Welcome to the Real-Time Mining project!

The Real-Time Mining project started its third year. Since the last newsletter has been published in fall 2016, the different working packages have further progressed. The main focus during this period has been on new method development and verification in the fields of automated data gathering, data management, modelling and optimization related to grade control in complex ore deposits. Also, the demonstration case Reiche Zeche mine in Freiberg has been prepared already for the validation and demonstration phase. Different test blasts and sampling programs have been conducted using newly developed technology.

Although only half way into the project, several remarkable and promising results have already been achieved, which have been partially published or presented at international conferences. The positive feedback, we have received so far, encourages us to further fully dedicate ourselves to a successful implementation of the Real-Time Mining project in all its aspects. To provide a platform for inter-project communication and for communication with project stakeholders, the first Real-Time Mining Conference has been initiated. It will be held in October in Amsterdam bringing together several European research projects in the field of industry 4.0 applied to mineral resource extraction. These are the projects VAMOS, SOLSA and UNEXMIN. It is hoped this platform serves for lifting synergies, strengthening the project focus and to initiate potential further developments and exploitation activities. We are looking forward to this event and perhaps we will have a chance to meet you there.

In this newsletter, recent activities related to the different building blocks of Real-Time Mining are summarized. Please feel free to contact us for comments, suggestions or questions. We hope you enjoy reading.

Kind Regards from the project coordination,

Project Coordination
Mike Buxton and Jörg Benndorf

The Real-Time Mining project has been awarded funding from the European Union’s Horizon 2020 Research and Innovation Programme under Grant Agreement No 641989
The project consortium comprises thirteen European partners from five countries and is led by the Resource Engineering Section of the Delft University of Technology assisted by an International External Expert Advisory Board. Besides Delft University of Technology, the partners involved include the Rheinisch-Westfälische Technische Hochschule Aachen; Imperial College of Science, Technology and Medicine; Associacao do Instituto Superior Tecnico para a Investigacao e Desenvolvimento (IST-ID); Nederlands Organisatie voor Toegepast Natuurwetenschappelijk Onderzoek-TNO; Geovariances, Dassault Systems GEOVIA Ltd.; LSA-Laser Analytical Systems & Automation GmbH; XGraphic Ingenieurgesellschaft mbH, SonicSampDrill BV; Technische Universität Bergakademie Freiberg; Spectral Industries B.V. and Ingenieurpartnerschaft für Bergbau, Wasser und Depo-
In work package three, the rtMine project undertook a leap forward! Three major Deliverables were completed and handed in on time. Finishing the developments on the ultra-wideband radio system (UWB), TNO’s marvellous DriftLess inertial measurement unit (IMU), and the laser-scanner, the focus for all work efforts lies with the development of the sensor fusion.

First steps in this direction were taken with a literature research that identified the sequential Monte Carlo method for particle filter as the fusion method uses. First trials using simulated test data, proved this to be right. After deciding on the overall system architecture in a workshop with both partners involved, we are now working on the implementation of the sensor fusion algorithm to run under the robot operating system (ROS) framework.

In detail, RWTH Aachen University finished developing the prototype system for the UWB radio. Further tests in the Reiche Zeche mine in Freiberg proved the concept. At the same time the labour on the laser-scanner was finished. We have now a working system that reliably detects standstills of the vehicle. Eventual drifts were reduced to a minimum so that the laser-scanner can really backup the IMU in the sensor fusion. Partner TNO worked ceaselessly on the IMU. They finalized the architecture and by now the DriftLess processing is running stable and real time in Python and ROS on a NUC i7.

Regarding future work in work package 3 another test measurement underground is scheduled for the end of this year. Between April 2018 and September 2018, we will finish our work with the demonstration action of the whole system in the Reiche Zeche in Freiberg.

