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Paper I 10

DIGITAL ENHANCEMENT OF MULTISPECTRAL MSS DATA FOR MAXIMUM IMAGE VISIBILITY

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ABSTRACT: A systematic approach to the enhancement of images has been developed. This approach exploits two principal features involved in the observation of images: the properties of human vision and the statistics of the images being observed. The rationale of the enhancement procedure is as follows: in the observation of some features of interest in an image, the range of objective luminance-chrominance values being displayed is generally limited and does not use the whole perceptual range of vision of the observer. The purpose of the enhancement technique is to expand and distort in a systematic way the grey scale values of each of the multispectral bands making up a color composite, to enhance the average visibility of the features being observed.

1. Introduction: The visual inspection of images of natural objects to provide qualitative or quantitative information is one of the most common uses of ERTS 1 data. With the advent of the digital computer as a useful image processing tool, black and white images with a grey scale and multispectral images, can be precisely manipulated before display to provide the viewer with an improved visibility of features of interest. The visual inspection of images to provide quantitative information is constrained by properties of human vision. The dominant properties are an excellent spatial resolution and a comparatively poor resolution to light intensity variations. For color vision an important property of the eye is the ability to distinguish a large number of color hues. This good resolution in the color dimension is exploited in pseudocolor and false color presentations in which the grey scale of images are mapped into color for improved visibility.

In this paper we consider several aspects of the enhancement of grey scale images by mapping into grey scale or color images. We are interested in the monotonic mapping of the grey scale of an image. By monotonic we mean that the order of grey scale values is preserved in the mapping into a grey scale or that the grey scale values map into a fixed and readily identifiable order of color hues.

For our defined task, elementary consideration of properties of human vision lead us to propose new enhancement methods for "optimum" image visibility. Another family of enhancement methods is then discussed which also takes into account statistical properties of the images themselves.

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2. Conditions of the Study: Since we are concerned with physical at-
tributes of light and color sensations, some terminology which differ-
entiates objective and subjective aspects is needed. For the objective
aspects we shall use the formalism of colorimetry in terms of a defined
"standard observer" and color-stimulus specification in terms of
tristimulus values [1]. Thus, luminance is a measure of energy while
brightness will denote the corresponding sensation. The dominant wave-
length in the spectrum yields a sensation of hue. The purity of the
color excitation is related to the sensation of color saturation. What
we hope to exploit, for the purpose of image enhancement, are some ele-
mentary aspects of the extensively studies relationship between the ob-
jective and subjective spaces. We shall assume that the techniques for
the recording and display of images are not limiting the range and reso-
lution of luminances reproduced. For the color rendition we have to
refer to specific color primaries and we shall use the standard NTSC
colors.

We thus consider a part of the image enhancement problem shown in the
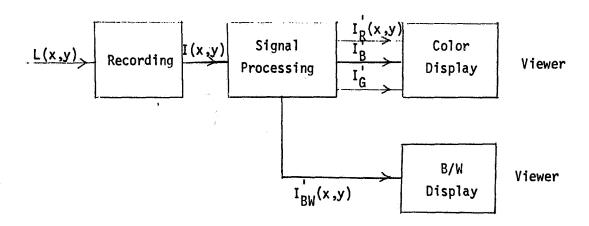diagram below.

FIGURE 1

If the recording system and display introduce nonlinear effects of
their own, these can be compensated to a substantial extent by signal
processing, but such compensation depends on the physical devices used.
Here we shall assume that the intensity variables I and the luminance
variables L are proportional. Referring to Figure 1 we can now describe
more precisely the problem of interest. We would like to process the
signal $I(x,y)$ in such a way that $L_R'(x,y)$, $L_B'(x,y)$, $L_G'(x,y)$, or $L_{BW}'(x,y)$
will allow the viewer a maximum discrimination of the luminance values

L(x,y) at each point, without substantial degradation of the spatial resolution. This image enhancement problem has two aspects. The first one is the choice of a mapping transformation of L into L' which provides the maximum number of distinguishable levels in L. The second aspect of the problem is the rational exploitation of the statistics of the image, recognizing that for each application only a small range of intensity values is generally relevant.

3. Mapping Intensities into a Grey Scale: It is well known that human vision adapts to an extremely large range of luminance levels of more than one million to one [4,5]. However, the total range of luminance that the visual system can discriminate simultaneously is rather small and 15 to 20 grey scale steps from black to white are claimed as typical. This discrimination corresponds roughly to constant thresholds of $\frac{\Delta L}{L}$, result which matches the commonly assumed logarithmic sensitivity of the eye to luminance values [4]. Thus constant brightness steps will correspond to luminance steps spaced exponentially. Given a total range of luminance from black, L , to white, L_W, $L_R = L_W - L_B$, the relation

$$I'_{BW}(x,y) = [L_R + 1]^I + L_B - 1 \tag{1}$$

in which $0 < I < 1$, will yield the desired mapping in a subjective linear scale from black to white. It will also provide maximum visual discrimination in the quantity I. In the viewing of a CRT display the available adjustment of brightness and contrast will take care of the adjustment to L_R and L_B and the signal processing has only to provide an exponential correspondence between I and I'. These theoretical results can be verified experimentally as discussed later on in this paper.

