SENSOR FUSION AND CORRELATION OF X-RAY TOMOGRAPHY AND LIBS DATA FOR DRILL CORE ANALYSIS

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Summary: With techniques of sensor data fusion, the acquired data from both, surface material sensors as well as penetrating X-ray CT are combined to estimate chemical and mineralogical information of internal structures of drill cores.

1. INTRODUCTION

State of the art techniques for drill core analysis for exploration purposes, including X-ray fluorescence (XRF), laser-induced breakdown spectroscopy (LIBS) or Raman spectroscopy are used to derive chemical or mineralogical information. Since the sensor data correspond to materials that occur on the surface of the core, inclusions (e.g. diamonds) are not detected. In addition, mineral information not registered by the sensors is not taken into account and may lead to misinterpretation or the simple miss of certain elements. X-ray computed tomography (CT) provides data about the entire sample as well as inlying structures based on X-ray absorption. As a drawback, CT is time-consuming and the material information is not as reliable as information extracted from fluorescence or spectroscopic techniques.
For the enhancement of geological interpretation in exploration and geoscience, we propose to apply sensor data fusion techniques in order to unite both, depth information as well as reliable material data from surface measurement techniques. This leads to more substantial information of the drill core.
For further insights in the feasibility we investigate the correlation of LIBS data at varying abstraction levels with CT data, i.e. grey value information.
In addition, the applied surface techniques acquire the data non-continuously but punctually discrete. This is accompanied by the circumstance that the data acquired may have a distinct sampling rate, which might result in a spatial resolution of different magnitude, compared to micro-CT data. Another challenge is to register the surface data (as raw or calibrated data) coming from a one-dimensional scan line or a two-dimensional scan area with a three-dimensional micro-CT volume. The experiments must hence be planned in a way that the location and orientation of the scan data are well-known and reproducible.
In the experiments, the registered data of defined drill cores is analyzed with respect to correlation and fusion capability. The experimental setup will be presented and results will be discussed.

2. EXPERIMENTAL METHOD

For the scans we chose two drill core segments with a comparably short length of approx. 16 cm (sample A) and 12 cm (sample B) respectively in order to use an existing mount for the reduction of spatial uncertainty which comes along with the usage of a handheld device. The sample has a diameter of 50 mm. We expected the core to contain mainly silicon and aluminum compounds. For the experiments we acquired LIBS and XRF data on four vertical scanning paths (1-4, sample A) and two scanning paths (5-6, sample B) respectively and CT data of the two segments.
CT: The axial CT data was generated using a micro-CT system with an Yxlon microfocus tube and a Perkin Elmer 4k detector with a pixel binning of factor 2x2. We acquired a set of 1200 projections with a total exposure time of 6 minutes at radiation energy of 220 keV with 1 mm Cu prefiltering. The volume was reconstructed with a filtered backprojection algorithm.

