Mine Ventilation Expert System*

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ABSTRACT

A growing trend in the area of artificial intelligence is the development of software that simulates the decision-making process of the human experts. The purpose of this paper is to advance the use of available tools from the area of artificial intelligence and, in particular, expert systems, into the field of mine ventilation management.

The authors have developed an expert system (i.e., a smart manager) that controls the operation of a mine ventilation network. The expert system is rule based and, hence, can be (independently) enhanced in an incremental fashion. It serves as a smart interface between the monitoring and control components of the mine ventilation system.

Keywords: Expert system, mine ventilation, monitoring and control.

1. Introduction

The paper describes the design and development of the Mine Ventilation Manager (MVM). The main issues addressed by MVM are:

(a) on site implementation and portability,
(b) mine modeling flexibility,
(c) data simplification and storage efficiency,
(d) relevant and timely use and inference of space varying knowledge,
(e) integration of disparate system modules.

A description of the requirements for a mine ventilation expert system is presented in Section 2. This serves as criteria for judging the legitimacy of MVM, which are discussed in detail in Section 3.

* This research has been partially supported by U.K. Robotics grant No. ??.
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2. Requirements for Mine Ventilation Management

The major objective of the underground mine ventilation system is to provide a safe and healthy environment for the miners. The demand for the ventilation system, (i.e., the air-flow distribution throughout the mine), is based on a number of factors such as: the rate of mining production, nature of liberated gases and dust, and the characteristics of the airways. The control of the ventilation system is achieved thru the adjustment of fan and regulator settings. Control of the system is asserted by management (operators) based on a number of constraints, regulated by statutory requirements, as well as operational objectives.

The quality of control exercised by management is limited by their ability to obtain timely information describing the state of the system, and their capability to arrive at decisions based on that information. This limitation, to gather timely information to support decision-making processes, has long been recognized, and is the triggering impulse for the development of automated mine monitoring and control systems.

Some aspects of automatic mine ventilation control fit nicely into traditional control techniques, especially when viewed in a *local* sense. The assertion of control in a *global* or mine-wide sense is based on more than measurements and their interrelationships. It is also based on judgment, intuition, and experience. This is particularly true during emergency conditions, e.g., situations subsequent to an explosion or during a mine fire. It is the inability of traditional control systems to utilize heuristics that has limited automatic control; as it is the strength of expert systems to utilize heuristics that will make possible a safe and efficient control of the mine environment.

In addition to the standard controlling functions, e.g., in air flow rates, gas concentration, etc., expert system should allow one to make factual updates regarding structural changes in the mine itself. That is, a mine ventilation expert system needs to have a sound, readily available, comprehensive mine updating facility. For example, as a mine expands, an expert system should have the capability to create, validate, and represent the new mine configuration. Otherwise, the expert system runs the risk of becoming unreliable through retention of an inaccurate or out of date information as part of its knowledge base.

The mine ventilation management process presents a number challenging problems. One of the major ones is that, in addition to being time dependent, the mine monitoring data is space varying. Another aspect of mine ventilation is that its areas of expertise are multidimensional, i.e., air flow in an underground mine has to be determined for a variety of different situations. These situations not only include meeting operational requirements, but also situations arising form: buildup of dangerous gases, fires, caveins, etc. Even within one of these problem categories, e.g., fires, there are varying circumstances, that may range from spontaneous combustion to an open fire, which would call for different responses.

3. The Mine Ventilation Manager (MVM)

The MVM expert system has its knowledge bases coded and processed under a production rule shell, INSIGHT2+, designed specifically for microcomputer use. MVM solves a broad range of ventilation problems, e.g., suggestions in response to drops in air flow, capability to check for device failures and methane buildup. In addition, MVM also detects and provides consultations about potential or actual fire emergencies.

MVM strives to integrate various domains of mine ventilation expertise into one system, whereby a user is provided with a consultation on any problem, or combination of problems, that arise in a mine. In this way, MVM attempts to addresses the issue of completeness in rule based expert systems (e.g., see [Suwa84]). MVM decides and lines up consultations for whatever ventilation problems it discerns from the latest sensory data. Moreover, it is able to prioritize the consultations so that the ventilation officer is advised about the more critical problems first, e.g., open fire or extremely high methane, and less severe problems later, e.g., a gradual drop in air flow.

