FEASIBILITY OF OBJECTIVE COLOR SYSTEMS

By Abraham Anson

FINAL REPORT
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U. S. ARMY ENGINEERS
GEODESY, INTELLIGENCE AND MAPPING RESEARCH AND DEVELOPMENT AGENCY
FORT BELVOIR, VIRGINIA

for

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

CONTENTS

PREFACE

Work on this study was authorized under NASA-Defense Purchase Request No. 47-009-002 dated 27 July 1964, to U. S. Army Engineer Geodesy, Intelligence and Mapping Research and Development Agency for a study of the feasibility of objective color sensing systems for manned orbital investigations as described in GIMRADA proposal, "Feasibility of Objective Color Sensors", dated 16 June 1964, a copy of which is attached as Appendix I.

This work is closely related and necessary to the proper design of the Apollo Extension System Color and Multispectral experiments. Initial research on the degradation of color across the field of view of a camera lens (Multispectral Experiments) was initiated and is continuing under Project No. 42013001A91D In-House Laboratory Initiated Research, Development (GIMRADA FUNDING)

The major portions of this study were accomplished by Abraham Anson, Project Engineer, assisted by Kenneth D. Robertson, Research Physicist, Lawrence P. Murphy, Frank E. Haddock and Terral Jordan under the supervision of Bernard B. Scheps, Chief, Systems Branch. Development, testing, fabrication and evaluation were performed under the general direction of James E. Gillis, Jr., Chief, Intelligence Division.

Work on the multispectral experiments was accomplished with the material assistance of Dr. Robert N. Colwell, School of Forestry, University of California, Berkeley.

FINAL TECHNICAL REPORT
FEASIBILITY OF OBJECTIVE COLOR SYSTEMS

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SUMMARY

This report describes the experimentation for determining the feasibility of objective sensing of color for manned space geoscience application.

Several approaches were explored in the research performed in the implementation of this task. Literature listed in the bibliography, which includes 17 international patents (1) was reviewed to avoid duplication of previous efforts in the field of optics and spectral measurements.

The first approach involved the development of a small spectrum analyzer and tristimulus sensor. The spectrum analyzer employed the principle of passing white light through a monochromator, allowing narrow spectral bands to fall on a sample, then comparing its reflectance to that of a reflecting standard. By repetition of the above procedure in small increments, a spectral curve was generated for the sample in percent reflectance vs wave length of light. Comparison with National Bureau of Standards curves served as comparison standards for evaluation.

In the second approach, three filters were fabricated for use in a tri-stimulus sensor. The transmission of the filters duplicated the tri-stimulus values of the CIE standard observer (2). The filters were used with incandescent light and photovoltaic barrier layer cells. Both systems are described by K. Robertson, Co-investigator, in Appendix II.

A third approach explored was in the color stereo-effect experiment which required the attachment of optical wedges to standard photographic cameras. This approach employed the physical property of differential refraction of light frequencies in a pair of prisms causing a visual stereo image in which the spectral elements were displaced in a relative parallax, apparent as "Z" coordinates. The method described employed the exposure of two photographs of a group of color chips through an optical wedge, with the base of the wedge toward the lens and the wedge angle toward the right, then rotated for the second photograph toward the left. The resulting diffraction of the spectra were in opposite directions, thus both normal and color parallax were created from a single (monocular) camera position. Details of the experiments and the hardware designed during experimentation are presented.

Multispectral experiments performed with Dr. R. N. Colwell at the University of California, for the National Aeronautics and Space Administration Photography Team, are also discussed.

Among the conclusions reached from this group of experiments are the following:

1. Small, hand carried, reasonably accurate, spectrum analyzers for the visible, possibly near ultra-violet and near infrared areas can be built. Review of the classified image intensifier work now in progress (Reference 3) shows that they can operate with high light gains and, by including their own illuminant, be used in darkness. It is also probable that they can yield emission spectra if a spark generator is included with the device.

2. Tri-stimulus sensors can be made portable and reasonably accurate. Their value is diminished since they yield chromaticity rather than spectra. Based on the foregoing work, an additional approach is suggested which merits full investigation. This concept envisions a TV type sensor with a special purpose computer which computes an algorithm capable of assigning objective color values to the sensor field viewed, despite a wide range of fluctuating illuminating conditions (Appendix III) References (4, 5 & 6).

3. Color stereo-effect sensors do not presently seem realistic in that the parallaxes are about the same magnitude as the random errors. This phenomenon constitutes a dramatic visual effect and could have other applicability, such as enhancement of visibility and the recognition of colored objects in unfamiliar visual environments.

( ) Numbers in parentheses refer to the Bibliography.

I. INTRODUCTION

1. Background. Color reporting is a vital part of geoscience exploration either on the earth or in other planetary exploration. Human vision and photographic recordings in themselves are highly subjective. Human vision is a psycho-physical sensation which varies with differing subjects and environmental conditions of heat, humidity, pressure, and incident illumination. In the strange environments of space this highly subjective sense becomes less trustworthy. Photochemical reactions of photographic films are biased by environmental factors and by the initial selection of the particular photosensitive chemicals and developers as well as the latitude of exposure and the nature of the incident illumination.

The measurement of color has been a nebulous area since it depends upon illumination, texture, surround and perception. Recording of the full Spectra is the only certain description of a color. The International Commission on Illumination (CIE - France) has defined a standard observer whose spectral response is defined in terms of tristimulus values; these values represent the amount of each primary color required to reproduce the sample. The part of this report concerned with tristimulus values will describe hardware designed around this principle and is described in Robertson (Appendix II).

Experimentation reported in a study for the Army Medical Corps by Hajos (7) has established that reflected light from color chips with a known dominant wave length can be photographed twice through a wedge prism sequentially rotated 180 degrees for each photo and thus yield a stereo effect because of the differential refraction of the light rays when compared to color chips whose dominant wave length is longer or shorter. Confirmation of this phenomenon is reported as part of this research.

II. INVESTIGATION

2. Portable Color Sensors (Robertson - Appendix II).

2.1. Spectrum Analyzer. White light from a GE Model PR2 Lamp in a flashlight reflector was passed through a Bausch & Lomb wedge filter and a narrow band of light frequency was allowed to fall on the sample to be tested. The reflectance of the sample was compared with a National Bureau of Standard White 3" x 5" Color Chip illuminated in the identical manner. By repetition of the above procedure at small wave length increments, a curve was drawn for the sample showing percent reflectance vs wavelength. A mathematical treatment of the curve also yielded tri-stimulus values for the sample according to the CIE coordinates.

The components were mounted on an optical bench as shown in Figure 1. The Components characteristics are shown in Table 1 as follows:

TABLE I
Component Characteristics of the Spectrum Analyzer

A. Wedge Interference Filter

Filter area	20mm x 65mm
Useful wavelength range	400-700 millimicrons
Average linear dispersion	5.5 millimicrons/mm
Peak transmittance	35%
Half width	10 millimicrons

