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COMPUTER AIDED ASSESSMENT OF REVEGETATION ON SURFACE MINE LAND UTILIZING COLOR INFRARED AERIAL PHOTOGRAPHY

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I. ABSTRACT

A computer based methodology has been developed for assessing the extent of revegetation on surface mined lands utilizing digital image scanning of color infrared (CIR) aerial photography. Digital images, created from CIR photography of coal strip mines, were classified into three categories: bare soil, water and vegetation. The results of repetitive scans were compared to determine precision. Classification accuracy was established by comparing the results to known ground cover quantified by quadrat and area-metering methods of established accuracy. Results indicate that digital image analysis of CIR aerial photography is a feasible tool for measuring the extent of revegetation on surface mine land. Agreement to within 3% with ground observations for several mine sites was obtained. This methodology cannot replace all ground survey work for cover verification but it can greatly reduce the degree of subjectivity now inherent in decisions regarding the extent of revegetation on surface mined land.

II. INTRODUCTION

Re-establishment of vegetative ground cover is an important indicator of successful coal surface mine rehabilitation. Increasing strip mine activity coupled with new federal and state regulatory legislation generate the need for more efficient ways to measure and monitor revegetation activity. The goal of this research was the development of a technique that would offer a reasonable compromise, in terms of accuracy, time, expense and expertise, between manual photo interpretation and automatic machine processing strategies for assessment of the extent of vegetative ground cover on strip mined lands from remotely sensed data.

INTERACTIVE GRAY LEVEL SLICING

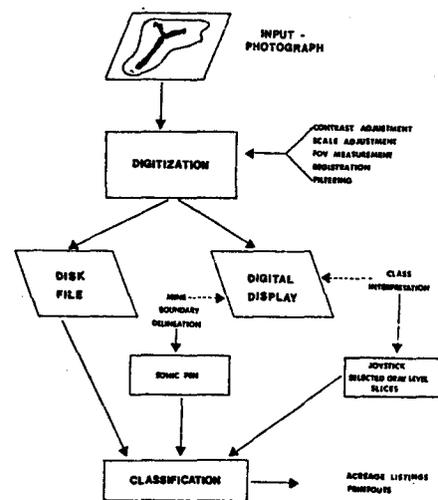


Figure 1. Interactive gray level slicing routine flow diagram.

This paper reports on the development of a computer based technique for measuring the extent of revegetation on coal strip mine sites based on digital image scanning of color infrared (CIR) aerial photography. An interactive gray level slicing method demonstrates the best overall results for classification accuracy and consistency. This approach combines the user as an interpreter of visual data and the computer as a fast data analyzer. Kodak Aerochrome Infrared Film Type 2443 in 70mm film positive format and Type 2443 9" x 9" film in positive and negative format were utilized. Film scales ranged from 1:6,000 to 1:46,000. The study was designed around the immediate monitoring needs of the Missouri Land Reclamation Commission and extensive facilities at the Image Analysis Laboratory, Bioengineering Program, University of

III. METHODS AND PROCEDURES

A. DIGITAL IMAGE GENERATION

The analysis techniques discussed in this report are based on conversion of standard Kodak Aerochrome Infrared Film 2443 aerial photographs into digital images using a television image digitizer. The effective spatial resolution of the digital images analyzed is determined by three factors: (1) the spatial resolution of the scanner; (2) the size of the field of view scanned; (3) the scale of the aerial photograph. A field of view (FOV) is established for the image scanner that allows maximum presentation of a contiguous strip mine site. The field of view is measured at the image scanner, converted to the scale of the aerial photograph and then divided by the spatial resolution of the scanner to determine the digital point size. The digital image is scanned and transferred to one of two displays for evaluation and analysis. The digital image is also stored on disk file for immediate recall and processing. The images can then be transferred from disk file to nine-track magnetic tape for long-term storage.

A digital image has two primary components: spatial digital resolution and gray level resolution. The spatial digital resolution is the matrix size of the two dimensional array of numbers that constitutes the digital image. The digi-

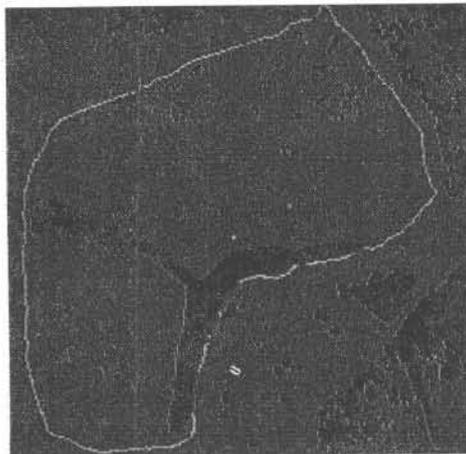


Figure 2. Digital display of gray level slice representing water (Black Areas) within mine boundary (White) at post-law site 2, Strip Mine 2.



