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Study on Human Evacuation Plans during Mine Fires Using Genetic Algorithm

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ABSTRACT Mining fire is one of the critical disasters in coal mine. When it breaks out, it can destroy generous coal resources, roads and equipments, and kill miners. Sometime mine fires induce coal- dust and/or gas explosives thus enlarge fire risks and fire scopes. This is one of the main reasons that mine fires are dangerous to miners.
In this paper, Genetic Algorithm (GA) is used to study human evacuation plans during mine fires. GA is introduced in section 1; mathematical models of optimal control of airflow states under influence of mine fires, the selections of coefficients of GA, and how to evacuate fire risk sites are proposed in section 2; and an computation example is taken in section 3.
KEYWORDS: Mine Fire, Human Evacuation Plan, Genetic Algorithm.

1 INTRODUCTION

Mining fire is one of the critical disasters in underground coal mining [1]. Once fire accidents happen, they cause a large loss of livers, destroy generous coal resources, roads and equipment. If they are not handled properly and timely, they maybe induce more serious consequences such as gas or/and dust combustion and explosion leading to the further expansion disasters. According to differences of fire causing, mining fires are divided into two types, breeding fire and exogenous mine fire [2,3]. From some reports 85% of the total number of mining fires is breeding and 10~15% is exogenous.

Mining fires break out and continue in confined scopes where the ventilation network is very complicated. They have their own characteristics during their starting, propagating and fire fighting [4,5]. The burning objectives of mine fires are different from those which are obvious in the surface. The toxic and high temperature fumes such as CO, H_2, and HS produced during mine fire are fairly dangerous, in the meantime density of O_2 declines quickly, so miners who inhale polluted air can be poisoned or even die. Smokes, which fire emits, reduce visibility to shelters and itineraries for avoiding fire, at the same time, they hinder miners from evacuating fire places and fire fighting. Moreover, thermodynamics effects of high temperature airflow disorder mine ventilation systems, when fire scopes attain some extents, air quantities of galleries decrease quickly, even cause the reversals of airflow directions in some airways so that spread scopes of fire fumes may be expanded [6,7,8].

In order to understand combustion characteristics of mine fires, researchers lay stress on experiment studies of mine fires for long term. A number of experiments in experiment roadways or in underground roadways had been done [9,10,11]. Since the late 1970's, computers was used to calculated mining ventilation, so airflow states under influence of mine fires could be solved with computers [12,13,14,15].

In this paper, we introduce genetic algorithm to analyze human evacuation plans during mine fires and determine the safe evacuation lines and controls to mine fires, propose mathematical models of optimal control of airflow states under influence of mine fires, and take an computation example.

Presently, computations of mathematical models for the optimal control devices of mine ventilation systems under influence of mine fires are performed by CVM (Constrained Variable Metric Method), GRG (Generalized Reduced Gradient Method), and MPOP (Mixed Penalty Optimization Program) [16]. Sometimes these methods stop in local optimal points and their objective functions must be continuous and differential. So we lead GA (genetic algorithm) into optimal control of airflow states in fires, and the testing results confirm that GA reaches the best point in the search space quickly when its parameters are selected properly. The concept of GA was developed by John Holland [17]. GA are search techniques for global optimization in a complex search space. As the name suggests, GA employ the concepts of "natural selection" and genetics. GA was applied to many fields such as optimization of engineering design, machine learning, recognition of handwritten numerals and reliability optimizations [18,19,20]. The detailed steps for optimization of airflow controls in fires are in figure 1.

2 GA FOR QUANTITATIVE ANALYSIS ON OPTIMAL CONTROL OF AIRFLOW IN MINE FIRES

2.1 Mathematical Models of Optimal Control of Airflow States Under Influence of Mine Fires

The objective function of optimal control of air ventilation is the product of two absolute values, controls of branches, H_i, and air quantities of branches q_i. Simultaneously, control possibility and limits of control capacity of branches are considered. So we can gain the following mathematical models:

$$\min.\ J = \sum_{i=1}^{n} |H_i||q_i| \tag{1}$$

$$\text{s.t.} \quad \sum_{i=1}^{n-m+1} h_{ij} = 0 \qquad (j \in i) \tag{2}$$

$$\sum_{i=1}^{m-1} q_{ij} = 0 \qquad (j \in i) \tag{3}$$

$$q_L \le q_i \le q_U \qquad (i = 1,2,\ldots,n) \tag{4}$$

$$H_L \le H_i \le H_U \qquad (i = 1,2,\ldots,n) \tag{5}$$

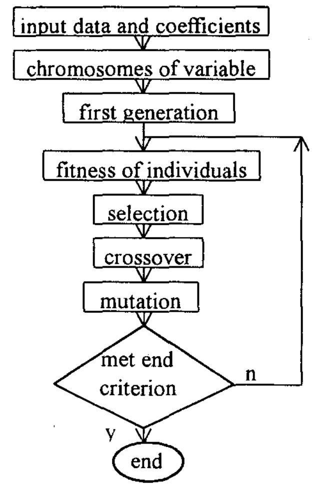

FIGURE 1. Flow of GA.

where J is objective function of optimal control, n is number of branches of mining ventilation, m is number of junctions of mining ventilation, h_{ij} is sums of ventilation energy of branch j in mesh i, and q_{ij}—is air quantity of branch j which is correlated with junction i. Equation (2) is mesh equations (conservation law of energy), and equation (3) is junction equations (conservation law of mass). Equation (4) represents up and low limits of airflow and equation (5) represents up and low limits of control variables.

