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TECHNICAL REPORT

March 1, 1994 through May 31, 1994

**Project Title: CHARACTERIZATION OF COAL PARTICLES
USING RULE BASE ON-LINE IMAGE ANALYSIS**

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ABSTRACT

In the past, an in-depth database of the light reflectance characteristics of different materials in coal has been established. This process is still being continued to extend the database of coal images. Based on the grey level database of the ultrafine coal particles under microscope, a C-language computer program has been developed. This program reads an image and analyzes it according to the database and decision-making criteria developed for differentiating coal particles. The earlier version of this computer program tends to account for more particles than what are presented in an image. This is attributed to the electronic noise produced through the CCD camera. The electronic noises are in the order of one or two pixels and have been rectified through an additional decision-making rule embedded in a newer version of the image analysis computer program. This is by recognizing that a particle of one to two microns size is very unlikely to be in the form of inertinite and vitrinite. Therefore, the particles of one to two microns size fall in these two maceral group will be disregarded. In general, this computer program picked up the particles without any intervention from an operator. In other words, this computer can replace an operator to perform the analysis of ultrafine coal particles. Another computer program is currently being developed in order to be implemented into a mechanism for controlling the auto focusing mechanism of a microscope system. This computer program will be based upon the knowledge base regarding the image characteristics of the focused and unfocused image. Specifically, the shift in grey level histogram as well the edge characteristics of during the focusing of coal particles

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EXECUTIVE SUMMARY

To obtain the ultraclean fuel, coal must be pulverized into particles of ultrafine sizes. As a result, the characterization of ground coal, in particular, the assessment of pyrite liberation, becomes extremely difficult. The assessment of pyrite liberation is the most important way of determining whether a batch of ground coal obtained through a grinding process is acceptable. At present, the liberation analysis is conducted manually through a microscope with commercial image analysis software. Sometimes, this procedure causes discrepancies from one operator to the other in the interpret of microscopic images. On the other hand, the amount of coal can be inspected in each experiment is limited by the particle sizes of the ultrafine coal and the magnification factor of the microscope. Therefore, a large number of samples must be analyzed in order to assess the degree of pyrite liberation. This makes the present method of liberation analysis of coal a very labor intensive and a very time consuming process. In light of that, an automation procedure based on the principles of image processing is being developed to perform the analysis of pyrite/minerals liberation of coal.

Different materials reflect light in different manners and therefore can be identified based on their image of light reflectance characteristics (i.e. shade of gray). Furthermore, liberated and nonliberated pyrite particles are surrounded by media of different shades of gray. With these two pieces of information, the degree of pyrite liberation can be analyzed through a microcomputer. To make the automated image analysis system possible, an expert knowledge base and a rule base decision mechanism utilizing the light reflectance characteristics of different constituents of coal (pyrites, vitrinite, inertinite, etc.) must be established. This will include the consideration of the effect of the actual operating parameters such as inclined incident of light, uneven focal planes of the sample. It is believed that such an automation process for image analysis of coal particles is very feasible in the laboratory operation involving polished pellet. Recently, the laboratory studies conducted at SIUC have demonstrated that pyrite analysis can be accomplished in a matter of less than one minute rather than a few hours if conducted manually. However, in this evaluation process, the light reflectance characteristics of pyrite was predetermined manually used as an input into the image analysis program.

It should be pointed out the automation in the recognition of coal particles requires a wide spectrum of

optical images of ground coal. Specifically, one should realize that every microscopic image (through an optical microscope) of ground coal exhibits distinct characteristics. This is due to the fact that the distribution of coal particles is different from one frame to another. As a result, the image features such as the average gray level of pyrites, the particles size distribution of each maceral, the material composition etc. are unique for each frame. Under such a circumstance, assessment of pyrite liberation using image analysis with one optical feature (e.g. a fixed value of gray level for pyrite) will be insufficient. Rather, a set of rules simultaneously evaluating the distinct optical and physical characteristics of coal particles (including pyrites) must be established. Recent research results at Southern Illinois University at Carbondale (SIUC) have led to development of several criteria for analyzing images of coal with different characteristics. Undoubtedly, an extensive characterization of coal images is still needed in order to develop a broad expert knowledge base about coal particles.

