

NIR Spectral Imaging in the Minerals Industry

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Abstract. Near-infrared spectroscopy is used for laboratory identification of pure minerals and as a remote sensing tool for geological exploration. The separation of minerals in technical processes using sensing technologies is a new field of application. Recent tests on ores show encouraging results with near-infrared spectroscopy (NIRS) sorting. With NIRS it is possible to detect a fingerprint of each sample, which is directly related to the mineralogical composition. This can be used for the separation of ore and waste rock, for example in the processing of industrial minerals and metal ores.

A major amount of minerals can be classified based on their spectral response in the near-infrared. Minerals show diagnostic absorption features in the region between 1300 nm and 2550 nm. The spectral response of heterogeneous material is much more complicated; wavelength shifts, overtones, overlapping of the absorption features etc. and mixed spectra occur. All this spectral variation needs to be taken into account during the design of the classification system.

Mixed spectra are caused by diluted minerals, contact zones of different rock types (with different mineral content) and the presence of water (hygroscopic and free pore water). During the detection of the spectral response in the sorting process mixed spectra can be caused by a too low spatial resolution. Increasing the spatial resolution and taking into account more varieties in the classes of the classifier can improve the sorting result. If the spatial resolution is not high enough mistakes in the classification can be caused, especially for small heterogeneous samples.

The combination of NIRS and object recognition brings the advantage of the possibility to introduce decisions for every particle individually based on statistical properties of the classification results related to the particle. For the sorting of inhomogeneous particles the object recognition can therefore improve the overall classification result. Based on the classification results of a particle also material rates can be calculated. This allows to quantify the mineralogical composition of the samples, which is essential for the application of this technology in sensor based sorting.

1 NIRS sorting in the minerals industry

Since two years the Department of Mineral Processing of the RWTH Aachen University explores, in cooperation with TITech, the technical feasibility of the implementation of Near-Infrared Spectroscopy (NIRS) sorting in mineral processing. NIRS sorting is not yet implemented in the minerals industry. In current sensor-based sorting processes, a large number of minerals cannot be sufficiently distinguished from each other by only using secondary properties (colour, brightness, transparency, conductivity, etc.). Recent tests on ores, also ores inseparable with traditional sensor-based techniques, show sufficient results with NIRS sorting, which is based on a primary property of the minerals (the specific and individual spectral response in the NIR range)¹.

NIRS sorting has its roots in the recycling industry, particularly recycling of plastics; more than 1500 NIRS sorters have already been installed with high technical availability. Besides this, the potential of sensor-based sorting in the mineral processing is high and the implementation can lead to advantages as for example water, energy and costs savings². It is therefore time to transfer the NIRS sorting technique to the minerals industry.

The method of near-infrared spectroscopy applied to minerals is known from the exploration of mineral deposits, using portable spectrometers and the analysis of drill cores extracted by exploratory drilling, where velocity is not a critical issue. Reflectance spectroscopy is also widely used in the remote sensing discipline and geologists have recognized that this method has far reaching applications in, for example, lithology mapping³. This is especially because with NIRS it is possible to create a fingerprint of a sample, which is directly related to the mineralogical composition.

The fingerprint is actually the spectral response on a NIR source; a mineral depending part of the electromagnetic radiation is absorbed which results in a spectrum with absorption features. Two processes are causing the absorption of near-infrared radiation in molecules; the electronic transitions and the vibrational transitions⁴.

The most common electronic process revealed in the near-infrared spectra of minerals is due to unfilled electron shells of transition elements (Ni, Cr, Co, Fe, etc.) and is called the crystal field effect. The crystal field varies with crystal structure from mineral to mineral, thus the same ion produces different absorptions, making specific mineral identification possible with spectroscopy⁵.

