

INTELLIGENT ONLINE MONITORING SYSTEMS FOR HIGH-REVOLUTION ROTARY FURNACES

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Abstract

This paper characterizes the important features of intelligent monitoring systems and demonstrates how it is transforming mining or raw materials sectors. It reviews and identifies research areas that need to be investigated further, such as adaptation, data fusion and tracking methods in a cooperative multi-sensor environment, extension of techniques to classify complex activities and interactions between detected objects. The growing demand for production variability and safety or security has led to more research in building more efficient intelligent monitoring systems. Therefore, a future challenge is to develop a wide-area distributed multi-sensor monitoring system which has robust, real-time information algorithms able to perform with minimal manual reconfiguration on variable applications. Such systems should be adaptable enough to adjust automatically and cope with changes in the environment like production parameters change, aggregate geometry or aggregate activity.

Keywords: Intelligent monitoring systems, intelligent decision-making platform, real-time information algorithms

Introduction:

The raw materials extraction and treatment area and mining sector of tomorrow will need a transition from static control model to the dynamic control one, to be able to process large amount of varying kind of data (Cehlar, Rybar, Soušek, Szabo, 2011). The solution resides in novel mass flow and logistics system model based on centralized plant design, economic parameters management principles and an intelligent technological logistics system designed and based on a vertical/gravity principle. Further to that,

the mass flow management and logistics processes have to be renewed and monitored. Technology logistics (TL) is such an approach solving technological issues of process nodes or aggregates, which enable to design, control and monitor equipment not according to technical sites, which is often limiting, but according to technology effectiveness (Dorcak, Kostial, Husarova, 2011). Upon this principles could be solved the new intelligent online monitoring systems, process and equipment integration, production process balancing, stock and equipment flow capacity, operating and transportation batch harmonization at production process (mass flow management) and gravity principles leading to minimization, directness and flow regularity within production process. Monitored information within the raw materials extraction and treatment processes is not concerns only minerals, but necessarily includes the area of tangible raw materials of a different nature (such as renewable raw materials, wastes, value-added products etc). An important category of raw materials consists of intangible nature – data, by processing which are information and knowledge. The aim is an integrated holistic monitoring solution, which encompasses the entire value chain of raw materials - from seeking mineral resources, their extraction, primary and secondary processing, to finalize the product (Dorcak, Spisak, 2011).

The intelligent monitoring systems could transform mining or raw materials sectors. It identifies research areas that need to be investigated further, such as adaptation, data fusion and tracking methods in a cooperative multi-sensor environment, extension of techniques to classify complex activities and interactions between detected objects. The growing demand for production variability has led to more research in building more efficient intelligent monitoring systems. The future challenge is to develop a wide-area distributed multi-sensor monitoring system which has robust, real-time information algorithms able to perform with minimal manual reconfiguration on variable applications.

This innovative tendencies for the raw materials thermal processing follows also our research (VRP workplace) consisting of digital models creation of technological processes and apparatuses and their integration. VRP systems research in this area consists of information support, material flow optimization, scheduling, logistics, intelligent monitoring systems, predictive monitoring, integrated automated data processing in order to implement and support intelligent plant –Digital/SMART factory (see Figure No. 1). This concept and direction also fully supports the concepts of European relevant institutions within sustainable mineral resources, like ETP SMR, ERA-MIN, I²Mine, EIP RM and KIC RM.

The main goal for the future intelligent mine structure is to develop a decision support system for real time production control and optimization.

Such a system will be beneficial to analyze real time data, take prompt necessary actions and utilize the front-edge techniques to increase productivity and decrease energy consumption for mineral sectors. The system should have inputs from the several sources. One is real time data acquisition in plant operation, e.g. signals of RFIDs (Radio Frequency Identification) and environmental sensors, work parameters and coordinates of aggregates, etc. The others include digital models of production infrastructure.

The raw material and mining industry is highly dependent upon the acquisition and interpretation of data. For instance, until the mineral resource is extracted from the host rock, every ton of ore is virtual, that is entirely based on data. Physical asset valuation is intelligent based and depends on information; therefore it is critical to manage the knowledge that is acquired within organizations.

