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Special Color Analysis Techniques

An experimental console has been fabricated to permit an interpreter to perform spatial and photometric analyses at a single location.

Introduction

One of the mission objectives of Rome Air Development Center (RADC) is advancement of the state-of-the-art of imagery interpretation. RADC's Special Color Analysis Techniques program offers a method to improve the United States Air Force's capability for extracting added intelligence information from reconnaissance sensor records through the use of the photometric properties of the sensor records.

Abstract: *A new interpretation technique and the associated equipment for extracting additional intelligence from reconnaissance sensor records is introduced. Reconnaissance sensor imagery is a film record of images having spatial and photometric properties. Image spatial properties such as size, shape and pattern can be enhanced through the use of aids such as magnification, mensuration and stereo equipment. On the other hand, equipment to enhance image photometric properties such as tone, color, contrast and density (which are a function of ground object reflectance and contain valuable intelligence information) is not available to the operational interpreter. This new interpretation technique enhances photometric properties by generating and displaying ratios of target reflectance obtained from the spectral data presented on color and color-infrared films. The photometric properties are presented in new spatial patterns for interpretation by the interpreter. An example applies the ratio technique to evaluate surface texture. An experimental image interpretation console has been fabricated to allow rapid and accurate enhancement of photometric properties. The console permits an image interpreter to perform all necessary spatial and photometric analyses at one station.*

Reconnaissance sensor imagery is a film record of images having two basic properties: spatial properties and photometric properties. Spatial properties consist of size, shape and pattern, and are related to the resolution capability of a sensor system. The interpreter primarily uses these properties in the interpretation process, and the equipment available to assist his analysis, such as aids for stereo, magnification and mensuration, is designed to improve or enhance the spatial aspects of targets.

Photometric image properties consist of tone, contrast, color and density, and are related to the reflectances of ground objects. Photometric image properties may be thought of as relative brightness changes across a photographic record. Image interpreters have never been trained to utilize these changes and no equipment exists for the interpreter to exploit photometric information directly. The Special Color Analysis Techniques program has provided the interpreter with a console with which to perform photometric analyses and obtain more information about the status or condition of a target.

The program has the following objectives: design and fabrication of a photometric image interpretation console; development of photometric interpretation techniques for operational applications; and training of interpreters in both the selection of correct photometric interpretation techniques, and in the use of the experimental console. Results achieved to date have demonstrated the value of photometric analysis and indicate photometric interpretation techniques warrant continued development. At the present time, photometric analyses seem to have their greatest potential in improving the capability for deriving technical intelligence. The full range of technical applications remains to be investigated during evaluation of the photometric image interpretation console at the Rome Air Development Center.

Significant fall-out technology also is anticipated from this program. For example, the photometric process and interpretation console have been successfully utilized on tasks such as crop analysis,[1] mapping of flooding conditions,[2] monitoring of water quality,[3,4] analyses of power plant discharges, and analyses of ERTS and Skylab imagery.[5-7] The list of such applications is expected to grow as familiarity with the photometric image technique grows. In the present article the history of the development of the interpretation technique and the experimental image interpretation console is detailed. Discussion of the development is concentrated on the original purpose of the console—that of assisting the Air Force interpreter. Discussions of applications more directly related to civilian problems can be found in References 1-7.

History of the Special Color Analysis Techniques Program

In June 1970 RADC and Calspan Corporation (formerly Cornell Aeronautical Laboratory, Inc.) held technical discussions to review work Calspan had completed under internal research and development funds. Calspan had developed a technique which demonstrated the commercial aspects of photometric analysis using color film as the collection agent. Examples included an analysis of the stress levels of a sugar beet field and thematic mapping of flooded acreage along the Mississippi River.[2] A feasibility study was then conducted to determine if color film could accurately record spectral reflectance information, and if photometric analysis techniques could be applied to Air Force exploitation problems.

The results of the feasibility study were positive, and a program was undertaken to refine photometric analysis for application to Air Force exploitation problems. It was first necessary to verify that color film could be used to record spectral reflectance information accurately under operational conditions. Secondly, the research was to investigate and define what additional intelligence photometric information could provide to the interpreter. If the first two objectives were successful, a preliminary design of a new interpretation console specifically intended for exploitation of photometric information was to be developed.

