actual determination of the heuristic values is best described as a refinement process, predicated on the specific setup of the video digitizer. The more map images used to determine the heuristics the better the correctness of any one random image processed through phase one.

The greatest limitation of the initial pixel naming process is the clarity and consistency of the red, green and blue images produced by the video digitizer.

#### 1. Resolution

It is necessary to have at least a resolution of 500 pixels per inch to determine the fine detail found in USGS 1:24,000 maps. This is the minimum resolution that effectively produces adequate final products. A resolution greater than this is desirable because the greater resolution will substantially decrease the "fuzzy" edge effect caused by area sampling of the paper map. This allows a broader range of heuristics to be used for the initial pixel naming.

## 2. Filter Alignment

The alignment of the red, green and blue images produced by the video digitizer is another factor influencing the "fuzzy" edge effect. Misalignment of the images causes a significant amount of image blurring adversely effecting the ability to assign heuristic values. This alignment problem can be partially corrected by an interactive preprocessing routine designed to align the three images. However, this is time consuming and must be executed on every digital map representation produced. A concerted effort to align the actual color filters properly before digitization will produce a better resultant map representation and will need to be accomplished only once.

## 3. Lens Spherical Aberration

Spherical aberration of the digitizer lens is a problem that can only be minimized through the procurement of a quality video digitizer. Spherical aberration plays a greater part in the overall system's success when the lens must be positioned close to the paper map. The need to lower the digitizer lens close to the paper map is again dependent on the resolution of the video digitizer. A 1600 by 1600 resolution digitizer can be positioned more than twice as far away from the paper map and still provide the 500 pixels per inch resolution needed to provide detail, compared to a 480 by 640 resolution digitizer that must be positioned a mere few inches away from the paper image. The closer the lens is to the paper map the greater the angle is between the sample area and the lens-paper central axis. Pixels positioned at the extremes of the digital image may

have to be removed before processing due to the spatial and red, green and blue value inaccuracies. The 480 by 640 resolution video digitizer used in this thesis required that the lens be positioned approximately three inches from the paper map surface to maintain the 500 pixel per inch resolution, resulting in the necessary discard of all but the center 280 by 440 pixel map image.

#### 4. Illumination

The majority of phase one processing relies on the ability of the digitization process to provide consistent red, green and blue values for similarly colored pixels. This ability is strongly affected by the light sources used to illuminate the paper map during digitization. A standardized light source must be used for map illumination and must be tested frequently for consistent illumination. A darkroom to prevent random light sources (i.e., room lights) from interfering with the digitization process is necessary.

#### 5. Focus

Focus is also important to the digitization process to minimize image blurring and to provide consistent map values. This is usually not a problem. However, focus must be strictly maintained.

#### 6. Recommended Digitization Station

The digitization station must provide the following:

- a. Located in a darkroom like those used for photography.
- b. The video digitizer must be high quality with:

- (1) High resolution.
  - (2) Minimal lens spherical aberration.
  - (3) Fine focusing, height, and aperture adjustments.
  - (4) Automatic red, green and blue image generation.
  - (5) The filters must be linearly independent colors.
  - (6) Fine adjustment of filter alignment.
  - (7) Excellent linear frequency response for visible light.
- c. The light source must provide consistent illumination of the paper map and provide light frequencies similar to that of sunlight. This source must be circular in shape and centered around the digitizer lens to provide consistent lighting.
  - d. The video digitizer and paper map platen must be relatively vibration free. Damping pads under the supports for the digitizer are needed to reduce vibrations.
  - e. The entire system must be able to be locked into position once the heuristics for the initial pixel naming have been determined. Any changes in video digitizer setup may destroy the correctness of the initial naming heuristics. Once the digitizer setup is locked in place, the user need only insert the paper map on the platen and start the digital image generation process.

## B. REGION GROWING

The subroutines used for region growing are consistently able to resolve most pixel name assignments based on the pixels selected in the initial naming process. As discussed in the previous section, the initial pixel naming process is significantly influenced by the digital images produced by the video digitizer.



Since region growing is based on the initial naming process, any inaccuracies created by the initial naming process are further aggravated by region growing.

The heuristic parameters used in the region growing routines are relatively general in nature. However, the refinement of these parameters for the specific video digitizer setup is needed to insure correctness of the rendered image and to improve processing speed.

### C. REMOVAL/ASSIGNMENT OF SINGLE PIXELS

The removal of single known pixels and assignment of single unknown pixels is not necessary to the overall effectiveness of the phase one process. However, depending on the resolution at which the image was digitized, the inclusion of these single pixel areas is normally inaccurate and adversely effects the size of the polygonal map database as all information (color, description, speed, etc.) must be maintained for the single pixel area. Since single pixel areas are insignificant and usually inaccurate, the inclusion of them in the database also adversely effects the phase two processing time as each of these pixels must be corrected interactively. Further, the single pixel area represents a corresponding ground area of approximately 2 feet in diameter when the map is digitized at a resolution of 500 pixels per inch. Since the polygonal maps produced by this system are to be used for autonomous vehicle route planning, the inclusion/exclusion of such a small area in the database neither aids nor hampers the determination of optimal routes.

#### D. FINAL COLOR NAME ASSIGNMENT

Due to the misalignment of the color filters and the discrete area sampling of the video digitizer, region growing will not be able to determine all pixel names. Some pixels, particularly those around black named pixels, take on totally different values than of the pixels surrounding them. In this case, one of two alternatives are feasible. Either allow the unknown pixels to remain as unknown and assign their color names during the interactive phase two processing, or assign the remaining unknown pixels a color name based on which named pixel in their immediate vicinity has the most similar red, green and blue values. The later solution was taken to this problem. The usefulness of the polygonal map image to autonomous vehicle route planning doesn't necessitate the perfect naming of every pixel. However, if pixels are left as unknown, the route planning algorithm has to take into account the uncertainty as to what the pixels represent, or the pixels must be interactively named in phase two. The individual naming of pixels in phase two is a repetitious, and undesirable activity. The correction of any pixels misnamed by the final color name assignment requires less attention, since most pixels are correctly named. In addition, the size of the polygonal map database is adversely affected by allowing unknown pixels since many of these represent very small areas.

## E. POLYGONAL MAP PRODUCTION

The polygonal map production subroutine used proved extremely fast. It satisfactorily compressed the map information into an easily managed database. The information contained in the database is sufficient for currently anticipated autonomous vehicle route planning. It also provides flexibility for the addition of other database information due to its group record format. Although better algorithms can be used for polygon production, the speed of this subroutine provides easy use and reasonable data compression, with very little processing time.

## F. PHASE ONE FINAL RESULTS

Figures 4.1a and 4.1b are printouts of the Corral de Tierra color determined map immediately after the initial pixel naming. The initial pixel naming subroutine has sparsely named many of the pixels in the map. The black pixel map and white pixel map are better defined primarily due to their existence at the lowest and highest extremes of the color spectrum. These are the easiest to determine heuristic values for initial pixel naming. The blue, green and brown pixel maps are very sparsely populated due to the difficulty of determining value heuristics that not only select the correct pixels, but correctly fail to select those pixel colors that are the result of filter misalignment and discrete sampling. This "fuzzy edge" effect is the greatest obstacle to rapid, accurate color determined map images. The correct absence of identified pixels in the purple and red maps

is due to the absence of any red and purple areas in this map section. The data for the initial naming of the Corral de Tierra map segment are contained in Table 4.1.

Figures 4.2a and 4.2b are printouts of the Corral de Tierra map segment after one pass through the region growing subroutines. Each color has been significantly improved, but numerous pixels remain unknown. Of particular note is the relatively complete white map. Although most of the white pixels have been determined, numerous small areas still remain unknown. The data for the Corral de Tierra map segment after the first pass of region growing are contained in Table 4.2.

The color determined map of Corral de Tierra, after completion of region growing, is contained in Figures 4.3a and 4.3b. At this point most of the pixel names have been determined and few unnamed pixels remain. Those pixels that are still unknown are primarily due to filter image misalignment and discrete sampling. On inspection of the green, brown, white and unknown images, the occurrence of singleton unknown pixels are observed. Many of these unknown pixels will be changed to the same color as their surrounding neighbors during the removal/assignment of single pixels process. The data for complete region growing are contained in Table 4.3.

