**Fifth Quarter Technical Report For**

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

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## Abstract

This fifth quarterly technical report discusses the progress made on a machine vision technique for determining coal content and ore grades. Recent work has been devoted to implementing new hardware and examining defects in titanium sponge, a new application for the machine vision system. With the improvements in hardware and software, the data collection is much improved. Early results from data taken on titanium sponge defects indicate that some defects will be relatively easy to identify, but others will be much more difficult. Consequently, additional work is required with software algorithms for target recognition. Ongoing work will be divided into several fronts, which include data collection and analysis, improving the target recognition capabilities, and improving the electronic interface.

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**1. Introduction.**

Significant improvements have been made in the machine visions system, including hardware and software. Additionally, potential new opportunities for the technology have been found in talc mining and titanium sponge defect monitoring. Ongoing work is being devoted to demonstrating the capabilities of the technology to potential customers as well as making additional improvements in the technology.

During the fifth quarter, improved hardware was delivered to the research team at Montana Tech, a visit was made to a talc processing plant to explore possible applications of the machine vision system, and hyperspectral data has been collected for titanium sponge defects. Preliminary analysis based on the data from the titanium sponge samples indicate some defects will be quite easy to identify, but others may be difficult.

At the beginning of the fifth quarter of this effort, a meeting was held to organize the research effort for Year 2. The team has been divided into three groups. One group will be devoted to improving the hardware, including the optical and scanning system. A second group will be devoted to improvements in the interfacing electronics and target identification software. The third group will devote itself to data collection and analysis. Thus, the three teams together will simultaneously improve the machine vision system as well as take and analyze data for potential customers.

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, TIMET Inc., Barrett's Minerals Inc., and the Montana Board of Research and Commercialization. MSU TechLink, an organization devoted to fostering high-tech businesses in the western U.S. has also recently provided valuable assistance.

**EXPERIMENTAL**

**2. Experimental Apparatus.**

In the previous report it was noted that substantial upgrades in the optical laboratory, the software, and the imaging spectrometer were being made. Nearly all of these improvements are complete.

A new optical table and tower have been installed. This mounting systems adds considerable stability and is much more robust than the previous setup. Additionally, the new mounting system is substantially easier to use and adjust, which improves the speed and repeatability of experiments.

Software routines have been written and implemented that greatly decreases the time required to collect data. This development is perhaps the most significant development because it greatly increases the amount of data that is being taken.

The second-generation imaging spectrometer has been delivered and calibrated. This system is considerably more robust than the previous imaging spectrometer and is shown in Figure 1. The new system should have improved resolution and stability. Additionally, this provides the research teams at Montana Tech with two instruments, which will allow one team to have an instrument to work on for system improvements while another team concentrates on data collection and analysis.