In addition to the development of a rule base image analysis program, a complete on-line coal characterization system must include the mechanisms for the transport of samples to a stage for measurement. To be more specific, in order to bring the coal sample pellets under an image analysis device (e.g. optical microscope), a conveyer system allowing for an in-plane travel is needed. In addition, a mechanism to bring the specimen into the focal plane of the microscope should be implemented. With today's technology in the digital I/O system, the procedure for motion control of the conveyer and staging system can be interfaced with a computer. As a matter of fact, the development of a computer controlled X-Y table has been completed and tested successfully. The work ahead will be the development and design of an interactive image focus scheme. In other words, the step for bringing an image into focus will be accomplished by the computer instead of by human operator. In this regard, an image analysis technique is necessary for the sensing and adjustment of optical depth of the test sample. Ultimately, it is believed that the procedure for characterization of coal such as pyrite liberation analysis can be fully implemented through a computer from the initial sample preparation to the final image analysis.

The completion of the studies outlined in the previous sections will bring the following advantages:

1. Improves the current coal characterization technology, in particularly, the assessment of pyrite liberation.

2. Greatly reduces the time and effort in performing liberation analysis. The new image analysis procedure developed in this research will provide faster and more accurate pyrite liberation analysis.
3. Provides a realistic assessment of a coal characterization process as a part of the coal cleaning and preparation processes.
4. Offers potentials for the commercialization of research results such as image analysis program for coal particles and design of the on-line system.

Currently, the measurement of the light reflectance characteristics of different materials in coal is still being continued in order to extend the database of coal images. A C-language based image analysis computer program has been completely developed. This program contains the database of ultrafine coal particles and the decision-making criteria established in the previous study. This program is designed to analyze the images directly obtained from the CCD camera. In addition, during this past quarter, the following tasks have been conducted,

- a. The evaluation of the decision-making algorithms of the image analysis program versus the results obtained through an human operator has been obtained.
- b. The development of a users friendly manual for the image analysis computer program.
- c. The development of the computer program for the auto-focus mechanism of the long distance optical microscope stage.

OBJECTIVES

The overall objectives of this project are:

1. To continue the development of a rule base automated image analysis computer program for assessment of pyrite liberation, and
2. To upgrade the image analysis system into an integrated package.

These two phases will be conducted simultaneously. In the laboratory scale, the specimens to be analyzed will be under somewhat ideal conditions. However, the image analysis computer algorithm to be developed in this stage is essentially the foundation for any rule base coal characterization procedure. In addition, the completion of the first goal will represent a drastic improvement of the current technology in the coal characterization such as liberation assessment. For the integrated system, we will attempt to emulate the automated image analysis into a part of the overall coal cleaning process. Under this constraint, a conveyor system as well as an auto-focusing mechanism will be designed and built.

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INTRODUCTION AND BACKGROUND

Needs for the Evaluation of Ultrafine Coal

The coal industries, today, are facing with a very stringent requirement on the emission and/or release of sulfuric compound to the living environment set forth by Environmental Protection Agency (EPA). As a result, the need for producing ultra-clean coal effectively (Yen and Hippo 1990) has greatly increased. It has been reported by McCartney (1969) and Jao (1991) that for the Illinois #6 coal the mean particle size of pyrite is less than 10 micron. Therefore, from the viewpoint of statistics, coal must be ground to ultrafine sizes in order to liberate the microscopically dispersed pyrite particles and to obtain the clean coal that meets the EPA requirements. The development of the procedure for effectively producing ultrafine coal is a difficult task and has been pursued by many researchers. On the other hand, to evaluate the degree of success of each of the newly developed coal pulverization procedures, a method for examining the ultrafine coal is needed. The traditional method (ASTM, 1973) for evaluation of coal fines is a two step approach. First of all, ground coal is subjected to centrifuge in heavy media for the separation of fraction with different specific gravities. Secondly, each fraction of a given specific gravity is then subjected to TGA for element analysis or SEM for the microscopic observation. However, these steps are quite time consuming and labor intensive. For example, the drying process after the centrifuge usually takes a few hours while the SEM inspection requires a tedious sample preparation. Clearly, the liberation analysis procedures recommended by ASTM is not suitable for the high volume ultrafine coal production which requires a quick analysis of coal particles. In our view, an effective characterization procedure for analyzing pyrite/mineral liberation should require a minimal specimen preparation. The actual measurement of ground coal particles should be conducted by taking the advantage of high speed data processing of computer. This is to ensure that a large number of samples can be accounted for whereby the liberation assessment will be statistically meaningful and will be accomplished in a very short time. Ultimately, a high magnification device (such as optical microscope) is needed to examine the ultrafine coal particles. To develop into an on-line quality assurance mechanism, the sample preparation, sample inspection, and liberation analysis must be integrated into an automated mechanism. It is believed that the recent development of image analysis technique and long distance microscope may make such an integrated system possible.

