An Optimized Artificial Bee Colony Algorithm for the Shortest Path Planning Problem

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ABSTRACT

Considering the shortcomings of traditional artificial bee colony algorithm in slow convergence and easily falling into local optimum, this paper presents an optimized artificial bee colony algorithm, and use it to solve the shortest path planning problem. First, the artificial bee colony algorithm is designed to solve the shortest path planning problem. Second, the genetic hybrid genes, elite reserved strategy, and dynamic scout bees are introduced to improve the performance of traditional artificial bee colony algorithm. Finally, the proposed optimized artificial bee colony algorithm is compared with the traditional bee colony algorithm for solving the same problem in the tested area. The results show that the optimized artificial bee colony algorithm has a better performance than the traditional artificial bee colony algorithm in solving the shortest path planning problem.

INTRODUCTION

The shortest path planning problem is a basic topic about path planning problem. Studies on path planning problems of different fields (Huang et al. 2016; Hu et al. 2016; Zheng et al. 2016) can draw on experience from the method of solving the shortest path planning problem. The common methods for solving the shortest path planning problem include Dijkstra algorithm (Deng et al. 2012), Floyd algorithm (Zeng et al. 2012) and Bellman-Ford algorithm (Liang et al. 2015), which are famous for their accuracy. However, with the scale of road network becoming larger, the common algorithms will consume more time cost and computer memory. Usually, we are more concerned with achieving satisfactory results within acceptable cost. With the artificial bee colony algorithm coming out, it presents us a new method to solve the shortest path planning problem.

The artificial bee colony (ABC) algorithm was proposed by Karaboga in 2005 (Karaboga et al. 2005). Because of its fewer parameters and ease of use, it gets researchers' favor. However, the ABC algorithm is in slow convergence and easy falls into local optimum due to its new algorithm status (Bi et al., 2012). Many researchers have studied how to improve its optimization performance. In order to avoid falling into local optimum, Wei et al. (2017) introduced the adjustable voltage ranking selection strategy. Zhao et al. (2016) were inspired by the particle swarm optimization algorithm and improved the traditional artificial bee colony algorithm, which had been applied in CNC cutting parameter. Wei et al. (2017) proposed an improved artificial bee colony algorithm based on logistic model. In order to achieve a precise convergence to the global optimum, Song et al. (2016) improved the searching equation of employed bees and onlooker bees. Song et al. (2016) proposed an improved artificial bee colony algorithm based on center solution and proved its feasibility by standard function library. These researches inspire us to combine some advantages of other heuristic algorithms to improve the performance of traditional ABC algorithm.

This study aims at improving the traditional ABC algorithm in application of solving the shortest path planning problem. The rest of this paper is organized as follows. In the next section, the ABC algorithm is designed to solve the shortest path planning problem. Then, the traditional ABC algorithm is optimized by the strategies of the genetic hybrid genes, elite reserved strategy, and dynamic scout bees. At last, the proposed optimized artificial bee colony (OABC) algorithm is compared with traditional ABC algorithm in a tested area.

THEORY OF ABC ALGORITHM FOR THE SHORTEST PATH PLANNING PROBLEM

Problem Formulation

The road network is the foundation for planning path. In this paper, it is denoted by the directed graph $G=(V,A)$ (Ahn et al. 2012), where $V=\{v_i\}$ presents the nodes of road network. v_S presents the origin point and v_D presents the destination point. $A=\{a_{ij}=\langle v_i,v_j\rangle \mid v_i,v_j\in V\}$ are a set of road arcs. a_{ij} presents an arc from node v_i to node v_j. c_{ij} represents the length of arc a_{ij}.

