

Potential of NIR hyperspectral imaging in the minerals industry

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Abstract Material characterization by Near Infrared Hyperspectral Imaging (NIR HSI) is based on specific absorption features of different minerals. These absorption features are caused by the movement of molecular bondings of NIR active minerals on the material surface. Therefore, pollutions, such as dust and water, may influence the measurement outcome. An insufficient spatial resolution of the measurement can additionally falsify the hyperspectral image, because of mixed spectra effects at grain boundaries caused by the simultaneous collection of two or more spectra from unequal minerals. In order to compare NIR HSI to conventional analytical methods the above mentioned characteristics have to be investigated to reveal the potential of NIR HSI. The present paper describes investigation conducted on copper porphyry ore derived from the Kajaran copper mine, Armenia. During an extensive feasibility study rock samples are characterized by different measurement techniques. Two major analysis technologies are used for characterization including Mineral Liberation Analysis (MLA) and NIR HSI by using the Hyperspectral Imager SisuCHEMA (SPECIM) and Spotlight 400 FTIR Imaging System from Perkin Elmer. On basis of test-results derived from the feasibility study advantages and disadvantages of NIR HSI, in comparison to conventional measurement techniques in the minerals industry are discussed.

1 Introduction

To build up a process in the mineral processing industry, material characterisation is indispensable. Material characterisation is necessary to

obtain all necessary material specifications to choose the optimum sorting criteria. Nowadays several analytical techniques are used for elemental (e.g. XRF (X-ray fluorescence)) or mineral component detection (e.g. MLA). Sensors used for material characterization cover most of the electromagnetic spectrum (EM).

The non-destructive Near Infrared Spectroscopy (NIRS), as a surface measurement technique allows the determination of molecular compositions and quantitative mixtures of a sample at any state. In addition to that NIRS sources are not hazardous to health in contrast to other methods [1]. Necessary sample preparation prior to analysis is reduced or can even be neglected. NIRS is a rapidly operating measurement technique which is used for mineral analysis in different fields of applications.

Former investigations have shown that NIRS can be applied for sensor-based sorting in the raw material industry. The principle of sensor-based sorting includes the singularly detection of particle properties by a sensor with subsequently mechanical separation in two or more fractions [2]. NIRS is an emerging sensor technology for sorting applications by using spectral differences in the NIR region as sorting criteria. In the borate and talc industry first NIR sorters have already been implemented. Investigations on the potential of NIR sorting in the minerals industry are on-going. Further sensor technologies applied for sensor-based sorting include optical, electromagnetic, XRF, XRT (X-ray transmission) to name a few [3].

Application fields for NIRS in the minerals industry further include the on-line moisture analysis of bulk streams. Experiences in remote sensing, including spectral interpretation, can even be applied for analysis at smaller spatial resolutions down to microscope usage. The narrow pixel size of NIR HSI allows the characterization of mineral distribution of particles at rock sample surfaces [4]. The crystal structure, in addition to the molecular composition of a sample, has major influence on the measured spectra. Therefore minerals with identical chemical composition, but differentiating crystal structures can be distinguished (e.g. Calcite [CaCO_3] & Aragonite [CaCO_3]). These advantages, among others show the large potential of NIR HSI for the minerals industry. The following investigation is used to evaluate the potential of applying NIR HSI for the characterization of a copper porphyry ore type. The major goal of the present investigation is a comparison of NIR HSI with

NIR point-measurements and MLA. The comparison is completed on basis of literature research and practical test-works. Second aim of the investigation is the determination of influences of the water content on the sample surface and impacts of spatial resolution variations on the NIR HSI measurement outcome. Results of the investigation are given in the following chapters.

2 NIR point measurement

In the first phase of the test-work each particle is measured by NIR point-measurements to evaluate the applicability of point-measurements for differentiating of particles. Each particle is therefore measured ten times by the NIR spectrometer.

The desktop NIR spectrometer used for analysis is a Fourier Transform Infrared (FTIR) spectrometer from the *TENSORTM* series, Tensor 27 from Bruker Optics. FTIR spectra in a range of 1000-2632 nm were recorded for analysis. Exemplary measurement results are shown in Figs. 20.1 and 20.2. Detected NIR-spectra are illustrated by applying varying colours to each spectrum.

