Assume now that a week or so later it rained for a few days. Upon returning to the site the day after the rain there was little evidence of the rain on the surface. Figure 5c is a panchromatic photograph of the site area taken the day after the rain. Comparing this to the panchromatic photograph taken earlier (5a) it is obvious that to the camera's eye there has been a major change in the areas enclosed by the dotted lines. Since this change is not man-made it could only be attributed to a growth of vegetation or a change in reflectance due to moisture. Because of the short time interval involved and the recent rain, the change is definitely attributable to moisture. It is doubtful, however, that even the most experienced interpreter could deduce the significance of this dark area without having the comparison photograph of an earlier date (5a). Yet, if the interpreter were given an infrared film-filter combination photograph of this site, taken after the rain, he would immediately realize the severity of the subsurface drainage problem and the reason why this section of exposed rock appears dark on the later panchromatic photograph and not on the earlier photograph. Figure 5d is an infrared film-filter combination photograph taken the day after the rain. The black areas are locations where ground water movement is present, moisture content of the soil is very high, or surface water is present. It is interesting to note that the surface channels are light-toned on this print, indicating that they are dry. In order to have obtained the maximum amount of information regarding this site on a single photograph, camouflage detection film should have been used after the rain. Not only is the subsurface water condition detectable but the joint patterns are also present.

The second major factor to be noted is that there are indications that narrower reflectance band aerial photography than is presently possible may provide a means of increasing the quantity and quality of engineering and geologic data which can be extracted by photo interpretation. Until an aerial photographic system is developed to obtain this type of aerial photography, improvements can be obtained by using aerial photography taken specifically for interpretation tasks rather than merely using aerial photography taken for purposes of mapping or photography which can be inexpensively obtained from some organization which has libraries full of aerial photographic negatives. Expecting an interpreter to extract the whole story from a photograph which was not taken specifically to record the whole story is like trying to extract a cork from a bottle of wine with a jacknife. The best to be expected are bits and pieces.

Additive Color Photography and Projection for Military Photo Interpretation

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(Abstract is on next page)

INTRODUCTION

IN THE past the value of color aerial photography for photo reconnaissance has been limited by the nature of available color emulsion films. Except for special cases the additional information provided by color has not been believed to justify its use.

This paper describes a research program investigating the potential of additive color techniques for satisfying the requirements of aerial photography.[1] This effort is prompted

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[1] This work was supported by Contract Nonr-3137(00) between the Office of Naval Research and Dunlap and Associates, Inc. It was also presented at the Annual Conference, Society of Photographic Scientists and Engineers, May 22, 1961, Arlington Hotel, Binghamton, New York.

ABSTRACT: *In order to assess the value of additive color photography for photo reconnaissance, the Colorvision system was analyzed in terms of its inherent capability for projecting black-and-white, full-color, and color-separation records. A laboratory study was conducted to confirm some of the hypothesized advantages of the additive color technique. Detection and visual resolution data were obtained on artificial matrices. More targets were detected and more detail resolved in the three separated images than either full-color or simulated panchromatic. Full-color permits increased target detection but shows no apparent increase in detail resolved on simulated panchromatic.*

by the advent of a highly operational additive color system designed by Colorvision, Inc. A detailed description of this system has been presented elsewhere (11, 12) and will not be repeated here. Basically, additive color for photography and projection consists of the simultaneous, but spatially separate, recording of the red, green, and blue content of a scene on a black-and-white negative. When the three records are separately projected through appropriate filters, the varying densities in the detail of each of the photographic records will modulate the proportion of red, green, and blue light; so that the superimposition of the three records will produce a color image of great fidelity to the color of the original subject.

The Colorvision additive color technique has not been developed according to photo interpretation criteria; however, there is nothing to indicate that it cannot be adapted to an acceptable format. At present, operational equipment is limited to 35 mm. motion pictures with each individual record occupying 0.1654 sq. in. The important aspect of the system is that an excellent color image can be obtained from black-and-white film with maximum light efficiency. This fact alone justifies a re-examination of the value of color information to photo interpretation, in both the traditional sense and according to wave-length breakdown, which is accomplished naturally with the additive system.

ADVANTAGES OF ADDITIVE COLOR

A three-color additive system permits examination of any single photographic image in three distinct manners: (1) Black-and-white, (2) Full-Color, and (3) As a function of selected wave-length. Each possibility has certain advantages for the interpreter.

BLACK-AND-WHITE

Information in black-and-white is important for retaining present interpretation procedures. Initially, the colored information might be supplemental or used only in special cases. It could be expected that as the use of color pictures becomes more common, the color format would become basic and black-and-white used only in special cases. Retention of black-and-white, aside from its own unique qualities, provides for transition to color and evaluation of color for increasing the interpreter's efficiency.

