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PSEUDOCOLOR TRANSFORMATION OF ERTS IMAGERY

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ABSTRACT

For several years, a group at Rand has been studying human vision and the effectiveness for improving detection and recognition. In the course of this work, a number of image enhancement techniques have been developed.

One of the photographic techniques which shows great promise as an aid in interpreting ERTS imagery is pseudocolor transformation. It is a process where each shade of gray in an original black-and-white image is seen as a different color in the transformation. The well known ERTS-1 MSS image of the Monterey Bay-San Francisco area was transformed using a technique which requires only two intermediate separations. Possible faults were delineated on an overlay of the transformation before referring to geologic maps. The results were quite remarkable in that all large active or recently active faults shown on the latest geologic map of California were interpreted from the image for all, or much, of their length. Perhaps the most interesting result was the Reliz fault. The fault is shown as covered; however, a lineation corresponding to the position of the fault is visible on the image.

The usefulness of ERTS images in identifying recently active faults is demonstrable. Although the faults are also visible in the unenhanced image, they are clearly accentuated and more easily mapped on the pseudocolor transformation.

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The eye can distinguish a difference in any of the three visual coordinates (hue, saturation, and luminance), and is quite sensitive in this regard even for complex images.⁽¹⁾ In discrimination tasks with a black-and-white image, the eye responds to differences in only one of the coordinates -- luminance -- over its gray-scale range from black to white. In a pseudocolor enhancement of a black-and-white image, a particular chromaticity/luminance combination is obtained from each shade of gray in the original black-and-white image. By thus using all three visual coordinates, one can transform a small gray-scale difference in the black-and-white original into an easily distinguished color (chromaticity/luminance) difference in the pseudocolor enhancement.

Numerous techniques, both photographic and mechanical, have been developed for creating pseudocolor transformations. Among the mechanical devices are Aerojet-General's Spectrovision,⁽²⁾ which produces a video display with up to 64 colors, and Spatial Data Systems'⁽³⁾ color display system with 32 colors. International Imaging Systems'⁽⁴⁾ additive color optical viewer projects up to six images onto a rear projection screen with a variety of optical filters on each channel to create natural, false, and pseudocolor effects.

The transformation of a black-and-white image into a pseudocolor version can be effected photographically in a variety of ways. Perhaps the simplest is the transformation of shades of gray to colors in such a way that the progression of grays from white to black is transformed to successive colors in the spectrum -- white to red, light gray to orange, etc. This can be accomplished by using several black-and-white separations in which information on the intensity levels in the original image is encoded. Each separation contains information relating to a limited range of intensities. Many such high-contrast "masks" may be used, with each one encoding only a very narrow range of intensities in the original. Examples of such laborious techniques are an early effort by Gazley, Stratton, and Rieber⁽⁵⁾ involving 64 separations and also one developed by D. S. Ross⁽⁶⁾ a number of years ago where discrete density levels are recorded on separate sheets of film and color is produced from each separation. Such procedures are time consuming and expensive, and produce results that are more easily

obtained by computer techniques.⁽⁷⁾ A more realistic approach to photographic transformation processes is to limit the number of separations, such as the recent example by Robert Gooding⁽⁸⁾ in which the original is divided into four density regions, each illuminated with a different color of light, superimposed, and then photographed on a single piece of color film. Our approach to photographic transformations has been to develop a process which transforms a continuous gray scale into a continuous chromatic scale.

Two techniques have been developed at Rand, both of which employ intermediate black-and-white records or separations. One involves three separations,⁽⁹⁾ the other only two.⁽¹⁰⁾ The two-separation process relies on the following characteristics of the color material used in the final stage of the process: (1) the use of relatively broad-band "blue" and "red" filtered light sources, which affect the green-sensitive emulsion as well as the red- and blue-sensitive emulsions; (2) the overlapping spectral sensitivity of the three emulsion layers; and (3) the relation of the density to the exposure of the three emulsion layers when exposed to these light sources. Thus an exposure of a negative color material to a "blue" light source will increase the density of not only the blue-sensitive layer (yellow dye formation) but also the green-sensitive layer (magenta dye formation). Similarly, exposure to a "red" light source will increase the density of not only the red-sensitive layer (cyan dye formation) but also the green-sensitive (magenta dye formation). Furthermore, above a certain level of exposure of the red- and blue-sensitive layers to the respective red and blue light sources, the response of the green-sensitive layer can be affected with minor change to the other layers.

Although the final pseudocolor print is on color material, the intermediate separations are on black-and-white materials. In the two-separation process, the density ranges of these separations must be carefully controlled. Let us assume that our transformation will be such that the light areas in the positive form* of the original black-and-white will appear red, the medium areas green, and the dark areas blue.

