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Direct Additive Printing

. . . is a viable technique for producing color composite imagery from multispectral separations (such as ERTS imagery) using only conventional darkroom equipment.

ABSTRACT: *The simultaneous gathering of imagery in more than one independent spectral channel has led to increasing demands for systems of data analysis capable of fully exploiting and displaying the available information content of ERTS-type of imagery. This paper discusses techniques of direct additive photographic printing with particular emphasis on the ERTS-1 system.*

INTRODUCTION

THE SIMULTANEOUS gathering of imagery in more than one independent spectral channel has led to increasing demands for systems of data analysis capable of fully exploiting and displaying the available information content of this type of imagery. It is generally accepted that significant advantages can be gained by presenting such multispectral data in a single analog color combination mode as opposed to sequentially viewing the individual band images. Very often the potential users of this type of imagery do not have access to additive viewing equipment and therefore the availability of additive multispectral photographic prints and transparencies is desirable. Specifically the advent of the ERTS-1 project has led to a need for the production and supply of high-quality additive color imagery. One convenient method of doing this is via direct additive printing. As the method requires only conventional darkroom equipment it should be of particular interest to many data users who have access to such facilities.

Direct additive printing refers to the sequential formation of a color composite photograph from multispectral separations. This is as opposed to the use of additive viewers, video systems or various types of digital readouts and displays. The technique of direct additive printing has significant technical characteristics which are discussed in this paper.

TECHNIQUE

Five basic techniques of direct additive printing are illustrated in the flow diagrams in Figure 1. The alternative appropriate to a given situation depends on the initial mode and the desired system contrast. The individual steps are as follows:

STEP 1. ENLARGEMENT

The initial stage is to enlarge the first generation separations to the desired final size. This is a straightforward procedure but care should be taken to use a long focal-length enlarger lens to avoid significant fall-off in irradiance at the extremities of the enlarged format. A 300-mm lens can be used for the ERTS-1 70-mm separations, thus achieving an irradiance that is uniform to about 3 percent. If the imagery is enlarged carefully, the band-to-band scale changes introduced by this step should be limited only by the differential size changes due to processing.

The exposure should be such as to place all the densities of the first-generation separations on the straight-line portions of the characteristic curve of the printing material. In working from ERTS-1 separations, it is desirable that this step should result in a positive image because the corner crosses supplied for registration purposes are then dark against a light background. The following materials have proved suitable for the production of the enlarged separations.

- *Kodak 2422 Direct Duplicating.* This material, which is used if working from NASA positives, has a limited straight-line characteristic but it is usually adequate for the ERTS imagery. However, wedge densities will be distorted.
- *Kodak 2420 or Ilford FP3.* This material is used if working from NASA negatives. The

METHOD NUMBER	FLOW DIAGRAM.							COMMENTS.
1	2nd. or 4th Gen. 9.5" NEGATIVES.	Neg	3rd. or 5th Gen. 9.5" POSITIVES.	Pos.	REGISTER CONTACT PRINT ON TO NEGATIVE COLOUR, AERIAL FILM, KODAK 2445.	Neg	PRODUCE FINAL POS. PRINT OR TRANSPARENCIES. (CONTACT OR ENLARGED)	METHOD USED BY NASA.
2	3rd. Gen. ERTS 70mm POS.	Pos.	ENLARGE 1:1000000 POS. KODAK 2422.	Pos.	REGISTER CONTACT PRINT ON TO NEG. COLOUR PRINT. FILM EKTACOLOR 4109.	Neg	PRODUCE FINAL POS. PRINT OR TRANSPARENCIES. (CONTACT OR ENLARGED)	VARIABLE MEDIUM TO HIGH CONTRAST.
3	3rd. Gen. ERTS 70mm POS.	Pos.	ENLARGE 1:1000000 NEG. KODAK 2430.	Neg	REGISTER CONTACT PRINT ON TO REVERSAL COLOUR FILM.	Neg	PRODUCE FINAL POS. PRINT OR TRANSPARENCIES. (CONTACT OR ENLARGED)	VARIABLE LOW TO MEDIUM CONTRAST. EXCELLENT SYSTEM SENSITOMETRY. REGISTRATION NOT EASY BECAUSE CROSSES ARE CLEAR AGAINST BLACK.
4	4th Gen. ERTS 70mm NEG.	Neg	ENLARGE 1:1000 000 NEG. ILFORD FP 3 OR KODAK 2420.	Pos.	REGISTER CONTACT PRINT ON TO NEG. COLOUR PRINT. FILM EKTACOLOR 4109.	Neg	PRODUCE FINAL POS. PRINT OR TRANSPARENCIES. (CONTACT OR ENLARGED)	VARIABLE HIGH TO VERY HIGH CONTRAST.
5	3rd Gen. ERTS 70mm POS.	Pos.	ENLARGE 1:1000000 POS. KODAK 2422.	Pos.	REGISTER CONTACT PRINT ON TO POS. COLOUR FILM e.g. CIBACHROME.	Pos.	PRODUCE FINAL POS. PRINT OR TRANSPARENCIES. (CONTACT OR ENLARGED) ON DIRECT POSITIVE STOCK.	VARIABLE LOW TO MEDIUM CONTRAST. BEST SYSTEM M.T.F.

