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Sensitometry in Color Aerial Photography

Once the standards are established, sensitometry provides the best means of control of any aerial photography or processing system

(*Abstract on next page*)

Introduction

The science of photographic sensitometry is very helpful in color aerial photography. In a broad sense, this science is concerned with the measurement of all photographic steps between the actual terrain and the observer, or photographic interpreter. It is essential in the manufacturing processes of all photographic materials, but the discussion here is limited to the use of photographic materials in color aerial photography: optimum film exposure, color balance adjustments, processing control, utilization of density-contrast characteristics, and control in the preparation of reflection of transparency prints.

Practical Sensitometry

The practical use of sensitometry in color aerial photography will require the establishment of standard sensitometric references based on practical judgment of aerial photographs made under like conditions. These standards, then, will serve as the basis for control of any of the parts or all of the photographs made under like conditions. These standards, then, will serve as the basis for control of any of the parts or all of the photographic system. Although the same principles may be applied to all of the color photographic systems—negative or reversal—one must be careful not to substitute in parts of, the system, such as the film of one design (manufacturer) with that of another, without re-establishing the standard of reference. Another brand of film, for example, should not be substituted for Anscochrome film in a system involving printing or duplicating without running practical and related sensitometric tests to adjust for color balance and printing-time differences introduced by the substitutions.

The term *Characteristic curve* is applied to each of the individual curves derived by plotting the densities measured through red, blue, or green filters (corresponding to cyan, magneta, or yellow layers of the final processed film) against the logarithm of the exposures given to the combined three layers (or tri-pack). As it is usually best to make use of the film manufacturer's sensitometric data and processing recommendations as a starting point for establishing a controlled photographic system, USA Standards should be employed wherever practicable. For ex-

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ample, densities should be spectral diffuse densities as defined in USA Standard PH2.1-1952. USA Standards, by the way, is the new name for what was formerly known as ASA Standards. They are produced by the United States of America Standards Institute, the new body that replaces the American Standards Association. (Filters different from those given in PH2.1-1952 may be required in special applications, and if this is so, the filter used should be incorporated in the sensitometric data. The same holds true for any other deviation from the normal or standard procedure.)

camera performance standards can lead to false interpretations of the sensitometry. Variables extraneous to the sensitometric system can best be eliminated by making sure that the sensitometry is related to the actual light meters, camera shutter speed settings, camera lenses, vignetting filters, and the other elements of the photographic system employed for the photographic mission.

Processing

The sensitometric processing should be identical with that used for actual photography. In other words, if a continuous processing machine is employed, then the sensitometric exposures should be processed with the same conditions as those for the photography. If the processing method involves a wind-rewind processor, then sensitometric strips, or preferably exposures on non-image areas of the actual pictorial film, should be included at both ends and in the center portion of the roll when processing is accomplished. The roll length, even if it is a *dummy*, should be equal to that to be used in the actual aerial photography. This procedure will not only reflect the average level of the processing throughout the roll, but will also indicate the variation existing between the ends of the roll and the center.

ABSTRACT: *Sensitometry is useful for the practical determination of film speed and setting correct exposure, control of processing conditions, adjustment of color balance, and control of printing. Measurement of densities and plotting of characteristic curves provides data to carrying out these aims. From the practical viewpoint, sensitometric techniques have limitations, but these are relatively insignificant if they are recognized and the relationships between sensitometry and practical photography are established for color photographic systems. Choice of density range, for example, and therefore speed rating, can lead to some control of contrast and gradation in the final photographs. Sensitometry is also essential in making black-and-white negatives, color separations, or duplicates from color positives or negatives.*

Exposure

The quality of light used for sensitometric exposure, exposure time, processing, etc., should be as nearly identical as can be attained to the conditions employed in the actual photography. This will eliminate most of the failures that are introduced by: (1) a sensitometric exposing source of different quality from that illuminating the terrain photographed; (2) the use of an exposure time different substantially from that of the camera shutter; and (3) using processing conditions that differ from those actually used for processing the aerial photographs.

