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DIGITAL PICTURE PROCESSING AND ITS IMPACT ON IMAGE INTERPRETATION*

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ABSTRACT

The paper reviews digital picture processing as applied to improve the image for subsequent visual interpretation. This type of image processing is clearly set apart from automatic image interpretation by methods of spectral or textural classification and recognition of spatial patterns.

ZUSAMMENFASSUNG

Die Arbeit behandelt die digitale Vorverarbeitung von Bildern zur Verbesserung der darauffolgenden Bildinterpretation. Diese Art der Bildverarbeitung unterscheidet sich deutlich von der automatischen Bildinterpretation, wie sie zum Beispiel durch spektrale oder Texturklassifikation und Erkennung geometrischer Formen angestrebt wird.

RESUME

Ce papier discute le traitement numérique des images du point de vue d'une amélioration de la photo-intérprétation manuelle suivant le procédé numérique. On présente une révue de méthodes de "pre-processing" et une analyse des possibilités d'améliorer l'intérprétation.

1. INTRODUCTION

Digital image processing has evolved from several separate historical sources, namely (a) from the computer preparation of panchromatic extra-terrestrial images for subsequent visual planetological photo-interpretation, (b) from the automatic information extraction using multispectral scanning (MSS-) images, (c) from automatic pattern recognition.

Digital pre-processing of images (area a) began at the Jet Propulsion Laboratory (JPL), USA, about 1962 in the planetological environment, using lunar TV-imagery but no ground truth (Nathan, 1966). At the Laboratory for Application of Remote Sensing (LARS) of the Purdue University, USA, digital MSS-classification (area b)began around 1966 (Hoffer, 1967) in the agricultural environment, using aircraft scan imagery. Obviously, agriculturists are concerned with dynamic phenomena at frequent time intervals and have a

*Part of this paper presents results of research carried out at JPL under contract NAS 7-100, sponsored by the National Aeronautics and Space Administration, USA.

desire for automation of repetitive routine interpretations. Geologists/ planetologists study essentially static phenomena, where the need for automation is less obvious and where desired results may be more difficult to achieve.

Pattern recognition has a longer tradition. It began with research on automatically recognizing symbols using *non-natural* images, i.e. two-dimensional formats for general data presentation (Andrews and Hunt, 1977). With the advent of digital *natural* images it was logical to subject them to pattern recognition techniques. Today the terms *pattern recognition* and *image processing* sometime, are used synonymously when in fact, however, they denote technologies that overlap only partly.

Digital image processing methods may be subdivided in various ways. Goetz et al. (1975) for example use the following grouping of methods: (a) rectification - elimination of systematic geometric and radiometric errors, (b) cosmetics - elimination of random noise and defects, (c) analysis - data extraction,(d) display. A similar grouping of processing techniques is used by Pratt (1978): (a) restoration, (b) enhancement, (c) analysis, (d) image coding. In this context classification with multispectral scan (MSS) images is one of many analysis techniques.

To many a photo-interpreter, however, image processing techniques fall in one of two groups: pre-processing and automatic data analysis (classification or feature extraction). This view is shared for example by Holderman et al. (1976) and Anuta (1977).

The paper presents a review of techniques to pre-process digital images for subsequent photo-(image) interpretation, using recent experiences and current results. In our discussion of pre-processing methods we separately address single panchromatic images and multiple images (MSS) as well as image synergisms. This latter concept denotes techniques of compositing images from different sources (e.g. radar/Landsat etc.).

Digital image processing is a complex technology that has been developed in an environment in which the actual users are not always involved. Therefore there exists a user/technologists interface problem that we discuss in a concluding section.

2. WHY DIGITAL PRE-PROCESSING ?

The need for digital techniques in automatic analysis (information extraction, decision making) from images is obvious. Far less obvious is this need when it concerns the preparation for subsequent traditional photo-interpretation.

Aerial photography has been electronically dodged for a long time to improve contrasts. It seems obvious that telemetered images that present themselves in a digital format undergo digital contrast manipulations.

Density requantisation (Histogram equalisation*) and contrast stretching are indeed the most common and basic techniques of pre-processing (Goetz et al., 1975).

* "Histogram equalisation" in the U.S.A. may be understood to relate to the correction of LANDSAT six -line striping.

But from an interpreters point of view an image should present, apart from optimum contrast, also:

- clarity of patters;
- relief, or no effects of relief, depending on application;
- information from different seasons;
- correct or specifically coded radiometric densities;
- correct geometry, etc.

Pre-processing may aim at optimizing a given image so that these requirements for interpretation are met. The interpreter can then work *qualitatively* with images, but many encounter difficulties in various types of *quantitative* work: The eye can differentiate many tens of different gray of color tones on a gray or color wedge; but this may reduce to only 1o - 2o when the gray-tones or colours are chaotically mixed, as is the case in remote sensing images. Digital recording and analysis offers abundant capabilities in this respect: a system with 8 bits storage per picture element (pixal) permits to operate quantitatively with 256 gray (color) tones.