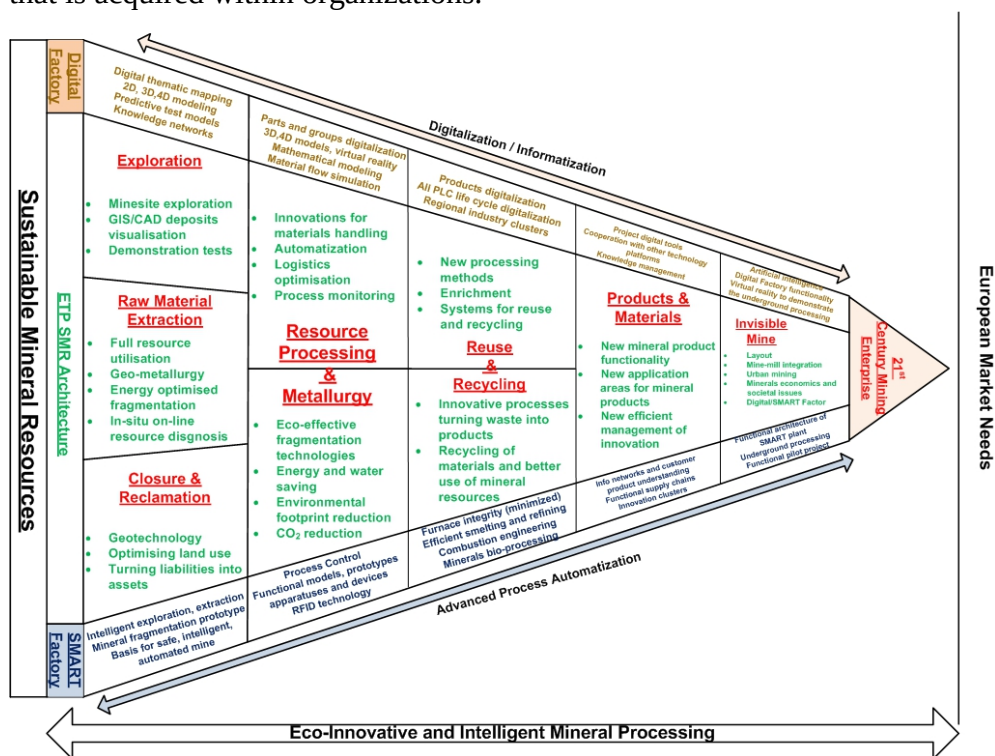


Fig. 1 VRP Research Conception

1. The elements of advanced control:

Intelligent online control system needs not be technology-intensive and should not be technology-driven (Horizon2020, 2011). Although technology can be a powerful enabler of business processes and organizational transformation, it is merely a means to implement control and monitoring practices on a large scale across and beyond the production

plant. As a result, the output of the system should assist to supervise and control the production, back to predefined short-term production targets with most likelihood and optimal approaches. The implementation of such an intelligent system mainly consists of multi-criteria analysis, algorithms design, programming, simulation and/or commissioning. For raw materials extraction and treatment area, the multi-criteria are normally comprised of production rates, ore grades, time, environmental quality, and consumption of water, electricity and fuel.

Advanced control methods are beneficial for the management area, from a number of reasons: part of these methods is to optimize the control interventions, or a prerequisite for economical operation of systems with economic benefits include the ability to control algorithms and a limitations of process variables without changing the structure and finally it is a multi-dimensional systems management. In order to realize the stated properties, it is necessary to apply complex optimization procedures. Research and development in the field of an intelligent monitoring continues and brings new advanced solutions. Such an intelligent control system should monitor and control in real-time mode key components of the production activities and safety policy related to intelligent mining. It should include:

1. Wide-area distributed multi-sensor monitoring system – represents integration of information requirements as well business and domain models, data integration, distributed computing and storing system for mining production, development of relation model for interconnection to wide-area network and real-data distributed multi-sensor monitoring platform. This creates the cooperative multi-sensor environment capable to run an intelligent monitoring system. Such a multi-scale and multi-frequency monitoring are both the quasi static (1D and 3D) and dynamic fields (through induced monitoring) in raw materials extraction and treatment area. Most practical industrial process data contain contributions at multiple scales in time and frequency. Unfortunately, conventional statistical process control approaches often detect events at only one scale. Multi-scale process monitoring uses a tool condition monitoring in a machining process, which integrates discrete data transform and statistical process control. Discrete process is applied to decompose the collected data from the manufacturing system into uncorrelated components. Then, the detection limits are formed for each decomposed component. Multi-frequency monitoring systems monitor vital signs and events. The main advantage of using multi-frequency architecture is the possibility to improve the detection sensitivity of dynamic field in technologic aggregate while cancelling movement with signal processing. Real-time monitoring of the natural and induced changes within and around active aggregates provides critical data to mitigate potential

