7 An investigation into the use of colour in the analysis of aerial photographs

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7.1 INTRODUCTION

Currently, most of the information from aerial photographs of archaeological crop mark sites is derived from monochrome prints. This is basically because of the expense of preparing colour prints of the necessary quality. Yet archaeologists often declare that the features of interest are shown with clearer contrast in colour slides than in monochrome prints. Recent reductions in the cost of colour digital image processing systems have brought them within the reach of a much wider range of users. The main objective of this paper is to report on the quantitative examination of the perceived information available in colour and monochrome, starting from aerial photographs in the form of colour transparencies. This work is a logical extension of a paper presented at CAA91 describing an inexpensive PC–based image processing system for analysing monochrome aerial photographs (Booth 1992). In the current paper we briefly describe representations of colour that are relevant to video imaging and to the problem of making a comparison between colour and monochrome images. We then describe the image processing system that we have used for this work and present examples using colour transparencies of some Roman and Iron Age sites in Scotland. These transparencies were loaned to us by the Royal Commission on the Ancient and Historical Monuments in Scotland as part of a general collaboration in archaeological photogrammetry. We close the paper with some conclusions about the usefulness of colour imaging for this type of application and with some suggestions for further work.

7.2 THE RGB AND HSI REPRESENTATIONS OF COLOUR

7.2.1 General remarks

In the RGB representation, any colour can be expressed as an additive combination of Red Green and Blue components. This representation of colour is important because the human eye responds to colour through the presence in the retina of receptors separately sensitive to red green and blue light. Colour TV cameras and display monitors also work with red green and blue sensors and phosphors respectively. The decomposition of any colour, including white, into RGB components is summarised in the CIE chromaticity diagrams (Foley *et al.* 1990:579–584) which represent the perception of colour averaged over a large number of different observers.

Although the RGB colour system is fundamental to the measurement and generation of colour images, it is not the most obvious way in which people perceive and describe colour. The HSI or hue, saturation and intensity representation of colour is one of several similar representations which form a more natural basis for any discussion of the colour content of an image. For example, an observer would not normally think of the colour pink in terms of varying amounts of green and blue added to red but rather as a pale shade of red. In this case red diluted with white, or unsaturated red, would represent a more intuitive description of pink. In the HSI model hue and saturation are the colour attributes whereas intensity represents the brightness of the image and is the only attribute measured by a monochrome TV camera. Specifically, hue is the essential colour content expressed as a pure colour of the rainbow or its complement. Saturation measures how deep or faded the colour is by the addition to it of white such that the saturation co–ordinate varies from 1 for any fully saturated colour to 0 for a shade of grey.

The HSI representation is more appropriate for colour image processing than RGB for several reasons. In the first place HSI is closer to human perception of colour vision than RGB. Of even greater significance is the fact that the H, S and I co–ordinates are relatively independent attributes whereas R, G and B are strongly correlated co–ordinates. In order to preserve the original colours in a colour image, exactly the same processing operation on the image must be applied to each of the red green and blue components in the RGB representation, whereas in the HSI representation, processing is required solely in the intensity plane. Several manufacturers provide image processing cards that can instantaneously convert from RGB to HSI and back again; such systems will effectively perform true colour image processing three times faster in HSI than in RGB. This is not of fundamental significance since the conversion between RGB and HSI could always be carried out with software, although much more slowly, using the formulae quoted below. In practice, however, it is of some importance because it allows experimentation with different image processing techniques to be performed rapidly and efficiently. The conversion from RGB to HSI need only be performed once on a given image but the reverse process must be carried out many times in order to display the results of different image processing operations. Of particular

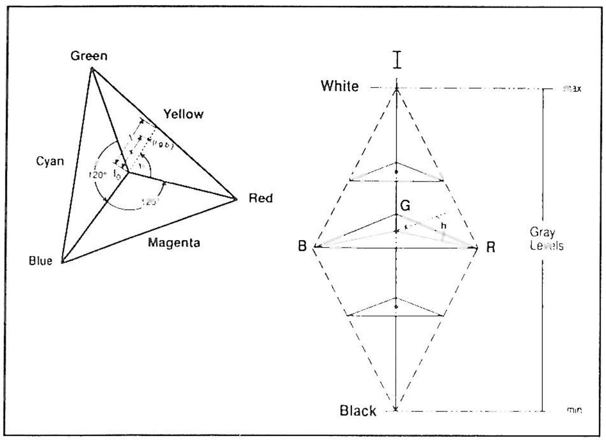

Figure 7.1: HSI colour space represented as a hexcone with hue defined as an angle about a vertical axis, saturation as distance from the axis and intensity along the vertical axis.

significance for this paper is the fact that in the HSI representation the colour information is separated out from the monochrome information, thereby allowing a quantitative assessment of the colour information content to be made.