Optical Microscopic Image Analysis

Image analysis (Dawson 1987, Gonzales et al 1987) is a relatively new technique that is being applied to scientific and engineering research. Basically, image analysis is used to determine the optical characteristics (e.g. intensity of light reflectance) of objects. This is then followed by a logical assessment of the measured data and a comprehensive numerical calculation.

Typically, an optical microscopic image analysis system consists of a microscope, a CCD camera, a monitor, and a personal computer equipped with a data acquisition board (frame grabber). The microscope is to provide a proper image for observation, the video camera along with the data acquisition board are to record the various optical characteristics of different objects, and finally computer software is used to analyze data in order to distinguish different materials, and particle sizes. When an object is presented under a microscope several of its characteristics such as shades of gray, physical dimensions (length, width, area), shape, boundaries, texture are noticeable. Most of these characteristics, in general, are distinct among different objects. In the image analysis, an image is divided by a set of horizontal and vertical grids (or pixels). Within each grid area, optical characteristics are electronically recorded and analyzed through a computer system. Also, using a proper calibration procedure, the actual area represent by a group of grids can be calculated. Such an analysis procedure is referred to as the optical microscopic image analysis.

Recently, the utilization of optical microscope with the Automated Image Analysis (AIA) has resolved some problems involving the visual interpretation of the objects at microscopic levels. For example, AIA has been applied successfully by Yen et al (1991) to determine the fiber angle orientation and fiber volume ratio of composite materials, and by Huggins et al (1982), Straszheim and Markuszewski (1985 and 1986) to analyze the particle size distribution of ultrafine coal, to identify different minerals and macerals in coal and to assess the pyrite liberation after coal grinding. This is primarily based on the principle that, in general, different materials have different light reflectance. Such characteristics appear as different shades of gray (or colors) under the video camera observation and can be distinguished and analyzed through computer programs.

Current Application of AIA to Liberation Studies

At present, for pyrite liberation analysis (Yen and Hippo 1990, Blankenship 1991, Jao 1991), a pellet is prepared

by mounting samples of ground coal in epoxy resin. This pellet is subjected to several steps of polishing. The polished pellet was then brought to an optical microscope for examination and analysis using a commercial image analysis software. This software can only perform a limited number non-sequential routines in image enhancement and image analysis such as picture sharpening, and area counting. In other words, a sequential logical analysis of pyrites with different surroundings (i.e. liberated and nonliberated) is beyond the capacity of this computer program. Therefore, an interaction between operator and the computer program is necessary make a single measurement.

After the image of the desired area of the sample is adjusted for better human interpretation, a threshold gray level value is set for the pyrite particles. The operator records the area of the pyrite particles, their total number on the examined frame and the total area. Then, based on visual inspection, the person has to decide whether or not the pyrite particle is free and label it accordingly. This process is repeated until at least a total of about 200 pyrite particles are analyzed (Florek, 1991). Obviously, this procedure was laborious and time consuming. Even visual inspection is a rather daunting task and the operator is always doubtful as to whether or not the pyrite particle is free. In addition to these problems, due to the extreme brightness of the pyrite particles, the pixels in their neighborhood acquire a glow that makes it all the more difficult to establish the properties of the surroundings. Therefore, the results varied, depending on the decision made by different operators.