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To achieve this, potential sensor technologies are identified and sensor combination concept based on definition of sensor specification is defined. Currently, laboratory scale test work and validation of sensor specifications is in progress. Later, statistical inference rule which links KPIs with sensor measurements will be developed.
Field campaigns

Two field campaigns were undertaken in the Freiberg mine test case. During the first field campaign, a mine face with ~22m lateral extent was defined, mapped and imaged using thermal camera and RGB camera. Moreover, to collect fully representative samples, a channel sampling method, which is advantageous to sample from each lithotype and ore type independently, was deployed. A total of 23 channels were cut and about 102 samples were collected at different intervals of each channel. To acquire other dimension information, 6 drill core samples were collected from different locations at the defined mine face. As a follow up from the first field campaign, a second field campaign was undertaken and a demonstration block (DB) with lateral extent of ~4m was defined, mapped and imaged. The demonstration block is part of the primarily defined mine face. Moreover, channel samples were acquired. At the DB, drilling and blasting activities were performed and a muck pile was generated from the blasted material. Likewise, representative samples were acquired from the muck pile. To demonstrate LHD, the blasted materials were organized into wagons and the wagon materials were imaged and sampled.

Test measurements

Using the identified potential sensor technologies and the collected samples test measurements are in progress:

Red-Green-Blue (RGB) imaging - a well-defined imaging procedure was deployed to image the defined ~22m lateral extent mine face. The acquired images are georeferenced, mosaicked and a mineral map is produced using supervised image classification technique. The developed supervised classification identified 5 mineral types. The approach showed the potential of the technique for delineation of ore zone, host rock and weathered material boundaries in underground mine.

Thermal Imaging - thermal imaging is conducted in the laboratory and in -situ (in the underground mine). Thermal images are acquired for the whole ~22m mine face and at the demonstration block mine face. The thermal images evaluation task is in progress. The technology showed promising result for textural and compositional information.

Fourier transform infrared spectroscopy (FTIR) - The measurement is optimized for the test case materials and it was performed using pulverized rock samples. Using the spectral response of the materials and adopted design of experiment we are able to classify the material into three classes namely ore, clay (weathered material) and the host rock (Gneiss). The test measurement will be extended to more spectral data analysis. Later, peaks will be identified using the observed feature of FTIR spectral data.

Hyperspectral Imaging - over VNIR and SWIR region was carried out using rock chips samples acquired from the channel cuts. Hyperspectral image preprocessing work is completed. Currently, end-member collection and classification work is in progress. The technology shows promising result in the identification of alteration products.

Laser Induced Breakdown Spectroscopy (LIBS) - LIBS measurement will be performed using two instruments: a newly developed LIBS system and a commercially available system. Later, the results of the two systems will be compared and the improvement of the developed system over the commercially available one will be assessed. The newly developed LIBS system measurement setup is finished. Fine-tuning will be done and measurement series are planned in September. SI is able to perform gated LIBS with the new spectrometer. The in-house developed electronics and synchronization scheme allows to operate the camera with less than 100nsec jitter. The reported jitter by the manufacturer is 14mu seconds so 2 orders of magnitude more. SI is considering to apply a patent on this development.

RAMAN - test work will be performed soon. Raman consideration for this project will be decided later based on the planned test work.

LSA - worked on an efficient way of determining elements concentrations based on spectra captured by SI. A program reads the files produced after each measurement cycle and calculates the integral out of some sections where isolated and element signature peaks are located. As the intensity of these peaks could vary between two measurements, even on the same sample, the integral is then divided by a reference, which could be either a specific area or a sum of all integrals. These corrected values can then be compared to a calibration model to get in the end of the process a list of elements together with their estimated concentration.
Measuring machine performance and acoustic fingerprints of cutting and drilling machinery (WP5)

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“It’s ‘still’ dark ahead of the pick”. The old miners’ proverb has already been quoted in the last Real-Time Mining newsletter and reveals the uncertainty about the rock and its geology for material extraction and drift processes. Especially for underground mining, it is still impossible to reliably predict the material that extraction machinery or drill rigs will come across during operation. In terms of safety, tool wear and the entire machine performance it would be beneficial to gain more information about the process in real-time. [1] [2]

The IMR of RWTH Aachen University and the Royal Eijkelkamp SonicSampDrill company are currently investigating different kinds of monitoring systems and sensor technologies to be able to conclude on the machine performance, as well on mechanical rock properties. A variety of sensors has been installed on a cutting test bench (RWTH Aachen), as well on a drill rig (SonicSampDrill). To serve as a single tangible example for monitoring machine performance, the torque of the drill string is recorded constantly. It is plausible that an increasing rock strength during drilling may simply result in an increasing torque. But, it is also plausible that two different rock types with a common rock strength could lead to similar results and false interpretations. Therefore, the correlation of different sensor signals for different rock types is currently evaluated.