Let the black-and-white separations, which are positive and negative versions of the original, be designated O_p and O_n . If O_n is contact printed onto the negative color material using the red light source, the

*The original may be in either positive or negative form.

processed image will have color steps which follow the left dashed line of Fig. 1. Similarly, if O_p is printed using the blue light source, the color steps of the processed image will follow the right dashed line of Fig. 1. With proper exposure, the image density of each will vary from no noticeable exposure at one end to a dense and highly saturated image at the other. The high-density portions of the two film images are of course at opposite ends of the gray scale. If these two film images are now sandwiched in register and illuminated from the rear, the hues of the resulting subtractive dye layers of each step will follow the dashed line of Fig. 2.

If this process is exactly repeated using a double exposure on only one sheet of color material, the resulting image will be nearly identical to that of the two individual sheets. Thus one may produce a full gamut of spectral colors by two exposures.

A schematic of the resulting two-separation process is shown in Fig. 3. The original is positive, and the light areas of the original are to be reproduced as red. If either but not both of these conditions were reversed, the red and blue exposures would be interchanged.

-Figure 3 is almost self-explanatory; the process is as follows:

1. The first separation, O_n , is made from the original positive and developed. (The original is not ordinarily used as a separation because its density range and physical size are rarely compatible with the process.)
2. The second separation, O_p , is contact printed (not emulsion to emulsion) from O_n and developed.
3. O_n is contact printed (emulsion to emulsion) on color material with a red light source.
4. O_p is contact printed (emulsion to emulsion) on the same color material with a blue light source.
5. The color material is processed.

The steps in the pseudocolor transformation of a 5-step gray scale are illustrated in Fig. 4 for the two-separation process. Shown schematically are the density levels in the original, the density levels in the

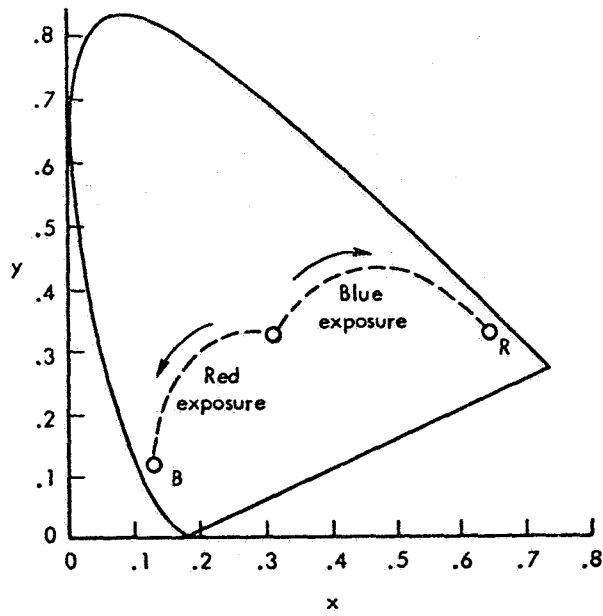


Fig. 1 -- Chromaticity changes with increasing exposure to either red or blue light sources.

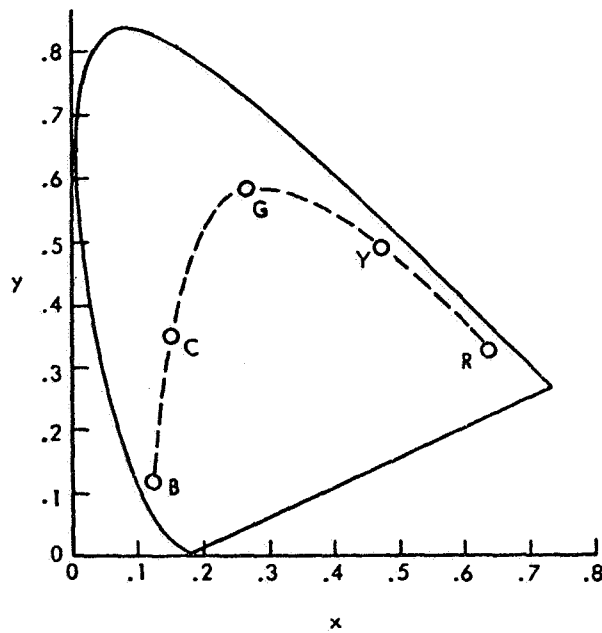


Fig. 2 -- Chromaticity gamut resulting from various double-exposure combinations of red and blue light sources.

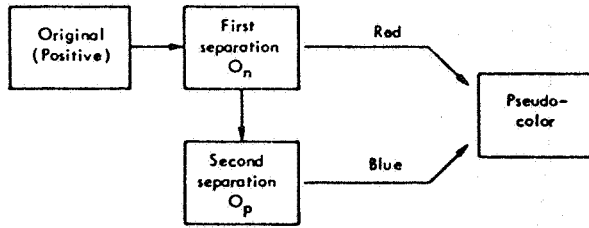


Fig. 3 -- Schematic of two-separation process.