An entire new perspective opens up in the area of radiometric and geometric manipulations. Digital approaches improve the flexibility of *geometric corrections* that have been previously possible, e.g. by photogrammetric rectification and orthophoto techniques, however, with limitations by optical and mechanical designs. *Radiometric corrections*, on the other hand, were hardly possible at all until the advent of image processing methods. These, however, have led to impressive capabilities to combine data from different seasons (Blanc et al., 1977), different sources (Anuta et al., 1976; Dailey et al., 1978) and permit to control perturbating effects of the sensing systems (Soha et al., 1977),and of the relief (Kahle et al., 1977).

Data compression of multiple images is another important image pre-processing step. Digital techniques offer flexibility of applying mathematical and statistical methods for this task.

Visual image interpretation is seen as opposed to automatic analysis. In fact, however, the two may complement or overlap each other in an interactive type of operation so that automation would only support some of the visual interpretation. Such approaches are presently emerging in a wide variety of interactive hardware and generally involve a digital component.

Digital pre-processing of aerial photography is very uncommon. Experienced photo-interpreters argue that there is no increase in the diagnostic value of photography and that apart from dodging no pre-processing techniques are needed. These considerations, and the effort required for digitization as well as the potential loss of resolution that could occur, have so far prevented the use of existing image processing capabilities for this purpose.

3. PRE-PROCESSING OF SINGLE IMAGES

According to Anuta (1977) image pre-processing serves to "rectify sensor problems, placing the data in the form desired for analysis, and to combine, transform or transmit the data". One may groups and discuss these pre-processing techniques in seven categories, resulting from a sub-division of categories as proposed by Goetz et al. (1975) and Pratt (1978) (compare section 1.):

- data format manipulations; - radiometric restoration; - geometric rectification; - image enhancement; - image compression (decompression); - pattern recognition; - image annotation.

Data format manipulations, compression and image annotation will not be discussed here. They are important topics and deserve thorough consideration in an image processing system, but are of limited relevance in the present context.

3.1 Radiometric Restoration

Andrews and Hunt (1977) define image restoration as the techniques to remove degrading phenomena from images. Image degradations are numerous and familar to photo-interpreters: optical diffraction effects and aberrations, focussing, electronic noise, image motion, atmospheric perturbations, chromatic aberrations, vignetting etc. Radiometric restoration aims at the elimination of these perturbations using *a-priori* information derived from sensor calibrations prior to actual imaging, or *posteriori* informations derived from imagery already taken of test objects.

Image restoration serves to relate the image densities to the energy used to produce the object's image. It attaches thus a quantitative value to the images and is a pre-requsite to quantitative data analysis based on image gray values.

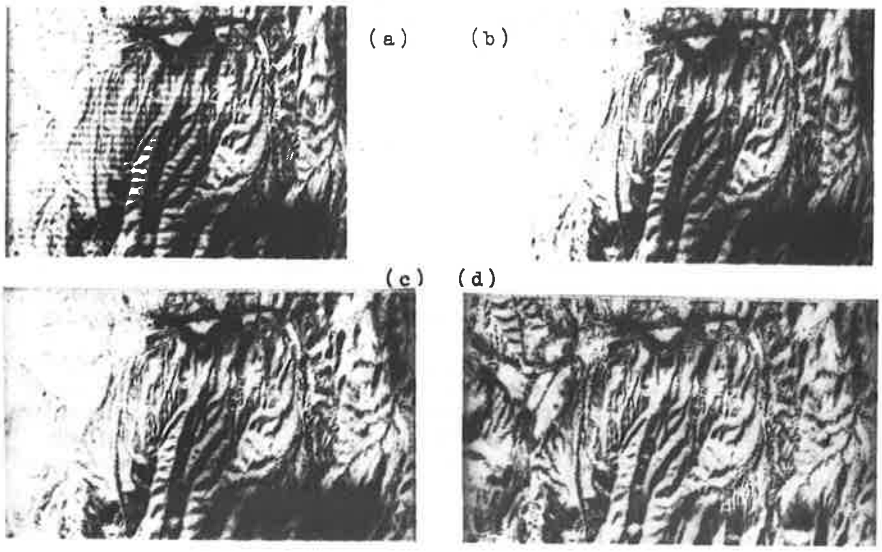


Figure 1: Aircraft scanner image of Red Mountain, Arizona; (a) with coherent noise; (b) after noise removal; (c) after geometric correction for panoramic distortion; (d) after low frequency notch filtering to reduce shading.