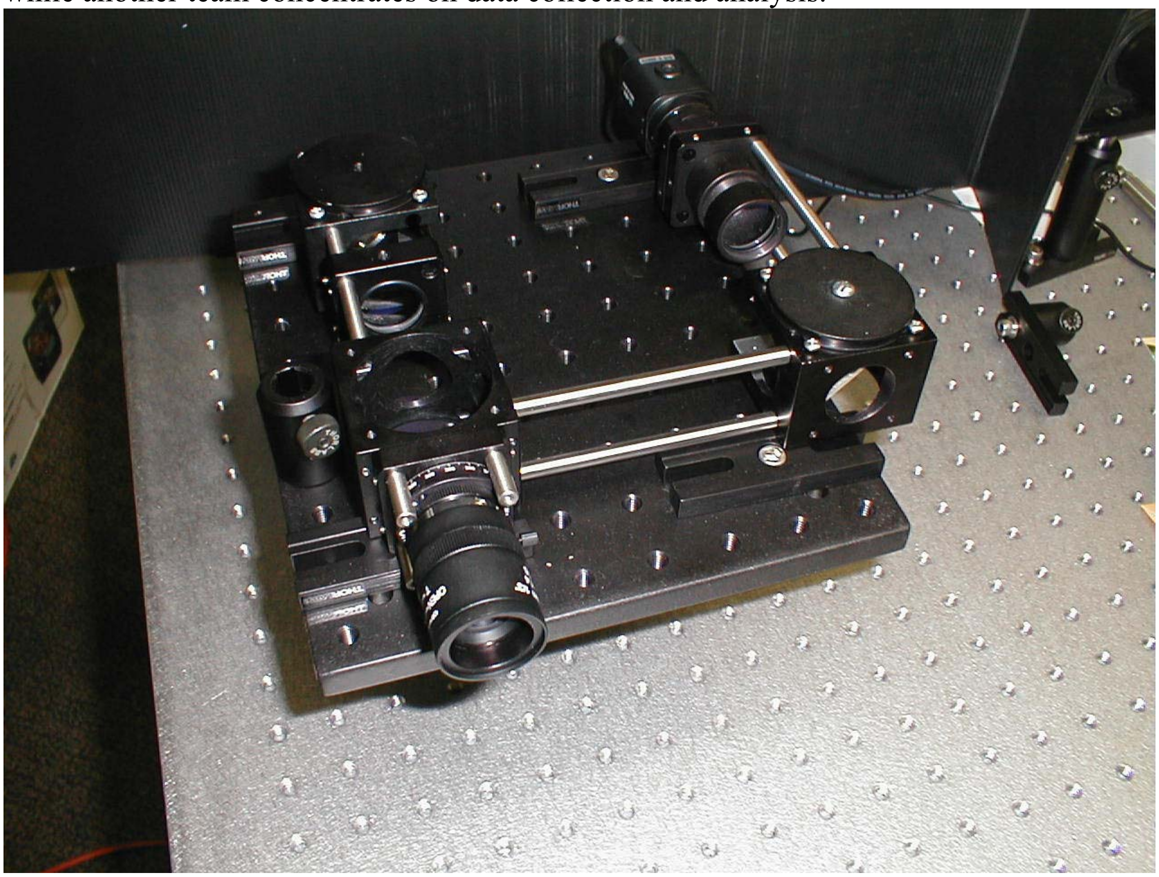


**Figure 1.** Second-generation imaging spectrometer. This instrument was designed and built at Resonon and has been delivered to the developmental teams at Montana Tech.

**3. Experimental and Operating Data.**

Recent work has been devoted to collecting and analyzing hyperspectral data on titanium sponge samples supplied by TIMET Inc. The goal of this work is to identify defects within the sponge samples. Currently these defects are identified manually, which is labor intensive and prone to variations associated with using manual labor.

The imaging spectrometer records the spectrum for each pixel in a linear segment of an image. The complete image is obtained by sweeping the line across the object of interest. Because we are not accustomed to viewing the spectrum from an image, the raw data provided by the imaging spectrometer is difficult to interpret. An example of the raw data is shown in Figure 2.