B. Cadmium Sulphide Photocell

Wavelength sensitivity	400-800 millimicrons
Temperature range	-40°C to 60°C

Resistance

Ohms	at	Ft. Candles
10,000,000		0
1,000,000		1
200,000		10

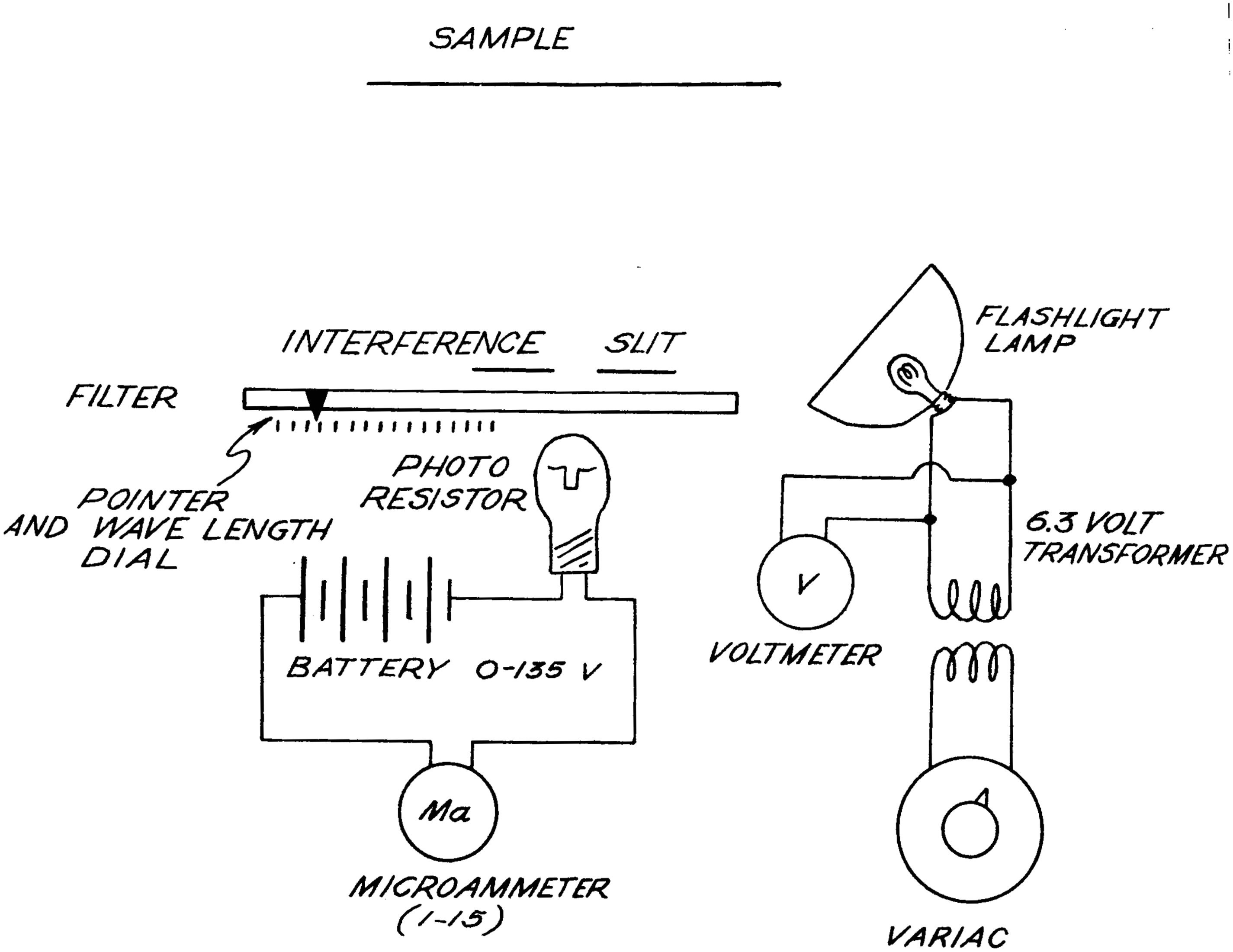

SAMPLE
INTERFERENCE FILTER
SLIT
FLASHLIGHT LAMP
POINTER AND WAVE LENGTH DIAL
PHOTO RESISTOR
6.3 VOLT TRANSFORMER
V
VOLTMETER
BATTERY 0-135 V
Ma
MICROAMMETER (1-15)
VARIAC

Figure 1

Light from the PR2 lamp was projected at 45 degrees on to a 3 x 5 inch painted color chip. A portion of the reflected light, normal to the plane of the sample was passed through a 2 millimeter slit, and a wedge type interference filter. The reflected light struck the detector, a cadmimum sulphide photoresister Lafayette Radio Electronics MS855. As resistance of the detector changed with illumination, the resistance was read as an electrical current on a microammeter.

Two calibrations were required in operation. First, a wave length calibration of the wedge filter was performed by comparison with the color chips of known characteristics. This was done by illuminating the slit with monochromatic light from the lamp, then adjusting the wedge for maximum current through the detector, repeating in increments of 30 millimicrons throughout the spectrum. Next, the wave length response of the system was calibrated since the microammeter reading depended upon the spectral distribution of lamp output, detector, and transmission characteristics of the wedge filter as well as the reflectance of the sample.

In operation the wedge filter was moved across the slit between 400 and 700 millimicrons. The readings were corrected by the use of calibrated multipliers and a reflectance curve was drawn.

2.1.1. Results. The results of testing two color chips are shown in Table II.

TABLE II
Spectrum Analyzer Values for Two Samples

Wavelength	Reflectometer Value (% Reflectance)	True Value (% Reflectance)
	Sample 33538	
450	11.8	3.0*
510	21.8	28.0
520	66.2	63.0
630	75.5	76.0
690	54.0	79.0*
	Sample 27144	
450	30	27
510	17	15
520	15	11
630	22	26
690	31	28

* Ref. Paragraph 2.1.2

Despite the elementary nature of this device, the largest error in reflectance (other than blue or red) was 7.2%.

2.1.2. Conclusions.

a. It was concluded that: the spectrum analyzer is feasible for objective color sensing, although the wedge interference filter transmits a small amount of blue at the red end of the spectrum because of second order interference. Placing a yellow filter over the red end can help this condition.

b. A condenser lens placed in front of the light source would concentrate the sample illumination into a smaller area and yield a more positive response.

c. The cadmimum sulphide photoresistor has a poor blue response which accounts for the error in the low end of the spectrum. Using a vacuum tube resistor could help this condition.

2.2. Prototype Tri-Stimulus Reflectometer. In the Tristimulus Reflectometer, three filters were obtained from Gardner Laboratories Inc. These filters duplicate the tristimulus spectral transmission curves of the CIE standard observer. An additional correction was built in to compensate for the spectral distribution of the illuminant and sensitivity of the detector. Barrier layer cells which produce electrical current as a function of incident illumination have a low sensitivity. Three barrier layer cells were arranged as shown in Figure IV; the circuit included a voltage regulator, a variable transformer and a filament transformer combined to provide 3 volts regulated AC to a PR13 lamp. An optical galvanometer with a 1000 Ohm resistance was used to record the resistance. Three by five inch Federal Standard 595 Color Chips were used for calibration, and measurements were made on the cards through the three filters. A quantitative treatment of this method is given in Appendix II.

The breadboard model was mounted on a bench, with the color chips placed three inches from the illuminating lamp. Each of the three filters in turn were placed over the lamp and the colored light allowed to fall on the surface of the color chip so that the reflected light returned to the barrier layer cells which were mounted at an angle of 45 degrees to the color chip. As the reflected light was received by the barrier layer cells, the deflection of the galvanometer was noted. Three readings were made, for each color chip one reading for each filter, corrections were then applied and the tristimulus values computed from the appropriate formula: (Appendix II).

2.2.1. Results. Upon calibration of the light source and the system, 14 Federal Standard color chips were tested as sampled; the results are listed in Table 3 Appendix II. The Mean Xe (error in X)= .0060; Mean Ye (error in Y)= .0063; Mean Ye (error in Y)= .0095. All errors are expressed as units of the chromaticity scale.

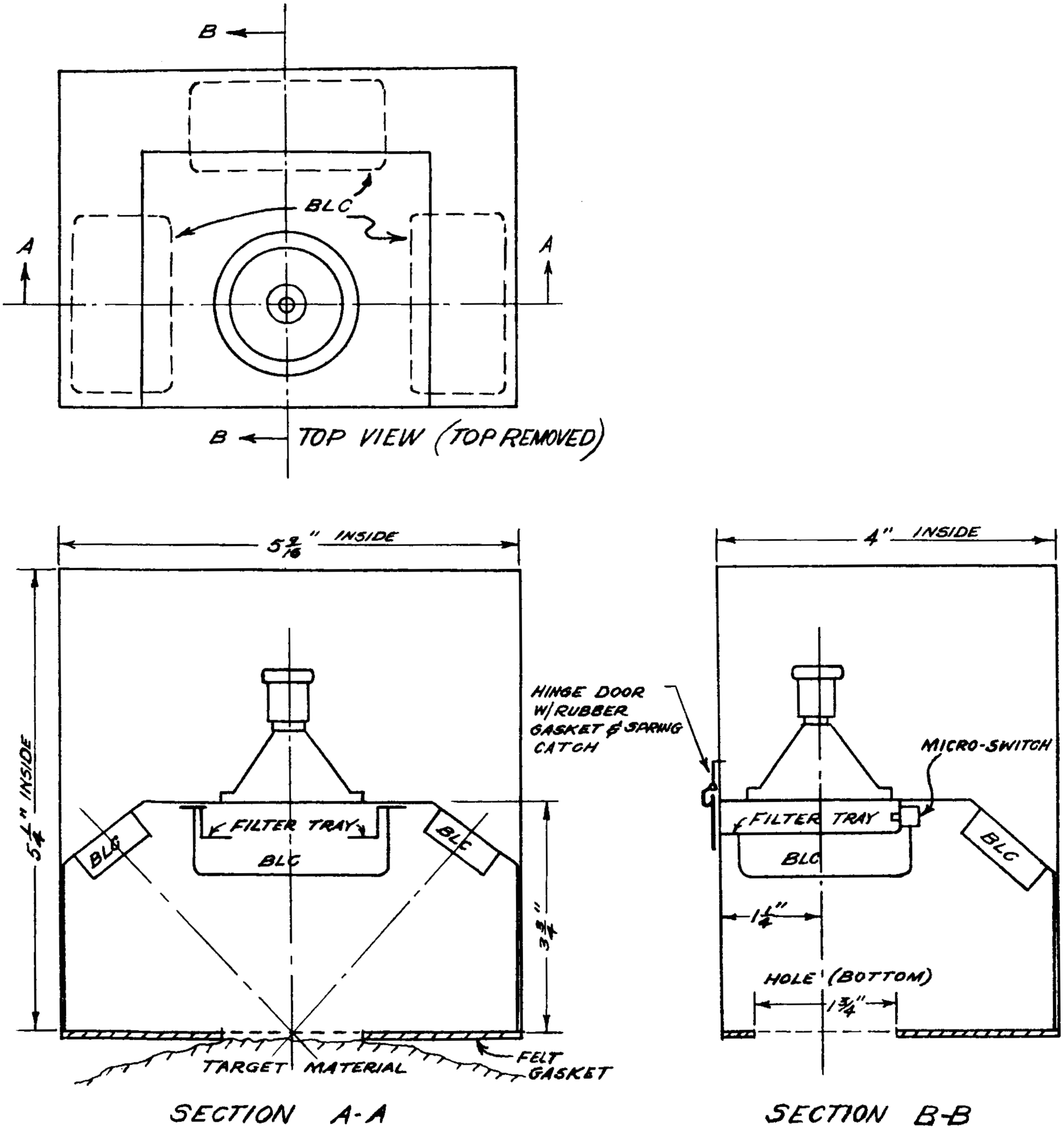
2.2.2. Conclusions. The Tri-Stimulus Reflectometer is a simple instrument which can be quickly set up and operated with a minimum requirement for judgement or skill. Three readings are required in order to obtain a set of tristimulus values, with the present breadboard device. In a fully developed device, the three readings would be made simultaneously and computation by a small analog computer would yield immediate chromaticity values.

