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The Examination of Color

Scope of Examinations

The examiner of questioned documents must make observations of form, area, mass, length, width, angle, curvature, and texture, and other features not so readily named. Many of the features observed are subject to reasonably exact and fairly convenient measurement. There is one element of examination; namely, color, which is not usually measured. One can make close judgments about differences and similarities of color, especially when there is good control over the method of lighting and when the two objects being compared can be brought close together and studied at the same time under magnification. These judgments are highly useful in the solution of questioned document problems and they sometimes constitute the most important elements in a determination that a particular document is spurious. But a judgment is not a measurement.

Levels of Fineness in Specifying Color

Kelly [*1*] describes five different levels of fineness for specifying color. Three of these require the generic names for colors such as red, blue, green, yellow, black, grey, white, along with an orderly series of modifiers. The fourth level requires comparison with a standard sample. The fifth level requires measurement in a spectrophotometer or colorimeter. The document examiner must describe colors with the degree of fineness required by the situation, which may, of course, involve any of the five degrees of fineness: the basic terms of blue, red, green, yellow; compound terms, such as blue-green, yellow-green, red-purple, and modifiers such as light, medium, dark, greyish, blackish; and direct comparison of the subject color with a standard sample, such as those of the Munsell system [*2*], or those of the National Bureau of Standards system [*3,4*].

The foregoing embraces four of the degrees of fineness of color description. When it comes to the fifth degree, that of measurement in terms of a determination of amount of energy in each wavelength of light; in each short span of wavelengths for production of a more or less smooth and continuous curve; or in terms of the tristimulus values of red, green, and blue; there is one prime difficulty for the examiner of questioned documents, namely, that the objects needing measurement of color are not usually in the form or size required by the measuring instruments. Spectrophotometers and colorimeters are designed to handle color samples that are within the control of the user with regard to size and form. The subjects requiring study by the document examiner are often found in various awkward places and in very small areas. In short, it is quite unlikely that items that require measurement of color on documents will occur in a form susceptible of being inserted into ordinary commercial instruments.

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Procedure

Photographic Measurement

It is proposed that measurements of color be made by a method that promises success at any point where the document examiner would be successful in making a photograph of the object. In other words, if a photograph can be made on panchromatic film, then color can be measured.

The elements of the proposed photographic system for measurement of color are: (1) light sources of good uniformity, such as the R-2 photoflood bulbs, or 3200 K lamps; (2) colored filters for isolating segments of the spectrum, such as the Wratten filters, A, B, C5 (25, 58, 47); (3) photographic film having constant and uniform characteristics; (4) developers for film which produce constant results when used at controlled time and temperature; (5) calibrated sensitometric step wedges or grey scales; and (6) densitometers for reading discrete areas of the processed photographic film. The only items of equipment listed not routinely found in the photographic laboratory are the calibrated step wedge and the densitometer.

Radiant Energy

Colors of objects may be measured by photographing them in the sense that the radiant energy of a particular color is recorded on the processed photographic film as grains of silver and the number of grains or densities are proportional to the amount of energy the film received. Measurement of densities, therefore, may constitute measurement of color.

Equality of Illumination

The object to be inspected for color is set up for photography under a tungsten light source, such as R-2 photoflood bulbs. There must be included with the subject a calibrated grey scale, and that step on the scale which is judged to be closest to the estimated luminosity of the subject color should be placed nearest to the subject. The step wedge and the subject must receive exactly the same illumination. Exposure should be determined by use of a meter and the aim should be to secure a highlight density of about 1.5 or 1.6 when the subject color is at the highlight end of the grey scale, or a density somewhat higher when the subject color is at the shadow end of the scale. In the latter case, good separation of steps of the scale at the shadow end would be important so that a density in the darkest area should be from 0.30 to 0.60.

Filter Factors

Exposures are made through the tricolor Wratten filters, A (red), B (green), and C5 (blue). Other combinations of filters may be used. The exposure factors of the filters must be adjusted to secure equal, or nearly equal, densities of the grey scale in each negative. The procedure for making these negatives is exactly the same as that for making tricolor separation negatives for production of a color print or plate. The difference is that one stops short of making the print and instead examines certain features of the negatives.

It is improbable that precise correspondence can be secured for each step in each of the three negatives, but ordinary care will insure that they are quite close. It is axiomatic that similarity of density at the shadow end of the scale will indicate approximate equality of exposure, and that similarity of density at the highlight end will indicate equality of exposure and development. When such a similarity is achieved the intermediate steps will correspond if development was uniform over the whole surface of the negative, and, of course, care must be taken to make it so. Development of negatives should be in accordance with recommendations for the film, with an aim of securing the longest scale and straightest line of the exposure density curve. Generally, the negative made through the blue filter requires longer development to produce the same contrast as the other two.

