APPLICATION OF COLOUR SCANNERS IN THE REPRODUCTION OF REMOTE SENSING IMAGES

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Abstract : The distinguishing features of the reproduction of remotely sensed images are discussed. The geometric accuracy and resolution of scanning systems are examined and a reproduction approach has been described.

Introduction

In the last few decades, much work has been done in the graphic arts industry concerned with the improvement of colour reproduction. This has been directed at the quality and economics of production, but more importantly the consistency between reproductions. It has been demonstrated by many workers that consistency can only be achieved by proper control of the parameters in reproduction which affect the reproduced colours and image details, and this must be the starting point of any system. (8). In recent years Johnson, Birkenshaw and Sunderland at Pira have undertaken a series of research in these areas, and have set up a practical colour reproduction system for the systematic principles developed in the Pira studies. The particular cartographic requirements in the reproduction of remote sensing images have been tried using colour scanners DC-300B and M-550 at Pira, the objective of which was: (1) to investigate the geometric accuracy of scanning systems, (2) to examine the resolution of scanning systems, (3) to specify an improved approach to the reproduction of remotely sensed images, (4) to determine the possibilities application of colour scanners in the reproduction of remotely sensed images.

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The distinguishing features of the reproduction of remote sensing images

Remotely sensed images, in general, include many types of imagery such as multispectral scanned images, aerial photographs (colour or black-white), infra red pictures, side-looking airborne radar images and Landsat images etc. As an example, the multispectral scanning images from Landsat No.1 have four spectral bands (green, red and two bands in near infra red). The object scene on the earth is scanned by an oscillating flat mirror between the sense and a double-reflector telescope. The cross-track field of view substends a swatch of 185 km from the nominal 915-km altitude. The along-track scan is provided by the forward motion of the spacecraft. The instantaneous field of view of the detectors subtends 79 m on the ground. The detector signals are sampled, digitized, and transmitted to receiving stations where they are recorded on tape. At space flight centre the Electron Beam Recorder can produce black-white images from each of the four bands on 70 nm film at a scale of approximately 1 : 3,370,000. Then, the four black-and-white images can be composited subsequently to produce colour images with nearly the same rendition as colour infra red film. In recent years a series of satellites have been launched, and therefore interest in remote sensing images increases from day by day. Experts in many disciplines have tried to apply the images produced in their own fields of interest. Cartographers also showed a great interest at a very early stage. The cartographic application of Landsat imagery has already been discussed in many articles. We know that remote sensing images can be used for evaluating photomapping, map revision, thermatic mapping, polar mapping and the overall cargoraphic application. For instance, US Geological Survey produced the Arizona photomap at the scale 1 : 5,000,000 in 1973. For this map image many Landsat pictures of Band 4 (0.5 - 0.6 μm wavelength), band 6 (0.7 - 0.8 μm) and band 7 (0.8 - 1.1 μm) were used. Morever, another black-and-white mosaic at 1 : 5,000,000 scale for the whole state of Arizona was assembled from 14 MSS images. In this case, the original base map was cast on a single Lambert conformal conic projection designed to cover the whole United States. Versions were printed both with and without the planimetric line detail from the standard map. Besides America, cartographers in Japan, West Germany, England, The Soviet Union, China and France have also produced many colour image or different aerial photographs. After having analysed these maps printed in different countries, from the point of colour reproduction and tone reproduction, we can find some technical drawbacks: (1) there is a lack of systematic approach to tone and colour reproduction, similar image processed by different companies may look totally different, (2) these colour image maps appear in poor colour rendition and image details, (3) there is a shortage of colour balance in reproduction.

To overcome the technical problems mentioned above and to set up a practical approach to reproduction of remote sensing images, we have undertaken some research for several years. Compared with colour reproduction in conventional graphic arts, reproduction of remotely sensed images has its own distinguishing features which may be summarised as follows:

1. A system for reproduction of remote sensing images must provide high enough geometric accuracy, because image maps are used not only for identifying what images represent on the earth, but also for determining where they are located.

2. It is important to obtain more image details of reproduced prints rather than accurate colour rendition.

3. The reproduction approach must have flexibility because of particular requirements for different originals, for instance, sometimes over or under-exposed transparencies have to be dealt with.

4. It is necessary to maintain resolution through many reproduction steps (scanning-platemaking-printing). The tolerance margin of resolution for the reproduction of remotely sensed images is about 6 lines/mm at magnification 1.