The most challenging task in making image analysis into an automated process is image segmentation, wherein, the classification of image regions into different objects. This is primarily because of the complexity of the image and the contrast variations in the particular video camera setting and in the light source of the object. For this purpose, numerous images of a sample must be analyze to determine their distribution of shades of gray (i.e. histograms), pixel values along a line, etc. These information are then used to establish an expert knowledge database regarding the relative gray levels of different macerals in coal. This is followed by a decision making through a rule base artificial intelligent (Batchelor 1974, Pavlidis 1977) to detect the liberation of each individual particle.

Development of the Rule Base for Image Analysis of Coal

In analyzing a typical gray level image, one usually determines the pixel distribution of different gray

levels (this is referred to as the histogram). During the inspection of ground coal particles, it is possible that the use of histogram may provide the information leading to the pyrite liberation analysis. This is because that different materials in coal appear to have distinct gray levels when a coal image is viewed through the computer monitor. In general, the distinction in gray levels may be interpolated as (a) a gray level with zero pixel in a histogram represents the division between two types of maceral, or (b) the difference in gray level between macerals is greater than that of within the same maceral. In other words, there should be a distinct boundary between pyrites to inertinite and inertinite to vitrinite. Clearly, the images with different composition of particles will result in histograms of distinct characteristics. This suggests that analysis of coal images must be conducted on an individual frame basis.

Theoretically, there should be only four gray levels (or ranges of gray level) with zero pixel in an image. This will naturally divide the ground coal into voids/boundaries (in black), epoxy background, vitrinite, inertinite, and pyrite. However, the data extract from the histogram of several coal images have shown many gray levels with zero pixel. This will definitely bring confusing in the determination of boundaries between different macerals. On the other hand, since pyrite is the brightest among all the particles in an image, development of an computer algorithm searching for the upper gray scales of zero pixel may be worthy.

To further study the optical characteristics of ground coal, an gray level averaging technique was introduced (Yen and Chu, 1993). In general, in a particle there exists a distribution of (perhaps, continuous) gray levels. One can identify a particle much easier by using its average gray level. In addition, it was found that using the gray level averaging technique particles of the same kind (e.g. vitrinite, inertinite, pyrite) tend to group closer in their gray values. In other words, the relative distance in gray level between vitrinite to inertinite and inertinite to pyrite becomes larger. As a result, the distinction among pyrite, inertinite, and vitrinite using the average gray value approach is possible. More importantly, it was found that, for most of the images studied, the gray level spreads between vitrinite to inertinite (ΔG_1) and inertinite to pyrite (ΔG_2) tend to be the two largest values among the difference in gray level between two particles with adjacent light reflectance. In this regard, the particles that define the two largest differences in gray level are those which define the lowest gray level for

pyrites, the highest and the lowest gray levels for inertinite, and the highest gray level for vitrinite. Furthermore, it was found that ΔG_1 usually greater than ΔG_2 .

Several special cases that do not fit the descriptions given in the previous paragraph have also been identified. For example, it is likely to have an image without the presence of pyrites and/or vitrinite. Also, it is possible that the particles involved in obtaining the first two largest gray level difference (i.e. ΔG_1 and ΔG_2) are not the particles define the boundaries between vitrinite to inertinite and inertinite to pyrite. To resolve these cases, it is necessary to investigate the spread in gray level of each individual maceral and mineral, the shape factor and size of each particle, the location where ΔG_1 and ΔG_2 were calculated, etc. Each distinct case of gray level characteristics of an image will then become a case of the overall expert data base for decision making algorithm. Undoubtedly, extensive laboratory characterization of coal samples is necessary to build into a broad data base.

Integrated On-line Image Analysis Stage

It is believed that the automated image analysis system proposed here can be used as a part of the coal cleaning process. The automated image analysis system can be used at the down stream of the liberation process and/or the separation process. Based on this concept, there will be a mechanism to collect coal samples from the cleaning process, a process for sample preparation, a conveyer system to transport coal samples into the inspection station, a mechanism to bring the test sample into the focal plane of the image instrument, and finally the computer program for the characterization of the liberation status. All these subsystems can be integrated into a single interactive feedback and control package. This integrated system emulates the quality inspection process used in the manufacturing industry. However, the computer programming and data acquisition in this proposed feedback/control system is far more complicated.