Using the definitions above, the shortest path planning problem can be formulated as an optimization problem, minimizing the objective function (1) as follows:

$$\text{Minimize} \quad \sum_i \sum_j c_{ij} \bullet I_{ij} \tag{1}$$

Subject to

$$I_{ij}=\begin{cases}1, & \textit{if the arc from node } v_i \textit{ to node } v_j \textit{ exists in the planned path}\\ 0, & \textit{otherwise}\end{cases} \tag{2}$$

$$\sum_{\substack{j=S\\ j\neq i}}^{D} I_{ij}-\sum_{\substack{j=S\\ j\neq i}}^{D} I_{ji}=\begin{cases}1, & if\ \ i=s\\ -1, & if\ \ i=D\\ 0, & otherwise\end{cases} \tag{3}$$

$$\sum_{\substack{j=S\\ j\neq i}}^{D} I_{ij}\begin{cases}\leq 1, & if\ \ i\neq D\\ =0, & if\ \ i=D\end{cases} \tag{4}$$

$$\text{and} \qquad I_{ij}\in\{0,1\},\ for\ all\ i \tag{5}$$

The constraints (2) - (5) ensure that the computed result is indeed a path without loops between the original point and the destination point.

Steps of ABC Algorithm for Solving the Shortest Path Planning Problem

Considering the discrete characteristic of path planning problem, the ABC algorithm is designed to solve this problem in detail. The ABC algorithm mainly consists of four elements (Develi et al. 2015): food source, employed bees, onlooker bees, and scout bees. Each food source represents a feasible solution. Each cycle of the algorithm consists of three phases: employed bee phase, onlooker bee phase and scout bee phase. The end condition is to find a satisfactory solution. The correspondence between the bee colony behaviors and the shortest path planning problem is shown in Table 1.

Table 1. The Correspondence between Bee Colony Behaviors and Path Planning Problem

Bee colony behaviors of taking honey	The shortest path planning problem
Position of food source	Planned path
Profitability of food source	Fitness value of planned path
Best food source	The shortest planned path

A. Food Source Representation

As discussed above, a food source represents a planned path. In this study, a food source consists of sequences of nodes that a planned path passes across. An example of food source encoding from original point v_S to destination point v_D is shown in Figure 1. This food source is represented as $v_S \to v_1 \to v_2 \to v_3 \to v_4 \to v_5 \to v_D$.

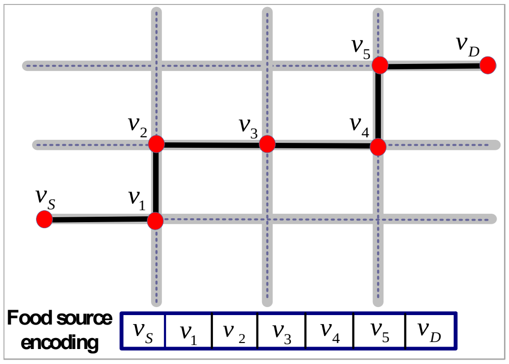

Figure 1. Example of food source encoding.

B. Fitness Function

As discussion previously, the fitness function is defined as function (6):

$$F_k = \sum_i \sum_j c_{ij} \bullet I_{ij} \tag{6}$$

Where F_k represents the fitness value of food source k. The smaller the fitness value, the better the planned path. c_{ij} represents the length of arc a_{ij} and I_{ij} represents the arc connection indicator, which plays the role of providing information on whether the arc from node v_i to node v_j included in the planned path or not.

C. Employed Bee Phase

In this phase, each employed bee combines with a food source and searches a new food source in its neighboring area. If the new food source has a better fitness value than the old food source, the new one will be conserved and the old one will be abandoned. On the contrary, the old food source will be conserved.

In the shortest path planning problem, the theory of employed bees searching in neighbor areas is as follows. According to the previous section, an employed bee chooses a node of its associated food source at random. This chosen node is not the original node and destination node, and it is called neighbor start point (NSP). Then the employed bee chooses a node of associated food source between NSP and the destination point at random. This chosen node is called neighbor destination point (NDP). Conserving the part between original pint and NSP and the part between NDP and destination point, the employed bee obtains a new partial path between NSP and NDP. In this way, the employed bee will obtain a new food source by searching the neighbor area. Through comparing the fitness value between new food source and old food source, the employed bee will conserve the better one.

An example is shown in Figure 2. There is a food source $v_S \to v_1 \to v_2 \to v_3 \to v_4 \to v_5 \to v_6 \to v_7 \to v_8 \to v_D$. The employed bee chooses node v_3 as the NSP and chooses node v_6 as the NDP. Conserving the partial path between the original point and NSP and the partial path between NDP and the destination point, the employed bee searches a new partial path between NSP and NDP. In this way, it obtains a new food source, which can be represented as $v_S \to v_1 \to v_2 \to v_3 \to v_6 \to v_7 \to v_8 \to v_D$. The fitness value of the old food source is 9km (supposing the the length of each arc is 1km). The fitness value of the new one is 7km. So, the new one will be conserved and the old one will be abandoned.