The analysis of geometric accuracy of scanning systems

In recent years the cartographers and the geographers in the world have compiled a lot of new maps using different coloured (or black-white) remotely sensed images. As these images, in general, are taken at quite small photoscales, when applying them, map-makers must enlarge these pictures several times, especially satellite images having scales of 1 : 3,300,000 or smaller. It is known that the bigger the enlargement, the less the geometric accuracy of reproduction, and vice versa. Consideration of the accuracy of reproduction is necessary before we use colour scanners, to determine the maximum acceptable enlargement indexes of the colour scanning systems. For this reason we have examined the practical accuracy of scanning systems. The objective of this examination is : (1) to detect if there is any spherical distortion in scanning systems, such as pin-cushion distortion and barrel-shaped distortion, (2) to determine if colour scanners produce the same distortion in both vertical and horizontal directions, (3) to determine whether the standard deviations of the scanning systems are acceptable (according to the instruction for surveying and mapping, the maximum acceptable error in reproduction is $\pm$ 0.3 mm).

We know that in process of reproduction there are a great many factors influencing the accuracy of scanning systems, such as lens distortion (linear or spherical), film distortion, tolerance of the optical and mechanical construction of the colour scanners, working conditions, measuring errors and so on. For practical purposes we have confined ourselves to examination of the total accuracy of the scanning systems only, instead of analysing every factor separately. To this end, we have prepared a line original in polyester base with a high-accuracy electronic plotter. The original is shown at figure 1.

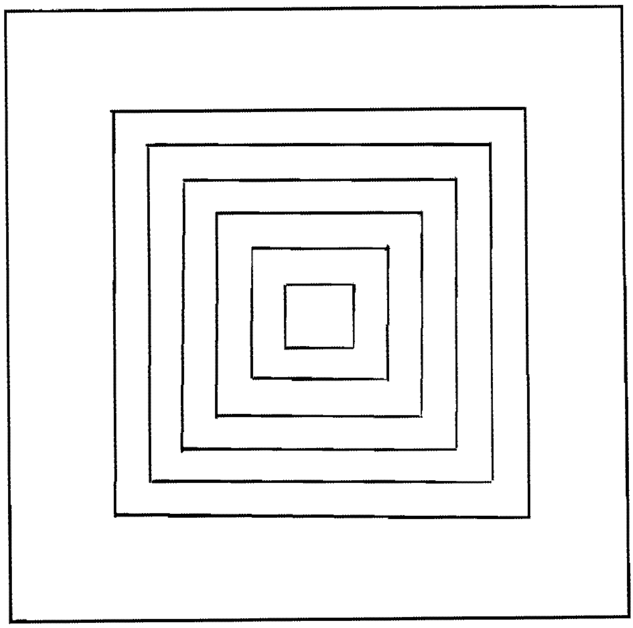


Figure 1. Original used for scanning

Before scanning the line original, we measured the 24 lines and the 12 diagonals of the six squares twice using the measuring microscope providing a reading accuracy of 0.01 mm. The average values of measurements are considered as the standard values (Rs). To determine the relationship between the enlargement indexes of scanning systems and the accuracy of reproduction we scanned the line original at different enlargements (1*, 2*, 4*, 6/, 8*) using DC-300B and M-550 colour scanners at Pira. The films were processed automatically under controlled conditions. The Kodak film was processed with Kodak Readymatic processor for DC-300B, and Kodalith MP II film was developed with Kodalith processor for M-550. The separation transparencies were measured with the same microscope in the same working conditions. To analyse the accuracy of the reproduction, having finished the dimensional measurements of the separation transparencies we have done some error calculation using the principles of the least square method. Formulae used for computation are shown below:-

1. Root mean square error (r)

This can be used to evaluate the overall accuracy of the measurements. As the errors of the scanning systems cannot be considered in terms of standard deviation, the root mean square error is calculated by

$$Y = \sqrt{\frac{\Sigma\ [\Delta]^2}{n}}$$

Here, $[\Delta_1]$, $[\Delta_2]$ ---- $[\Delta n]$ ... are the errors at n measured lines.