One of the problems in sensitometry is that of correlating the sensitometric exposures to the light meters employed to measure the terrain being photographed. This problem may involve meters that are directly coupled to the camera system, in which case the referenced values used in the meter system should be very carefully determined and related to the exposure given to the film in sensitometry. Other factors, such as efficiency of shutters, transmission of lenses, etc., should be established. These must then be taken into account when relating sensitometry to practical photography. Failure to recognize the

Date Recording

The sensitometric data derived in any aerial photographic or sensitometric system should be carefully preserved. This can then be referenced at any time that the need should arise. The problems that require a solution on any given day can be related to the experience gained with previous aerial photography; or it can be referred to in order to arrive at exposure and processing condition. Sensitometric curves and other information relating to them should be carefully documented. Such data as exposing light and filtration, exposure time, processing, date, related sortie, etc., should be available immediately when any curve or other data are consulted. To save time and confusion, the relative log exposure scale should be filled in and the fiducial mark corresponding to the mark on the sensitometric step should be indicated on all the density-log-exposure graphs. The density scale should also be filled in.

Interpretation of Results

The standards of sensitometric reference and control will depend on the aerial color photographic system being used. For example, the sensitometry may be related to pictures that are to be interpreted by direct viewing; or it may be related to pictures that are to subsequently be duplicated on transparent or opaque base material; or to pictures that are to have black-and-white (monochrome) or color separation negatives made for further study or printing.

Color negatives may be used for direct printing to produce black-and-white positives using a suitable color positive printing material on either transparent or opaque base. The color negatives may also be the source of separation negatives for further study or printing. Although the duplicating or printing step for color negatives may seem to be the same, the sensitometric reference and standards may be quite different from those for color positive originals.

For example, the two different systems may make use of printing materials (receivers) made up of layers having different spectral sensitivity peaks. Thus, the densitometer measuring filters will require different absorption peaks to make the sensitometry of the system really significant. The same situation holds true with reference to the printing correction filters. If the absorption peaks do not correspond to the spectral sensitivity peaks of the layers making up the printing material, then the sensitometric response may not be equal to the practical response of the materials.

Several factors enter into the assignment of speed to color films for aerial photography. One of the most important and most difficult aspects is that of relating the speed of the film to the brightness of the scene being photographed. The measurement of luminance of the terrain would at first seem to be a straight forward process. However, the effects of specular reflections from bright surfaces such as water, the influence of clouds, the necessity to penetrate shadow, and flare light in optical systems, all contribute to the rationalizations that must be made in establishing the speed of a film, and then making use of the assigned speed for photography in a given situation. For high altitude photography, an integrated measure of any sizable area should provide a suitable luminance value that can be related to the exposure required to produce a given density on the film. Under these conditions the luminance range is relatively small.

For low altitude photography the luminance range will usually be much greater and an integrated luminance may not be as useful in determining the exposure required to register the various luminance values in the scene within the desired density range on the film. It may be desirable, for example, to expose more for the shadow areas, sacrificing density in the highlight areas of a reversal film; yet, on the other hand, highlight areas may represent the primary information to be recorded.

Speed and Contrast

At the present stage of the art, it seems that past performance in aerial photography with a given system is the most useful source of information that can be called on to arrive at an arbitrary film speed value. The sensitometric reference standard related to this performance can then be used, along with any necessary correction tables and computers to determine the shutter time and lens aperture for any particular terrain to be photographed.

With a given photographic system (camera-exposure meter-film-processing-interpretation), then, if one emulsion number is substituted for another, the ratio of the sensitometric speeds of the reference emulsion and the new one can be applied to the exposure system. If another type of film (another manufacturer, for example) having similar contrast is substituted, then the ratios may be less valid; and if a film of entirely different contrast (and sensitometric curve shape) is substituted in the system, then the ratios may not hold true at all.