damage to aggregate infrastructure. This invaluable digitalization provides the basis for making informed decisions about production optimization and adjusting operational practices over the field's life time. Permanent installation of a wireless network of ultra-sensitive sensors is designed for high-resolution real time detection of production-induced changes over the entire area of raw material interest. The cloud monitoring technology, for instance offers the architecture of the future with high-level information distribution and displaying of the current mining and ground conditions through web based services for quick access to various specialists and end-users, and other relevant capabilities related to computing resource sharing aiming cost-cutting thanks to near real-time remote services through the cloud.

2. Intelligent decision-making platform - an intelligent decision platform that aids the decision makers in making the right decision in a timely manner. An intelligent decision making platform would use the information from simulation models, historical data and current signals to propose new or altered production strategies, performance, risk and cost analysis in long-term mining planning and safety strategies. The platform form will achieve real-time data from several mining sub systems. There are three main steps to be taken: analysis, evaluation and determination of the requirements, development of the models as well as modelling of the scenarios and connection to the intelligent platform for the support of the decision makers as above. The final aim is to build a Mine-wide information network by creating real-time information algorithms and a knowledge based network structure in the form of new knowledge creation through the in depth analysis of process data. Integral part of such systems is the costs-to-benefit monitoring, which offers the cost-to-benefit evaluation and intelligent monitoring of cost aspects accomplished by organizational, logistics and technology changes. Such a system should provide dynamic economic comparison of real data of the present state compared to data after technologic logistics optimization. Mining companies would benefit from such a cost monitoring system taking into account their specific production and financial goals. Overall costs will be reduced to enable exploiting lower grades, extending life of mine and overall profitability. The results are monetary statements to mine life cycle costs, mining costs, mining risks and performance of mining performance units. The benefits from cost monitoring are the following:

- the holistic and synchronous consideration of costs, risks and performance already during the strategic planning,
- the analysis and evaluation of technique and economic planning alternatives as well as the utilization analysis of multiple planning scenarios.

Among process data belongs:

- numerical models, historical data and field signals using,
- new or alternative production plans,
- performance-risk-cost analysis in long-term mine planning,
- real-time data from several operating sub-systems acquisition,
- reference models and digital engineering tool; modelling of scenarios,
- ground control system and rock bolt sensor technology,
- SCADA (supervisory control and data acquisition) system to monitor the performance of equipment.

3. Predictive Monitoring System - this system should monitor in real-time mode key components of the production activities and safety policy related to intelligent mining processes. Technological processes represents a complex processes with a large number of sub-processes and variables with different types of control algorithms, optimization, planning and decision-making. Predictive control methods are important to control for several reasons. One of the most important is the fact that part of these methods is the optimization control interventions that is a prerequisite for cost-effective operation of systems with economic benefits, where these methods are implemented. Another important feature of these methods is the ability to include control algorithms and limitations of process variables without changing the structure, which does not apply to conventional structures. Another important capability is the control of multidimensional systems, which are not governed by conventional regulators. So it is possible to implement the features, it is necessary to apply complex optimization procedures. They are often the limiting factor for these methods, since they are time consuming. Research and development in the field of predictive control systems continues and brings new advanced and intelligent solutions. One such solution is a procedure based on a genetic algorithm, whose contribution is that it gives even in case of early termination of the algorithm (such as the cancellation terms) some sub-optimal solution that can pull through the local extremes. Predictive monitoring and its control algorithms are characterized by the following features:

- the computation of the sequence of control actions that minimize the management criterion,
- allow to take into account major traffic delays, inverse response and a relatively complex dynamic processes,
- compensate the impact of measurable and immeasurable disturbances,
- formulate an optimization problem, taking into account border management,

- explicitly predict the behavior of the process in the future,
- calculate a sequence of management intervention values that ensures monitoring of reference variable by output process variable.