2.2.3. Portable Tristimulus Reflectometer. The breadboard model of the Tristimulus Reflectometer was assembled on a bench, powered by standard 115 Volt current reduced by transformers. In order to make the instrument portable for field use, a housing was designed and fabricated, (Ref. Figure 2) a power source and voltage regulator were designed (Ref. Figure 3) and the entire assembly, as shown in Figure 4., was the field tested.

In order that a field device be practical, it was essential that it operate at low power levels. It was originally assumed that the low voltage requirements of the Reflectometer could be satisfied with Mercury D cells, 1.35 V (BA 1030/U), however the cells had an inherent instability which affected the color temperature of the readings. A voltage regulator was designed, based on circuitry used in electronic field surveying instruments. In its final form the regulation of voltage was 0.4% per 10 minutes of operation. The most stable arrangement for the power pack included a 6 volt Hotshot battery.

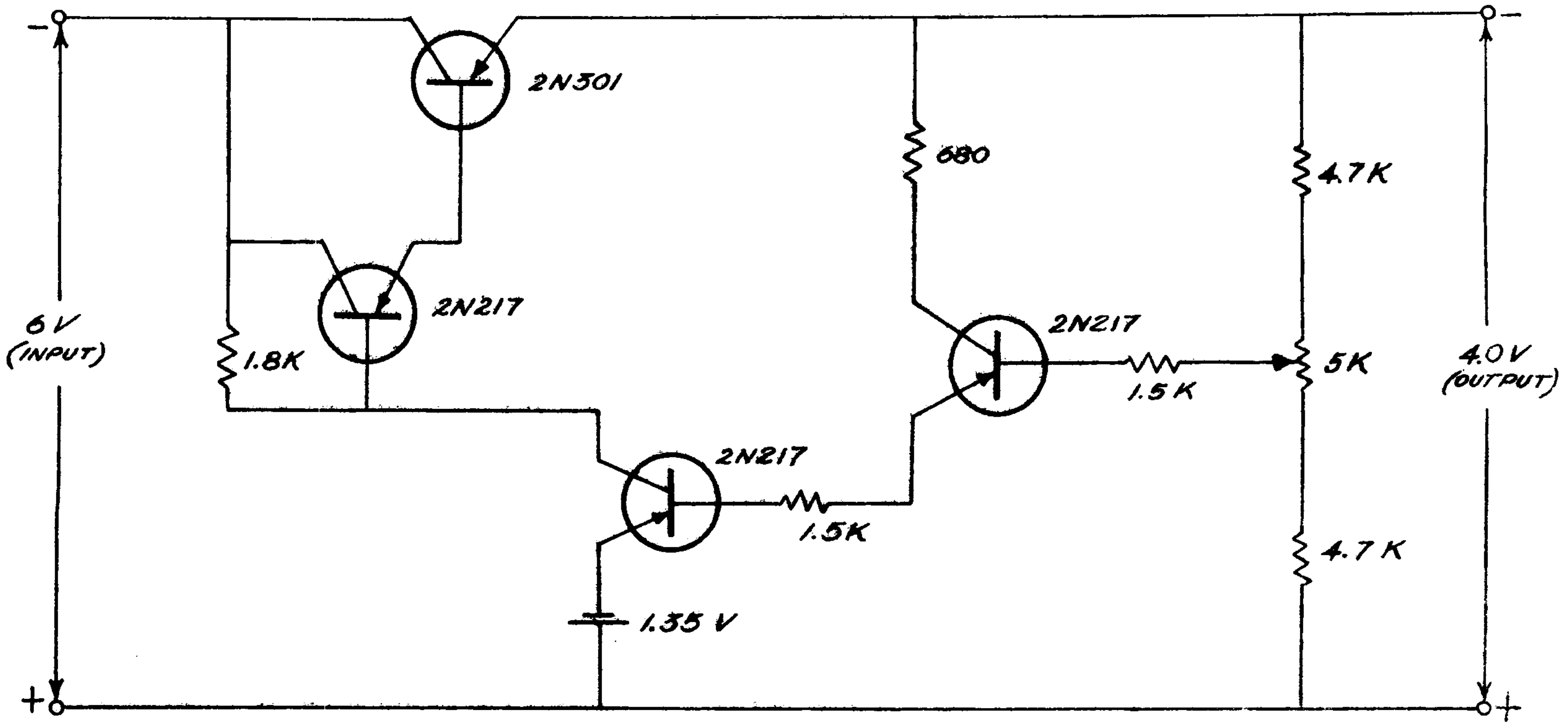
2.2.3.1. Field Test-Color Chips. Upon completion of the circuitry and illumination problems, twelve Federal Standard Color chips were used to obtain a set of Filter Correction Factors. These are listed in Table III and illustrated in Figure 5.

2.2.3.2. Soil Samples. A final test of the Portable Tristimulus Reflectometer was made with soil samples and data supplied by the Combat Research Branch. The samples were jars of desert soils collected from different locations throughout Western United States. All of the samples (38) had been measured on a Beckman P.V. Spectrophotometer to determine their spectral characteristics and their tristimulus values. The loose soils were placed in circular culture dishes (Petri) 3 inches in diameter by ½ inch in depth, smoothed, and made flush with the top of the dish, tapped at the bottom to assure a uniform surface (Ref. Figure 6). The reflectometer was inverted and placed over the sample, with the aperture, 2 inches in diameter, completely covered by the sample. A black velvet cloth draped over the box cut off all stray light allowing only the light source to illuminate the sample. Figures 7 and 8 illustrate the method of operation.