Figure 3. Digital display of gray level slice representing vegetation (Black Areas) at post-law site 2, Strip Mine 2.

tal image is thus composed of N points on a line with M lines constituting a complete image. Taking a digital scan of 256 points (N) by 256 lines (M) over an area of photography 2 inches square (field of view) scaled at 1:2000 feet results in an effective sampling spot size of approximately 16 feet on a side. Therefore, each digital picture point (pixel) at that scale represents a true area of 256 feet.

Gray level resolution in conjunction with dynamic range is the second primary component of a digital image. Dynamic range is defined as the range of film densities that the scanner can accommodate. Low contrast images present a small dynamic range while high contrast images present a large dynamic range. The number of different levels into which the scanner can divide its maximum dynamic range is defined as the gray level resolution. These gray levels are called quantization levels and represent minimum contrast that can be detected.

A Spatial Data Model 108 Computer Eye was used to digitize all aerial photographs at a spatial resolution of 256 x 240 with a gray resolution of 256 levels. A Ramtek GX 200 Color Display was used for display of the digital image at a spatial resolution of 256 x 240 with 16 levels of color within each of three primary colors giving a maximum color range of 4096 different shades of color. A Ramtek 9051 Black and White Display was also used to attain higher spatial resolution (up to 512 x 512) for display of the digital image and interaction with the user in selecting image parameters. The Graph-Pen Model GP-3 was used in conjunction with the displays for interactive data manipu-

lation and processing. Nine track 800 bpi tape drives and disk drives were used for image storage and retrieval as well as program development and storage. The PDP-11 RSX-11M operating system and programs are primarily Fortran IV with some special purpose assembly language sub-routines.

B. TECHNIQUE EVALUATION

Three computer based techniques have been developed for assessing the extent of revegetation on strip mined land utilizing digital image scanning of CIR aerial photography. Each technique attempts to segment the digital image of a strip mine site into three classes: water, vegetation and bare soil. The techniques differ in their method of determining gray level thresholds for class separation. The three techniques have been labeled: (1) training field method, (2) automatic gray level slicing from a histogram (clustering method) and (3) interactive gray level slicing (interactive slicing method). Each technique was evaluated for precision and overall classification accuracy to determine which of the three would be best suited for routine use. Results of repetitive scans were compared to evaluate the precision of each technique. Classification accuracies were evaluated by comparing the results to known ground cover quantified by quadrat and area metering methods of established accuracy.

A 40 acre pre-law strip mine was selected as a control site for evaluation of each technique. Reference standard acreage figures were compiled for each class. Each technique was used on three different scans of the test site, each scan representing a new independent trial, since it is virtually impossible to produce identical digital images from two scans of the same aerial photograph. The three separate scans were performed at one week intervals. The original site boundary used in the compilation of the reference acreages was stored on disk and reused for each technique and scan to hold that variable constant between computer and reference standard comparisons.

The interactive slicing method proved the most viable of the three in terms of classification accuracy and precision. Classification results fell within $\pm 3\%$ of the reference standards for each class and repeated scanning yielded variations of 1% or less within each class. Although the clustering technique also produced classification results within $\pm 3\%$ of the reference standards less success was obtained in reproducing simi-

lar results. Repetitious scanning of the same area yielded variations from 2% to 5% within individual classes. Training field results were the least satisfactory with classification errors running greater than 10% for bare soil and vegetation. Results of repetitive scans were somewhat inconsistent with variation from 2% to 4% within individual classes.

The interactive slicing technique is easily adapted to both pre-and post-law mine site conditions and averages forty-five minutes for complete analysis of a mine site. The clustering routine only takes five to ten minutes but requires ideal contrast conditions to produce an accurate three category classification. The training field technique requires careful selection of training samples for the decision rule to accurately discriminate water, vegetation and bare soil. To approach the accuracies of the interactive technique would require an estimated two to three hours of analysis per mine site. Supervised training procedures are much more efficient when attempting classifications involving numerous classes where a high degree of accuracy is desired.