Filtering may be considered the essential restoration tool. Generally, filtering is visualized in terms of spatial frequencies. *Notch filtering*, i.e. the reduction or removal of specific frequency components, can be helpful in removing noise from an image, such as might be introduced by electronic defects in the sensor. Figure 1 a shows an aircraft image with coherent noise, followed by the final version of the image after removing the noise (Fig. 1 b). Low frequency notch filtering can be useful removing large scale shading which obscures more interesting local detail. This procedure is most frequently implemented in terms of a subtractive box filter, in which a local average value is subtracted from each pixel (e.g. Soha et al., 1977). Care must be exercised to avoid artifacts (Gillespie, 1976). High frequency boost filtering can be used to sharpen edges. Where sensor characteristics are known a priori, including noise level, Wiener filtering can be employed to quantitatively restore image sharpness with minimum mean square error (Helstrom,1967; Arp and Lorre,1976). Figure 2 demonstrates restoration filtering applied to a Mariner 10 view of Earth.

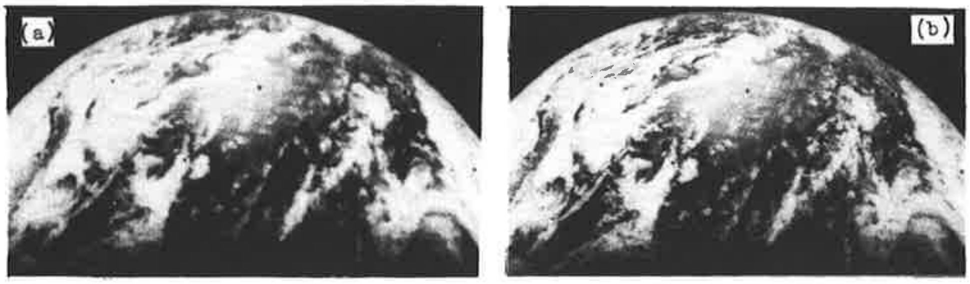


Figure 2: Example of restoration filtering applied to Mariner 10 view of the Earth: (a) before, (b) after filtering.

3.2 Geometric Rectification

Imagery is mostly acquired with a geometry that needs correction for efficient image analysis. The main purpose of rectification is to relate the image to other data, be they in the form of maps, of other images or of non-images such as terrain relief etc. Anuta (1977) differentiates between (a) the "open-loop" rectification employing merely information on predictable geometric errors derived from the imaging process, sensor attitude and position (compare Fig. 1c); and(b) the "fine correction" using ground control points. Photogrammetrists have been working in this field for many years (see ISP - Working Group III/1 on "Metric Aspects of Remote Sensing", operating since 1972).

It is well established that presently available digital satellite images (Landsat, Nimbus) can be rectified with remaining errors of less than one pixel and limits set by the geometric resolution (Figure 3). For aircraft scanner images, the rectification accuracy has been found to be several pixels (Baker et al., 1975). The limits of accuracy seem to be set by the random errors of sensor motion and imaging, not by geometric resolution. The accuracy numbers for both the satellite and the aircraft strongly depend on the density of ground control. Experiences on the interrelation of image resolution, type of imagery and control point density are however not extensive.

Geometric rectification may result merely in a mathematical expression for the deformations, or it may in addition produce a rectfied image.

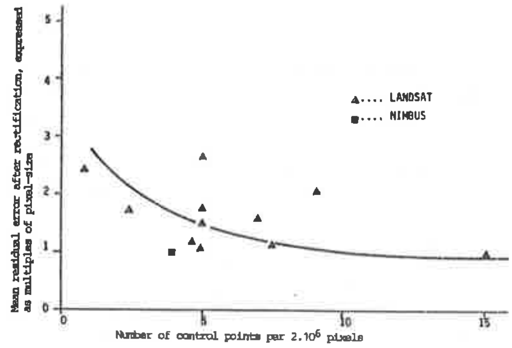


Figure 3: Rectification accuracy of satellite scan imagery, obtained by various authors under different conditions.

Procedures for this task have been extensively described in the literature (Konecny, 1976). The most common are indirect or "resampling" methods, where a new, rectified image is produced,starting from the regular raster of pixels of the rectified image. The gray value for each pixel is found by looking for the corresponding location in the unrectified image. The gray value encountered in that location or a function of the surrounding gray values is attached to the pixel in the rectified image.

3.3 Image Enhancement

We understand "enhancement" to be an operation to make non-obvious information that is presented in an image more obvious to someone visually interpreting it.

(a) *Contrast enhancement* is by far the most commonly applied image enhancement procedure. It consists of an intensity transformation which maps brightness values in the input image to other values in the output image. Several techniques are in common use. The simplest is a linear contrast enhancement in which some image density L is mapped to black, some value H is mapped to white, and values in between are scaled proportionately. Values extreme of L and H are saturated to black and white respectively. L and H can either be found manually be inspection of the histogram, or automatically by a program which saturates pre-specified percentages of the image histogram to black and white.

