DTIC FILE COPY

TECHNICAL REPORT
NATICK/TR-90/049

AD____________________

AD-A226 494

EXTENDING THE CAPABILITIES OF THE NATICK TERRAIN ANALYSIS SYSTEM

BY
ARTHUR GOLD
DECILOG, INC.
MELVILLE, NY 11747

AUGUST 1990

FINAL REPORT
JULY 1986 - MARCH 1990

Approved for public release; distribution unlimited

UNITED STATES ARMY NATICK
RESEARCH, DEVELOPMENT AND ENGINEERING CENTER
NATICK, MASSACHUSETTS 01760-5019

INDIVIDUAL PROTECTION DIRECTORATE

DISCLAIMERS

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

Citation of trade names in this report does not constitute an official endorsement or approval of the use of such items.

DESTRUCTION NOTICE

For Classified Documents:

Follow the procedures in DoD 5200.22-M, Industrial Security Manual, Section II-19 or DoD 5200.1-R, Information Security Program Regulation, Chapter IX.

For Unclassified/Limited Distribution Documents:

Destroy by any method that prevents disclosure of contents or reconstruction of the document.

REPORT DOCUMENTATION PAGE

Form Approved
OMB No 0704-0188

1. AGENCY USE ONLY *(Leave blank)*

2. REPORT DATE
AUGUST 1990

3. REPORT TYPE AND DATES COVERED
Final, July 86 - Mar 90

4. TITLE AND SUBTITLE
Extending the Capabilities of the Natick Terrain Analysis System

5. FUNDING NUMBERS
C-DAAK60-86-C-0085
PE-1L162786
PR-AH98

6. AUTHOR(S)
Arthur Gold

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)
Decilog, Inc.
555 Broadhollow Road
Melville, NY 11747

8. PERFORMING ORGANIZATION REPORT NUMBER

9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)
U.S. Army Natick Research, Development & Engineering Center
ATTN: STRNC-ITC
Natick, MA 01760-5019

10. SPONSORING/MONITORING AGENCY REPORT NUMBER
NATICK/TR-90/049

11. SUPPLEMENTARY NOTES
IPD-433

12a. DISTRIBUTION/AVAILABILITY STATEMENT
Approved for Public Release.
Distribution Unlimited.

12b. DISTRIBUTION CODE

13. ABSTRACT *(Maximum 200 words)*

The Natick Terrain Analysis System (TAS) was developed to satisfy the need for a more scientific method of designing camouflage patterns and coloration based on actual terrain reflectance data. This report describes the three phase expansion of the TAS. Phase I extended the TAS capabilities to acquire and process reflectance data to 900 nm, and to predict the appearance of a scene through an image intensifier or with three dye, false color, infrared sensitive film. Phase II added the capability to quantify the brightness of targets in imagery recorded through an image intensifier or thermal imager, and determine a probability of detection of a target against the background. Phase III allows the user to interactively create camouflage patterns and overlay the patterns on a scene to perform a subjective analysis of its effectiveness.

14. SUBJECT TERMS

CAMOUFLAGE	TERRAIN	DYES	COLOR
PATTERNS	REFLECTANCE	THERMAL IMAGERY	
COLORANTS	IMAGE INTENSIFICATION	INFRARED FILM	

15. NUMBER OF PAGES
33

16. PRICE CODE

17. SECURITY CLASSIFICATION OF REPORT	18. SECURITY CLASSIFICATION OF THIS PAGE	19. SECURITY CLASSIFICATION OF ABSTRACT	20. LIMITATION OF ABSTRACT
Unclassified	Unclassified	Unclassified	UL

NSN 7540-01-280-5500

Standard Form 298 (Rev 2-89)
Prescribed by ANSI Std Z39-18
298-102

GENERAL INSTRUCTIONS FOR COMPLETING SF 298

The Report Documentation Page (RDP) is used in announcing and cataloging reports. It is important that this information be consistent with the rest of the report, particularly the cover and title page. Instructions for filling in each block of the form follow. It is important to ***stay within the lines*** to meet ***optical scanning requirements***.

Block 1. Agency Use Only *(Leave blank)*.

Block 2. Report Date. Full publication date including day, month, and year, if available (e.g. 1 Jan 88). Must cite at least the year.

Block 3. Type of Report and Dates Covered. State whether report is interim, final, etc. If applicable, enter inclusive report dates (e.g. 10 Jun 87 - 30 Jun 88).

Block 4. Title and Subtitle. A title is taken from the part of the report that provides the most meaningful and complete information. When a report is prepared in more than one volume, repeat the primary title, add volume number, and include subtitle for the specific volume. On classified documents enter the title classification in parentheses.

Block 5. Funding Numbers. To include contract and grant numbers; may include program element number(s), project number(s), task number(s), and work unit number(s). Use the following labels:

C	- Contract	PR	- Project
G	- Grant	TA	- Task
PE	- Program Element	WU	- Work Unit Accession No.

Block 6. Author(s). Name(s) of person(s) responsible for writing the report, performing the research, or credited with the content of the report. If editor or compiler, this should follow the name(s).

Block 7. Performing Organization Name(s) and Address(es). Self-explanatory.

Block 8. Performing Organization Report Number. Enter the unique alphanumeric report number(s) assigned by the organization performing the report.