FULL-COLOR

Although the consensus on whether color film should be used extensively has been essentially negative, a number of special applications have been identified. Lueder (5) lists the following:

1. Geologic mapping
2. Geo-chemical and geo-botanical studies
3. Forestry studies
4. Specialized ecological studies
5. Detailed land use studies
6. Certain river, harbor and coastal studies
7. Certain military studies.

"A comparative analysis of color and black-and-white aerial photography as aids in the mapping of soils in wildland areas" (1) evidences the superiority of color information for soil mapping. The color information used in this study contributed to both the speed and accuracy of interpretation. Although the photographed colors did not exactly duplicate the soil surface colors, the difference did not appear to effect interpretation significantly (Fidelity of color reproduction would be enhanced with an additive system.)

An evaluation of high-contrast reversal color-film over arctic terrain (10) provides the following conclusions:

1. There was useful information available in the color-transparencies which probably would be difficult to detect in the black-and-white images of the same scenes.
2. Color aids the interpreter in detecting,

recognizing, and identifying types of terrain and man-made objects.

3. Mountains, deltas, rivers, coastlines, landing strips, installations, dwellings, and water-depths along coast-lines are clearly defined by color contrast.

The gains to the interpreter from color information of arctic terrain should generalize to desert terrain as well. Such areas constitute low-information-density type reconnaissance. Brightness contrast is generally low in such areas due to a common cover of sand or snow plus very high brightness values for the over-all scene. Similar cases would be encountered in very high altitude photography, such as in satellite reconnaissance, where contrast is attenuated over great distances, and even gross shapes, such as land masses, are difficult to distinguish from cloud patches.

SELECTED WAVE-LENGTH VIEWING

The use of selective spectrum photographic analysis for detection of objects or conditions is not a new technique. O'Neill (8) has studied the problem for a number of years with the apparent purpose of recommending optimum color-emulsion and apparatus for viewing reconnaissance photographs. Colwell (2) has demonstrated the feasibility of detecting various conditions of vegetation through selective filtering techniques. Colwell's efforts, however, have been most fruitful when using the infrared portion of the spectrum.

At present a number of programs based on selective filtering techniques are under development. A popular technique is to select a single film and filter which in combination will be most sensitive to a predetermined spectral band and to use them with conventional photographic equipment.

If one is given a specific photographic search problem in which the exact spectrophotometric data were available on all the elements involved, single film/filter techniques should produce optimum results. This is not to say that even such a straight-forward technique is without problems, such as variation in spectral composition of the solar-radiator as a function of time of day and season, selective attenuation by the atmosphere, field spectrophotometry, and the volume of data required. In addition, it would seem that occasions for use of such a technique would be special cases, due to the high cost of that type of reconnaissance and analysis.

Collection of spectrophotometric data, especially for natural objects, may be one of the lesser problems of the film/filter technique for many data have already been collected (3). Development of reliable recording and field spectrophotometers adds to the feasibility of such an effort. In addition, the presentation of spectral distribution data on acetate overlays, per Bureau of Standards format (4), provides an excellent means for manual selection of films and filters. The next step would seem to indicate the application of computer programming.

Although state-of-the-art projections indicate the feasibility of using individual film/filter techniques for special purposes, the economics involved plus the lack of generality of the information stand as valid and critical objections.

In an additive system the selective feature may not provide maximum sensitivity to any particular narrow-band variable; however, the sensitivity should be adequate for most purposes. Furthermore, the simultaneous availability of black-and-white records and combinations of color records should make interpretation of the information more complete.

The capability of viewing three separate spectral records, or combinations of records, is expected to facilitate interpretation in the following ways:

1. Objects which vary (contrast) from their background only in hue will not be visible on black-and-white photographs. Hue contrast only will be detectable in a full-color picture; however, experimental evidence (9) indicates that it may be relatively difficult to perceive a form which is equated for luminance with its surround (Liebmann effect). The property of the monochromatic record which will aid detection and recognition of an object in a photograph is translation of hue differences into brightness differences. For practical purposes, an enhanced object-background brightness contrast should be available on one of the primary color records or a combination of the color records. Enhanced recognizability, in the above case, would be assumed due to increased definition of target detail.

The assumption of enhanced detectability is based on the principles for use of special illuminants to exaggerate color differences decribed by Nickerson (7). By using the illuminant as "an abridged spectrophotometer," maximum differences in the spectral-reflectance of two objects will become apparent when viewed under a source of particular spectral-composition. Nickerson cites results of Taylor which indicate that the illuminant best adapted to detection of small color differences is one rich in energy in the region of minimum reflectance (maximum absorption) of the object examined. The principle is also employed in special variable source light tables for viewing color transparencies.

