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COMPUTER TECHNIQUES USED FOR SOME ENHANCEMENTS OF ERTS IMAGES

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ABSTRACT

The JPL VICAR Image Processing System has been used for the enhancement of images received from the ERTS for the Arizona Geology Mapping Experiment[1]. This system contains flexible capabilities for reading and repairing MSS digital tape images, for geometric corrections and interpicture registration, for various enhancements and analyses of the data, and for display of the images in black and white and color.

An initial decision was made in the design of the experiment to use the ERTS MSS tapes as the prime data source in anticipation of using the VICAR System for the data reduction. This decision was made on various counts:

1. Previous experience with digital image processing at JPL for deep space missions, Apollo, and on other pictures had demonstrated the usefulness of digital processing.

2. Meaningful accurate calibration could be applied if the calibration data were available.

3. Various geometric manipulations such as map matching and overlay registration could be done without loss of photometric fidelity.

4. The multiple inaccuracies which would be suffered in attempting to use film data could be avoided.

5. Various special products such as ratio pictures could be easily produced.

6. Multispectral classifications could be obtained.

7. Various spatial filters for such as lineament emphasizing could be easily applied.

8. It was expected that the MSS would present appreciably more uniform data than would the RBV cameras.

9. The VICAR system with its extensive gamut of processing programs was available to the experimenters.

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ERTS PROCESSING

The early MSS tapes received from GSFC contained bad data occurring on every sixth line of the green and near IR, which appeared to be a scale factor and offset problem. To avoid loss of data, initial cleanup attempted to correct these two factors. Subsequent tapes, however, contain other types of errors which seem to be caused by random bit drop-outs for major parts of lines, and which seem to occur on random lines. Consequently, the ERTSFIX program has been modified to detect each picture line which deviates more in average value from its two neighbors than a preset tolerance. These bad lines are eliminated and the average of the neighboring lines is substituted. This produces a fairly clean picture but reduces the vertical resolution at these points. Errors over small parts of lines which are not detected by the ERTSFIX thresholding are located manually and averaged out.

The original MSS data have not been skewed to compensate for earth rotation. Although for the majority of the processing this would make no difference, skew correction for registration to maps appreciably aids the field investigator and so is routinely done. A skew correction is applied using a program which laterally shifts the data in each picture line by a progressively changing amount as required to produce the desired output skew. Following this, flexible rubber sheet stretching may be applied if desired for precise overlay matching or for registration to maps. Final adjustment for aspect ratio is accomplished by film recording at differing horizontal and vertical pixel spacings.

The images as received are relatively low contrast and it has been found useful to stretch the contrast before presenting the data for visual inspection. Stretching to the limits of the available digital number (DN) range has been used for black and white presentation (Figure 1). This produces stretches which vary for the different colors and vary between pictures. Stretching in the digital domain has the particular advantage that it is under precise control, can be linear or non-linear, and does not suffer from the toe and shoulder saturations encountered with photographic stretching. For color presentation it is desirable to have uniform color presentation throughout a series of pictures. A fixed predetermined stretch is therefore used. Comparison of the stretched pictures with the original GSFC color prints reveals considerable additional detail not visible in the original.

A second presentation which has been found useful is obtained by forming the ratios of pictures, the two most useful of which have been the ratios of each of the bands to red and each of the bands to an average of all four colors. Figure 2 shows the ratios of red and the 0.8-1.1 IR to the average. This ratioing process largely eliminates the brightness components of the original pictures and produces a color display whose color variations are more indicative of material variations than the simple pseudo color displays.

A program FUNC has been written which allows the function

$$DN_{out} = (\frac{Ax + By + C}{Dx + Ey + F}) (Gx + H)^I + J$$

to be performed on two pictures where x is the input DN of one picture
and y is the input DN of the second. By suitable manipulation of the
coefficients this program may be used to perform the ratioing, picture
averaging, picture differences, offset and gain change, and exponen-
tiating. A two dimensional table is first built up to 8 bit precision
using the coefficients entered as parameters. The two input pictures
are then read in parallel and an output picture assembled in synchro-
nism by reference to the table at a location determined by the DN's of
the two input pictures, pixel-by-pixel. Rapid processing speed is
afforded by the table lookup method.