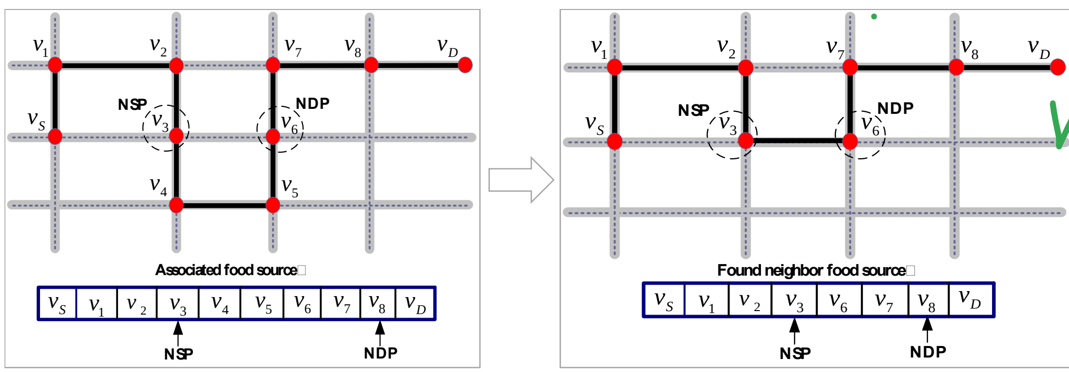

Figure 2. Example of searching new food source in neighbor area.

D. Onlooker Bee Phase

After the employed bee phase, the employed bees transfer food source information to onlooker bees, and the algorithm enters into onlooker bee phase. In this phase, onlooker bees select food source by roulette strategy. Then the onlooker bees will search the neighboring area of the selected food source the same way as employed bees. The probability of a food source to be selected by an onlooker bee is as function (7):

$$P_k = \frac{1/F_k}{\sum 1/F_k} \tag{7}$$

Where P_k represents the probability of food source k to be selected. F_k represents the fitness value of food source k. Obviously, the food source which has a better fitness value will have a greater probability to be selected by onlooker bees.

E. Scout Bee Phase

If a food source has not been updated for more than limited times, the algorithm is considered as following into the local optimum. In this phase, the employed bee corresponding with this food source will transfer into scout bee. The scout bee will abandon this food source and obtain a new one in the searching space.

In solving the shortest path planning problem, the principle of scout bees is as follows. A food source is shown in Figure. 3. It is represented as $v_S \to v_1 \to v_3 \to v_2 \to v_7 \to v_5 \to v_6 \to v_8 \to v_D$. It has not been updated for more than limited times, and it is abandoned by the scout bee. Then the scout bee will search a new food source to replace the abandoned one. The new food source is presented as $v_S \to v_1 \to v_3 \to v_5 \to v_6 \to v_8 \to v_D$.

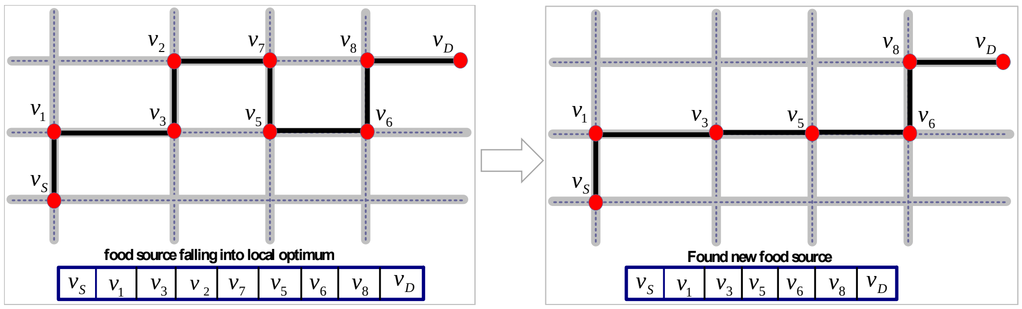

Figure 3. Example of principle of scout bees.