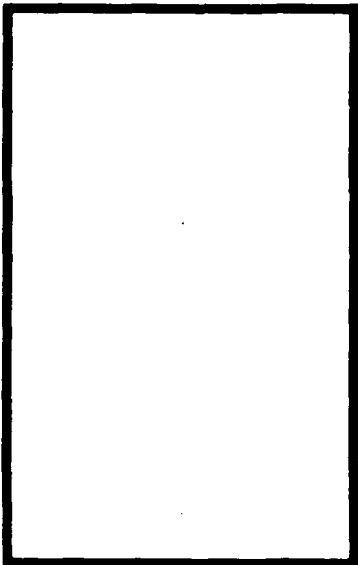
Figure 4.4a and 4.4b are the color determined images for the Corral de Tierra map segment after removal single known pixels and assignment of single unknown pixels. Few pixels remain unnamed after this process. Those that are still

unknown are totally due to filter image misalignment and discrete sampling. At this point either the color determined map can be used as is and the editor can be used to assign the unnamed pixels their proper color name, or as presented here, the color determined map can be further processed to name all remaining unnamed pixels. This final process may produce incorrectly named pixels that must be renamed by phase two, however, the majority of the unnamed pixels will be correctly named. The data for the Corral de Tierra map segment after completion of the single pixel removal and assignment are contained in Table 4.4.

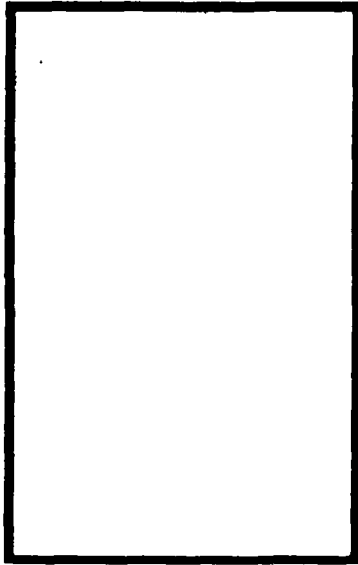
The final output of the Corral de Tierra map segment is contained in Figure 4.5a and 4.5b. During the final process of phase one, the unnamed pixels remaining in the color determined map are compared to their immediate neighbors and are assigned the color name of the neighbor best resembling the unknown pixel. In each color map of Figures 4.5a and 4.5b, careful inspection will reveal the occurrence of thin, short lines extending from some areas. This inaccuracy results from the blurry edges at the interfaces to these areas. Another inaccuracy is observable in the brown map printout. Between the middle and upper arm of the "E", the contour lines are merged into one solid brown area. This too is a result of edge blurring. Small, light areas surrounded by dark areas are significantly reduced or, in this case where brown contour lines surround small white areas, are totally eliminated. These two types of errors are easily discovered and corrected by the phase two editing process.

Process data for the Corral de Tierra map segment after completion of phase one processing are contained in Table 4.5.

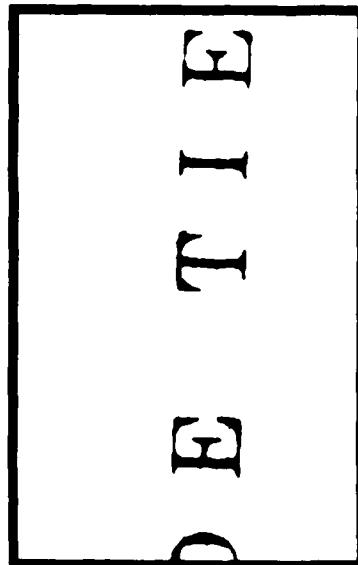
The final polygonal map representation produced by phase one is identical to Figures 4.5a and 4.5b. Table 4.6 contains relative data to the generation of the polygonal map representation of the presented Corral de Tierra map segment. Of particular importance is the reduction in storage with the increase in information maintained. Each pixel represented has associated with it a color code (2 bytes), description (6 bytes), speed (2 bytes), group, and sub-area. Depending on the relative complexity of the map segment the storage requirement will correspondingly change. However, due to the intrinsic grouping of pixels on topographical maps, at no time will the size of the database for a map segment reach the 369,600 bytes required to store the original digital map image.



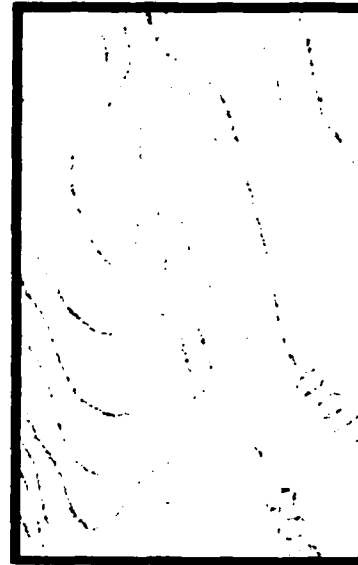
**BLUE**



**GREEN**

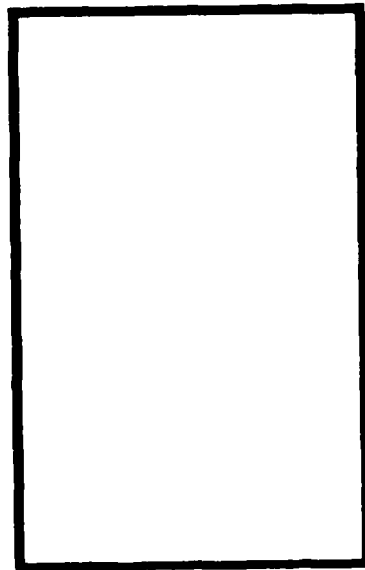


**BLACK**



**BROWN**

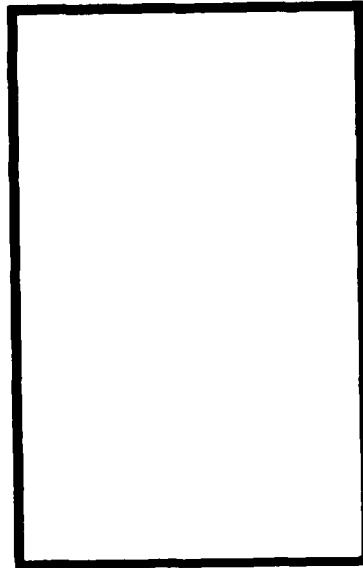
Figure 4.1a - Corral de Tierra Map After Initial Pixel Naming



**RED**



**UNKNOWN**



**PURPLE**



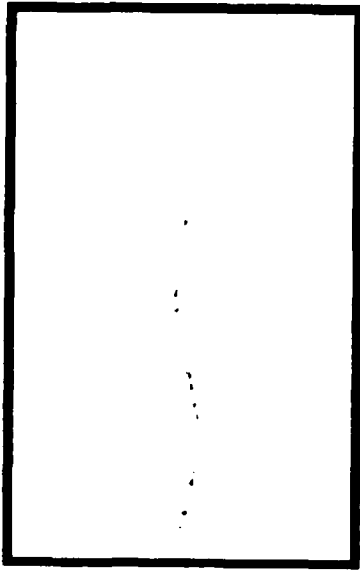
**WHITE**

**Figure 4.1b - Corral de Tierra Map After Initial Pixel Naming**

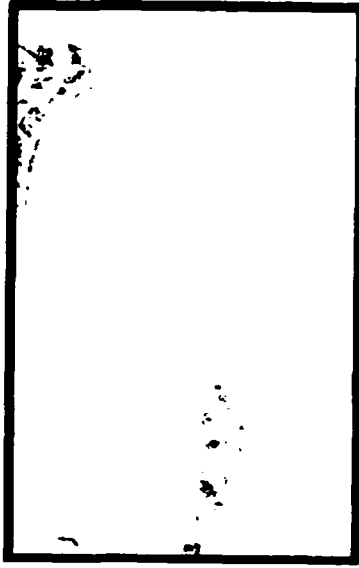


**TABLE 4.1**  
**DATA FOR CORRAL DE TIERRA MAP**  
**AFTER INITIAL PIXEL NAMING**

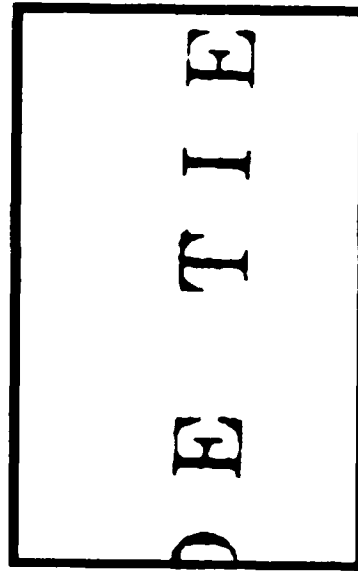
<b>COLOR</b>	<b># PIXELS NAMED</b>	<b>% PIXELS NAMED</b>
BLACK:	3,675	2.98 %
BLUE:	93	.08 %
BROWN:	3,880	3.15 %
GREEN:	419	.34 %
PURPLE:	0	.00 %
RED:	0	.00 %
WHITE:	39,339	31.93 %
UNKNOWN:	75,794	61.52 %
TOTAL:	123,200	100.00 %
Processing Time:	IRIS-2400	1.78 secs
for Initial Naming	VAX 11/780	5.34 secs
Processing Time:	IRIS-2400	2.00 secs
TOTAL	VAX 11/780	6.76 secs



