SIMULATION OF LONGWALL COAL MINING TECHNOLOGIES

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ABSTRACT
This paper describes our own visual interactive discrete simulation system specialized in simulation of technological processes in coal mines. The simulation system allows creating complex simulation models fast, interactively, as well as using them for all kinds of simulation tasks: "what-if" ones, presentation, training, hardware development with all "in-the-loop" manners. This is ensured by the presence in the simulation system visually interactive interface and a set of libraries. There are libraries for simulation the following subsystems of coal mine: belt conveyor subsystem, power supply subsystem, ventilation subsystem, and pumping subsystem. A new library contains models of coal seam, and mining machines. Models of longwall technologies for coal mining in various types of coal seams were developed with the help of the new library.

Keywords: visual interactive simulation, coal mining, longwall mining

1. INTRODUCTION
Different investigations in various areas of underground mining that require automatic control (e.g. coal mining) specify that resources are becoming less available, and harder to be extracted.
The technologies of coal mining are well known. Today mine uses mining machinery for mining, transportation, roof support, etc. How exactly will these machines function? What additional machines will be required? What is the cost of machines installed in the mine? Will big universal machines be more appropriate rather than many small, specialized mechanisms? What will the cost of a final product be? The particular mining installation is effective in terms of minimum costs and maximum productivity only if it is correctly planned. Usually big layout has many components from different vendors interconnected. That makes it hard or, even, impossible to predict the exact effectiveness. The situation gets worse if there is also a requirement to create new components for management of a part of such layout. In all these cases, computer-based simulation can be used to solve these problems.
Because of the importance of these problems, there are a large number of papers on the use of simulation in the development and optimization of coal mining systems (Sturgul 2001; Kizil et al. 2011; Cai et al. 2012).
There are also a great deal of simulation tools both universal simulation systems and specialized systems and packages for simulation of coal mining systems.
A number of models for various technologies of coal mining were developed with the help of our own simulation system. Brief description of this simulation system is presented in section 2. Section 3 contains description of a new library and examples of the models of longwall coal mining technologies.
These models are used for developing of process control systems for underground coal mines in Kuznetsk Coal Basin (Russia, Western Siberia).

2. THE SIMULATION SYSTEM
A visual interactive Manufacturing and Transportation Simulation System (MTSS) is developed and used at Design Technological Institute of Digital Techniques (DTIDT). It is a process-oriented discrete simulation system intended to development and execution of models of technological processes (Okolnishnikov et al. 2010, 2011, 2014). MTSS is a set of program interfaces for creating *elementary* models as well as forming complex models from them. This corresponds to bottom-to-top simulation style. The elementary model is verified according to its specifications, ready-to-use simulation model of an equipment unit with capability of low-level control for it.
The elementary model consists of the following parts:

- Two-dimensional and three-dimensional animated graphic images.
- Input and output parameters.
- Functionality algorithm describing dependence between parameters.
- States that the elementary model can reach during the simulation process.
- Control commands defining switching process between elementary model states.

A model in MTSS is created by graphical connection of images of elementary models.
MTSS is also a tool for running of complex models built from elementary models. The running model performs the movement of the model time and visualization. Statistics is collected as well. Statistics are available as a short overview when model runs, and more statistics are available after model completion.
Elementary models can be then combined in a libraries forming simulation goal-specific tool, used by field specialists.
Such tool can be an application for rapid creation of correct simulation model by mining engineers. Usually engineers have not enough qualification to create simulation models in details, but they know how to connect correctly elementary models to create the required topology. MTSS uses 2D as a graphical editor and 2D, 3D for visualization of model running. Such approach seems more natural for mining engineers, when all installations and machines appear first on 2D plans. 3D is more useful for visualizing complex vertical movement.
Process control systems often have two levels: the low level of equipment and simple control logic in it and the upper level of complex control of production. One of the distinguishing features of MTSS is a division of the logic of a simulation model into two parts: a low-level logic and an upper level logic.
Such division allows us not only to correlate to the usual structure of the process control systems but also to use such models for embedding them into actual process control systems in the following ways: to emulate equipment, to simulate upper level logic, and to send commands to actual process control system for debugging and testing. The division into upper and lower logics let us also organize a switch between various implementations of decomposition. It makes possible coexisting simulation of upper level logic and a proxy that allows communicating with the upper level logic of actual process control system.
The model of coal mining can communicate with a new process control system developed in DTIDT, to be a source of input signals, emulate equipment, test actual control program with simultaneous visualization of overall process of mining. This allows debugging and tuning of a new process control system in accordance with behavior of simulated system, even simulating various accidents. This permits to minimize time and costs on site for commissioning.
There are libraries for simulation the following subsystems of coal mine (Okolnishnikov et al. 2013a, 2013b, 2015) like:

- Belt conveyor subsystem.
- Power supply subsystem.
- Ventilation subsystem.
- Pumping subsystem.