STRATEGIES FOR OPTIMIZING THE TRADITIONAL ABC ALGORITHM

Considering the shortcomings of traditional ABC algorithm in slow convergence and easily falling into local optimum, this part will optimize it with the genetic hybrid genes, elite reserved strategy and dynamic scout bees. The proposed strategies are corresponding to employed bee phase, onlooker bee phase, and scout bee phase.

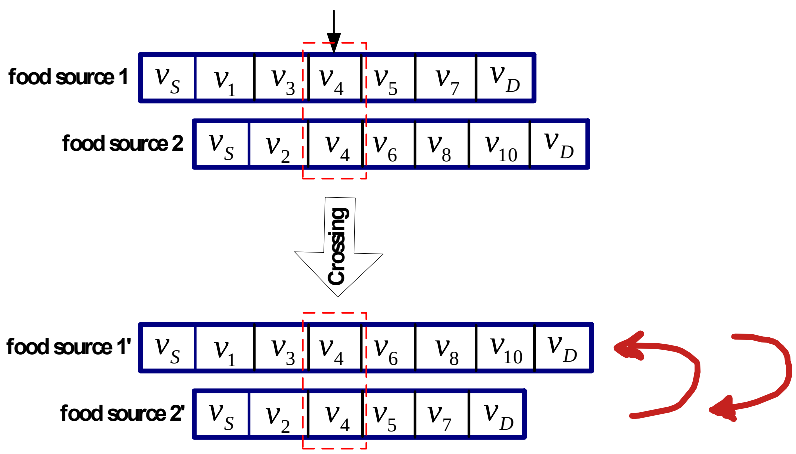

Figure 4. Example of crossing with genetic hybrid genes strategy.

Genetic Hybrid Genes

In this part, the genetic hybrid genes strategy is introduced in detail. Many studies have shown that ABC algorithm is better than genetic algorithm in solving discrete problems (Wei et al. 2014). Our team tries to introduce the genetic hybrid genes strategy from genetic to improve the performance of traditional ABC algorithm. By this strategy, the worse food sources will generate a new one through crossing. Not only does the genetic hybrid genes strategy increase diversity of population, but also it accelerates the speed for convergence.

An example is shown in Figure 4. There are two food sources with worse fitness value. One is $v_S \to v_1 \to v_3 \to v_4 \to v_5 \to v_7 \to v_D$, and the other is $v_S \to v_2 \to v_4 \to v_6 \to v_8 \to v_{10} \to v_D$. Node v_4 is chosen as the crossing point. The two offspring food sources are $v_S \to v_1 \to v_3 \to v_4 \to v_6 \to v_8 \to v_{10} \to v_D$ and $v_S \to v_2 \to v_4 \to v_5 \to v_7 \to v_D$.

Elite Reserved Strategy

In onlooker phase, onlooker bees select food source by roulette strategy and update them. Because the roulette strategy is a choice with some randomness, the food source with greater chosen probability may also in fact be ignored. In order to make up this deficiency, this study introduces elite reserved strategy to optimize the traditional ABC algorithm. In this way, the best food source will be reserved in the next phase in OABC algorithm.

The detailed operation of the elite reserved strategy is as follows. In the onlooker phase, the food source with the best fitness value in this generation will enter into the next phase without roulette strategy, and the others enter into the next phase by roulette strategy. In this way, it can avoid the better food source to be ignored.