In an additive system, "wave-length screening" is accomplished between the objects photographed and the film emulsion. This means that a color filter would not be required for viewing a single record. When combinations of records are viewed, color filters may serve the purpose of coding the information as to the contribution of the individual records. In cases in which the color bears no intrinsic meaning, its elimination avoids problems of chromatic adaptation, "small field tritanopia," and simultaneous contrast. In those cases in which the true color of an object is meaningful, reference to the composite picture would be advantageous.

2. In complex scenes, individually filtered records may serve to suppress irrelevant information. Many of the interpreter's tasks involve detection or recognition of complexes of objects. In cases in which such complexes are related by common elements, the object colors may be a clue to their commonalities. Occlusion of information (color), not related to the particular complex, will serve to emphasize certain relations. Some examples of applications for this procedure are:

a. Rock and soil composition: related to type of materials and structure of building in area . . . also related to type of manufacture or supporting industries in area.
b. Vegetation types: used as camouflage, but mainly in conjunction with (a) above, to determine trafficability.
c. Military objects: especially at low altitude where uniform fabrics or painted vehicles can be picked out from terrain and vegetation.
d. Tracing the course of narrow bodies of water.

3. A third advantage of the selectable records is that most efficient use can be made of variations in composition of ambient illumination. For example, the scattering of the blue portion of the light energy on a clear day will be filtered out in one record to render maximum sharpness of image and shadow outline. For increased detail in shadow, the blue information is available.

CONTRAST ENHANCEMENT

Basically, then, there are two major ways in which the use of color may aid the photo interpreter:

1. An object may be identified by its color when color is a unique, integral, and undisguisable characteristic of that object. (Such utilization of color for recognition is limited almost entirely to natural phenomena or purposeful signalling situations.)
2. A difference in brightness or chromaticity between an object and its background, in many cases, can be used to detect an object or discriminate its form.

Certain unique features of an additive-system permit manipulation of brightness and chromaticity components of color in the laboratory. These features of additive-color may make possible increasing either chromatic-contrast or brightness-contrast or both types of contrast between an object and its background, depending on spectral composition of the light which they reflect.

An exact statement of the difference in chromaticity between any object and its background can be made on the basis of their respective x, y values in the *ICI* chromaticity coordinate system. In order for such a difference to be relevant to photo interpretation, three factors must be considered: (1) object and background of approximately the same brightness; (2) differential sensitivity of the eye to chromatic differences; and (3) object size greater than .01 degree visual-angle.

Chromatic-contrast may be essential to photo interpretation when brightness differences are minimum, but only for objects larger than the threshold size for chromatic perception. For these reasons, factors 1 and 3, above, will be considered important for situations where chromatic-contrast enhancement may be applied.

Starting with the brightness and size postulates, just stated, it would be convenient if linear separation on the *ICI* coordinate-system were an exact reflection of visually appraised chromatic differences. However, such is not the case and the distortions which exist have led to development of coordinate-systems transformed on the basis of psychophysical data (6). Although a nearly linear situation can be achieved, the additional calculations required somewhat lessen the attractiveness of transformed sys-

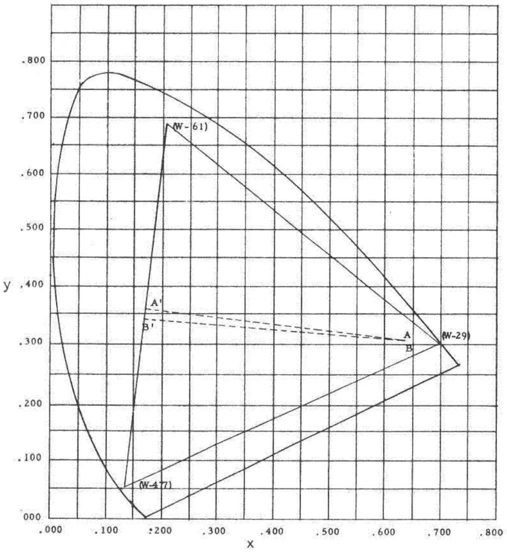


FIG. 1. Illustration of the change which can be effected in the chromaticity of two photographed paint chips by decreasing light intensity through red filter in additive-projection. (Values plotted on ICI chromaticity coordinate system.)

tems when a high degree of precision is not required. In the present case no transformations will be made, but the psychophysical data will not be ignored. In the first place, the chromatic space defined by the primary filters in an additive system eliminate those areas of the color space in which the largest variability of chromatic discriminations is found, i.e., the extreme upper and lower portion of the diagram. Secondly, advantage may be taken of those areas of the color space which represent the greatest chromatic discrimination without data transformation.