2. Intelligent monitoring system:

Mining technological processes are complex processes with a large number of sub-processes and variables of different types of control algorithms, optimization, planning and decision making. Advanced control methods are beneficial for the management area, from a number of reasons: part of these methods is to optimize the management interventions, or a prerequisite for economical operation of systems with economic benefits include the ability to control algorithms and a limitations of process variables without changing the structure and finally it is a multi-dimensional systems management. In order to realize the stated properties, it is necessary to apply complex optimization procedures. They are often a limiting factor in these methods, since they are time consuming. Research and development in the field of an intelligent control continues and brings new advanced solutions. One such a solution is a procedure based on genetic algorithms, whose contribution is that it gives in the case of early termination of the algorithm (such as cancellation terms) a sub-optimal solution that can get out of the local extremes. Such an intelligent monitoring system should monitor in real-time mode key components of the production activities and safety policy related to intelligent mining (Spišák, Zelko, 2010). It should offer the following breakthroughs.

For intelligent monitoring of technological processes we need tools for monitoring resp. tracking product and process that will capture and communicate with production data in real time and automatically provide insight into production in real time. These tools provide the ability to look at data from several different perspectives, such as the product, in terms of work progress, direction, tools, equipment, materials and labor. This option helps meet the needs of different users in the organization. Intelligent monitoring systems for product and manufacturing supplement the systems for Enterprise Resource Planning (ERP) by collecting data from the production to the level of detail and accuracy that ERP systems are not capable of achieving. The resulting information allows the rapid identification of causes of problems and reacts quickly to limit their impact on production.

The role of intelligent monitoring system in a real-time is the continuous monitoring of input variables for a given process technology node. The monitoring system can be gradually extended and supplemented. Existing condition for monitoring system of complex magnesite processing (CMP) technology may be the starting point for the informatization of raw

materials extraction and treatment processes. Subsequently the matrix of works already completed may be supplemented by other activities in order to build a comprehensive information and communication secure system.

In the field of informatization for process monitoring it is effectively to use research methods that are based on mathematical and physical modelling, such as using the principles of similarity and equivalence. Research and analysis of the sensors functionality principles can provide new functional models. The results of these experiments on functional models can be used for creation of mathematical models, thus creating a virtual prototype of a process that will serve the research of processes in the sensor and its interaction with the environment.

Intelligence within the technological advanced control sphere lies in how we measure input to the system. It depends on whether it is a direct measurement, indirect measurement or model measurement, where we cannot measure. The first two types of measurements we call reference. Advanced measurement model will be gradually built on the basis of the reference measurements. It is based on verification in practice, so that gradually it will be fully used as input and eliminates and optimizes a number of previous reference measurements. The basis is the mathematical modelling of processes as a basic research, the system of measurement based on new types of sensors for very specific use, intelligent monitoring systems, and predictive control systems of technological processes.

3. Online monitoring systems for high-revolution rotary furnaces:

The Development and realization workplace (VRP) of raw materials extracting and treatment solves the issues of practice: research, development and improvement, innovations design and pilot implementation through improvement of research-development capacities and its effective exploitation during actual company problem solutions and education process improvement and innovation business development. Among others research, development and innovation activities the Thermal research program is the core of our activities consists of development, optimization and innovation of new technologies and devices for thermal treatment. These include rotary, shaft, microfluid furnaces, high-revolution rotary furnace, three-stage furnace for thermal biomass recovery and communal wastes run on high heat value synthetic gas and high temperature (attained 1550°C) basis. The high-revolution rotary furnace and the last one three-stage furnace use an original method and potential for recovery of biomass and wastes energy. Its technical parameters allow the high quality of operation with effective appreciation of environmental impact.

On that workplace a new advanced monitoring system for granular materials thermal treatment was also developed. Based on this principle,

the high-revolution furnace control system was developed with process model prediction and 3D visualization.

The high-revolution rotary furnace runs on the mechanical fluidization principle. The mechanical fluidization occurs by balance of centrifugal gravitational forces – at that time the particles are equally unfolded cross the furnace. This way is ensured an intensive heat and substances movement between particles and a gas medium. The heat exchange intensity is increased about approximately 25 times opposed to classical rotary furnaces. The high process intensity enables to have a small size of furnace and low energy consumption on the level of technological optimum. The main advantage is the ability to process dusty materials effectively. The developed high-revolution furnace control system based on process model prediction and 3D visualization is on the figure No. 2. (Ján Spišák, Ján Mikula, 2012).