**BLUE**



**GREEN**

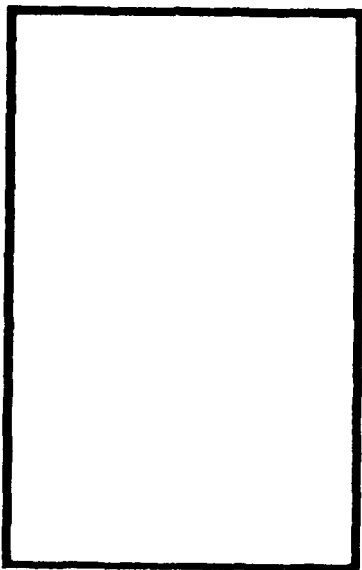


**BLACK**



**BROWN**

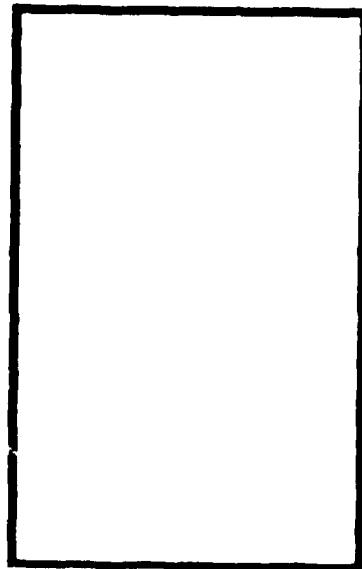
Figure 4.2a - Corral de Tierra Map After One Pass Through Region Growing



RED



UNKNOWN



PURPLE



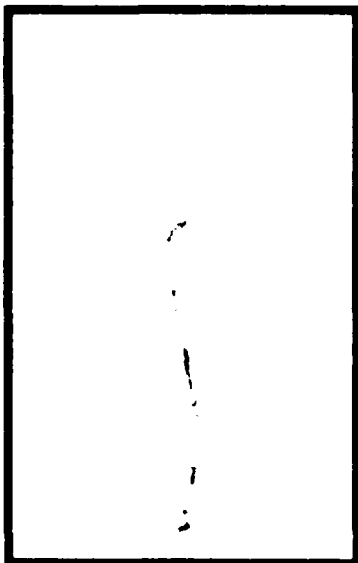
WHITE

Figure 4.2b - Corral de Tierra Map After One Pass Through Region Growing

**TABLE 4.2**

**DATA FOR CORRAL DE TIERRA MAP AFTER  
ONE PASS THROUGH REGION GROWING**

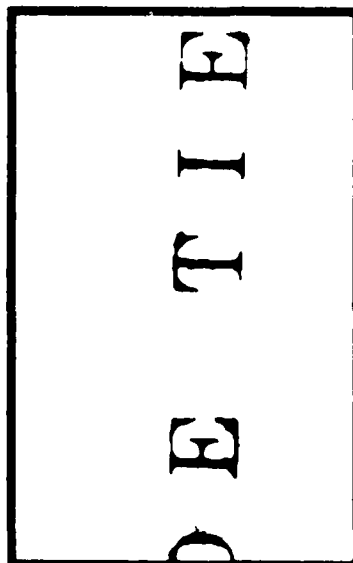
<b>COLOR</b>	<b># PIXELS NAMED</b>	<b>% PIXELS NAMED</b>
BLACK:	3,783	3.07 %
BLUE:	189	.15 %
BROWN:	9,332	7.57 %
GREEN:	1,689	1.37 %
PURPLE:	0	.00 %
RED:	0	.00 %
WHITE:	64,600	52.44 %
UNKNOWN:	43,607	35.40 %
TOTAL:	123,200	100.00 %
Processing Time: for First Pass	IRIS-2400  VAX 11/780	47.34 secs  336.25 secs
Processing Time: TOTAL	IRIS-2400  VAX 11/780	49.60 secs  344.03 secs



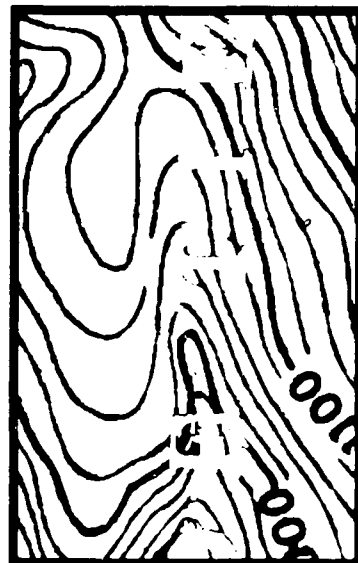
BLUE



GREEN

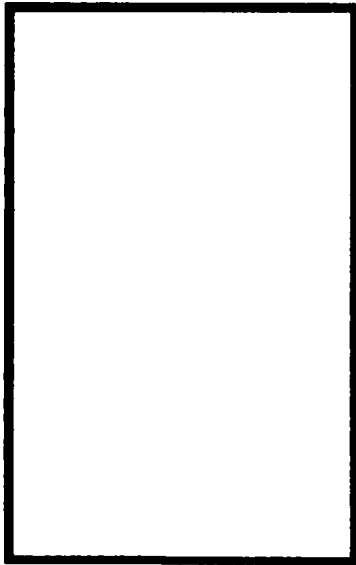


BLACK

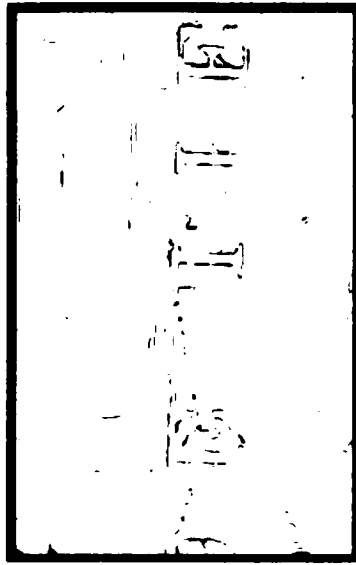


BROWN

Figure 4.3a Corral de Tierra Map After Completion of Region Growing



RED



UNKNOWN



PURPLE



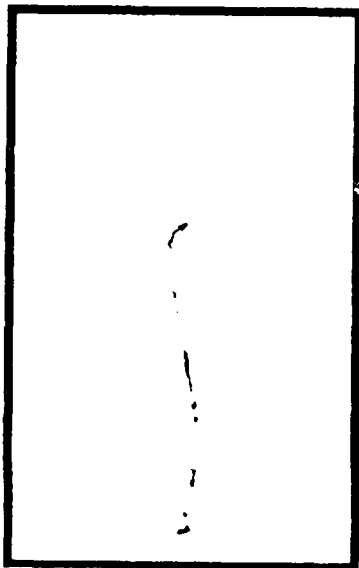
WHITE

Figure 4.3b - Corral de Tierra Map After Completion of Region Growing

TABLE 4.3

DATA FOR CORRAL DE TIERRA MAP  
AFTER REGION GROWING

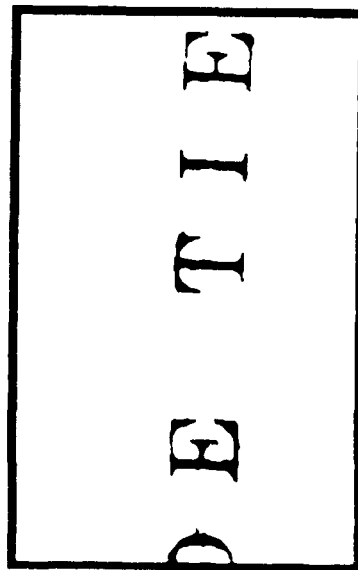
COLOR	# PIXELS NAMED	% PIXELS NAMED
BLACK:	4.074	3.31 %
BLUE:	510	.41 %
BROWN:	27.349	22.20 %
GREEN:	7.213	5.85 %
PURPLE:	0	.00 %
RED:	0	.00 %
WHITE:	81.017	65.76 %
UNKNOWN:	3.037	2.47 %
TOTAL:	123.200	100.00 %
Processing Time:	IRIS-2400	75.39 secs
for Region		
Growing	VAX 11/780	507.85 secs
Processing Time:	IRIS-2400	77.65 secs
TOTAL	VAX 11/780	515.63 secs