Within this framework, the ability to enhance chromatic-contrast by additive color techniques will be a simple function of the chromaticity coordinates of the object relative to its background as demonstrated by the example illustrated in Figure 1. Two samples, points A and B, were chosen from the color population used in the present study. Sample A is located at $x=.637$, $y=.309$, sample B is located at $x=.638$, $y=.306$. The distance between the two points on the coordinate scale is .00316 unit. By using an additive system and systematically reducing the contribution from a red filter (for example, Wratten 29), A and B may be relocated continuously until they reach A' and B', when the red contribution becomes zero. The coordinates for point A' are $x=.174$, $y=.366$; for point B′, $x=.172$, $y=.346$. The linear distance between A' and B' is 6.6 times as great as the linear distance between A and B; therefore, the difference between A' and B' should be much more noticeable than the differences between A and B.

The proximity and spatial orientation of the chromatic-coordinates of samples A and B to the chromatic-coordinates of Wratten filter 29 are important in this manipulation, and points located differently could not be manipulated to as great an advantage so simply. More difficult cases may be limited by the light intensity available in the system, since all techniques for contrast-enhancement presently contemplated involve brightness reduction.

Chromatic contrast-enhancement has been considered for the purpose of demonstrating that it will occur under certain conditions of additive projection. Previously, specific size and brightness contrast situations were postulated; such restrictions define the conditions under which this technique is of value to the photo interpreter. In addition, aerial scenes frequently involve complexes of objects and backgrounds which complicate the simple situation described with simultaneous contrast phenomena. Finally, the technique described above requires a change in brightness to effect a change in chromaticity. The situation, then, involves a complex distorted three-dimensional space and is not adequate to handle all contingencies on a predictable basis. The technique will be most valuable when used as an exploratory tool, in spite of the fact that chromaticity probably cannot enhance contrast to as great an extent as brightness alone.

It has been pointed out that the illuminant best adapted to detection of small color differences is one rich in energy in the region of minimum reflectance of the object examined (7). The technique described above is analogous to the special illuminant technique; that is, by reducing the light through the filter most proximal to the coordinates of two samples, the chromaticities become the resultant of the lower transmission components. The assumption is that when two objects are of very similar apparent color, any significant hue differences between them probably exist in the spectral region of the lowest reflectances (transmission, in the projection situation). In the case of the present example, the Y value of point A is 9.637, the Y value of point B is 14.897. The contrast value according to $\Delta I/I \times 100 = 5.260/14.897 \times 100 = 35.3\%$. The Y values of A' and B' are

1.249 and 2.082 respectively, so that $\Delta I/I \times 100 = .833/2.082 \times 100 = 40\%$.

Contrast should be further enhanced if the spectral-reflectance region of the sample is further reduced. Obviously, the chromatic contrast cannot be enhanced by projection through a single filter; however, the brightness contrast will be maximum on one of the individual records. In our present example, the brightness contrasts between the two samples based on the transmission values of the red, green, and blue records are 34.5%, *40.6%*, and 32.7%. Although the increase in contrast is slight, enhancement could be demonstrated more dramatically if samples were selected specially for the purpose.

The brightness contrast-enhancements in many of the cases used in this study are as much as two to three times. While brightness contrast-enhancement techniques are less confounded by related psychophysical phenomena than chromatic contrast-enhancement, one fact in particular should not be overlooked. The brightness contrast threshold decreases as a function of increasing background brightness. For this reason, it is important that the projection device employed be capable of high brightness output, so that target detectability and recognition are not reduced when brightness is sacrificed in order to increase contrast.

The discussion of contrast-enhancement is intended as an illustration of the principles and variables involved in the application of an additive system. Although it may be possible to define the system effects precisely for any given aerial scene, the task would be prodigious. In any case, such is not the proposition; rather, it is suggested that without *a priori* knowledge of the photographed material (as is required by a fixed filter-film system), a minimum of exploration with an additive system can provide the majority of enhanceable situations. Furthermore, general expectancies can be developed on the basis of the predominate features of the photograph which will be of value when interpretation time is limited.

