RESCUE - KNOWLEDGE BASED EXPERT SYSTEM FOR MINE RESCUE OPERATIONS BASED ON GAS ANALYSIS

By

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ABSTRACT

An experienced and reliable knowledge of fire fighting procedures is necessary for mine emergency situations. Since experts in this area are scarce, the technology of expert systems lends itself as a suitable component in the decision making process.

This paper describes an expert system that is being developed for this purpose. The expert system, RESCUE, is a knowledge-based computer programme which incorporates the judgement, experience, rules of thumb, mine environmental conditions as well as human intuitions in the mine rescue operation. RESCUE makes decisions such as whether or not the affected area should be sealed, whether or not rescuers should be withdrawn, and which fire fighting agent is most appropriate for the situation.

The IF....THEN rules written in the VP-EXPERT shell contains antecedents and conclusions based on environmental as well as other conditions prevailing in the mine. For example, the CO/O2 deficiency ratio indicates the progress or healing; explosibility trends are given by varying flammable gases (CH4, H2, CO) in relation to oxygen concentration, and barometric pressure falls may affect explosibility by increasing CH4 content in workings. The interaction of such numeric-based rules with others rules reflecting the experience and judgement of the experts assist the system to arrive at is conclusions and subsequent course of action.

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put into the system by the user. When the location (and panel) has been selected, the expert system picks up the location (and panel), searches through the database for the file for the selected location and, picking up the relevant data, passes them on to a graphically displaying BASIC program to graphically display the results.

WHAT IS AN EXPERT SYSTEM

An expert system is a computer program that mimics the performance of a human expert in some intellectual endeavor. The archetypal expert system attains this high level of proficiency by embodying the heuristic informally framed knowledge of the human expert along with the experts' not-always rigorous method of reasoning in the subject domain. As illustrated in figure 1, a knowledge-based expert system consists of the following:

1) A knowledge base
2) A control structure or inference engine
3) A working memory
4) A natural language processor.

The knowledge base is the general collection of knowledge about a given problem domain. It contains general facts, e.g., methane gas is explosive, class A fire involves carbonaceous material, etc. It also contains heuristics, rules of thumb or rules of good judgement that the expert uses in arriving at a solution. An example of a heuristic is "since deeper coals are usually gassier, the Appin coaled (depth = x metres) probably has higher methane emission rate than the Westcliff coaled (depth = y metres), where x is assumed to be numerically greater than y. This type of knowledge is stored in production rules, which in the case of RESCUE take the form of IF...THEN statements.

The inference engine stands between the user and the knowledge base and it provides the strategy for drawing inferences from the production rules stored in the knowledge base and new data provided by the user. Its second function is to control the order in which the expert system draws inferences and communicates with the user.

The working memory is the "scratch pad" where dynamic information is kept about the specific problem being analysed. For example, information involving sample location (i.e., panel name, number or sample points, etc.) are entered by the user and any inferences drawn about the problem (e.g., gas atmosphere around location D4 in panel NORT-H-2-SECTION is potentially explosive) would be stored here.

Finally, the natural language processor provides a simple method of querying the user for input then supplying him back with results that are easily understood. For example, RESCUE queries the user in various ways in an attempt to determine relevant information: multiple choices, true or false and yes and no questions. A simple true or false question may be:

Is it true that:

The color of the smoke is black?

TRUE   FALSE

The user answers this question by selecting either TRUE or FALSE with the keyboard cursor keys, then pressing the RETURN or ENTER key. In RESCUE, the natural language processor is provided by the VP-EXPERT shell which is being used to develop the system.

Fig 1 Block diagram for knowledge based system

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OPERATIONAL AND COMPUTING REQUIREMENTS OF “RESCUE”

RESCUE is being developed to handle fire emergency situations in which gas sample results and knowledge of other environmental conditions are required as basis for decision making. The data needed for consultation is typical of what mine rescue personnel would have readily available such as gas contents, temperature, date and time of sampling, pressure, geological information (e.g., coal rank, heat propagation rates, ventilation rates etc.). Also if the user lacks certain data RESCUE equates the value of the variable to “UNKNOWN” and the consultation proceeds.

