AN IMPROVED IMAGE ENHANCEMENT TECHNIQUE AND ITS APPLICATION TO FOREST FIRE MANAGEMENT

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ABSTRACT

The image enhancement capabilities of ARIES (Applied Resource Image Exploitation System) are described and practical application of image enhancement is discussed.

A Karhumen-Loeve (principal component) transform is used to reduce the number of features required to carry a given amount of information. In the ARIES enhancement system, the K-L transform is used to rotate the axes of the image space so as to align them along the axes of a hyperellipsoid defined by the signature of a specified training area. The use of a training area to define the K-L transform allows the enhancement of specific selected classes.

The second part of the image enhancement process is the mapping of features into a colour space. The colour mapping process is extremely flexible as any feature may be selected as input. An enhancement may be composed of a combination of unaltered image data, contrast stretched or filtered data, ratio or additive combination of bands, as well as components from one or more K-L transforms.

A project using image enhancement techniques to produce large scale colour imagery over large areas for field use in forest fire management is described.

RESUME

Dans cette communication, on donne une description des fonctions de renforcement des images de ARIES (Système d'exploitation des images de ressources utilisables), et on analyse les applications pratiques du renforcement des images.

Une transformée de Karhumen-Loeve (composante principale) sert à réduire le nombre de caractères minimal pour véhiculer une quantité donnée d'informations. Dans le système de renforcement ARIES, la transformée K-L fait tourner les axes de l'espace image de façon à les aligner sur les axes d'un hyperellipsoïde défini par la signature d'une zone modèle particulière. L'emploi d'une zone modèle pour définir la transformée K-L rend possible le renforcement de certaines classes choisies.

La seconde étape du procédé de renforcement des images consiste à cartographier les caractères dans un espace couleur. Le procédé de cartographie couleur est très souple, car tout caractère peut être choisi comme donnée d'entrée. Une renforcement peut se composer, par exemple, de données images non modifiées, de données au contraste accentué ou filtrées, d'additions ou de divisions de bandes, ou de composantes d'une ou de plusieurs transformées K-L.

On décrit un projet mettant en oeuvre des techniques de renforcement des images pour produire des images couleurs de grande échelle que l'on prévoie employer sur le terrain pour le contrôle des feux de forêt.

THE ARIES SYSTEM AND IMAGE/ENHANCEMENT

INTRODUCTION

The purpose of this paper is to describe the ARIES image enhancement procedure and to describe its current application and potential role in Canadian forest fire management.

The ARIES image analysis system consists of a 45 IPS (inches per second) tape drive, an 88 megabyte image disk, 2 RK05 disks, a PDP-11 40 minicomputer and a Control Data high speed processor/display refresh subsystem. The latter is used to drive a CONRAC colour display and also to perform rapid arithmetic operations. In addition to the above, a DICOMED digital image recorder is used to produce 4096 x 4096 pixel colour imagery on 70 mm Polaroid, colour negative or colour positive film.

When enhancing images, data flow through the system is as follows. Sensor data are read in from magnetic tape and, if

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necessary, destripped. When undertaking a multidate enhancement, a feature from one date is selected as the master and the remaining images are registered to it. A representative subarea, about 100,000 pixels, is selected for the initial work. A number of different training areas are created within this subarea and are used to derive different enhancements. Any three-feature subset selected from the transformed features may be mapped into the colour space suggested by Taylor*. The operator examines three-feature combinations until a visually satisfactory image has been selected.

This image is recorded on the DICOMED image recorder. The enhancement procedure which was used to create the satisfactory subimage, is applied to the entire image. If required, the enhanced image may be warped to the UTM coordinate system.

The reason for the initial use of a subarea is to allow rapid execution of the enhancement software. In a typical enhancement session, 15 to 20 transformed features may be created, of which only three will be used in the final one.

The image enhancement procedure consists of a modified Karhumen-Loeve (K-L) (principal component) transform followed by a mapping into a colour space.

IMAGE TRANSFORMATION OPTIONS

In order to allow maximum flexibility in the enhancement process, the following options are built into the software which implements the K-L transform:

(1) Any number of features may be specified as inputs and outputs, providing the total number does not exceed 15 and the number of transformed features is less than or equal to the number of input features. This allows the creation of multi-date, multi-sensor enhancements. Since the calculations are done directly in the high speed processor, rather than through lookup tables, an increase in the number of input features does not cause a decrease in the precision of the calculations.