Non-linear intensity transformations can also be used. In their most general form, these consist of a table assigning an output intensity value for each possible input value. Again the transformation can be manually specified based on inspection of the histogram, or a particular transfer function, e.g. logarithmic or power law, could be applied.

Alternatively, after scanning the input histogram, a program can specify a tabular transformation which will produce an output histogram approximating a predetermined shape, such as a uniform or Gaussian distribution. Forcing a uniform distribution results in the greatest contrast enhancement being applied to the most populated range of brightness in the input image. This property makes the uniform distribution stretch particularly useful as a quick look evaluation procedure. Principal difficulties are that it is sometimes too harsh, and tends to compress and hence loose information in the light and dark "tails" of the histogram. Definition of detail at the extremes of the histogram tends to be preserved or increased more effectively with a Gaussian transformation of user specified width (standard deviation). There will be correspondingly less emphasis in the central brightness zone. A Gaussian enhancement can be particularly valuable in dealing with a biased non-symmetric input histogram, such as a log normal distribution. Figure 4 illustrates a portion of a Landsat scene of Chile and Bolivia unstretched (a), after a linear 2 percent saturation enhancement (b), after a Gaussian transformation (c) and after a uniform distribution contrast enhancement (d).

(b) *Filtering* is another common enhancement procedure. Filtering can be thought of as any process which differentially modifies image content, tending to emphasize desireable features while suppressing less desireable ones (compare section 3.2).

The *enhancement of edges* or lines can be a valuable tool for crispening an image particularly when the contrast is moderate.

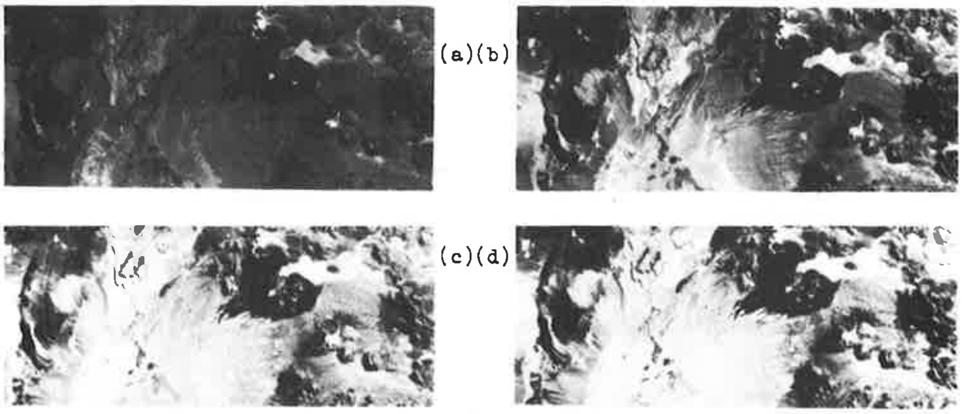


Figure 4: Section of Landsat-scene of Chile and Bolivia border (a) unstretched; (b) with linear stretch, 4% saturation;(c) Gaussian standard deviation 2.7; (d) uniform distribution.

3.4 Pattern Recognition

One may find in the literature euphoristic statements like the following: "It is possible to produce working systems for most pattern recognition problems" (Aleksander, 1978). However, the computer recognition of terrain patterns in single images for automation of geo-science photo-interpretation presently hardly exists. Although pattern recognition is an extensive field of research its potential in phto-interpretation is largely unexplored.

Pattern recognition is a tool for automation of image interpretation, not for image pre-processing. It may, however, fulfill a support function. Generally, the line between pre-processing and analysis cannot always be clearly drawn. Density slicing and texture classification are some of the few pattern recognition techniques of use or under investigation for image interpretation. Montoto (1977) reported of an investigation to detect linear features in Landsat images to be used for drainage interpretation. Dune and glacier crevasses pattern have been analysed by optical filtering of coherent laser light (Verstappen, 1977).

4. PRE-PROCESSING OF MULTIPLE IMAGES

Multiple images are either (a) taken simultaneously in various spectral bands (MSS), with different polarizations, with different sensors, or (b) taken sequentially. In addition there are manipulations dealing with images and combining them with non-image data (or synthetic images). Appropriate pre-processing of the individual images may precede the work with multiple images. We group the various methods according to their applications as follows:

- image registration;
- data compression and enhancements;
- data display.

The digital classification and clustering methods generally concern automatic image analysis and therefore are considered to fall outside the scope of this review.

