A Real Time Coal Content Ore Grade (C²OG) Sensor

Third Quarter Technical Report

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Abstract

This third quarterly technical report discusses the progress made on a machine vision technique for determining coal content and ore grades. The work done this quarter has utilized a miniature imaging spectrometer. Procedures to collect and process the spectral and spatial data from the imaging spectrometer have been established, and software routines have been employed to use this data to differentiate sulfides from background rock in platinum/palladium core samples. These sulfides are indicator minerals for high-grade platinum/palladium ore. Mappings of the sulfides generated with this procedure have been quite accurate. Samples of coal have also been obtained and preliminary measurements with the imaging spectrometer have been made.

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1. Introduction.

The purpose of this effort is to develop a machine vision system for visual coal and/or ore grade evaluation. In many instances, trained eyes can evaluate coal and ore, often by utilizing the distinctive colors of small particles within the sample. To mimic this capability, a machine vision system with good spatial resolution and good spectral resolution is being developed.

During the third quarter, an imaging spectrometer has been used to collect the high-spatial and high-spectral resolution data necessary to identify distinctive colors of small regions within the coal or ore sample. Software algorithms were then used to generate mappings of specific colors that are characteristic of important indicator minerals within the sample. This provides a quantitative measure of the indicator minerals evident on the surface of the sample. Much of the work done during this quarter resulted in a Masters thesis for Mr. Brock Bolin.[1]

As discussed in more detail below, measurements taken with the imaging spectrometer have yielded convincing mappings of sulfides in platinum/palladium ore samples from the Stillwater Mine in south-central Montana. Measurements on coal samples have recently been taken, but the ability to use this data to distinguish between coal samples has not yet been determined.

The technical portion of the report below is organized into subsections as dictated by the DoE contract for this effort. These sections are: Experimental Apparatus, Experimental and Operating Data, Data Reduction, and Hypothesis and Conclusions. Partners in this effort are: Montana Tech of the University of Montana, Stillwater Mining Co., Western Syncoal, and the Montana Board of Research and Commercialization.

EXPERIMENTAL

2. Experimental Apparatus.

The experimental apparatus used during the third quarter relies on an imaging spectrometer, also known as a hyperspectral camera. This imaging spectrometer was described in the second quarterly report. The imaging spectrometer utilizes a standard, two-dimensional camera with one dimension devoted to spectral data and the other to spatial data. To obtain two dimensions of spatial data, a scanning system is required. For the data shown in this report, the scanning was accomplished by placing the samples on a stepper motor driven translation stage to move the sample while multiple images were taken with the camera. The experimental apparatus is shown in Figure 1.

Figure 1. Pictures of the experimental apparatus. The imaging spectrometer is mounted on a pole system above a stepper motor driven translation stage. The sample is placed on the translation stage for scanning. This apparatus is located at Montana Tech.

The raw images taken by the imaging spectrometer are transferred to a computer, where the data is arranged into a “data cube.” Once this is accomplished, commercially available software was used to generate classification maps, as are shown below.

3. Experimental and Operating Data.

The data cube effectively allows one to look at 320 images of the same object, with each picture “seeing” a slightly different color. Examples of this are shown in several images on the following page. Each image shows the same object “seen” at a different color. Note that different features stand out at different colors, as one would expect.

Although the images on the following page clearly demonstrate how individual images at specific spectral channels (colors) allow one to see different features clearly, in practice, one may need to consider multiple spectral channels to pick out a feature of interest. This is a task for which computers are ideally suited. Software developed primarily for remote sensing applications from satellites and high-altitude aircraft accomplishes this task. Classification maps generated using this software are presented in section 4 of this report.

The images shown along the left-hand side of this page are all of the same section of platinum/palladium ore. The bright pattern in the upper right-hand side of the second image from the top is due to a collection of sulfide minerals within the sample. This pattern can be picked out in the top image, but not as clearly. In the fourth image down, the sulfides appear dark in color whereas they can hardly be picked out at all in the third and fifth images from the top of the page.

Because the complete spectral information is collected for each pixel of the image, one can use this technology to classify objects based on very small regions within the sample. This is useful for mining applications that exhibit spectrally distinct indicator minerals within the ore that would not be differentiated with an average spectrum of the entire sample.

A color image of the sample is shown in the image to the right. Note the distinctive gold color of the sulfides.

Figure 2. Five pictures of a platinum/palladium ore sample, each taken at a different wavelength are shown to the left. A color image of this sample is shown to the right. Note that different features stand out at different wavelengths.

RESULTS AND DISCUSSION

4. Data Reduction.

Currently, Stillwater Mine uses sulfide minerals as indicators of high-grade ore, the larger the percentage of sulfides, the better the ore. An obvious limitation of the imaging spectrometer is that only the surface of a sample can be used, whereas the actual grade of the ore is a bulk property. However, for real-time assessment of ore grades, the presence of sulfides on the surface is believed to be a reasonable indicator of ore grade, and mining geologists currently use visual assessments on the sulfide concentration to make mining decisions in the Stillwater Mine.

Consequently, a central goal of this effort is to obtain accurate mappings of the sulfides on the surface of samples. As noted above, this is done using commercial software developed for remote sensing applications. Several examples of this mapping are shown in the following pictures. Color images are shown above, and the sulfide mapping for these images are shown below in Figures 3 and 4.

Figure 3. The upper two images show color images of ore samples. The gold color indicates sulfides. The lower two images are sulfide mappings of these images generated from data taken with the imaging spectrometer. White indicates sulfides. Note that the mappings pick out sulfides we miss visually, but there are also sulfides that appear to be missed by the algorithm.

Figure 4. Additional images and classification maps. Note that the algorithm picks out sulfides even when they have different shadings and brightness. The ability to do this is crucial for a real-world device.

CONCLUSION

5. Hypothesis and Conclusions.

The image processing results from the imaging spectrometer and remote sensing software clearly demonstrate that quite accurate, quantitative mappings of sulfides can be obtained using the technique developed for this effort. Although the amount of sulfide is currently used for on-the-fly classification, the correlation of the actual ore grade as measured by assays to the amount of sulfide on the surface is not accurately known. Due to the random nature of the sulfide distribution as well as the distribution of the desired minerals within the ore, one would not expect a perfect correlation. Consequently, measurements on a large number of samples will be required to obtain statistically meaningful conclusions on the correlation between sulfides and platinum and/or palladium. The apparatus shown in Figure 1 and the techniques developed for this study provide the means to perform this study.

The apparatus used for the results presented in this report are much too slow for real-world applications, or even in-depth laboratory studies, with approximately 20 minutes required for a single image. This time can be substantially reduced in several ways, including incorporating on-board processing capabilities into the imaging spectrometer. Once this is done, it will be much more efficient to collect the large amount of data needed to do correlation studies. Consequently, developing a second-generation data collection system will be a major emphasis in the following quarter.

Although preliminary data has been taken of coal samples with the apparatus shown in Figure 1, no additional significant progress has been made. Coal will likely be a somewhat more difficult medium to study because it will be broken up into different sizes. Consequently, the coal samples will have issues with shading and reflections not evident in the platinum/palladium samples. Dealing with these problems will likely involve an improved lighting system.

REFERENCES.

1. B.J. Bolin, "*Sulfide detection in drill core from the Stillwater Complex using visible-near infrared imaging spectroscopy*," unpublished Master's Thesis from Montana Tech of The University of Montana, Department of Geophysical Engineering; 1300 West Park Street; Butte, MT 59701.