Measurements show that spectral differences between the particles

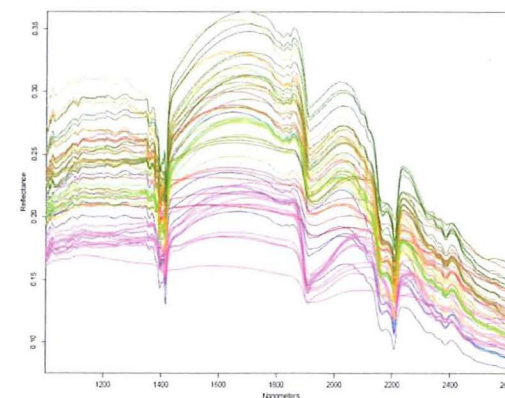


Figure 20.1: Examples of spectra of one of the groups based on spectral response [5].

are to minor in order to distinguish between each sample, based on NIR point-measurements. As a result from this investigation it was evaluated that the dissemination of valuable contaminants within the samples is too fine for the use of NIR point-measurement spectroscopy. Therefore the applicability of NIR HSI is evaluated.

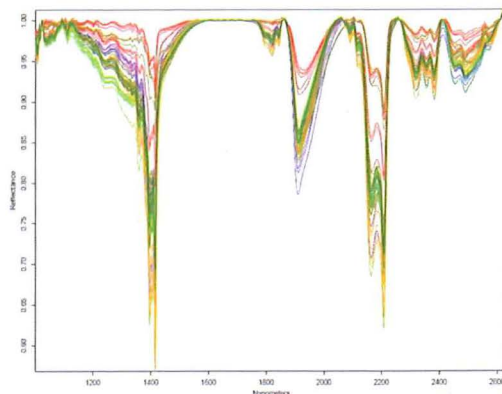


Figure 20.2: Examples of baseline corrected spectra of one of the groups based on spectral response [5].

NIR HSI in contrast to NIR-point measurement adds an additional venue coordinate to the measurements outcome, by using the ability of pattern recognition. Spatial and spectral resolution is much higher in case of NIR HSI in contrast to NIR point-measurements, which increases the level of detail. Therefore, the measurement enables the detection of small, minor constituents in the sample. Furthermore the impact of illumination complications is decreased [6].

3 SisuCHEMA hyperspectral imaging measurements

All NIR HSI measurements for this feasibility study were conducted at Specim Spectral Imagine Ltd. in Oulu Finland. The spectral imaging system used for analysis is the SisuCHEMA SWIR workstation shown in Fig. 20.3. The SisuCHEMA is a high speed imaging system which operates at wavelengths between 900- and 2500 nm. Features of the

system include a spatial resolution of 320 pixels with a scalable pixel size of 31- to 625 microns. Samples are placed on a mobile platform which moves the sample through the detection area during measurement. All settings used for analysis are listed in Fig. 20.4.



Figure 20.3: SisuCHEMA SWIR [7].

pixel size	625 μm	312 μm	156 μm	31 μm
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Figure 20.4: Used pixel sizes with the SisuCHEMA [8].

Each particle is measured at pixel sizes of 625-, 312-, 156-, and 31 μm . The UmBio Evince software is used for data processing and can display the results derived from SisuCHEMA NIR HSI as false colour pictures. These pictures are subsequently analysed in regard to mineral liberation to evaluate the influence of spatial resolution on the measurements outcome.

Additional to that influences of surface water on the measurements outcome are evaluated by applying three different moisture contents ("dry", "slightly wet", "wet") to each particle. For this measurement a fixed spatial resolution of 31 μm was used.

3.1 Influence of spatial resolution on NIR HSI

Evaluation of hyperspectral images derived from measurement of sample surfaces shows that a reduced spatial resolution increases the effect

of spectral mixing at grain boundaries which is a logical result. Additional to that a lower spatial resolution could lead to an incorrect interpretation of mineral distribution for hyperspectral images of the sample surface. Two separate grains could be displayed as one particle, therefore incorrect interpretation is the consequence.

Figure 20.5 illustrates hyperspectral images derived from NIR HSI at varying spatial resolutions. It can be observed that the level of detail increases with higher spatial resolutions. The top-left picture illustrates a particle measured at the highest resolution with pixel sizes of $31\text{ }\mu\text{m}$. Following pictures illustrate the same section at varying spatial resolutions from $156\text{ }\mu\text{m}$ up to $625\text{ }\mu\text{m}$ with the lowest level of detail. It can be observed that besides drying the samples surface, the minimum particle size has to be identified in order to reduce effects of spectral mixing at the grain boundaries.