4.1 Image Registration

This is a technique of matching overlapping images (or natural and synthetic images) that differ both geometrically and radiometrically. Image registration may be achieved much in the same way as geometric rectification: homologue features are identified in both images and two pairs of coordinates are measured for each feature: x,y in image 1 ("master", "search" or "reference" image) and X,Y in image 2 ("slave" or "input" image). The two sets of coordinates for each feature define a geometric transformation between the two images:

$$x = g(X,Y)$$
$$y = h(X,Y) \qquad (1)$$

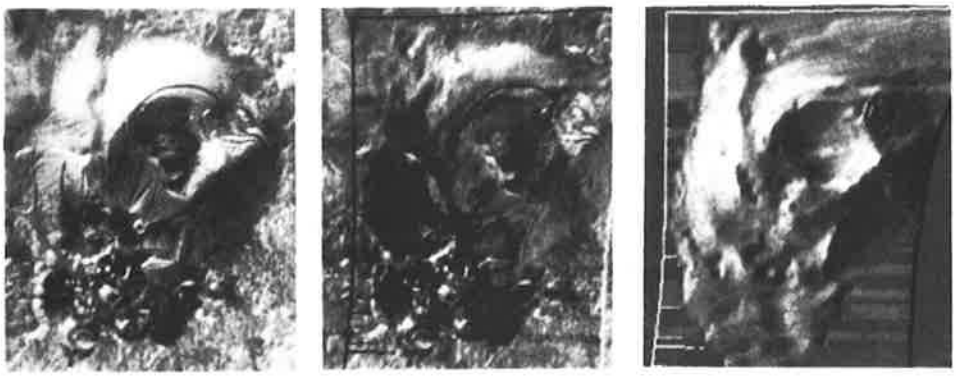
Often, this transformation (1) is denoted by *rubber-sheet stretch* or *warping function*.

The identification of homologue features may be manual or automatic; the latter methods fall into two categories:
(a) sequential similarity detection algorithms (SSDA),
(b) correlation methods.

SSDAs are less expensive than correlation methods (Barnea et al., 1972). The latter can be carried out most economically using Fast Fourier Transforms (FFT) methods (Anuta, 1970). Even then they are more expensive than similarity measures. However, correlation methods are statistically more satisfying.

Details of registration procedures are not to be discussed in the present context since they are not important for interpretation. However, the procedures enable one (a) to join overlapping images into mosaics, (b) to detect stereo parallaxes automatically, (c) to composite an MSS-image with N bands and one with M bands into an image with N + M bands, (d) to merge multitemporal images for change detection. There is fairly clear evidence that the time dimension is very important in many interpretation tasks: multitemporal images with few spectral bands may be more useful than images with a large number of spectral bands all taken at the same time. In the former there is less redundancy than in the latter, because of dynamics in seasonal vegetation, hydrology and others.

Registration of images with non-image data, e.g. of digital terrain relief, leads to an improved capability of image enhancement by presenting object characteristics without the obscuring effect of shadows caused by relief (Horn et al., 1977). Kahle et al. (1977) had to eliminate the slope angle effects from thermal inertia images (Fig. 5).



(a) (b) (c)

Figure 5: Thermal inertia images and correction of slope effects (Kahle et al., 1977): (a) raw image; (b) slope corrected; (c) synthetic slope image.

An interesting demonstration of the capabilities of image registration as a pre-processing step was reported by Anuta et al., (1976). A total of 20 images (Landsat, radar, photography, non-natural (synthetic) images such as terrain relief and geophysical parameters) were registered into a data set with 20 channels. Further processing aims then at the compression and transformation for subsequent interpretation. This matching of non-correlated imagery in a wide range of the electro-magnetic spectrum with data bands employing geographically denoted cells, may become an important field of development in the near future.

4.2 Data Compression and Enhancement

Photo-interpretation is of records that are spatially two- or - three-dimensional (stereo). For reasons of redundancy and cost, interpretation of records of many spectral dimensions is not done, but for limited test areas. Therefore, there is a need to compress multi-dimensional images spectrally to a format of least dimensions.

However, some of the techniques applied to compression can also serve to emphasize specific information (enhancement) in images that are already of limited dimensionality. The most important techniques used are: principal component transformation (PCT), ratioing, differencing, direction consine transformation.

4.2.1 Principal Component and Canoncial Transformation

This is the most commonly used technique of compressing and enhancing multiple, geometrically registered images. Given are n values x_1, x_2, x_3, ...x_n per pixel, where x_i may be a spectral density (n perfectly registered images). PCT results in a new ordered set of n images called first, second etc. principal component (PC1, PC2,...), denoted by $y_1, y_2, y_3, \ldots y_n$. The new images contain the same information as the original ones, however concentrated in the first component (PC1), to a lesser extent in the second component (PC2) and so forth. Hardly any information is contained in the higher order components. "Information" thereby is variation of gray tone corresponding to transformed radiance levels, or in another context the significance of the pattern appearing on the image for interpretation.