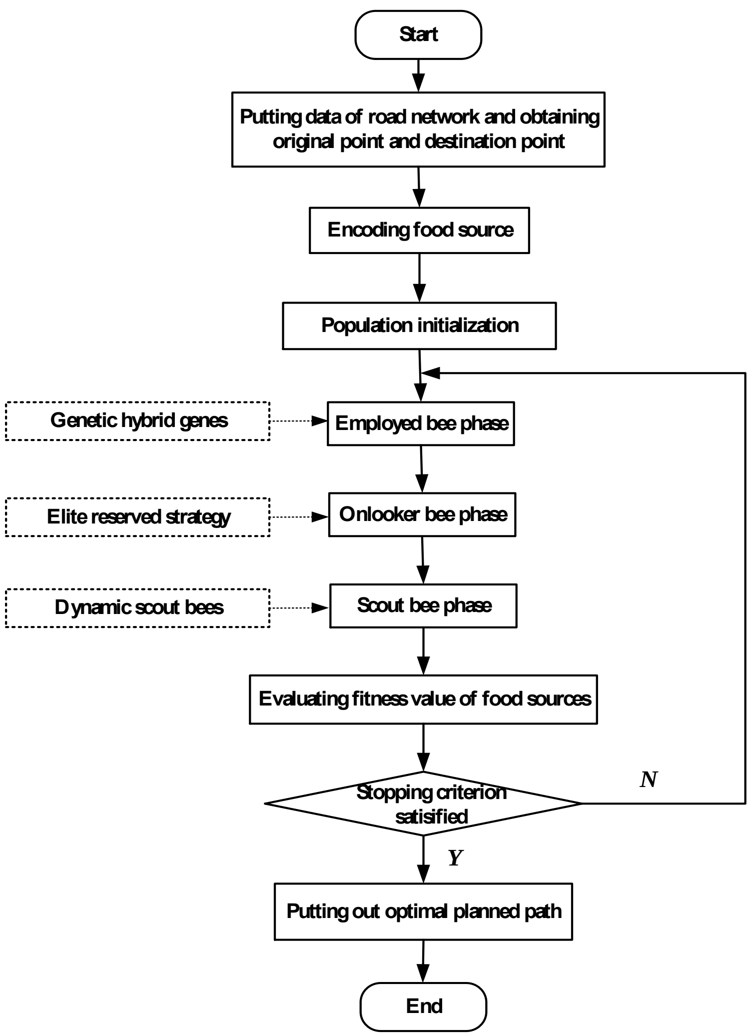

Figure 5. Flowchart of OABC algorithm.

Dynamic Scout Bees

In the traditional ABC algorithm, there is only a scout bee and it only can abandon a local optimum. If more than one food source fall into local optimums simultaneously, they must be abandoned by several generations, which can delay the optimization progress.

Facing this shortcoming, the dynamic scout bee's strategy is designed to optimize the traditional algorithm. In this strategy, the number of scout bees is dynamic with the local optimums. If there is more than one local optimum, it will generate the same number of scout bees. In this way, all the local optimums will be abandoned simultaneously, and the same number of new food sources will be generated. In order to avoid abandoning the global optimum, the best food source at the current generation will be conserved. With the dynamic number of scout bees, the algorithm can avoid premature convergence.

The flowchart of OABC algorithm for solving the shortest path planning is shown in Figure. 5.

Analysis of Time Complexity

The time complexity of algorithm only considers influence of the scale of population (Lu et al. 2015; Liu et al. 2013). Supposed the number of population is N, the analysis of time complexity of ABC algorithm and OABC algorithm for a loop is shown as follows:

For ABC algorithm, the time complexity of initializing population is $O(1)$. The time complexity of calculating fitness value and choosing the best one is $O(N)$. The time complexity of searching new food sources in neighbor areas by employed bees and updating food source is $O(N^2)$. The time complexity of calculating probability of choosing a food source by onlooker bees is $O(N)$. The time complexity of searching a new food source in a neighboring area and updating food source by onlooker bees is $O(N^2)$. The time complexity of comparing the times of not updating of food source and judging whether to send scout bees is $O(N)$. If a food source needs to be abandoned, the time complexity of searching a new food source by scout bee is $O(N)$. After a generation, the time complexity of choosing the best food source so far is $O(N)$. So, the time complexity of ABC algorithm for a loop is $O(1)+O(N)+O(N^2)+O(N)+O(N^2)+O(N)+O(N)+O(N)$, which is $O(N^2)$ for short.