A new library of simulation models of mining machines for coal mining was developed. This library is based on MTSS and its prime goal is to simulate interactively and visualize various aspects of coal mining in coal seams of various types and by various coal mining technologies, hiding simulation specifics from the end-user (field engineers).
The library consists of new elementary models of:

- Highwall mining system.
- Longwall mining system.
- Coal seam.
- Mining machines.
- Self-moving coal wagon.
- Storage area.

3. SIMULATION OF LONGWALL MINING

Longwall mining system is a highly automated, very powerful and productive way to mine coal. It is most-widely applied around the world. Its main advantage is that it leaves almost no coal inside mines. However, the depth of the mine (measured from the surface) limits it. In addition, it is applied in relatively flat areas of coal, from 0.8 up to 10 meters high, from 150 to 450 meters face, and up to 4 kilometers in depth. The depth of mine itself is relatively small – up to 200 meters.
Longwall system consists at least of an armored face conveyor (AFC), a shearer, and roof support sections. The AFC is connected to outbound belt conveyor. The shearer cuts the coal from coal seam face, in a series of passes along the AFC. The AFC delivers coal to the belt conveyor connected. The roof support moves itself and the AFC, pushing it (and itself) forward with hydraulics.
One of the problems of longwall mining is roof caving, which can lead to serious environmental problems. Another problem is that longwall requires significant amount of work to be done before its massive equipment is installed in production.
For detailed simulation of longwall mining system, we closed the following decomposition: an armored face conveyor, a shearer, and roof support sections.
Simulation model for longwall mining system can function only if it is connected (in terms of MTSS) with belt conveyor simulation model.
The simulation model built from the content of the library simulates movement of all mobile objects of the simulated system. Both 2D (top view) and 3D visualization are available. Statistical data is also collected.
Figure 1 presents a sample layout in a simulation model of longwall coalface.
Main window consists of at least 4 areas:

1. Main simulation window. The origin is at the left top corner of the view.
2. Parameters of a simulation model.
3. Specialized view for fast navigation in simulation model.
4. Settings for the time start, time end and current model time.