The transformation from x_i to y_i is rather simple, consisting for each pixel of a weighted average of each spectral dimension i:

$$y_i = a_{i1} x_1 + a_{i2} x_2 + \ldots + a_{in} x_n$$

The weights (coefficients a_{ij}) form a rotation matrix which diagonalizes a covariance matrix estimated over a subset of the image either selected automatically or specified by the interpreter. Many discussions of the method exist, e.g. Landgrebe et al., (1972), Ready and Wintz (1973), Mulder and Hempenius (1974) and Anuta (1977).

The advantage of PCT applied to MSS data is twofold:

(a) An effective compression of the data is achieved. For the example of the 4 channels of Landsat, almost all information is contained in the first two principal components. With aircraft MSS, a drastic reduction from e.g. 12 channels to the first few PC's is possible.

(b) This reduced dimensionality allows the operator to define, on the basis of a proper sample set, the best products for interpretation (compare section 4.3).

With Landsat, PCT has shown valuable results not only by dimensionality compression, but also as a method of enhancing certain phenomena. In the view of some image processing experts, however, results of PCT are somewhat unpredictable. These experts may call it a *hit or miss* technique. The so-called deficiencies of PCT relative to information extraction can be alleviated by the addition of training: The image is appropriately sampled using interpretation expertise and the PCT is based on the manually selected sample. One may rightfully generalize that image processing techniques should always be applied under the control of the interpreter and that without such control (training) most methods are *hit or miss* techniques. Transformations that maximize the variation between identified class means in certain of the transformed components have been termed *canonical* and have been applied successfully to the geologic analysis of multispectral images (Podwysocki et al., 1977). Linear discriminant analysis procedures have also been used effectively to deal with a large multispectral data base (Siegal and Abrams, 1976; Jennrich, 1977).

4.2.2 Ratioing

Enhancement of multiple, in particular multispectral images using ratio B_i/B_j of spectral bands i, j has been extensively applied in planetological interpretation of lunar images (B_i, B_j are gray values of bands i, j). These methods can be analog using photographic techniques (Mulder and Donker, 1977). With the advent of digital data ratioing is applied digitally to remove effects of the spectral brightness, leaving entirely the spectral differences. Thus hill shadow (variations of intensity) effects are eliminated and the colour information is brought out (compare Fig. 6). Three spectral band ratio images are generally color composited in a false color display. Most interband correlation is coupled with scene *intensity*. Hence colour context of a scene appears to be strongly improved.* Where intensity information is crucial, ratio should not be used.

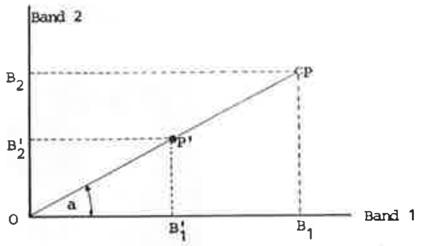


Figure 6: Principle of ratio processing: points P1, P2 may have the same color (be the same type of terrain cover), but have different intensity. Ratio B1/B2 is color information: values for P1, P2 are identical. (After Quiel, 1975).

4.2.3 Direction Cosine and Equal Vector Length Transforms

This transform results in enhancing the colour information like the ratioing method does. Each pixel has associated with it a feature vector, for Landsat with 4 elements B_4, B_5, B_6, B_7. First the vector length (x) of each pixel k is calculated;

$$x_k = (B_4^2 + B_5^2 + B_6^2 + B_7^2)_k^{1/2}$$

and is stored as a transformed data set related to intensity or spectral brightness. Vector length output produce imagery with enhanced topography due to shadow effects. Then the direction cosines $\cos \theta_i / x_k$ are calculated. Particularly in mountainous areas the direction cosine and equal vector length method are powerful preprocessing methods (Donker and Meijerink,1977). The direction cosine and band ratio techniques are nearly equivalent. Figure 7 includes an example of a vector length image.

4.2.4 Differencing

Taking the differences between two spectral bands of the same multiple image serves according to Goetz et al., (1975) to produce an enhanced image for interpretation. Its usefulness as a pre-processing method is reported to be comparable to that of ratioing.

4.3 Data Display

The registered, compressed and enhanced images must be displayed to the interpreter as several black and white images, or as a composite color image depending on the purpose. In addition a feature space plot may be useful. Imagery on TV screens is useful only as a check during the processing stage but generally inappropriate for actual interpretation.

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* An illustration of the performance of band ratio color composites and comparison with PCT (unsupervised) would require color. Cost considerations prevent us from including such illustrations.