(2) The polarity of any transformed feature may be optionally reversed by multiplying the appropriate row of the eigenvector matrix by -1.

(3) The standard K-L transform causes a rotation of the axis of the image space while maintaining orthogonality between the axes. In the ARIES system, the axes of the image space are rotated so as to align them with the axes of a hyperellipsoid defined by the signature of a training area, rather than the signature of the entire image. This training area is defined in the same way as for maximum likelihood classification procedure.

(4) In addition, the transformed features may be forced to have an operator specified mean and standard deviation within the specified training area. This is accomplished by applying a scale change to the eigenvector matrix before it is applied to the image data and a translation to the transformed features. The judicious use of options (2), (3) and (4) allows the operator to enhance a specific ground cover type at the expense of other cover types by specifying a pure training area. Alternatively, it allows the enhancement of an entire image by specifying a training area containing all cover types. Experience has shown that a compromise between these two extremes usually yields the best results. No "cookbook" procedure has been found that will give optimum results for all types of image data. Rather, each image should be treated individually to obtain the best results.

TRANSFORM CORRECTION CONSTANTS

Assuming that the input data comprise of a N-dimensional normal distribution and that the following are known:

[F] the input feature matrix
N the number of input features
[M] the mean of the input features within the specified training area

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*Paper entitled Principal Component Colour Display of ERTS Imagery, Third ERTS-1 Symposium NASA SP-351, 1973.

[C] the input feature covariance matrix within the specified training area
[E] the matrix of eigenvectors of [C]

the mathematics of the image transform is as follows:

The standard transform without any corrections consists of the eigenvector matrix multiplied by the input feature matrix to give [O], the output feature matrix. The "kth" pixel in the "ith" output feature can be calculated from:

$$O_{ik} = \sum_{J=1}^{N} (E_{ji} * F_{jk})$$

We know that, in adding 2 normal distributions, the variance of the resulting distribution will be the sum of the individual variances plus twice the covariance, while multiplying a distribution by a constant multiplies its variance by the square of the constant. Extending this to the "ith" output feature, V_i', the approximate variance that the "ith" output feature would have without correction can be calculated from

$$V_i' = \sum_{l=1}^{N} \sum_{m=1}^{N} (E_{il} * E_{im} * C_{lm})$$

To force the output feature variance to be close to V_i'', a desired value, the appropriate eigenvector is multiplied by a correction factor K_i before the transform is applied. The correction factor is

$$K_i = V_i''/V_i'$$

The calculation of the "kth" pixel in the "ith" output feature may now be expressed by

$$O_{ik} = \sum_{J=1}^{N} (E_{ji} * K_i * F_{jk})$$

M'_i, the approximate mean that output feature O_i would have without correction can now be calculated from

$$M'_i = \sum_{J=1}^{N} (E_{ji} * K_i * M_j)$$

To force the output feature mean to be close to M''_i, a desired value, a correction factor, A_i, is added to the output feature after the transform has been applied. This correction factor is

$$A_i = M''_i - M'_i$$

The complete transform used to calculate the "kth" pixel in the "ith" output feature of the ARIES system can be summarized by

$$O_{ik} = \sum_{J=1}^{N} (E_{ji} * K_i * F_{jk}) + A_i$$

GRAPHICAL REPRESENTATION OF THE IMAGE TRANSFORM

Figure 1 illustrates the transformations which are possible under the ARIES enhancement package. For the sake of simplicity, the diagrams are in two dimensions only. Figure 1A is a diagramatic representation of a training area signature. Figure 1B illustrates the effect of a standard K-L transform, which has caused the principal axis of the image data to lie along the principal axis of the ellipse representing the training area signature. In Figure 1C, offsets have been applied to the transformed features to move the origin of the image space to the center of the ellipse representing the signature of the training area. In Figure 1D, a scale change has been applied as well to cause the new image space to span only the ellipse. Figure 1E shows a scale change and rotation which causes the mean of the training area transformed feature data to be away from the origin of the transformed feature space. Finally, Figure 1F shows two separate transformations for different training areas. Transforms may be combined to make a single enhancement under the ARIES enhancement system.