2. Systematic error (s)

It is necessary to examine the consistency of the measurements on one or a group of separation transparencies. There may be two possibilities: if the errors are random, then $\Sigma\ [\Delta] = 0$. In this case, the consistency of the measurements is its root mean square error. If, however, $\Sigma\ [\Delta] \neq 0$, it means that an overall shift has been introduced and this error must have systematic character. It is computed by:

$$s = \frac{\Sigma\ [\Delta]}{n}$$

3. Standard error (b)

The consistency of the measurements can be found by taking the systmeatic error from the individual errors at each measurement and this gives:

$$\delta = \sqrt{(r^2 - s^2)} \quad \text{or}$$

$$\delta = \sqrt{\frac{\Sigma([\Delta] - s)^2}{n}}$$

By the use of the standard error the random or accidental component in the inaccuracy can be isolated and the δ value provides an estimate of the range on either side of the best results by fallible readings within which the true results may be expected to lie.

The results of all error calculations for both DC-300B and M-550 colour scanners are shown in table 1 and illustrated by figures 2 - 4.

	Enlargement	(Δ) max		γ (mm)			$S_{H.V}$	$\sigma_{H.V}$	
		(Δ)H	(Δ)V	γ H.	γ V.	H.V			
DC-300B	1x	-0.10	-0.07	±0.06	±0.04	±0.05	-0.04	±0.04	Large Drum
	2x	-0.15	-0.06	±0.11	±0.04	±0.08	-0.06	±0.06	Large Drum
	4x	-0.22	+0.08	±0.17	±0.17	±0.13	-0.08	±0.11	Large Drum
	6x	+0.09	-0.10	±0.081	±0.1	±0.91	0	±0.091	Medium Drum
M-550	1x	-0.23	+0.09	±0.132	±0.043	±0.098	-0.055	±0.08	Large Drum
	2x	-0.29	-0.05	±0.265	±0.027	±0.188	-0.124	±0.141	Large Drum
	4x	-0.35	+0.13	±0.304	±0.093	±0.225	-0.123	+0.19	Large Drum
	9x	-0.73	+0.20	±0.561	±0.053	±0.398	-0.22	±0.332	Large Drum

Table 1 - Results of the error calculations

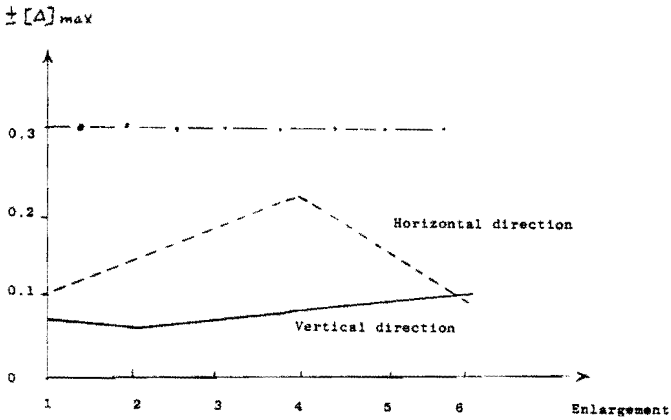


Figure 2 - Relationship between enlargement and the maximum distortion of lengths (DC-300B)