Another opportunity is to conclude on different characteristic rock fracture behaviour by measuring acoustic waves. Acoustic waves are particularly generated due to different crack initiation and crack growing processes within different rock types. Basically, these acoustics are daily used by a machine operator. He simply listens to the fracture behaviour or senses the vibrations of the machine body as a reaction to the penetrated material. These waves can also be recorded by using appropriate acoustic sensors. An intelligent combination of low frequent vibration sensors and also high frequent Acoustic Emission (AE) sensors allows to gain not only audible but also non perceptible emissions. Hence, an entire acoustic fingerprint of cutting and drilling processes can be built. Such a fingerprint allows to depict the energy demand of drilling and cutting machinery as well to distinguish different crack initiation and crack growing procedure during cutting and drilling. [1] [2]

Acoustic fingerprints have been taken from cutting and drilling processes in a laboratory environment, as well in field tests. [1] As an example, some test results, of setting up an acoustic fingerprint of a drill tests, are shown in figure 1. Acoustic sensors have been mounted to a drill rig before drilling through granite, concrete and clay. Analysing the acoustic data clearly allows to distinguish the three phases due to their different cracking behaviour. [3]

Cutting tests in a laboratory environment ended within the project as scheduled. Currently algorithms are evaluated that allow an online analysis of the machine performance as well to draw conclusions on mechanical rock properties. Chosen specific values like the energy demand and an estimated rock strength could be visualized within the Real-Time Mining project for cutting processes. Due to the promising results of acoustic sensors during drilling, a second test campaign is planned for September this year. Hereafter, also data processing algorithms will be evaluated that should also allow real-time visualisation of chosen specific values.

Results of drill tests with a SonicSamp Drill CRS-T mast drilling trough granite, concrete and clay. [3]


The purpose of work package 6 (WP6), "Data Integration, Management and Visualization", is the development of an integrated data management system and a 3D visualization cockpit to collect, exchange and visualize all the accumulated data in the project. Different tasks have been carried out by the involved partners:

**LSA**

LSA worked on an efficient way of determining elements concentrations based on spectra captured by SI. A program reads and processes the files produced after each measurement cycle. These results can then be compared to a calibration model to get in the end of the process a list of elements together with their estimated concentration.

**Geovia**

Geovia’s part in WP6 is the development and integration of a central data management framework (DMF): Based on existing software solutions from Dassault Systemes for information exchange for mine planning, monitoring and for gathering and alignment of data, specific requirements have been carried out with all partners and a first instance has been implemented. Latest work has been the testing of the web interface for the DMF and the completion of the initial setup of the server. The windows based integration to the workspaces in the DMF will enable any user to manage the data through the Windows Explorer interface. Geovia has also performed an update on the bench server infrastructure to enable utilisation of the latest version of the 3DEXPERIENCE PLATFORM 2017x FD03. This provides additional collaboration tools that were not previously available. Next tasks will be to publish the server for external testing by the partners and to develop a daemon to allow automatic data uploads.

**XGraphic**

XGraphic is responsible for the implementation of the visualization cockpit software, based on the data provided by the DMF. The cockpit is planned as fully interactive 3D application. Different screens for mine layout overviews and the visualization of active operating points with details about mineral content, tonnage, schedule information and the local grade control model will be available. Latest work include the development of different libraries for required visualization modules of the program. In a first instance, different block model datafiles have been considered and tested. XGraphic works very close with RWTH university with regard to WP8: One important feature of the cockpit software will be the parameterization and execution of the optimizer that will be developed within this project. Finally, the visualization of the resulting scenarios will help the decision maker to evaluate the optimizer results. Next steps will be the implementation of graphical user interfaces for the different screens as well as further.
Sequential Resource Model Updating (WP7)

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One of the corner stones of the Real-Time Mining concept is the ability to rapidly integrate different sensor data gathered during extraction, such as face images, material characterization data on conveyor belts or energy usage records of the mill, and feed it back into decision making models.