4. Pseudocolor Mappings: For black and white images (or MSS monospectral scans) it is of interest to examine pseudocolor maps which provide a color scale with improved discrimination. There are a number of aspects in this problem which have lead us to examine mappings with a constant luminance and also mappings using a luminance variation as well as a variation in hue. Because of space limitation we shall omit this discussion and refer the interested reader to reference (11).

5. Experimental Determination of Differential Visibility: In the experimental application of image enhancement, one is confronted with the limitations of the display devices, the photographic processes, etc. It is thus desirable to verify experimentally the differential sensitivity of each grey scale mapping. We have developed a simple technique to perform this measurement which is specially suitable to interactive work, using a digital computer. The table of values shown in Figure 2 is displayed using whatever grey-scale mapping techniques

and display devices are to be tested.

FIGURE 2:   Test Image

The test table is designed so that the distance between adjacent strips
is variable between 1 and 16.   The total range 0 - 256 corresponds to
the commonly used 8-bit integer display.   An image of the test table is
shown in Figure 3.   We observe the vertical lines of the test table,
but careful examination reveals that each line cannot be perceived verti-
cally across the entire image.   Assume that the line between strips 2
and 3 cannot be perceived for values of strip 2 between 8 and 9.   That
means that 16 - 8 = 8 is the threshold of visibility of the input vari-
able for the proposed mapping in the range of input values 8 to 16.
Thus by a single image one can verify the linearity of the scale and even
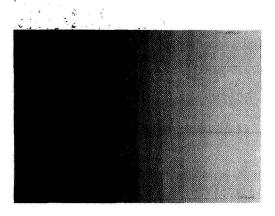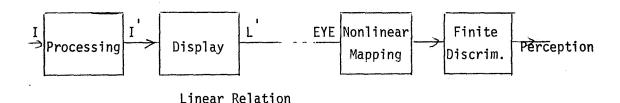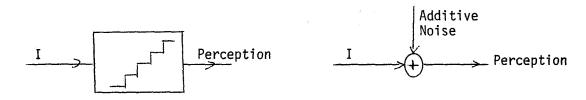devise a compensation table if needed.

FIGURE 3:   Image of the Test Table

6. Mappings Based on the Statistics of Intensity Values: In our discussion of the mapping of intensity I into a linear perceptual space we have not made any assumption about the statistical distribution of I. It is clear, however, that some consideration of the distribution of I is needed, if for nothing more than to scale the range of I so that the image enhanced covers the whole perceptual range available. Considerably more can be said by combining the concept of perceptual space with a constant differential with some previous work on quantization and estimation of the authors and others [8,9,10]. Assuming that we have still a limit on the increment ΔI which can be perceived, we can model this situation by assuming that the perceptual space is quantized, with uniform quantization steps, or by assuming that we have some additive noise which prevents the differential perception of small input increments. Figure 4 illustrates the situation.
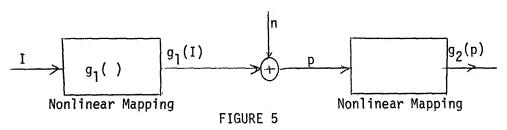

Linear Relation

a) Linearization of Perceptual Scale

b) Models of Finite Discrimination

FIGURE 4

For both models of Figure 4b a precise mathematical optimization problem can be solved. Consider the model of Figure 5.

FIGURE 5

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We would like to determine the nonlinear mapping g_1, ( ) and g_2 ( ) such that the distortion D is minimized

$$D = E\{W[I - g_2(p)]\} \qquad (2)$$

$I - g(p)$ is the error between the input and output variables of Figure 3, W( ) is an error weighting function, E denotes statistical expectation over the distribution of the random variable I. In a communication context the optimization problem considered corresponds to the design of nonlinear scalar transmitters and receivers [10]. If a uniform quantizer is substituted for the additive noise we are then designing a non uniform quantizer [9]. Under the conditions of small additive noise or small quantization steps the solution to both problems is the same.

Consider the class of error weighting function $W(e) = |e|^c$ and let us assume that the range of the variable $g_1(I)$ is limited. Then D of equation 2 is minimized by choosing

$$g_1(I) = K_1 \int_{-\infty}^{I} [f_I(x)]^{\frac{1}{c+1}} \, dx + K_2 \qquad (3)$$

in which $f_I(x)$ is the probability density function of I and the constant K_1 and K_2 are chosen to yield the desired range for $g_1(I)$. For small noise $g_2($) is then the inverse of $g_1($). We have assumed in (3) that the range of I is limited and that $f_I($) does not have a long tail. For a discussion of the effects of the tails of $f_I($) see [9].