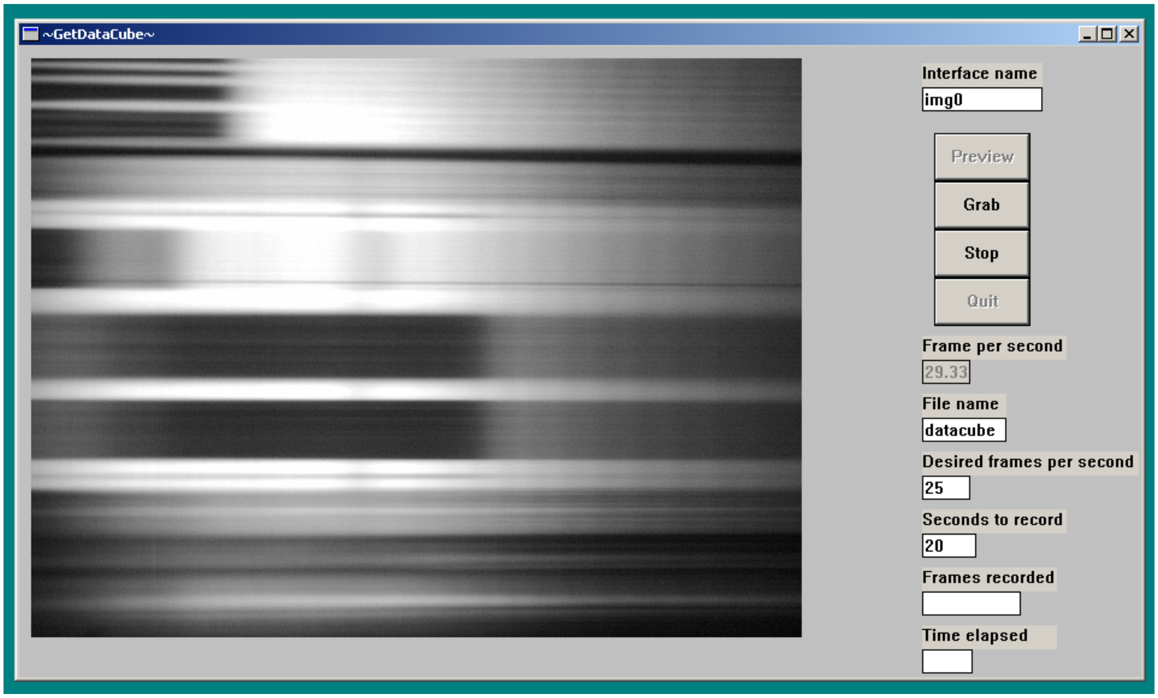
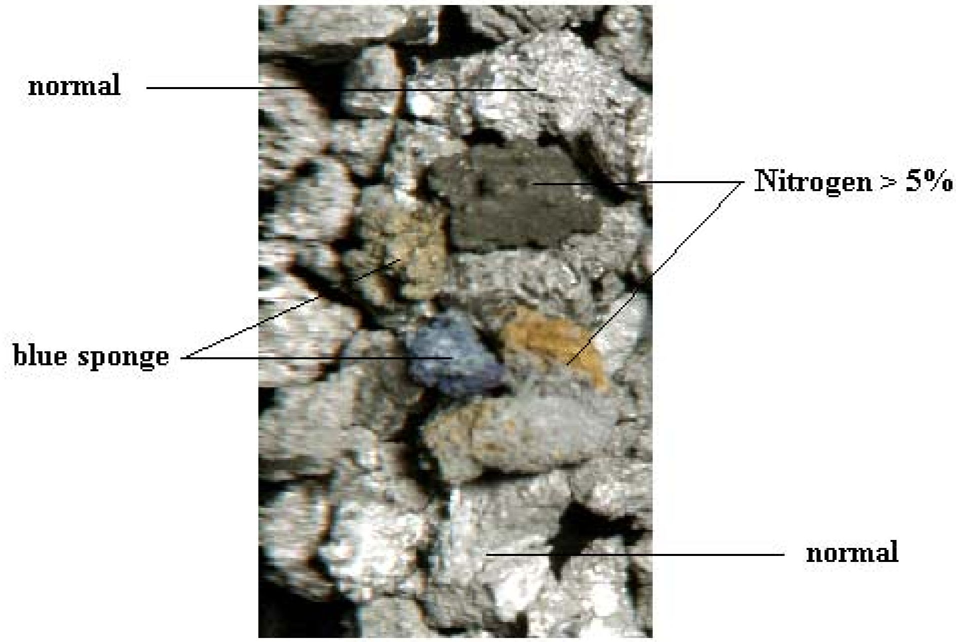



**Figure 2.** An example of the raw data recorded by the imaging spectrometer. The image shown displays spatial information along the vertical axis and spectral information along the horizontal axis. The buttons and windows to the right of the image are the software interface used to collect the data.