7.2.2 Transformation formulae between RGB and HSI

In the right half of Figure 7.1 is shown the relationship between the RGB and HSI colour co–ordinates represented as a hexcone of triangular cross section with intensity being the vertical axis ranging from black to white. The colour information is contained in the triangular section which is shown in more detail on the left in Figure 7.1. Hue is seen to be an angle between 0° and 360° and by convention pure red is 0°, pure green is 120° and pure blue is 240° with pure yellow, cyan and magenta having angles midway between the pure spectral colours. Saturation is the distance in the triangular plane from the intensity axis. In the mathematical transformations it is usual for each of the co–ordinates *R, G, B* and *H, S, I* to be normalised to lie within the range 0 to 1.

The specific formulae we have used for the RGB to HSI transformation are as follows (Genz 1991:14–16):

[1] $$I=\frac{R+G+B}{3}$$

[2] $$S=1-\frac{\min(R,G,B)}{I}$$

[3a] $$H=\frac{1}{360}\left[90-\arctan\left(\frac{F}{\sqrt{3}}\right)\right] \text{ when } G>B$$

[3b] $$H=\frac{1}{360}\left[270-\arctan\left(\frac{F}{\sqrt{3}}\right)\right] \text{ when } G<B$$

where $$F=\frac{2R-G-B}{G-B}$$

The inverse transformation equations derived from eqs. [1], [2] and [3] are considerably more complicated in form, so for brevity we do not reproduce them here. The particular frame–grabber hardware which we have used performs both these forward and reverse transformations on an entire video image frame in one frame period.

7.3 IMAGE PROCESSING SYSTEM

The major components in the image processing system include a colour TV camera and monitor, a 386 IBM compatible PC, colour frame–grabbing and high speed frame–processor cards and appropriate software. In this type of application it is necessary to have good spatial resolution in each of the red, green and blue colour planes and we have used a Hitachi HV–C10 three sensor CCD camera with RGB output and a 50 mm focal length lens. The frame–grabber card chosen was the DT2871 from Data Translation which has real–time conversion between RGB and HSI and is able to store images in either format. To speed up image processing operations we have used the Data Translation DT2868 high speed frame processor. Each of these cards occupies one expansion slot in the PC. To operate these cards we have used the Global Lab (Colour) software from Data Translation and our own in–house software to perform particular manipulations of the images and also to print labelled images. The optical system used for illuminating the transparencies and capturing the images was similar to the one used in reference (Booth 1992).

7.4 APPLICATION TO AERIAL PHOTOGRAPHS OF CROP MARK SITES

During flights commissioned by the Royal Commission on the Ancient and Historic Monuments in Scotland over sites of potential archaeological interest, both monochrome and colour photographs are usually taken. Several such colour transparencies have been loaned to us for the purpose of this investigation into whether there is any additional useful information in the colour slides compared with their monochrome equivalents.

For the purpose of illustration, we have selected three transparencies from those provided to demonstrate the range of image characteristics observed. In order to gain an overall impression of each transparency for the purposes of this paper, we set up the system optics to capture the whole of the 35 mm transparency and each resulting image was grabbed with 512 by 512 pixels spatial resolution and with each of the red, green and blue colours digitised to 256 levels. The transparencies actually contain a great deal more detail than is visible under the imaging conditions we chose to employ and an archaeologist would normally need to examine these images at a much higher magnification. This requirement could easily be satisfied by the inclusion of optical panning and zooming facilities.