Two components of the on-line system have been put together. An X-Y table consists of two stepping motors with platform and a computer interface system have been received. The table has a stepping capability of 0.0025 in. with a resolution of 0.0001 in.. A C-language based computer program was developed to manipulate the motion of the X-Y table. It should be pointed out that this system control program can be integrated as a part of the image analysis program. In the envisioned process, this

table will bring coal samples to a position under the viewing path of a long distance video imaging system through the computer algorithm. Next, a z-axis motion has to be introduced to provide an automation mechanism in focusing. This will require an elaborated programming in pattern recognition as well as depth detection through an image correlation.

A long distance imaging system was also integrated during this quarter. This system consists of a long distance microscope (up to 660x), a color CCD video camera, a color frame grabber, and a 486 computer. The light source of the long distance imaging system is provided through a fiber optic ring light attached with the long distance microscope. The minimum working distance of the long distance microscope is 10 mm. It is necessary to calibrate the long distance imaging system so that an optimal working distance for observing coal pellet is obtained.

EXPERIMENTAL PROCEDURES

Task 1: Sample preparation

Ultrafine coal (Illinois #6 coal) samples that have different degree of liberation will be used in this study. These samples were prepared through a previous CRSC/DOE project and are available at the Civil Engineering and Mechanics Department, Southern Illinois University. Both pelletized and particulate coal samples are needed. To prepare the pellet sample, ultrafine coal particles will be mixed with epoxy resin and cast into a plastic cylinder. Upon cured, the circular surfaces of the pellet will be subjected to several steps of polishing until they are mirror like. To prepare the non-pelletized sample, ultrafine coal particles will be spread on a thin glass plate. A light brushing will be applied to minimize the overlapping of coal particles. Finally, a second glass plate will be used to clamp the coal particles in place.

Task 2: Determine the Image Characteristics of Pyrite and Coal Macerals

In this task, the expert knowledge base regarding the image characteristics of each coal constituents such as pyrite and vitrinite are to be developed. Normally, the light reflectance of each material in coal will have a band width of shades of gray. However, the gray levels of a material can shift under different light sources. Therefore, it is necessary to determine the gray levels of each material in coal as well as to determine its relative difference in gray levels with other macerals/minerals. Sometimes, in a random sample, the gray level data may not be sufficient to differentiate one material from the other. In this case, particle characteristics such as shape factor (length to width ratio), particle size, surface texture will then be useful in assisting decision making. Therefore, in this task, we will attempt to measure as many image features as possible for pyrite, minerals, macerals in coal. The image analysis will be primarily conducted using a commercial image analysis software. In the meantime, we will develop an image analysis computer program of the similar capacity.

Task 3: Development of a Rule Base Liberation Criterion

So far, there is no commercial software which can do liberation analysis without the intervention of an operator. In this project, a computer program (to be added on the one being developed under an ICCI grant) will be developed to perform pyrite liberation assessment as well as the analysis of coal particles. It is known that a liberated pyrite particle will be surrounded by the epoxy matrix of the pellet rather than the coal. As a result, base on the analysis of the gray level of the

material surrounding to a pyrite particle. The status of liberation may be determined. On the other hand, the liberation status can also be determined based on the difference in gray between a particle and its surrounding. Ultimately, the variation of gray levels of an image containing the liberated and nonliberated particles can be modeled by Fourier series. Based on this mathematical model, the characteristics of the functional changes for liberated particle can be established. In this proposed study, the liberation criteria based on the gray levels of the surrounding to the pyrite particles will be developed into a computer program. Also, the distinct features of different image frame will be documented and will be implemented into the criteria for coal characterization. This program will take an image (in terms of a computer file) and perform the liberation analysis. Interactive computer graphics will be developed and used to show the image with the results of the liberation analysis. The computer program developed in Task 2 will be combined with the computer program developed in this Task to form an integrated interactive image analysis software.