No standard method of determining aerial color film speed has yet been established. It is doubtful that a single film speed value would be suitable for all types of photography because the characteristic curve shapes of films of different manufacturers tend to be quite varied. With a given film, the film speed reference point on the characteristic curve may depend on the type of photography being

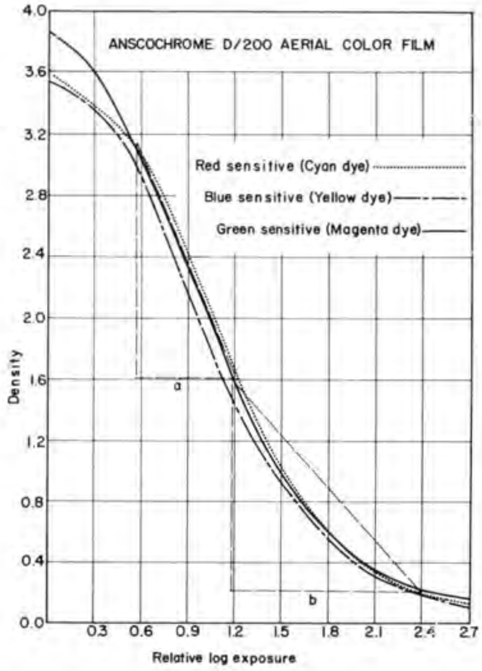

FIG. 1. Characteristic curves for the three primary colors on one type of film.

done (low altitude versus high altitude, for example), as well as on the type of information desired from the finished photographs. In high altitude photography, it may be desirable to record the image with densities that would fall on the steepest portion of the characteristic curve to provide maximum contrast. By using densities in this high range, maximum image contrast amplification is achieved in the original. Any problems of viewing can be compensated for by increasing the illumination from the viewing table; or by duplicating the film to a lower density.

If, on the other hand, photographic latitude is required when photographing terrain of wide subject contrast, then the pictures should be recorded with densities falling on the lower portion of the characteristic curve of the film, and on which the average gradation is considerably lower than in the example given above. In this region, the characteristic curve departs considerably from linearity, with highlights being registered with relatively low gradation, whereas the shadows are registered with relatively high gradation.

Both of the situations described above will call for different density criteria for establishing film speed (Figure 1). In the first one, *a*, in which heavier densities are utilized to make up the image, a density of 2.4 might be the criterion. In the second instance, *b*, a density of 0.8 might be more appropriate. The approximately 0.6 difference on the log exposure scale corresponding to these two densities represents two lens stops, or arithmetic speed values having a ratio of 1 to 4. As a given speed may be assigned to a given film, and the two situations handled by suitable factors, it is evident that the needs for aerial color photography present serious problems in establishing a single speed for films of this kind.

Although considerable latitude is available in the higher density of a typical aerial film for photographing at high altitudes, considerably less latitude in exposure is present if long-scale scenes are being photographed, such as at low altitudes. The subject luminance range of high altitude terrain is quite small, and considerable deviations from the optimum exposure can be made without serious change in gradation (only a density change). On the other hand, although greater latitude of recording scene brightnesses is permitted for photography with the lower densities, very little latitude exists for overall exposure variation without sacrificing information at one end of the scale or the other.

A third condition might be to base speed on a medium density, say 1.6, representative of the average of the range available with a given film. As the density range of the aerial film might approach 3.2 and represent a scene brightness ratio on the order of 1:500, a great deal of latitude is available for recording information. Aerial photographs made utilizing the full density range of the material may be difficult to read without adjusting viewing intensity for particular areas of interest. If, however, the films are subsequently duplicated, or separations made, printing exposures can be selected for best reproduction of the densities of primary interest.