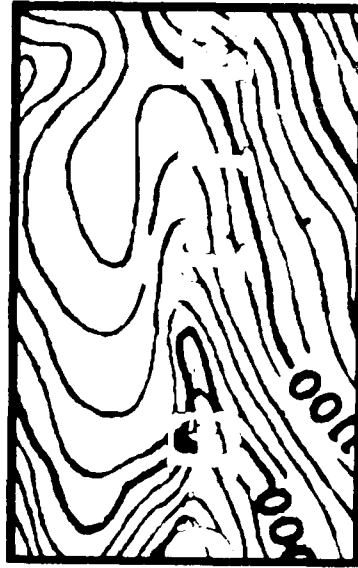
BLUE



GREEN



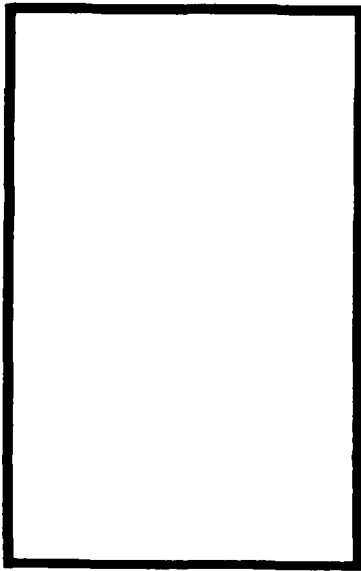
BLACK



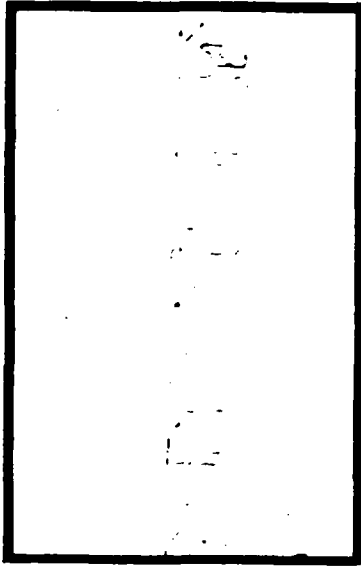
BROWN

Figure 4.4a - Corral de Tierra Map After Removal/Assignment of Singleton Pixels

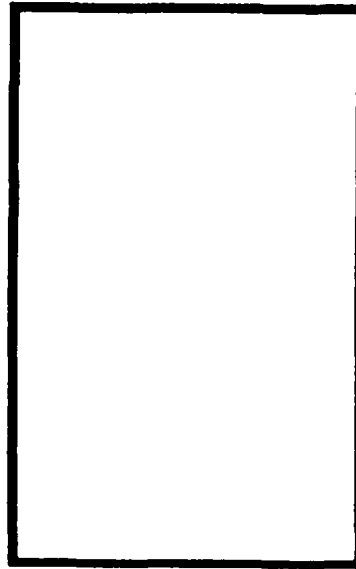




**RED**



**UNKNOWN**



**PURPLE**



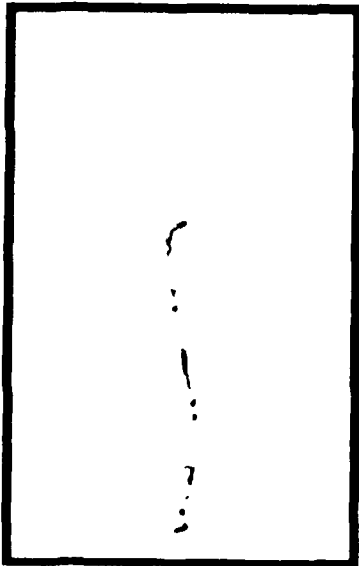
**WHITE**

Figure 4.4b Corral de Tierra Map After Removal/Assignment of Singleton Pixels

**TABLE 4.4**

**DATA FOR CORRAL DE TIERRA MAP AFTER  
REMOVAL/ASSIGNMENT OF SINGLETON PIXELS**

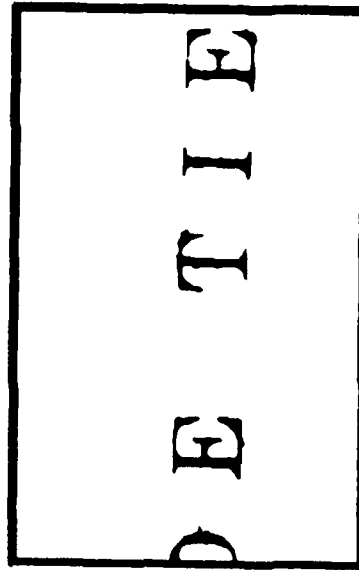
<b>COLOR</b>	<b>PIXELS NAMED</b>	<b>% PIXELS NAMED</b>
BLACK:	4,095	3.32 %
BLUE:	555	.45 %
BROWN:	27,740	22.52 %
GREEN:	7,432	6.03 %
PURPLE:	0	.00 %
RED:	0	.00 %
WHITE:	82,338	66.83 %
UNKNOWN:	1,040	.84 %
TOTAL:	123,200	100.00 %
Processing Time: for Removal/ Assignment	IRIS-2400 VAX 11/780	1.32 secs 4.90 secs
Processing Time: TOTAL	IRIS-2400 VAX 11/780	78.97 secs 520.53 secs



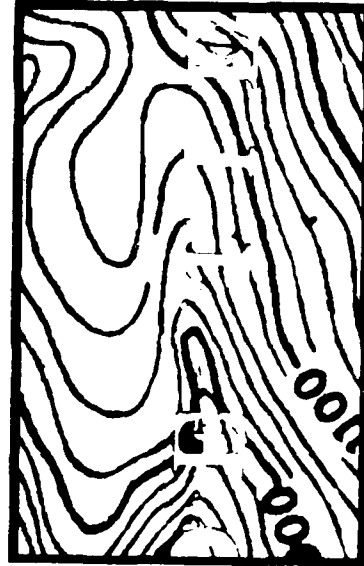
BLUE



GREEN

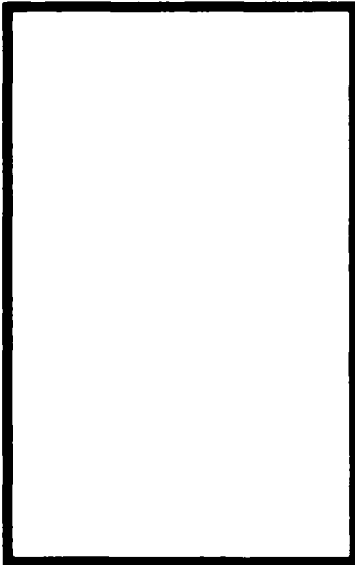


BLACK

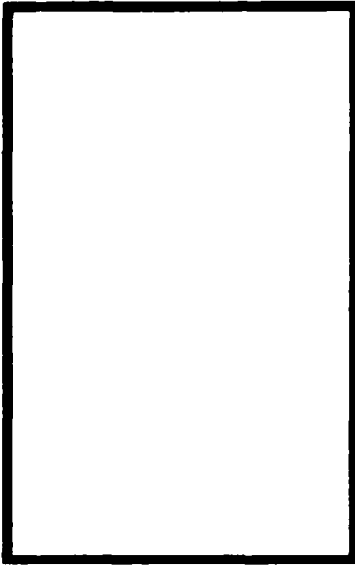


BROWN

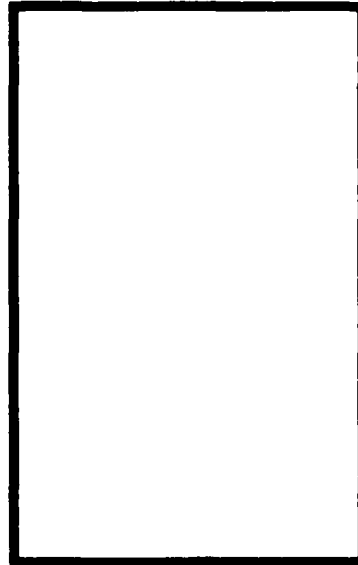
Figure 4.5a - Corral de Tierra Map After Completion of Phase One Processing



**RED**



**UNKNOWN**



**PURPLE**



**WHITE**

Figure 4.5b - Corral de Tierra Map After Completion of Phase One Processing

TABLE 4.5

DATA FOR CORRAL DE TIERRA MAP AFTER  
COMPLETION OF PHASE ONE PROCESSING

COLOR	# PIXELS NAMED	% PIXELS NAMED
BLACK:	4,270	3.47 %
BLUE:	650	.53 %
BROWN:	28,109	22.82 %
GREEN:	7,473	6.07 %
PURPLE:	0	.00 %
RED:	0	.00 %
WHITE:	82,698	67.13 %
UNKNOWN:	0	.00 %
TOTAL:	123,200	100.00 %
Processing Time:	IRIS-2400	1.08 secs
for Final		
Processing	VAX 11/780	3.95 secs
Processing Time:	IRIS-2400	80.05 secs
TOTAL	VAX 11/780	524.48 secs

**TABLE 4.6**

**DATA FOR CORRAL DE TIERRA MAP  
POLYGONAL MAP GENERATION**

Processing Time:	IRIS-2400	62.88 secs
TOTAL	VAX 11/780	252.89 secs

# Groups	167
# Sub-Areas*	13,765
Map Size (pixels)	123,200
File Size (bytes)	174,970

\* sub-areas consist of the triangles, lines and points that makeup a group.

