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A literature Review of Ant Colony Algorithm Based on Cite Space

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Abstract: Ant colony algorithm is a kind of biological heuristic algorithm, which has been applied in the fields of combinatorial optimization, path planning, task scheduling and other fields and has achieved significant optimization results, so it is necessary to sort out the literature of ant colony algorithm and deepen the understanding of its research status, hotspots and future development directions. In this paper, the process, principle and application fields of ant colony algorithm are sorted out, and the literature related to ant colony algorithm is bibliologically analyzed based on Cite Space software, and the number of publications, the current situation of researchers and research institutions are summarized, and the research hotspots and trends of ant colony algorithm are revealed through citation network and keyword co-occurrence analysis. Through bibliometric analysis, we understand that the research on ant colony algorithm is stable, and there is overlap and integration with other optimization algorithms. Future research can continue to focus on the improvement and application of ant colony algorithm, and explore its combination with other algorithms to promote the application of ant colony algorithm in a wider range of fields.

Keywords: Ant Colony Algorithm; Cite Space; Bibliometrics

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1.Introduction

As a biological heuristic optimization algorithm, ant colony algorithm is inspired by ant foraging behavior, in nature, ants find the shortest path and optimal solution through collective behavior through pheromone release and perception. By simulating the pheromone communication and collective behavior of ant colonies, the ant colony algorithm introduces bio-inspired intelligence into the field of computing, and is committed to solving complex problems such as integrated circuit layout (Wu et al., 2022), path planning (Guo et al., 2023), combinatorial optimization (Hu et al., 2023), and image recognition (Shi et al., 2021). Compared with the limitations of traditional optimization methods, which are easy to fall into local optimum, the proposed algorithm can quickly search for the global optimal solution in the distributed self-organizing model with the help of positive feedback mechanism and pheromone guidance, which fills the technical gap of large-scale optimization problems (Yang et al., 2020). Although the early version had the defects of local convergence and “deadlock”, through continuous improvement and algorithm “mutation”, it has shown strong potential in scenarios such as shortest path search for travel merchants, optimization of graph vertex coloring, route planning and resource allocation of logistics vehicles, and significantly shortened the time and cost (Yu et al., 2021). However, in the face of challenges such as dynamic environment adaptation, multi-objective constraint processing, and convergence efficiency improvement, current research still focuses on the in-depth optimization of algorithm performance (Xu Wei, 2023). Therefore, based on the Cite Space bibliometric method, this paper systematically reviews the theoretical development, research trends and application hotspots of ant colony algorithm, aiming to comprehensively understand the application status and development trend of ant colony algorithm in optimization problems, provide reference and inspiration for researchers, promote the application and development of ant colony algorithm in a wider range of fields and problems, and provide methodological reference for cross-domain optimization research.

2.Introduction to ant colony algorithms

2.1 The Proposal and Development of Ant Colony Algorithm

The development process of ant colony algorithm can be divided into four key stages:

1. Initial exploration (1992-1996): Proposed by Italian scholar Marco Dorigo in 1992, inspired by ants’ foraging behavior, it was the first time to transform biological swarm intelligence into an optimal computing method. Although the initial theoretical framework did not receive much attention, Dorigo laid the foundation for the algorithm in 1996 by comparing traditional methods such as genetic algorithms to highlight its potential to solve complex optimization problems.
2. Theoretical improvement (1997-2003): The academic community focused on the deepening of core theories such as pheromone models and heuristic rules, and the first International Conference on Ant Colony Algorithm (ANTS’98) in 1998 promoted the research boom. In 2000, Bonabeau et al. published the first systematic review, and Gutjahr’s team explored the convergence of algorithms from the perspective of graph theory.
3. Application Expansion (2004-2010): The algorithm verifies its effectiveness in combinatorial optimization scenarios such as traveling salesman problem and vehicle path planning, and its distributed optimization ability shows engineering value in the fields of logistics scheduling and task allocation, and promotes the transition of the algorithm from theory to practice.
4. Variant innovation (2011-present): The research has shifted to the direction of multi-objective optimization, adaptive parameter adjustment, etc., integrating local search strategies and other intelligent algorithms (such as particle swarm optimization) to improve performance. Derivative algorithms, such as the maximum-minimum ant colony system (MMAS) and multi-objective ant colony optimization (MOACO), have emerged one after another, which strengthens the robustness of the algorithms in dynamic environment and high-dimensional problems.

Over the past 30 years, the ant colony algorithm has gradually evolved from the initial idea of biological behavior simulation to a mature optimization tool with both theoretical depth and application breadth, and continues to drive innovation in the field of intelligent computing.