The determination of speed of color negative films presents a somewhat different problem inasmuch as the characteristic curves tend to be individually somewhat more nearly linear than those for reversal processed material. The determination of film speed may be more nearly related to that of black-and-white aerial films, and a reference point near the threshold of the curve may be appropriate. A proposed USA Standard is under consideration for determining the speed of films intended for amateur photography, and this may be limited to that determined for the slowest emulsion layer where the agreement of characteristic curve shape among the three layers is at an acceptable minimum.

Color Balance

When aerial photographs are to be judged by visual inspection, the film should be balanced to provide as nearly as possible a neutral rendition of a gray scale. This will not necessarily mean that the sensitometric curves obtained with exposures to light having a quality equal to that used for the practical photographs will lie on top of each other. In fact, they will generally be displaced by some amount, and this is governed by the sensitivities of the emulsions and the absorption characteristics of the image dyes in the aerial film in question. The relative position of these curves is also determined by the choice if filters used in making the density measurements. A set of sensitometric curves, which represent the exposure and processing conditions that provide a neutral rendition of a gray scale as obtained by practical photography under similar film and processing conditions, should serve as the basis for judgment for color balance. This will hold true only for one given photographic film product, as part of a given exposure processing system. Other films and/or systems will require different references for neutrality.

Color balance differences, where one fresh emulsion number of a given aerial color film is compared to another, may amount to the equivalent of a 0.10 density color correction filter, in yellow, magenta, or cyan (or any combination of these). Aging may increase this to the equivalent of a 0.20 density filter. This may require some correction if exact uniformity is required. Also, over a given period of time the processing may vary, and a further correction of color balance of a given film may be required. Thus, if it is desirable to balance a film-emulsion-processing system to produce results equal to those achieved with another system, an estimation of the camera or printer filtration that will be required is in order. This is done best with trial-and-error practical or sensitometric exposures using color correction filters of various color and density. The log E displacement of given density points of curves made with various filters can be used as reference for estimating the amount of filtration required with a given system. Caution must be exercised to make such comparisons only at or near a given density level, because the effects of color correction filters are different at different density levels.

Because the sensitivity regions and the color correction filter absorption regions are not sharply defined and have low efficiency in

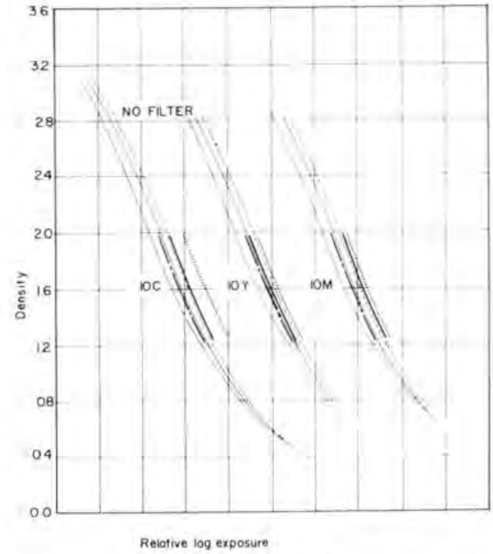

FIG. 2. Sensitometric curves for different filters. Because the sensitivity regions and color correction filter absorption regions are not sharply defined, the shift on the log E scale may amount to only about 0.06 units. (The exposure scale is the same as that shown in Figure 1.)

color discrimination, only 50 per cent to 70 per cent of the *filtration* is effective. Hence, the shift on the log E scale may amount to only about 0.06 units where a color correction filter having a density of 0.10 is applied (Figure 2).

In both original aerial photography and duplicating or printing the exposure time should be taken into account when conducting sensitometry. This is made necessary because the reciprocity characteristics of the three emulsion layers making up the tri-pack may not always be similar. Wide variations in exposure time may affect both the color balance and the relative gradation characteristics for the individual dye layers, resulting in lack of *curve conformity* in the sensitometry. If the time used in the sensitometric exposures approximates that to be used in the practical photography, the problems of establishing corrective filtration and speed adjustment are simplified. Also, if there is some departure from *conformity* of the layer gradation characteristics, as shown by the curves, the best approximation of speed and filtration for a given density range to be employed in the photography can be determined if the sensitometry time corresponds to the practical exposure time.