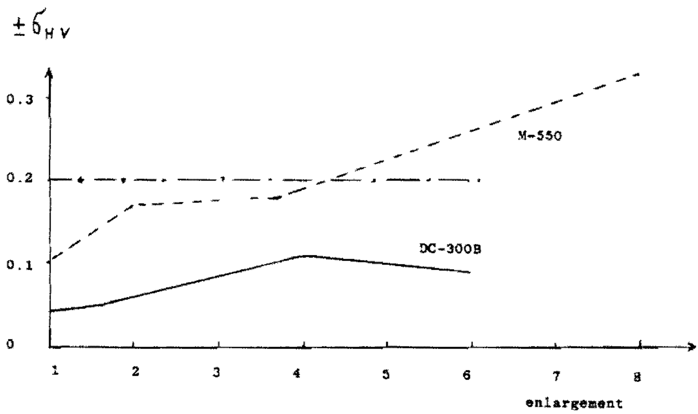


Figure 3 - Relationship between enlargement and the standard error

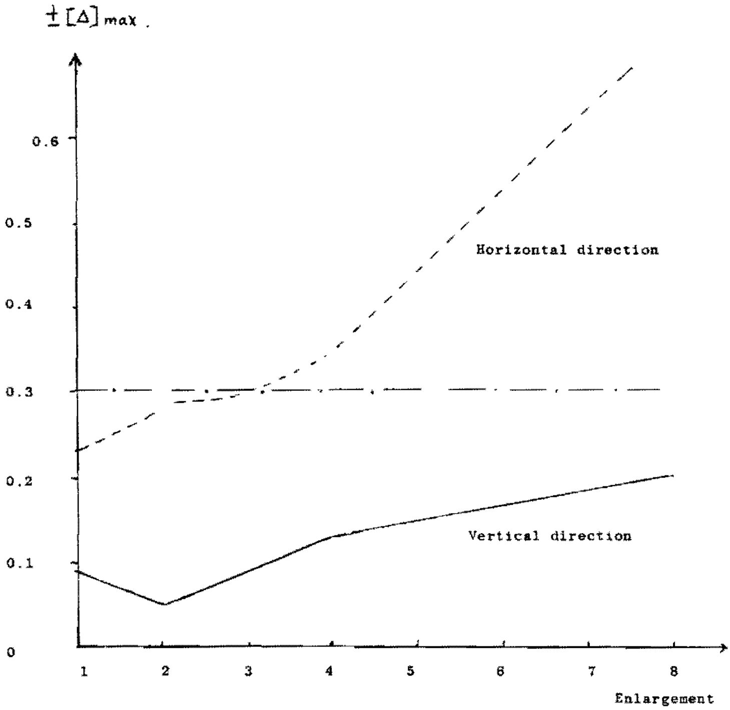


Figure 4 - Relationship between enlargement and the maximum distortion of lengths (M-550).

After analysing data in table I and figures 2-4 it can be pointed out:

1. The vertical and horizontal directions of scanning systems produce different dimensional distortion. The former for colour scanners both DC-300B and M-550 has less distortion than the latter, and the distortion in vertical direction appears quite stable in range of magnification from 1x to 8x.

2. Consideration of the tolerance margins in reproduction of remote sensing images ($[\Delta]$ max = $\pm$ 0.3 mm, $\delta = \pm$ 0.2 mm) it can be seen that the colour scanner DC-300B can provide the acceptable geometric accuracy until enlargement factor 6x. While the colour scanner M-550 can be used till enlargement factor 4x.

3. No spherical distortion in scanning systems has been found. This means that there is no pin-cushion or barrel-shaped distortion, and that straight lines on an original are kept straight on separation transparencies.

4. Most of the $[\Delta]$ values have the same sign, so that they may be easily corrected by modifying the software.

Resolution test of scanning systems

In an effort to obtain more information from prints (or transparencies) of remotely sensed images, scanning systems must provide high resolution through the whole process. We know that in scanning systems there are many factors influencing resolution, such as resolution of lens and photographic films, component of developer, time and temperature of development, exposure etc. For practical purposes, we are discussing the total resolution of scanning systems only, instead of analysing every factor separately. To this end, we have applied the Alphanumeric Resolution Test Object, developed by the Rochester Institute of Technology. This test object consists of arrays of alphanumeric characters ranging in size from 1 line/mm to 18 lines/mm. It allows the observer to assess the ability to resolve the characters, eliminating disagreement about the limit of resolution of any tested subjects. In our case, we scanned a resolution test object at different magnification from 1/3 to 6x, with a Kodak film and Kodak Readymatic processor for the DC-300B colour scanner.

After processing we examined the resolution on reproduced transparencies of an Alphanumeric Resolution Test Object using magnifier. The objective of resolution test is: (1) to investigate relationship between resolution of scanning system and magnification, (2) to determine the resolution of scanning systems and application possibilities of scanning systems in the reproduction of remote sensing images.

The results of examination are shown in table 2 and figure 5.

Having analysed the resolution test data, it can be seen that: (1) Scanning system (DC-300B) has a different resolution in horizontal and vertical directions; the former provides a little higher resolution than the latter, (2) Resolution of scanning system increases with reduction factor, and decreases with enlargement factor, (3) Colour scanners can be used for the reproduction of remotely sensed images in cartographic applications.

Resolution of scanning system (DC-300B)

Table 2

M	Horizontal direction		Vertical direction	
	N	Lines/mm	N	Lines/mm
1	19	9.0	18	8
2	22	6.3	21	5.7
4	23	3.6	22	3.2
6x	25	3.0	25	3.0
1/2	13.5	9.5	12	8
1/3	11	10.7	10	9.5

$$\text{Resolution (lines/mm)} = \frac{2^{N/6}}{M}$$

Here N - group number of the RIT Alphanumeric Resolution Test Object.

M - the magnification at which the target has been imaged.