## V. CONCLUSIONS

This study has presented the first phase of a two phase approach to polygonal map database generation and maintenance. Although the digitization equipment used was outdated by current standards, the non-interactive generation of polygonal map representations is feasible and economically advisable for today's technology.

The only drawback to the non-interactive phase of the this system is the time required to determine the heuristic parameters used in the initial pixel naming process. For this study these heuristic values were all determined by trial-and-error. A more rapid and less painful method of heuristic determination is required. A "learning program" using a language such as Prolog is recommended. This tool is designed to accept input from the operator, such as "this is a black pixel" or "this is not a white pixel", and using the user provided examples and the red, green and blue values at the example pixels, the tool would automatically determine the heuristic parameters for the specific setup of the video digitizer. This type of tool is consistent with today's technology.

The second phase of the presented system is an interactive database editor for the correction, merging, refinement and updating of the polygonal map

segments. This interactive editor is similar to the map editors used by the USGS today but designed to share the database produced by phase one. [Ref. 2].



## APPENDIX PHASE I EXECUTION INSTRUCTIONS

This Appendix contains the operating instructions for the first phase of the system.

### EYECOM MAP IMAGE DIGITIZATION

The EyeCom Video Digitizer is located in Room 506, Spanagel Hall. The following instructions are for generating the red, green and blue digital images of the paper map and for transferring these image files to the Silicon Graphics Inc., IRIS-2400. The EyeCom video digitizing system consists of the EyeCom Vidicon Television Camera and Monitor, and an Adm3a Terminal. This system is connected to a PDP-11 minicomputer and tape drive. The materials need for this part of the process are contained in Table 1.

<b>TABLE 1</b>
<b>MATERIALS NEEDED</b>
USGS 1:24,000 map
Red Filter - Cokin A.003
Green Filter - Cokin A.004
Blue Filter - Cokin A.020
Tape (for attaching filters to lens and map to light table)
Transfer Magnetic Tape

1. Turn on the EyeCom Monitor by pulling out the upper right knob located on the back of the Monitor. This knob is also the brightness control.

2. Turn on the EyeCom Vidicon Television Camera by setting the silver toggle switch, located on top of the camera, to the "ON" position.
3. On the monitor, push the "VIDEO" key on the keyboard until the LED is on.
4. Lower the camera to the lowest possible position by turning the large knob located on the left side of the camera mount and lowering the camera until the mount-stop is reached.
5. Turn on the two 60 watt incandescent lamps, and position them on the left and right of the camera.
6. Loosely place the map on the light table platen, directly under the camera lens. (Note: do not turn on the light table.)
7. Remove the lens cap of the camera. At this time you should see an image of the map on the monitor. (If no image is on the screen, wave your hand between the map and the camera lens. You should see the monitor change as your hand is moved. Adjust the monitor brightness by turning the upper right knob located on the back of the monitor. Adjust the monitor contrast by turning the lower right knob located on the back of the monitor.)
8. Adjust the focus and aperture of the camera until an image of the map is seen on the monitor. (The aperture setting is the lowest silver ring on the camera lens. There are two focus settings. The coarse focus setting is the highest black ring on the camera lens. The fine focus setting is the knob located on the top of the camera, next to the on-off toggle switch.)
9. Center the light table under the camera, center the map segment desired on the light table, and securely tape the map to the light table. (Ensure that the map is taped so that it is flat.)
10. Adjust the focus and aperture on the camera, the brightness and contrast on the monitor, and the positioning of the lights until a crisp image is shown on the monitor and the illumination of the image is relatively consistent.

11. Now you are ready to start digitizing the filtered map images. Turn-on the Adm-3a Terminal by pressing the toggle switch located on the right, rear of the terminal.
12. When the system prompt "-" is observed type "HEL DEMO <CR>". After receiving the prompt "PASSWORD", type a <CR>. This places you in an executing program that controls the video digitizer.
13. The program will give you a list of instructions and then prompt you for an answer. When ">\*please enter option letter [S]:" is presented, type "E <CR>". This tells the program you wish to use the EyeCom.
14. Now you are ready to calibrate the system. After more instructions, the program will prompt you with ">\*please enter suboption [S]:". Type "C <CR>". This starts the calibration process.
15. After a list of instructions are given you will receive a prompt "SET ". Type "I". This initializes the calibration routine.
16. You will then receive another "SET >" prompt. Type "S S". This sets up the video digitizer for system use.
17. You will then receive the question "LENS CAPPED?". Place the lens cap on the camera lens and then type "Y".
18. The program will then execute and display a lot of information on the screen which is of no consequence. You will again receive the prompt "SET >". REMOVE THE LENS CAP.
19. Now you are ready to calibrate the video digitizer for the first filter image. Cut two pieces of tape about 12 inches long. Place the pieces of tape on two opposing edges of the red filter. Place the tape so the filter is approximately centered along the tape. CAREFULLY place the filter up to the lens of the camera and attached the tape to the left and right side of the camera body. Ensure that the filter is flush against the camera lens, but do not pull the tape so tight that the filter is bent. (DO NOT move the focus ring, bump the camera, bump the light table, or in anyway change the overall setup of the camera/map system.)

20. Readjust the camera aperture and focus, and monitor brightness and contrast to get a clear, crisp image. (ENSURE THE FOCUS IS CORRENT at this time. After this step NEVER touch the focus again.)
21. TURN-OFF all room lights. Leave the two lamps on.
22. On the Adm3a Terminal type "S B". You will be prompted with "SET CURSOR ON BLACK". VERY CAREFULLY place the lens cap on the paper map approximately in the center of the monitor image. Using the controller stick on the right front of the monitor, move the cursor approximately to the center of the monitor image of the lens cap. Type "<Control (^)> E" on the Adm3a. This process zeros the video digitizer. The program will output a lot of information of no consequence and then print "RANGE = 000". The prompt "SET >" will return. CAREFULLY REMOVE the lens cap from the paper map.
23. Now you must set the range of video digitizer. Type "S W". You will be prompted with "SET CURSOR ON WHITE". Using the controller stick, move the cursor onto an area of white closest to the center of the monitor image. Type "^E". The program will output a lot of information of no consequence and then print "RANGE = XXX" (XXX will be some value between 000 and 255).
24. Now you must ensure that the illumination of the paper map segment being digitized is as consistent as possible. This is the most important and time consuming step. If the range statement received from the last step was not 052, CAREFULLY adjust the camera aperture higher or lower depending on the range received (moving the aperture ring toward a larger aperture setting will decrease the range value). Re-execute from Step 23 until the range is 052.
25. Now you have the range properly set, except the consistency of the illumination must be refined. Select four white areas of the map that are approximately in the four quadrants of the monitor image and about one inch from the center of the image. By trial-and-error you must repeatedly test the range at each of the selected areas and readjust the lamps and the aperture setting until the range at each selected area are all 052. The range testing is the same procedure as Step 23, except the selected area is used instead of the center area.