The other process causing absorption of NIR radiation in molecules is the vibrational transition. At temperatures above absolute zero, all the atoms in molecules are in continuous vibrations with respect to each other. A molecule absorbs radiation when the incoming infrared radiation is of the same frequency as for one of the fundamental vibration modes of the molecule. The exact frequency at which a fundamental vibration occurs is determined by the strengths of the molecule bonds involved and the atoms joined by the bond. Beside this the number

of atoms in the molecule uniquely determines the vibrational degrees of freedom and thus the number of fundamental vibration modes. Thus molecular vibrations do not represent random motions but well-defined displacements of the individual atoms. The same or similar functional groups in different molecules will typically absorb within the same specific frequency range. The vibrational transitions have a bigger influence on the spectra than the electronic transitions and are therefore more significant as identification criteria^{6,7}.

A major amount of minerals can be classified based on their spectral response in the near-infrared. Minerals show most diagnostic absorption features in the region between 1300 nm and 2550 nm⁸. The main molecule bondings which cause absorption features in the near-infrared region for minerals are given in table 1. Examples of NIR active minerals are listed in table 2. The number is limited because not all minerals are active in the NIR and therefore do not show diagnostic absorption features (like sulphides).

Table 1. Main molecule bondings causing absorption features in NIR

Molecule bondings	Absorption features in NIR (nm)
Hydroxyl (OH)	1400 (1550, 1750, 1850)
Water (H₂O)	1400, 1900
Carbonate (CO₃)	2300 – 2350, (1870,1990,2155)
Ammonia (NH₄)	2020, 2120, 1560
FeOH	2230 – 2295, (2330)
MgOH	2300 – 2360, (2250)
AlOH	2160 – 2220, (2200)

Table 2. Examples of NIR active minerals

NIR active mineral groups (examples)	Minerals in that group (examples)
Phyllosilicates	Clays, Chlorite, Serpentine minerals
Hydroxylated silicates	Epidote, Amphiboles
Sulphates (selected)	Alunite, Jarosite, Gypsum
Carbonates	Calcite, Dolomite, Ankerite, Magnesite, Rhodochrosite
Ammonium-bearing minerals	Buddingtonite, NH ₄ -illites Alunite group

Minerals that do not have structural OH, H₂O, CO₃ or NH₄ will not display strong diagnostic absorption features in the NIR region. The spectrum of samples dominated by other minerals can however display absorptions associated with non-diagnostic secondary components;

- Broad water features caused by fluid inclusions or surface moisture
- Clay absorptions from present weathered material and feldspathic components.

If differences in spectral response or fingerprints are large enough for detection, identification and classification based on the mineralogical composition is possible. Differences in absorption features make material sortable with NIRS sorters¹.

Shape, temperature, and moderate moisture content do also cause differences in absorption features but these are smaller than the difference caused by chemical variance. Test work showed that the influence of shape, temperature and moderate moisture content do not hinder the sorting. Other test work showed very exciting results like the possibility of sorting Baryte and Fluorite from Calcite and Dolomite. The results for sorting Marble, Talc and Borat out of waste material are also very promising. If the major components do not show specific absorption features, minor components like alteration minerals can be used as markers for the sorting task as indirect sorting criteria. Additionally to all direct applications, large potential is expected for the NIRS sensor for numerous indirect sorting tasks¹.

2 TiTech PolySort, NIRS Sorter

Till so far test work was conducted with the PolySort (Figure 1). The PolySort is a NIRS sorter designed specifically to sort polymers or mixed plastics by material properties. With its NIRS sensor, the PolySort detects the characteristic NIR wavelength reflected by illuminated objects at two wavelength ranges lying roughly in between 800 and 1800 nm. Based on the characteristic of the absorbed infrared wavelengths the material can be sorted. The working width of the machine can vary between 600-2800 mm. The manufacturer claims the sortable object size range to be between 12-300 mm^{9,10}.