This research concluded that both color and color-infrared films could be used to obtain spectral reflectance or photometric information, that the photometric technique had definite Air Force application, and that a prototype interpretation console should be fabricated to facilitate the development of photometric interpretation techniques.

A major advancement made under these studies was the development of a method to remove the effects in the original film record caused by light scattered by the atmosphere into the camera (commonly called atmospheric flare or path radiance). Such scattered light is not reflected from the target and is the exposure that the camera would receive at an image point if the corresponding target in the scene is perfectly absorbing or black (a zero reflectance). Once the effects of scattered light are removed, true ground object reflectance can be calculated. The method to remove scattered light is documented in References 2, 3 and 8.

The photometric technique developed consists of four steps and requires that reflectance ratios be made of two spectral regions. A reflectance ratio of any target is the reflectance in one spectral region divided by the reflectance in another region. The reflectance ratio is generated photographically by making a positive image of one emulsion layer and a negative image of a second layer, superimposing the two and displaying the combination. The display is a representation of the reflectance ratio of the two spectral regions. The four steps of the photometric technique leading to the interpretation of the reflectance ratio display are as follows.

First, spectral reflectance information of a target must be collected. Color film (regular color or color-infrared) acts as the collection agent by recording the target simultaneously in three spectral bands of information on a single film. Photographic color records are a function of the spectral reflectance of ground objects. Spectral reflectance information provides photometric clues for interpretation. Therefore, color records can be used to extract photometric information for analysis. As stated previously, the initial acquisition of photometric information does not interfere with operational mission parameters. The combination of any two of the three emulsion layers provides three unique ratio combinations from one film record. For Ektachrome film the three rations are red/blue, red/green, and green/blue.

Second, the two emulsions or spectral layers to be rationed must be *separated* and scattered light effects must be determined and removed. This is accomplished by making black-and-white separation transparencies of the two spectral layers. The black-and-white separation transparencies remove the scattered light that has affected the exposure of the original color film, but which does not relate to the true reflectance of the target of interest. Removal of the scattered light is achieved by carefully controlling the contrast of the separation transparencies. The scattered light reduces scene contrast on the original record; hence effects of the scattered light can be removed by appropriate control of the contrast of each transparency. The selection of the two layers of the color record is not arbitrary. The interpreter makes the selection according to the nature of the target scene he is analyzing.

Third, division of reflectance of the two layers is accomplished by superimposing a negative separation transparency of one spectral band with a positive separation transparency of the other spectral band. This superimposition represents the ratio of reflectance of the two emulsion layers. The interpreter now has the ratio of reflectances encoded in density variations of a black-and-white format.

Fourth, the ratio presentation or superposition is density sliced and color encoded for display on a TV screen, and comparative interpretation with the original film record. The photometric patterns which appear on the screen are related to the reflectance properties of objects in the scene. The complete photometric process is documented in References 8-11.

The four steps described above require equipment for interpretation, densitometric analysis, copying and processing separation transparencies, and a capability to color code photometric information. In previous research these steps were accomplished in such separate locations as the densitometer room, the photographic laboratory, and the display room. The first model of a photometric console combines the necessary equipment to allow the interpreter to perform the four steps in his analysis at one location quickly and easily.

The Photometric Console

The photometric console enables an interpreter to extract photometric information from a color film record, in a color-coded, spatial form for subsequent analysis. The components of the console incorporate the four basic steps of the process outlined above. Figure 1 is a line drawing depicting the completed console. Figure 2 is a photograph of the completed console.