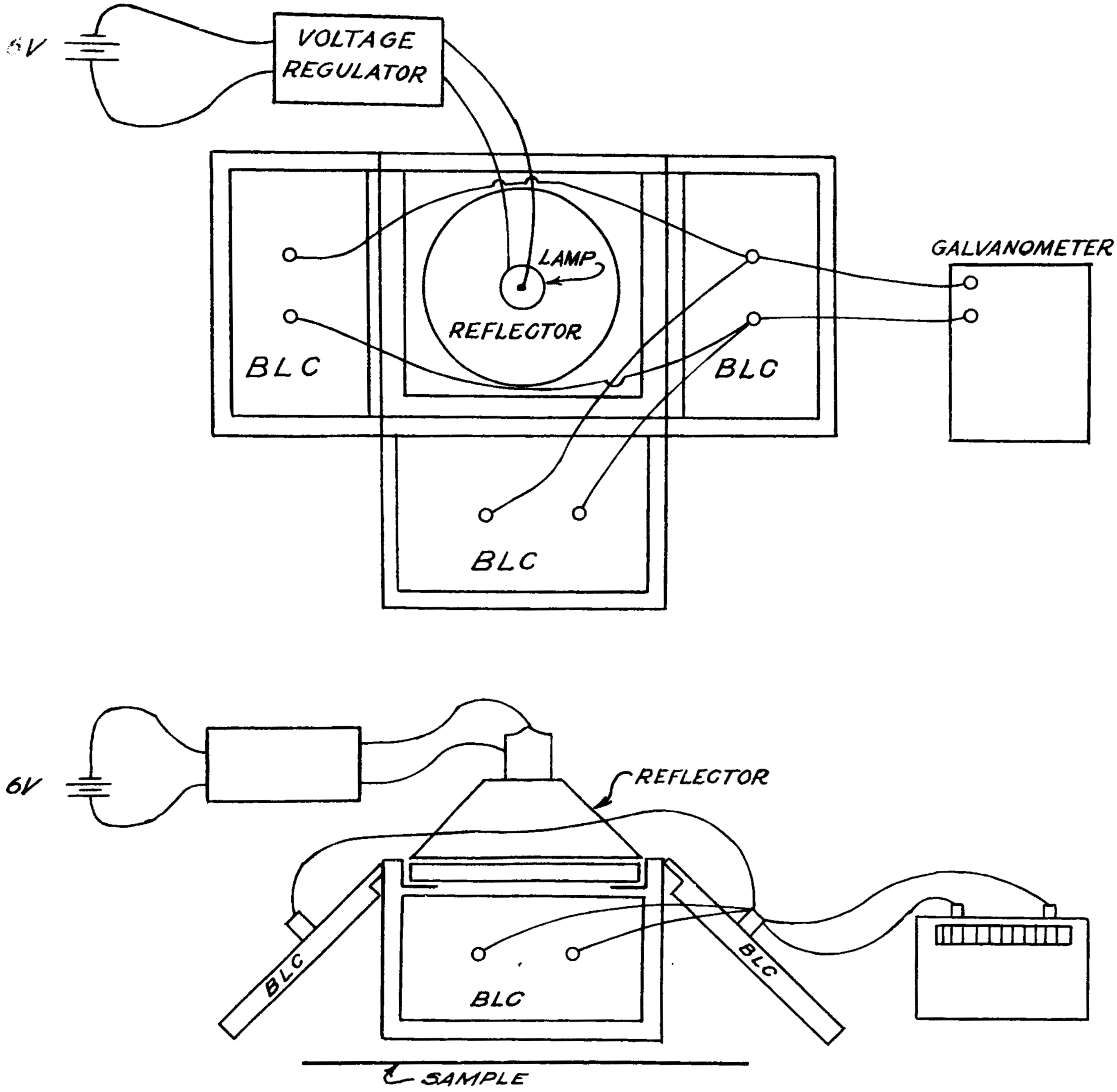
PORTABLE THREE FILTER REFLECTOMETER
WITH PRINCIPAL DIMENSIONS

Figure 2



VOLTAGE REGULATOR USED TO STABILIZE BATTERIES

Figure 3



THREE FILTER REFLECTOMETER

Figure 4

TABLE III. FILTER CORRECTION FACTORS FOR THE PORTABLE TRISTIMULUS REFLECTOMETER

Fed Std No.	Tristimulus Values			Green Reading	Amber Reading	Blue[1] Reading	Fx (10^{-2})	Fy(10^{-2})	Fz(10^{-2})
16307	.2751	.2871	.3141	36.3	33.5	35.5	.643	.791	.897
20109	.1403	.1101	.0740	13.8	17.6	7.5	.717	.798	1.060[2]
36307	.2949	.3069	.3313	37.5	35.0	35.7	.663	.818	.928
36231	.2213	.2300	.2809	27.6	25.0	30.3	.672	.833	.927
34277	.2372	.2663	.3049	33.2	27.5	34.0	.652	.802	.897
30277	.2745	.2796	.2129	35.3	35.5	23.0	.659	.815	.926
30313	.3243	.3098	.2660	39.9	42.3	29.5	.647	.776	.902
30111	.1152	.0988	.0799	12.2	14.4	8.1	.695	.810	.986
30219	.2121	.2011	.1409	25.0	27.1	14.9	.684	.804	.946
30099	.0866	.0834	.0625	10.8	11.0	6.6	.679	.772	.947
34148	.1228	.1435	.1780	17.3	12.9	19.0	.690	.829	.937
30109	.1374	.1052	.0622	13.8	18.2	6.5	.690	.762	.957

Average Filter Factors

Fx	Fy	Fz
.674 (10^{-2})	.801 (10^{-2})	932 (10^{-2})

[1] Each reading has to be corrected to 0 by subtracting .5 unit.

[2] Omitted as being too far out of line.

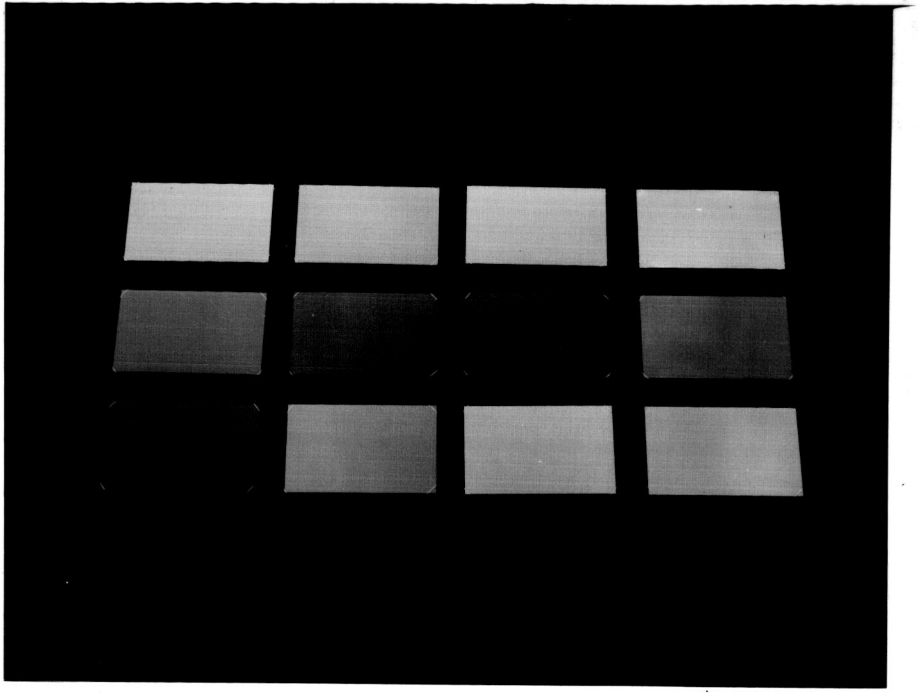


Figure 5

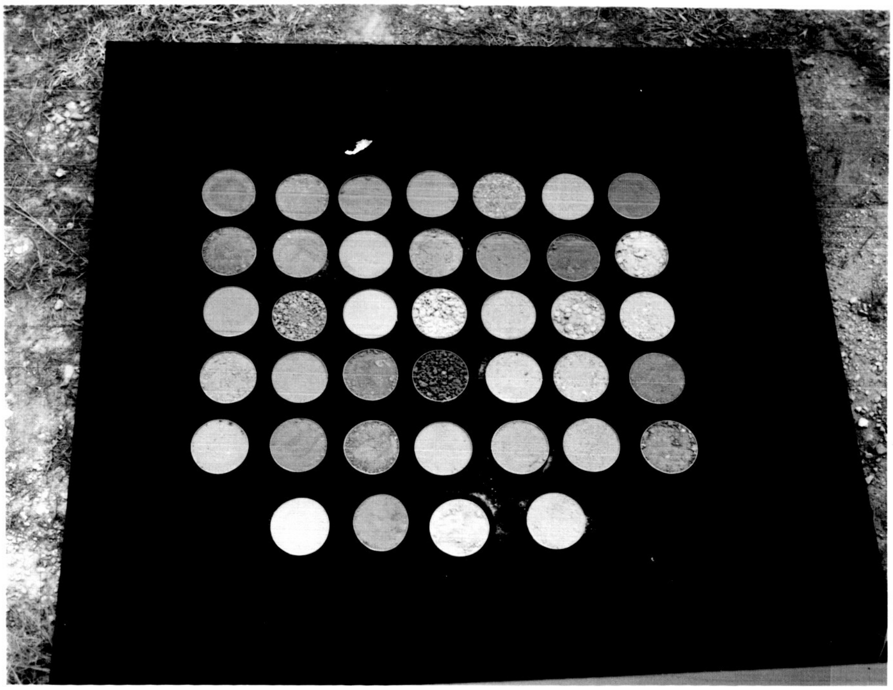


Figure 6

Measurements were made with the instrument at five different positions on the soil sample, thus integrating the surface of the sample. A warming up period of 1 minute allowed the barrier layer cell output to drop so that the output change approached zero, thus a more accurate reading was made.

2.2.3.3. Results. The results of the measurement of the 38 soil samples, each measurement being repeated 5 times, are shown in Table IV. The calculated tristimulus value represents the value for each component obtained by applying the correction factor to each reading, and averaging the 5 readings. The correct tristimulus value represents those obtained in 1951 by the Materials Laboratory, Engineer Research and Development Laboratories on the Beckman D. U. Spectrophotometer. A statistical analysis of the errors was performed and the mean errors were as follows:

		Standard Deviation
x=	.00122	.00496
y=	.00303	.00581
z=	.00722	.02489

Measurements are in units of the tristimulus values.

2.2.3.4. Conclusions. Although there are several spectrophotometers on the market which can be used in the field, the author is not aware of any employing the particular principles involved in the Tristimulus Reflectometer. The feasibility study has proved the practicability of this particular objective color sensor. The total weight of the prototype portable Tristimulus Reflectometer with two Everready BA-44 batteries is 27 pounds. The accuracy of the system approaches the accuracy of the large laboratory spectrophotometer.