To obtain readily understandable images, several hundred images are combined, each of which has imaged a neighboring slice of the object of interest. This data is assembled in a three-dimensional datacube. One dimension of the datacube is spectral information and two dimensions are spatial information. Slices of the datacube can be viewed to see the object of interest at any "color" recorded by the imaging spectrometer. A complete color image of the object can be reconstructed by assigning red (r), green (g), and blue (b) colors to specific slices of the image. This has been done in Figure 3, where an rgb reconstruction of an image of titanium sponge samples is shown.




**rgb composite of titanium samples from ALIS datacube**
**red = 700 nm, green = 600 nm, blue = 500nm**

**Figure 3.** Reconstructed rgb image of titanium sponge samples with defects. This image was assembled from several hundred images of raw data like that shown in Figure 2. Several titanium sponge defects are labeled in Figure 3. Some of the identically labeled defects have significantly different colors.

## RESULTS AND DISCUSSION

### 4. Data Reduction.

The data shown in Figures 2 and 3 was analyzed to determine how well the machine vision system can find titanium defects. This is done by differentiating between spectral signatures from pixels associated with defects as compared to defects associated with normal titanium sponge. The average spectra from several distinct sections of the image shown in Figure 3 are presented in Figure 4.

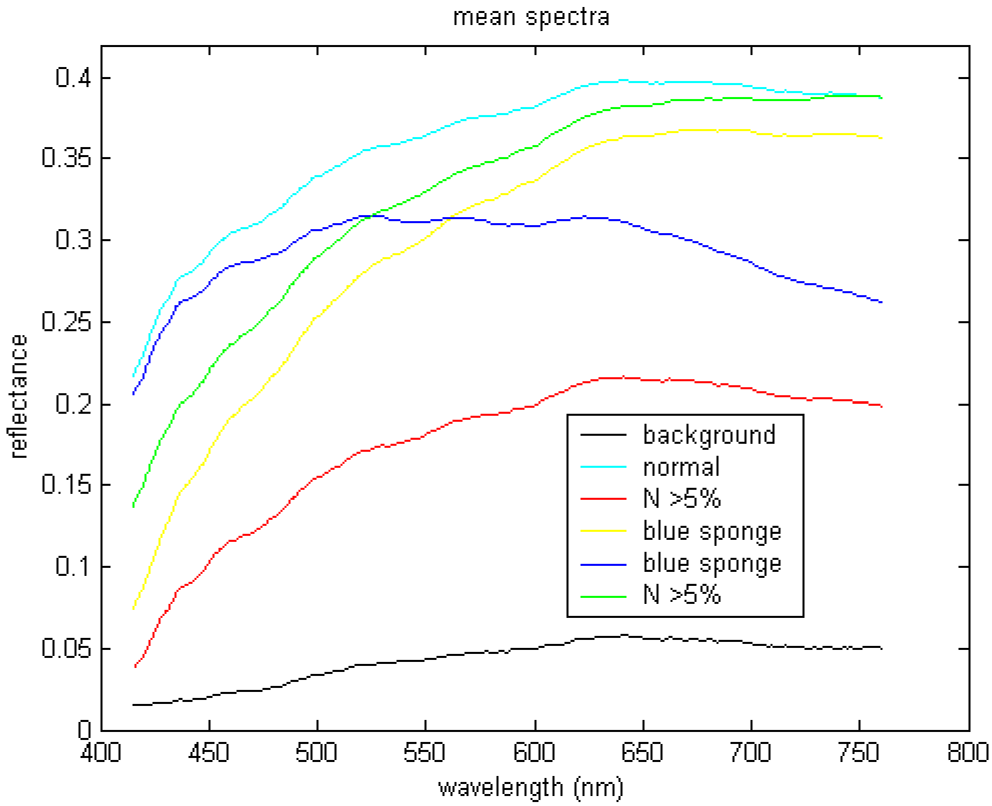



**Figure 4.** The spectral signatures of various defects, normal titanium sponge, and background. Note that the overall shape of some of the defects is quite distinct from normal titanium while others are similar.

As can be seen in Figure 4, there is considerable spectral variability associated with titanium sponge and their defects. From this data, one would expect it to be relatively easy to differentiate some of the defects, but quite hard to differentiate others. Using ENVI software, two classification maps have been generated to identify the various constituents of the image shown in Figure 3. These maps are shown in Figure 5.