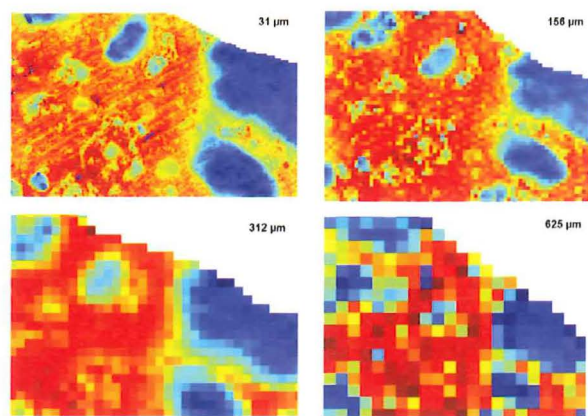


Figure 20.5: NIR-Hyperspectral Images by different spatial resolutions at pixel sizes between $31\text{ }\mu\text{m}$ and $625\text{ }\mu\text{m}$. The blue areas contain mainly dolomite and halloysite. In contrast, quartz and feldspar are displayed red [8].

3.2 Influence of moisture content

Measurements with different moisture contents show that surface-water has a major influence on the detected NIR-spectra. Images ob-

tained by NIR HSI become blurred at high moisture contents (Fig. 20.6). This effect is even more distinctive for NIR active minerals [5].

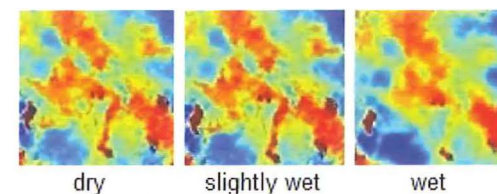


Figure 20.6: NIR-Hyperspectral Images at different moisture contents "dry", "slightly wet" and "wet". Halloysite and dolomite are displayed in red. The blue areas show quartz and feldspar [5].

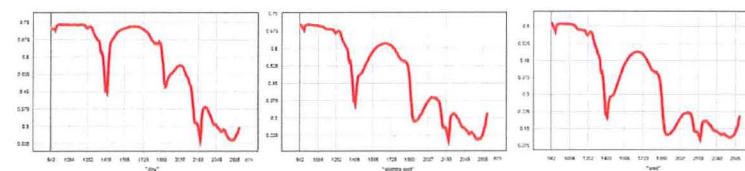


Figure 20.7: Average spectra of the measured area in Fig. 20.6 at different moisture contents on the sample surface [8].

Results additionally show that influences of surface-water on detected spectra increase with higher moisture contents (Figure 20.7). Measurable effects of surface water on measured spectra include smoother mineral boundaries shown at hyperspectral images making the identification of mineral distribution more difficult. Drying the sample surface is needed as sample preparation to decrease these influences.

4 Comparison of NIR hyperspectral imaging (Spotlight 400) and MLA measurements

MLA is the abbreviation for Mineral Liberation Analysis. The MLA is capable of measuring mineral components on sample surfaces. An MLA device consists of a Scanning Electron Microscope (SEM) and

a multiple energy dispersive X-ray diffraction detector. Mineralogy software is used for data processing. Sample preparation for MLA-measurements includes different stages. Prior to each measurement samples have to be cut in order to fit in the MLA sample holder. Subsequently each sample is betted in epoxy resin and the substantiated surface is grinded and polished.

Parameters used for MLA analysis include a magnification of 175 and a resolution of $20\ \mu\text{m}$ between each measurement point. The duration for MLA analysis (depending on applied spatial resolution and measured area) plus sample preparation time amounts to several hours per sample. Figure 20.8 shows four exemplary results of different samples derived from MLA measurement.

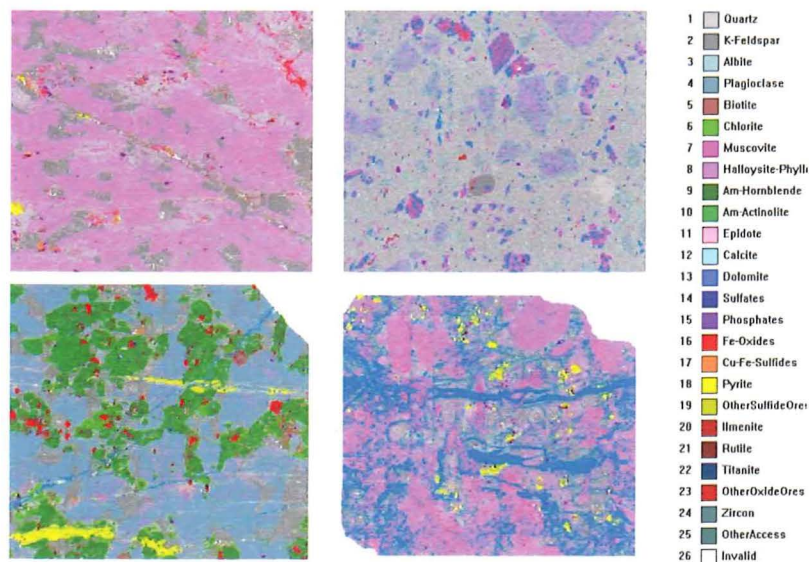


Figure 20.8: Distribution of mineral components obtained from the MLA measurements [8].