3. Color Stereo-effect (Determination of Relative Color Values By Parallactic Displacement). In the quantitative analysis of the Color Stereo-effect, several experiments were performed. The first experiment was based on an extension of the work done by Hajos (7). A Federal Standard 595 Blue painted Color chip 615 mu, 79% purity and a FS 595 Red painted Color chip 476 mu, 55% purity were mounted on an easel at eye level. A graflex 4 x 5 inch format camera equipped with an 8½ inch focal length Ilex lens was mounted on a tripod and centered on the easel. The two color chips were photographed through a stock Edmunds Scientific Company 3235 Wedge, prismatic 37 x 18 mm of crown glass, at a distance of 120 inches (Reference Figure 9). One exposure was made with the prism base parallel to the camera lens so that the reflected image of the chips was displaced toward the right at the negative plane, a second exposure was made after rotating the wedge so that the reflected image of the color chips was displaced toward the left at the negative plane. When both photographs were processed and examined with a stereoscope,

PORTABLE THREE FILTER REFLECTOMETER
Figure 7

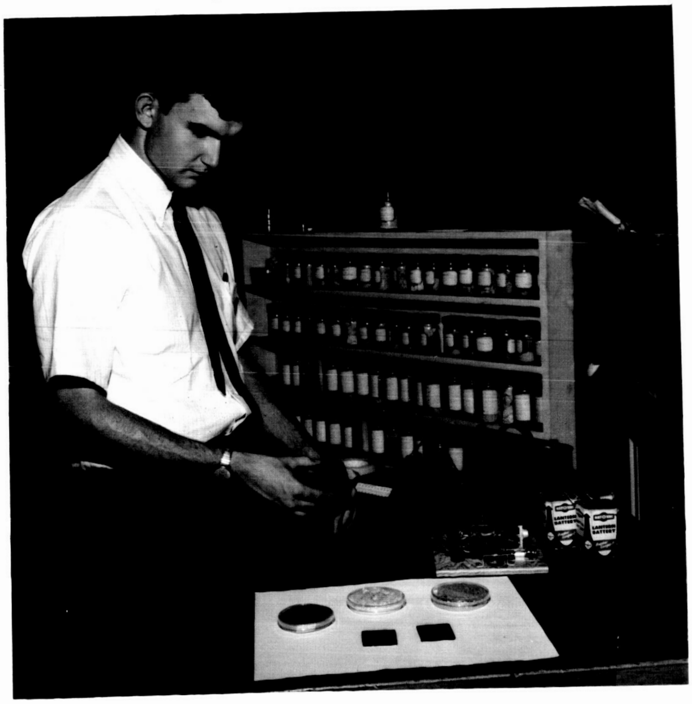


Figure 8

TABLE IV. - CHROMATICITY COORDINATES OBTAINED FROM 38 SAMPLES OF DESERT SOIL COMPARED TO PREVIOUSLY ESTABLISHED COORDINATES OBTAINED ON THE BECKMAN D.U. SPECTROPHOTOMETER

SOIL SAMPLE	x^1	x^2	y^1	y^2	Y^1	Y^2
3	.403	.390	.360	.344	.142	.120
4	.388	.393	.365	.367	.207	.204
7B	.394	.364	.367	.368	.177	.132
*8A	.356	.341	.334	.342	.081	.093
9A	.416	.411	.367	.363	.157	.132
10	.413	.414	.374	.370	.193	.204
13	.369	.366	.364	.349	.239	.253
15	.347	.349	.344	.339	.255	.263
*16	.351	.349	.355	.340	.421	.322
18	.360	.355	.360	.357	.266	.268
*19	.373	.364	.367	.363	.193	.182
*19A	.360	.358	.361	.356	.323	.273
21	.371	.372	.365	.366	.202	.188
22	.361	.359	.356	.353	.389	.320
23	.375	.378	.362	.259	.260	.265
S1	.387	.383	.390	.390	.285	.269
S2	.355	.363	.351	.350	.315	.260
S3	.394	.395	.357	.358	.161	.137
S5	.381	.424	.363	.365	.293	.178

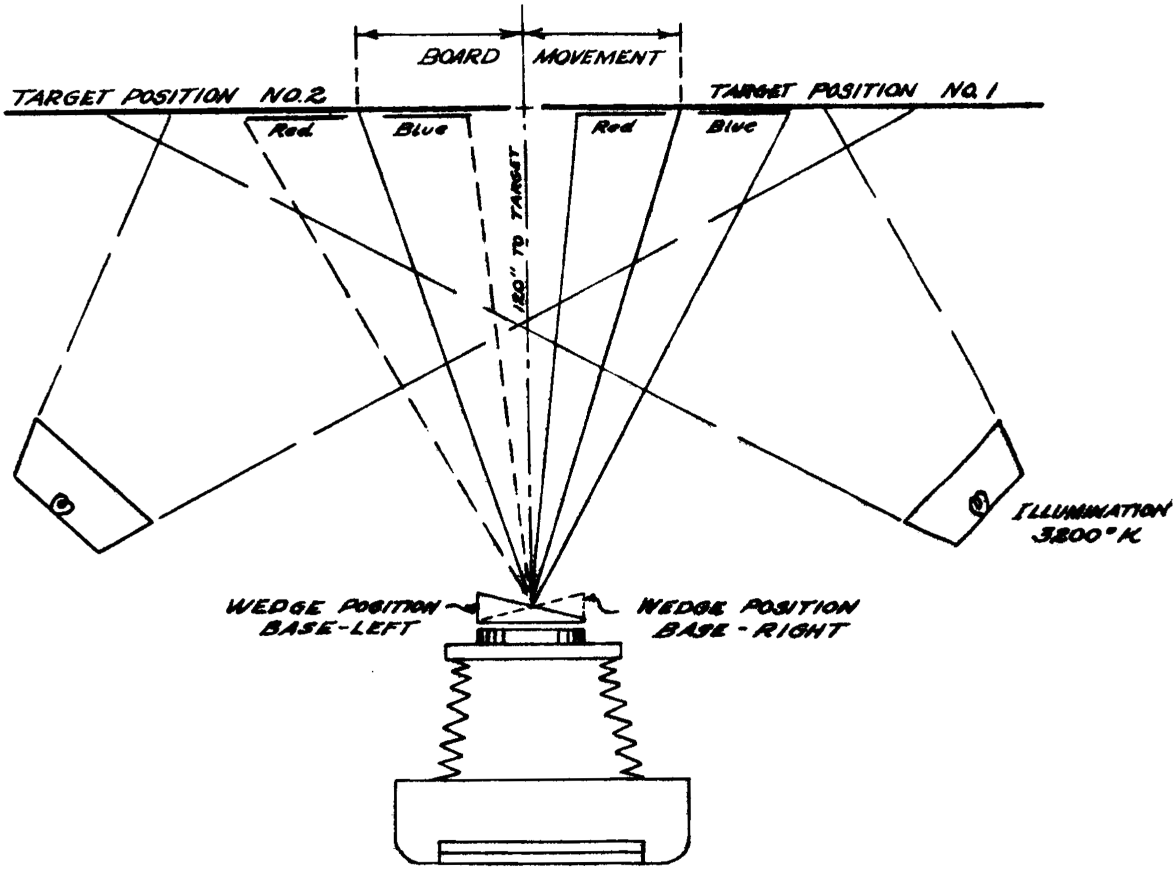
CONTINUED

SOIL SAMPLE	x^1	x^2	y^1	y^2	Y^1	Y^2
S6	.395	.391	.376	.377	.257	.271
S7	.389	.386	.359	.360	.192	.171
S9	.371	.371	.358	.348	.204	.209
S10	.394	.387	.359	.362	.146	.160
S11	.373	.373	.348	.343	.156	.125
S12	.377	.377	.366	.371	.262	.181
S13	.368	.366	.366	.359	.208	.187
S14	.382	.386	.364	.361	.216	.149
S17	.420	.413	.366	.373	.188	.113
S18	.408	.408	.368	.366	.194	.123
S19	.377	.376	.349	.342	.154	.125
S20	.376	.382	.370	.357	.308	.223
S21	.419	.417	.370	.365	.189	.118
S24	.379	.379	.350	.349	.157	.115
S25	.390	.391	.363	.362	.243	.150
S26	.372	.378	.351	.347	.201	.151
S27	.383	.386	.362	.359	.228	.161
S29	.393	.397	.357	.358	.163	.103

*aggregate sample composed of particles with granular size in excess of ¼" in diameter.