Laboratory Experiment

PURPOSE AND DESIGN OF EXPERIMENT

The physical contrast values attained with an additive system may be accurately expressed in terms of the difference of two brightnesses in relation to the brighter of the two. Prediction of the effects of contrast on performance, however, can only be made within the framework of existing data. Classical data which may be applied are based on experimental conditions controlled to give an accurate indication of the effect of a single variable. The present experiment is designed to simulate many of the parameters of operational photo interpretation problems. However, every attempt was made to control all variables which are not integral to the particular methods of projecting the stimulus materials.

The specific question that the experiment is designed to answer is whether panchromatic, full-color, or three additive color-separation presentations will yield differential amounts of information from similar photographs. In view of the application to photo interpretation, detection of the object and resolution of detail were selected as valid criteria for evaluating differences in performance.

In order to compare the three modes of stimulus presentation a large sample of chromatic targets were shown against six achromatic backgrounds. The targets were presented in eight sizes in panchromatic, full-color, and the three separated records shown independently. Two subjects were used on the total experiment; four additional subjects were shown only one size target.

APPARATUS

The apparatus for the experiment consisted primarily of an additive color projector. The major deviations of the projector from a standard projector are as follows: rhomboid prisms are used to form three independent but equivalent light paths; the three paths are focused in a common plane by separate projection lenses, each equipped with an independent iris adjustment; a slide mechanism permits simultaneous entry into the light paths of Wratten filters 29, 47, and 61 or three neutral density filters which balance the brightness of the three paths to simulate projection of a panchromatic film.

The projector was mounted at the subject's left on a triangular-shaped table, which was enclosed except for an aperture through which the light was projected. A front-surface mirror at the far end of the projection table reflected light onto the rear of a neutral-density, ultra-matte screen. Viewing distance was maintained by a foam-covered headrest extending from the wall on the subject's right. Ambient illumination was provided by a 40-watt tungsten filament bulb, shielded to illuminate only the area below the subject's waist. See Figure 2.

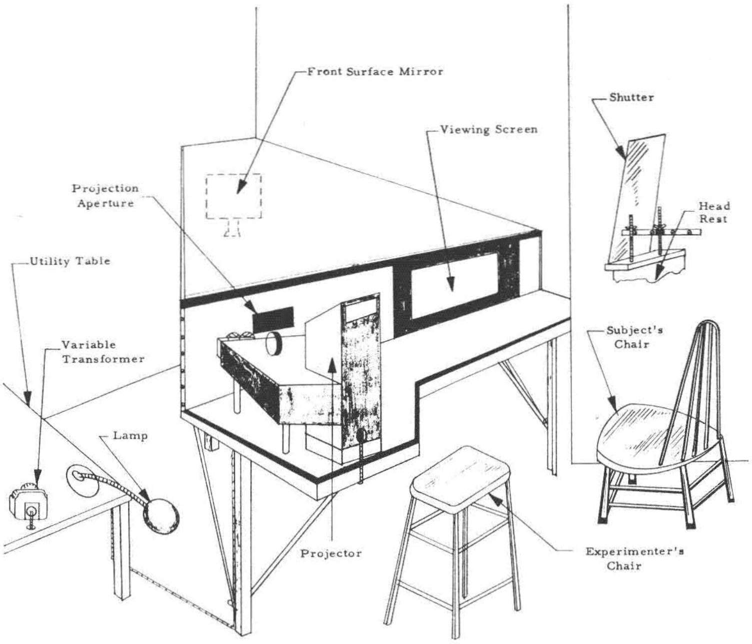


FIG. 2. Experimental apparatus.

TEST MATERIAL FORMAT

The test targets were mounted on 8- by 6-in. cardboard rectangles whose reflectances constituted a neutral series. The background cardboards were divided into 6 by 4 matrices of 2-in. squares. The matrices on the dark backgrounds were defined by white lines; on the light cardboard, by dark lines. See Figures 3a and 3b.

The target squares were $\frac{1}{4}$-in. square color chips. A $\frac{1}{8}$-in. square was cut from one corner of the chip and 1/32-in. from two adjacent sides of the small square. When assembled on the background card, the target appeared as a $\frac{1}{4}$-in. square with a 1/32-in. line of background forming a right-angle perpendicular to two adjacent sides of the square. The colored target squares were divided into six groups and apportioned among the six backgrounds, so that the lightest of the six target groups was affixed to the lightest of the six gray cardboards.

Each test card had a different number of targets, depending upon how many targets were in the lightness category corresponding to the particular background gray-scale value.

Within each card the targets were assigned randomly to one of the 24 squares. The targets were further randomly assigned to one of the four corners of a square, and to one of the four possible orientations which would permit the sides of the target square to be parallel with the sides of the matrix square.

The test cards were then photographed at eight sizes. The resultant test material sizes are shown in Table I.