A feature provided by MVM is its ability to determine optimal flow distribution (with respect to the amount of energy required to satisfy environmental constraints). To fully exploit expert system reasoning about ventilation in mine networks, they must conform, not only to a mine's physical structure, but also to certain *ventilation requirements*, e.g., the locations of where airways may split or have terminating source or sink nodes. These requirements are particularly crucial in places where the ventilation management relies on a limited number of sensors strategically located in the mine. To ensure that these requirements are met, MVM provides a means by which a mine model, either proposed or assumed, is verified as viable for application of normal ventilation strategies. Finally, MVM's knowledge bases comprise an expert system which is applicable to any mine, the structure of which is described independently of the knowledge base itself.

Beyond merely indicating which regulators need readjustment, the MVM determines the settings for the regulators in order to accommodate new air flow distribution. MVM incorporates software with which to perform critical path air flow calculations, from which the required regulator settings are computed.

3.1. Overview of MVM.

The functional structure of the expert system is displayed in Figure 1, and as shown, the MVM knowledge based expert system (KBES) is its central component. As described in the last section, MVM consists of a hierarchy of production rule knowledge bases, coded in INSIGHT2+ procedure language (PL), and a set of Pascal procedures called by production rule actions within these knowledge bases. Below, MVM is described in terms of how its component knowledge bases and Pascal programs interact, as diagramed in Figure 2.

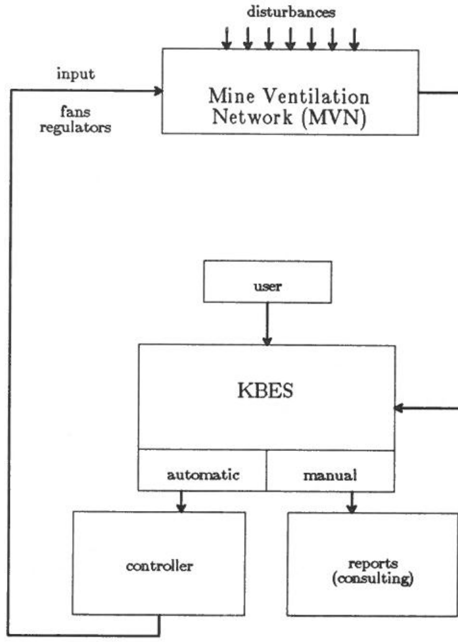

Figure 1. The MVM.