X^1, Y^1 Y^1 - Beckman D.U. Spectrophotometer

X^2, Y^2 Y^2 - Portable Tristimulus Reflectometer



SINGLE WEDGE FOR STEREO EFFECT WITH
BOARD MOVED TO COMPENSATE FOR DISPLACEMENT

Figure 9

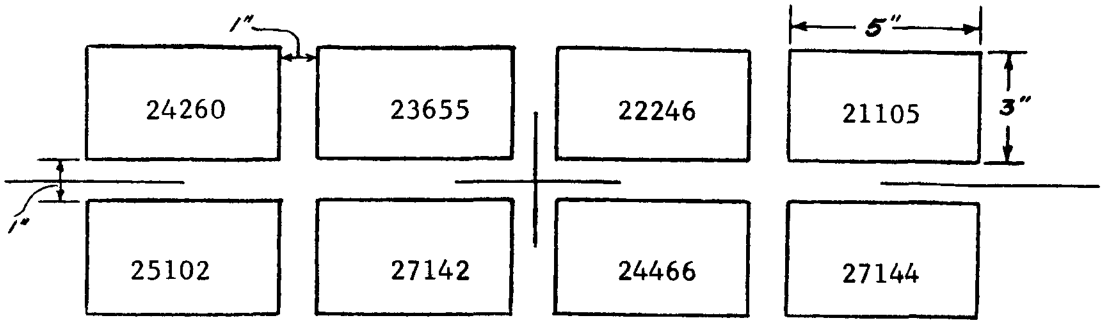
it was apparent that a relative parallax existed which placed the red image at a lower plane than the blue image, although they were in the same plane on the easel. This effect is analogous to the prismatic defect of the human eye.

The first experiment was performed in a photographic studio with an artificial light source rate at 3500 degrees Kelvin temperature. Further experiments were completed with a group of four FS 595 Color Chips; the colors used were red, blue, green, and yellow. Photographs were made with a Polaroid Camera through a 10 degree Lucite wedge designed at GIMRADA and fabricated in the Model Shop, ERDL. The photography was exposed in daylight at approximately 4500 degrees Kelvin temperature. The relative differences were noted as parallaxes when viewed through a stereoscope. Black and white Polaroid prints as well as Polacolor both produce similar effects. A more elaborate test based on a test plan "For the determination of Relative Color Values by Parallactic Displacement" dated 3 February 1965, was performed in full sunlight.

3.1.1. Field Test. Eight Federal Standard 595 Color chips ranging from 476.4 mu to 619.0 mu were mounted on a black painted board (Reference Figure 10). The color chips were photographed through several combinations of optical wedges, including the 10 degree Lucite wedge, a flint glass 9 degree 57 minute wedge fabricated by McMinn Optical Company, and combinations of both Lucite and flint glass wedges. Figure 11 illustrates the wedge positions; Figures 12, 13, 14 and 15 reproduce the resulting photographs. The color stereo-effect persists under poor image forming conditions. Examination of Figures 14A and 15A with a stereoscope demonstrates the persistence of the effect when the images are edge enhanced by Xerox printing. Figures 12, 13, 14, 15, 14A and 15A should be examined with a stereoscope to determine the color stereo-effect.

The optical wedges were used in combination to yield the optimum image definition and the maximum color diffraction for the determination of parallactic displacement. Camera lenses of 100mm, 127mm, 135mm, and 200mm focal lengths were employed in the field tests. Test photographs were exposed at varying distances to the target. The exposures were varied as much as 64 times over exposure based on the theory that binary (black and white) images would have no fringes. Despite the extreme over-exposure, fringing effects interfered with precise measurement.

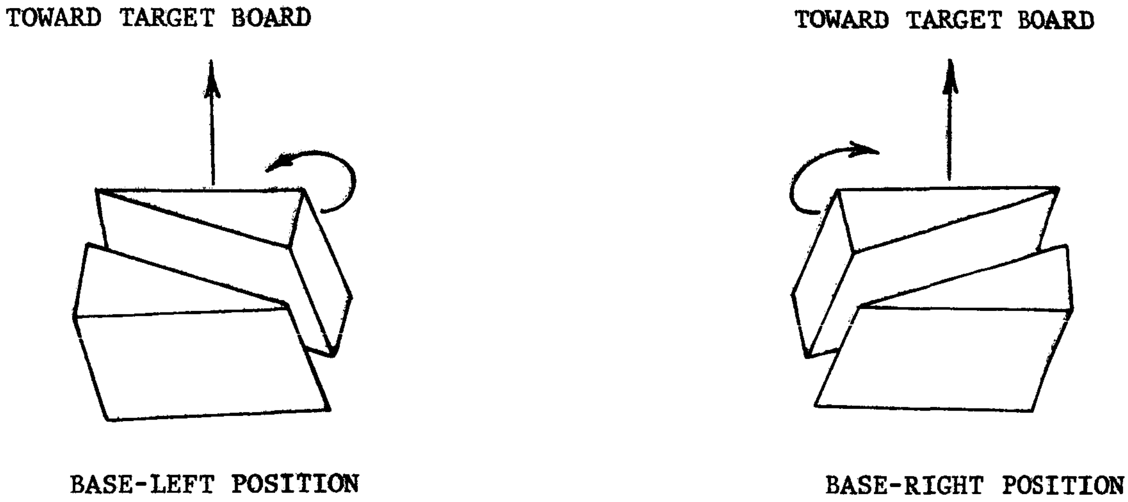
3.1.2. Results. Photography obtained with the flint glass wedge had the maximum stereo-effect from the color diffraction, however the diffraction of the colors caused the imagery to suffer in resolution. Less color diffraction was produced by the Lucite wedge, thus yielding better edge definition for the imagery. Combinations of Lucite and flint glass wedges minimized the diffraction of the colors which aided the resolution, yet the distortion of imagery was too great to permit accurate parallax measurements. Table V represents the results of measurements made by



Color Chip No.	Predominant Wave Length	Color
21105	610.0	RED
22246	596.8	ORANGE
23655	578.5	YELLOW
24260	518.0	GREEN
25102	476.4	BLUE
27142	508.0	PURPLE
24466	550 (APPROX)	LIGHT GREEN
27144	500 (APPROX)	LIGHT PURPLE

RELATIVE POSITION AND COLOR OF TEST COLOR CHIPS AS MOUNTED ON TARGET BOARD.

Figure 10



COMBINED WEDGES FOR STEREO EFFECT. FRONT ELEMENT ROTATED TO SIMULATE VARIABLE WEDGE ANGLES AND TO MINIMIZE DEVIATION WHILE MAXIMIZING REFRACTION AND DISPERSION

Figure 11

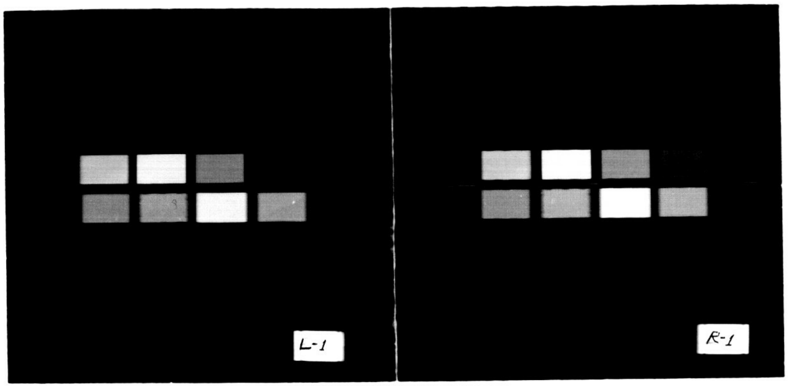


Figure 12

STEREO PAIR FROM 10 DEGREE LUCITE WEDGE.
NORMAL EXPOSURE, 8.5 INCH LENS, 14.8 FEET TO TARGET

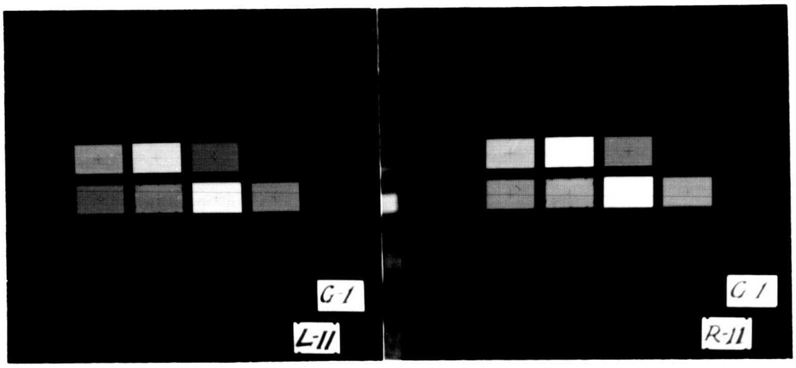


Figure 13

STEREO PAIR OBTAINED WITH COMBINED LUCITE
WEDGES. FRONT WEDGE ROTATED 30 DEGREES

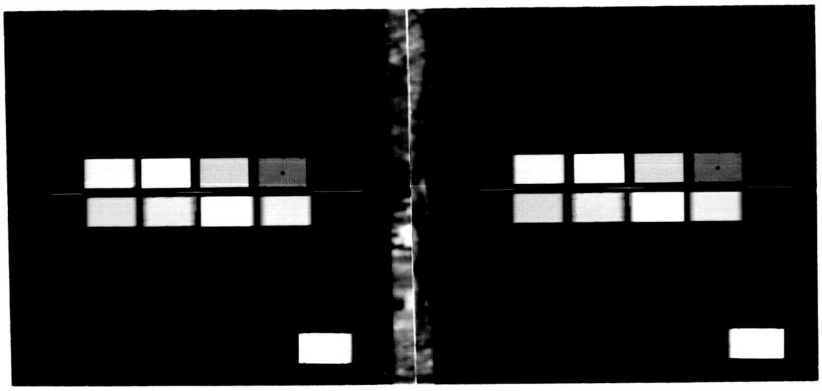


Figure 14

STEREO PAIR OBTAINED WITH COMBINED LUCITE AND FLINT GLASS WEDGES. ELEMENTS IN 180 DEGREE OPPOSITION. 8.5 INCH LENS, 14.8 INCH LENS, 14.8 FEET TO TARGET