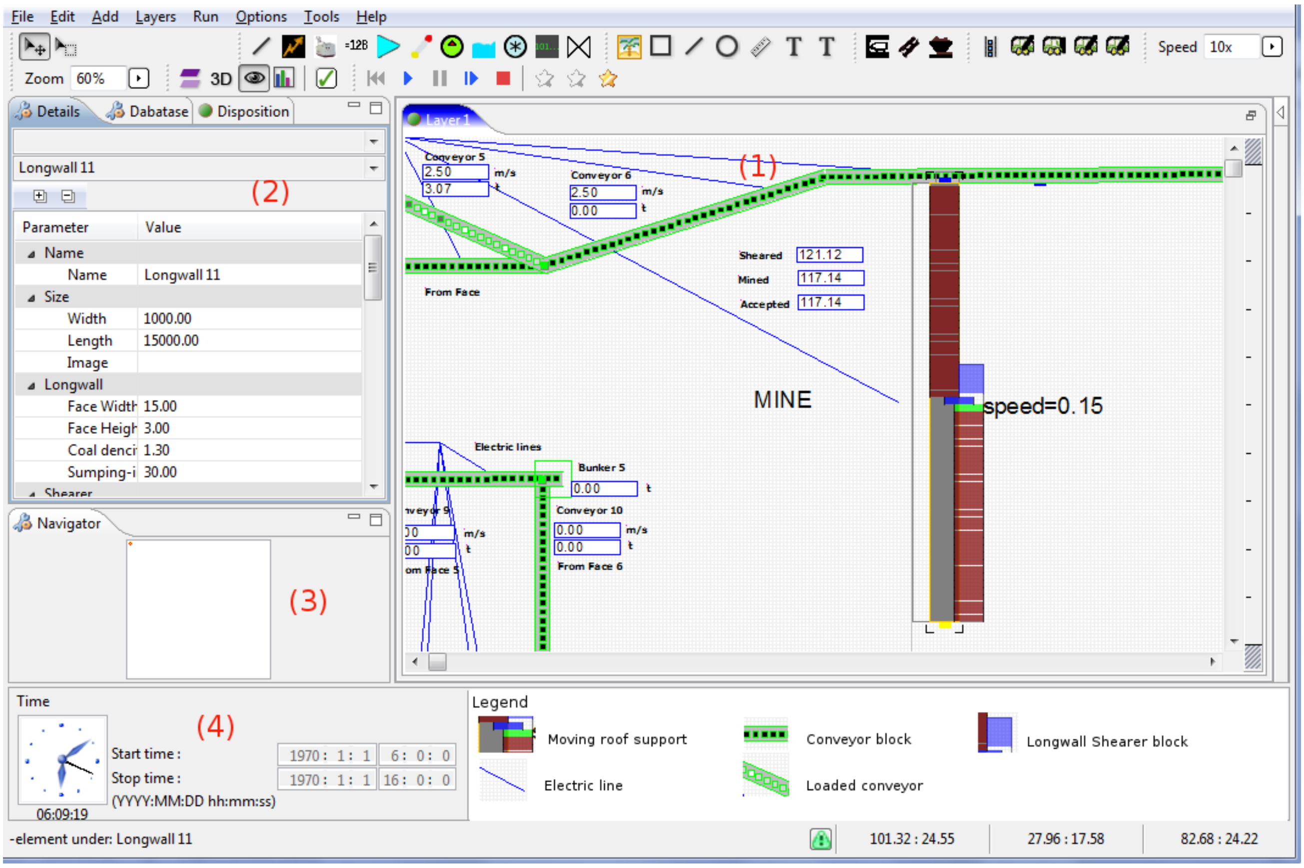

Figure 1: Main window of MTSS system running simulation model of longwall coal mining

The main task for the simulation model of longwall coal mining is to show how longwall automation produces the coal for the rest of the underground factory.

In the other words, it is a model of mine face. In contrast with “face” model, which is primarily statistical, this model will show “pulse” of coal. Figure 2 presents it.

Changing the algorithm the longwall model functions, it produces different loading for the rest of the simulation model.

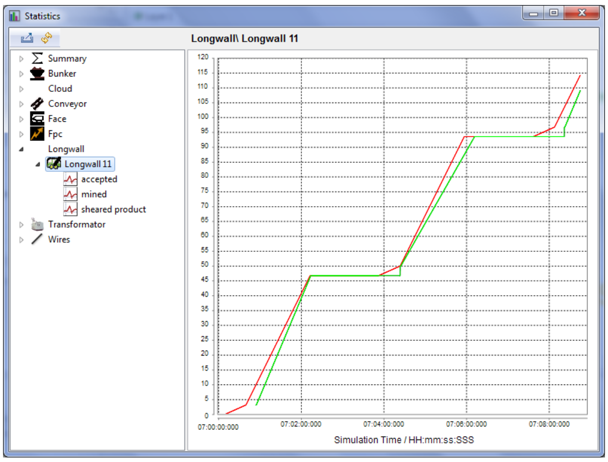

Figure 2: "Pulsing" coal by longwall

The algorithm for longwall mining system simulation is closer to the control algorithms of a real longwall mining system. There are some variations of the shearing task (Mitchell, 2009).

Longwall is managed by tasks, which are state machines in its nature. Tasks are:

- To shear (dig in and shear), with detailed animation. This is the main task.
- To deliver coal outside the longwall simulation.
- To move roof support when it is possible.

The main task will define the amount of time for the shearer to move from one end to the other. Task for roof support is required to simulate roof support advance. The amount of coal will be moved to the AFC that will deliver it to the belt conveyor. Tasks will repeat these steps until the “done” or “postpone” conditions will be achieved.

Main task is done when shearer reaches the end of an AFC line. Task is postponed when belt conveyor is overloaded and cannot accept the next portion of coal or gas level is not safe.

During any of these steps, the simulation model simulates roof fall (behind the roof support) and gas level increase. In addition, ventilation is simulated (remove gas from working area).

In most cases, there is no need to simulate in details any technology like longwall or flat-lying coal mining, if it is used just as a source of a coal for belt conveyor system, for example. Everything really needed in such cases is:

- To define that longwall is a source of coal for a big mining system like a conveyor.
- To know the performance of the longwall coal mining during some time (working day, 8-hour time interval, 1-hour time interval). Note that the emergency stops (like gas or coal dust) are already included in this statistical data.

However, if the goals of simulation are:

- To predict how longwall mining automation will behave in details (i.e. movement of its parts depending on various situations in mines).
- To make a detailed visualization of mining process.
- To define how this mining will influence on the overall performance of mines.
- To define scenarios of broken or temporarily inaccessible parts interactively -

then achieving these goals will require detailed decomposition of common longwall mining system and a detailed visualization of all its parts.
In our work, both detailed and statistical approaches are presented.

4. FUTURE WORK

Detailed simulation of longwall system, connected with detailed simulation of flat-lying coal seam (or multiple flat-lying coal seams), will allow creating of simulation that will not only predict the behavior of big underground mining system, but also simulation of land subsidence while using longwall, especially with very heavy longwall systems that can cut 10-meters-high coal seams.
Simulation system MTSS can be used not only for simulation of existing coal mining techniques but also for perspective robotized techniques (Sinoviev et al. 2015, 2016).

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