High frequency detail may be contrast stretched to enhance its visi-
bility or anisotropically filtered to emphasize geologic structures
with differing orientations. Spatial filtering by convolution (our
normal method) has two important practical advantages: For the large
pictures and the reasonable size filters used for ERTS it is faster
than doing the required two-dimensional FFT, and since filtering is in
the real domain the effects may be easily visualized and to some extent
the filters may therefore be designed heuristically. Examples of a
horizontal filter is given in Figure 3. Filtering in the Fourier
domain has been advantageous primarily where the filter function in
frequency space is fairly complex. This process has not been necessary
for the ERTS images.

Clustering and classification is accomplished using an extension of the
techniques previously described[2] for the Apollo S-158 experiment.
Training samples are chosen by the analyst (Figure 4) to represent the
various materials for which classification is desired, and their average
value and deviation for the four bands are found by a program CLSTRN and
tabulated. The four-dimensional decision volume is defined using three
two-dimensional decision spaces of 128x128 locations each. Within each
space rectangular areas based on the previously determined average and
deviation for each material are delineated. A subsequency rule is used
to eliminate the effects of overlap. Alternatively, the defined areas
may be of any shape desired by manual delineation.

A two-dimensional cluster diagram in which increasing darkness repre-
sents increasing quantity of pixels at a given DN intersection may be
presented to the analyst for inspection, either in image form or on a
line printer. For better visualization this cluster picture may be
contrast stretched and contoured with the results shown in Figure 5.
The analyst manually defines in the two-dimensional cluster spaces the
areas corresponding to the various materials based on the CLSTRN
parameters.

Four dimensional classification using these two-dimensional spaces is
done in three passes using the two-dimensional classifier HSTLOC2, first
using two bands, then the output of the first pass with the third band,

and finally the output of the second pass with the fourth band. Because of the way the VICAR system is organized this multiple pass approach is quite simple to apply. While not as sophisticated as the LARS approach, it has provided a useful interim capability.

Areas containing fine detail will show a variance larger than those in which there is not much activity. Therefore, edges, lines, and fine structure will be visible in such a picture with a brightness related to the variance. Figure 6 is a variance picture of the same area as Figure 1.

Registration is normally accomplished in two steps. First, translational offsets are simply accomplished utilizing the truncating capabilities of VICAR. The required translations of small areas used for pass points are then obtained by cross correlation. One of several rubber-sheet stretching programs may then use these parameters to distort the picture to accomplish the desired overlay match. The basic operation of these programs is to systematically generate a uniform-grid output picture, obtaining the required data by weighted interpolation from the four nearest neighbors surrounding the precise calculated location in the input picture. It has not been found satisfactory to use simply the nearest neighbor to the calculated location for the output data, as this reduces the resolution. The location in the input picture is calculated from the array of distortion parameters, using linear interpolation between. We have considered higher-order generating functions for the location calculations, but have not found them necessary.

After registration, any inter-picture operation, such as DIFFPIC to detect temporal changes by picture differencing, may be applied. VICAR is designed to handle multiple input and output pictures where appropriate to the required tasks. Figure 7 is such a DIFFPIC of the Verde Valley area.

VICAR - THE JPL IMAGE PROCESSING LANGUAGE

A large amount of picture processing can be done with normal general-purpose computers and the standard Fortran batch processing software. This is not particularly efficient, however, so with large numbers of pictures to be processed, special attention must be given to reducing or by-passing the inefficient parts of the Fortran language and/or doing programming in machine language. In addition, an image processing laboratory should make available to the analyst an efficient data handling system for the development of algorithms and for the recording, processing, and display of pictures.