During the second project year the focus was on the methodological development of sequential updating algorithms. For applications related to the two case studies, the Reiche Zeche Mine (Germany) and the Neves Corvo mine (Portugal), algorithmic approaches have been derived to sequentially integrate data from different face images (RGB images, Hyperspectral Images, Thermal Infrared Images) or point data taken from the mining face (hand held XRF data, sensor data on the belt conveyor) into grade control models.


During a three field campaign related to blasts of mining blocks, complete data sets have been taken including images (RGB, hyperspectral, thermal, IR), and point data. These data are processed in WP4 and deliver information for a subsequent mining block, mainly additional information about proportions of minerals. A new algorithmic approach based on data assimilation (a modified version of the Ensemble Kalman Filter) has been developed and coded to sequentially integrate these data in a prior grade control model to continuously improve prediction of mineral content for the next mining blocks. Validation investigation using the synthetic environment provided by the Virtual Asset Model of the Reiche Zeche Mine show promising results. The figure (down left) shows a stope, which has already partially been mined. Data from synthetic sensor data have been continuously integrated for updating the occurrence or proportion of three relevant minerals. The figure illustrated that the estimation lower decreases significantly, not only in the mined out area, but also in mining blocks, which will be mined during the next mining pass.

Case Neves Corvo Mine, Portugal: VMS copper zinc deposit (Partners: IST Lisbon, Imperial College)

For the Neves Corvo case a method has been developed to integrate soft data derived from hand held devices (XRF scanner) with grade control samples (chip and channel samples) for unbiased and improved prediction of block grades. The approach is based on the bi-variate distribution between hard data and point sensor information, which is derived from historic data. The integration of this bi-variate distribution with the grade control model is achieved using the method of Direct Sequential Simulation with Point Distributions (See Figure below). At the moment the method is tested for Zimbujal orebody.

During the second project year, several presentations have been given/ will be given at following conferences:

- SME Annual Meeting in Denver, USA – February 2017
- Geokinematisher Tag in Freiberg, Germany – May 2017
- CoDawork 2017 - 7th International Workshop on Compositional Data Analysis, Italy – June 2017
- IAMG conference in Perth, Australia – September 2017
- Real-Time Mining Conference in Amsterdam, Netherlands – October 2017
The overall aim of WP 8 is to analyze and evaluate the total potentials of integrating real-time data generated by WP 2 to WP 5 into the mine planning procedures and production control. Thus deviation between the origin prediction and the real resource can be easier considered in future plans.

**Mine Planning under Geological Uncertainty**

In Task 8.1 a computational tool for optimizing long-term mine planning under geological uncertainty is developed. The overall approach can be seen in Figure 1. Multiple resource models, generated by WP 7 represent the geological uncertainty as input. The computational optimization tool generates multiple mine plans under defined constraints by maximizing economic success. The risk management takes control over present uncertainty. Parts of the deposit that are classified as uncertain based on probability functions are penalized. Therefore, the influence of these parts is reduced and a resource model including uncertainty is created. Based on this resource model an optimal long-term mine plan is generated using the developed optimization tool. Thus, over-and underestimation of a mining project can be prevented and a more rigid mine plan is generated.

Currently, we are working on Task 8.2. In the framework of the long-term optimizer a short-term optimization tool is developed. To further reduce uncertainty real-time data is implemented to update production scheduling.

**Analysis of Smart Tag Integration in Mining Industry**

The particular application of Smart Tags has been used to track materials mined to link spatial mine date to time based processing data, to increase confidence in ore blending, to apply proactive process changes for known ore types and to measure accurately the residence times in stockpiles and bins.

Currently, it is being set up a campaign to investigate the use of Smart Tags for Mine Call Factor control, in particular the spatial characterization of main factors which condition the errors of misclassification: distance to the main ore type sills, intermediate stockpiles, grades, etc.