2.2 Principles of the ant colony algorithm

The ant colony algorithm dynamically optimizes path selection based on pheromone positive feedback and heuristic rules by simulating the cooperation mechanism of ant colonies. The core of the problem lies in the fact that ants construct solutions probabibly based on the pheromone concentration and heuristic information (such as path length) on the path, and strengthen the high-quality path by releasing pheromones to form a positive excitation. In the process of algorithm iteration, the pheromones are dynamically adjusted through the volatilization mechanism and the enhancement mechanism, so that the ant colony gradually converges to the global optimal solution in multiple searches. After the initial parameters are set, the ant continuously updates the path until the termination conditions are met, such as the maximum number of iterations or the solution quality is met, and finally realizes the efficient solution of complex combinatorial optimization problems through the self-organizing characteristics of swarm intelligence.

The transition probability of ant k moving from city i to city j at time t $P_{ij}^{(k)}$ formula is:

$$P_{ij}^{(k)}\begin{cases}\frac{\left[\tau_{ij}(t)\right]^{\alpha}*\left[n_{ij}\right]^{\beta}}{\sum_{j\notin J_k}\left[\tau_{ij}(t)\right]^{\alpha}*\left[n_{ij}\right]^{\beta}}, j\notin J_k\\ 0, j\notin J_k\end{cases} \tag{1}$$

In Eq. (1), $\tau_{ij}(t)$ is the concentration of the pheromone, n_{ij} is the heuristic, and is calculated as the reciprocal of the Euler distance from i to the j node, i.e.

$$n_{ij}=\frac{1}{d_{ij}} \tag{2}$$

When all ants complete the search, the pheromones on the path are updated with the following rules:

$$\tau_{ij}(t)=(1-\beta)\tau_{ij}(t)+\Delta\tau_{ij} \tag{3}$$

In Eq. (3), β is the volatility coefficient, and $\Delta\tau_{ij}$ represents the increment of pheromones on the ij path, which is calculated as:

$$\Delta\tau_{ij}=\begin{cases}\frac{Q}{L_k}, When\ passing\ through\ ij\\ 0,\ other\end{cases} \tag{4}$$

In Eq. (4), L_k is the total length of the path taken by the k-th ant in this cycle, and Q is the total amount of pheromones released by the ant after completing a complete path search.

The specific steps of the ant colony algorithm are as follows:

1. Initialization: First, you need to initialize a set of ants and the relevant parameters of the problem. The initialization process includes determining the number of ants, the solution space of the problem, the initial value of pheromones, etc.
2. Ant path selection: Each ant chooses the next path according to the heuristic rules and pheromone concentration. Heuristic rules can be problem-related heuristics, such as path length, feasibility, and so on. Pathways with high pheromone concentrations are more likely to be chosen.
3. Construction and update of the solution: The ants select the path in turn and construct a solution according to the selected path. The construction of the solution can be sequential or parallel. After each ant selects the path, the pheromone is updated according to the quality of the solution, and the forward probability update method is generally used.
4. Pheromone update: After the ant selects the path, the pheromone will be updated. The renewal of pheromones follows the principle of pheromone volatilization and pheromone enhancement. Pheromone volatilization indicates that pheromones gradually decrease over time to prevent premature convergence. Pheromone enhancement indicates an increase in pheromone concentration based on the quality of the path chosen by the ant.
5. Judgment of termination conditions: After each iteration, it is necessary to judge whether the termination conditions are met. A common termination condition can be to reach the maximum number of iterations, to obtain a satisfactory solution, or to satisfy a problem-specific stopping condition.
6. Iterative update: If the termination condition is not met, the algorithm will continue to iteratively execute steps 2 to 5 until the termination condition is met.