Task 4: Verification Study

It is believed that the image analysis program to be developed here is capable of performing fast and accurate liberation analysis. To verify this, pyrite liberation data and the kinematics of ultrafine coal particles that obtained from the elaborated analysis through human operators will be used to compare with the results obtain from the image analysis program developed based Tasks 2 and 3. Extensive liberation data as well as particle size distribution of ground coal that established by Yen and Hippo (1990a) will be used as a reference.

Task 5: Design of an On-line System

In our view, the automated image analysis at its ultimate application should be built in as a part of the coal cleaning process. The automated image analysis system can be used at the down stream of the liberation process and/or the separation process. Thus far, the plan for this proposed on-line system has been developed. The following steps are to build and to calibrate the conveyer system (X-Y table) and the automation in specimen focusing (Z-axis). For example, a vertical motion mechanism will have to be added to the existing X-Y table. The computer program for the motion control of X-Y table as well as focusing in Z-axis must be developed. In particular, the fine tuning in the focusing step must interact with the attached imaging system equipped with an image correlation program (to be developed). It should be pointed out that the focusing of the test specimen may be substituted by a feedback mechanism between operator and the computer.

RESULTS AND DISCUSSION

A C-language based image analysis computer program has been developed. This program contains the database of ultrafine coal particles and the decision-making criteria established in the previous study. In general, it is believed that the image analysis computer program contains all the necessary options that we envisioned. The major emphasis, at present, is to compare the data obtained through an operator against the results obtained from the image analysis computer program.

It should be emphasized again that this image analysis computer program is designed to carry out the image analysis routines automatically once an image file is given. This will allow for a teach-and-learn process leading to the modification of the decision-making criteria of the image analysis computer program. Previously, the image analysis program could pick-up small particles at 1 pixel resolution. Knowing the fact that only the pyrite particles can have a particle size as small as one pixel in an image, any particles that have a size of 1 to 2 pixel and a gray level well below that of pyrite must be the noise received by the image equipment (i.e. the CCD camera and the image acquisition board). Taking this into consideration, a newer version of the image analysis computer program that ignores smaller particles for inertinite and vitrinite was developed. In addition, this computer also contains a module to terminate the particle search mechanism when the average grey level of the entire image has been detected. It should be pointed out that in a coal image the average grey level always falls below the grey level of vitrinite. Therefore, it is not necessary to search for any additional particle when the average grey level is detected.

The development of the auto-focus mechanisms of the automated long distance optical microscope are still being continued. The characteristics of the images that depart slightly from the actual focal plane are being studied. Specifically, this will require an understanding of the image blur (distribution of gray level) and edge detection characteristics of a slightly unfocused image.

The auto focusing system will make use of a computer controlled motorized vertical positioning system. This will move the coal sample up and down to assess the degree of focus based on a rule based algorithm. After finding the optimal focus position, the main program will then acquire the focused image for pyrite liberation assessment status.

Seven sets of eleven images have been acquired from the AIA imaging system where the epoxy pellet coal sample is placed on the microscope stand and the image is manually focused. Five images were taken above and below the focused image position in small increments such that the image becomes blurry. These images were used as a database to investigate different algorithms for the auto focusing system and were converted to the TIFF image format to be accessed by the algorithm as such. The language used to generate the program to control this system will be C language and will become a subroutine of an automated image analysis computer program. This program is written in C language using the Microsoft C version 7.0 compiler. The C-compiler is able to directly access the frame grabber subroutines that control the image acquisition board in the microcomputer for the image acquisition system.

Image processing techniques were employed to develop two auto focusing algorithms. They were based on the standard deviation of the image histogram and edge detection of the center of the image. The standard deviation algorithm program opens the image file and counts the number of pixels per grey level for the entire image (histogram). Since, the more jagged the histogram the sharper (more in focus) the image is. The average of the last 8, 16, and 32 grey levels are calculated for the determination of spikes at the end of the histogram. Using a rule based system, this algorithm looks at the average of the last grey levels in the histogram and if the average of the last 16 grey levels is below 10, the algorithm looks at the standard deviation of the histogram. It then calculates the standard deviation of the histogram to determine the difference in peaks. Based on the result of this algorithm the program will determine the degree of focus for this image in comparison to the other images in the series and determine the best focused image.