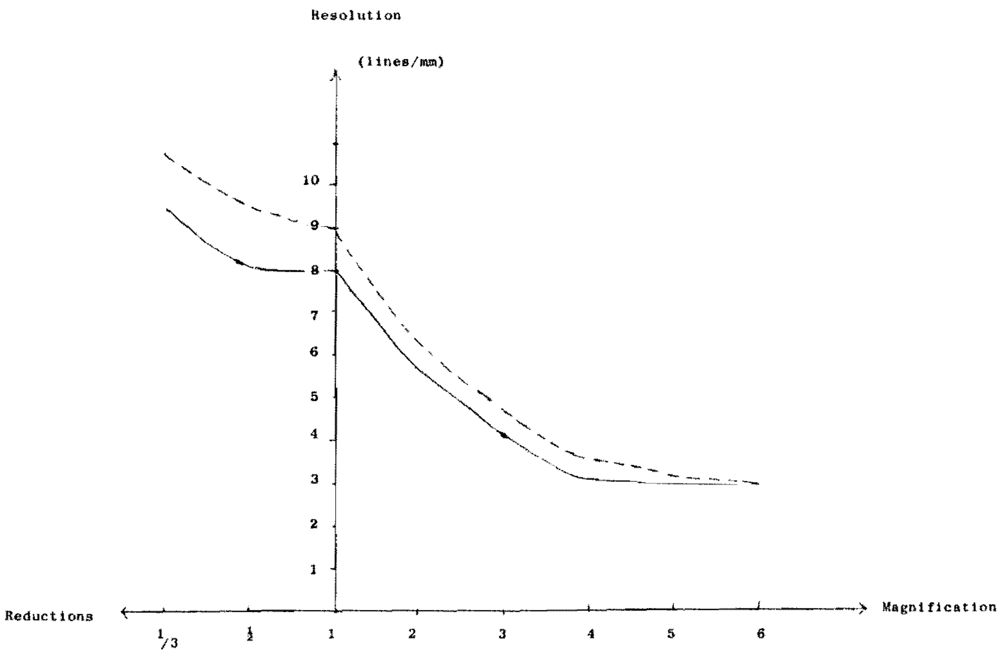


Figure 5 - Relationship between magnification and resolution of scanning system (DC-300B)

Systematic approach to the repoduction of remotely sensed images

It is known that to define the characteristics of a good reproduction it is necessary to determine tone reproduction, grey balance and colour rendition, after having established the parameters to be specified for colour reproduction, such as paper, ink sets, ink sequence, trapping, dot gain etc (8). Tone reproduction has been discussed at length by Johnson, Birkenshaw, Elyjiw and Archer. They have shown that optimum tone reproduction is generally achieved with linear compression of brightness as defined by Bartleson and Breneman (1967), although a tone is sometimes necessary where specular highlights are present in the original. Sunderland also pointed out that since the perception of tone in density has been shown to be non linear and varies with viewing conditions (1), the tone reproduction requirements may be shown to vary between originals provided. Therefore, to get the desired reproduction results, there is a need for reproduction systems to have some flexibility.

Grey balance is another important factor influencing the reproduction results, otherwise the whole illustration will appear to have a significant colour cast. We know that the printing process may reproduce a scale of grey tones with different amounts of the printing inks which depend on the printing methods, the strength of the solid primary colours, the substrate and the means of producing tone values. It is, therefore, necessary to determine the relationship between the value of each of the three primary colours in order to produce a range of neutral greys (8). In our experiments of doing this, we used the TRAND system, produced by Rochester Institute of Technology. We have found such techniques to be a useful method.

Colour rendition means how faithfully the colours in an original are reproduced by the process. However, it is known that both tone reproduction and grey balance play a significant role here since variations in both these factors will affect the appearance of the reproduction (8). In our experiments we used a modified approach to colour correction described by Sunderland (11, 13).

Operational Procedure

We have found a quadrant diagram to be a useful tool, in order to establish the relationship between an original and its separations. This takes account of the printing conditions and the influence of viewing conditions on the appearance of transparencies and final prints. The procedures of the improved approach for the reproduction of remotely sensed images can be summarised as follows (11, 12, 13):

1. Original analysis and densitometric measurement.

It is necessary to analyse carefully the originals provided, and to determine the density range in the original. In our case we scanned three transparency originals of aerial remotely sensed images which are different to each other in density range, colour appearance, subject material and photoscales.

One of the transparencies is a false colour aerial photograph. It covers forestry and water areas. Its photoscale is about 1 : 3,000. Shadow density in this transparency is 2.4 and the highlight density is 0.4. The density range, therefore is 2.0.