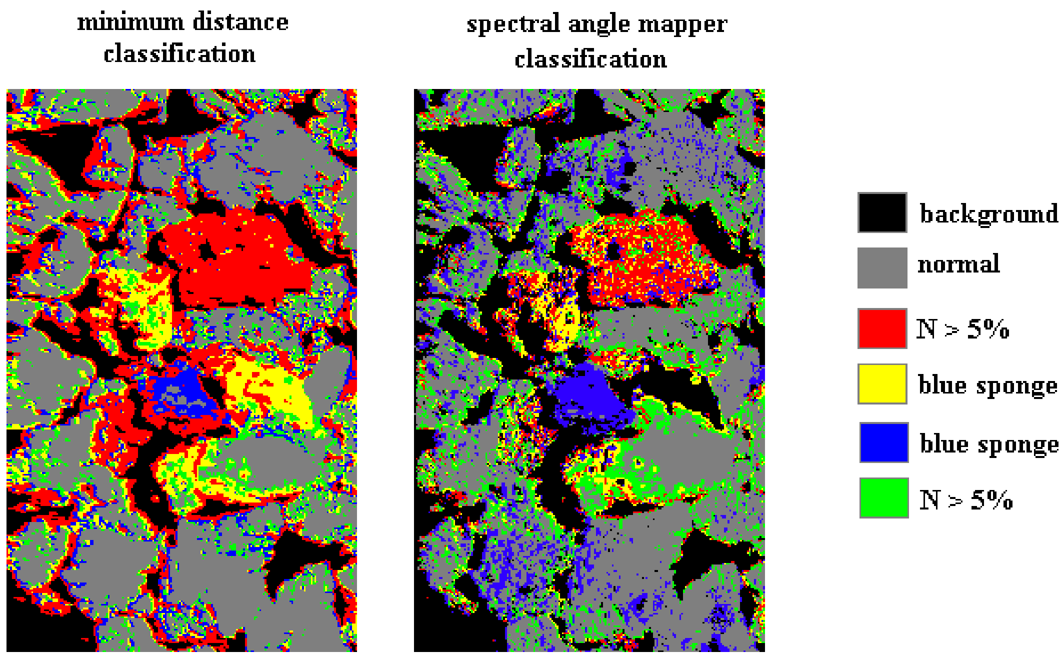



**Figure 5.** Two classification maps of titanium sponge and defects. The minimum distance classification utilizes the brightness as well as the spectral signature whereas the spectral angle mapper does not utilize the relative brightness for classification.

Figure 5 clearly shows that important defects can be differentiated, but it also shows that the simple classification schemes used for this preliminary work have considerable error associated with them, especially around the edges of the sponge samples. This is not surprising because the signals from near the edges of the samples are quite dim, which leads to a noisy signal.

If one examines previous reports, it is clear that the classification problem for titanium sponge is significantly more complicated than identifying sulfides in platinum/palladium ore. Thus, initial classification maps for titanium sponge defects are not as convincing as the results from our work with platinum/palladium ore.

## CONCLUSION

### 5. Hypothesis and Conclusions.

The machine vision system based on a hyperspectral imaging spectrometer is quite functional and takes high quality data. However, there is room for improvements in the hardware, particularly in the computer interfacing. Ongoing efforts will be devoted to this.

The classification results indicate that improved classification software is required. To address this need, we are initiating a Cooperative Research And Development Agreement (CRADA) with the Naval Research Laboratory (NRL) to adapt some of their target recognition software for this application. If this CRADA can be implemented, considerable effort will be devoted to improving the classifications using NRL software.

Additional data needs to be taken on the existing samples as well as new samples to test the system and to obtain statistically meaningful results. Therefore, two graduate students have been assigned to this task for coal and talc. The results from student labor vary widely. This work, however, will be significant portions of the students' theses, and consequently we expect to see creative and high quality work.