Block 9. Sponsoring/Monitoring Agency Name(s) and Address(es). Self-explanatory.

Block 10. Sponsoring/Monitoring Agency Report Number. *(If known)*

Block 11. Supplementary Notes. Enter information not included elsewhere such as: Prepared in cooperation with...; Trans. of...; To be published in.... When a report is revised, include a statement whether the new report supersedes or supplements the older report.

Block 12a. Distribution/Availability Statement. Denotes public availability or limitations. Cite any availability to the public. Enter additional limitations or special markings in all capitals (e.g. NOFORN, REL, ITAR).

- **DOD** - See DoDD 5230.24, "Distribution Statements on Technical Documents."
- **DOE** - See authorities.
- **NASA** - See Handbook NHB 2200.2.
- **NTIS** - Leave blank.

Block 12b. Distribution Code.

- **DOD** - Leave blank.
- **DOE** - Enter DOE distribution categories from the Standard Distribution for Unclassified Scientific and Technical Reports.
- **NASA** - Leave blank.
- **NTIS** - Leave blank.

Block 13. Abstract. Include a brief *(Maximum 200 words)* factual summary of the most significant information contained in the report.

Block 14. Subject Terms. Keywords or phrases identifying major subjects in the report.

Block 15. Number of Pages. Enter the total number of pages.

Block 16. Price Code. Enter appropriate price code *(NTIS only)*.

Blocks 17. - 19. Security Classifications. Self-explanatory. Enter U.S. Security Classification in accordance with U.S. Security Regulations (i.e., UNCLASSIFIED). If form contains classified information, stamp classification on the top and bottom of the page.

Block 20. Limitation of Abstract. This block must be completed to assign a limitation to the abstract. Enter either UL (unlimited) or SAR (same as report). An entry in this block is necessary if the abstract is to be limited. If blank, the abstract is assumed to be unlimited.

Standard Form 298 Back (Rev. 2-89)

TABLE OF CONTENTS

	PAGE
Preface	v
1. Introduction	1
2. Phase I.	2
a. Video Data Processing Software Modifications	2
b. Convert 400-900 nm Data to L* Values	3
c. Plotting of a Single Pixel vs. Wavelength	4
d. Varying Density Symbol Plots	4
e. Three Dye, False Color, Infrared Film	5
f. Domain Plots on the Digital Letterwriter 100	5
3. Phase II.	6
a. Analysis of Image Intensifier Imagery	6
b. Analysis of Thermal Imagery	8
4. Phase III.	9
a. Generation of Background Scenes	9
b. Camouflage Pattern Creation	10
c. Overlaying of Patterns onto Background Scenes	12
d. Monitor Calibration	12
5. Conclusions and Recommendations	13
6. References	14
Appendix A - Analysis of Image Intensifier Imagery Equation Set	15
Appendix B - Analysis of Thermal Imagery Equation Set	18
Appendix C - Calibration of the DTAS Color Monitor for CIE L*a*b* Color Coordinates (Modified Short Form Procedure)	23

PREFACE

This report of the three phases of the Natick Terrain Analysis System was prepared by Arthur Gold of Decilog, Inc., Melville, NY under U.S. Army Natick RD&E Center contract DAAK60-86-C-0085, funded by Program Element 1L162786, Project AH98. The work was performed during the period July 1986 to March 1990.

Project Officer at Natick was Lisa B. Hepfinger, Individual Protection Directorate.

EXTENDING THE CAPABILITIES OF THE NATICK TERRAIN
ANALYSIS SYSTEM

1. Introduction.

The Natick Terrain Analysis System[1-3] was designed to satisfy the need for a more scientific method of designing camouflage patterns and coloration based on actual terrain reflectance data. This report describes the three-phase expansion of the Terrain Analysis System to include reflectance data in the near-infrared, to allow for the analysis of video data obtained through an image intensifier or thermal imager, and for the interactive creation and evaluation of camouflage patterns.

The Phase I effort can be subdivided into six tasks:

a. Modify the Video Data Processing software to allow for wavelengths in the range of 720 nanometers (nm) to 900 nm.

b. Convert the 400-900 nm data to L* values using published photocathode sensitivities and nighttime illumination data.

c. Plot the reflectance curve of a single pixel representative of each clustered domain.

d. Produce varying density symbol plots of the clustered domains.

e. Model three dye, false color, infrared film.

f. Plot the clustered domains on the LA-100 printer.

The Phase II effort can be subdivided into two tasks:

a. Quantify the brightness of nighttime imagery recorded on 3/4" video cassettes from an image intensifier.

b. Quantify emitted radiation in the 8-14 micrometer spectral band taken by a thermal imaging radiometer.

The Phase III effort can be subdivided into four tasks:

a. Cluster a CIELAB[1] data file and generate a data file that can be used as a background scene.

b. Interactively create camouflage patterns.

c. Overlay patterns onto background scenes.

d. Calibrate the color monitor.

Each of these tasks will be discussed in the following sections. All of the software has been implemented and tested on the existing Terrain Analysis System.

