Seventh Quarter Technical Report For

A Real Time Coal Content Ore Grade (C^2OG) Sensor

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Abstract

This seventh quarterly technical report discusses the progress made on a machine vision technique for determining coal content and ore grades. Considerable progress has been made on coal analysis. Naval Research Laboratory (NRL) target recognition software has been tested and incorporated into the system. This software decreases analysis time considerably and is more intuitive to use. Work with board-level computers has proceeded well; ultimately this will make the technology more compact and fieldable. Work with talc will be delayed because the graduate student working on this project is leaving the program. Ongoing work is devoted to more detailed coal analysis, improving the software interface, and developing procedures and a users manual.

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1. Introduction.

Much of this reporting period was devoted to coal analysis, as shown in figures below. Additional work went into incorporating board-level computers to the system and testing target recognition software from the Naval Research Labs (NRL). Gains have been made in the application of the imaging spectrometer as well as in the technology itself.

Although technical progress has continued to go quite well, the commercial aspects of this project are problematic. As noted in previous reports, our two major mining company partners, Stillwater Mining Company and Western Syncoal, have both undergone major changes. (Stillwater mining has had two leadership changes and was recently sold to a Russian company and Western Syncoal was sold.) Stillwater Mining Company continues to have an interest in the technology if it can be deployed in blast holes; the technology can be adapted for blast holes, but developing down-hole imaging is beyond the scope of this effort. With the results obtained from coal analysis we will soon be visiting two coal companies to assess the future of imaging spectrometer technology for this industry.

Previously reported results indicated our technology worked well for detecting defects in titanium sponge, and it appears that TIMET Inc. has the same impression. However, they have decided to try optical fruit and nut sorters initially, largely due to the maturity of these systems. There may also be applications for the imaging spectrometer in talc production, but this portion of the effort is delayed because the graduate student working on this project is leaving school.

The overall approach will be to continue with coal analysis and system improvements, primarily in software procedure and user manual development. Additionally, concerted efforts will be made to identify appropriate platforms for implementation. This will require additional time, and therefore we will apply for a no-cost extension for this project.

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 Energy Company A Westmoreland Mining Company, and the Montana Board of Research and Commercialization. Additional contributions have come from TIMET, Inc., Barrett's Minerals Inc., and MSU TechLink. The Naval Research Laboratory has also provided assistance.

EXPERIMENTAL

2. Experimental Apparatus.

The primary work with experimental apparatus has been devoted to board-level computers this quarter. Two types of board-level computers have been worked on simultaneously, as shown in Figure 1.

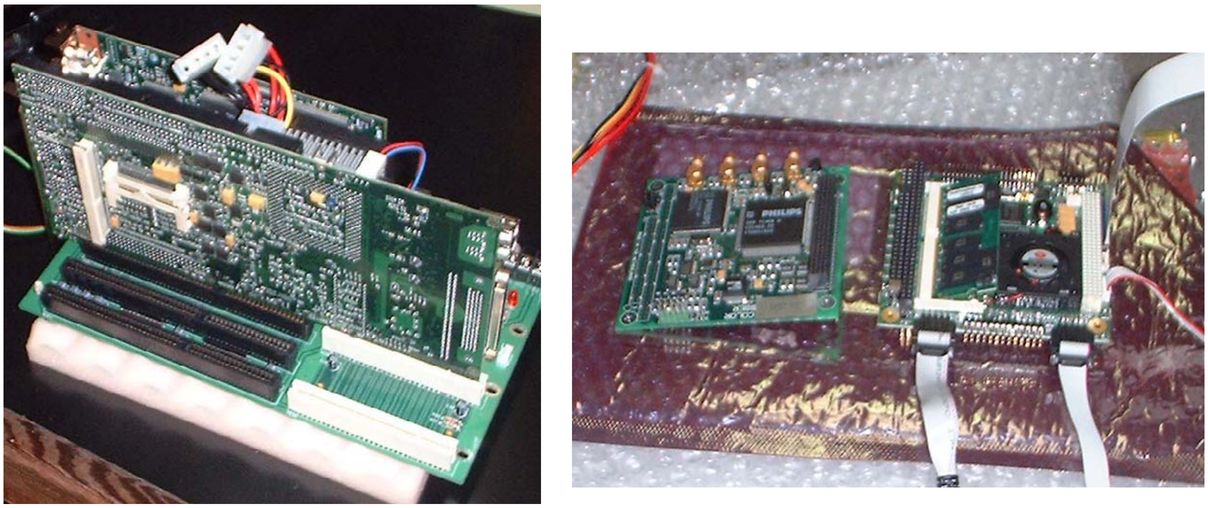

Figure 1. Photos of a board-level computer (left) and a pc/104 computer system (right). Both of these systems will decrease the footprint of the machine vision system and make it easier to utilize the technology in harsh environments.