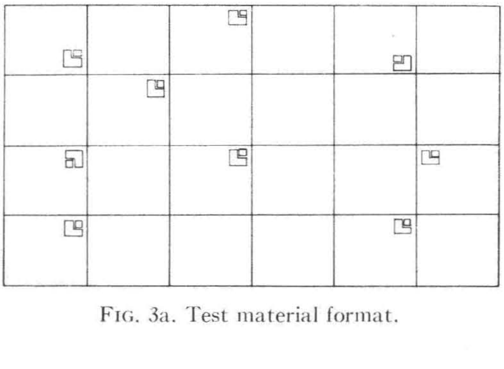


FIG. 3a. Test material format.

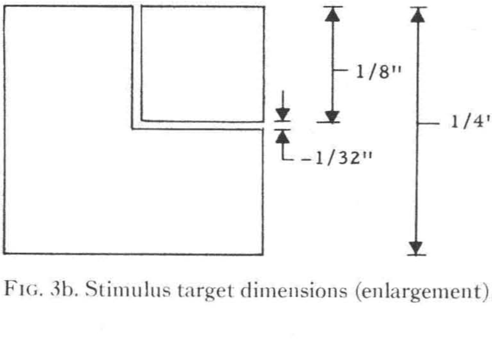


FIG. 3b. Stimulus target dimensions (enlargement).

TABLE I

TEST STIMULUS SIZES
IN MINUTES OF VISUAL ANGLE AT 28 INCHES

Target No.	*Target (Diagonal Dimension)*	*Target Detail*
1	43.0	4.00
2	21.5	2.00
3	14.6	1.33
4	10.8	1.00
5	8.6	0.80
6	7.2	0.67
7	6.2	0.57
8	5.4	0.50

SELECTION AND CALIBRATION OF TEST MATERIALS

In order to evaluate a wide range of conditions which would be easily controlled and economical, target materials were selected from paint sample catalogues supplied by a local manufacturer's representative.

Two hundred paint color chips were chosen as a random and representative color population. Each chip was photographed with the additive color movie-camera. The photographic conditions consisted of 200 foot-candles falling on the materials from two 300 watt tungsten-filament photo-flood lamps at 3,200°K. with a 125 mm. additive lens at 3.5 f-stop. The camera was placed as close to the materials as sharp focus would permit in order to obtain a large image-area.

Positive transparencies of the 200 paint samples were used for calibration. Each sample appeared three times: once on each of three records (red, green, and blue information separately imaged on a single 35 mm. frame). The density of each record was read on a densitometer. Each color, then, could be designated by its three densities (converted to per cent transmission).

Based on a standard projection source at 3,200° K. corrected for the heat absorbing glass in the projector, the ICI standard observer sensitivity curve, and three Wratten filters, 29, 47, and 61; X, Y, and Z values were computed from the per cent transmission of filmed color chips.

Seventy-one chips were selected from the population of color chips and grouped into six Y value categories. No attempt was made to categorize the chips on the basis of chromaticity, since the Y value breakdown accounts for much of the chromatic variability between categories. That is, the highest Y value category naturally tends to cluster about the equal energy point; while the more saturated, or more pure, colors fall in lower Y value categories. The principal exception is the achromatic series.

Essentially the same calibration was performed on the backgrounds and on the chips. The calibration data permit calculation of brightness contrast-values based on several viewing conditions.

Six common brightness values were used for each method of projecting the stimulus materials. In order to equate background brightness between conditions, additional Wratten neutral-density, filters were added to the neutral-density filters used for panchromatic simulation. Settings, based on the transmission of the individual records, were used to equate the brightness of the red, green, and blue records viewed separately with the panchromatic and full-color. The brightness of each of the six background conditions was measured with a Macbeth Illuminometer. The brightnesses (foot-lamberts) were I = 4.48, II = 3.52, III = 3.35, IV = 2.40, V = 0.64, and VI = 0.24.

SUBJECTS

Two subjects, *AJM* and *JE*, performed under all experimental conditions and four additional subjects were used on a single size condition. All subjects demonstrated 20/20 near and far Snellen acuity in both eyes. American Optical Company H-R-R Pseudoisochromatic plates were used to screen the subjects for color anomalies.

PROCEDURE

Two subjects were run through the entire experiment in a series of five sessions. The first and second sessions consisted of six stimulus matrices for each of eight target-sizes presented in panchromatic and full-color respectively. Each of six matrices, for target-size from smallest to largest, constituted a one-hour session. Three one-hour sessions were completed in the afternoon; each session consisted of the red, green, or blue separated information presented in the same order as for panchromatic and full color.