For OABC algorithm, the time complexity of initializing population is $O(1)$. The time complexity of calculating fitness value of good source and choosing the best one is $O(N)$. The time complexity of searching a new food source in a neighboring area by employed bees and updating the food source is $O(N^2)$. The time complexity of sorting the food source with genetic hybrid genes strategy and crossing is $O(N)$. The time complexity of conserving the better food sources with elite reserved strategy by onlooker bees is $O(N)$. The time complexity of calculating probability of choosing a food source by onlooker bees is $O(N)$. The time complexity of searching a new food source in a neighboring area and updating the food source by onlooker bees is $O(N^2)$. The time complexity of comparing the times of not updating of a food source and judging whether to send scout bees is $O(N)$. If one food source needs to be abandoned, the time complexity of searching a new food source by scout bee is $O(N)$. After a generation, the time complexity of choosing the best food source so far is $O(N)$. So, the time complexity of OABC algorithm for a generation is $O(1)+O(N)+O(N^2)+O(N)+O(N)+O(N)+O(N^2)+O(N)+O(N)+O(N)$, which is $O(N^2)$ for short.

In summary, the time complexity of OABC algorithm is equal to ABC algorithm, which means the optimizing operations do not exacerbate the time complexity.

CASE STUDY

The area of Guangzhou Higher Education Mega Center is chosen as the tested area in this study. The exit of the Nanshagang freeway is chosen as the original point and the entrance of Sun Yat-sen University is chosen as the destination point. It needs to plan the shortest path between original point and destination point.

In order to test the better performance of OABC algorithm over the traditional ABC algorithm, we use these two algorithms to solve the same optimization problem. The test is with the platform of ArcGIS 10.0 and visual studio 2010. The parameters are set as shown in Table 2.

Table 2. Parameters of Two Algorithms

Algorithm	Iterations	Food source	Employed bee	Onlooker bee	Scout bee	Limit
OABC	30	50	50	50	dynamic	5
ABC	30	50	50	50	1	5

The results of two algorithms are shown in Figure. 6. The OABC algorithm only needs ten generations to converge into the best result, and ABC algorithm needs twenty generations to converge into the best result. On the other hand, ABC algorithm follows into the local optimum more times. Through comparison, we can know that the OABC algorithm has a better performance than ABC algorithm, not only in convergence speed but also in optimization stability. The optimization result is shown in Figure. 6. The length of the shortest path is 4.4 km.

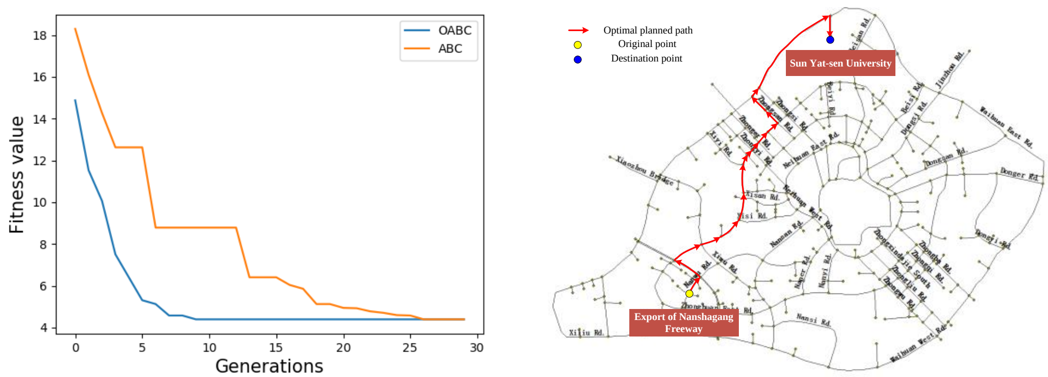

Figure 6. Results of two algorithms.

In summary, we can conclude that OABC algorithm has a better performance in solving the shortest path planning problem over the ABC algorithm. The optimized algorithm proposed in this paper solving the optimization problem with a faster convergence speed and higher stability, which proves the superiority of OABC algorithm.

CONCLUSIONS

In this paper, we have focused on optimizing the traditional artificial bee colony for solving the shortest path planning problem. Firstly, the details of artificial bee colony algorithm designed to solve the shortest path planning problem are shown. Then, we introduce strategies of genetic hybrid genes, elite reserved strategy, and dynamic scout bees to optimize the traditional artificial bee colony algorithm. At last, the proposed optimized artificial bee colony algorithm is compared with the traditional artificial bee colony algorithm in a tested area and the result shows that the OABC algorithm performs better than the ABC algorithm in solving the shortest path planning problem.

This study can be a significant reference for the area of discrete optimization problem by artificial bee colony algorithm in the future.

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