To facilitate the use of the system by the analyst and to enable him to rapidly call for new processes, an image processing software system based upon English language commands has been designed for the Image Processing Laboratory of the JPL. This system requires a minimum of programming knowledge and data inputs from the analyst, and performs automatically the input/output processing and routine bookkeeping. This language has been designed to allow the analyst to easily and quickly process one or a string of pictures through one or more processes automatically.

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Philosophy

The fundamental philosophy of the VICAR system is that the image analyst, in accomplishing his picture processing, will call for execution one or more of a group of programs from the system library, entering parameters at the time of execution to suit his particular needs. These library programs will have been previously debugged and documented, and are available for any analyst to call on. A continually growing system is thus provided as various analysts require new processes and write the required executable programs. Over 200 executable programs are presently available.

Standard Format

A standard format has been established for both tape and disk data sets. All of the standard VICAR processing programs are designed to operate with this standard data set format.

Video samples are normally represented as 8-bit data bytes. With the Data Converter Feature of the IBM 360 tape controller, both seven and nine track tapes may be logically equivalent. The standard tape format in use at JPL is IBM-compatible seven-track tape written with ODD parity at 800 b.p.i. Each reel of tape may contain up to 99 files, determined only by the size of the files. Each file contains one video frame and is followed by a trailing file mark. The last file on a reel must be followed by two trailing file marks.

All data are recorded in an 8-bit mode, compatible with that specified in IBM SRL A22-6866. The 8-bit data samples are written in a mode where three 8-bit data bytes are recorded on tape as four 6-bit characters.

Tapes from outside sources should meet the above standards generally, but may be at other tape densities.

Vicar Summary

The primary features of VICAR as compared to separate programs are:

1. Easier to use due to standardization of procedures and formats and the reduction in the number of control cards.

2. Saves time and money in programming by providing buffering, housekeeping, label processing, and many other capabilities to the programmer.

3. Allows interaction between programs which would otherwise be difficult for a user to control.

4. Can be improved in the future without necessarily modifying all the programs.

5. Faster execution due to the elimination of returns to the operating system between tasks.

The Programs

Of the 200+ executable programs available, about half are of general purpose interest, the remainder being written around peculiarities of various projects, such as specialized programs for processing pictures from the Mariner spacecraft camera. Of the group of general interest, a moderate number have been used in ERTS processing, supplemented by some ERTS special programs such as ERTSFIX. Table I lists some of these, with typical execution times for a 1600x1700 pixel ERTS picture (i.e., two of the four strips comprising one ERTS frame). As a general rule, processing time is linearly proportional to the picture area, so small portions of the pictures - easily extracted by VICAR - are generally used for experimentation.

ERTS MSS PROCESSING TIMES
4 bands, two strips (1620x1620)

		Min.
VMSS	GSFC format to VICAR format on disk, 1 strip	$6\frac{1}{2}$
CONCAT	Join two strips to form 1620x1620, 4 colors	18
STRETCH	Expand to 8-bit range, 4 colors	$4\frac{1}{2}$
ERTSFIX	Cleanup bad lines, 1 color (depend on severity of problem)	$3\frac{1}{2}$-7
SKEW	Skew, 4 colors	$7\frac{1}{2}$
PICAVE	Average four bands	8
FUNC	Ratio band to average	$5\frac{1}{2}$/ratio
HISTOGRAM	Generate histograms, 4 colors	8
DIFFPIC	Difference picture, one pair	4
STRETCH	Contrast stretch, 4 colors	16
FILTER	Spatial frequency filter, 1 color	$12\frac{1}{2}$
AFILTER	Asymmetric filter, 1 color	$31\frac{1}{2}$
FASTFIL2	Suppress low frequency, 1 color	8
CLSTRN	Calculate x, σ up to 150 areas, 4 colors	3
HISTLOC2	2-dimensional classifier (1000x1200)	10
HISTLOCN	N-dimensional classifier (N=4)	30
TAPE	Generate save tape, 5 pix.	6
SAR	Read/Write 4-frames to tape	5
FOTO	Quick look Polaroid picture, 1000x1000	$1\frac{1}{2}$
REGISTER/ CROSS	Generate registration parameters by cross correlation	15
GEOM	Rubber sheet stretch for registration	5-20,typ

TABLE I

CONCLUSIONS

The VICAR image processing system has proven to be versatile and capable of handling the diverse array of digital processing functions required for ERTS.