Compared with the equivalent monochrome image, a true colour image is more natural and easier to view in the same way that a colour TV broadcast picture is more satisfactory than a monochrome one. Even though the human eye is very good at distinguishing between different colours, it was still found desirable to enhance all of the images we examined to make detail more apparent. Processing a colour image in HSI form allows several enhancements to be made rapidly and potentially automatically, or at least with little training. For example, applying a contrast stretch to the intensity plane alone yields a brighter yet still natural looking image. Similarly, applying a contrast stretch in the saturation plane alone increases the richness of the colours but again results in a natural looking image. Applying a contrast stretch in the hue plane alone changes the colour balance of the image so that it no longer looks natural but the image detail is enhanced rather than masked as it might be with false colour processing. These individual processes can be performed singly or in combination and contrast stretching in both intensity and saturation planes gives good natural looking results. More general image operations can also be applied on the individual HSI planes for true colour image processing.

Due to publishing restrictions on colour material, we have not been able to incorporate colour prints of the slides actually presented at the conference. Instead, for each colour image, we have chosen to display separately the intensity, saturation and hue planes and have restricted the size of the images printed for this paper to just the region of interest which we have taken to be 485 pixels wide by 385 pixels high. To produce hard copy on our laser printer with an appropriate compromise between spatial and grey scale resolution we used a 5 by 5 dither pattern (Hou 1983:83–99) with 26 printable grey levels. Before printing, each image plane was contrast stretched to emphasise as much as possible the features of interest. It was found to be true of all the images examined that the width of the image histogram was widest for the intensity data and narrowest for the hue information as perhaps would be expected for images that consist basically of open fields containing crops at various stages of ripeness.

Image number CT983 represented by Figures 7.2a, 7.2b and 7.2c was selected for inclusion here because it illustrates an almost ideal case where there is archaeological information in all three

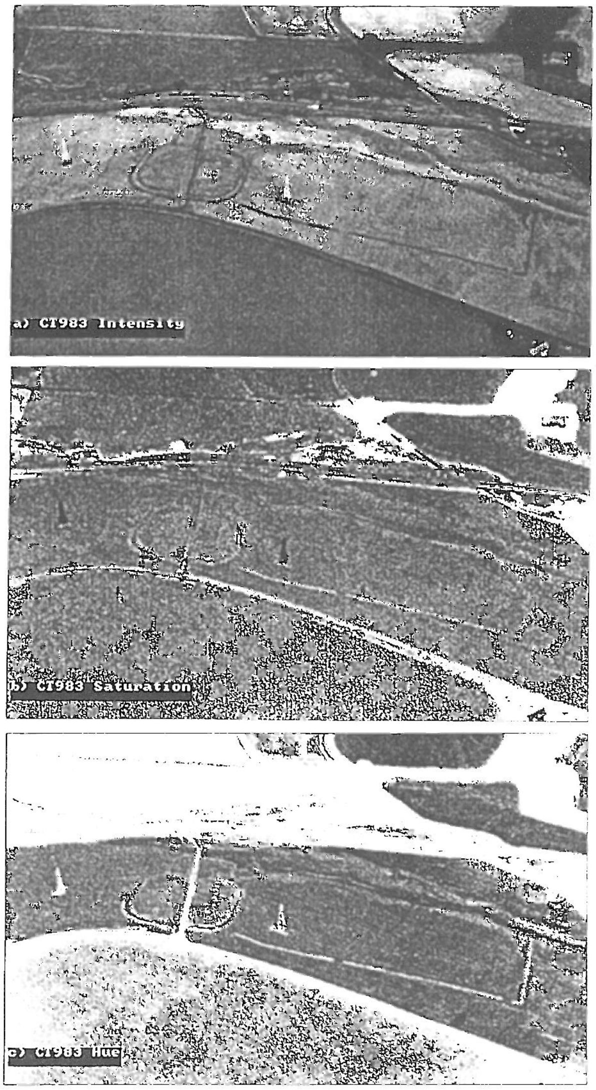

Figure 7.2: Part of colour transparency number CT983 as seen in the intensity plane a), in the saturation plane b) and in the hue plane c).