2. Determination of the requirements of reproduction.

There are particular requirements for the reproduction of remotely sensed images. The objective of reproduction for these transparencies are: (1) to reproduce it with standard improved reproduction approach, (2) to obtain more image details at shadow area using modified approach.

3. Determination of the logarithmic range of the original subject.

Using the transparency characteristics and the curve of tone relationship between the original subject and the coloured reproduction, the logarithmic range of the original subject can be defined. (Figure 6 first quadrant). Here, data of characteristic curves have been published (Hunt 1968; Hunt, Pitt and Ward, 1969). However, it is necessary to determine the data for specific material and equipment combinations.

4. Definition of the intermediate tone reproduction curve for four colours (Y, M, C, Bk).

This accommodates the influence of viewing conditions on the appearance of a transparency and printing conditions (Figure 7). In our case, we have used two light surrounding conditions in both quadrant 1 and 3. Printing density for four colours is 1.55. Quadrant No.3 is used only for transferring the data from the axis of a graph to the other.

5. Definition of the tone reproduction curve (four colours) using the intermediate tone reproduction curve and the transparency characteristic curve.

This allows for the highlight density on the LogE subject axis (Figure 6, second quadrant).

6. Determination of grey balance curves for four colours.

(Figure 8, third quadrant) includes the parameters for colour reproduction. Curves of grey balance show the dot area of colours in the separation positive needed to produce a grey of a specific density. Thus, they include the effects of platemaking and printing. The inclusion of the black printer in the grey balance curves includes an additivity correction (13).

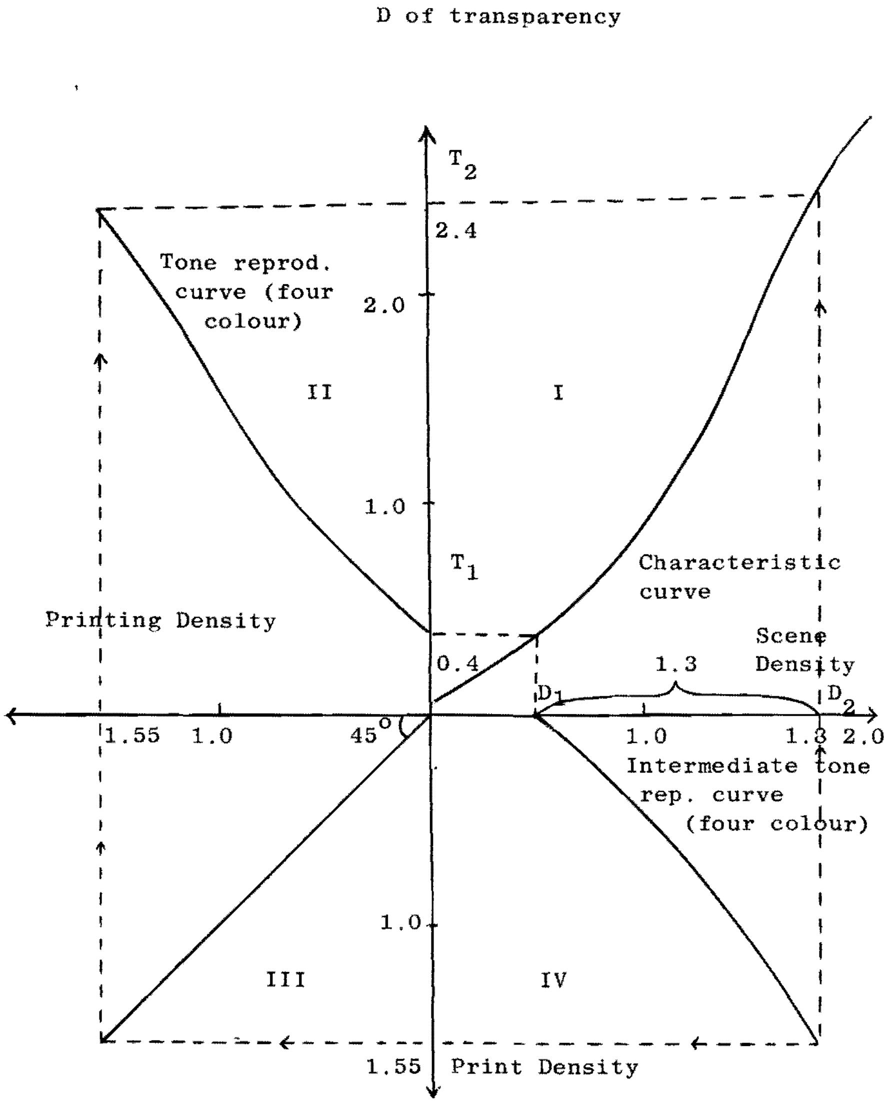
7. Defining the four separation images required.