Image processing for visual presentation may include such non-reversible processes as low-spatial-frequency filtering, since numerical output is not required. These must be avoided where subsequent numerical operations are required.

ACKNOWLEDGMENTS

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REFERENCES

1. Goetz, A. F. H., Billingsley, F. C., Elston, D. P., and Shoemaker, E. M., Preliminary Geologic Investigators in the Colorado Plateau Using Enhanced ERTS Images, ERTS-A Investigator's Symposium, March 1973.

2. Billingsley, F. C., Computer-Generated Color Image Display of Lunar Spectral Reflectance Ratios, Phot. Sci. & Eng. 16 #1, 1972, p. 51-57.
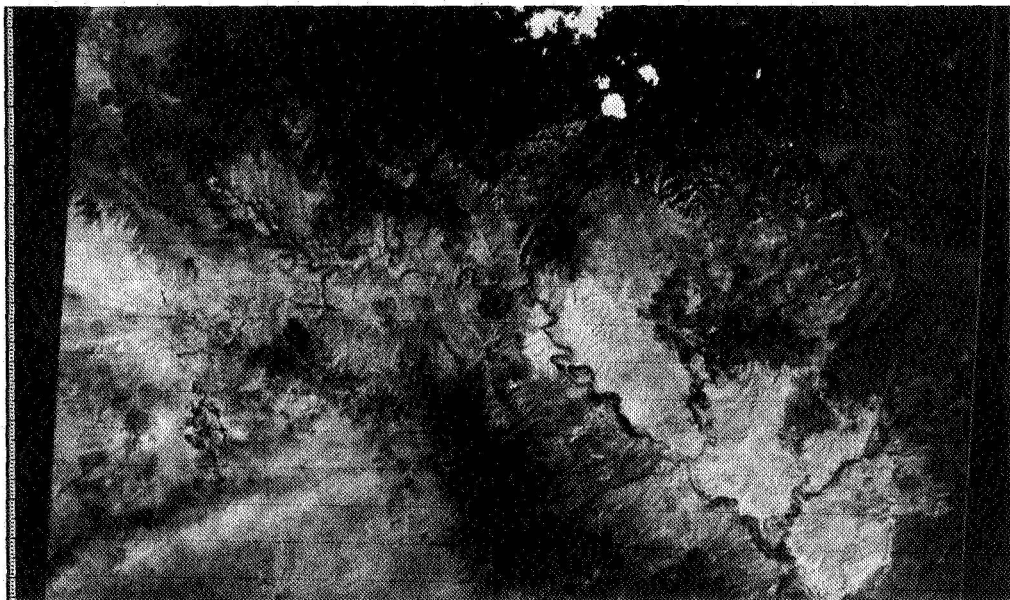

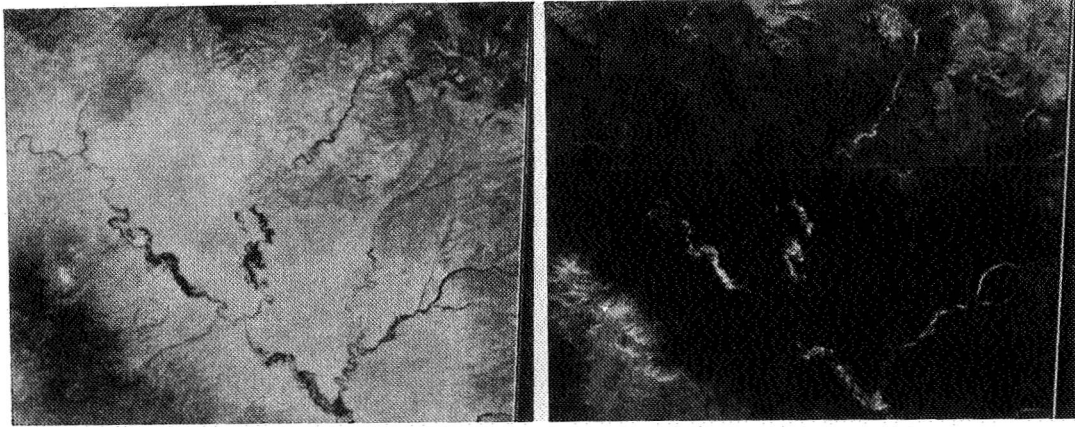Figure 1. A section of ERTS Frame 1014-17375 (Red band), contrast stretched.