Figure 1. TiTech PolySort, NIRS Sorter

The technical setup mounted above the belt (Figure 2) consists of a detector and a (in relation to the belt's moving axis) perpendicular rotating polygon mirror. This mirror moves with high speed and reflects the point signals into the spectrometer and it allows the point scanner to scan the whole belt width. On a standing belt a line will be measured perpendicular to the movement direction. On a moving belt the two movements of the scanning point on the belt and the belts velocity overlap and form a spiral scanning pattern on the belt.

The PolySort first needs to be trained with pre-classified (robust and clearly identified) samples. Groups are formed by statistical means and applied into the sorting algorithm, referred to as the classifier. The classification result can be improved by various image processing operations which take into account the neighbourhood of a scan point. It is possible to configure the sorting by the use of filter operations in a fixed neighbourhood (e.g. 4x4 filter). By adjusting filters, the software can be configured to for example eject at a position only if also a predefined number points in the neighbourhood would have been ejected or suppress ejection in a neighbourhood if a unwanted material was detected. For high throughput applications filter operations lead to stable sorting results even if the objects slightly overlap^{9,10}.

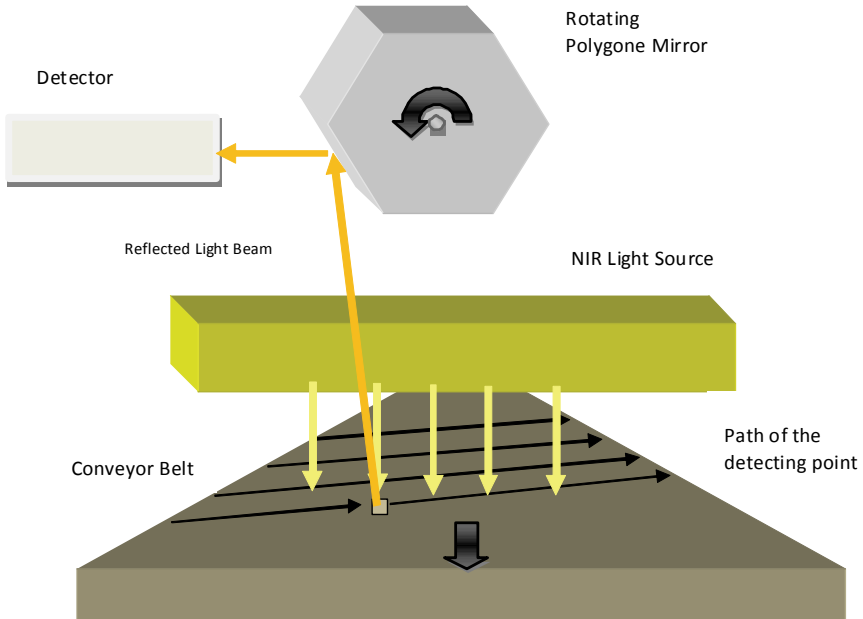


Figure 2. Technical set up of the PolySort

Homogeneous material is preferable for the sorting. The spectral response of heterogeneous material, which is the normal situation in mining, is much more complicated; wavelength shifts, overtones, overlapping of the absorption features etc. and mixed spectra occur. All this spectral variation needs to be taken into

account during the design of the classifier. Mixed spectra are caused by diluted minerals, contact zones of different rock types (with different mineral content) and the presence of water (hygroscopic and free pore water). During the detection of the spectral response in the sorting process mixed spectra can be caused by too low spatial resolution. Increasing the spatial resolution and include or “teach-in” more varieties in the classes of the classifier can improve the sorting result. If the spatial resolution is too low it can cause mistakes in the classifications, especially for small heterogeneous samples.

The software of the PolySort also allows object detection. For object detection, each measurement is classified into foreground and background. Connected foreground pixels are combined into logical objects during connected component analysis. For the detected objects, the sorting can be configured based on the statistics of the detected materials within one object or other properties of the object like shape or distribution of results. This leads to more flexibility and higher recognition rates compared to filter operations at low throughput when particles does not overlap. For the object detection a separation between conveyor belt and material must be possible and the objects should not overlap. Both conditions are considered to be critical for high capacity mining applications, but object detection might be of advantage for inhomogeneous material⁹. Preliminary test work shows the potential of the object detection.