The console has been designed so that an interpreter can perform his conventional interpretation tasks, as well as any photometric interpretation functions, at a single station. The intent of the console is to permit the interpreter to undertake a photometric analysis task with minimum interruption of

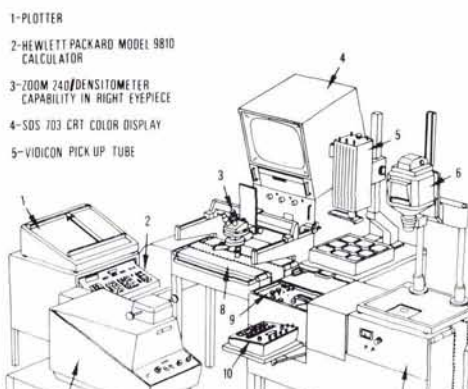


FIG. 1. The experimental photometric image interpretation console. The console is designed to permit the image interpreter to perform all necessary spatial and photometric analyses at one station.

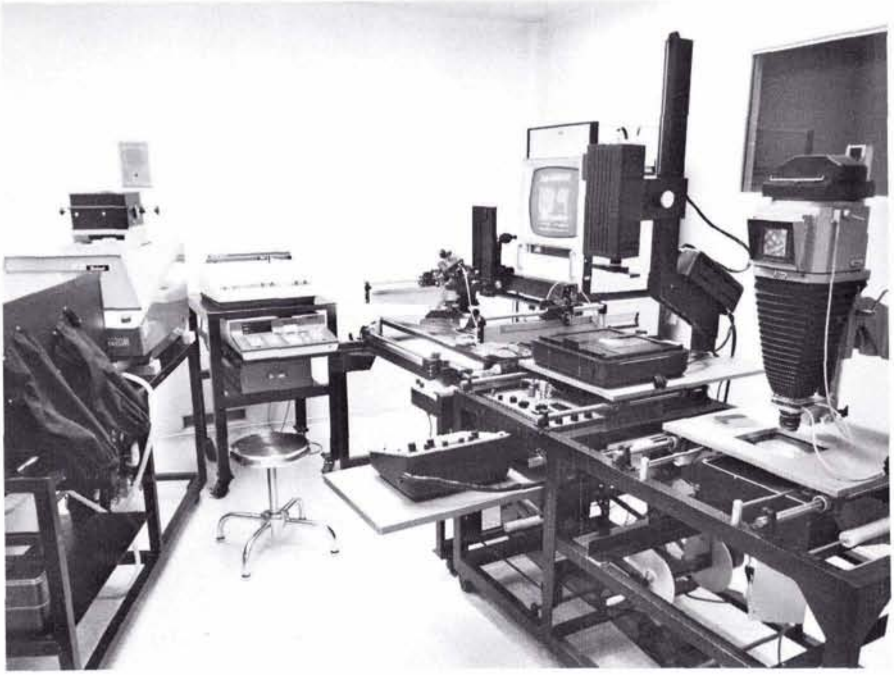


FIG. 2. The experimental photometric image interpretation console. This console was delivered to Rome Air Development Center in October 1973. A second console has been constructed for use at Calspan Corporation.

his interpretation process. To accomplish this, many photometric analysis procedures have been automated, or made semi-automatic through programming of the calculator/computer associated with the console. The description of typical use of the console is as follows.

An analyst interprets his color film record on the light table using Zoom 240 optics. If he sees an area requiring photometric analysis, the interpreter makes density measurements on the original film record using the microdensitometer built into the right eyepiece of the Zoom 240. The microdensitometer readings are fed directly into an on-line calculator-computer. Densitometry of shadow objects within the scene enables the calculator/computer to *calibrate* the imagery, i.e., determine the effects of atmospheric conditions on the density variations of the image.[8] Using the density-log exposure curve for the film stored in its memory, the calculator/computer determines how the contrast of each film layer needs to be modified to remove atmospheric effects. The calculator/computer then prints out the correct processing information (time, temperature) to obtain the desired contrast modification for each film layer. From measurements of the density range of objects in the scene under analysis, the calculator/computer also specifies the exposure data needed for making separation transparencies with the Nikon copy camera.

