ENHANCING MINERAL SEGMENTATION IN OPTICAL MICROSCOPY WITH MULTISPECTRAL IMAGING

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Colour Imaging in Optical Microscopy

Reflected light optical microscopy is a very common tool in the study of ores and metals. Experienced users take advantage of the different optical behaviour of minerals in order to identify these. Among the most prominent optical properties are : average reflectance intensity, colour, optical anisotropy, internal reflections, crystal habit, quality of polish, relative hardness, etc… (Ramdohr, 1978). Only but a few of these properties can be used for automated mineral identification procedures in optical microscopy. Among these the colour of minerals often appears to be the most easy property to grab, but only a rigorous approach of the reflectance theory (Criddle and Stanley, 1993; Criddle, 1997) will lead to efficient image segmentation.

As far as understood, human colour perception is best modelled by a tristimulus (R,G,B) theory. This is essentially why colour video cameras are based on a set of three filters corresponding more or less to 100nm bandwidth filters centred around 450nm (B), 550nm (G) and 650nm (R). Cheap colour cameras use a single CCD and build colour information at the expense of spatial resolution by using one pixel out of two for green intensity measurements and one out of four for both red and blue measurements. More professional 3-CCD cameras use a prism to triplicate the image and are able to give full resolution for each channel. However, they rely on synchronised imaging (40ms for broadcasting standards), which may lead to underexposure of one of the channels. To allow for optimal colour imaging more recent scientific systems use filter wheels or liquid crystal filters in front of a single CCD. By grabbing R, G and B channel images sequentially such systems permit different exposure times. Table 1 indicates typical exposure times observed with sequential filters technology in imaging iron sulphides. For many applications where strictly static scenes are involved (such as in materials microscopy), sequential RGB clearly supersedes parallel (synchronised) RGB.

Filter	
Blue	3000 ms
Green	280 ms
Red	40 ms

Table 1. Integration times for optimal exposure of a single CCD using Kodak Wratten R(n°25),G(n°47b),B(n°58) filters

Filter	
360	2 s
438	750 ms
489	150 ms
591	50 ms
692	100 ms
870	400 ms

Table 2. Integration times for optimal exposure of a single CCD using Melles-Griot interference filters on an Olympus BX-60 microscope.

An obvious extension of the filter wheel technology is to use narrow bandwidth filters instead of RGB. Although light intensities are much lower, this should not be a problem for scientific grade sensors and microscopes equipped with strong (100W) light sources. Table 2 gives indications of integration times using 10nm bandwidth interference filters (absolute values should not be compared to table 1 since the scene is different). This mode of imaging fills the gap between spectrophotometric databases (Criddle and Stanley, 1993) and imaging (Fig.1.). It opens the way to more efficient computer assisted phase identification under the optical microscope, although more research is still needed to take into account optical anisotropy.

Mineral pairs	Multi	RGB
Pentlandite - Pyrite	33.11	10.98
Pyrite - Mispickel	78.69	70.62
Pentlandite - Mispickel	188.42	85.05

Table 2. Mahalanobis distances indicating the superior discrimination between phases with multispectral imaging (438 nm - 498 nm - 692 nm) in contrast to sequential RGB

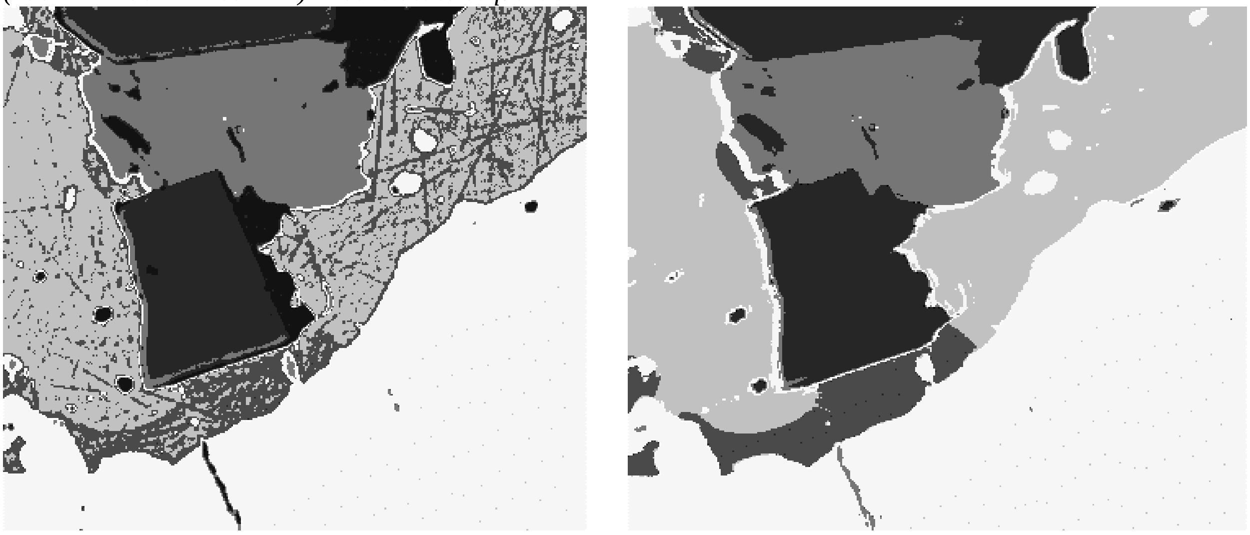

Figure 2. Minimum Euclidean Distance (MultiSpec ®) classification of a stannite, sphalerite, chalcopyrite ore from Tchequia. Identical training sets where used for both RGB and multispectral (6 channels) images. Misclassification of pixels along boundaries is mostly due to imperfect image superposition in the multispectral scene.

Multispectral image segmentation.

The benefits of using multispectral imaging in mineral segmentation can be quantified with multivariate statistics (Mahalanobis distances)(Table 2). Clearly subtle differences in reflectance spectra such as between Pyrite and Pentlandite are best contrasted with narrow bandwidth multispectral imaging. This superiority is evident from classified images issued by multivariate discriminant analysis procedures. In order to test these, several images of ore sections have been segmented with the MultiSpec software using either Gaussian Maximum Likelihood or Minimum Euclidean Distance classification. With identical training sets, multispectral images always offer more complete pixel segmentation. Residual imperfections are mostly due to defaults in the surface state of minerals (scratches, pits,…) and to the spatial drift between images. This last problem is due to the different focal planes corresponding to each wavelength and to imperfect perpendicularity between the specimen and the optical column. It is best compensated by checking image coincidence before starting the classification.

References :

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MultiSpec© – A Multispectral image data analysis system, http://dynamo.ecn.purdue.edu/~biehl/MultiSpec/