Eleventh Quarter Technical Report For

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

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Abstract

This eleventh quarterly technical report discusses the installation of a spectral machine vision system in the Stillwater mine's core room. In brief, the system has been fabricated, installed, and preliminary measurements have been made. A first round of refinements has been made, included replacing a bad bearing and applying filters to the lighting. A high-speed Spectral Angle Mapper (SAM) program was written to classify the cores in real time. This program identifies sulfides in the core sample quite well, but also produces false positives at boundaries and breaks in the core. Additionally, bright reflections from facets within the ore occasionally saturate the camera. Overall, the project is on schedule, but additional refinement in the algorithm and lighting is required to obtain more accurate results.

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1. Introduction.

During this first reporting period of Year-3 a system to take hyperspectral images of core samples has been fabricated and installed. Preliminary measurements have been taken to guide system refinement and adjustment.

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 for Year-3 of this effort are: Resonon, Inc., Montana Tech of the University of Montana, Stillwater Mining Co., and the Montana Board of Research and Commercialization. Additional contributions during years 1 and 2 have come from TIMET, Inc., Barrett's Minerals Inc., Western Energy Company A Westmoreland Mining Company, and MSU TechLink. The Naval Research Laboratory has also provided assistance via a Cooperative Research and Development Agreement (CRADA).

EXPERIMENTAL

2. Experimental Apparatus.

The system that was installed at the Stillwater Platinum/Palladium (Pt/Pd) mine core room in south-central Montana is shown in Figure 1.

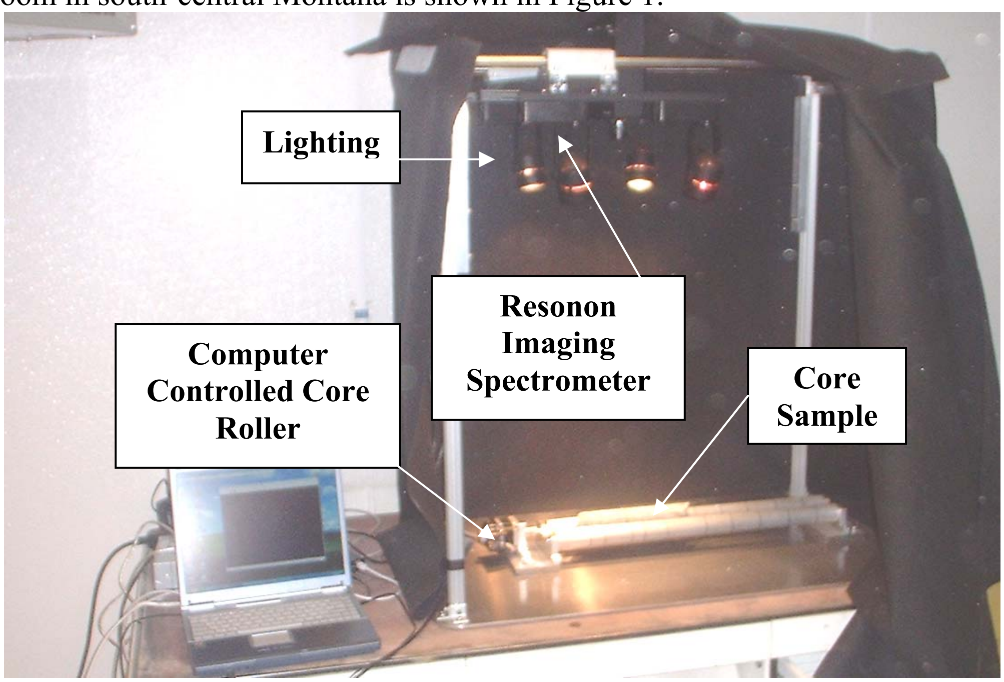

Figure 1. Apparatus currently in use at the Stillwater mine to develop accurate and fast algorithms for grading ore with hyperspectral imaging.

The system shown in Figure 1 works as follows. Core samples of platinum/palladium ore are placed on the core roller for imaging. The computer controls the rotation rate of the core roller so it rotates at the correct rate for the imaging spectrometer to image the entire core. The system is enclosed in flat black, rubber coated material to control the lighting, which is provided by four halogen bulbs with optical filters to flatten the spectrum. A sample of Spectralon is placed on the rollers before each run to back out spectral variations (from the lights and camera response) and spatial variations (from the imaging spectrometer and the lights) using software developed by Resonon. This system images 4.8 inches of core per scan in approximately 15 seconds.

3. Experimental and Operating Data.

The apparatus shown in Figure 1 collects the data, but this data must be analyzed in real-time to provide the benefits sought by Stillwater Mining Co. Currently available software packages such as ENVI do an excellent job of analyzing hyperspectral data, but they are far too slow for applications such as this. Therefore, Resonon wrote a high-speed classification algorithm based on Spectral Angle Mapping (SAM).