FIG. 1. Some techniques of direct additive printing.

generally high density of the ERTS 70-mm negatives makes the use of the slower, higher-resolution Kodak 2430 impracticable.

It is evident that the contrast at this stage can be controlled from low (suitable processing) to high (processing, multiple printing at $\gamma > 1$, use of lith films, etc.)

STEP 2. REGISTRATION

The separations can be registered with no more sophisticated equipment than the human eye, a 10X magnifier and a register punch. The ERTS-1 images are generally registered on the available corner crosses although these are sometimes disregarded if they do not correspond to the picture area itself. The three separations are individually registered (and punched) with respect to a master duplicate of any one band.

STEP 3. ADDITIVE PRINTING

The contact printing stage onto color material involves the selection of a suitable material and a set of additive filters chosen so that each exposes only one layer of the color film. For the examples included in this paper Ektacolor 4109 print film was used for this stage with Wratten 98, 99 and 29 filters. Kodak Internegative or 2445 Aerocolor Negative films could be used for lower contrast results. A lower contrast color material offers better system sensitometry in that the necessary contrast can be obtained in the earlier black-and-white step which is inherently more controllable. However, factors such as the unavailability of large-format sizes and the overlapping of individual layer spectral sensitivity curves (as in Kodak 2445) can dictate the choice of another material. Relative band-to-band exposures for this stage can be calculated by pointwise integration of the filter transmittance and film spectral sensitivity curves (if the latter are available) in combination with the densities of a particular step on the calibration wedge on the ERTS-1 imagery. A simple exposure series can then determine the actual exposure for all three bands. Exposures for subsequent imagery can then be calculated simply by measuring the difference in the densities of the same wedge-step in all three bands from one set to another.

STEP 4. PRODUCTION

The final printing stage from the master color negative is conventional. The use of transparent-base material with its large dynamic range for this stage exploits fully the potential of this technique.

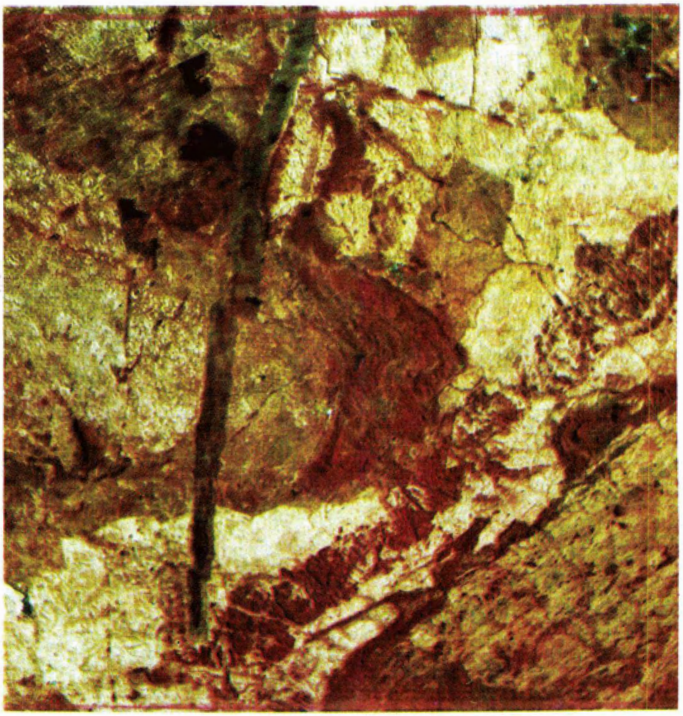

PLATE 1. NASA ERTS image using Technique 4 shown in Figure 1. The area is in Southern Rhodesia and includes part of the Great Dyke.