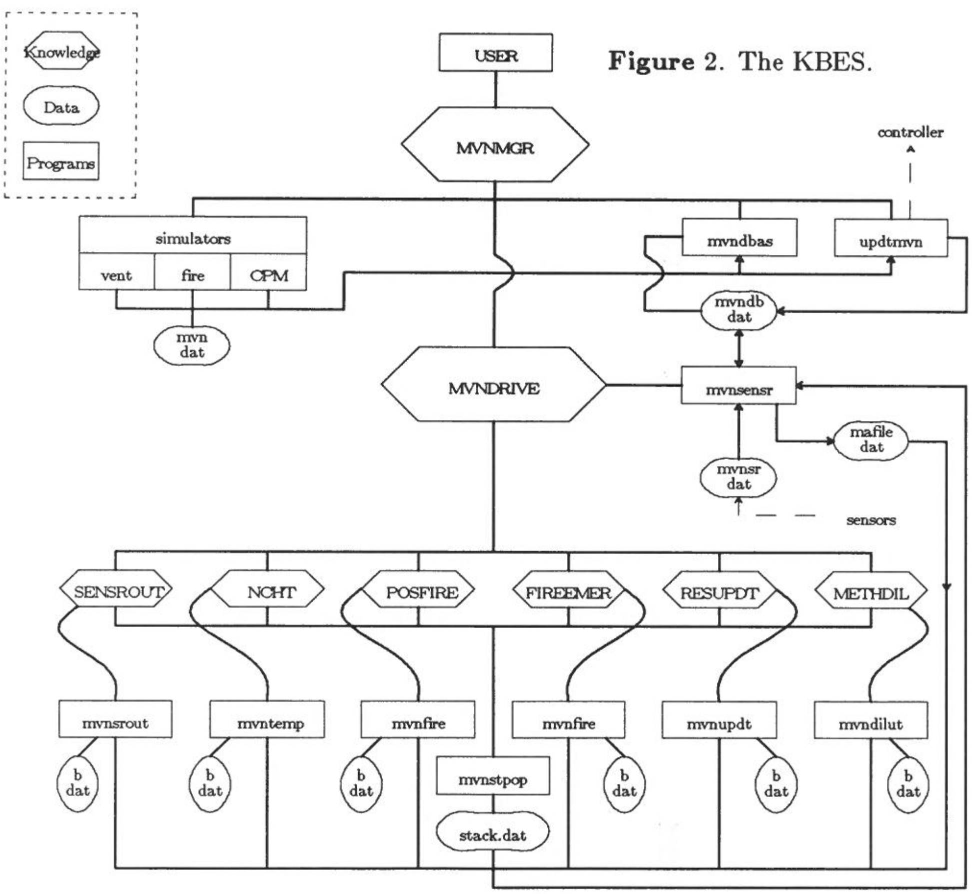

Figure 2. The KBES.

At the top of the knowledge base hierarchy is MVNMGR which prompts a user to select from one of four consultations, either:

(1) design and establish a mine ventilation system (MVS);
(2) update the parameters for an existing MVS;
(3) control of MVS thru adjustment of regulator settings;
(4) monitor and respond to the latest group of sensor readings.

In the first option, MVNMGR calls a program, *buildmvn*, which, analyzes the submitted data to determine whether they form a valid mine ventilation network in terms of the canonical diagram structure described by Wala and Altman [Wala87]. Once the ventilation network is completely specified and validated, *buildmvn* stores its description in a file called *mvn.dat.*

To assign initial data parameters to the network, a program *mvndbase* is called which:

(1) inputs the network file created by *buildmvn* and stores it as a set of adjacency lists;
(2) assigns air flow rates, natural resistances, coal characteristics, extraction tonnage per shift, passage opening area, etc.;
(3) allows the ventilation officer to assign natural resistances and passage opening areas for each airway of the MVN.

The second option presented by MVNMGR is updating an existing ventilation network's parameters. With this option, MVNMGR calls a program *updtmvn*, which prompts the user for possible revisions and then proceeds to compute new flow rates throughout the network. The network's database records, are then updated accordingly.

In option three, the automated control of airflow distribution in the MVS is carried out by regulator and fan adjustments. These are determined using the critical path method and implemented by the control system.

Finally, in option four, sensor readings from the mine are analyzed and the user is advised about any problems or emergencies discerned. To do this, MVNMGR *chains to*, or invokes, another knowledge base, MVNDRIVE, which in turn calls a program, *mvnsensr.* This program reads a file of sensor records, each containing values for the latest

(1) air flow rate,
(2) methane concentration,
(3) carbon monoxide concentration,
(4) carbon dioxide concentration,
(5) oxygen concentration,
(6) temperature,

in the mine ventilation network. Based on these readings, potential problems are identified and classified.

4. Concluding Remarks

Presently, MVM is a prototype expert system that has made a number of advances toward implementation beyond the pioneering work of Kohler's et al. In summary, these advances are in

(1) expansion of the areas of expertise (e.g., fire detection);
(2) mine modeling and validation of ventilation network structure;
(3) integration of problem specific subsystems into one system;
(4) conformance to efficient monitoring and control policies;
(5) independence of mine models from knowledge bases;
(6) automated regulator and fan control.

Additional developments, needed to make MVM a more complete expert, require a deeper interface between knowledge engineering and mine ventilation theory. A possible enhancement, is a refinement of the basis for determining the best escape pathways from mine fires. Factors such as the branches' length and incline, as well as the probability of a branch being subjected to reverse air flow as a fire develops, should be assessed and included in the determination of optimal escape routes.

Although MVM is not completed, enough has been said to testify to its overall degree of systematic coherence such that the location of new features can be readily ascertained, e.g., to specific knowledge bases or programs to be modified. Nontheless, while MVM's modularity is an asset for planning enhancements, it also harbors some problems concerning rule consistency. For example, one must consider the possibility that multiple simultaneous problems occur in a mine, for which the expert system suggests conflicting emergency handling advice.

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