The stimulus materials were presented separately five times; simulated panchromatic, full-color, and each of the additive color records viewed independently. However, since the comparison is being made between panchromatic, full-color, and additive separation; the three additive records are being handled compositely and only three projection conditions will be considered.

The two primary subjects were retested on the five projection conditions for the smallest target-size two days following the initial test. The retest was given in the reverse order of original presentation of projection conditions in order to determine if some of the between condition variance could be attributable to learning.

Four subjects were tested on the five projection conditions on all six matrices but only at the third-largest target-size. The choice of size was based on the data from the two primary subjects. Order of presentation among separated green, red, and blue records; simulated panchromatic; or full-color, was randomized among the four subjects. Since the two initial subjects were shown the materials in the same order, the duplication would indicate if an order effect would be present in the data.

All subjects were given detailed briefing before the experiment on what to expect and how to mark the data sheet. The data sheet was a replica of the stimulus matrix with an additional matrix within each square to permit indicating target and detail location by a simple *x* mark.

The subjects were instructed to take as much time as necessary and to mark any space which appeared to contain a target. It was suggested that the rows be scanned from left to right, from top to bottom, but that any scan pattern was acceptable.

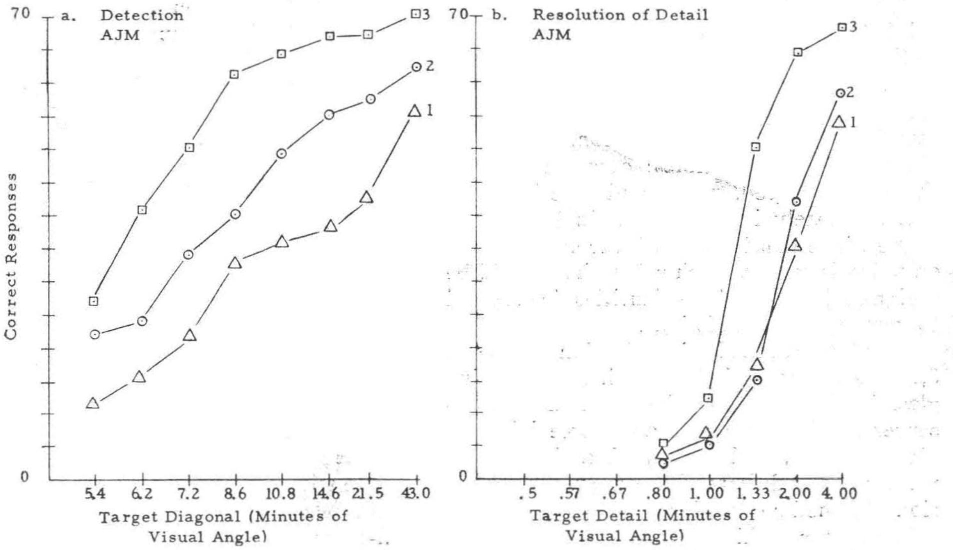
The sum of the conditions presented each of the two primary subjects totaled: 24 squares×6 cards×8 sizes×5 modes of presentations = 5,760 discriminations and 71 targets×8 sizes×5 modes of presentations = 2,840 possible positive detection and resolution responses.

TEST RESULTS

The test results for the two primary subjects are shown in Figures 4a and b. Performance is measured in terms of the number of targets correctly detected and the number of targets correctly resolved. The composite measure of performance on the three separated additive color-images reflects only the number of different targets detected or resolved. In many cases, the same target was seen on all three additive records; this is scored as only one correct response.

The composite scores of the three additive records are clearly higher than either panchromatic or full-color. Full-color projection resulted in a greater number of targets correctly detected than for panchromatic; but the difference in detail resolved does not appear reliable.

Data on the four subjects tested on a single target size confirm the data of the two



A

B

FIG. 4a. Number of correct responses as a function of visual-angle subtended by (A) target square diagonal and (B) target detail separation for (1) simulated-panchromatic, (2) full-color, and (3) composite score of three separations.