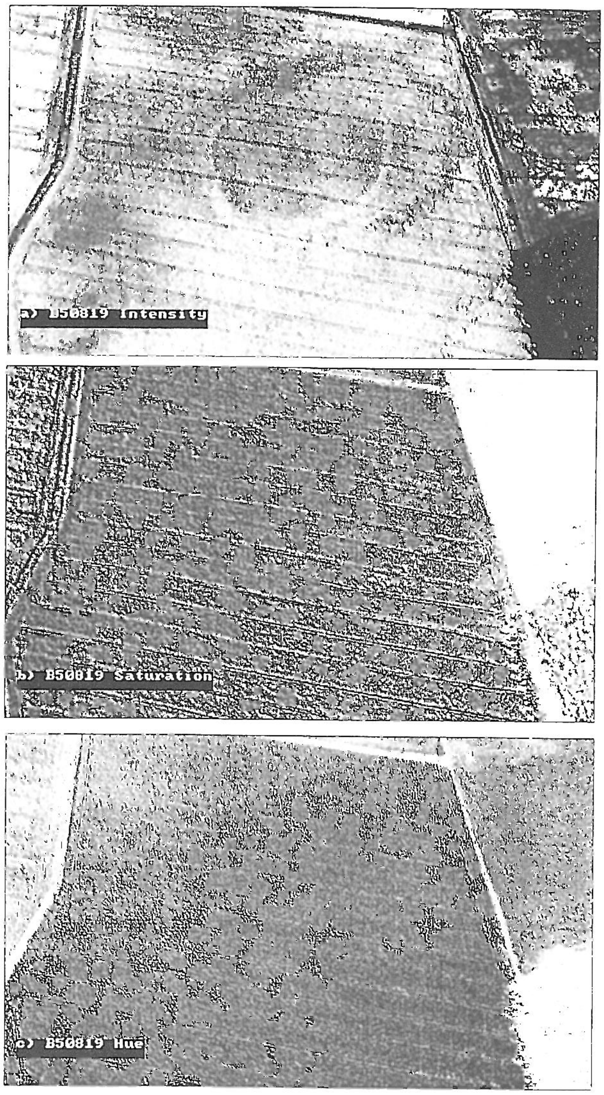

Figure 7.3: Part of colour transparency number B50819 as seen in the intensity plane a), in the saturation plane b) and in the hue plane c).

planes. The crop marks were most striking in the intensity plane before any contrast stretching was applied but they also became strongly visible in the hue plane after contrast stretching was applied. The crop marks revealed in the saturation plane are somewhat obscured by a granular effect but are still clearly evident although less continuous.

Image number B50819 represented by Figures 7.3a, 7.3b and 7.3c is quite different in character to the first image. The crop marks are considerably less visible and show up as two rings of which the inner one is a genuine archaeological feature and the outer ring is probably caused by wind damage. The real crop marks revealed in the intensity plane are also reversed in grey scale compared with those in the previous image. In this image there is practically no crop mark information revealed in the hue plane even after very strong contrast stretching. It is interesting that in the saturation plane, the real crop marks are again visible (reversed in grey scale compared with the intensity image) whereas the crop marks caused by wind damage have become extremely weak features. Close inspection of the hue and intensity information showed a shading effect across these image planes and this should be removed to optimise the visibility of the crop marks.

Image number B50727 represented by Figures 7.4a, 7.4b and 7.4c is again a case where there is crop mark information in all three planes but the