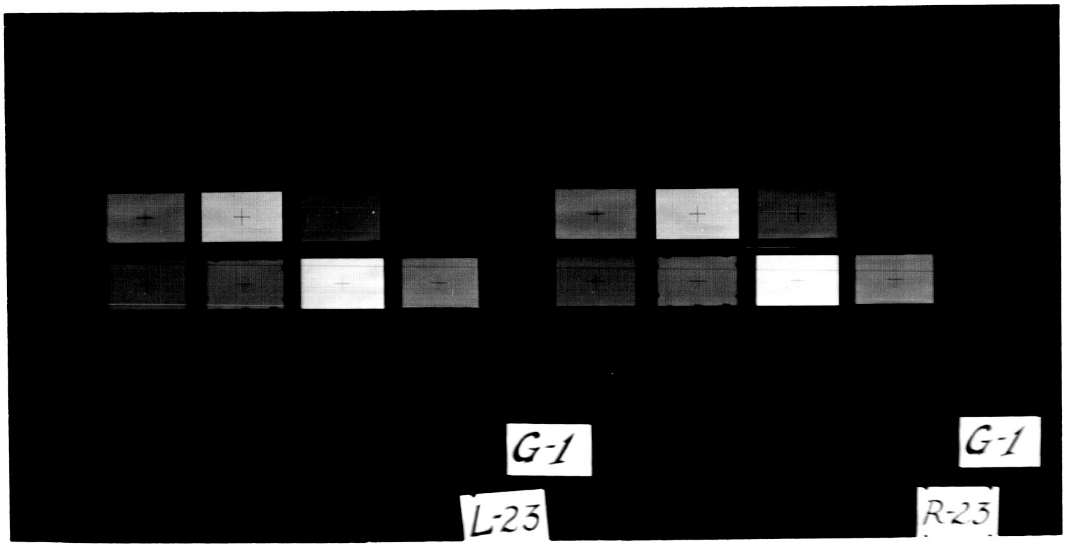


Figure 15

STEREO PAIR OBTAINED AS IN PRECEEDING FIGURE WITH COMBINED WEDGES. 135mm LENS, 69.5 INCHES TO TARGET

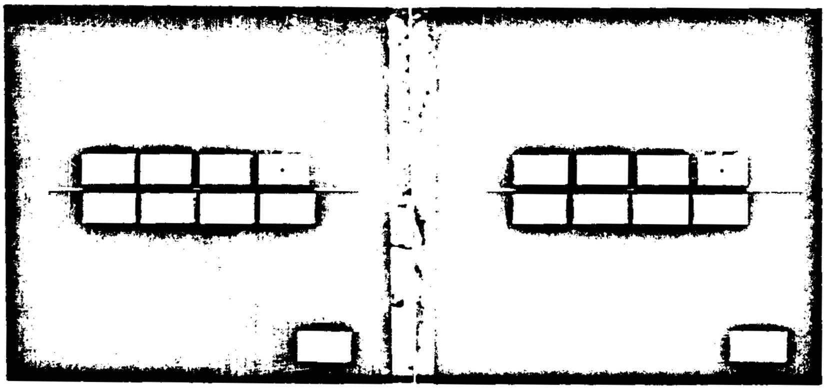


Figure 14 A

STEREO PAIR OBTAINED WITH COMBINED LUCITE AND FLINT GLASS WEDGES. ELEMENTS IN 180 DEGREE OPPOSITION. 8.5 INCH LENS, 14.8 INCH LENS, 14.8 FEET TO TARGET

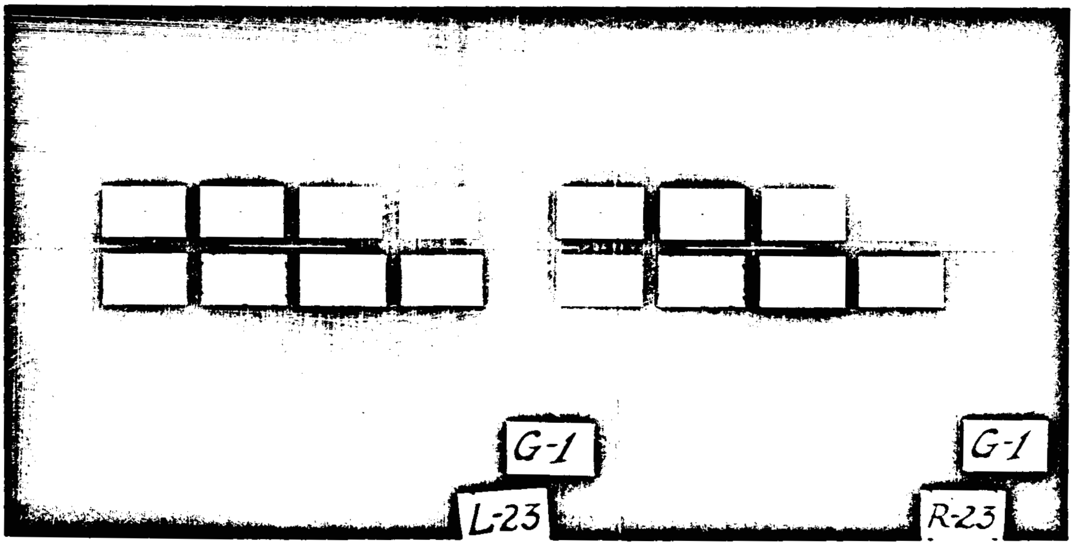


Figure 15 A

STEREO PAIR OBTAINED AS IN PRECEEDING FIGURE WITH COMBINED WEDGES. 135mm LENS, 69.5 INCHES TO TARGET several observers who used a Zeiss stereomicrometer while viewing the imagery through a Bausch & Lomb mirror stereoscope. All of the measurements are relative to the position of the red color chip (615.0 millimicrons). Efforts to measure the parallax differences on a Wild coordinatograph were not successful since the "fringing" effects caused by color diffraction resulted in a low confidence level of measurement.

3.1.3. Conclusions. It was concluded that:

a. Imagery is displaced when photographed through an optical wedge, being directly related to the wedge angle as well as the wavelength of reflected light.

b. The displacement is also relative to the wavelength of reflected light of other imagery in the same scene. This creates a "color stereo-effect".

c. The displacement is observable in both black and white and in color photography.

d. The displacement of imagery is measureable as parallax with viewing instruments of limited precision. The effect persists even when electrostatic (Xerox) images of the photos are viewed in a stereoscope.

e. The phenomena which produces the parallax displacements, also produce a color fringing effect causing comparatively poor resolution thus interfering with precise parallax measurements. Other recording means or edge-enhancement techniques may eliminate fringing and should be explored.

d. From examination of Table V it is apparent that the measurements made in these tests are of limited value since the parallax differences are so small that differentiation becomes difficult.

e. Although refined data was not obtained as the result of the foregoing experimentations, under special circumstances, this technique could prove a useful tool for making crude distinctions of color. Photographic emulsion is not a necessary adjunct to the system and the difference in parallax might be measured by other sensors, by recording or enhancing media.

4. Multispectral Photography Experiments. During the feasibility study for objective color systems, support was given the NASA Photography Team as requested by Dr. Peter Badgeley, NASA. One area of research was in study of the degradation of photographed scenes in color across the angular field of a wide angle camera lens. Work in this area was performed in cooperation with Dr. R. N. Colwell, Professor of Forestry, University of California, Berkeley.

TABLE V. - PARALLAX MEASUREMENTS IN MILLIMETERS

	OBSERVER I.	OBSERVER 2.	OBSERVER 3.	OBSERVER 3.	Δp^1	Δp^2	Δp^3	Δp^4
Red	50.820	50.940	50.805	50.850				
Orange	50.760	50.835	50.650	50.655	+.060	+.105	+.155	+.195
Yellow	50.700	50.960	50.670	50.705	+.120	-.020	+.135	+.145
Green	51.000	51.140	51.140	51.220	-.180	-.200	-.335	-.370
Blue	51.670	51.335	51.560	51.280	-.850	-.415	-.755	-.575
Purple	51.260	51.190	51.065	51.185	-.440	-.250	-.260	-.335
Lt. Green	51.140	51.185	51.055	51.220	-.320	-.245	-.250	-.370
Lt. Purple	51.540	51.470	51.560	51.600	-.720	-.530	-.755	-.750

Δp=difference in base distance between red color chip images and other color chips images in stereo model.