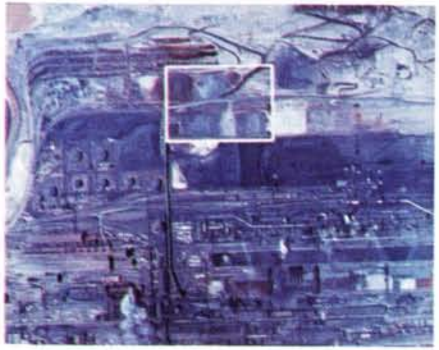
The original film record is transported under the Nikon copy camera to make separation transparencies (one positive, the other negative) of the two emulsion layers to be ratioed. The interpreter processes the transparencies in the Pako processor according to the information provided by the calculator/computer, and then superimposes them under the vidicon pick-up tube. The interpreter then density-slices the ratio mask and assigns color codes to the density values. A color coded display then appears on the Cathode Ray Tube (CRT) for comparison with the color imagery and further analysis of the target scene.

The display represents the ratio of reflectance of the two film layers selected and presents photometric information in spatial form for the interpreter. A polaroid copy camera is also provided with the console for photographing the CRT display.

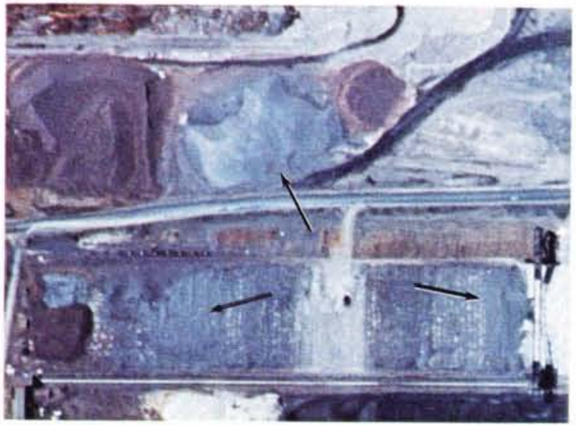
Final assembly of the console took place in mid-July 1973, and the console was delivered to RADC for evaluation in October 1973. A second console has been constructed by Calspan for use in its Buffalo laboratory.

PLATE 1. An application of photometric analysis.

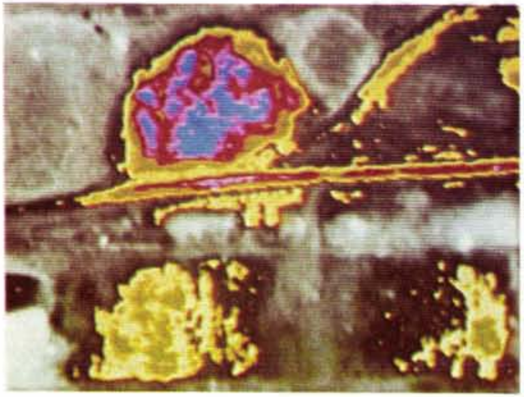
EVIDENCE OF IMPROVED STEEL PRODUCTION USING PHOTOINTERPRETATION OF COLOR FILM



COLOR PHOTOGRAPH OF STEEL MILL, ORIGINAL SCALE 1/40,000



5x ENLARGEMENT OF ORE PILES OUTLINED IN WHITE RECTANGLE AT LEFT



COLOR ENCODED DISPLAY OF RED TO BLUE REFLECTANCE RATIOS OF ORE PILES

THE THREE ORE PILES APPEAR VERY SIMILAR IN THE ENLARGEMENT ABOVE. INTERPRETATION OF THE RATIO DISPLAY SHOWS THEY ARE NOT (BOTTOM). THE TWO ORE PILES IN THE ACTIVE BINS HAVE VERY UNIFORM AGGREGATE SIZE COMPARED TO THE ORE PILE OUTSIDE THE BINS (TOP). THIS IS CONFIRMED BY THE TWO COLORS ENCODING THE FORMER COMPARED TO THE FIVE COLORS ENCODING THE LATTER. A UNIFORM AGGREGATE (PELLETIZED) ORE IMPROVES BLAST FURNACE EFFICIENCY THUS IMPROVING STEEL PRODUCTION. THE RATIO DISPLAY GIVES THE PHOTOINTERPRETER ANOTHER TOOL TO AID IN THE EXPLOITATION OF INFORMATION FROM COLOR FILM.

Ratio Signature Analysis

The second objective of the RADC program is development of photometric interpretation techniques. Appropriate techniques have been identified for crop analysis, for locating minefields, assessing runway conditions including extent of deterioration, and for other problems such as those listed in the Introduction.