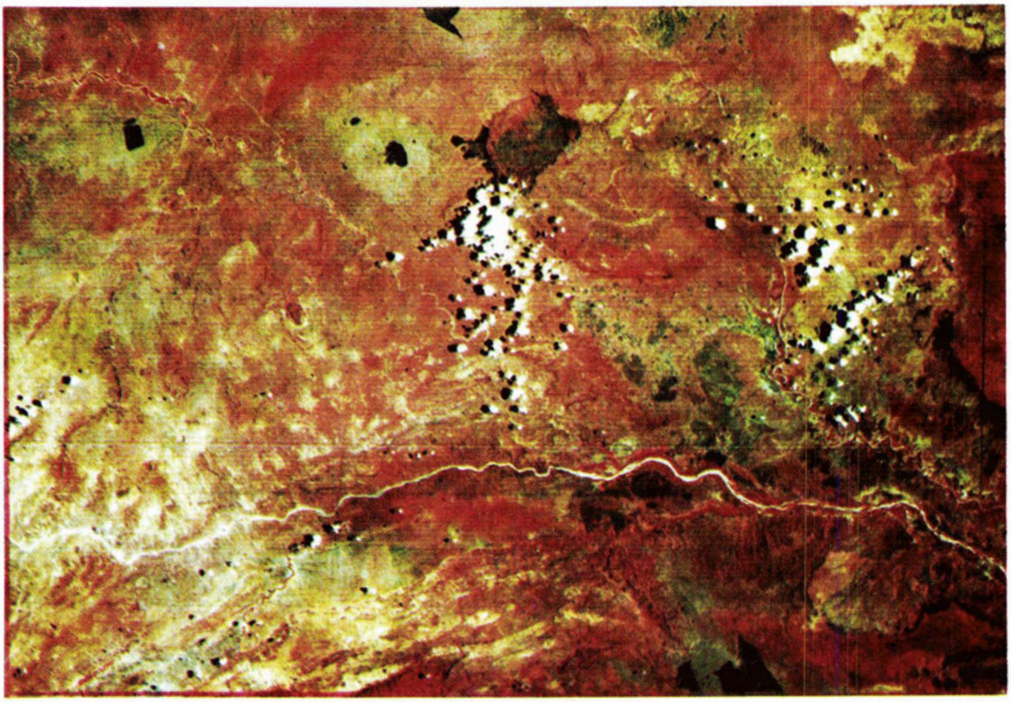

PLATE 2. NASA ERTS image using Technique 2 of Figure 1. The area shows the Limpopo River that forms the border between Rhodesia and South Africa.

Significant aspects of this additive printing technique in general are:

- ★ Only one optical system is required to produce all the enlarged separations;
- ★ Registration can be achieved at the final desired degree of enlargement;
- ★ The color printing is a contact stage, thus avoiding the use of lenses and making the use of narrow band printing filters practicable; and
- ★ In order to expand the relatively small density range of the ERTS-1 multispectral separations to utilize fully the available range of the final color material, a photographic system gamma of about 5 is usual. This system gamma can be varied particularly at the enlarged separation stage, by suitable choice of materials, processing and multiple printing at $\gamma > 1$.

System Performance

In evaluating the limitations and advantages of this direct additive printing technique the following system variables should be considered.

DYNAMIC RANGE OF THE END PRODUCT.

This is represented by the characteristic curves of either color paper or color print film, depending on the desired final product. These ranges are typically 1.7 density units for color paper and 2.6 density units for print film.

ACCURACY AND PRECISION OF MULTIPLE-BAND REGISTRATION AND THE EFFECT ON SYSTEM RESOLUTION

It is clear that any spatial misregistration of the bands is undesirable. Because the amount of misregistration is independent of the degree of enlargement of the images to be registered, it is desirable to enlarge these images to the point where the amount of unavoidable misregistration is significantly less than that distance on the picture area corresponding to the limiting ground resolution of the system as a whole. In the technique employed for the illustrations, unavoidable misregistration is usually of the order of 0.07 mm although it can be as low as 0.03 mm. If the ERTS-1 imagery is enlarged to a scale of 1:500,000, limiting ground resolution corresponds roughly to 0.1 mm on the picture.

In practice however, slight misregistration gives an effect similar to bas-relief and good registration seems to yield superadditive enhancement possibly due to increase in the signal-to-noise ratio. Therefore, the effect of registering spatially identical, spectrally different images is complex and further work is required to understand it fully.

Examples

Two color images prepared via direct additive printing from ERTS-1 separations are shown in Plates 1 and 2.

Plate 1 was prepared from NASA ERTS-1 image 1103-07291 using Technique 4 of Figure 1. ERTS bands 4, 5, and 7 were exposed through Wratten 98, 99 and 29 filters respectively to yield the "conventional false color" presentation with its characteristic red vegetation. This image, which is remarkable for its clear display of geological features, covers part of the southern sector of the Rhodesian craton and portion of the linear north marginal zone of the Limpopo mobile belt. The Great Dyke traverses the central part of the image and is the most clearly defined feature.

Plate 2 was prepared from NASA ERTS-1 image 1138-07240 using Technique 2 of Figure 1. The same color combination as for Plate 1 was used. The image covers the southeastern part of Rhodesia, and the Limpopo River, which forms the border between Rhodesia and South Africa, can be clearly seen.

The registration accuracy of Plates 1 and 2 are very nearly equal. However, the contrast of Plate 1 is considerably higher than that of Plate 2, as can be seen from the greater color range in the image areas.

Conclusions

Direct additive color printing is a viable technique for producing color composite imagery from multispectral separations using only conventional darkroom equipment. The end product is characterized by a large dynamic range and color gamut together with generally better band-to-band registration than is possible with conventional multiple-projection systems.