4.1 Preliminary Report on a Multispectral Experiment, (8). Experiments based on a test plan prepared by Dr. Colwell, were performed at the University of California, Berkeley, on January 20, 1965. Inclement weather forced postponement of tower photographic tests at Davis, California, however, two rows of 4' x 4' painted masonitepanels were photographed from an elevation of 60 feet with a Speed Graphic 4 x 5 inch camera equipped with a 127 focal length lens which has a field of approximately 45 degrees. Several film/filter combinations were exposed and some useful data obtained by study of densitometer measurements on the negatives. The report has previously been furnished NASA.

4.1.1. Conclusions. From limited data obtained during the experiment, it was concluded that:

a. Photography exposed through a 45° angle refracting lens corrected for chromatic aberration would be acceptable for photographing a scene in color without appreciable loss of color reflectivity throughout the field

b. Reflectivity differences may be compensated for, or removed by calibration.

4.2. Supplement to a Preliminary Report on a Multispectral Experiment, (9). A low altitude photographic flight was made over an array of color panels placed on the campus of the University of California on December 3, 1964. The target array was composed of seven colors; blue, chartreuse, Green, Brown, Rust, Yellow and Red and five shades of gray. Each color was composed of 6 - four by four foot masonite panels with a total area of 96 square feet. A T-11 aerial mapping camera equipped with a six inch focal length METROGON lens, (not color corrected), 9 x 9 inch format was operated in a runaway mode, mounted in a NASA Convair aircraft. The aircraft was flown over the target array, and the photographer managed to obtain photos with the target array in five different angular positions with respect to the nadir point.

4.2.1. Conclusions. Although the photography was in color, microdensitometer readings were made without color filters, since the imagery was so small (0.75mm x 1.00mm) that available color densitometers were not equipped to read such small areas. Based on microdensitometer traces from the Ansco No. 4 Microdensitometer, it was concluded that the 7 colors could be differentiated but with a high probability of confusion of Chartreuse, Grey, Red, Rust and Brown at a scale of 1:3,240 despite the small size of the images exposed at a low sun angle of 18 degrees. The photography was exposed at 1545 hours on December 3 at Latitude 38° N. Each of the five positions was directly related to the density of the imagery, as expected. The panel positions farthest from the nadir had the least density and greatest percent transmittance.

4.3. <u>Multispectral Experiment No. 2, (10)</u>. The encouraging results obtained from the limited tests (Paragraph 4.1.) conducted in January 1965, led to further tests at the University of California, Davis. Three rows of color panels were laid out at the base of a 144 foot tower. Thirty film/filter combinations were exposed and densitometer measurements prepared from all photographic negatives.

Color transparencies were measured on an Ansco-McBeth color densitometer equipped with blue, red and green filters; while the black and white Tri-X and Infra-red negatives were measured with the Welch Densichron.

4.3.1. <u>Conclusions</u>. From data obtained in the above experiment it was concluded that:

a. The results of Multispectral Experiment No. 2 reinforce the conclusions of the first Multispectral Experiment, namely that photography exposed through a 45° lens suffers a slight loss in color reflectivity. For well chosen film/filter combinations these losses are nearly linear regardless of wavelength the losses are thus calibratable at least out to 40° field of view.

b. The use of a number of narrow-band Bausch & Lomb Interference filters in combination with Tri-X Panchromatic film, orthochromatic film, Ektachrome and Ektachrome IR film provide a similar result, except that the design of each filter affect the transmission of the dominant wave length.

5. <u>Color Identification by Data Classification (Appendix III)</u>. A classification technique which is used to identify the colors of photographed scenes by the sensitometric response from a densitometer, regardless of a range of response variability because of different film/filter combinations and cameras was applied to data obtained from Multispectral Experiment No. 2. The data was measured from black and white film negatives on a Welch Densichron Ninety-six measurements of three rows of eight color panels, photographed on Tri-X panchromatic film with three different filters are represented in Appendix III. Selections were made of the 1st and third rows of panels which expressed both the greatest differences in their density for the same color panel, and those which expressed the least differences in their densities. Extraction techniques involved the identification of the second, or middle row of color panels, solely by the development of several matrices.

5.1. <u>Conclusion</u>. From the above exercise, it was concluded that:

a. Seven of eight unknown colors were correctly distinguished by this method despite the inability to sort them directly by the use of their gray scale, which had overlapping ranges of measured values.

b. The red colors (rust, red, and brown) provided the greatest sorting problem.

c. This limited exercise indicates a direction of research which should be followed further to determine scene colors by the use of a densitometer on black and white photography and a computational classification.

d. The method outlines above could also be used to develop optimum film/filter combinations for a particular color response. Since the feedback from the method indicates which combinations give the best "clumping" of data.

e. The results of the classification method are encouraging since straight forward computation, without weighting factors was employed. Further, investigating should reveal a basis for weighting certain measured values with a consequent ability to sort colors by this method.

III DISCUSSION

6. Portable Color Sensors. - Two types of color sensors were studied and developed under this contract. A Spectrum Analyzer, based on a wedge filter calibrated from a known light source against several color cards with known spectral characteristics, was constructed on an optical bench. The feasibility of this item was demonstrated by the results obtained and reported in Table I. A prototype tri-stimulus reflectometer was also constructed on an optical bench. This item employed a single white standard to measure color temperature, which was calibrated by using a constant based on the standard and measured the response of the target through three glass filters simulating eye response sensing. Encouraging results obtained from this system led to the development of a field unit since it was the simplest to operate and did not require a high degree of sophistication in manufacture. Both systems had a reasonable degree of success, thus proving the feasibility of objective color systems, based on reflectometry techniques.

7. Color-Stereo-Effect Determination of Relative Color Values by Parallactic Displacement. - A parallel effort was applied in the study of the "Color-Stereo-Effect." The existence of this effect has been described previously by Dr. Hajos, (7), Army Medical Research Laboratories (AMRL) in his work on "Discrimination Without Chromatic Vision".Not much has been written concerning this little known effect. The work at GIMRADA has been an extension of Dr. Hajos's work, applied to other situations. Measurements of the extent of this effect have been made, in addition to the limitations when the effect is employed. Further optical studies may overcome some of the problems involved, however, dispersion of the color bands resulting from refraction to yield a Color-Stereo-Effect degrades the resolution of photographed objects and hence degrades measurement capabilities.

8. Multispectral Photography Experiments. - Some research and quantitative analyses were accomplished in the Multispectral Photography experiments conducted with Dr. R. N. Colwell at the University of California. Spectral characteristics of several color panels photographed through standard filters, as well as narrow band Interference Filters were determined for Tri-X, IR, Ektachrome, Orthochromatic and Ektachrome IR emulsions. The amount of loss in spectral reflectance over the field of a 137 mm focal length lens was also determined. These findings are vital to determination of the utility of spectral measurements in any multispectral system planned for AES.

9. Color Identification by Data Classification. - The application of matrix techniques to color identification is an early experiment in objective color determination. The matrix used was a small one and only three film/filter combinations were employed. A more extensive matrix with more combinations should reinforce the results of the preliminary study. Recent work by Yilmaz and Land (3.0, 3.1) indicates a strong probability that computational algorithms can be implemented, perhaps in a color TV - like system, to produce objective color over a wide range of scene and illumination variables.

IV CONCLUSIONS

10. Based on the foregoing research and experimentation, it has been concluded that:

a. Light-weight, portable spectrum analyzers can be made and used for sensing the spectral response of unknown terrain by scanning.

b. The dominant color chromaticity of a viewed scene can be presented instantaneously as a tri-stimulus response in the terms of a humanoid eye, providing the sensor can be placed directly on the terrain with no extraneous light.

c. Such systems are manportable and can be employed with high precision and with a minimum amount of training.

d. Presently classified image intensifier technology can support the development of a flashlight size spectrophotometer with built in illumination and a spark chamber for emission spectra. This and the tri-stimulus reflectometer are strongly recommended in that order.

e. Optical attachments to standard cameras can be used to obtain a Color-Stereo-Effect by the refraction of the light rays reflected from photographed objects. The effects, although small, are easily discernible and measureable by a person with stereo vision, but with insufficient precision for useful results.

f. The loss of spectral response across the field of a camera equipped with 45° angle lenses (137 mm, 153 mm, focal length) are small and can be tolerated, for photographic color reporting. This is true for a large number of film filter combinations. In many other cases the losses are linear and can be calibrated.

g. Mathematical treatment of matrix techniques applied to multispectral photography may be used for color identification. They may further serve as the basis for advanced imagery objective color systems.

V RECOMMENDATIONS

11. Applying the above conclusions to the proposal for research outlined in Appendix A, it is recommended that:

a. The Portable Tri-stimulus Reflectometer be further adapted and tested for field use at, for example, Willcox Dry Lake Radar Geology Test Area, when completed.

b. Further study and design be continued in order to develop a better understanding of the phenomena and applications of Color-Stereo-Effects.

c. Work be continued in the development of a matrix technique for color identification by Data Classification.

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