If lack of *curve conformity* exists as the result of the color-film-processing system, then the densities employed in making the pictures will also affect the color balance. If the curves cross somewhere near the middle densities, the color balance of the heavier densities will tend to be opposite to the color balance of the densities below the cross-over point. Thus, different color balance treatments may be required if the films are used for photographs having high densities, compared to those for photographs having low densities.

For judging the neutrality of aerial films, it is important to take into account the viewing conditions. For example, the subjective interpretation of color balance can be largely affected by the color of the surroundings at the time the pictures are viewed. If the surrounding area is painted green, for example, the mind will tend to correct for this, and sensitometric strips and pictures may seem to be magenta. Likewise, a yellow surrounding will cause the strips or pictures to seem to be more cool than they would otherwise. Ideally, a gray surrounding should exist in the vicinity of a viewer used for judging aerial transparencies, and the sensitometric strips and photographs shoule be viewed together, if they are related. The spectral energy distribution at the illuminator should be approximately 3,800°K as recommended in USA Standard PH2.23-1961.

Duplicating

When making duplicates of aerial color photographs, the products of gradation of the original camera film and the duplicating film can be utilized to control the final result. If, for example, the full density scale of the camera film has not been utilized in making the original photography, some modification of photographic characteristics of the duplicate can be affected by the choice of printing density employed with the duplicating film.

The *tone reproduction diagram* in Figure 3 is used to illustrate the effects of gradation of the characteristic curves on the final result. The curves in this diagram are those obtained with the *visual* response filter on the densitometer. They are a practical approximation to the relative gradation characteristics of the original, the duplicating material, and final transparency. Actual *tone reproduction* studies of color films are much more complex than this, and are beyond the scope of the present discussion. They would involve the use of integral densities for the camera film, and analytical densities for the print film. The latter, then, must be computed and converted to integral densities in terms of the receiver, the human eye, if a print or duplicate for correct viewing is to be achieved.

Curve 1 in the upper left hand corner of this *tone reproduction diagram* represents an original transparency made utilizing camera film densities ranging from about 0.30 through about 2.0. If this is printed with an exposure that would make use of the lower portion of the duplicating film densities, shown on the curve in the upper right hand quadrant, with the minimum densities approximately matched, the projected curve is similar to that shown at 1 in the lower left hand quadrant. As can be seen, considerable photographic distortion exists in this curve, with practically one-half of the original brightness scale reproduced as a flat, low gradation *toe*. A considerable increase in the number of *tones* in the original transparency would be reproduced as *highlights* lacking in modulation.

If the printing exposure is decreased so as to utilize the upper densities of the duplicating film, less distortion is obtained. This may be represented by Curve 2 in the upper left hand quadrant which, if projected to the duplicating film in the right hand quadrant, yields a curve like that shown as 2 in the lower left hand quadrant. This may be considered to be a quite acceptable rendition of the tonal scale of the original aerial color photograph, with moderate amplification of density scale or contrast.

If this type of treatment is employed for high altitude photography where the original camera densities are within the range of 1.0 to 3.0, and are printed on a duplicating film in the same range of densities, a rather dense-appearing duplicate is produced, but the amplification of contrast, the approximate product of the average slope of the two curves, is greatly increased. Thus the ability to detect minor differences of both color and intensity levels in the original scene would be increased. (See Figure 4.)