Densitometer

The next step is to plot the densities of each negative against the densities of the original calibrated grey scale, the latter being entered at the base of a graph sheet. This produces the familiar H and D curve. The lightest end of the calibrated grey scale will be marked 0.00 to indicate that reflection of light at this step is to be regarded as 100 percent. Of course, no surface actually reflects all of the incident light but the concern is with the light that originates at the surface of the reflecting subject just as though it were the true light source and there is no reason why this may not be regarded as 100 percent for procedural purposes. The next step of the grey scale may be marked with a density of 0.16 which is equivalent to 69.18 percent reflection. The darkest end of the scale may be calibrated 1.66 or a reflection value of 2.188 percent. Different scales will have different calibrations, but the space between each step will be regular.

Densities

All of the calibrated densities of the grey scale serve as a base for plotting the densities as read from this scale on each of the three negatives. Extra convenience is gained by using colored pencils or ink, red, green, and blue, for the curves of negatives produced through filters of these colors. Ideally, each curve would lie on the same points so that the coincidence of the others could be drawn and verified. However, if they are close together and have about the same shape they will suffice. It may be supposed upon first review of this system that the densities at each step for each of the three negatives would have to be identical but this is not necessary for an acceptable result. The reason being that in the final analysis of the unknown color each density is referred to the comparable density on the calibrated grey scale.

Light Source

The system represented by light source, filters, and photographic film operates as though the light source had exact, equal quantities of red, green, and blue light; that is, 0.333 reflection of red, the same in green and blue. A tungsten light source does not actually have this composition but other elements in the system; namely, use of the correct filter factors, provide a control that makes the light source and sensitivity of the film appear to be uniform.

Measurement

One is now prepared to determine the three components of the unknown color, photographed with the calibrated step wedge. Of course this color is known to the examiner as a visual sensation, so the word "unknown" is used in the sense of not yet fully analyzed. The first operation is to read the density of the unknown color as recorded on the film. Begin with the red filter negative. From the point on the H and D curve for the red filter negative giving the density of the unknown color, a line is dropped to the base of the graph where the reflection value of the calibrated grey step wedge is recorded. The reflection value at that point represents the red light energy in the unknown color. The same operation is performed on the green and blue negatives.

Table 1 shows a typical set of readings to fix color characteristics of an unknown color. Column 1 identifies the filter through which the negative was made. Column 2 gives the densities of the unknown color on the negatives. Column 3 shows the densities on the

TABLE 1—*Readings used to fix color characteristics.*

Filter	Density	Grey Scale	Transmission	Percent of Total
A (red)	1.164	0.23	58.88	26.14
B (green)	1.328	0.08	83.18	36.93
C5 (blue)	1.163	0.08	83.18	36.93

calibrated grey scale that produced the densities of column 2. Then, in column 4 are found the transmission or reflectance values corresponding to the densities in the preceding column taken from published tables [5]. These are added and the percentage of each relative to the total is shown in column 5.

Color—The color analyzed in Table 1 (brightness value of 76.06 percent) is a light blue-green color tending toward a brilliant blue-green, and is actually a proposed standard for the safety tint for surface printing of a certain class of checks. One may be concerned that the density for the blue filter negative on the third line is shown with a grey scale reading of 0.08, whereas almost the same density for the red filter negative shows a much higher grey scale reading of 0.23. This will be understood if one thinks of these figures in the reverse order, that is, the light energy of the grey scale at the point having a density of 0.23 produced a density of 1.164 on the red filter negative and that is the reason these figures are associated. The density 0.08 on the grey scale for the blue filter negative produced the density of 1.163. The critical figures are those in column 3, repeated as transmission or reflection values in column 4, and repeated again as percentages of the total reflection in column 5. In practice one would need to report only the figures in column 5 plus a figure to represent total reflection or brightness of the color as described below.

Brightness—In column 4 the method for showing transmission or reflection values is such that a perfect white would be represented by a total of 300. Therefore, the actual total of the figures in this column divided by 300 gives 76.06 percent which is the total reflectance of the subject color relative to the kind of 100 percent white involved in this system. Observe that column 5 gives the proportions of the color components as red, green, blue. It would be possible to have a similar proportion in a color of a darker value, assuming admixture of a quantity of neutral grey. One must look at the total reflectance value gained from the figures in column 4 as an aid in visualizing the color from these figures in column 5. Hence, 76.06 percent means a bright color, whereas the deficiency in red and equality in green and blue shows that the color is a bright blue-green.