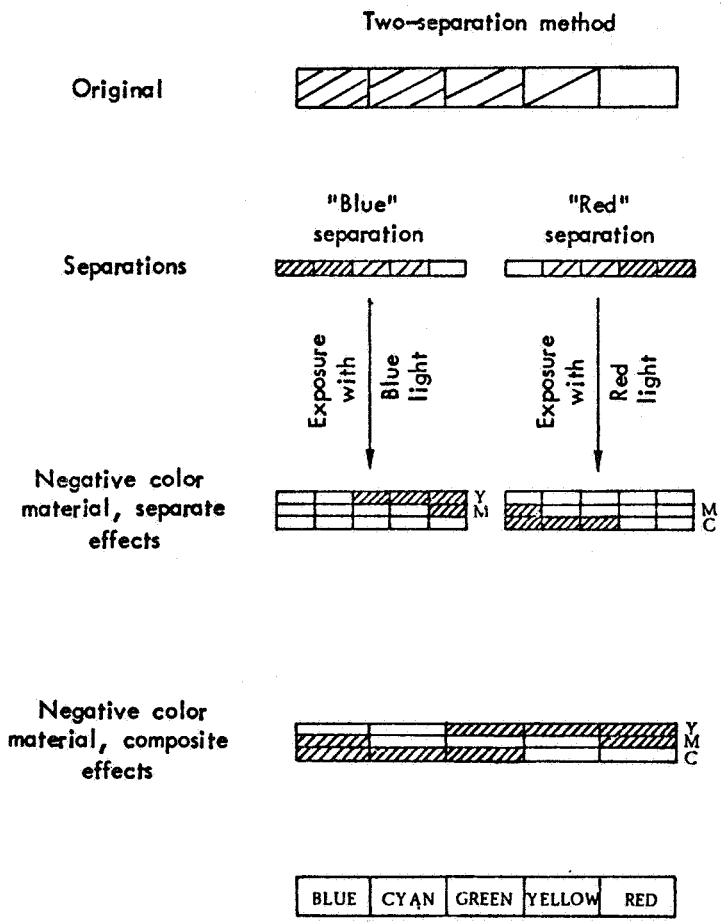


Fig. 4 -- The response of a negative color material to a 5-step gray scale for the two-separation process

black-and-white separations, the dye densities produced in the negative color material by separate filtered exposures, the composite dye effects in the negative color material, and the resulting subtractive color produced.

A trial-and-error method was used to determine a satisfactory combination of density limits for the separations O_p and O_n , the selection of red and blue filters, and the amount of exposure on color material. The color material used was Ektacolor Print Film, a negative material intended primarily for display transparencies from Kodacolor or Ektacolor negatives. This film has a speed range suitable for exposure with an ordinary photographic enlarger, and is processed with Kodak C-22 chemicals.

The light source was a No. 212 enlarging lamp (150 w) operated at 115 v. Several different red and blue filters were tried to give the approximate chromaticity traces of Fig. 1. The objectives was to select filters that pass an appropriate amount of light in the green range compared to that passed in the red or blue end of the spectrum. The results of these trials indicated the most satisfactory filters to be the Wratten 23 A (red) and 47A (blue).

Since one has no control over the form of the original, the initial task is twofold: (1) reducing or enlarging to a standard format, and (2) obtaining a density range of approximately .5 to 3.2. The latter task is one of determining exposure and development to obtain the desired density extremes. This requires a prior calibration of the black-and-white separation materials, which was done for both Commercial and Contrast Process Ortho film. Once both separations, O_n and O_p , have density ranges from .5 to 3.2, they may be successively contact printed (emulsion to emulsion) onto the color material with their respective red and blue filters. The amount of exposure should be such that the red and blue extremes of the image are highly saturated, but not so much as to cause muddy (brownish) yellows.

If the density ranges of O_n and O_p are too high, the greens and yellows will be underexposed and too light if the red and blue ends are correct. If the separations do not have enough density range, the greens and yellows will be too dark for saturated reds and blues.

The advantage gained by presenting an image in color are quite obvious even though color films do not possess the high resolution of black-and-white films. The processes which we have developed maintain between 34 and 40 lines/mm in the final transformation.

A pseudocolor transformation of the well-known ERTS-1 image of the Monterey Bay/San Francisco area was made. Possible faults were delineated on an overlay of the transformation before referring to geologic maps of the area. Figure 5 is a black-and-white print of the ERTS image with the overlay. The results were quite remarkable in that all large active or recently active faults shown on the latest geologic map of California⁽¹¹⁾ were interpreted from the image for all, or much, of their lengths. In addition, several other lineations were readily visible. It is unlikely that they are all faults, but they have similar appearance to known faults and justify being checked against larger-scale geologic maps and in the field. The most interesting result of this investigation was detection of the Reliz fault. This fault is shown as covered, or not visible from the ground by Jennings. However, a lineation corresponding to the position of the fault was discovered on the pseudocolor image. This fault is visible on the unenhanced image when one knows where to look, but it is clearly accentuated and more easily mapped on the pseudocolor transformation.