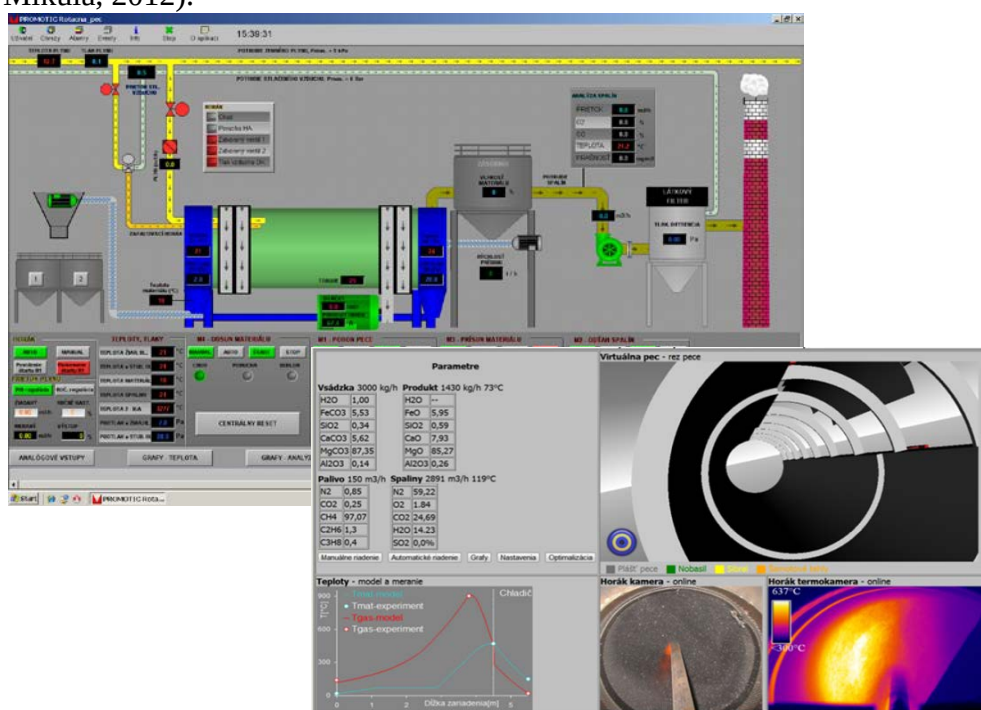


Fig. 2 Monitoring and control system for high-revolution rotary furnace

This intelligent monitoring system underpinned with a mathematical model of the process consists of three operational layers: basic control, process control and supervisory control level. Monitoring system is made up of instrumentation, mathematical model, and visualization layers. Instrumentation level was enriched by new types of sensors enlarging measurement possibilities and their precision. Mathematical model is based on first principals. Complex simulation enables to provide all required data

in advance. The adequacy of real and calculated data is secured by model calibration on measured data. Forward data gained by simulations enables predictive control. Visualization system is based on virtual reality. It enables very effective visual communication with the user. The monitoring system concept with visual communication in the virtual reality environment was applied on the high-revolution rotary furnace for magnesia sintering. Developed visualization system enables spatial presentation, interactivity, user easiness, platform independency and is financially undemanding.

Intelligent online monitoring system enables effectively present information about objects and processes executed inside. Visualization system can fulfill important task by support of operational activities as monitoring, diagnosis and solution of break down situations. Visualization system has to give support to the operator and engineer by diagnosis of complicated situations, predictions, and by selection of control actions. Important function is real time analysis, which enables to the user dynamic way of thinking and creating intuitive feeling about system work. At control system creation the key problem is its safety. Checking of basic functions on real objects is from many reason requiring. One of the alternatives is using of simulations on mathematical models, on which we can change not only operation but also design parameters. Advantage of such approach in research and development is the possibility of immediate correction of control algorithm, influence evaluation of different failures and break down situations, generation and testing of different working regimes. Simulations of technological process working conditions enables to analyze properties of the process and aggregate from view point of technological quantities which are not measured continually or are not measured at all. Analysis results gained from the research serve to deeper understanding of the process and its inputs. Important contribution lies within the risk minimization and decreasing number of experiments on the real plant.