Figure 2. Ratios may be taken to emphasize variations due to color
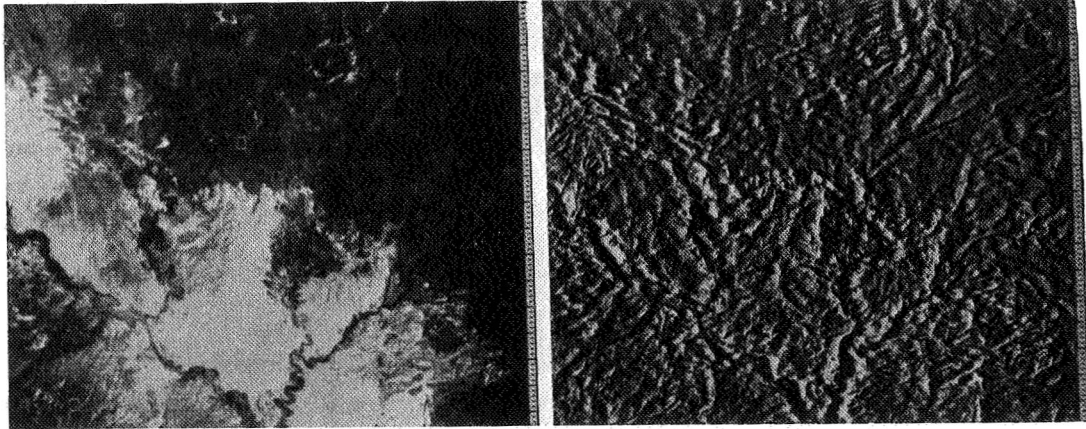 a) Ratio of Red/Average   b) Ratio of IR2/Average

Figure 3. Spatial filters may be used to emphasize structure
 a) Original   b) Horizontal elimination filter
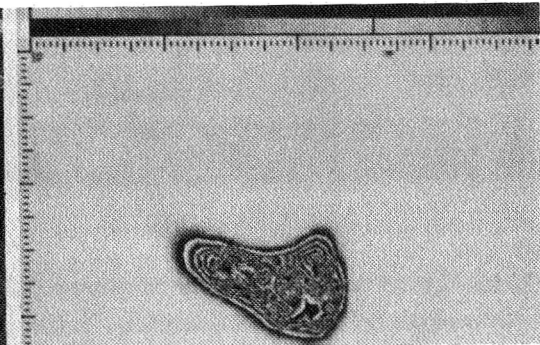