COLOUR MAPPING

Once transformed features have been generated, they are mapped into the colour space suggested by Taylor (1973). This consists of mapping one feature onto a brightness axis, one feature onto a red-to-green axis and one feature onto a blue-to-yellow axis. The Taylor mapping yields a good image in terms of human perception.

In the mapping stage, the ARIES system is again very flexible. It is not necessary that the three input features be the result of a single transform. In fact they do not have to be the result of a K-L transform at all, but rather may be such things as contrast stretched raw data, ratio or additive combinations of bands or properly registered data from different sensor systems.

EXECUTION TIME

Since ARIES is a dedicated system, discussing execution in terms of microseconds of machine time is not very useful. Instead, consider the approximate time required for the user to accomplish certain things on the ARIES system. Assuming the input image data are already on the image disk, an enhancement of a subarea (about 100,000 pixels) can be produced and displayed on the colour monitor in under 15 minutes of the user's time. The enhancement of an entire single-date LANDSAT frame, including reading the data from tape, producing a "good" enhancement of a selected subarea, recording the enhancement of that subarea on Polaroid film on the DICOMED image recorder, transferring the enhancement to the full LANDSAT frame and recording the full frame can usually be accomplished in a normal five hour session. The time required may be either increased or decreased depending on how rigorous the definition of a "good" enhancement is. Multidate enhancements obviously take longer as the input images must be registered before the enhancement process begins. Breaking up the final image into smaller images before recording in order to achieve a desired scale also adds to the required time.

APPLICATION OF ENHANCED IMAGERY IN DAILY FOREST FIRE MANAGEMENT DECISION-MAKING

FOREST FIRE FUEL PROBLEM

Forest fire fuel maps, that show forest vegetation classified into broad categories exhibiting similar fire behavior, are important to fire control agencies for many reasons. When a fire is reported, either by the general public or a detection aircraft, decisions concerning the speed and strength of initial attack must be quickly made.

The combustibility of the fuel at or near the fire is a key item in determining the nature of the initial dispatch. When initial attack fails and a large fire results, fuel type information is important in determining suppression strategy. Also, fuel information is essential for modelling the rate of growth of a fire. Fire growth models will be valuable in the future for decision-making associated with fire detection, initial attack and large-fire suppression activities.

In spite of the obvious need for fuel maps, few exist. Timber inventory maps contain the information required but rarely are they current. Major new disturbances such as clearcuts, burned and insect killed areas, that are so important from the fire behavior viewpoint, will not be present on older maps. In addition, the complexity of the conventional maps must be simplified before practical field use will occur. Colouring of stands with similar fire behavior characteristics accomplishes this but requires about one man-day per 100 square miles -- a prohibitively high cost.

LANDSAT FUEL MAPS

Soon after the launching of LANDSAT A, the Forest Fire Research Institute began to investigate, with the assistance of the Canada Centre for Remote Sensing (CCRS), the potential role of satellite data for fuel maps. The initial goal was simple -- map the new clearcut areas. Supervised classification methods used in conjunction with summer imagery immediately showed that this was possible at an accuracy suitable for fire control needs. In addition, pure stands of deciduous and conifers could easily be separated.

The use of highly magnified band 5, summer imagery without further processing produces excellent clearcut and road information. Small lakes, absent on most maps but so important to boreal forest fire control methods, clearly showed on highly magnified band 5, summer imagery. Our many experiments with classification and enhancement methods over the last 5 years have failed to make significant improvements over the display of magnified "raw" data for both these items.

USE OF ENHANCEMENT IMAGERY

When imagery produced by supervised classification programs showing lakes, clearcut areas, coniferous, deciduous and mixed stands were given to fire control personnel, a credibility problem quickly became obvious. The forest was not that simple. Gradual transition areas that are so common in the northeastern forest were lumped into only a few classes.