C. THE INTERACTIVE GRAY LEVEL SLICING TECHNIQUE

This section expands the description of the interactive gray level slicing technique and sets forth the procedure followed in performing an analysis using the technique. Figure 1 summarizes the technique in flow chart form. The thresholding routine includes man-machine interaction to quickly assign a range of gray level values to areas of water, vegetation and bare soil. Working from the digitized image displayed on the interactive display, the analyst begins the process by selecting an initial threshold value to produce a gray level slice at the lower end of the gray level scale. This corresponds to the class that appears the darkest on the displayed digital image. All picture points from 0 to the threshold cut off are set black and all others white. The analyst then visually evaluates the acceptability of a threshold for a particular class by comparing the displayed binary image with the original aerial photograph and the digitized image of the photo. Using the joystick the analyst can almost instantaneously change the threshold value until an acceptable proportion is obtained for a given class. Figures 2 and 3 show the binary image display of gray level slices representing water and vegetation for post-law site 2 at Strip Mine 2. When the gray level slices are established for each class, the site boundary is delineated with the sonic pen and a point by

point classification is performed on the entire site. A line printer printout (Figure 4) is made to present the results along with a tabulated summary of the number of picture points in each class. A scale factor is applied to translate these totals into acres. This scale factor is derived from measuring the field of view on the scanner for each mine site. The classification of the strip mine site is accomplished on a point by point basis for all points within the boundary delineated with the sonic pen. Each point was classified as water, vegetation or bare soil depending on its gray level value. The classification output was stored on disk and spooled out to the line printer which assigned selected characters to each point as a pseudo map output. Each character space represents a picture point on the image but the printout presents a scale and aspect ratio based on the mechanics of the printer. The printouts are useful for evaluation of spatial trends and overall technique performance in showing where there has been obvious misclassification. The printouts also summarize the number of picture points in each class from which acreage figures are calculated.

C. ACCOMMODATING INPUT VARIABLES

The input data for the computer based analytical process is photographic film. There are four major factors that influence the behavior of film when exposed and the character of the resultant image. These factors are: (1) film composition; (2) film handling; (3) film format; and (4) image acquisition. There are no absolute relationships between exposure of a film and the densities recorded. The ability of the analyst to group the resultant film densities (gray levels) into meaningful classes will be influenced to some degree by variables within each of the factors stated above. Only individual users can evaluate the trade-offs between costs and classification accuracy in determining the extent to which individual variables will be accommodated. In this study the priorities were placed on absolute minimizing of costs while generating an acceptable degree of overall accuracy in classification results. Within this context, some variables were accommodated to varying degrees while others were left totally uncontrolled and accepted as recognized limitations on the technique.

In considering film composition, a major variable is the wavelength composition of the exposing light. This variable was accommodated through film type selection and minimal amounts of filtering

during digitization. The emphasis on low cost ruled out the use of special multi-band film and camera packages and dictated the use of one standard readily available aerial film. Kodak Aerochrome Infrared Type 2443 was selected because it is a readily available standard product. Its sensitometric qualities provide excellent bare soil/vegetation enhancement as well as good discrimination between land and water interfaces. Also, the film is less susceptible to the influence of poor quality atmospheric conditions.

In addition to enhancing gray level separation through film type selection, better class separation can be obtained on some images using a combination of filtering and multiple scans. Specifically, a Kodak No. 25 Red Filter, commonly used in color print processing, was used for better discrimination between water and vegetation. Computer programs were developed which allow two images to be classified and then combined to give a composite classification. The image is scanned without filtering. Vegetation and bare soil are classified allowing water to fall into either of the two other classes. A subsequent scan is made using the red fil-

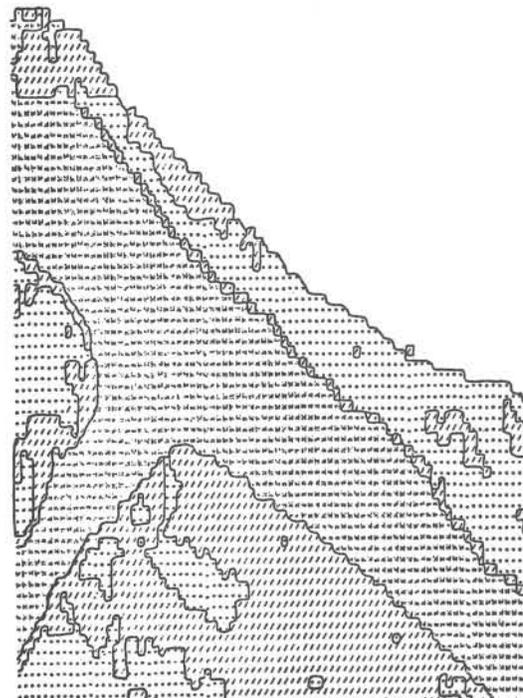


Figure 4. Line printer output upon which the individual classes have been delineated. Bare soil (.), water (W) and vegetation (/).

ter. This image is classified into water and other. The two classifications are then combined to produce a composite three category classification of water, vegetation and bare soil.