2. Phase I.

a. Video Data Processing Software Modifications

The EXPOSE routine creates a disk file of reflectance values for the wavelength being processed. The name that the EXPOSE routine assigns to the resultant disk file is in the format DL1:SCNxxx.yyy, where "xxx" is a three digit user assigned scene number and "yyy" is the wavelength number. The section of code that does range checking was modified to accept for the additional values between 720 and 900 nm.

The EXPOSE routine corrects the video signal level of each pixel within the scene area being processed for any nonuniformities in the camera tube. This corrected value is then converted to reflectance by using the reflectance target calibration curve built into the module. The reflectance curves of the calibrated targets have been expanded to include 720-900 nm data.

---

[1] 1976 International Commission on Illumination (CIE) L* a* b* (CIELAB). L* is a measure of lightness (0 = black, 100 = white); a* = a measure of redness (positive axis) or greenness (negative axis); b* = a measure of yellowness (positive axis) or blueness (negative axis).

The EX2DB routine, which combines the exposure files into a data base file, has been expanded to allow for the creation of a data base file that contains 27 wavelengths in the range of 380 to 900 nm.

b. Convert 400-900 nm Data to L* Values

A new software module has been written that permits the user to calculate L* coordinates for the image of a terrain scene as displayed on near-infrared viewing devices such as image converters, image intensifiers and low light level video imaging systems. The user selects the desired 400-900 nm scene data file and specifies an illuminant and the spectral response of the photocathode of the imaging device.

The L* coordinate for each scene pixel in the display is computed in a manner analogous to the calculation of the visual tristimulus value, Y[4]. Because the near-infrared viewing devices present an image that varies just in lightness, Y and its corresponding lightness value, L*, are the only values that need to be calculated. These values are calculated in the following manner.

A relative photocurrent, i, emitted by the photocathode of the imaging device at each pixel location is calculated from equation (1):

$$i = \int_{400}^{900} S(\lambda)R(\lambda)I(\lambda)d\lambda \text{ amps} \qquad (1)$$

where

- λ is the radiation wavelength (micron)
- $S(\lambda)$ is the spectral response of the photocathode (amps/watt)
- $R(\lambda)$ is the pixel reflectance spectrum (from the data base file)
- $I(\lambda)$ is the scene illuminant spectrum (watts/m^2-micron)

The Y tristimulus value on the display is then assumed to be Gi, where G is an arbitrary constant that represents the overall luminous gain of the imaging device. The constant cancels out in the computation of the color coordinates.

The tristimulus value Y_n of the white object stimulus is then computed from equation (2):

$$Y_n = Gi_n \qquad (2)$$

where:

$$i_n = \int_{400}^{900} S(\lambda)I(\lambda)d\lambda$$

This is the signal that would be generated at the photocathode by the image of a perfectly diffuse white target. (Reflectance = 1.0 at all wavelengths.) The L* coordinate for each pixel is computed from equation (3):

$$L^* = 116\left(\frac{Y}{Y_n}\right)^{1/3} -16 \qquad (3)$$

These L* values can then be clustered to obtain L* domains for the displayed image using the existing clustering routines.

c. Plotting of a Single Pixel vs. Wavelength

The software module REFLEC plots the spectral reflectance curves of the pixels closest to the centroids of each domain. The user is given three choices for the scale of the reflectance axis - 1.0, 0.5 or 0.2. All reflectance curves are plotted on the same 8.5" x 11" sheet of paper.

This software has been modified to plot the additional points in the range 720 to 900 nm.

d. Varying Density Symbol Plots

A capability has been provided to produce varying density symbol plots where the density of the plotted symbol is related to the L* value of the clustered domain. The user has the option of plotting any or all of the domains on the same plot or of separating them into individual plots of each domain. These plots, as well as all others produced by the TAS software, can be output on the Hewlett Packard Model 7550A plotter currently attached to the TAS. The Hewlett Packard Model 7220 plotter originally attached to the TAS could also be used with no change in software.

e. Three Dye, False Color, Infrared Film

In order to provide for a three-dimensional clustering process based on the spectral sensitivity of three dye, false color, infrared (IR) film, a new software routine has been written that calculates color values associated with each dye for each pixel in the scene. The existing clustering routine, CLUSTR, properly handles these new data.

It is desirable to have the capability to evaluate camouflage against the countermeasure of False Color IR Film. This type of film is exemplified by Kodak Ektachrome IR Film. The film contains three layers of emulsion, which are sensitive to the entire visual and near-IR spectrum to about 900 nm. It is normally exposed through a Wratten Number 12 filter, which has a sharp low wavelength cut off at 500 nm.

Upon development, the exposed silver halide in each layer results in the appearance of a proportionate quantity of each dye. If precisely processed in EA-5 chemicals, the appearance of the film will be proportional to the sensitivities.

Program FILM reads the reflectance values from the data base image. It then calculates the amount of energy that would be incident on the film at each 20 nm interval, based on the user-specified illuminant. Using the film sensitivity curves, the program then calculates the effective processed dye value for each of the three dyes. (This is analogous to the CIE values.) These three values are then stored in a file for clustering.

f. Domain Plots on the Digital Letterwriter 100

The Digital Letterwriter 100 is a dot matrix printer that is capable of producing graphic outputs. A program has been written that displays the clustered domains on the printer as (up to) 5 different densities of dot patterns. This produces the effect of a grey scale representation of the clustered domains. The user is able to specify the relative dot density associated with each plotted domain.