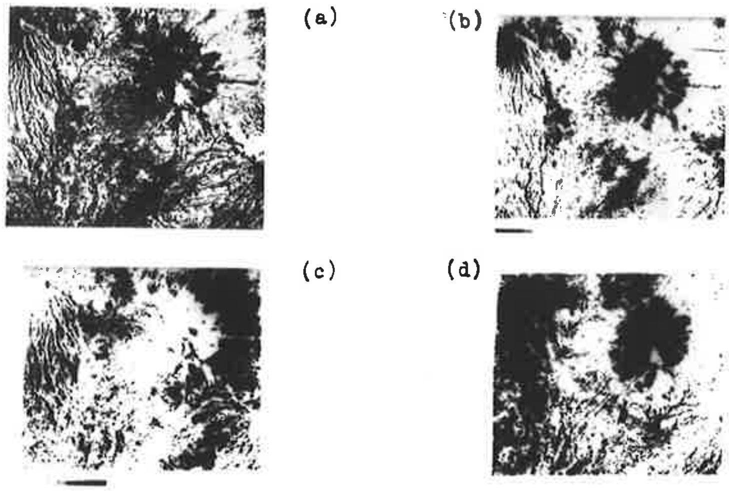

Figure 7: Section of Landsat image of Java: (a) vector length image; (b) PC1 image,display of low densities; (c) PC1 image, display of high densities; (d) PC2 image.

4.3.1 Feature Space Plot(FSP)

In general a sample set is chosen to represent the dominant terrain cover types and features of particular interest. The interpreter then uses the feature space plot (FSP) (a) to judge the spectral separation of the clusters representing ground covers and (b) to assign a colour scheme. Two non-correlated bands should be used as axes of the feature space plot. Therefore it is advantageous to work with a plot showing the first and second PC. A rotation of the axes of the FSP may result in better discrimination of the sample sets.

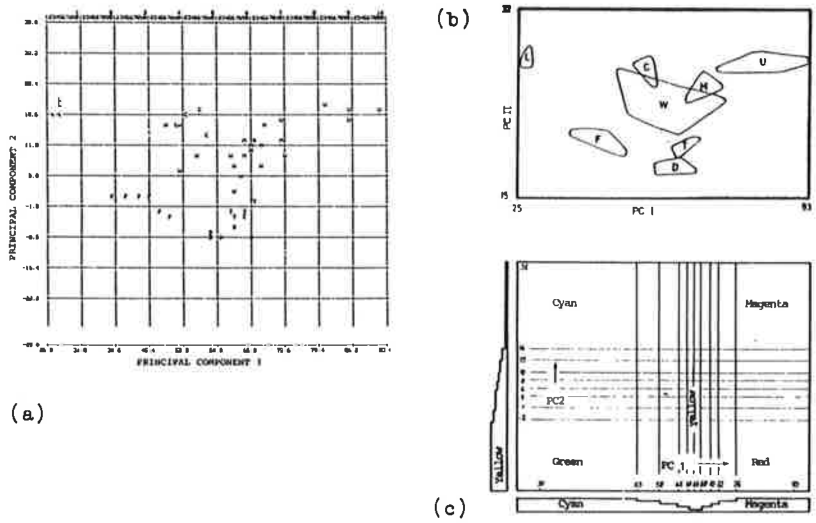

Figure 8: Java area: (a) Raw feature space plot using PC1, PC2 as axes; (b) Manually drawn class boundaries; (c) Color coding using the feature space (compare Fig. 7 b, c).

Such a transformed sample set, compressed from the 4 original Landsat bands is shown in Fig. 7. Color coding proceeds now acc.to Fig. 8 from associating a three-color system to the two PC's: PC1 is coded using 2 colors, PC2 with one color. Based on the plotted sample one then displays the full image, where the feature space plot with the clusters should be shown in colours as well, so that it serves as a sort of legend to the interpreter.

4.3.2 Color Image Presentation*

The successful use of color considerably increases the range of information which can be displayed in a single color image. Thus color enhancement for display is an essential component of any processing procedure. It could be dealt with also in section 4.2, enhancement, since these techniques are aimed toward bringing important scene information to the attention of the investigator.

Color images, just as black and white, must generally be contrast enhanced to produce a good color display. Most often, this contrast enhancement is performed individually (marginally) on the three component images. Color enhancement remains somewhat of an art form, but two basic rules of thumb are helpful. Satisfactory results are usually obtained, when

- each image is enhanced so that the resulting three histograms look similar (to produce a good color variation) and
- when each image has appropriate contrast when viewed as a black and white image (to ensure adequate intensity variation).

This can be accomplished either by manual selection of the transformations after inspection of the histograms, or by using one of the automatic or histogram normalization enhancements. Use of the uniform distribution transformation tends to produce high saturation due to the relatively high dispersion in the individual component images. The Gaussian enhancement is more moderate at the extremes of the individual histograms, but is sometimes too conservative for scenes with high inter-band correlation. Which approach will work best depends on the individual scene.