2.2 Selections of Coefficients of GA

The solution speed of problems using GA is dependent on selections of GA coefficients, so we do orthogonal experiments using 4 elements, which are population size, probability of crossover, probability of mutation and number of generations. Based on results and trend plots of experiments, the parameters of GA are determined. Using above methods, we develop a Visual C++ for windows 95 software to optimize control of airflow states under influence of mine fires. The software are applied to some coal mines, and the airflow states after fire-occurring are simulated. Some of the calculated control measures have been tested in-situ of coal mines, and the testing results confirmed the feasibility of the proposed methods.

3 EXAMPLE ANALYSIS

Now an example of mine fire is taken. A mine fire breaks out in east mining area no.1, and the ventilation system of the area is illustrated in figure 2. The ventilation system owns 21 branches, 14 junctions and 8 independent mesh. Normally, directions of airflows are listed in table 1. Fire source supposed is in branch 17 (9→11). If no controls are taken, the airflow directions of branch 4, 5, 20, 16 are reverse, and their air quantities are minus. At the same time fire fumes diffuse in branch 15, 16, 17, 18, 19, 20, and 21. Scopes of fire expansions are given in figure 3. Miners in these branches are in danger of toxic and high temperature fumes, so it is very difficult to evacuate away from fire areas for miners working in face 4 and face 5 without efficient ventilation controls.

TABLE 1. Air quantity before and after mine fire, and results of ventilation control.

Branch	(start → end)	Resistance (Nsm^{-8})	Airflow before fire (m^3/s)	Airflow after fire (m^3/s)	airflow with controls (m^3/s)	branch regulators
1	(1→ 2)	0.01816	59.959	60.332	63.057	
2	(10→12)	81.9610	4.005	4.047	3.051	
3	(2→ 1)	1.1265	38.494	38.005	33.861	
4	(14→13)	1.4616	3.867	-2.513	0.205	
5	(14→13)	0.5156	6.511	-4.231	0.345	
6	(2→ 3)	0.141	21.464	22.327	29.196	
7	(3→ 5)	22.3099	1.243	1.605	1.924	
8	(3→ 4)	0.08	20.222	20.721	27.272	
9	(4→ 5)	1.0	1.325	4.810	4.805	
10	(4→ 6)	0.411	18.897	15.911	22.467	
11	(5→ 7)	40.643	2.568	6.415	6.729	
12	(6→ 7)	1340.614	0.303	1.090	1.111	
13	(6→ 8)	0.093	18.594	14.822	21.355	
14	(7→ 9)	0.0012	2.870	7.505	7.841	
15	(8→ 9)	5.121	4.211	17.518	17.752	
16	(8→10)	0.125	14.383	-2.696	3.604	
17	(9→11)	0.0003	7.081	25.023	25.592	
18	(11→12)	4.1	17.459	18.279	26.143	Open air door
19	(12→ 1)	0.113	21.464	22.327	29.196	
20	(13→11)	0.2	10.378	-6.743	0.550	Add 6.655Pa
21	(10→14)	0.2	10.378	-6.743	0.550	

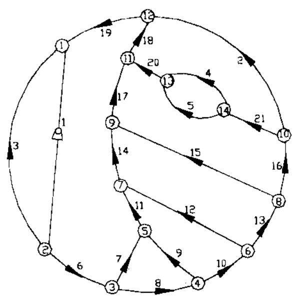

FIGURE 2. Ventilation network of a mine.

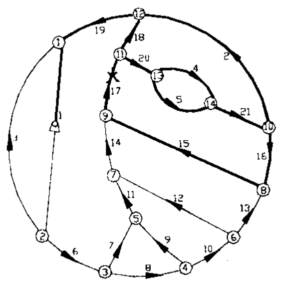

FIGURE 3. Airflow state under influence of mine fire(uncontrolled network).

Based on qualitative analysis, in order to evacuate miners safely from branch 4 and branch 5, their airflow directions must be kept in normal, and the fire fumes must be removed along the junctions 11→12→1, so miners can evacuate safely along junctions of 14→10→8→6→4→3→2

We prepare data files to compute, and do orthogonal experiments using orthogonal table $L_9(3^4)$ with 4 elements in 3 levels. The testing results show that the best parameters are 200 (population size), 0.7 (crossover probability), 0.01 (mutation probability), and 10000 (generations). So these parameter values are used to calculate the optimization of airflow control in fires. We use the GA program described above for the optimization, and the schemes of this fire are 1)open air door of branch 18(11→12), 2)increase resistance of branch 20(13→12), and its control amount is 6.655Pa. Using these controls and measures, miners in working face 4 and 5 can escape to safety place. The controlled airflow is shown in figure.4.

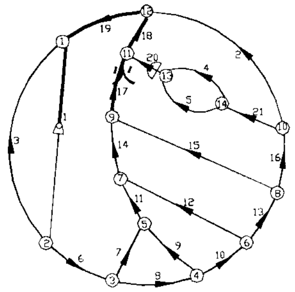

FIGURE. 4 Airflow state under influence of mine fire (controlled network).

4 CONCLUSIONS

(1) Using mutation operator, GA can reach the glob optimization in a complex search space quickly, thus many scientific and reliable decisions and plans of mine fire fighting and prevention can be determined conveniently.

(2) Based on orthogonal test, the coefficients of GA can be obtained. It is very valuable to make decision of fire fighting during mine fire.

(3) GA can not only be used in optimal control of airflow in a mine fire, but also be used in optimal design of mine ventilation system.

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