3. Phase II.

a. Analysis of Image Intensifier Imagery

The TAS is now capable of accepting imagery recorded on 3/4" video cassettes taken through an image intensifier. The cassettes must be placed in the video cassette recorder (VCR) and played through the FOR.A model

FA-410 digital time base corrector. This is the identical setup that is used to process multispectral scene data collected with the TAS field data acquisition system. Additional software has been written that allows the user to perform the desired types of calculations on the digitized image intensifier imagery.

The user is instructed to load the cassette into the VCR and to start the playback a few seconds prior to the beginning of the frames of interest. This gives the time base corrector a few frames in which to lock on to the video synchronization signal. The imagery is displayed on the black and white monitor so that the user is able to see what frames are being input to the TAS. When the user decides that the proper frame sequence is being displayed, a command to the software causes a single frame to be digitized and displayed on the red/green/blue (RGB) monitor (in monochrome). The VCR can then be stopped, since the frame of interest is in the TAS video memory.

A digitizing tablet has been added to the TAS hardware configuration and this tablet is used to select image areas of irregular shape. The tablet sits on a desk next to the monitor and has a "pen" attached to it. Movements of this "pen" on the tablet are reflected as movements of a cursor on the image displayed on the RGB monitor. Under instructions from the software, the user outlines areas of arbitrary shape on the digitized image intensifier image representing a target and a background.

A series of statistics are provided for each of the areas outlined. These statistics include:

Number of pixels in outlined target
Number of pixels in outlined background
Average video signal level (target)
Average video signal level (background)
Minimum video signal level (target)
Minimum video signal level (background)
Maximum video signal level (target)
Maximum video signal level (background)
Variance of video signal level (target)
Variance of video signal level (background)
Number of pixels in target critical dimension
Number of pixels in height of video image
Probability of detection

The probability of detection, P_D, is a function of the signal to noise ratio (SNR) in the image[5-7]. The equations used in the software for these calculations are presented in Appendix A.

The user is also given the option of determining the relative effect on P_D that changing system characteristics produces. The user is required to specify the conditions under which data were collected (CASE 1) and the proposed new conditions (CASE 2). Data sets representing these conditions are selected from user-maintained data files. The following characteristics may be specified:

Modulation transfer function (MTF) of the imaging system
Spectral sensitivity of the detector system
Atmospheric transmission
Illuminant
Reflectance curve characteristic of target
Reflectance curve characteristic of background

b. Analysis of Thermal Imagery

Thermal imagery is analyzed in a manner similar to image intensifier imagery, which was discussed in section 3.a. An additional capability is provided in handling the background. The user is given the option of either outlining an area representative of a background or of specifying a temperature and emissivity. In addition to the video signal level statistics presented for image intensifier imagery, statistics are provided for the calculated temperature values.

The provided statistics include:

Number of pixels in outlined target
Number of pixels in outlined background
Average video signal level (target)
Average video signal level (background)
Minimum video signal level (target)
Minimum video signal level (background)
Maximum video signal level (target)
Maximum video signal level (background)
Variance of video signal level (target)
Variance of video signal level (background)
Temperature of average video signal level (target)
Temperature of average video signal level (background)
Temperature of minimum video signal level (target)
Temperature of minimum video signal level (background)
Temperature of maximum video signal level (target)
Temperature of maximum video signal level (background)
Temperature equivalent of video signal level variance (target)
Temperature equivalent of video signal level variance (background)

The probability of detection, P_D, is a function of the contrast (C), contrast threshold (C_T) and the signal to noise ratio (SNR)[5-8]. The equations used by the software for these calculations are presented in Appendix B.

The user is also given the option of determining the relative effect on P_D that changing system characteristics produces. The user is required to specify the conditions under which data were collected (CASE 1) and the proposed new conditions (CASE 2). Data sets representing these conditions are selected from user maintained data files. The following characteristics may be specified:

MTF of the imaging system
Spectral sensitivity of the detector system
Atmospheric transmission
Minimum detectable temperature difference
Emissivity of the target
Emissivity of the background

4. <u>Phase III.</u>

The software for the Phase III effort has been developed as a separate module (DESIGN) that is fully described in the User's Manual[9]. All of the capabilities of the Phase III software are made available to the user through a series of menus.

a. Generation of Background Scenes.

The Background Scene Generation routine (BAKGND) is used to create a background scene by clustering a .LAB file. The routine clusters the three-dimensional color coordinate data into a maximum of 250 domains. The initial clustering is based upon a histogramming process, which breaks the three-dimensional CIELAB color space into cubical areas that are tested to see if their pixel density is greater than a threshold value. Cubes that exceed the threshold are considered to be domains. This process is repeated, with the cubes getting larger on each pass, until there are no more than 250 domains. An optimization routine may then be used to remove any of the clustering imperfections that may have been introduced by the nonoptimal histogramming process.

The background processing software is based upon the clustering software developed in previous phases of this effort. In these prior efforts, it was desirable to cluster the scene information into the best 3, 4 or 5 domains that could be used for the camouflage cloth. In this phase, in order to generate a realistic background scene, it was desirable to have as many domains as possible, within the hardware limitations of the display system. Since thehardware display system imposes a limit of 256 colors displayed simultaneously, and five colors need to be reserved for the camouflage pattern that is to be overlaid on the background and one color (white) reserved for textual information, the number of domains in the background scene can be no more than 250.

