Second Quarter Technical Report For
A Real Time Coal Content Ore Grade (C²OG) Sensor

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Abstract

This second quarterly technical report discusses the progress made on a machine vision technique for determining coal content and ore grades. To date, only tests on platinum/palladium ore have been made. Recent efforts have been devoted to the implementation of an imaging spectrometer. Preliminary results from the imaging spectrometer indicate this technique will provide good differentiation between sulfides associated with high platinum/palladium content and background rock. Considerable data will be required to obtain statistically meaningful correlations between imaging spectrometer machine vision results and actual assays. Collecting this data is a major emphasis for ongoing efforts.

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1. Introduction.

The overall approach of this effort is to spectrally image ore or coal, and then use the spectral content (i.e., the particular colors of the ore or coal) to differentiate between the ore or coal grades. Currently, experts with practiced eyes do just this to identify the grade of platinum/palladium ore from the Stillwater Mine in south-central Montana. Additionally, trained eyes can identify high-sulfur and high-ash coal visually. The premise of this effort is that machine vision can accomplish this same differentiation.

During the first quarter, machine vision results using a digital color camera did not correlate as well with assay results for platinum/palladium ore as would be required for a commercial device. One of the possible reasons for this is that the digital camera did not provide enough spectral information to obtain good differentiation between the sulfides associated with high-grade platinum/palladium ore and background interference, most notably yellow grease that contaminates some of the sample and green colored rock.

The second quarter efforts have largely been devoted to implementing an imaging spectrometer for machine vision. In brief, modifying an imaging spectrometer that was designed for remote sensing from a Remotely Controlled (RC) airplane has done this. The imaging spectrometer provides 320 spectral channels, allowing for much better spectral resolution that can be obtained with a digital color camera, which provides 3 spectral channels. Preliminary results, as discussed below in more detail, are encouraging.

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 second quarter relies on an imaging spectrometer, also known as a hyperspectral camera. The imaging spectrometer, shown in Figure 1, utilizes a standard two-dimensional CCD camera. The imaging spectrometer images a line of the sample, and disperses the spectral response from each element or pixel of this line across the CCD camera. Thus, one dimension of the CCD camera records spatial information and the other dimension records spectral information.

Figure 1. Photograph of the imaging spectrometer used for the second quarter effort. The small size and cost of this device, fabricated by AdvR, makes development of a commercial instrument based on this technology economically viable.

To access the information recorded by the imaging spectrometer, a frame-grabber is required, which is installed in a personal computer. (Future generation devices may be able to use a microprocessor.) With the frame-grabber, the images are transformed into digital data that can be analyzed using numerical algorithms. A typical example of the spectral data from the imaging spectrometer shown in Figure 1 is shown in Figure 2. The data shown in Figure 2 is from an airborne application.

As shown in Figure 2, the raw data from the imaging spectrometer does not look like an image of the object. The important thing to note from the data is that the spectral response from each imaged is recorded. This spectral information is what is used to differentiate the objects of interest from the background. Because the imaging spectrometer provides 320 spectral channels, there is sufficient data to differentiate between similar objects. For example, hyperspectral imaging spectrometers can differentiate between tree species from satellite platforms.[1]

Figure 2. Raw spectral data (left) and plots from three single pixel spatial points from sunlight illuminated sections of ground (right). Prof. Tom Moon acquired this data with AdvR’s imaging spectrometer from an RC airplane. Note that these curves clearly show spectral differentiation. Slice 140 is from dry grass and shrubs and 192 and 200 are from soil and gravel surfaces. Some of the spectral features in channel 140 correspond to plant pigments. The strong absorption near 760 nm is due to water vapor absorption.

To obtain a full two-dimensional image, multiple “lines” of the image are recorded temporally. This can be accomplished by either translating the imaging spectrometer or by translating the sample. For this effort, the ore samples are translated with a linear translation stage controlled by a stepper-motor. The stepper motor is interfaced to a personal computer to control the translation. The multiple images of the object are combined into a so-called “data cube” that includes two dimensions of spatial information and one dimension of spectral information. Thus, the full spectral responses from all pixels of an image are recorded for a two-dimensional image. Examples of this are shown in the following section.

