First International Symposium on Mine Safety Science and Engineering

Optimization of Mine Ventilation System Based on Bionics Algorithm

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Abstract

To solve the very complicated combination optimization problem of the optimization of mine ventilation system, the bionics algorithm-Ant colony algorithm proposed recently is used. Considering the essence of optimization of mine ventilation system, the ant colony algorithm is introduced here to solve the problem of mine ventilation system optimization. The detailed process of ant colony algorithm to optimization of mine ventilation system is described in this paper. At last, a mining engineering example is used to verify the effect of this new method. The results show that, ant colony algorithm is a very good method to solve complicated combination optimization problem. It not only can solve optimization of ventilation system, but also can solve the similar problem of scheme optimization.

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Selection and/or peer-review under responsibility of China Academy of Safety Science and Technology, China University of Mining and Technology(Beijing), McGill University and University of Wollongong.

Keywords: ant colony algorithm; combination optimization; mine ventilation system

1. Introduction

The mine ventilation system is a syntheses of ventilation connections, ventilation power and ventilation equipments et al. The purpose of ventilation system is to provide ozone to working area and remove exhaust gases. Now, as the scale of coal mining in China is becoming bigger as bigger, the scale of ventilation system is also becoming more complicated. But generally, the power consumption of ventilation system and the mining cost is all very high. So the economic performance of coal mining is very low. Considering from the environmental safety, the mining ventilation has changed to the

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environmental control in underground mining. So, to improve the method of environmental control and create the good working environment in underground mining has become an important problem for the mining engineering worldwide. And then, the optimization of ventilation system is very important for economic and society.

Actually, the optimization of ventilation system can be divided into two types [1-2]: the first one is the optimization of internal adjustment of ventilation network, which is to select the optimal parameters to one determined ventilation system scheme, and the second one is the optimization of the whole ventilation system. Nowadays, the above first optimization problem is studied more widely [2-5], and while the second one is researched little [2-6]. So, here the second optimization problem is studied.

Generally, the above second optimization problem can be called selection of ventilation system scheme. The optimization of ventilation system is to select the layout of ventilation roadways according to the original opening design, development design and mining design. The ventilation cost of one mine is different as the different layout of air roadways. So, it is very important to make the layout of air roadways optimal. So, the optimization of ventilation system is one kind of complicated combination optimization problem, which is a path optimization problem. To solve complicated combination optimization problem, there have been proposed many algorithms [7]. As intelligent bionics algorithm, the ant colony algorithm is a very good algorithm to solve complicated path optimization problem [8-9]. So, in this paper, the ant colony algorithm is applied to solve the path optimization problem of ventilation optimization.

2. Ant Colony Algorithm

2.1. Biologic principles of algorithm

Ant colony algorithm is a new meta-heuristic algorithm from the behavior simulation of natural ant colony. The food search process of ant colony is a process to find shortest path between food and nest through information intercommunion and cooperation among colony. The Italian scholars M. Dorigo et al find that this behavior can be abstracted to be a good method to solve combination optimization problem.

Ant is a typical social insect. The behavior of one ant individual is very simple. But the colony behavior is very complicated and can do a very complicated work. This phenomenon is a very interesting thing to many scholars. They have done many studies to disclose the essence of this phenomenon. They find that, the medium of information intercommunication among ant colony is a kind of hormone. Through this information intercommunication among colony, the ant colony can do a very complicated work by cooperation among them. It is very important of information intercommunication and cooperation among colony, and which makes the behavior of colony order. The hormone can be left along its path as ant moves. The follow ant can discover this hormone and recognize its density. It is a trend for ant to move along the path that has the larger density of hormone. So, the colony behavior of ants is a kind of information positive feedback. As more ants move along a path, the follow ants have more possibility to move along this path.

2.2. Implementation procedure of algorithm

The TSP is a very typical combination optimization problem. So, in order to describe simply, here the TSP is used.

Firstly, the follow symbols are introduced. \( m \) is the number of ants. \( d_{ij} \) is the length between city \( i \) and \( j \). \( b_i(t) \) is the number of ants at \( i \) city when time is \( t \). So, the there has the follow equation,
\[ m = \sum_{i=1}^{n} b_i(t) \]  

(1)

\[ \tau_y(t) \] is the hormone density along path \( ij \) at time \( t \). At beginning, the hormone density along all paths is same, which can be described as follows,

\[ \tau_y(0) = c \]  

(2)

where, \( c \) is a parameter.

The k-th ant is moved to one path based on hormone density along it. \( p_y^k(t) \) is the probability of k-th ant from city \( i \) to city \( j \) at time \( t \), which can be described as follows,

\[
p_y^k(t) = \begin{cases} \frac{\tau_y^\alpha(t)\eta_y^\beta(t)}{\sum_{j \in \text{allowed}_k} \tau_y^\alpha(t)\eta_y^\beta(t)} & j \in \text{allowed}_k \\ 0 & \text{otherwise} \end{cases}
\]  

(3)

where, \( \text{allowed}_k = \{0 \sim n - 1\} - \text{tabu}_k \) is the allowed cities for k-th ant to be selected, \( \alpha, \beta \) are two parameters, which describe the accumulative information and heuristic information as ant moves, \( \eta_y \) is the expected degree from city \( i \) to city \( j \), which is determined by one heuristic algorithm or selected as \( 1/d_{ij} \).