Variables introduced through film handling procedures remained basically uncontrolled. Standard storage procedures were followed prior to and after exposure. Fluctuations in recorded film densities due to variations in processing were, to some extent, handled by adjustments of scanner parameters as the film was digitized. All 70mm film utilized in the study was developed using standard processing techniques for the 2443 film type. A majority of the classification work performed with the nine inch film utilized film negatives with altered color balance to further enhance contrasts on the mine sites. This can be accomplished at no extra cost over standard development to film positive format.

The principle variables in film format are image scale, actual image size and image base. Variations in film size and scale are accommodated by magnification. By utilizing a bellows system and various lenses, the field of view can be reduced to one square inch or enlarged up to a 24 square inch size. This flexibility allows the analyst to use various scales of photography as well as film sizes. This study utilized both 70mm and 9 inch x 9 inch film sizes and contact scales of 1:6,000; 1:10,000; 1:24,000 and 1:46,000.

Variables introduced into the input data through image acquisition procedure were not accommodated. Calibrated RC-8 cameras were used for acquisition of 9 inch x 9 inch film. The 70mm camera was not calibrated. Scale fluctuations and distortions due to aircraft tilt and altitude variations went uncontrolled.

IV. RESULTS AND DISCUSSION

A. PRECISION OF ANALYSIS

Precision can be evaluated independently of accuracy and should be used to denote the consistency of a measuring system. The ability to reproduce results on the same input data is the measure of precision. A digital computer will provide the same numbers whenever it is given exactly the same input data. The techniques developed have certain inherent process variables which make it impractical to expect exactly the same numbers upon repetition. The process variables include: (1) image contrast due to scanning parameters; (2) gray level slices due to ana-

lyst interpretation; (3) noise in the image scanner; and (4) field of view measurement. Table 1 shows the evaluation of precision based on analysis performed on pre-law site 1 at Strip Mine 1.

The first two rows of the table show the precision of the reference standard. This data was used as ground truth for comparison of computer results. It is interesting to note the variation between these two results. In each case the same photo interpreter using the same technique analyzed the same mine site at two different times. There was 5% variation in the classification of bare soil and vegetation. Water was consistent. Under computer analysis #4 and 5 are the results of this same photo interpreter using the computer and the interactive gray level slicing method. There is much better consistency between these two results (1%) than between the two reference standards. While the area classified water is practically the same in all four cases the areas called bare soil and vegetation vary 4%-9%, depending on which of the reference standards we choose to call correct. The other three runs are from three different scans at three different times with the same photo interpreter-analyst as for all the rest of the computer results in this report. Note that while these numbers are not exactly the same as in analysis scan 4 and 5 there is less variation between all five of these examples than between the two reference standards. This experiment shows the possibility that the interactive slicing method is more precise, even between different analysts, than the reference standard interpretation.

B. CLASSIFICATION ACCURACY

The primary goal of computer based approach to vegetative cover assessment was to combine the accuracy of conventional photo interpretation methodologies with the speed and efficiency of machine processing. Accuracy evaluation was based on comparing the total acreage figures compiled by the computer for each class to reference standard acreages compiled by the surface observations team with techniques of established accuracy. This approach evaluates the overall accuracy of each class. It does not reflect the accuracy of the classification on a pixel by pixel basis. True scaled classification maps are required to obtain any kind of quantitative evaluation of errors. The requirements for this plotting of scaled maps was not included in this study. Table 1 can also be used to show the accuracy of the computer results to the reference standard, or ground truth. One must choose which reference to use. Choosing

TABLE 1. EVALUATION OF INTERACTIVE GRAY LEVEL THRESHOLDING, PRE-LAW SITE 1, STRIP MINE 1.

| Reference Standard | Bare Soil | | Vegetation | | Water | |
|--------------------|-----------|----|------------|----|-------|----|
| | Acres | % | Acres | % | Acres | % |
| # 1 | 18.9 | 46 | 17.6 | 43 | 4.5 | 11 |
| # 2 | 16.8 | 41 | 19.7 | 48 | 4.5 | 11 |
| Computer Analysis | | | | | | |
| Scan 1 | 20.3 | 49 | 16.3 | 40 | 4.4 | 11 |
| Scan 2 | 20.2 | 49 | 16.5 | 40 | 4.3 | 11 |
| Scan 3 | 19.7 | 48 | 17.4 | 43 | 3.9 | 9 |
| *Scan 4 | 20.9 | 51 | 16.0 | 39 | 4.1 | 10 |
| *Scan 5 | 20.5 | 50 | 16.0 | 39 | 4.5 | 11 |