3. Experimental and Operating Data.

As noted above, the raw data from a single “picture” taken by the imaging spectrometer must be combined with numerous additional pictures taken of neighboring lines of the image to obtain a “data cube” of the imaged object. This data cube is equivalent to 320 identical pictures, each of which “sees” a slightly different color. False- or real-color images can then be reconstructed. In Figure 3 a real-color reconstruction is shown of platinum/palladium ore from the Stillwater mine. Note the excellent image quality and the distinctive gold-colored sulfides.

Figure 3. Image of platinum/palladium ore reconstructed from data taken by the imaging spectrometer. Note the gold-colored sulfides.

Because the gold-colored sulfides have a distinctive color, one would expect the spectral response from the sulfides to be distinct from the background rock. This is the case, as shown in Figure 4.

Figure 4. Spectral response of four pixels shown in Figure 3. The upper, left spectrum corresponds to a sulfide pixel. Note the distinction from the other pixels and the characteristic lack of blue in the spectrum associated with gold coloring.

RESULTS AND DISCUSSION

4. Data Reduction.

Machine vision requirements. For the machine vision system to be commercially viable for platinum/palladium ore grade evaluation, it must be able to: 1) Have very few errors of omission; and 2) have very few errors of commission. That is, the system must not miss many sulfides and the system must not give many false positives.

With the digital camera system, algorithms were found that could satisfy one of the two requirements above, but not both. Although additional efforts may be able to overcome this problem, the probability of success with the imaging spectrometer is considerably higher because it provides 320 spectral channels as compared to 3 spectral channels with the digital camera.

Algorithms to evaluate the spectral response for each pixel from the imaging spectrometer are currently under development, and preliminary results are promising. It is expected that these algorithms will be developed and implemented for data collection during the next quarter.

Correlation with nature. Once the algorithm for sulfide detection is developed, it will be used to determine what fraction of the surface of the ore sample is sulfide. According to personnel at Stillwater Mining Co., this correlates well with the platinum/palladium ore grade, but the precise nature of this correlation is not known. As noted in earlier documents, Stillwater Mining Co. geologists currently use the presence of sulfides to evaluate ore in the mine. The correlation that will be done with the machine vision system will determine the correlation much more precisely than has been done in the past. Consequently, regardless of the outcome of the correlation measurements that will be made in this effort, useful information will be obtained for Stillwater Mining Co.

CONCLUSION

5. Hypothesis and Conclusions.

Preliminary results indicate that a machine vision system based on an imaging spectrometer will provide the results necessary for a commercially viable instrument. A dedicated laboratory has been set up at Montana Tech to perform the necessary experiments and collect enough data to make statistically meaningful conclusions. It is anticipated that much of this data collection will be completed within the next quarter.

Assuming the results from the imaging spectrometer system correlate well with assay results, the imaging spectrometer system will have to be adapted for in-mine use. This will require a robust instrument that can be operated by a geologist to obtain data within a short amount of time. Although the digital camera system would be faster, simply because there is less data to manipulate and because the camera images a 2-D image rather than a series of 1-D images that need to be stitched together, the imaging spectrometer promises to provide results in a timely manner once the software is developed.

In conclusion, the imaging spectrometer is providing promising results. Additionally, progress on the platinum/palladium ore is going quite well and is on schedule. Efforts devoted to coal analysis have not yet begun because there has been a death in the family of Prof. Courtney Young, who will take a leading role in collecting and analyzing the coal. It should be noted, however, that the system established for the platinum/palladium ore can easily be adapted for coal analysis, and consequently it is expected that the coal analysis portion of this effort will not require as much time as has been devoted to hard-rock ore analysis.

REFERENCES.

1. J. Marmo, "Hyperspectral imager will view many colors of Earth," *Laser Focus World*, pp. 85-92, Aug. 1996.