Virtual reality (VR) environment for intelligent online monitoring system enables representation of information about object and related processes. With the aid of virtual 3D modelling it is possible to treat system information precisely, and make him stable at different levels. Technological objects visualizations system and processes applied on thermal apparatuses were developed to fulfill these requirements. The impact was mainly given on platform independency, what brings huge distribution and integration possibilities as far as the possibility of remote approach. Further development of this system is focused on user interactions with objects and processes in real time and then support of control activities.

Intelligent monitoring system structure is on the Fig. No. 3. Forward monitoring based on simulations data gives complex information about the process and gives much higher decision support as presently used. Model

based decision support can be used for checking of the decision alternatives or for the training.

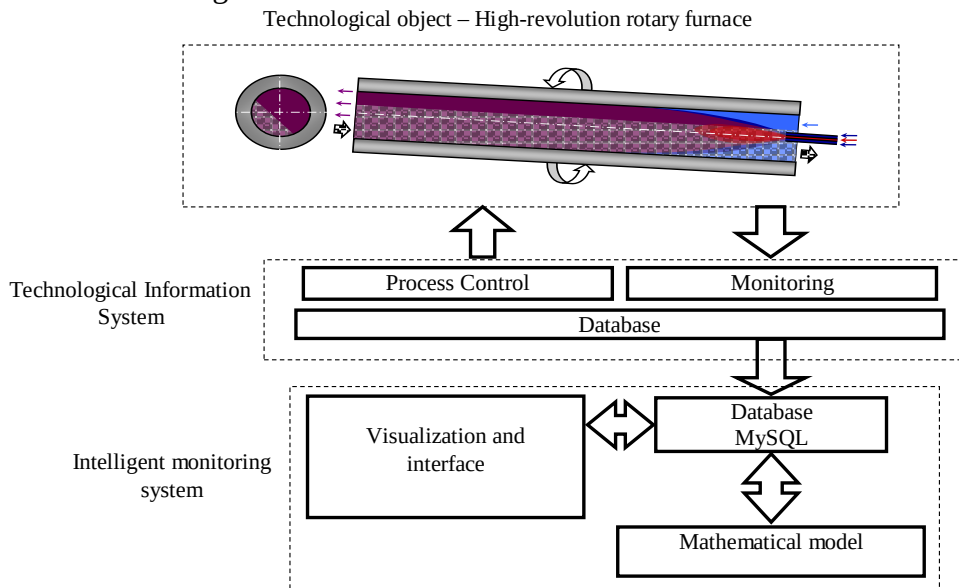


Fig. 3 Intelligent monitoring system structure

Conclusion:

The intelligent monitoring system of technological processes is an advanced tool for monitoring and tracking products and processes that capture and communicate with production data in real time and automatically provide insight into production in real time. These systems provide the ability to look at data from several different perspectives, such as the product, in terms of work progress, direction, tools, equipment, materials and labor. Information and Communication Technology (ICT) traditionally has been viewed as only a support or operational tool in business. New innovative and advanced development in ICT infrastructure, however, has facilitated the creation of intelligent infrastructure services and tailor-made and industry-specific applications, a more cost effective and diverse way of doing business (Zelko, Lavrin, 2011). Digitalization and informatization is currently the main mechanism for the streamlining of business activities that is now widespread amongst manufacturing and mining companies seeking to improve competitiveness. Technological change through the advanced technologies and organizational restructuring has been observed to bring gains in productivity and market share. The raw material and mining industry also faces similar acute competitive pressures.

A presented facts are supported by own original research used in some structural projects and international projects which promote the above

general presented facts. Intelligent online monitoring system for high-revolution rotary furnaces represents the online monitoring system which enables effectively present information about objects and processes executed inside. Moreover, it is a development that serves to solve specific control problems in practice of SMZ Jelsava mining company. This is the proof that intelligent online monitoring system has practical use and is not just a theoretical solution, which in practice has nothing to do. Intelligent monitoring of technological process working conditions enables to analyze properties of the process and aggregates from view point of technological quantities which are not measured continually or are not measured at all. Analysis results gained from the research serve to deeper understanding of the process and its inputs.

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