26. Once you have the illumination properly adjusted you are ready to make the filtered digital image. Type "**Z**". This terminates the execution of the EyeCom section of the program.
27. You will again be prompted with ">\*PLEASE ENTER OPTION LETTER [S]:". Type "**E <CR>**".
28. You will be prompted with ">\*PLEASE ENTER SUBOPTION [S]:". production mode.
29. You will receive the prompt "MOV >". Type "DP1:xxx.yyy=TV". ("xxx" is the name you select for this map segment. "yyy" represents what filter is being used (red = "RED", green = "GRN", blue = "BLU").
30. You will notice a scan line crossing the monitor image from left to right. This means the image is being produced. When finished, you will receive a prompt "MOV >". Type "**Z**". CAREFULLY remove the red filter from the camera lens. You have finished making the red filtered image.
31. You are now ready to make the blue and green filtered images. You will have to start over at Step 13, but this time sequentially use the green and blue filters. IMPORTANT -- DO NOT CHANGE THE FOCUS AT ANY TIME.
32. When the red, green and blue filtered images have been produced type "**Z**". When prompted with ">\*PLEASE ENTER OPTION LETTER [S]:". Type "**Z <CR>**". This will cause the EyeCom program to terminate and you will be logged off the system. Unless you plan to make more map images, you may now remove the filter and paper map from the system. Turn off the system by replacing the lens cap, turn off the lamps, turn off the camera, and turn off the monitor.

## MAP IMAGE TRANSFER TO TAPE

Once you have produced the three filtered images you must now transfer them from the PDP-11 to magnetic tape for subsequent transfer to the IRIS-2400. After digitization of the map the digital images on the PDP-11 in the EyeCom directory [7,20].

1. Turn on the Adm3a Terminal. You will receive the prompt ">". Type "HEL EE4910". When prompted with "PASSWORD", type the account password and type a <CR>. You will then receive a prompt ">". You are now in the EE4910 account which is directory [7,30].
2. You must transfer the three filtered map images to the [7,30] directory. Before transferring the three images list your files in [7,20] to be sure they exist. Type "PIP [7,20]xxx.\* /LI <CR>" (xxx is the file name you selected and the .\* will take care of the .RED, .GRN and .BLU.). You will receive the names of your three files and the prompt ">".
3. Now transfer your three files to directory [7,30] by typing "PIP \*.\*=[7,20]xxx.\* <CR>". You will receive the prompt ">" when completed. Ensure the files were properly transferred by typing "PIP xxx.\* /LI <CR>". The names of the three files will be listed and the prompt ">" will return.
4. Now you are ready to transfer the three files to the magnetic tape. Take your magnetic tape to the tape drive marked with the number 4. Open the door by pulling on the right edge. Pull out on the center knob of the lower spindle. Place your tape on the spindle as indicated by the directions located on the face of the tape drive. Push in on the lower spindle knob. Thread the magnetic tape through the tape head and onto the upper take-up reel as indicated by the directions on the face of the tape drive. Close the door. Push the button marked "LOAD" on the upper right of the tape drive unit. The tape will then be loaded. Push the button marked "ON LINE". The LED above "ON LINE" will light.

5. Return to the Adm3a Terminal. Type "FLX MT4:/ZE <CR>". This will erase any files left on the magnetic tape. Now you are ready to transfer your three files to the tape. Type "FLX MT4:/DO/IM=xxx.\*/RS <CR>". The tape drive will begin turning and your files will be copied to the tape. When the transfer is completed you will receive the prompt ">".
6. To ensure your files were transferred properly, type "FLX MT4:./LI <CR>". The tape will rewind and then start moving forward again. Your three files will be listed on the Adm3a with the number 640 next to the name. This indicates that 640 blocks (512 bytes/block) were received. This is the file size you should receive. If any other file size is received you must retransfer your files.
7. Remove the magnetic tape from the tape drive by pressing the "REWIND" button located on the upper right of the tape drive. The tape will rewind very fast until it gets to the beginning of tape indicator then it will stop. When the tape stops, press the "REWIND" button again. The tape will rewind slowly until it is removed from the upper take-up reel. Open the tape drive door, pull out on the lower spindle knob, remove the magnetic tape, push in on the lower spindle knob and close the tape drive door.
8. Now you must erase your files in the [7.20] and [7.30] directories. Type "PIP [7.20]xxx.RED;\*/DE <CR>". You will receive the prompt ">". Type "PIP [7.20]xxx.GRN;\*/DE <CR>". You will receive the prompt ">". Type "PIP [7.20]xxx.BLU;\*/DE <CR>". You will receive the prompt ">". Type "PIP xxx.RED;\*/DE <CR>". You will receive the prompt ">". Type "PIP xxx.GRN;\*/DE <CR>". You will receive the prompt ">". Type "PIP xxx.BLU;\*/DE <CR>". You will receive the prompt ">". All of the files you created have been deleted. Type "BYE <CR>". You will be logged off the PDP-11. Turn off the Adm3a by switching the toggle switch in the right, lower rear of the terminal.

## MAP IMAGE TRANSFER TO IRIS-2400

To transfer the three map image files to the IRIS-2400 you must have an account on the VMS VAX-11/780. Have one of the Computer Center Staff instruct you on how to load the magnetic tape onto the VMS tape drive, and how to log onto the VMS system.

1. Log onto the VMS system. When you receive the VMS prompt type "MOUNT MF:/FOREIGN <CR>". You will receive a message saying your tape has been loaded. When you receive the VMS prompt type "MCR <CR>". You will receive the prompt "MCR>".
2. Now you are ready to transfer the three images to your VMS account. Type "FLX/RS=MF:[\*,\*]xxx.\* /DO/IM <CR>" (xxx is the name you gave the files). The tape drive will start moving. When the prompt "MCR>" returns you files have been copied. Type " ^C" to exit MCR. You will receive the VMS prompt again.
3. Type "DIR <CR>" to list your directory. The three file names will appear. You will receive the VMS prompt again.
4. Now you must transfer the three files from the VMS VAX 11/780 to the IRIS-2400. Type "ftp npscs-iris2 <CR>". This will put you in the file transfer program (ftp). Type "login yyy <CR>" where yyy is your account name on the IRIS-2400. Type the password for your account on the IRIS-2400.
5. Type "binary <CR>". You are now ready to transfer your three files to the IRIS-2400. Type "put xxx.red <CR>". Use lower case letters for the file name. The xxx is the name you gave the files. When transfer is complete, type "put xxx.grn <CR>". When transfer is complete, type "put xxx.blu".
6. When the transfer is complete, type "bye <CR>" to exit the file transfer program. When the VMS prompt is received type "DELETE xxx.\*;1 <CR>" to delete your files on the VMS system.
7. Type "DISMOUNT MF: <CR>" this will dismount the magnetic tape from the VMS tape drive. Remove your tape.



8. Type "LOGOUT < CR >", to log off of the VMS VAX 11/780.

## MAP IMAGE ALIGNMENT

To align the three filter images the program "shift.c" on the IRIS-2400 is used.

1. In the directory where your "filename.red", "filename.grn" and "filename.blu" are located, make a copy of the red and green file. Type "cp filename.red test.red <CR>" and "cp filename.grn test.grn <CR>". These two new files will be used to align the red and green images. (Ensure there is no test.blu file in the directory).
2. Type "observe test". The digital image of the map will appear on the screen with only red and green images present. Move the cursor over the map image and press the right mouse button to display an enlarged copy of the map.
3. Using the "observe" program determine how much and in which directions the red or green image must be translated to produce proper alignment. Only one color image should be moved. After determining the translation requirements, exit the program.
4. Edit the program "shift.c". At the top of the program are six values for translating the three color images. Following the included diagram enter the translation requirements for the red or green image. Exit the program.
5. Type "cc shift.c <CR>". This compiles and links the shift program. Type "a.out test". This executes the shift program and produces three new files. "testo.red", "testo.grn" and "testo.blu". These are the properly translated files. (Note: testo.blu is a blank file.)
6. Type "observe testo" to observe the translated red and green images. If the image is not aligned, determine the new translation requirements and return to Step 4.

7. Once the red and green images are aligned you can now align the blue image with the red and green images. Type "a.out filename <CR>". This will align the red and green images of filename and produce "filenameo.red", "filenameo.grn" and "filenameo.blu". "filenameo.blu" will be a copy of "filename.blu".
8. Type "observe filenameo <CR>". This will display the aligned red and green images along with the non-aligned blue image. Determine the translation requirements to align the blue image with the red/green image. Only the blue image should be translated.
9. Edit the program "shift.c" and insert the translation requirements for the blue image.
10. Type "cc shift.c <CR>" and "a.out filename <CR>". This will align all three filter images.
11. Type "observe filenameo <CR>". Determine if the blue image is properly translated. If more translation is required, determine the new translation requirements and return to Step 9.
12. When all three images are aligned as much as possible, you are ready to start the phase one process.

## PHASE ONE - COLOR NAME DETERMINATION

Once the filter images have been properly aligned, the digital images are ready for the first processing step of phase one. This is a non-interactive process that requires considerable time (approx. 1 hour).