Total Area = 41.0 Acres

*Analyst for #4 and #5 scans was the interpreter for reference standards #1 and #2

the first reference yields 3% or less difference between the reference and the first three trials of the first photointerpreter, and 4-5% maximum difference between the reference and the interactive slicing results for the same person who computed the reference standard. This was the first time interpreter #2 had used the computer equipment.

It is important to note that the identical aerial photographs and mine site boundaries were used in all the direct comparisons made between the computer results and the reference standard results. Table 2 lists the results for the additional evaluations of the interactive gray level slicing technique on both pre- and post-law sites at Strip Mines 1 and 2.

The evaluation results indicate that the interactive gray level slicing technique is very competitive with the area metering manual photo interpretive method despite the fact that the computer is

TABLE 2. CLASSIFICATION ACCURACY EVALUATIONS FOR ADDITIONAL PRE- AND POST-LAW SITES UTILIZING THE INTERACTIVE GRAY LEVEL SLICING TECHNIQUE.

| Mine Site 1/ | Procedure 2/ | Bare Soil | | Vegetation | | Water | | Total Area (acres) |
|--------------|--------------|--------------|-----------|--------------|-----------|--------------|-----------|--------------------|
| | | Area (acres) | Cover (%) | Area (acres) | Cover (%) | Area (acres) | Cover (%) | |
| 2-1 | Reference | 27.0 | 38 | 27.5 | 39 | 16.7 | 23 | 71.2 |
| | Computer | 29.0 | 41 | 25.4 | 36 | 16.8 | 23 | 71.2 |
| 2-2 | Reference | 49.3 | 60 | 17.4 | 21 | 16.0 | 19 | 82.7 |
| | Computer | 42.4 | 51 | 19.1 | 23 | 21.2 | 26 | 82.7 |
| 2+2 | Reference | 49.5 | 80 | 6.7 | 11 | 5.2 | 9 | 61.4 |
| | Computer | 51.5 | 83 | 5.2 | 9 | 4.7 | 8 | 61.4 |
| 2+3 | Reference | 36.2 | 59 | 17.2 | 28 | 8.3 | 13 | 61.7 |
| | Computer | 31.6 | 51 | 23.0 | 37 | 7.1 | 12 | 61.7 |
| 1+2 (May) | Reference | 9.6 | 23 | 22.8 | 56 | 8.8 | 21 | 41.1 |
| | Computer | 11.1 | 27 | 23.2 | 56 | 6.8 | 17 | 41.1 |
| 1+2 (July) | Reference | 4.7 | 11 | 28.0 | 69 | 8.4 | 20 | 41.1 |
| | Computer | 4.9 | 12 | 28.6 | 70 | 7.6 | 18 | 41.1 |

1/ Strip Mine 1 or 2, site 1 or 2, pre-law (-), post-law (+).

2/ Reference acreages compiled by conventional photo interpretation and computer analysis by interactive gray level slicing.

working from a disadvantage in terms of effective spatial resolution. In general, the computer based approach cannot accurately measure objects less than two times the effective resolution and the preferred ratio is 5:1. The reference standard maps were compiled at a resolution (minimum mapping size) of .5m². In contrast, the effective spatial resolutions of the digitized images were always five to ten times the area metering resolution. Yet the computer technique produced comparable results.

V. CONCLUSIONS

Digital image processing of CIR aerial photography can be effectively utilized in the classification of pre and post reclamation law strip mine sites into three basic categories: vegetation, bare soil and water. Spatial estimates of each class can be compiled quickly and accurately. The methodology was developed exclusively for measuring the areal extent of ground cover on surface mines. This method cannot replace all ground survey work nor can it compete with more sophisticated monitoring schemes that use machine processed aircraft scanner data or conventional aerial photo interpretation methodologies and produce more detailed land cover classifications. However, our approach offers a substantial savings in time and money to persons who must make policy decisions based on the degree of successful revegetation in surface mines. A computerized interpretation of one contiguous mine site requires approximately 45 minutes, whereas traditional surface observations or photo interpretive methods may take anywhere from 4 to 20 hours to inventory the same mine site.

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