Unsupervised classification appeared to be more effective in non-homogeneous forest conditions than supervised methods. After arbitrary colour assignments to the myriad of transition classes produced by the unsupervised method, the transition effect was lost to most viewers of the output. The Taylor enhancement program on CCRS equipment using summer imagery immediately resulted in a much more acceptable output product. Water, deciduous and coniferous stands and clearcut areas were clearly visible. In addition, transition forest areas and major forest roads were present. Most important to the field personnel, the output resembled something like coloured aerial photography and definitely required human interpretation. Psychologically keeping the field personnel involved in the interpretation process appears to be essential for this application.

Complete enhancement coverage was prepared for an eight million hectare area of the Outaouais fire control region in Quebec. The output consisted of 120 prints (20 x 25 cm) spanning six Landsat frames at a scale of about 1:150,000. It took less than two man-weeks to construct at an estimated cost of less than five thousand dollars. It has been used for the past three fire seasons at the Outaouais fire control centre for aiding in initial attack dispatching. Field personnel report that it has paid for itself many times.

Work at the Forest Fire Research Institute continued with the goal of improving the output product. We have shown that enhancements of winter images enable very sharp delineations between coniferous and deciduous stands. Within coniferous stands in winter enhancements, colour differences are caused by the interaction of age class, species and density and are hopelessly confounded. Also new clearcuts, rock outcrops, and meadows cannot be separated from water because of the uniform snow cover. Winter imagery does offer the exciting possibilities of conifer regeneration monitoring and conifer understory mapping in deciduous stands. Overlays of winter-summer data can be tailored to take advantage of desirable features of both seasons. We have obtained significantly improved enhancements using various overlay combinations.

Carrying the temporal overlay process one step further, we have demonstrated the usefulness of enhanced winter-winter overlays for blowdown mapping and detection of total defoliation of coniferous stands. Here winter imagery before the disturbance occurred was overlaid onto winter imagry after the disturbance. The use of winter imagery eliminated the troublesome deciduous ground vegetation variable. Also, enhancements of winter-summer overlays have shown Landsat's ability to monitor forest road development and clearcutting progress.

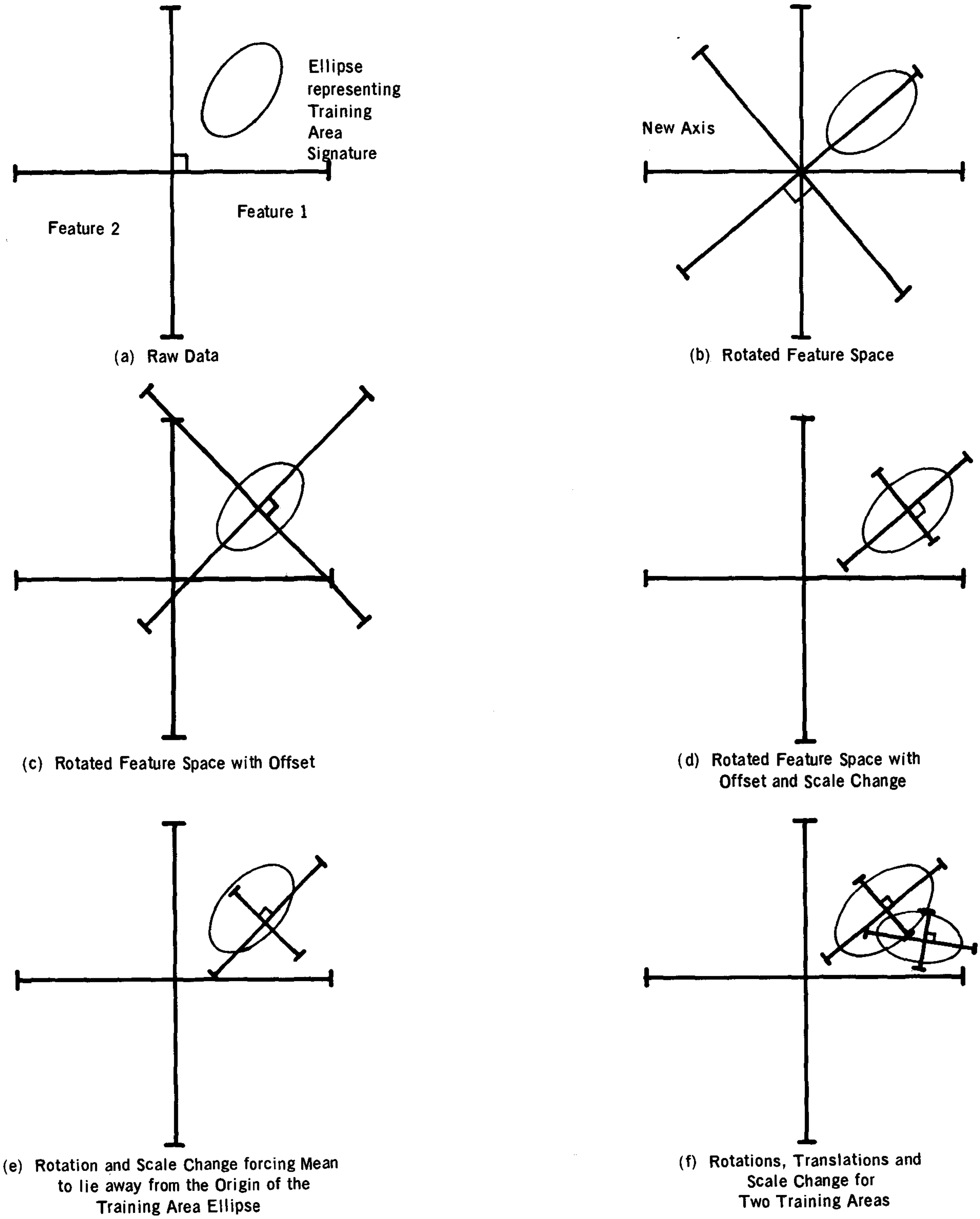
We have learned from experience to avoid spring and fall imagery. Physiological differences over short distances plus the possibility of snow patches smaller than the resolution size introduce unsolvable problems. Using summer imagery (July and August) or winter imagery (complete snow cover present), enhancements over several frames can be produced with a degree of consistency suitable for fire control purposes.