3 Preliminary test work

Preliminary test work is done on a sample collection consisting in different waste and ore material from a non-sulphide zinc mine. As well the ore material as the waste material contains minerals which are active in the NIR. Well-developed absorption features in the near-infrared region characterize the occurring Zn arsenates, carbonates, phosphates and sulphates (ore material). Those absorption features show spectral differences with the occurring waste material, which make NIRS sorting theoretically possible. The main goal of the sorting task in this case is the pre-concentration of the material to lower the acid consumption in the conventional process, which can save costs up to 20% of the operation costs. In addition to this task the sorting will only be economically feasible if the recovery of the zinc after sorting will be controlled and lies around 80%. Test work is done to unfold the potential of the combination of NIRS sorting and object recognition software.

The training suite, consists in six rock type classes, with 10 pieces for each class. A non linear Support Vector Machine was used to solve the classification problem. The training set is shown in a two-dimensional presentation (scatter plot) in Figure 3. Every cross in the scatter plot stands for a recorded spectrum.

Different samples are measured/detected on a running conveyor belt with object detection. The results can be seen in Figure 4. Every small square is one scan point and every colour stands for a different rock type (the same classifier as above is used)

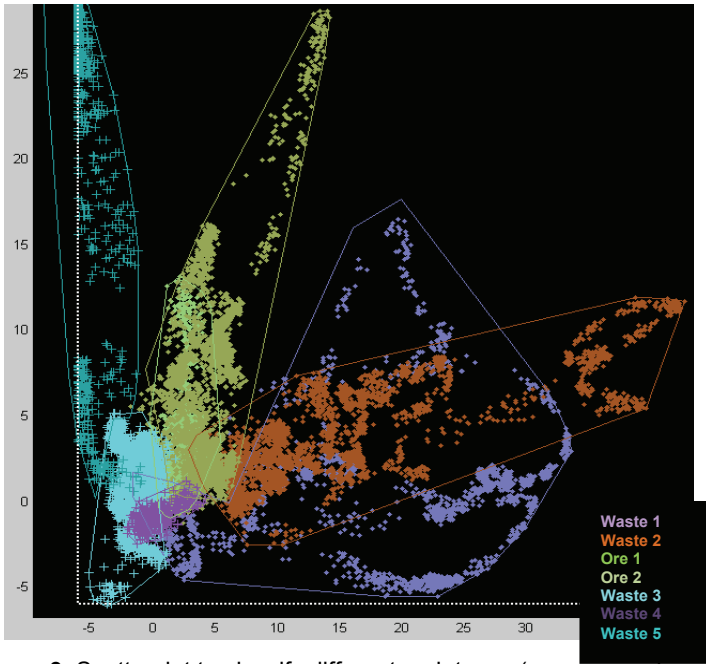


Figure 3. Scatterplot to classify different rock types (every cross is a detected spectrum)