Different from natural ant colony, there has some memory in artificial ant colony. The set \( \text{tabu}_k \) record the selected cities by k-th ant, which is changed dynamically. As the time passed, the left hormone is volatilized. Here volatility is described by parameter \( \rho - 1 \). When the whole cities are passed by ant colony, one cycle is finished. After one cycle is finished, the hormone density along all paths is changed as the follow equations,

\[
\tau_y(t + n) = \rho \tau_y(t) + \Delta \tau_y
\]

\[
\Delta \tau_y = \sum_{k=1}^{n} \Delta \tau_y^k
\]  

(4)

where, \( \Delta \tau_y^k \) is the hormone density left along path \( ij \) at this cycle by k-th ant.

\( \Delta \tau_y \) is the whole hormone density left along path \( ij \) at this cycle.

According to different problems, there have three descriptions of \( \Delta \tau_y^k \) as follows,

\[
\Delta \tau_y^k \begin{cases} Q/L_k & \text{if k - th ant uses path } ij \text{ in this cycle} \\ 0 & \text{otherwise} \end{cases}
\]  

(5)
where, $Q$ is a parameter, $L_k$ is the whole path length passed by k-th ant in this cycle.

In above three descriptions, the global information is used in the first one, and while the local information is used in the follow two descriptions.

Parameters $Q, c, \alpha, \beta, \rho$ can be determined by experiments or by other optimization algorithms, such as genetic algorithm.

3. Application of Ant Colony Algorithm in Optimization of Ventilation System

Optimization of ventilation system is to select the optimal ventilation roadway networks that have the lowest ventilation cost at the condition that all ventilation requirements are needed. Because the influencing factors of ventilation system selection are very large, and their relationships are very complex, the optimization of ventilation system is a very complicated network optimization problem. And then, ant colony algorithm should solve this problem very well.

Here, a ventilation system optimization example of one coal mining in Handan Mine Bureau is used to verify this new algorithm. Nowadays, the ventilation system of this coal mine is unsuitable, and must be improved. In this work, the original ventilation roadways must be utilized adequately to make the cost of this improvement work least. The follow Fig.1 shows the all ventilation roadways, which include original roadways and new excavated roadways.

Actually, there are many factors to affect an optimal ventilation system, such as optimization of roadways system, which could consider the cost of roadway excavation, roadway maintenance and roadway draught capability et al, optimization of fan layout, optimization of ventilating volume and
optimization of split ventilation, et al. As the primary study, in this paper only the optimization of ventilating roadway network system is studied. So, the optimization of ventilation system is become to a problem of optimization of roadways network. This problem of optimization of roadways network is very similar to TSP. And then, ant colony algorithm can be used to solve this problem.

The optimization model can be described as follows,

Objective function: \[ \min F = \sum_i C_i + \sum_i D_i + \sum_i E_i \]

Constraint conditions: \[ q_{ij} = 0, h_{ij} = 0 \]

where, \( C_i \) is the excavation cost of roadway \( i \), \( D_i \) is the maintenance cost of roadway \( i \), \( E_i \) is the ventilating cost of roadway \( i \), their unit is ten-thousand-yuan, \( q_{ij} \) is the air volume from node \( i \) to node \( j \), whose unit is m³, \( h_{ij} \) is the wind pressure of roadway \( j \) in mesh \( k \), whose unit is KPa.

Combined with the ant colony algorithm, the two parameters \( d_{ij} \) and \( L_k \) are calculated by the above optimization model.

To solve the optimization of ventilation system problem, the algorithm described in section 2.2 should be revised as follows,

City \( i \) is a roadway end point, which is a network node. \( d_{ij} \) is the ventilating cost of roadways between \( i \) and \( j \) in ventilating network. The allowed roadways set \( allowed_k \) is the roadways assembly after node \( k \). Because the objective of this problem is to make the all cost of ventilation system to be least, the equation of \( \Delta \tau_{ij} \) takes the first description. In this description, \( L_k \) is the total cost of ventilation system in this cycle.

The results of computation using ant colony algorithm are as follows,

The optimal ventilation system is as that, the four roadways at the center of mining area are abandoned, the roadway \( b_1 \) at the west part is left, two new roadways of \( b_2 \) and \( b_4 \) are excavated, and the roadway \( c_1 \) at the east part is also left.

The total cost of optimal ventilation system is 445 496.37 ten-thousand-yuan.

The above results are the same as the results in reference [4]. So, ant colony algorithm can solve this problem very well.

Actually, using ant colony algorithm, the optimization of whole ventilation system can be solved more easily correspondingly, such as considering the air volume when \( d_{ij} \) is calculated can do the optimization of split ventilation, and considering the fan site when \( L_k \) is calculated can do the optimization of fan layout. So, optimization of ventilation system using ant colony algorithm can be extended to more complicated problems easily. And then, through this kind of studies, a more suitable method to optimization of whole ventilation system can be found.

4. Conclusions

(1) Optimization of ventilation system in mining is a very complicated path combination optimization problem. To this problem, ant colony algorithm is more suitable.

(2) Ant colony algorithm not only can solve the part optimization problem of ventilation system, but also can solve the more complicated whole optimization problem. And this method is not only suitable to optimization of ventilation system for new mine, but also suitable to improvement of ventilation system for old mine.

(3) Ant colony algorithm is a very good method to complicated combination optimization problem. It not only can solve optimization of ventilation system, but also can solve the similar problem of scheme optimization.
In this paper, the problem for optimization of ventilation system is studied preliminarily. The more complicated and comprehensively study is our next work.

Acknowledgements

This work was financially supported by The National Natural Science Foundation of China under Grant No. 41072233.

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