This uses the predetermined curves of grey balance and the tone reproduction curve (Figure 8). Operational procedures were adjusted to produce the required "toe" in the reproduction. (This will be discussed in a later paper).

8. Determining the amount of colour correction required.

The three dimensional appearance of colour cannot be easily displayed graphically. In our experiments we used the approach described by Sunderland (11, 13).

Examination of the proof sheets and prints on coated paper produced at the Pira laboratory, we found that the quality of the prints are good and accord with the cartographic requirements in reproduction of remotely sensed images. The result of the experiments indicates that the approach provides the flexibility required and is capable of the required refinement needed.



D of transparency
T2
2.4
Tone reprod. curve (four colour)
2.0
II
I
1.0
T1
Characteristic curve
Printing Density
Scene Density
0.4
1.3
D1
D2
1.55
1.0
45°
1.0
1.3
2.0
Intermediate tone rep. curve (four colour)
1.0
III
IV
1.55
Print Density

Figure 6

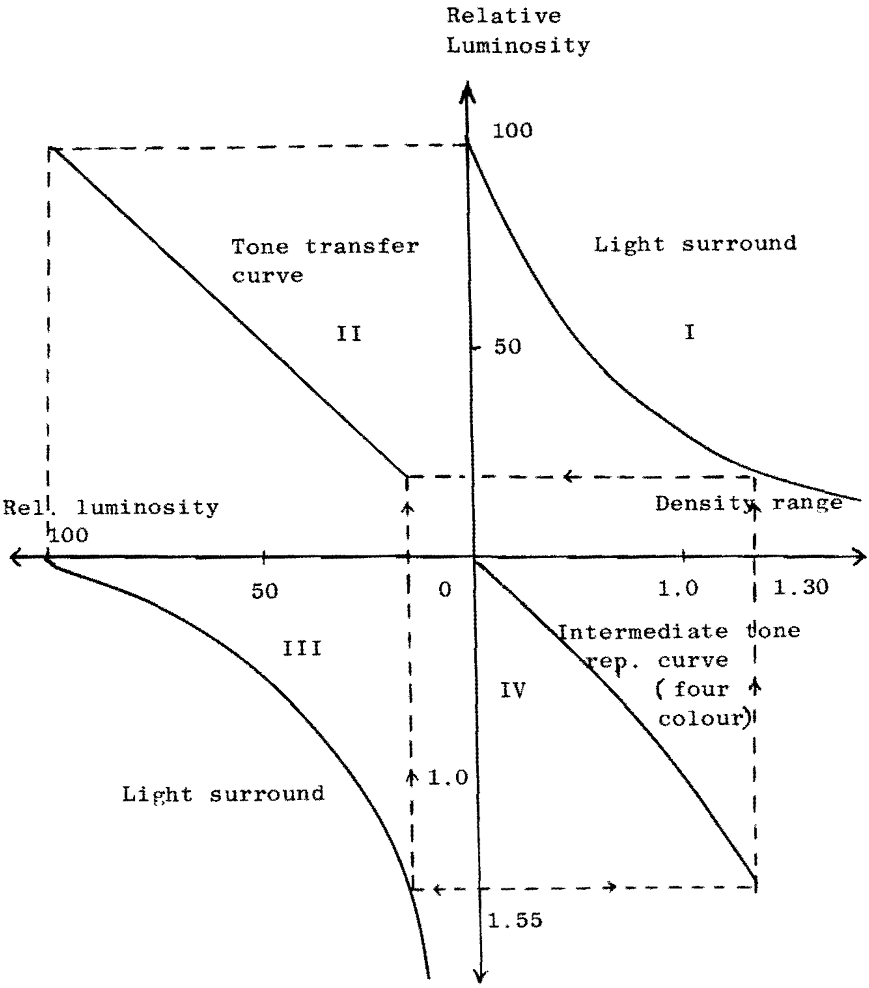

Relative
Luminosity
100
Tone transfer
curve
Light surround
II
50
I
Rel. luminosity
100
Density range
50
0
1.0
1.30
Intermediate tone
rep. curve
(four
colour)
III
IV
1.0
Light surround
1.55