The BAKGND routine is not an interactive routine. The main system routine, DESIGN, requests information concerning the .LAB files to be clustered, as well as the names to use for the output files, and stores this information in the file BAKGND.DAT. This file is then read by the BAKGND routine, which runs in the background and creates the clustered scene file. An output report is printed when BAKGND has created the Background Scene file.

b. Camouflage Pattern Creation

The pattern creation module (PATTRN) is called from the main program (DESIGN) when requested by the user. The pattern creation software is actually a set of interactive modules that may be selected by the user through the menu structure. Each of the individual functions (modules) will be described below.

When the PATTRN routine is started by the DESIGN process, it initializes the color monitor to contain a blank drawing area below some descriptive information. The descriptive information depicts the color of each of the (up to) five "pens" that may be used to draw a pattern, an indication of the color of the current pen, and a chart showing the priority level of each of the colors.

One of the first options that would normally be selected is to specify the CIELAB values for each of the colors in the pattern to be drawn. The user enters the number of the color to be set and its CIELAB coordinates. The RGB values for the entered CIELAB coordinates are calculated and the box associated with the selected color is filled in with the calculated color.

Each of the colors that may be used to create the pattern has a priority level associated with it. This level is a user-assigned number between one and five, with each color having a unique number. The level can be thought of as determining in which order the color layers are applied. First level one is applied to the "fabric", and then level two is applied on top of it. This process continues until all of the (up to) five levels have been applied. The priority level, therefore, determines which color will be visible if two colors overlap on the pattern. Careful assignment of level numbers allows the user to draw overlapping patterns without trying to match the border areas.

Once this preliminary information is entered, the user may begin to draw the desired pattern. This is accomplished by telling the system which color is to be applied and then using the pen on the digitizing tablet to either draw an arbitrary closed shape or to draw a rectangle. As the pen is moved on the digitizing tablet, the outline of the shape is drawn on the color monitor in the selected pen color.

At any time during the pattern creation process, the user may select the menu option to fill in the outlines drawn. The software uses the priority level number to determine which color is visible in overlapping situations.

The system also provides an erase utility that can be used to erase selected rectangular regions of the drawn pattern.

When the pattern has been completed, or at any time during the drawing process, it may be saved to the disk. In order to correctly overlay the pattern onto a background scene, however, a scale for the pattern must be specified. This is done by using the pen to point to two locations on the pattern and entering the distance between these two points in the "fabric" (in centimeters). The system also provides the capability to save any portion of the drawing area by allowing the user to point to the upper left hand corner and lower right hand corner of the area to be saved.

Saved pattern files may be recalled for editing. The full complement of pattern creation routines described above is available to edit patterns.

c. Overlaying of Patterns onto Background Scenes.

Patterns created using this software may be overlaid onto clustered background scenes and displayed for evaluation. First, the name of the background scene is entered, and the scene is displayed on the monitor. The CIELAB coordinates of the (up to) 250 domains are translated to RGB values and the background scene is shown in color.

The user is then asked to point to the upper left hand and lower right hand corners of the section of the background that is to be overlaid by the pattern. The software scales the pattern (using the user-specified scale) to match the scale of the background scene (determined during data collection and stored as part of the file). The camouflage pattern is then painted onto the screen in the desired area. If the user-created pattern is not large enough to cover the selected area, the pattern is repeated in the horizontal and vertical directions as necessary.

Once the pattern is overlaid onto the background, the system allows the user to zoom the displayed image by a factor of two.

d. Monitor Calibration

As described in the above sections, background scenes and overlaid patterns are displayed in color on the monitor. The numeric color coordinates known by the software are in the CIELAB color space. The monitor needs a digital number (0-255) for each of the red, green and blue guns to display a color. Software has been provided to transform any specified L*, a* or b* coordinate into RGB values to produce a "visual match" to an object with the same L*, a*, b* coordinates. The fidelity of this conversion and subsequent display depends upon the calibration data for the color monitor.

A complete calibration procedure[10] is described in the TAS Users Manual and will not be repeated here. Appendix C of this report presents a modified monitor calibration procedure. This short procedure is not as rigorous as the full calibration procedure and is useful only to display colors within a small area of CIELAB space.

5. Conclusions and Recommendations

All of the software modules for the three phases have been installed and tested. A demonstration was held at Natick using the Terrain Analysis System at the completion of each phase.

A number of limitations of the current system have become apparent as more and more requirements have been placed upon it. It is therefore recommended that the following steps be taken:

a. The number of analytical software routines that form a part of the TAS has increased dramatically over the past few contractual efforts. The slow speed of the PDP-11/23+ processor greatly hampers the user's efficiency in performing analyses. The processor should be upgraded to allow for faster and more efficient analyses.

b. The current hardware configuration has two disk drives, each of which uses removable 20 MByte cartridges. The data associated with each scene has increased dramatically as the system has been expanded into the near-IR and thermal regions. It is strongly recommended that additional disk storage be added to the system.

This document reports research undertaken at the US Army Natick Research, Development and Engineering Center and has been assigned No. NATICK/TR-90/049 in the series of reports approved for publication.