On the other hand, if low altitude reconnaissance photographs have been taken, utilizing the lower portion of the characteristics curve to achieve maximum latitude, a print made on the low density portions of the duplicating film would retain the maximum latitude. Considerable distortion, or reduction in contrast, may occur in the highlight portions of this duplicate, printed in this way. However, should it be desirable to amplify a certain small portion of the lower contrast (lighter density original) it could be printed to high densities on the duplicating

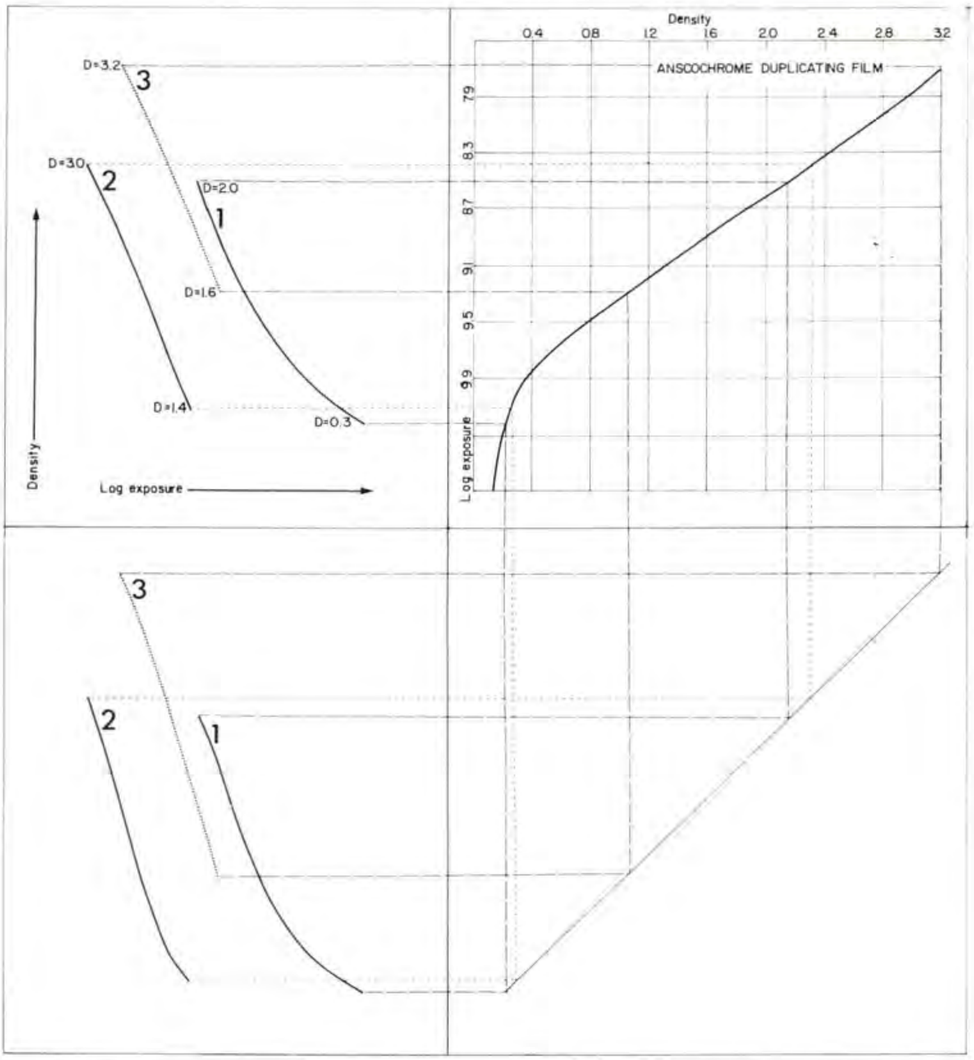

FIG. 3. This tone reproduction nomograph illustrates the effects of gradation of different portions of the characteristic curve on the final result.

film, thus amplifying the particular detail in question, even though a sacrifice in both contrast and color balance may have to be accepted in other densities than those of primary interest.

Where monochrome negatives are printed from aerial color positives, the usual monochrome film sensitometric control can be employed. The desired exposure and gradation level should be established through trial and error to provide sensitometric references for control of printing of negatives. Also, the use of contrast and separation filters can be used, similar to those appropriate for original black-and-white photography, and sensitometry can be used to determine contrast effects and filter factors, based on practical tests.