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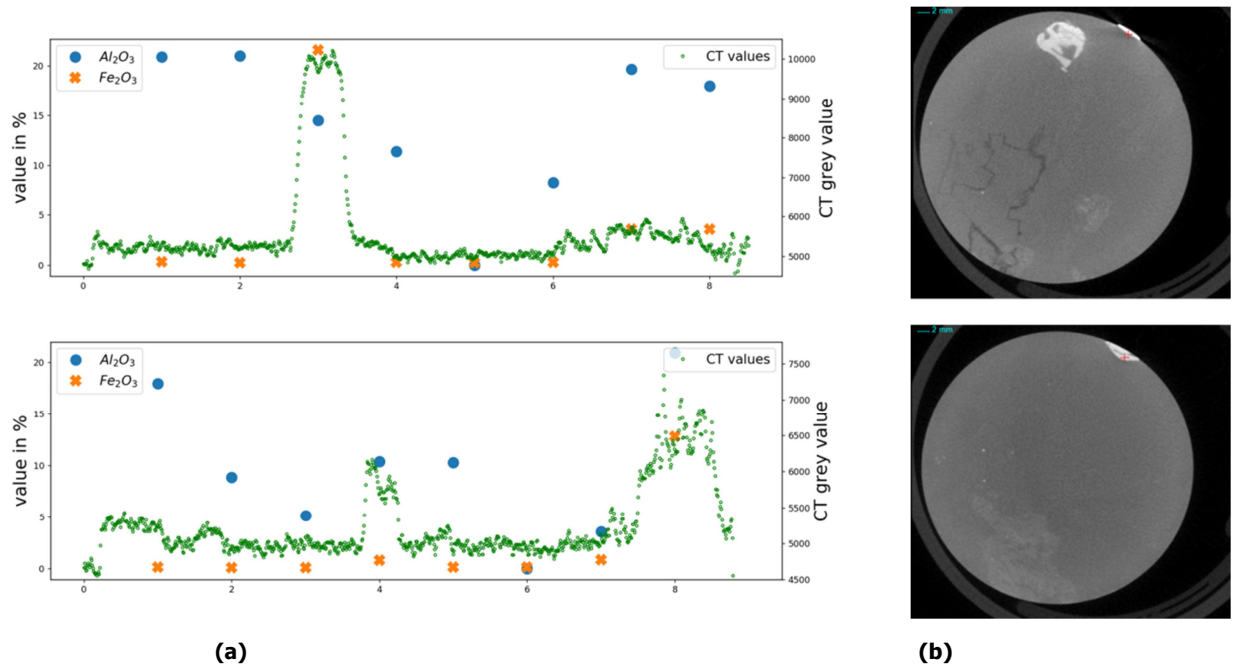
LIBS: The LIBS data were acquired at a setup optimized for geological samples at 20 Hz with a Laser of 50 mJ power and a 1064 nm wavelength.
XRF: For XRF scans we used a Bruker S1 Titan 800. The device is equipped with a silicon drift detector and a Rh-target (5 mm spot size). We used a total measurement time of 14 s per measurement point using two different X-ray spectra. We intended to use the same scanning path as used in the LIBS scan within the inaccuracy of a manually positioned sensor.
For the analysis we first extracted features from CT data, then compared LIBS data with XRF. As a next step we registered CT and LIBS data and evaluated the correlation. Finally, we did further analysis of the information content in CT data exceeding the information gathered by the LIBS measurements.
For registration purposes we stuck a zinc foil on the sample, having verified beforehand, that neither LIBS nor XRF sensors detect any significant zinc content in the sample.

3. RESULTS

The results include the CT, LIBS and XRF data. The features extracted from the CT include data corresponding to a grey value profile extracted from the scanning path used for XRF and LIBS scans. The XRF scans lead to the insight that the core segments apart from SiO_2 mainly consist of Al_2O_3 with occasional occurrences of Fe_2O_3, K_2O, MgO, CaO and others (< 1%). For a verification of the experimental method, we picked Al_2O_3 and Fe_2O_3 as an example. Figure 1 (a) shows the concentration of Al_2O_3 and Fe_2O_3 determined in scans 1 (sample A, Figure 1 (a) top) and 5 (sample B, Figure 1 (a) bottom) compared to the grey value level. The concentration of both Al_2O_3 and Fe_2O_3 varies significantly for the benefit of SiO_2. Measurement point 3 on scan path 1 shows a concentration of Fe_2O_3 of 0.216 while the adjacent concentration level does not exceed 0.01. In the same region, CT grey values increase from ~5,000 grey values up to ~10,000 grey values, while the overall mean grey value in the core segment resulted in ~5,100. The corresponding slice is show in Figure 1 (b, bottom). On the other hand it is obvious that occurrences of Fe_2O_3 will only be detected by XRF if it is tangent to the surface of the drill core (Figure 1 (b), top).
A closer look at the plots leads to the assumption that the occurrence of Fe_2O_3 has a much higher impact on the grey value than Al_2O_3. Scan path 5, measurement point 4 shows a grey value increase of 20% while the concentration of Fe_2O_3 develops as follows: $9*10^{-4}$; $82*10^{-4}$; $15*10^{-4}$ for measurement points 3; 4; 5 (see Figure 1 (a), bottom). The increase of Al_2O_3 concentration on the other hand is not visible in the grey value profile. This is plausible since Al and Si have a similar density, their atomic numbers only differ by 1 and they hence show a similar X-ray absorption behavior.
Results considering further compounds, results of the correlation, suggestions for data fusion techniques and discussion will be presented.



(a) **(b)**

Figure 1: (a) Concentration of Al_2O_3 (o) and Fe_2O_3 (x) determined by means of XRF and corresponding grey value profile (spots) extracted from the reconstructed CT volume. (b) Reconstructed CT slice corresponding to measurement point 3 of scan 1 (bottom) and slice showing an inclusion which is not detectable with XRF or LIBs techniques (top). The zinc foil on the surface is intersected.