6. References

1. J. Richard Goldgraben and Bruce Engelberg, "Data Acquisition and Analysis for Camouflage Design", U. S. Army Natick Research and Development Laboratories Report No. NATICK/TR-82/037, August 1982 (AD A121 818).

2. Arthur A. Gold, J. Richard Goldgraben, C. Thomas Goldsmith and Nancy Monastero, "Modifications to Improve Data Acquisition and Analysis for Camouflage Design", U. S. Army Natick Research and Development Laboratories Report No. NATICK/TR-83/011, January 1983 (AD A129 650).

3. W. J. Cardozo, "A Method for Spectral and Spatial Analyses of Natural Terrain for Camouflage Effectiveness", NRDEC Science Symposium Proceedings, Volume I, 2-4 June 1986, U. S. Army Natick Research, Development and Engineering Center Report No. NATICK/TR-86/050, pages 51-72, June 1986 (AD A179 101).

4. Alvin O. Ramsley and Walter G. Yeomans, "Psychophysics of Modern Camouflage", Army Science Conference Proceedings, pages 79-93, June 1982.

5. Bailey, H. H., Target Detection Through Visual Recognition: A Quantitative Model. The Rand Corporation, Memo RM-6158-PR, Feb 1970.

6. Rosell, E. A., and Wislon, R. M., Performance Synthesis (Electro-Optical Sensors), Air Force Avionics Laboratory, AFAL-TR-71-137 (AD 884829), May 1971.

7. RCA Corporation, Electro Optics Handbook, Technical Series EOH-11, 1974.

8. Wolfe, W. L., The Infrared Handbook, Office of Naval Research, Department of the Navy, Washington, DC, 1978.

9. Decilog, Inc., "Decilog Terrain Analysis System Camouflage Design and Evaluation User's Manual", Decilog Report No. 294, October 1989.

10. William B. Cowan, "An Inexpensive Scheme for Calibration of a Color Monitor in Terms of CIE Standard Coordinates", Computer Graphics, Vol 17, No 3, July 1983.

Appendix A
ANALYSIS OF IMAGE INTENSIFIER IMAGERY
Equation set

Appendix A

$$P_D = 1 - e^{-(SNR^* - 1)}$$ Ref (5)

$$SNR^* = SNR * FACTF * FACTM$$

$$SNR = \frac{\overline{V}_T - \overline{V}_B}{\sqrt{\sigma_T^2 + \sigma_B^2}}$$ Ref (6)

$$\overline{V}_T = \frac{1}{N_T} \sum_{N_T} V(x,y)$$

$$\overline{V}_B = \frac{1}{N_B} \sum_{N_B} V(x,y)$$

$$\sigma_T^2 = \left(\frac{1}{N_T} \sum_{N_T} V^2(x,y) \right) - \left(\overline{V}_T \right)^2$$

$$\sigma_B^2 = \left(\frac{1}{N_B} \sum_{N_B} V^2(x,y) \right) - \left(\overline{V}_B \right)^2$$

$$FACTF = \frac{L_{T_2} - L_{B_2}}{L_{T_1} - L_{B_1}}$$

where:

$$L_{I_J} = \int_{400}^{1200} S_J(\lambda)\, T_J(\lambda)\, R_{I_J}(\lambda)\, I_J(\lambda)\, d\lambda$$

and I=T,B (Target,Background)
J =1,2 (Case1,Case2)

$$FACTM = \left. \frac{MTF_2}{MTF_1} \right]_{\nu}$$ Ref (7)

where:

$$\nu = \frac{N_H}{2 * N_{CD}}$$

The following terms were used in the previous equations:

P_D	Probability of Detection
SNR	Signal to Noise Ratio
SNR^*	Modified Signal to Noise Ratio
$V(x, y)$	Digital video signal level for a pixel at coordinates (x, y)
$\overline{V_T}$	Average video signal level for the outlined target
$\overline{V_B}$	Average video signal level for the outlined background
σ_T^2	Variance of the outlined target pixels
σ_B^2	Variance of the outlined background pixels
$FACTF$	Spectral Sensitivity and Atmospheric Factor
$FACTM$	Modular Transfer Function (MTF) factor
N_T	Number of pixels in outlined target
N_B	Number of pixels in outlined background
S	Spectral response of the detector (milli-amps/watt)
T	Atmospheric Transmission (0-1)
R	Reflectance (0-1)
I	Illuminant $(watts/cm^2 - micron)$
N_H	Number of pixel heights in image
N_{CD}	Number of pixel heights in critical dimensions of target

Appendix B
ANALYSIS OF THERMAL IMAGERY
Equation set

$$P_D = 1 - e^{-(SNR^* - 1)}$$ Ref (5)

$$SNR^* = |SNR * FACTH * FACTM * FACTN|$$

$$SNR = \frac{\overline{V}_T - \overline{V}_B}{\sqrt{\sigma_T^2 + \sigma_B^2}}$$ Ref (6)

$$P = \begin{cases} \frac{1}{2} + \frac{1}{2}\left(1 - e^{-4.2\left(\frac{C^*}{C_T} - 1\right)^2}\right)^{\frac{1}{2}} & \text{for } C^* \geq C_T \\ \frac{1}{2} - \frac{1}{2}\left(1 - e^{-4.2\left(\frac{C^*}{C_T} - 1\right)^2}\right)^{\frac{1}{2}} & \text{for } C^* < C_T \end{cases}$$