Plate 1 describes one special application of photometric analysis for technical intelligence on an iron-smelting and steel mill complex. The top left scene shows a conventional color photograph, the top right scene an enlargement of the ore pile area from the conventional color scene, and the bottom enhancement a photometric enhancement of the enlarged ore piles. The problem posed by these scenes is to determine from the imagery if the mill has converted to a uniformly sized or pelletized ore to improve the efficiency of its blast furnaces. The area outlined on the original color scene is easily recognized as bulk storage of raw materials, iron ore in this instance. It is apparent that the storage area contains two small piles of ore and one larger pile. All three have the same bluish-gray color. The interpreter trained in spectral ratio interpretation knows that the red-to-blue spectral ratio provides information on surface texture, or aggregate size, and moisture content.[8] He is also aware that there is a relationship between aggregate size and moisture content. He would generate a red-to-blue spectral ratio as shown in the bottom scene. The following ratio rule applies to this particular analysis.

If two surfaces appear identical in color to the eye on the original color photograph, but the densitometer indicates one is slightly darker, the cause of the brightness difference will be moisture if the red-to-blue ratio of the darker surface is greater than the red to blue ratio of the lighter surface. Conversely, the dominant cause will be texture or size of the particles if the red-to-blue ratio of the darker surface is less than the red-to-blue ratio of the lighter surface.[8]

Direct examination of the ratio scene shows a marked difference between the red to blue ratios and ratio variations of the large and small piles. The interpreter can immediately expect that there has been an ore switch at the mill, although he must still use the photometric interpretation rule to establish the origin of the difference. Density measurements on the original scene indicate that the two small piles (yellow on the ratio scene) are darker than the larger pile, and that there is a significant brightness variation within the large pile.

Inspection of the darker regions within the large pile shows that these regions have a lower ratio than the brighter regions of the large pile. Hence the variations are predominantly textural. The larger pile thus appears to be composed of a nonuniformly graded substance. Darker regions within the small piles have higher ratios than the lighter regions indicating that the tonal difference is caused by moisture and suggesting a more uniformly sized aggregate within these piles. (Ambient moisture conditions for both piles are identical, hence the small piles must be of a more uniform size.) The ratio difference between the small and large piles indicates more moisture in the smaller piles, which is consistent with a smaller, more uniformly sized aggregate. The conclusion that the mill has switched to a uniformly sized ore to increase efficiency was verified by ground inspection.

Interpreter Training and Future Plans

A necessary program objective is training interpreters to understand and perform photometric analyses using the console. A ratio combination which works for one interpretation problem may not be the appropriate ratio for another problem. For example, for surface-texture analysis it was found that the red/blue spectral ratio was ideal; for vegetation stress the infrared/red spectral ratio was best. Each interpretation problem requires study to determine the proper ratio combination and associated analyses required to solve the problem.

The training program which was started at RADC after delivery of the interpretation console will continue concurrently with an in-depth evaluation of the equipment on a number of different target problems. Training materials are presently being assembled to aid in instructing interpreters.

Future plans include efforts to compile a photointerpretation key and instruction manual for photometric interpretation, and research to expand the types of analyses that can be performed using the photometric interpretation technique. Upon completion of equipment evaluation and the additional target analyses, two photointerpretation consoles similar to the present console will be built for operational evaluation. During the same time period, an interpretation console which uses electro-optical techniques to generate the ratio display directly from the color film record will be developed. Such a console will eliminate the photographic processing steps in the interpretation process, thereby shortening the time required for photometric analysis. The Air Force photointerpreter will then hopefully have the techniques and equipment necessary to incorporate photometric information and interpretation techniques into his standard interpretation procedures.

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Articles for Next Month

G. W. Erio, Plotter orientation from aerotriangulation output.
T. F. Howell, Automated mapping system implementation.
H. M. Karara, Aortic heart valve geometry.
S. J. Kristof and *A. L. Zachary*, Mapping soil features from multispectral scanner data.
E. M. Mikhail, Hologrammetry: concepts and applications.
G. H. Schut, Two interpolation methods.