A standard board-level computer (left image in Figure 1) has been programmed and can operate the machine vision system and can download the data to a standard PC computer. The pc/104 computer system shown to the right will be able to perform the same functions with a smaller footprint. The work done to date lays the foundation for a more rugged imaging spectrometer system, but is not essential for the technology development. Consequently, there will not be a major emphasis on board-level computers until an application requiring these systems is found.

3. Experimental and Operating Data.

Experimental work has concentrated on coal analysis this quarter. In particular, investigations have concentrated on coal and the primary contaminants of pyrite and shale. None of these objects have exciting spectral features, but they can readily be distinguished from each other. A reconstructed image of coal and spectra from several pixels is shown in Figure 2.

The RGB (Red-Green-Blue) reconstructed image of coal is essentially black, which produces relatively flat spectra with small amplitudes. The spectra from coal are quite noisy because the signal levels are low, which leads to small signal-to-noise ratios. Although the low, flat signal levels lead to a somewhat noisy spectrum, this characteristic is potentially useful because it means there will be minimal spectral interference from the coal with contaminants of interest and because the low reflectance makes the coal radiometrically distinct from contaminants.

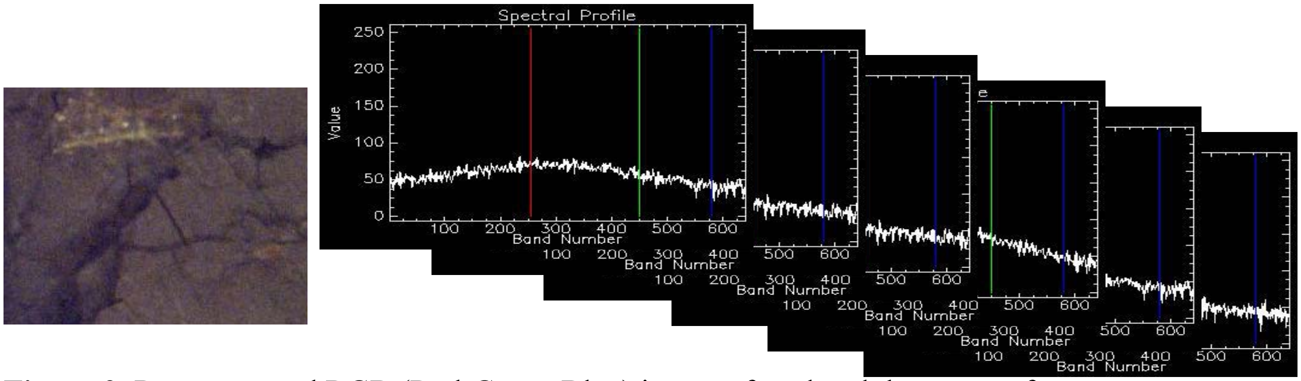

Figure 2. Reconstructed RGB (Red-Green-Blue) image of coal and the spectra from several pixels in the image.

Images of pyrite and shale are shown in Figures 3 and 4. Both pyrite and shale are contaminants of coal. Pyrite contains a significant amount of sulfur and therefore increases the sulfur content of coal when it is present. Shale increases the amount of ash produced when the coal is burned.