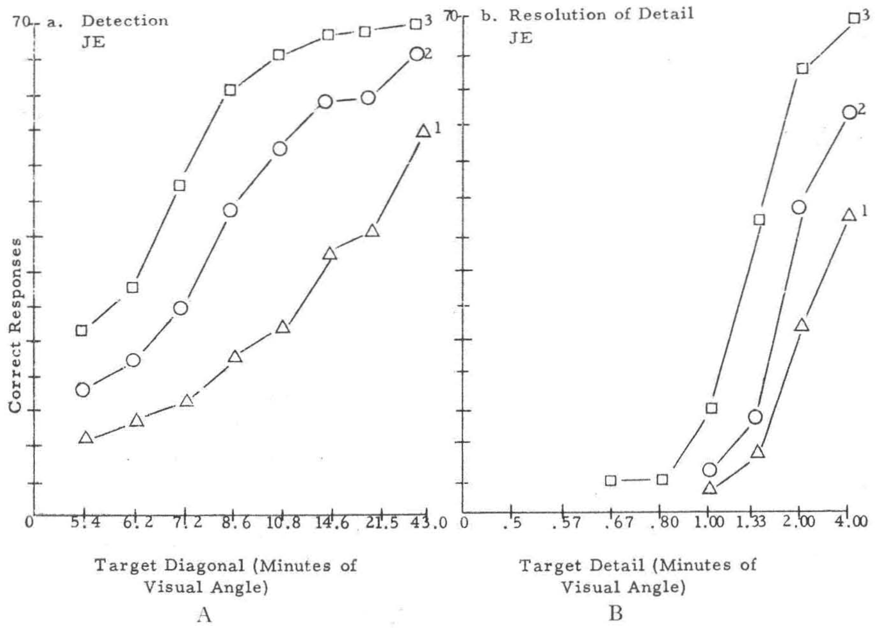


FIG. 4b. Number of correct responses as a function of visual angle subtended by (A) target square diagonal and (B) target detail separation for (1) simulated panchromatic, (2) full color, and (3) composite score of three separations.

primary subjects. These comparisons are shown in Table II

Retest scores of the two primary subjects on the smallest size matrices show an increase of approximately ten per cent over their original detect scores. The relation between the scores and the size of the differences is unchanged.

DISCUSSION

Within the population of target colors and backgrounds used in this study, a wide range exists in the ability of the additive-color system to enhance contrast. The basic data contained in Figures 4a and b show the effects of increased contrast on the observer's ability to detect and resolve detail as a function of size. The brightness contrasts with simulated panchromatic and full-color are equivalent within the precision of the measurement techniques. Between these two conditions the differential ability of the observer to detect targets within the stimulus matrices must be attributed largely to the effects of chromatic-contrast between targets and background.

TABLE II

COMPARISON OF SCORES ON SIZE 3 TARGET

Presentation Condition	*Average Number Detected*		*Average Number Detail Resolved*	
	Subjects		*Subjects*	
	1 and 2	*3, 4, 5 & 6*	*1 and 2*	*3, 4, 5 & 6*
Simulated Panchromatic	37.0	36.5	12.5	16.0
Full Color	56.5	54.8	14.0	16.3
Composite of Three Color Separate Records	67.0	67.8	45.5	40.8

Since there appear to be real differences between full-color and simulated panchromatic in the number of targets detected but not in the amount of detail resolved, chromatic-contrast can be expected to aid the interpreter primarily in the number of targets which he is able to detect.

The additional brightness-contrasts provided by the additive-color separations result in a striking increase in both the number of targets which can be detected and the amount of detail resolved. In comparing the scores of the four subjects which were tested only on the third-largest size, 77.5 per cent of the targets are detected in full color and 95.5 per cent among the three additive separations; detail is resolved in 22.5 per cent of the targets in full-color and in 57.7 per cent with the three separations.

On the retest using the smallest size stimulus the increase in number of targets detected indicates a probably significant learning effect. However, relative differences between the three types of stimulus presentation is unchanged, and additive still indicates more targets detected. The most likely effect of learning is in the steepness of the slope for increased detection as a function of size.

Data in the present study suggest that the additive-color system could be of considerable value to the photo interpreter. The results obtained confirm the general predictions which could be made on the basis of the physical, computed contrast-values and indicate the order of magnitude of such effects in a task of greater complexity than is traditionally used to describe the effects of contrast alone.

CONCLUSIONS

The experiment described in this report was designed to test the effects of contrast variables on some of the basic visual problems involved in photo interpretation. The results indicate that color projection provides additional object/background contrast to enhance the detectability of photographed images. More significantly, the separated images provide even greater contrast enhancement which is important to the detection and recognition of objects. Based on the results of this study, it may be concluded that the simultaneous availability of three separated additive-color records can be expected to provide the photo interpreter with additional useful information.

Where so many variables, explored and unexplored, affect human performance, a major concern is the actual consequence of manipulating information content in the operational situation. In the first place, how representative or subject to generalization are the conditions which have been used in the laboratory and what, if any, increase in performance could be expected under such conditions. The next phase of this program will include aerial photography using the additive-color system and testing of the materials with trained photo interpreters. Adaptation of the additive system to a format which is closer to the requirements of military reconnaissance will be based on future results.

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