Ref (5)

$$C_T = 0.024 * 10^{\Delta x}$$

Ref (5)

$$\Delta x = -\Delta y + \sqrt{\Delta y^2 + 0.484}$$

$$\Delta y = \log_{10}\left(\frac{\theta}{4.22}\right)$$

$$\theta = 3438\left(\frac{NUMCD}{VIEWD}\right)\left(\frac{ACTWTH}{NUMHGT}\right)$$

$$C^* = FACTM * (FACTHC * (C + 1) - 1)$$

$$C = \left|\frac{\overline{V}_T - \overline{V}_B}{\overline{V}_B}\right|$$

$$\overline{V}_T = \frac{1}{N_T}\sum_{N_T} V(x,y)$$

$$\overline{V}_B = \begin{cases} \frac{1}{N_B}\sum_{N_B} V(x,y) \\ \text{or} \\ \text{function of user specified } \overline{T}_B \text{ and } \epsilon_B \end{cases}$$

$$\sigma_T^2 = \left(\frac{1}{N_T} \sum_{N_T} V^2(x,y) \right) - \left(\overline{V}_T\right)^2$$

$$\sigma_B^2 = \begin{cases} \left(\frac{1}{N_B} \sum_{N_B} V^2(x,y) \right) - \left(\overline{V}_B\right)^2 & \text{if outlined} \\ NEVD^2 & \text{if user specified} \\ & \text{an average temp} \end{cases}$$

$$FACTM = \left. \frac{MTF_2}{MTF_1} \right|_{\nu}$$

Ref (7)

where:

$$\nu = \frac{NUMHGT}{2 * NUMCD}$$

$$FACTH = \frac{K_{T_2} - K_{B_2}}{K_{T_1} - K_{B_1}}$$

$$FACTHC = \frac{K_{T_2}}{K_{T_1}} * \frac{K_{B_1}}{K_{B_2}}$$

where:

$$K_{I_J} = \int_a^b S_J(\lambda) T_J(\lambda) L_J(\lambda)\, d\lambda$$

and I=T,B (Target,Background)
J =1,2 (Case1,Case2)

$$\text{a,b} = \begin{cases} 3,5 \text{ for analysis} \\ \quad \text{in 3-5 micron region} \\ 8,14 \text{ for analysis} \\ \quad \text{in 8-14 micron region} \end{cases}$$

$$L_I\,(\lambda) = \frac{2c^2h \cdot \epsilon_I}{\lambda^5\left[exp\left(\frac{hc}{\lambda k\overline{T}}\right) - 1\right]}$$

where:

$$2c^2h = 1.911 \times 10^{-16} \times 10^{30} = 1.911 \times 10^{14}$$

$$\frac{hc}{k} = 0.014388 \times 10^6$$

$$\overline{T}\,(\deg K) = \overline{T}\,(\deg C) + 273.15$$

$$FACTN = \left(\frac{\sigma_T^2 + \sigma_B^2}{\sigma_T^2 + \sigma_B^2 + 2 * (NEVD_2^2 - NEVD_1^2)}\right)^{\frac{1}{2}}$$

Ref (8)

where:

$$NEVD_I = \frac{MDTD}{1.7 * \alpha}$$

The following terms were used in the previous equations:

P_D	Probability of Detection
P	Detection probability of uncluttered targets and backgrounds
SNR	Signal to Noise Ratio
SNR^*	Modified Signal to Noise Ratio
C_T	Contrast Threshold
C	Contrast
C^*	Modified contrast
$NUMCD$	Number of pixel heights in target critical dimension
$VIEWD$	Viewing distance to display device
$ACTWTH$	Size of display device (height)
$NUMHGT$	Number of pixel heights in image
$V(x,y)$	Digital video signal level for a pixel at coordinates (x,y)
$\overline{V_T}$	Average video signal level for the outlined target
$\overline{V_B}$	Average video signal level for the outlined background
σ_T^2	Variance of the outlined target pixels
σ_B^2	Variance of the outlined background pixels
$FACTM$	Modular Transfer Function (MTF) factor
$FACTH$	Spectral Sensitivity and Atmospheric Factor
$FACTHC$	Spectral Sensitivity and Atmospheric Factor (Contrast)
$FACTN$	Noise factor
ϵ	Emissivity
N_T	Number of pixels in outlined target
N_B	Number of pixels in outlined background
S	Spectral response of the detector (milli-amps/watt)
T	Atmospheric Transmission (0-1)
N_H	Number of pixel heights in image
N_{CD}	Number of pixel heights in critical dimensions of target
$NEVD$	Noise Equivalent Video Difference
$MDTD$	Minimum Detectible Temperature Difference

Appendix C

Calibration of the DTAS Color Monitor for CIE L*a*b* Color Coordinates

(Modified Short Form Procedure)

Appendix C

This appendix describes a procedure to calibrate the DTAS color monitor. The user chooses four colors with known LAB coordinates that are representative of the colors that are to be displayed. Interactive software is used to play with the RGB values until a "good" visual match is obtained between these four displayed colors and the four known samples. Off-line mathematical procedures are then followed to calculate the monitor calibration matrix that can then be used by the software to convert an LAB value into the appropriate RGB values.