Figure 4. Portion of frame   Figure 5. 2-dimensional cluster
showing typical training areas   diagram
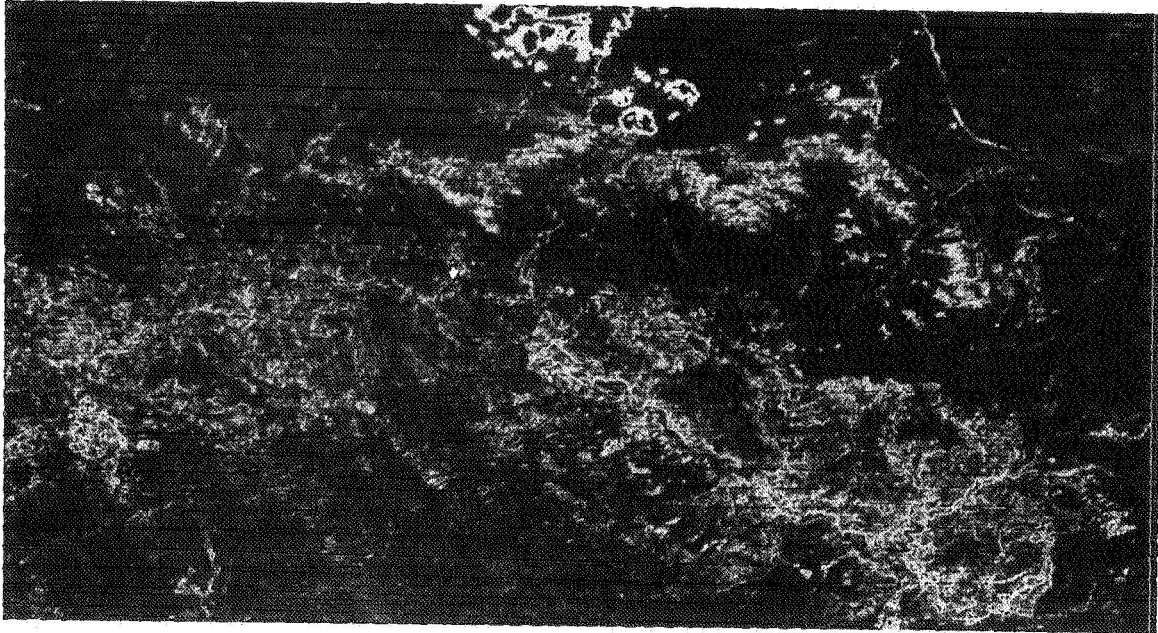
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Figure 6. Variance activity picture displaying the local variance at
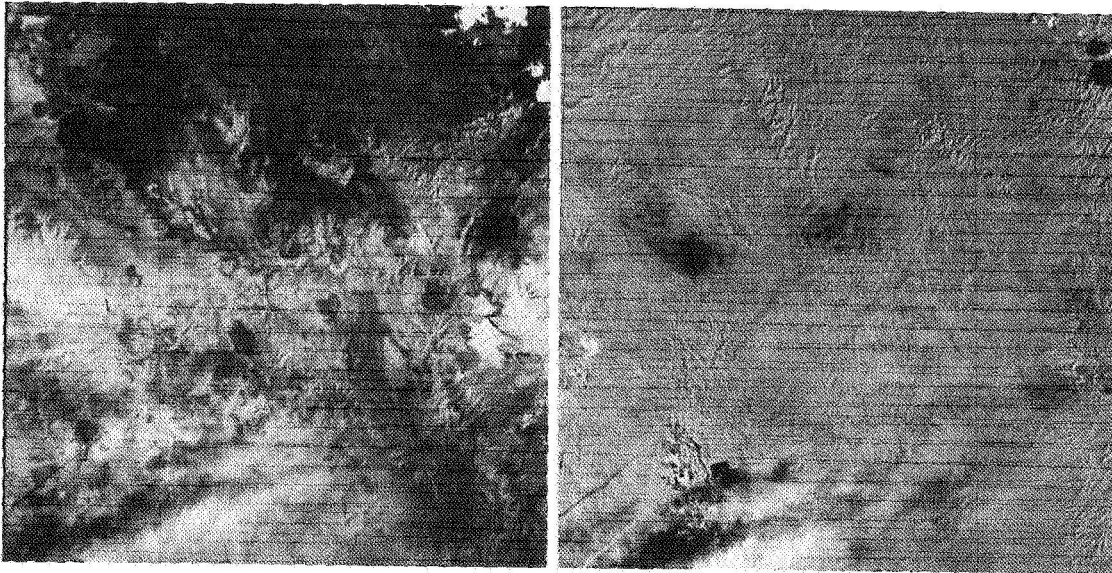each picture point.

Figure 7. After registration, picture *differencing*, temporal changes
which would otherwise require close inspection to detect *show
up clearly.*

a) Original

b) DIFFPIC, Aug. 24-Aug. 6, Red