Let us now interpret and adapt these results to image enhancement. We can adapt the diagram of Figure 5 to the case of vision as shown in Figure 6.
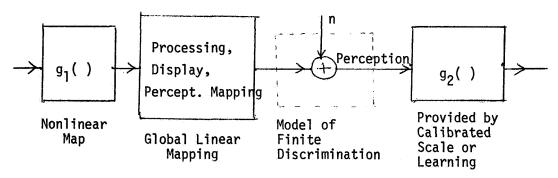

FIGURE 6

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The significant part of Figure 6 is the interpretation of the nonlinear operation $g_2(\ )$ as occuring in the brain and provided by learning. For instance the display of a linear scale in I at the same time that the processed image is displayed allows the viewer to calibrate his visual scale and compensate for it. The compensation is indicated by $g_2(\ )$.

What the introduction of the mapping $g_1(\ )$ has done is to reassign the intensity values I according to their frequency of occurrence so that the more frequent values are spread out farther in a perceptual scale. Thus, the mapping $g_1(\ )$ provides a global mapping from I to p with a nonlinear perceptual scale but which maximizes the total average visibility of the image.

Note that under the condition mentioned earlier $g_1(\ )$ does not depend on the specific number of quantization steps or additive noise in the model of Figure 4c and the results are applicable to all the mapping into a linear perceptual space discussed before.

A question remains open in the choice of constant c in equation 3. Recall that the class of error weighting function is $W(e) = |e|^c$. Since I is an intensity or energy variable one would expect that c = 1 is a good choice. Note that the choice c = 0 has been proposed on an ad hoc manner [6].

Another result pertinent to image enhancement is available from reference 9. It is possible to evaluate quantitatively the improvement in the visibility of the image due to the nonlinear mapping $g_1(\ )$ as a function of the probability density function $f_I(\ )$. If A and B are the range of $F_I(\ )$, then

$$F = \frac{D \text{ Nonlinear}}{D \text{ Linear}} = \frac{1}{[B-A]^c}\left[\int_A^B [f_I(x)]^{\frac{1}{c+1}} d_x\right]^{c+1} \tag{4}$$
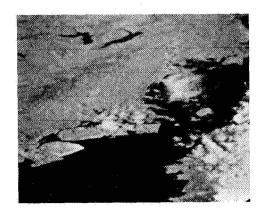
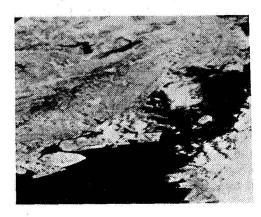We find F = 1 as expected if $f_I(\ )$ is uniform.

7. Implementation of the Enhancement Technique: The following steps are followed in the enhancement of MSS multispectral data:

    1. Extraction of a geographic area of interest from NASA CTT.
    2. Display on a color monitor of standard color composites.
    3. Generate histograms of each spectral band.for subareas of the image with features of interest.
    4. Generate an enhancement table for each of the spectral bands corresponding to the histogram of intensity values in that band.

5. Apply enhancement table to the spectral components and display of enhanced images.

The procedure can be iterated if needed.

8. Examples: We demonstrate the technique on two examples, Figure 7a and 7b are from MSS band 6 for the East Bay region (San Francisco Bay) showing the cities of Oakland, Berkeley and Richmond. Figure 8a and 8b are from MSS band 6 for the Bucks Lake region in California, a NASA test site. The improved visibility due to enhancement (7b and 8b) is striking for water, urban areas and forestry and wildlands.
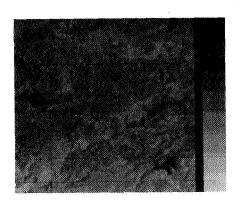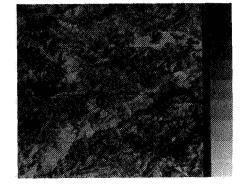

a) Original   b) Enhanced

FIGURE 7:   East Bay (1003-18175), MSS Band 6

a) Original   b) Enhanced

FIGURE 8:   Bucks Lake (1002-18125) MSS Band 6

9. Conclusions: A powerful technique for the systematic enhancement of multispectral MSS data has been presented and illustrated - the technique is specially suited for interactive work since the digital processing takes only a few minutes once the data has been reformatted. Since the method provides enhanced visibility of whatever is present in the area on which the enhancement algorithm is designed it provides a powerful experimental tool for the discovery of new patterns and relationships.

10. References:

[1] See for instance J.J. Sheppart, Jr., Human Color Perception, American Elsevier, 1968.

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[3] R.W. Burnham, R.M. Hanes, C.J. Bartleson, Color, John Wiley & Sons, 1963.

[4] T. Cornsweet, Visual Perception, Academic Press, 1970.

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[6] H.C. Andrews, A.G. Tescher, R.P. Kruger, "Image Processing by Digital Computer," IEEE Spectrum, July 1972, pp. 20-32.

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[11] V.R. Algazi, "Image Enhancement by Grey Scale Mapping," Chapter 8, Appendix A. Integrated Study of Earth Resources in the State of California based on ERTS 1 data - Semi-Annual Report, January, 1973.