Figure 7

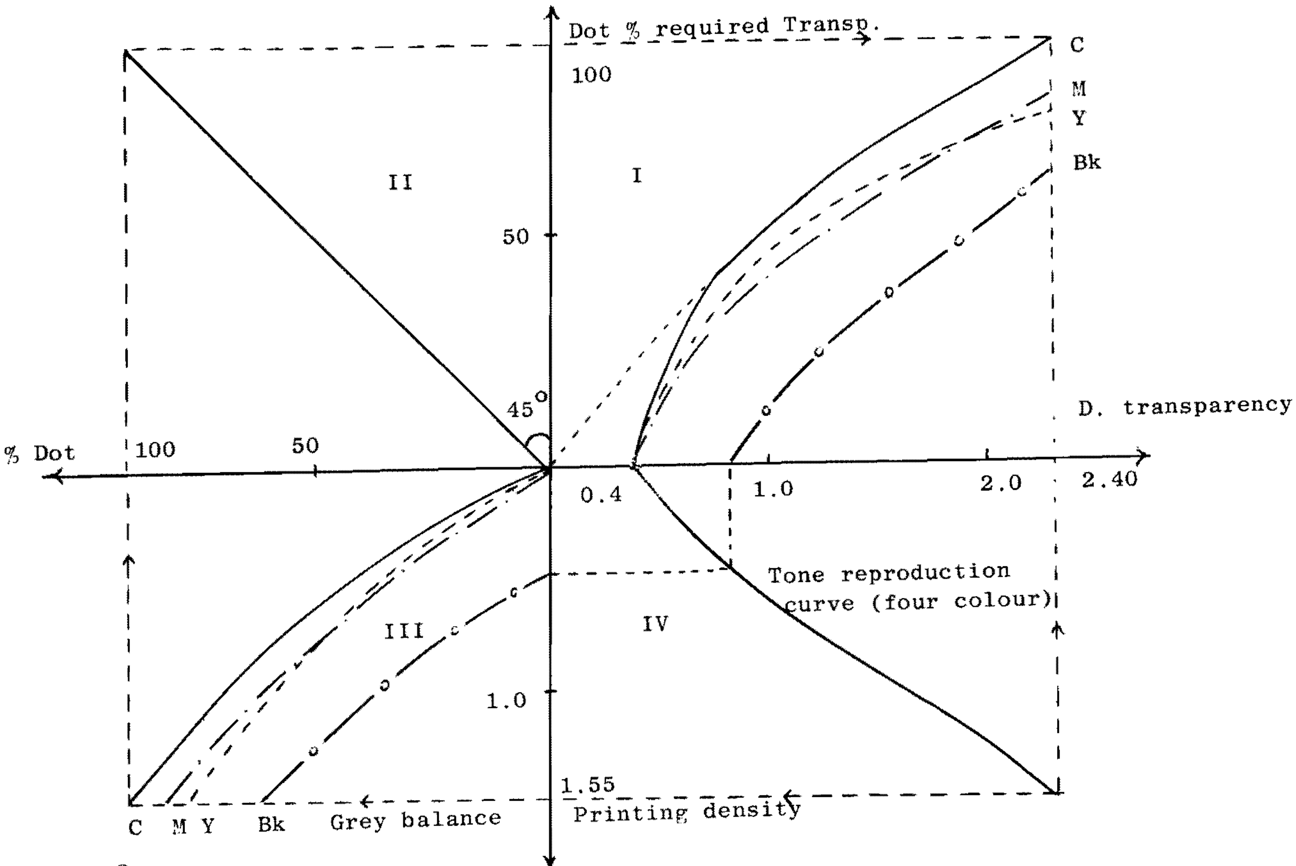

Dot % required Transp.
100
50
1.0
1.55
C
M
Y
Bk
I
II
III
IV
45°
% Dot
100
50
0.4
1.0
2.0
2.40
D. transparency
Tone reproduction
curve (four colour)
C
M
Y
Bk
Grey balance
Printing density

Figure 8

Conclusions and recommendations

1. Considering the cartographic requirements in the reproduction of remotely sensed images, DC-300B colour scanner can produce acceptable geometric accuracy at magnification from x1 to x6, while the M-550 colour scanner can be used at magnification from x1 to x4. This relates to the particular units used.

2. With regard to resolution requirements, both DC-300B scanner and M-550 scanner can be used for reproduction of remotely sensed images.

3. The flexible reproduction approach described in this paper is valid, and will be developed further.

4. The horizontal direction of scanning systems have too large a dimensional distortion, and therefore there is need for improving the geometric accuracy in the horizontal direction.

Acknowledgements

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