In brief, the brightness measured in each spectral channel of the imaging spectrometer can be mapped to an independent axis to define a vector. Thus, for the Resonon imaging spectrometer, each pixel of an image can be represented as a 213 dimensional vector (because there are 213 spectral channels with our device). By calculating a vector dot product, the angle between sulfide "vectors" previously collected in a library and the "vectors" of each pixel in the image can be determined. Pixels with an angle sufficiently close to the library sulfide vectors are classified as sulfides. The spectral angle can be calculated faster than the camera can record data. An example of a classification map from Resonon's SAM program is shown in Figure 2.

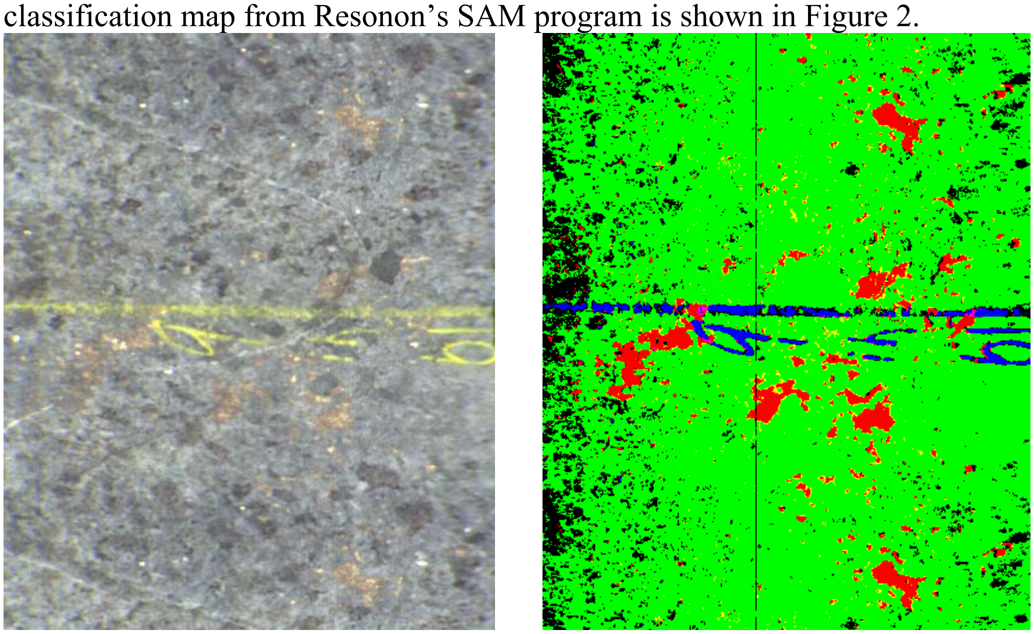

Figure 2. A color image showing distinctive gold-colored sulfides in a core sample from the Stillwater mine (left) and a classification map of the same section of core using Spectral Angle Mapping (SAM). Red indicates the pixels classified as sulfides, blue is from yellow chalk, and green and black are non-sulfides. Note that the sulfides are easily distinguished from the similarly colored chalk.

Using the SAM software, the fractional sulfide coverage of the cores is readily calculated. Because sulfides are "pathfinder" minerals for Platinum/Palladium ore, the sulfide coverage should correlate with fire assays of platinum/palladium.

RESULTS AND DISCUSSION

4. Data Reduction.

Early attempt to use the system were hampered by a bad bearing in the core-roller, especially with small, broken sections of core. Additionally, the signal-to-noise level at short wavelengths (~450 nm) was poor. To correct the core-roller problem the bearing was replaced. The poor signal-to-noise ratio at short wavelengths (which are extremely useful for the detection of sulfides) is thought to result largely from the low output of blue wavelengths by the halogen lights. To decrease this problem, blue pass-band filters were put on the lights. This decreased the amount of light at longer wavelengths, which enabled us to increase the gain in the camera.

The initial correlation between results from the imaging spectrometer and the fire assays was not strong. One possible reason for this is that the SAM classification routine does not perform well with dark pixels. The reason for this is that the spectral angle calculated by the SAM routine is independent of the brightness of the pixel. Consequently, dark pixels that have a poor signal-to-noise ratio can easily be misclassified. This appears to be the case, as numerous false positives have been observed at the edges and at breaks in the core.

Another possibility is that the correlation between surface sulfides and bulk platinum/palladium may not be strong. If this is the case, it would mean the technique used by Stillwater for on-the-fly grading is flawed. A major goal of this effort is to determine this correlation.

CONCLUSION

5. Hypothesis and Conclusions.

We will continue with the work at the Stillwater mine to obtain a good understanding of how well surface measurements correlate with bulk properties of the ore. Understanding this relationship is clearly essential to penetrate the mining market. Improvements need to made in the classification algorithm to eliminate false-positives from dark pixels. Additional improvements in lighting may also yield more accurate results. In particular, small facets tend to act as mirrors that reflect the light too strongly, thereby saturating the pixels. Putting optical diffusers in front of the lights should greatly decrease this effect.

Overall, the project is proceeding well and is on schedule. With the system installed the remaining efforts can be focused on obtaining accurate results and fully characterizing the relationship between surface sulfides and bulk platinum/palladium. Additionally, the system installation provides experience and credibility for future commercialization.