An example of the use of a false color^{*} transformation is in the determination of the density and temperatures of clouds. Two negatives of a hurricane, one IR, one visible, were obtained from the Air Weather Service at Offutt AFB. Two composites of these images were created, a blue record with the visible transparency, and a red record with the IR transparency. As the hue of composite one goes from white to black, the cloud temperature drops from high to low, the cloud density is high when the hue is white, yellow, or red, medium when the hue is cyan, green, or dark orange, and low when the hue is blue, dark aqua, or black.

In composite two, the visible is the red record and the IR is the blue record. As the hue progresses from white to black, the cloud density progresses from low to high, the low temperatures are seen as white, yellow, or red, the medium temperatures as cyan, green, or dark orange, and the high temperatures as blue, dark aqua, or black.

* False color differs from pseudocolor in that the color image is constructed from information from more than one spectral band.

We intend to combine the various combinations of the four spectral bands from MSS data in a similar manner in our investigation of earthquake fault detection.

If we use computer techniques to generate the separations, more sophisticated classes of transformations will become possible. As an example, color can be keyed to density gradient instead of density level. Figure 6 shows this type of transformation for a boundary region of varying

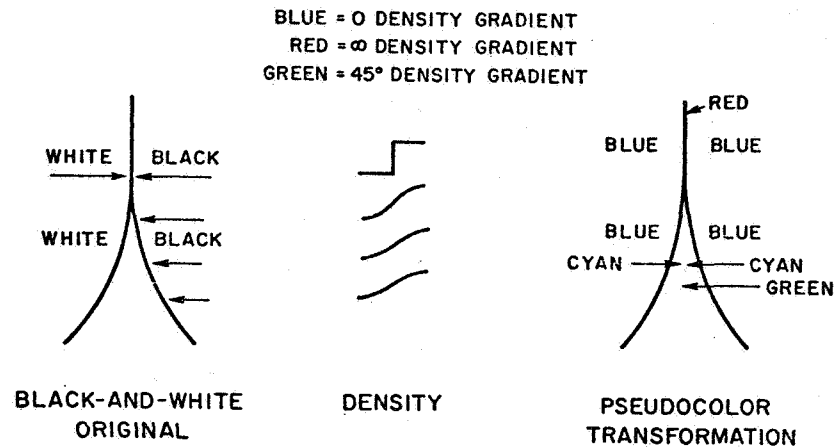


Fig. 6 -- Schematic illustration of a pseudocolor system in which color is keyed to density gradient

density gradient. The computer will also allow freedom from the restrictions of photographic emulsions so as to utilize more effectively the added perceptual dimensions of hue and saturation. For example, an effective transformation scheme may be the keying of hue to density level and brightness to density gradient. Such a transformation is illustrated schematically in Fig. 7 for the same boundary region as seen in Fig. 6.

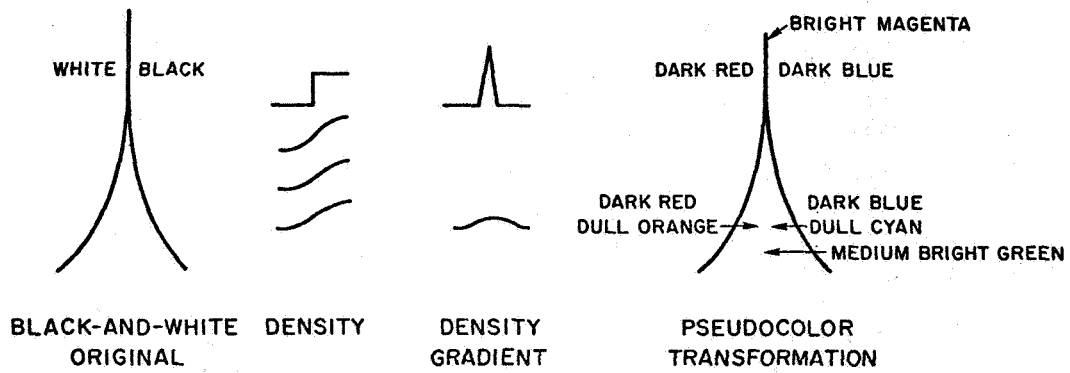


Fig. 7 -- Schematic illustration of a pseudocolor system in which hue is keyed to density level and brightness is keyed to density gradient

These computer techniques are under investigation presently and seem to show great promise for future image enhancement.

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