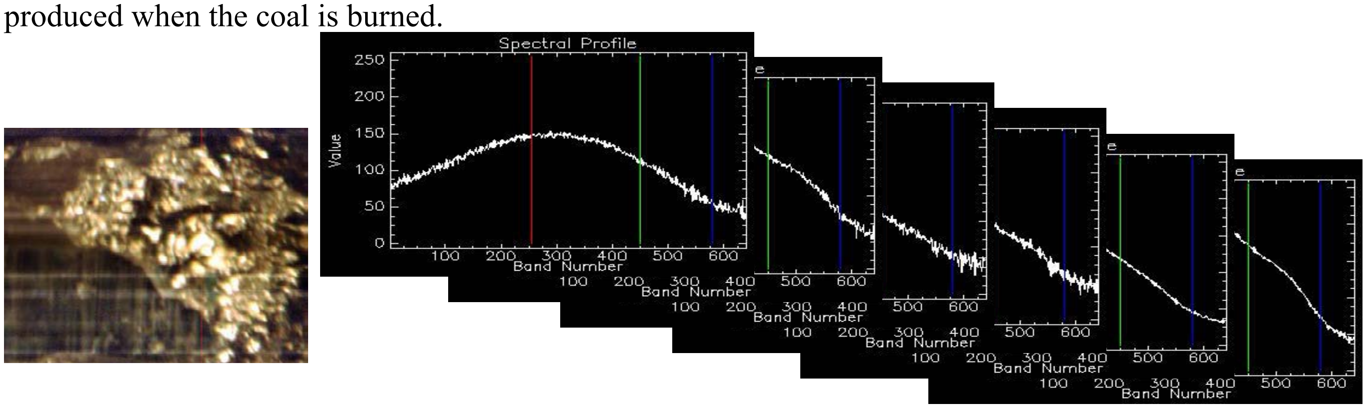

Figure 3. Reconstructed RGB image of pyrite and the spectra from several pixels in the image. The distinctive gold color of pyrite is due to the strong absorption of blue wavelengths, as seen by the weak reflectance on the left side of the plots.

Pyrite has a distinctive gold color due to a strong absorption of short wavelength (blue) colors. This feature, along with the much higher average reflectance of pyrite, make identification of pyrite from coal relatively straight forward.

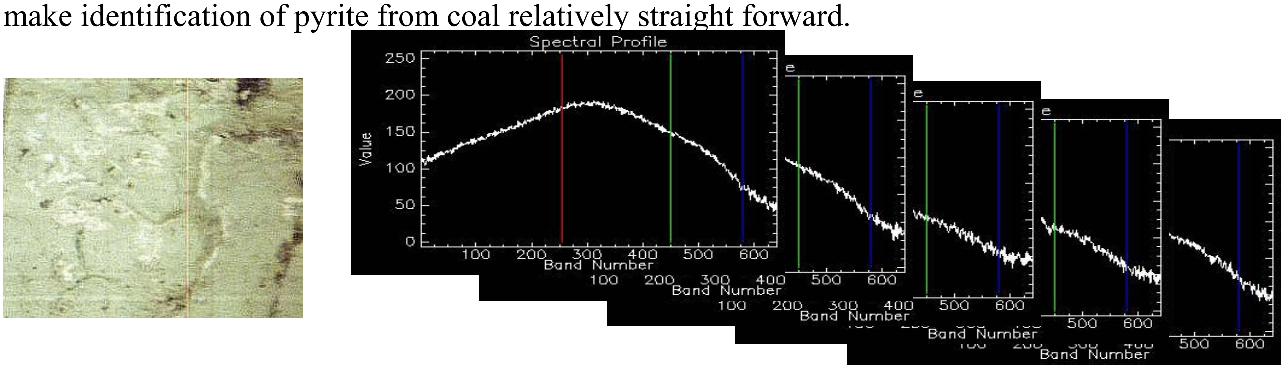

Figure 4. Reconstructed RGB image of shale and the spectra from several pixels in the image. As with coal and pyrite, there are no distinct spectral features.

RESULTS AND DISCUSSION

4. Data Reduction.

The spectra shown in Figures 2-4 show no strong spectral features in coal, pyrite, or shale. A point to note about these three quantities, however, is that they are distinct to the human eye. The plots shown in Figures 2-4 demonstrate that the human brain is an outstanding processor for color. Additionally, the human eye's ability to easily distinguish between coal, pyrite, and shale tells us there is far more information in the spectral curves shown above than is initially apparent.

A next step will be to generate classification maps of coal samples with pyrite and shale to demonstrate the system's ability to identify contaminants in coal. Ideally, it would be beneficial if the system could identify so-called organic sulfur in coal as well. Organic sulfur is disseminated in microscopic quantities and will be much more difficult to identify than the macroscopic impurities considered above. Discussions with coal company officials should help us determine the relative importance of the different contaminants.

CONCLUSION

5. Hypothesis and Conclusions.

The machine vision system has now been developed to the point that it is user friendly and provides results quickly. Spectral responses from objects that appear distinct to the human eye may not show dramatically different spectral curves. Consequently, sophisticated target recognition software, such as the target recognition software from NRL we are using, is required to implement our machine vision system in many applications.

The next big step will be to take the machine vision system from laboratory, proof-of-principle environments to production environments. Ongoing efforts will be devoted to additional coal analysis, refinement of procedures, and the development of user manuals. The procedure and user manual advancement will be particularly useful for system deployment.