This procedure only produces "good" matches for LAB coordinates that fall within the area of the original four values. LAB coordinates that fall outside this region may produce totally false RGB values. The complete monitor calibration procedure described in the users manual will produce visual matches over a much greater area in LAB space.

STEP 1.

Select four color samples with known LAB coordinates that are representative of the colors that are to be displayed. Enter their LAB coordinates on lines 1-3 of the Linear Calibration Data Sheet (Figure 1).

STEP 2.

Using the monitor calibration software modules available through the DESIGN menu structure, select the option to display uniform boxes of a user specified RGB value. Adjust the RGB values until the displayed image is a "good" visual match to the first known LAB sample. Enter these values on lines 4-6 for color one (j=1). Repeat this process for the remaining three colors and enter the data in the appropriate columns in lines 4-6 of the data entry form.

STEP 3.

Using the equations shown below calculate F_1, F_2 and F_3 for all four colors (j=1 to 4).

$$F_{1j} = \left[\frac{a^*_j}{500} + \frac{L^*_j + 16}{116} \right]^3 \qquad j=1,2,3,4$$

$$F_{2j} = \left[\frac{L^*_j+16}{116}\right]^3 \qquad j=1,2,3,4$$

$$F_{3j} = \left[\frac{L^*_j+16}{116} - \frac{b^*_j}{200}\right]^3 \qquad j=1,2,3,4$$

Enter these values on lines 7-9 of the data entry form.

STEP 4.

For each of the four colors (j=1,2,3,4) solve the following three equations.

$$\left[V_{ij}\right] \begin{vmatrix} b_{Rx} \\ b_{Gx} \\ b_{Bx} \\ D_x \end{vmatrix} = \begin{vmatrix} F_{11} \\ F_{12} \\ F_{13} \\ F_{14} \end{vmatrix}$$ Solve for b_{Rx}, b_{Gx}, b_{Bx}, D_x

$$\left[V_{ij}\right] \begin{vmatrix} b_{Ry} \\ b_{Gy} \\ b_{By} \\ D_y \end{vmatrix} = \begin{vmatrix} F_{21} \\ F_{22} \\ F_{23} \\ F_{24} \end{vmatrix}$$ Solve for b_{Ry}, b_{Gy}, b_{By}, D_y

$$\left[V_{ij}\right] \begin{vmatrix} b_{Rz} \\ b_{Gz} \\ b_{Bz} \\ D_z \end{vmatrix} = \begin{vmatrix} F_{31} \\ F_{32} \\ F_{33} \\ F_{34} \end{vmatrix}$$ Solve for b_{Rz}, b_{Gz}, b_{Bz}, D_z

where:

$$V_{ij} = \begin{bmatrix} V_{R1} & V_{G1} & V_{B1} & -1 \\ V_{R2} & V_{G2} & V_{B2} & -1 \\ V_{R3} & V_{G3} & V_{B3} & -1 \\ V_{R4} & V_{G4} & V_{B4} & -1 \end{bmatrix}$$

STEP 5.

Now invert the b matrix as shown below to yield U.

$$U_{ij} = \begin{bmatrix} b_{Rx} & b_{Gx} & b_{Bx} \\ b_{Ry} & b_{Gy} & b_{By} \\ b_{Rz} & b_{Gz} & b_{Gz} \end{bmatrix}^{-1}$$

STEP 6.

Create a disk file using the editor called MONCAL.DAT on disk 0 under UIC [1,15]. This will be a four line file that contains the following data:

```
Line 1:   U(1,1) U(2,1) U(3,1)
Line 1:   U(1,2) U(2,2) U(3,2)
Line 1:   U(1,3) U(2,3) U(3,3)
Line 1:   Dx     Dy     Dz
```

The format for the data is 3F10.3

LINEAR CALIBRATION DATA SHEET

		J=1	J=2	J=3	J=4
1.	L^*_j	______	______	______	______
2.	a^*_j	______	______	______	______
3.	b^*_j	______	______	______	______
4.	V_{Rj}	______	______	______	______
5.	V_{Gj}	______	______	______	______
6.	V_{Bj}	______	______	______	______
7.	F_{1j}	______	______	______	______
8.	F_{2j}	______	______	______	______
9.	F_{3j}	______	______	______	______

Figure 1. Data sheet for linear calibration.

DISTRIBUTION LIST

	No. of Copies
Administrator Defense Technical Information Center Alexandria, VA 22314	2
Technical Library U.S. Army Natick Research, Development and Engineering Center Natick, MA 01760-5000	3
Mr. Arthur Gold Decilog, Inc. 555 Broadhollow Road Melville, NY 11747	5
Mr. Jerry Blimbaum Naval Coastal Systems Command Code 2110 Panama City, FL 32407-5000	1
Mr. Randall Williams Waterways Experiment Station ATTN: CEWESEN-C/R. Williams 3909 Halls Ferry Road Vicksburg, MS 39180-6199	1
Commander U.S. Army Natick RD&E Center ATTN: STRNC-ITC Natick, MA 01760-5019	38