For the comparison between MLA and NIR HSI the same particles used for MLA are measured by NIR HSI measurements on the Spotlight 400 FTIR Imaging System [9]. During NIR HSI measurement each particle is measured at the same area which was previously measured by

MLA. A pixel resolution of $25\ \mu\text{m}$ is used for NIR HSI test work. Figure 20.9 shows an exemplary NIR HSI measurement result after data processing such as noise reduction and baseline correction. Because no data base is available it is not possible to identify minerals directly with NIR HSI. Therefore, MLA results have to be used to identify minerals in the NIR HSI Image. Figure 20.9 illustrates exemplary spectra for dolomite, halloysite, feldspar and pyrite, derived from NIR HSI measurement. It can be seen that NIR inactive pyrite shows low absorption features and no spectral response, whereas spectra for NIR active dolomite shows characteristic spectra. In most cases halloysite and feldspar is finely distributed and intergrown with other contaminants such as quartz.

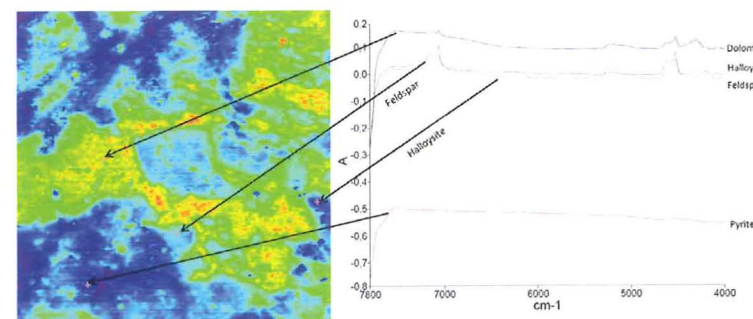


Figure 20.9: Example: NIR HSI Image with spectra of the some main minerals of the sample.

In Fig. 20.10 a monochromatic RGB (left), MLA (middle) and NIR HSI Image (right) derived from NIR HSI and MLA measurement are shown. Pictures from the different measurement techniques are derived from same sections of a particle. Based on the measurements outcome it can be seen that the level of detail of the NIR HSI image is lower compared to results from MLA measurement. Besides the level of detail it can be stated that NIR HSI enables a determination of mineral component distribution.

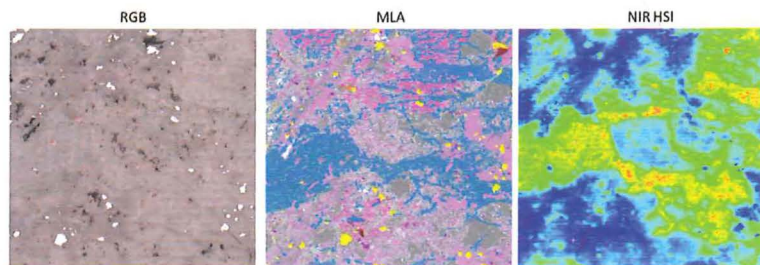


Figure 20.10: Example: Comparison between monochromatic RGB, MLA, and NIR HSI image of the same sample area.

5 Conclusion

The above described investigation has shown the general applicability of NIR HSI for the determination of mineral distributions on sample surfaces. NIR HSI however cannot be used without prior generation of a mineral data base. During this investigation MLA measurement is used for the identification of mineral components in the NIR HSI Image. Future investigation could enable the establishment of an NIR spectrum data based on NIR HSI test work.

Furthermore it has shown that surface moisture-content, as well as the applied spatial resolution have substantial influence on the measurements outcome. Surface moisture leads to blurred hyperspectral images due to the influence of water on the detected NIR-spectra. In addition to influences of surface water an insufficient spatial resolution leads to a wrong interpretation of the hyperspectral image.

Due to the promising results derived from the test-work, further applications for NIR HSI for process control in the minerals industry are imaginable, besides the laboratory usage. NIR HSI is not yet applied in sensor-based sorting due to long measurement time, in contrast to NIR-line scan sensors. Further improvements in data-processing speed however could make applications in the field of sensor-based sorting feasible.

Summing up it can be stated that NIR HSI seems to be a good alternative to conventional analytical methods. NIR HSI may become a major measurement instrument for analytical applications in the min-

erals industry. Further investigations will be conducted to evaluate the full potential of NIR HSI for applications in the minerals industry.

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