To make the accessibility of the program feasible for the mining industry, it was deemed appropriate that RESCUE be developed for use on personal computers.

The development tool selected ("shell") serves as an advanced development environment and delivery vehicle for production rule base. This software has the capability to activate other programs (written in other languages) during execution of a knowledge base. For example it is able to activate a compiled PROLOG program so that the user can manipulate data in the database environment (such as putting sample data in database) and when ready returns the user to the expert system environment for continuation of consultation. This capability also allows the expert system to "call" the FORTRAN program which utilizes the data stored in the database file to calculate for the explosibility status of the atmosphere and other parameters required for decision making. These results are passed back to the expert system for its inferences and conclusion.

The recommended hardware configuration is 16K bytes of RAM with a minimum of 10M bytes of hard disk or two double sided floppy disks. This configuration ensures that sufficient memory will be left to run externally activated programs.

Knowledge of RESCUE is embodied within facts specified by production rules and a database of information (gas contents, airway dimensions, air velocities etc.) available for access by the system while it is conducting a consultation session. A simple set of facts expressed as a production rule is:

\[
\text{IF } \text{xcord} > 0 \text{ AND } \text{ycord} > 0 \text{ OR } \text{methane concentration} > \text{normal} \\]
\[
\text{THEN atmosphere = explosive (note: pcoord = p coordinate on Elliott diagram)}
\]

As it can be seen this simple rule provides factual information (xcord, ycord) and rules of thumb (if methane concentration > normal) indicating the explosive nature of the atmosphere and that a control strategy is required.

RESCUE’s inference engine is goal driven in that first a goal is selected and then evidence is sought to support or contradict the goal (i.e., the deductive reasoning process) in the field of artificial intelligence, this problem-solving process is commonly known as backward chaining. This designation comes from the fact that since the goal or conclusion is known, but the path that leads to it is not, then the inference engine must work backwards. This is contrasted with forward chaining in which a set of facts is used to chain towards some conclusion or goal. However, since there is no control over the goal being pursued in a forward chaining process, a problem that may arise is the pursuit of a goal remote to the question at hand.

The inference engine also employs the depth-first search method in acquiring information about the selected goal. This strategy forces the engine to dig deeper and deeper into the details of a particular goal and to try and prove as many sub-goals as possible. The effect of a depth-first, backward chaining inference engine strategy is that all the relevant questions about a particular goal will be asked at the same time. The alternative, breadth-first search, results in random questioning that may be disconcerting to the user.

USING RESCUE

Fig. 2 is the structure of operation of RESCUE. The system begins in the expert system environment and the following menu is presented to the user:

1) Input/Add gas sample data
2) Delete data

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3) Plot/display graph
4) Display input/output (results)
5) Consult expert system
6) Quit

If the system is being used for the first time the only logical choice is option 1 since the system by this time has not processed any data for the other options to be meaningful. When option 1 is selected the user is immediately taken into the database environment to put in his gas sample data. These inputs are transformed into system data format (SDF) files. A FORTRAN program is then "called" which uses the created TEXT file as its input for analysis of the explosibility status of the atmosphere. When this stage is completed control is transferred back to the expert system which activates a database program and "APPENDS" the gas analysis results (from the FORTRAN) to a database file for storage and subsequent utilization during the expert system consultation process.

The user is then taken back to the main menu where he can repeat the process described above (ie input more sample data) or select any of the available options.

In addition to plotting graphs the system stores all the input and output results and can present them to the user at his request. Due to the large number of input and output involved the results are divided into four lists.

**LIST 1** contains all gas input, x, y, d, t, and Trickett’s ratios.

**LIST 2** contains all gas input and Air Free Values.

**LIST 3** contains all gas input, CO, COr, all ratios.

**LIST 4** contains all gas input as well as other inputs (pressure, humidity, temperature).

Table 1 is computer run of LISTS 1.