Discussion

The advantages of a photographic method for measurement of color by the examiner of questioned documents are apparent when one considers some of the special problems involved in this work. It is difficult—one might say impossible—to carry the memory of a color, or impression of a small difference in color from one place to another, even for a short period. It is even difficult to do this when closely similar colors are on the same document but on opposite sides of the sheet.

Wright [6] states, "Our powers of discrimination [of a just noticeable difference in color] are at their best when we are looking at two adjacent areas of color with a sharp and almost invisible boundary line between them, when the areas are large, when the illumination is good and when we are using unrestricted binocular vision free from any optical encumbrances such as eyepieces or exit pupils." He continues, "There is no doubt, however, that much of the intensity of color is lost when its area is reduced and it would seem as if stimulation of a large number of receptors [of the eye] accompanied presumably by a correspondingly extensive activity in the brain, is an essential element in the evocation of a full color sensation." The photographic camera and other elements of the system described herein can overcome some of the difficulties described by Wright.

Certain advantages of the use of photographic materials for measurement of radiant energy are given by Jones [7], and while he does not mention the use of color filters for the purpose of measuring radiant energy in separate areas of the spectrum, he does describe the use of a stepped wedge method of calibrating exposure, followed by comparison of the unknown density with a density of the stepped wedge corresponding to a known exposure.

Each step of the procedure must be rigidly controlled; however, it seems clear that most of the variables would affect the step wedge and the unknown color equally. Hence, if one should receive a supply of film that was slightly more red sensitive than previously used film this would mean a higher density in the red filter negative, but the higher density would apply to both the unknown color and the density produced by the step wedge and both densities would be referable to the same step on the calibrated wedge. For a wide difference, say where one elected to change the type of film being used, adjustments could be made in filter factors. The critical element is the stability of the calibrated grey step wedge. These are usually supplied on photographic paper. One used in the measurement of color should be reserved for that purpose only, handled as little as possible, kept absolutely clean and stored under the best conditions, and the same care should apply to the colored filters. It would be desirable to have step wedges in a more permanent and durable form, say ceramic, but the surface must reflect light diffusely and must otherwise be comparable to the kind of surface being measured.

Summary

The making of a photograph of any object means measurement and recording of light or radiant energy on the film. Whether or not these measurements are tranalated into figures, they exist in the negative. Light may be divided into separate areas of red, green, and blue for separate exposures, followed by inspection of the result by means of a densitometer. The advantages of the system described over other methods for measurement of color are: (1) measurement of surfaces or colors *in situ*; (2) production of a permanent record on photographic film; (3) reading of low intensities of color by increasing the time of exposure; (4) inspection of very small areas such as pen strokes by photographic enlargement (limited only by the need to insert a small stepped wedge); and (5) recording several measurements on the same film, that is, several areas of the same subject by use of a large film size.

References

[1] Kelly, K. L., "Coordinated Color Identification for Industry," NBS Technical Note 152, Nov. 1962.

[2] *Munsell Book of Color*, 1960 ed., Munsell Color Co., Inc., Baltimore, Md.

[3] Kelly, K. L. and Judd, D. B., "The ISCC-NBS Method of Designating Colors and a Dictionary of Color Names," NBS Circular 553, 1955 (reprinted May 1965), Superintendent of Documents, Government Printing Office, Washington, D.C.

[4] "ISCC-NBS Color-Name Charts Illustrated with Centroid Colors," SRM 2106, Office of Standard Reference Materials, National Bureau of Standards, Washington, D.C.

[5] *Kodak Wratten Filters, Scientific and Technical Data Book B-3*, Eastman Kodak Co.

[6] Wright, W. D., *The Measurement of Colour*, London, 1958, pp. 156, 158.

[7] Jones, L. A. in *Measurement of Radiant Energy*, W. E. Forsythe, Ed., New York, 1937, pp. 246, 271.

Additional Sources

The Science of Color, Committee on Colorimetry of the Optical Society of America, Thomas Y. Crowell Co., New York, 1953.

Evans, Ralph M., *An Introduction to Color*, Wiley, New York, 1948.

Cole, Alwyn, "Control Factors in Color Photography of Documents," presented at the Milwaukee American Society of Questioned Document Examiners, Aug. 1962.

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