1. Type "determine filenameo <CR>". This is all that is required to start the process.
2. After completion of this program, you can observe the results of the process by typing "observe filenameo <CR>".

## PHASE ONE - POLYGONAL MAP GENERATION

The final process of phase one is the conversion of the first process output into the polygonal database form. This too is accomplished non-interactively. This process requires approximately 5 minutes.

1. Type "polygon filenameo <CR>". This is all that is required to start the process.
2. After completion of this program, you can observe the results in polygonal form by typing "compare filenameo <CR>". This will display the original digital images and the final polygonal map representation.
3. The polygonal map representation is now available for interactive editing and use with autonomous vehicle route planning programs.

## LIST OF REFERENCES

1. McEwen, R.B., "U.S. Geological Survey Digital Cartographic Data Acquisition," Mapping Software and Cartographic Data Bases, The Harvard University Laboratory for Computer Graphics and Spatial Analysis, pp. 136-142, 1979.
2. Ammann, Joann M., "User Interface Design For Two-Dimensional Polygonally Encoded Geological Survey Maps," Master's Thesis, Department of Computer Science, Naval Postgraduate School, Monterey, California, June 1986.
3. Fegeas, Robin G. and others, USGS Digital Cartographic Data Standards, Land Use and Land Cover Digital Data, Geological Survey Circular 895-E, 1984.
4. Cowan, William B. and Ware, Colin, Colour Perception Tutorial Notes: SIGGRAPH '85, 1985.
5. EyeCom Handbook, Spatial Data Systems, Inc., 1977.
6. Jagadeesh, Jogikal M., A Real Time Image Processing System Using A Color Television Camera, Digital Systems Laboratory, Ohio State University, Dec 1974.
7. Pavlidis, Theo, Algorithms for Graphics and Image Processing, Computer Science Press, 1972.

## DISTRIBUTION LIST

Defense Technical Information Center,  
Cameron Station.  
Alexandria, VA 22314 2 copies

Library, Code 0142  
Naval Postgraduate School,  
Monterey, CA 93943 2 copies

Center for Naval Analyses,  
2000 N. Beauregard Street,  
Alexandria, VA 22311

Director of Research Administration,  
Code 012.  
Naval Postgraduate School,  
Monterey, CA 93943

Dr. Henry Fuchs,  
208 New West Hall (035 A),  
University of North Carolina,  
Chapel Hill, NC 27514

Dr. Kent R. Wilson,  
University of California, San Diego  
B-014.  
Dept. of Chemistry,  
La Jolla, CA 92093

Dr. Guy L. Tribble, III  
Next, Inc.  
3475 Deer Creek Road.  
Palo Alto, California 94304

Bill Atkinson,  
Apple Computer,  
20525 Mariani Ave.  
Cupertino, CA 95014

Dr. Victor Lesser,  
University of Massachusetts, Amherst  
Dept. of Computer and Information Science,  
Amherst, MA 01003

Dr. Gunther Schrack,  
Dept. of Electrical Engineering,  
University of British Columbia,  
Vancouver, B.C., Canada V6T 1W5

Dr. R. Daniel Bergeron.  
Dept. of Computer Science,  
University of New Hampshire,  
Durham. NH 03824

Dr. Ed Wegman,  
Division Head,  
Mathematical Sciences Division,  
Office of Naval Research,  
800 N. Quincy Street,  
Arlington, VA 22217-5000

Dr. Gregory B. Smith,  
ATT Information Systems,  
190 River Road,  
Summit. NJ 07901

Dr. Lynn Conway,  
University of Michigan,  
263 Chrysler Center,  
Ann Arbor, MI 48109

Dr. John Lowrance,  
SRI International,  
333 Ravenswood Ave.  
Menlo Park, CA 94025

Dr. David Mizell,  
Office of Naval Research,  
1030 E. Green St.  
Pasadena. CA 91106

Dr. Richard Lau,  
Office of Naval Research.  
Code 411.  
800 N. Quincy St.  
Arlington, VA 22217-5000

Dr. Y.S. Wu,  
Naval Research Laboratory,  
Code 7007.  
Washington, D.C. 20375

Dr. Joel Trimble.  
Office of Naval Research.  
Code 251.  
Arlington, VA 22217-5000

Robert A. Ellis.  
Calma Company.  
R & D Engineering,  
525 Sycamore Dr., M/S C510  
Milpitas. CA 95035-7489

Dr. James H. Clark,  
Silicon Graphics, Inc.  
2011 Stierlin Road,  
Mountain View, CA 94043

Edward R. McCracken,  
Silicon Graphics, Inc.  
2011 Stierlin Road,  
Mountain View, CA 94043

Shinji Tomita,  
Dept. of Information Science,  
Kyoto University,  
Sakyo-ku, Kyoto, 606, Japan

Hiroshi Hagiwara,  
Dept. of Information Science,  
Kyoto University,  
Sakyo-ku, Kyoto, 606, Japan

Dr. Alain Fournier,  
Dept. of Computer Science,  
University of Toronto,  
Toronto, Ontario, Canada  
M5S 1A4

Dr. Andries Van Dam,  
Dept. of Computer Science,  
Brown University,  
Providence, RI 02912

Dr. Brian A. Barsky,  
Berkeley Computer Graphics Laboratory,  
Computer Sciences Division,  
Dept. of Electrical Engineering and Computer Sciences,  
University of California,  
Berkeley, CA 94720

Dr. Ivan E. Sutherland,  
Carnegie Mellon University,  
Pittsburg, PA 15213

Dr. Turner Whitted,  
New West Hall (035A),  
University of North Carolina,  
Chapel Hill, NC 27514

Dr. Robert B. Grafton,  
Office of Naval Research,  
Code 433,  
Arlington, Virginia 22217-5000



Professor Eihachiro Nakamae,  
Electric Machinery Laboratory,  
Hiroshima University,  
Higashihiroshima 724, Japan

Carl Machover,  
Machover Associates,  
199 Main Street,  
White Plains, New York 10601

Dr. Buddy Dean,  
Naval Postgraduate School,  
Code 52, Dept. of Computer Science,  
Monterey, California 93943

Earl Billingsley,  
43 Fort Hill Terrace,  
Northampton, MA 01060

Dr. Jan Cuny,  
University of Massachusetts, Amherst  
Dept. of Computer and Information Science,  
Amherst, MA 01003

Robert Lum,  
Silicon Graphics, Inc.  
2011 Stierlin Road,  
Mountain View, CA 94043

Jeff Hausch,  
Silicon Graphics, Inc.  
2011 Stierlin Road,  
Mountain View, CA 94043

Robert A. Walker,  
7657 Northern Oaks Court,  
Springfield, VA 22153

Dr. Barry L. Kalman,  
Washington University,  
Department of Computer Science,  
Box 1045,  
St. Louis, Missouri 63130

Dr. Wm. Randolph Franklin,  
Electrical, Computer, and Systems Engineering Department,  
Rensselaer Polytechnic Institute,  
Troy, New York 12180-3590

Dr. Gershon Kedem,  
Microelectronics Center of North Carolina,  
PO Box 12889,  
3021 Cornwallis Road,  
Research Triangle Park,  
North Carolina 27709

Dr. Branko J. Gerovac,  
Digital Equipment Corporation,  
150 Locke Drive LMO4/H4, Box 1015  
Marlboro, Massachusetts 01752-9115

Robert A. Schumacker,  
Evans and Sutherland,  
PO Box 8700,  
580 Arapeen Drive,  
Salt Lake City, Utah 84108

R. A. Dammkoehler,  
Washington University,  
Department of Computer Science,  
Box 1045,  
St. Louis, Missouri 63130

Dr. Lynn Ten Eyck,  
Interface Software,  
79521 Highway 99N,  
Cottage Grove, Oregon 97424

Kazy K. Yokota,  
Japan Tech Services Corporation,  
3F Ohkura Building,  
1-4-10 Shiba-Daimon,  
Minato-Ku, Tokyo 105, Japan

Toshiaki Yoshinaga,  
Hitachi Works, Hitachi Ltd.  
1-1, Saiwaicho 3 Chome,  
Hitachi-shi, Ibaraki-ken.  
317 Japan

Takatoshi Kodaira,  
Omika Works, Hitachi Ltd.  
2-1, Omika-cho 5-chome,  
Hitachi-shi, Ibaraki-ken.  
319-12 Japan

Atsushi Suzuki,  
Hitachi Engineering, Co. Ltd.  
Model Group,  
2-1, Saiwai-cho 3-Chome,  
Hitachi-shi, Ibaraki-ken.  
317 Japan