This task involves one important implementation step at the mine site (Neves-Corvo). The main design and planning the Smart Tag monitoring campaign involves the following steps:

- Selection of homogeneous sets of stopes – panel- in terms of factors which can impact on the misclassifying errors.
- Implementing the campaign of ore type tracking by using the Smart Tags.
- Statistical and geostatistical treatment of the main results of ore type tracking.
The partners in Workpackage 9, TU Bergakademie Freiberg (TU BAF) and IBeWa Consulting (IBeWa), proceed the development of data handling in underground mining, as well as their support of the Real-Time-Mining’s project partners at sampling and testing activities in the research and education mine Reiche Zeche. In this respect the data engineering foundation of the Mine Control Station developed by TU BAF for small to medium scale mining operations got defined and is under construction according to the prerequisites of today’s mining industry.

The first project going into construction by the beginning of the year, is the installation of a wireless network area for development and testing of mobile devices at the Reiche Zeche mine. Particularly the partners of Workpackage 3, RWTH Aachen and TNO, use this for transmitting collected data of their Underground Positioning System, installed on a mobile cart, in real-time. The WLAN network is designed to meet high bandwidth and network coverage, as research and testing activities are mostly reliant on high accuracy for data transmission.

The requirements of this sub-project had become more challenging compared to classical WLAN installations, since the environment in the underground mine Reiche Zeche is challenging for radio transmission for multiple reasons:

- cross sections of the drifts < 2.5 m²
- curvy drifts with low sight ranges
- highly slated gneiss as host rock with very numerous reflection layers
- high humidity of 97%
- technical rules for explosives call for low spot energy exerted by electromagnetic fields

Radio transmission via conventional radio antennas, either omnidirectional, has met the demands for research applications neither from economical nor transmission and reception point of view. Alternatively, the leaky feeder approach was chosen and subsequently installed, providing direct and short range distance between the mobile devices and the radio transmitter all along the installed loop of 600m.

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Accompanying this installation, IBeWa Consulting proceeds the development of its Through the Earth (TTE) technology, presenting a transmission approach for radio signals through the host rock by very low frequency (VLF). The objective of IBeWa within the Real-Time-Mining project is the integration of remote sensor technologies into central data transmission infrastructure of an underground mine. This technology is highly dependent on the environmental and geological conditions. Currently, IBeWa is aligning the TTE technology to the conditions of underground ore mines, being characterized by wet and fissured host rocks.

Previously, TU Bergakademie Freiberg has analysed the prerequisites and problems to data management and SCADA systems defined by the mining industry. While lack of functionality for mining equipment was not considered to represent a major problem, integrity and compatibility of (multi-) vendor systems is. TU BAF, as a result, dealt in detail with the transmission architecture OPC Unified Architecture and its applicability to mining environment. OPC UA is a platform independent architecture, which allows communication and interaction across systems from shop floor to Enterprise and Cloud level. It is going to become the fundament of the Mine Control System developed by TU BAF for small to medium scale mining operations.

Beyond the technical developments, TU BAF is glad to have hosted again the partners of Real-Time-Mining at its Research and Education mine Reiche Zeche. TU BAF is organizing, preparing and supporting sampling and testing activities of partners requiring on-site results from an underground mine environment. In particular the partners

- RWTH Aachen (Workpackage 3) performed test runs of its Underground Positioning System basing on the Ultra-Wide-Band principle.
- RWTH Aachen and TU Delft (Workpackage 4) performed sampling and imaging activities at one of the mine’s ore bodies, in order to obtain a database for validation of the material characterization sensor development.
- IBeWa (Workpackage 9) performed test runs of their Through the Earth data transmission technology in the gneiss / ore formation of the mine.

The whole activities will be rounded off by the Real-Time-Mining’s demonstration activities at Reiche Zeche mine in April 2018, organized by TU BAF. Each partner will bring its system online, present the individual capabilities and finally merge the systems to the global Real-Time-Mining Control Cockpit with the aim to shift decision making processes in mining into real-time.
The conference will be held in Koninklijke Industrieele Groote Club, Dam 27 located at the heart of Amsterdam and easily reachable by public transport, 15 minutes from Schiphol airport and 45 minutes from Rotterdam airport.
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