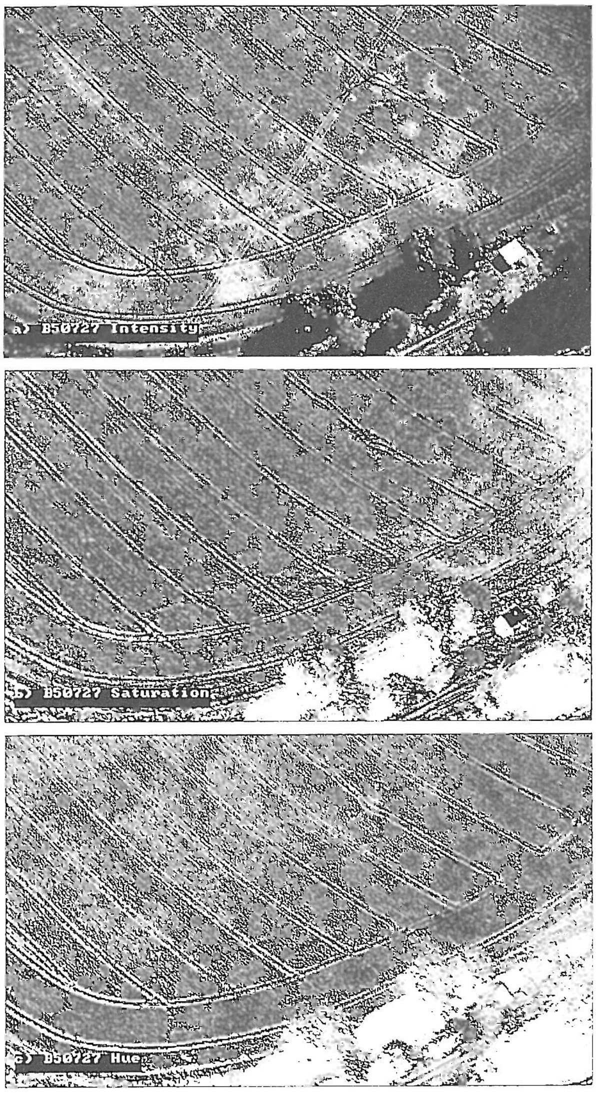

Figure 7.4: Part of colour transparency number B50727 as seen in the intensity plane a), in the saturation plane b) and in the hue plane c).

visibility of these marks is considerably less pronounced than in the first image. However, some features that might be of archaeological significance are present in H, S and I planes but others are not and it requires the judgement of an archaeologist to assess the significance of this. The fact that the hue and saturation information appear to be discriminating against some features present in the intensity plane is an interesting observation.

7.5 DISCUSSION AND CONCLUSIONS

It is worthy of note that the intensity images we obtained by processing the colour photographs were of excellent quality. In the case of the best of the images presented here, number CT983 of Oxton moor, we also have a full set of monochrome originals of this site for comparison. The intensity part of the colour images appears just as good if not better than the monochrome version so nothing would be lost and there might be something to be gained by working from colour slides rather than monochrome. The approach adopted by the Royal Commission of taking both monochrome and colour photographs appears to be worthwhile and should be followed by other organisations taking aerial photographs.

For all the colour images of crop marks described in this paper the analysis of the information into RGB co–ordinates showed, as expected, that the red, green and blue planes were of similar appearance apart from differences in average brightness. When analysed in terms of HSI co–ordinates, it was universally found that there was much more detailed information in the I plane than in either the H or S planes. As far as the colour information is concerned, every image has to be treated on its own merits. Some of the images contained a significant amount of information in both colour planes but others, which appeared to the eye to contain only a single colour in the region of interest, were found to have significant information in the saturation colour plane. The extra information in the colour planes could be used in one of two ways, either to produce an enhanced colour image or combined with the intensity data to produce a further enhanced monochrome image. The fact that there is information present in more than one image plane suggests that the application of methods previously used in multispectral analysis (Jain 1989:261–263) of satellite and industrial images should be investigated. Among the standard methods, the use of direct or logarithmic ratios of intensity to saturation values is certainly worthy of pursuit. Principal component analysis and algorithms designed to saturation–enhance the intensity using appropriate convolution masks are also possible techniques that might work well in this case. The Global Lab software provided by Data Translation does not contain any of these facilities and we have already started writing routines to allow us to evaluate each method for crop mark enhancement. When this extension to the current work has been completed, its usefulness will be fully evaluated in collaboration with archaeologists from the Royal Commission for Ancient and Historic Monuments of Scotland.

The major conclusion of this work is that there is useful information in the colour planes of all the images we have examined and that further work as outlined above is worthwhile. Another conclusion is that working with HSI colour co-ordinates allows useful colour image processing to be carried out in a straightforward manner requiring little training. It has to be said that the colour system which we have used and described in this paper is relatively expensive by archaeological standards, with a total cost in the vicinity of £15,000. It was purchased primarily for the purpose of carrying out research on a variety of projects requiring fast colour image processing. It is our opinion that it would not be good use of limited resources for archaeologists to purchase a similar system until a clear need for one has been demonstrated. We believe that it makes better financial sense for archaeologists to collaborate with researchers who already possess such systems and in this context we would be prepared to join in with any archaeologist who has any colour-analysis problem that our equipment might be capable of solving.

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