The science of sensitometry can prove to be a very useful tool in aerial color photography, duplicating, printing, and separating. However, in all instances the necessary references need to be established based on practical photography or printing tests, using sensitometry that is processed at the same time. Although filtration requirements can be estimated from sensitometry, even here closest approximations are made where sensito-

1. 2. 3. 4.

FIG. 4. These black-and-white reproductions from color aerial photographs illustrate the effect of exposure (average density in the color reversal aerial photograph) on contrast. Photograph 1, made at 8,000 feet but exposed to utilize densities above about 1.6, gives good contrast. Photograph 2 was exposed to record most of the details of densities below 2.0 on the film. Here the contrast is considerably lower, and might be considered to be inadequate. Photograph 3, made at an altitude of 4,000 feet and exposed to utilize densities above 1.6, has contrast that may be higher than desired. Photograph 4, made at the same elevation as Photograph 3 but utilizing densities below 2.0, has considerably lower contrast and preserves good detail in both shadow and highlight areas.

metric references have been established, using tests with the actual filters that will be used in practice.

Once the standards have been established, sensitometry provides the best means of control of any aerial photography or processing system.

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RESUMEN

RESUMEN DE LOS ARTÍCULOS TÉCNICOS PUBLICADOS EN EL MES PREVIO*

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PRINCIPIOS DE FOTOGRAFÍA AÉREA A COLOR

Por *Allan L. Sorem*

La adición y substracción de los tres colores primarios, son conceptos básicos en el diseño y la utilización de los materiales fotográficos a color. Una reproducción no debe tener necesariamente, y en la mayoría de los casos, no tiene, las mismas características espectrales de la escena original. Los materiales de negativos a color, pueden ofrecer ventajas significativas de flexibilidad sobre los tipos de color, reversibles. Las placas diapositivas de color, se utilizan satisfactoriamente en la cartografía estereoscópica. Hay disponible un computador de exposición que ayuda al fotógrafo aéreo, y el uso correcto de los filtros quizá requiera decisiones difíciles, mientras que el proceso a colores no presenta ninguna dificultad seria. Las características de color de la luz de enfoque, pueden limitar la cantidad de información recuperable de un sistema.

PHOTO. ENGR., SEPTIEMBRE 1967, PÁGINA 1008

FOTOGRAFÍA AEREA MULTI-ESPECTRAL A COLORES

Por *Edward Yost y Sondra Wenderoth*

Se ha construido una cámara para obtener fotografías multi-espectrales en cuatro bandas, en la porción de 360 a 980 nm del espectro. La fotointerpretación se efectúa en un visor acoplado que presenta una versión a colores compuesta de las cuatro fotografías por medio de técnicas de adición de color. Este sistema de cámara y visor combina la sensibilidad espectrofotométrica con los principios de la colorimetría, permitiendo la detección de las diferencias geofísicas apropiadas del terreno.

Se han efectuado numerosos experimentos utilizando sistemas con equipos basados en estas técnicas. Los resultados promisorios que se han obtenido, indican aplicaciones potenciales de este sistema a la agricultura, contaminación de las aguas usadas en silvicultura, análisis de suelos, determinación de profundidad de aguas, así como en los problemas militares de adquisición de blancos y detección de camuflaje.

La aplicación satisfactoria de la tecnología multiespectral en una gran variedad de condiciones fotográficas halladas en la detección remota práctica, depende de la precisión de las técnicas empleadas. Un procedimiento fotográfico preciso, es esencial para obtener resultados continuos correctos.

PHOTO. ENGR., SEPTIEMBRE 1967, PÁGINA 1020

(*Concluded on page 1166*)

* *Nota:* Traducido por la Sección de Tracucciones de la Escuela Cartográfica del Servicio Geodésico Interamericano (IAGS).