The success of any of these marginal contrast enhancement approaches depends largely on the degree of correlation between bands. Correlation between components is the factor which most hinders full use of the available color range (Algazi, 1973). Joint enhancement of the component images is required. A recently developed procedure (Soha and Schwartz, 1978) solves this problem by first applying a PC - transformation to produce a new set of uncorrelated components. These components are contrast enhanced to increase color dispersion, then the inverse transformation (rotation) is applied. If a Gaussian contrast stretch is applied to each of the components, then a symmetrical (i.e. equal variance in all directions) 3-dimensional (or in general, n-dimensional) Gaussian histogram results. If linear contrast transformations are applied to the PCs so as to equalize their variances, then the final component images (after the inverse rotation) will remain uncorrelated, while preserving the basic shape of the original 3-dimensional histogram. The return rotation, while not necessary to increase color content, is employed to preserve the color relationships of the original scene. A key feature of the procedure is that an effective table lookup implementation is available, so that the time consuming rotations

* see footnote on page 11.

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4.3.2 Color Image Presentation*

The successful use of color considerably increases the range of information which can be displayed in a single color image. Thus color enhancement for display is an essential component of any processing procedure. It could be dealt with also in section 4.2, enhancement, since these techniques are aimed toward bringing important scene information to the attention of the investigator.

Color images, just as black and white, must generally be contrast enhanced to produce a good color display. Most often, this contrast enhancement is performed individually (marginally) on the three component images. Color enhancement remains somewhat of an art form, but two basic rules of thumb are helpful. Satisfactory results are usually obtained, when

- each image is enhanced so that the resulting three histograms look similar (to produce a good color variation) and
- when each image has appropriate contrast when viewed as a black and white image (to ensure adequate intensity variation).

This can be accomplished either by manual selection of the transformations after inspection of the histograms, or by using one of the automatic or histogram normalization enhancements. Use of the uniform distribution transformation tends to produce high saturation due to the relatively high dispersion in the individual component images. The Gaussian enhancement is more moderate at the extremes of the individual histograms, but is sometimes too conservative for scenes with high inter-band correlation. Which approach will work best depends on the individual scene.

The success of any of these marginal contrast enhancement approaches depends largely on the degree of correlation between bands. Correlation between components is the factor which most hinders full use of the available color range (Algazi, 1973). Joint enhancement of the component images is required. A recently developed procedure (Soha and Schwartz, 1978) solves this problem by first applying a PC - transformation to produce a new set of uncorrelated components. These components are contrast enhanced to increase color dispersion, then the inverse transformation (rotation) is applied. If a Gaussian contrast stretch is applied to each of the components, then a symmetrical (i.e. equal variance in all directions) 3-dimensional (or in general, n-dimensional) Gaussian histogram results. If linear contrast transformations are applied to the PCs so as to equalize their variances, then the final component images (after the inverse rotation) will remain uncorrelated, while preserving the basic shape of the original 3-dimensional histogram. The return rotation, while not necessary to increase color content, is employed to preserve the color relationships of the original scene. A key feature of the procedure is that an effective table lookup implementation is available, so that the time consuming rotations

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* see footnote on page 11.

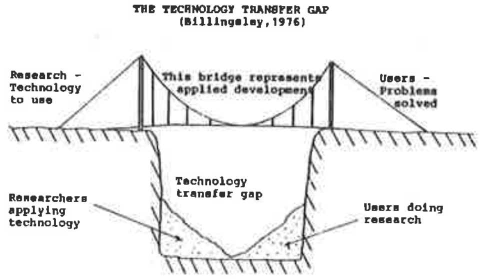

Figure 9: Technologists-users gap.

Symptomatic for the gap is that many users are even unaware of the difference between digital pre-processing and digital classification techniques. Similarly, the omittance of a good facility for obtaining hard copies of processed images for subsequent interpretation, in some processing set-ups, demonstrates that technologists also have a limited understanding of the other side's needs.

The statistical classifiers tend to be considered by many users as black boxes. Improper use of such classifiers to areas not suited for automatic data extraction has been an dditional source of frustration. The pre-processing techniques meet less resistance among interpreters (user). The essential concepts of the operations can easily be outlined, the results are often predictable and are appreciated by users skilled in interpretation.

6. CONCLUSION

We have reviewed some of the techniques that may serve to pre-process digital images for improved visual geoscience interpretation. The techniques originate from space research and artificial intelligence work. We argued that digital methods of image processing have a number of distinct advantages over analog methods and over interpreting unprocessed images. The actual review of techniques addresses separately single and multiple images, grouped into serveral classes of techniques.

We believe that there is a wide range of capabilities added by processing digital images. Presently the techniques of pre-processing are being applied in an environment of research and development using remote sensing images (electronic image formation, telemetering). However, with increasing efficiency of algorithms, improved capability of image input-output and of computing, the advantages of digital processing will eventually lead to some wide-spread operational use of these techniques. This expectation is based however, on the assumption that digital (satellite) MSS data will continue to reach the users community.

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