Finally option 5 (from main menu) takes the user into the expert system consultation mode.

**CONSULTATION**

Option 5 of main menu takes the user into the consultation mode of the system. The main goal of the system is to assist decision makers as to the course of action to take following the outbreak of fire. In view of the complexity and the multiple number of decisions that can be reached in such situations, it was decided that the backward chaining, depth-first search method of knowledge representation would be most appropriate for the inference engine. The following are an example of the type of rules RESCUE will utilize albeit the syntax of representation in the shell is not strictly followed here:

**RULE 5**

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### Table 1 - Gas Input and Partial Results

IF fire is too intense for fire fighting OR
fire is expanding more quickly than fire fighting can cope OR
fire is inaccessible for fire fighting OR
fire location is unsafe for fire fighting AND
direct air access to the fire bed is limited to one opening AND
gas ignition risk is too low
THEN apply a high expansion foam plug using generator in opening for 24 hours, monitor the fire gas products for lower oxygen and increased flammable gas content AND control air such that flammable gas in main return does not exceed 2%

RULE 6

IF gas analysis is as follows:
CO2% <= 5.00
CN2% <= 0.5
NH3% <= 0.5
O2% <= 10.00
N2% is balance to 100%
THEN The fire atmosphere is confirmed as oxygen rich.
Fire fighting can proceed

Assuming rule 6 is fired, the inference engine will try to establish all the sub-goals that lead to the conclusion of the fired rule (in this case rule 5). The engine will look for rules that concern a sub-goal. If there are no rules to validate or invalidate a particular sub-goal the user will be asked to supply a value for the sub-goal. Specifically in rule 5, the system will first try to establish the intensity of the fire. Since there are no rules to establish this, the user will be asked to supply a value for the intensity of the fire and a question such as “What is your estimate of the intensity of the fire?” could be asked. To help the user with the possible answers expected by the system, a list of answers will be provided along with the question. Again to establish the sub-goal “gas ignition risk too low”, a rule such as the following will need to be provided:

RULE 5A

IF flammable composition <= 1.5%
THEN gas ignition risk is low.

Now the system should establish the value for this sub-sub-goal (i.e. value for flammable composition) at this point the system will go into the database (where results of gas analysis are stored) and will fish out the value of the combustibles.

CONFIDENCE FACTORS

In real life, very little is known with absolute certainty. Even “experts” frequently resort to likely conclusions and best guesses when handing out advice. RESCUE makes room for uncertain responses by the user by allowing confidence factors. A confidence factor is an integer between 0 and 100 indicating the degree of certainty that a particular conclusion is valid. The system allows the user to enter confidence factors when responding to a prompt. As an example consider rule 7

IF smoke is dark AND
smoke is dense AND
no ventilation control over fire zone is possible AND
smoke backup is observed AND
fire is intense and well established
THEN there is evidence of fuel-rich fire tending to rectructure CNF 100

This rule says that if the antecedents are all true then the conclusion will be true with 100% confidence. However, if the user is not absolutely sure of his answers to the prompts, then the confidence factor of the conclusion reduces correspondingly. For example if responses to rule 7 were to be:

smoke is dark CNF 90
smoke is dense CNF 100
fire is intense CNF 100
smoke backup is observed CNF 90

These confidence factors from the user will be combined in a formula (0.9 x 0.9 x 0.9 x 0.9 = 0.729) and this will be the confidence factor for the conclusion of rule 7

There is evidence of fuel-rich fire tending to rectructure CNF 72

CONCLUDING REMARK

The primary objective of the
exercise is to provide fire-fighting
decision makers with a computerised
assistance in the form of an expert
system. In other words even though the
programme can be used by the management
of a particular colliery, it was
developed mainly for use by the
personnel of a mine rescue station. The
system has not got any physical
connection with remote (automatic) gas
sampling equipment. Input to the
programme is manual and it does not
help in any way to set off fire
detection alarms. It is assumed that
all preparations will have been made
(e.g. establishment of Fresh Air Base,
precise location of fire etc.) before
the system is called to assist.

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