Atmospheric haze is still one of the more serious problems associated with enhancements. A great deal of searching often is required before suitable imagery is chosen. The chance of getting one cloud and haze-free frame during the summer period in eastern Canada on a given year must be less than 50%. On the other hand, our long winters make it much more likely that cloud-free clear imagery can be obtained for any specific winter.

Our new work will be concentrating on improved enhancements using the ARIES system. Combinations of principal components plus "raw" data (i.e. contrast stretched band 5 for roads) offer considerable promise for the future. We hope to explore the limits of temporal change detection and answer questions such as Landsat's ability to monitor regeneration progress, the degree of defoliation detectable with multidate overlays and the reasons for improved species separation obtained with certain temporal overlay combinations. We have already seen that temporal overlays are "unstable" in that they are most difficult to reproduce from frame to frame. The effect of snow cover on different conifer species must also be investigated. We foresee the day, in the not too distant future, when field stations monitoring haze conditions, cloud cover, snow conditions and phenological states at times corresponding to satellite passes will provide valuable support data to our Landsat programs.

The most serious problem in the fire control application area is the cost and quality of the final output product. The ideal scale of imagery for field use appears to be about 1:100,000. The areas that should be mapped exceed 2.5 million square kilometers. However, the cost of photographic prints is so high and the quality so variable that fire control agencies are discouraged from general application. Because of this high cost of producing photographic prints at scales large enough to fully utilize the information available in the data, alternative methods should be investigated. Perhaps high-quality back screen projectors, or high resolution video cassette systems, will provide the answer.

In conclusion, we can safely say that the information contained even in the more sophisticated Landsat enhancements is still very elementary. Those who expect Landsat to replace low level aerial photography or to obtain detailed timber inventory information will be very disappointed. Nevertheless, there are many useful areas where Landsat has an important role to play -- forest fire control being one. The forest fuel information available from Landsat enhancements is most useful and unique. No other economic alternative exists.



(a) Raw Data

(b) Rotated Feature Space

(c) Rotated Feature Space with Offset

(d) Rotated Feature Space with Offset and Scale Change

(e) Rotation and Scale Change forcing Mean to lie away from the Origin of the Training Area Ellipse

(f) Rotations, Translations and Scale Change for Two Training Areas

Figure 1. Illustrations of transformations that are possible under the ARIES enhancement package.