Toshio Nishimura,  
Hitachi Engineering, Co. Ltd.  
Model Group,  
2-1, Saiwai-cho 3-Chome,  
Hitachi-shi, Ibaraki-ken,  
317 Japan

Dr. John Staudhammer,  
Dept. of Electrical Engineering,  
University of Florida,  
Gainesville, Florida 32611

Dr. Lewis E. Hitchner,  
Computer and Information Science Dept.  
237 Applied Science Building,  
University of California at Santa Cruz,  
Santa Cruz, California 95064

Dr. Jane Wilhelms,  
Computer and Information Science Dept.  
237 Applied Science Building,  
University of California at Santa Cruz,  
Santa Cruz, California 95064

Dr. Pat Mantey,  
Computer Engineering Department,  
University of California at Santa Cruz,  
Santa Cruz, California 95064

Dr. Walter A. Burkhardt,  
University of California, San Diego  
Dept. of Computer Science,  
La Jolla, California 92093

P. K. Rustagi,  
Silicon Graphics, Inc.  
2011 Stierlin Road,  
Mountain View, CA 94043

Peter Broadwell,  
Silicon Graphics, Inc.  
2011 Stierlin Road,  
Mountain View, CA 94043

Norm Miller,  
Silicon Graphics, Inc.  
2011 Stierlin Road,  
Mountain View, CA 94043

Dr. Toshiyasu L. Kunii,  
Department of Information Science,  
Faculty of Science,  
The University of Tokyo,  
7-3-1 Hongo, Bunkyo-ku, Tokyo 113,  
Japan

Dr. Kazuhiro Fuchi,  
Institute for New Generation Computer Technology,  
Mita-Kokusai Building 21FL,  
1-4-28 Mita, Minato-ku, Tokyo 108, Japan

Tony Loeb,  
Silicon Graphics, Inc.  
1901 Avenue of the Stars,  
Suite 1774,  
Los Angeles, CA 90067

Kevin Hammons,  
NASA AMES-Dryden Flight Research Facility,  
PO Box 273,  
Mail Stop OF1,  
Edwards, California 93523

Sherman Gee,  
Code 221,  
Office of Naval Technology,  
800 N. Quincy St.  
Arlington, VA 22217

Dr. J.A. Adams,  
Department of Mechanical Engineering,  
US Naval Academy,  
Annapolis, MD 21402

Dr. David F. Rogers,  
Dept. of Aerospace Engineering,  
US Naval Academy,  
Annapolis, MD 21402

Dr. Robert F. Franklin,  
Environmental Research Institute of Michigan,  
PO Box 8618,  
Ann Arbor, MI 48107

LT Mark W. Hartong,  
900 Cambridge Dr 17,  
Benicia, CA 94510

Capt. Mike Gaddis,  
DCA/JDSSC/C720,  
1860 Wiehle Ave  
Reston, VA 22090

Lt. Cdr. Patrick G. Hogan, USN  
102 Borden Avenue,  
Wilmington, North Carolina 28403

Dr. Edwin Catmull,  
LucasFilm,  
PO Box 2009,  
San Rafael, CA 94912

Dr. John Beatty,  
Computer Science Department,  
University of Waterloo,  
Waterloo, Ontario,  
Canada N2L 3G1

Dr. James Foley,  
George Washington University,  
Dept. of Electrical Engineering and Computer Science,  
Washington, D.C. 20052

Dr. Donald Greenberg,  
Cornell University,  
Program of Computer Graphics,  
Ithaca, NY 14853

Dr. Leo J. Guibas,  
Systems Research Center,  
Digital Equipment Corporation,  
130 Lytton Avenue,  
Palo Alto, CA 94301

Dr. S. Ganapathy,  
Ultrasonic Imaging Laboratory,  
Dept. of Electrical and Computer Engineering,  
University of Michigan,  
Ann Arbor, MI 48109

Dr. Hank Christiansen,  
Brigham Young University,  
Dept. of Civil Engineering,  
368 Clyde Bldg.,  
Provo, Utah 84602

Dr. Thomas A. DeFanti,  
Dept. of Electrical Engineering & Computer Science,  
University of Illinois at Chicago,  
Box 4348,  
Chicago, IL 60680

Dr. Lansing Hatfield,  
Lawrence Livermore National Laboratory,  
7000 East Avenue,  
PO Box 5504, L 156,  
Livermore, CA 94550

El Wells,  
Naval Ocean Systems Center,  
Code 443,  
San Diego, California 92152

Dr. Al Zied,  
Naval Ocean Systems Center,  
Code 443,  
San Diego, California 92152

Richard L. desJardins,  
Defense Advanced Research Projects Agency/IPTO,  
1400 Wilson Boulevard,  
Arlington, VA 22209

Zsuzsa Molnar,  
Silicon Graphics, Inc.  
2011 Stierlin Road,  
Mountain View, CA 94043

Robert Comperini,  
NASA ADFRF,  
PO Box 273,  
Datamax,  
Edwards, California 93523

Shohei Tomita,  
Hitachi Software Engineering Co., Ltd.  
6-81, Onoe-Machi,  
Naka-Ku, Yokohama 231, Japan

Tomo Yamada,  
Digital Computer Limited,  
No. 25 Kowa Building 8-7,  
Sanbancho, Chiyoda-Ku,  
Tokyo 102, Japan

Tohru Gotoh,  
Digital Computer Limited,  
No. 25 Kowa Building 8-7,  
Sanbancho, Chiyoda-Ku,  
Tokyo 102, Japan

Eiji Kurihara,  
Digital Computer Limited,  
No. 25 Kowa Building 8-7,  
Sanbancho, Chiyoda-Ku,  
Tokyo 102, Japan

Kouichi Morimura,  
Mitsubishi Heavy Industries, Ltd.  
CAD/CAM Engineering Section,  
Systems Engineering Department,  
1-1, 1-chome, Wadasaki-cho,  
Hyogo-Ku, Kobe 652, Japan

Takayasu Obata,  
Mitsubishi Heavy Industries, Ltd.  
CAD/CAM Engineering Section,  
Systems Engineering Department,  
1-1, 1-chome, Wadasaki-cho,  
Hyogo-Ku, Kobe 652, Japan

Dr. Arthur I. Karshner,  
Box 3CRL,  
Computing Research Laboratory,  
New Mexico State University,  
Las Cruces, New Mexico 88003

Kazuhiko Ohmachi,  
Systems Development Laboratory,  
Hitachi Ltd.,  
1099 Ohzenji Asao-ku,  
Kawasaki-shi, 215 Japan

John W. Denson,  
Computer Aided Engineering Program,  
Naval Weapons Center,  
Code 3603,  
China Lake, California 93555

Paul Mlyniec,  
Silicon Graphics, Inc.  
2011 Stierlin Road,  
Mountain View, CA 94043

Surasak Mungsing,  
13/2 Tamintorn Village,  
Wipawadeerangsit Rd.  
Bangkok 10210 Thailand

Don Rector,  
Digital Equipment Corporation,  
2525 Augustine Drive  
Santa Clara, California 95054

M. Creon Levit,  
NASA Ames Research Center  
Mail Stop 233-1  
Moffett Field, California 94035

Dr. Velvin R. Watson,  
NASA. Ames Research Center  
Mail Stop: 202A-14  
Moffett Field, California 94035

Phyllis F. Flynn,  
Trancept Systems, Inc.  
521F Uwharrie Ct.  
Raleigh, North Carolina 27606-1456

Mr. Zesheng Tang,  
Palo Alto Research Center,  
XEROX Corporation,  
3333 Coyote Hill Road,  
Palo Alto, California 94304

Larry Ledden,  
Hughes Aircraft,  
MS-604D216,  
PO Box 3310,  
Fullerton, California 92634

Dr. Robert Leighty,  
Research Institute (CUDE Bldg),  
U.S. Army Engineer Topographic Laboratory,  
Fort Belvoir, VA 22060-5546

Dr. Olin Mintzer,  
Research Institute (CUDE Bldg),  
U.S. Army Engineer Topographic Laboratory,  
Fort Belvoir, VA 22060-5546

Mr. Russell Davis,  
HQ. USACDEC,  
Attention: ATEC-IM,  
Fort Ord, California 93941

Capt. Roger K. Diehl,  
1105 Richmond Drive,  
Stafford, VA 22554

LT Joann M. Ammann,  
Naval Security Group Activity,  
Skaggs Island,  
Sonoma, California 95476-5000

Dr. Edward Riseman,  
University of Massachusetts, Amherst  
Dept. of Computer and Information Science,  
Amherst, MA 01003



END

DTIC

9-86