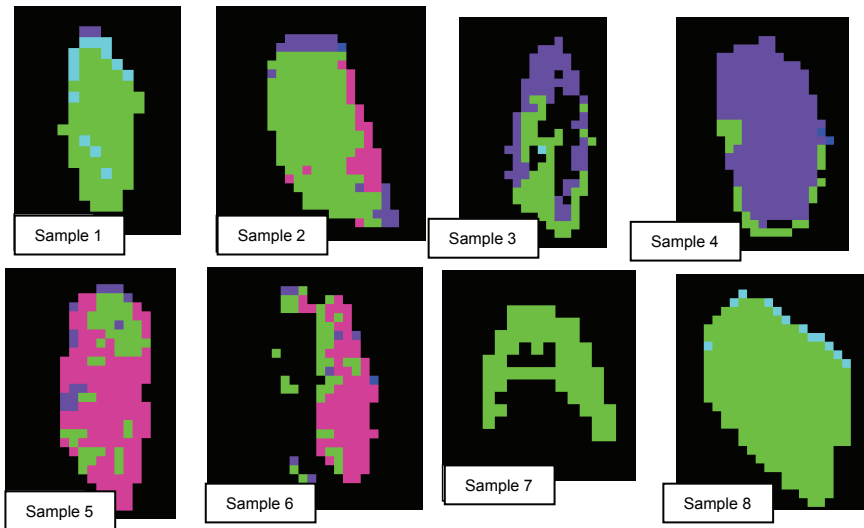


Figure 4. Object detection of eight samples. Black= Conveyor belt, Green= Waste 1, Light blue=Waste 2, Pink= Waste 3, Dark blue=Ore 1, Purple=Ore 2.

It is directly visible in Figure 4 if ore material is present in the samples and in which quantity in relation to the waste material. For example; sample 1 contains mostly waste and only a very low amount of ore material. Sample 4 is the opposite and contains mostly ore material and only a very low amount of waste material. The spectral image of sample 3 shows around 50% waste material and 50% ore material. It is possible to define the limits of the sorting classes in terms of grade and recovery and eject or reject every single particle based on those limits. This means that if we are interested in material containing 50% ore we teach the sorter to keep sample 3.

4 Potential of NIR spectral imaging in the minerals industry

The combination of NIRS, object recognition and a high spatial resolution brings the advantage of the possibility to decide for every particle individually in which class it belongs. For the sorting of inhomogeneous samples NIR spectral imaging can be the solution, because of the possibility to use a large mathematical toolbox to define the limits of the classes (grade, recovery etc). This way it is not only possible to qualify but also quantify the mineralogical composition of the samples. Therefore NIR spectral imaging has a high potential in the minerals industry.

It will be necessary to test and study every mineral deposit separately to see if the implementation of NIR spectroscopy brings the expected advantages and if object recognition can even improve the sorting.

Literature

1. Wotruba, H., Robben, M. R., & Balthasar, D. (2009). [Conference] Near-infrared sensor-based sorting in the minerals industry. Conference in Minerals Engineering 2009. Lulea, Sweden.
2. Riedel, F., & Wotruba, H. (2005). [Project] Review of Sorting Technologies, Chapter 5. AMIRA Project P902: "Dry Processing Review". RWTH Aachen.
3. PIMA. [Online] Spectral International Inc, Infrared field spectrometer. October 2008 <<http://www.pimausa.com/index.html>>
4. Hollas, J. M. (2004). [Book] Modern Spectroscopy, fourth edition. Chapter 1,2 and 3. Chichester, England: John Wiley & Sons.
5. Clark, R. (1999). [Book] Manual of Remote Sensing, Volume 3, Remote Sensing for the Earth Sciences (A.N.Rencz,ed.), John Wiley and Sons, New York. Chapter 1: Spectroscopy of Rocks and Minerals, and Principles of Spectroscopy, p 3-58.
6. Atkins, P., & De Paula, J. (2006). [Book] Atkins' physical chemistry. Oxford : Oxford University Press. Chapter 13: Molecular Spectroscopy 1: Rotational and Vibrational Spectra, p. 431-477.
7. Clark, R. (1995). [Online] AGU Handbook of Physical Constants, Reflectance Spectra. June 2008 <www.agu.org/reference/rock/14_clark.pdf>
8. Robben, M. R. (2008). [Unpublished] NIR Sensor Sorting, Basic study for application of NIR spectroscopy for sorting minerals. Bachelor Thesis . RWTH Aachen.
9. Robben, M.R. (2009). [Unpublished] Feasibility study on the use of NIRS sorting in the process of Skorpion zinc ore. Master Thesis. RWTH Aachen/Tu Delft
10. TiTech, www.titech.com