The edge detection algorithm program opens an image file of a series, and accesses the middle 10 lines of the image. The middle of the image is chosen so that when the sample is raised and lowered, very few features will change. It finds the absolute difference for each pixel in the 10 lines with its right and bottom neighbors and adds the value to the previous value of the differences such that the function is

$$f = \sum \text{ABS}(P-5) + \sum \text{ABS}(P-7) \quad (1)$$

Where P is the pixel of interest, 5 is the right neighbor, and 7 is the bottom neighbor (see Figure 1).

Using the results of the summation, the algorithm will determine the degree of focus for this image in comparison to the other images in the series and determine the best focused image.

1	2	3
8	P	4
7	6	5

Figure 1 8 neighbors to a pixel of interest.

Figures 2 and 3 give the examples of the characteristics of unfocused and focused coal image. The analysis of the pixel count for the last 32 grey levels for both images is given in Figure 4. The grey level counts of the two images showed a slight shift. In general, the pixel count at the grey level for pyrite increased when an image is in focus. However, the standard deviation algorithm did not work as effective as was expected for the series of coal images obtained from the AIA system. The observed changes in the histogram between focused and unfocused images did not provide a conclusive evidence for developing into a rule base. This is may be due to the compensation the AIA camera for very dark or very light images. This compensation shifts the histogram and compresses the top and bottom grey levels thus, affecting the count of the last 8, 16, and 32 grey levels. Also with the absence of pyrite particles, this approach becomes nullified. The shift also affected the standard deviation of the histogram since as the camera moved farther away from the sample, more area of the sample entered the image outskirts. These new features in the image caused a shift in the histogram, thus, altering the correlation between images of different focusing status.

The edge detection algorithm did work on the series of images except where the distance out of focus become large. It was found that within a range of small distance above or below the focused position, the image still seemed to be well focused by standards of the human eye. Currently this algorithm is being implemented into the development of the auto focusing system.

Figure 2 Unfocused coal image.

Figure 3 Focused coal image.

Histogram of Last 32 Grey Levels

Figure 4 The histogram of unfocused and focused images.

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PROJECT MANAGEMENT REPORT
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Rule Base On-Line Image Analysis**

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ICCI Project Number: 93-1/6.2B-1P
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COMMENTS

Projected and Estimated Expenditures by Quarter

Quarter*	Types of Cost	Direct Labor	Fringe Benefits	Materials & Supplies	Travel	Major Equipment	Other Direct Costs	Indirect Costs	Total
Sept. 1, 1993 to Nov. 30, 1993	Projected	11,566	1,463	475	467	3,000	750	1,772	19,493
	Estimated	5,400	0	800	0	0	700	500	7,400
Sept. 1, 1993 to Feb. 28, 1994	Projected	18,132	1,463	950	934	3,000	1,500	2,598	28,577
	Estimated	8,349	0	1,550	400	1,000	1,342	1,152	12,784
Sept. 1, 1993 to May 31, 1994	Projected	24,698	1,463	1,425	1,401	3,000	2,250	3,424	37,661
	Estimated	22,838	435	1,900	690	1,500	1,605	1,800	30,768
Sept. 1, 1993 to Aug. 31, 1994	Projected	53,910	5,939	1,900	2,000	3,000	3,000	6,975	76,724
	Estimated								

*Cumulative by Quarter

COSTS BY QUARTER**Characterization of Coal Particles Using Rule Base On-Line
Image Analysis**

Cumulative \$
(thousands)

O = Projected Expenditures -----

Δ = Estimated Actual Expenditures _____

Total Illinois Clean Coal Institute Award \$76,724

SCHEDULE OF PROJECT MILESTONES

Milestones:

- A. Sample preparation (Task 1).
- B. Determine the image characteristics of pyrite and coal macerals (Task 2).
- C. Development of a rule base liberation criterion (Task 3).
- D. Verification study (Task 4).
- E. Design of an on-line system (Task 5).
- F. Reporting.

DATE

FILMED

10/6/94

END