3.Bibliometric analysis of ant colony algorithms

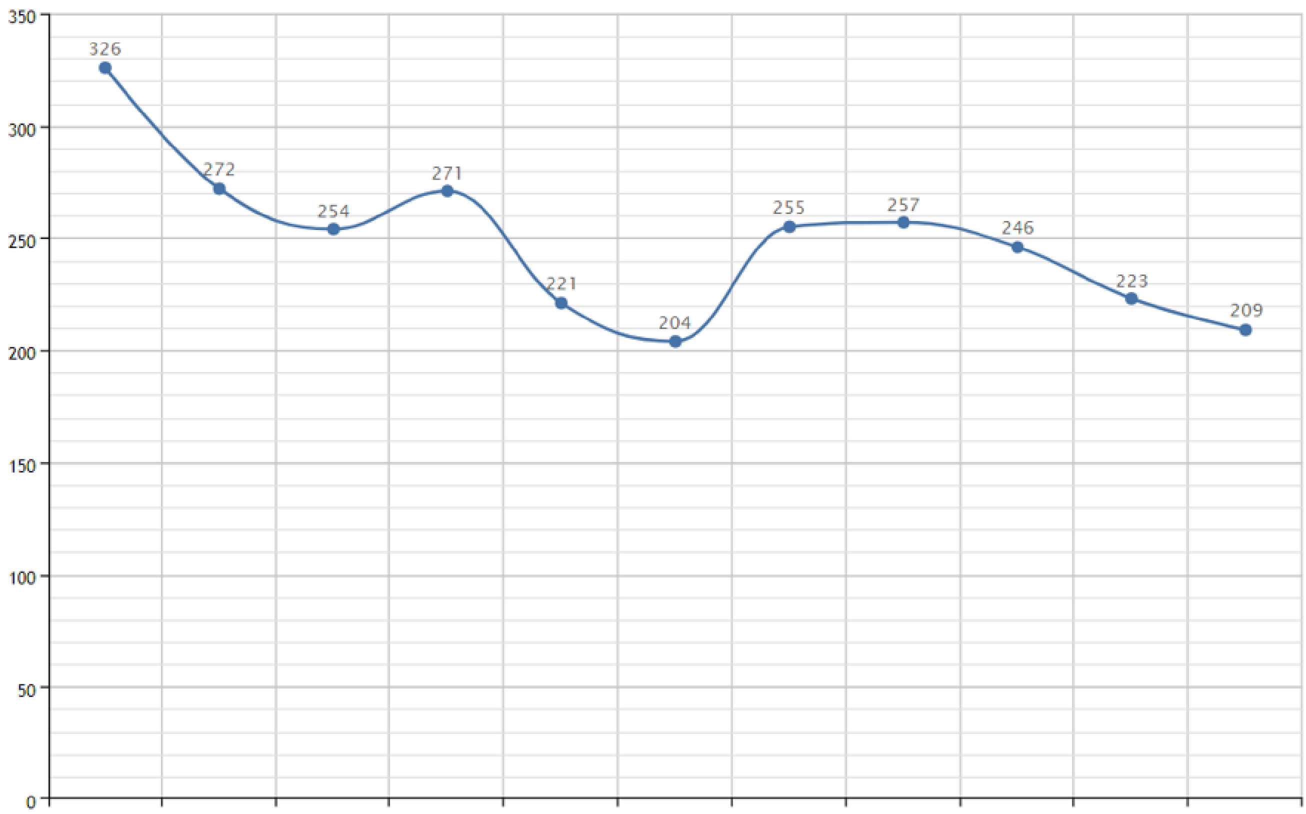
3.1 Data source

Cite Space is a powerful academic research tool designed by Dr. Chaomei Chen of Drexel University in the United States, focusing on the field of literature analysis and visualization. Built in the Java programming language, the software is designed to provide users with a high-performance platform to measure and explore the trajectory of specific academic fields. Through Cite Space, researchers are able to uncover the critical path of discipline evolution, and its core competency is to generate a series of intuitive graphs that help users deeply understand the dynamics and cutting-edge trends of the discipline. Cite Space is designed to help researchers explore knowledge structures, research hotspots, and academic trends in the field of academic research. It provides a wealth of features and tools that enable users to analyze and present bibliographic data in an intuitive and interactive way.

In this paper, “subject name = ‘ant colony algorithm’” was searched in the China Academic Journals Network Publishing Database (CNKI). The search results were screened, and the journal literature was selected, as long as the journal with a high level of quality was selected, only the journal literature whose source was Peking University Core and CSSCI was selected, and the time span of this study was limited to 2013-2023, and a total of 2738 journal articles were retrieved, which constituted the literature sample of this study. The resulting data was exported in txt file format, named and processed with file names that could be recognized by Cite Space, and some of the data was deduplicated and lost after processing, leaving a total of 2000 articles.

3.2 Overall study overview

Figure 1: A line chart of the number of posts published



It can be seen from the line chart of the number of published papers that the literature volume of ant colony algorithm was the highest in 2013, with 326 articles, and the literature volume in 2014 and 2015 decreased compared with the literature volume in 2013, with 272 articles and 253 articles respectively, and in 2016, the literature volume rebounded again, with 270 articles, and began to decline continuously in 2017 and 2018, with 223 articles and 206 articles respectively, and the literature volume rebounded from 2019 to 2022, which was flat and relatively stable, with 253 articles respectively, 258 and 246, dropping to 209 in 2023. It can be seen from the trend of the number of published papers that although the research on ant colony algorithm is not in the emerging hot stage, the research enthusiasm is still objective, and from 2013 to 2023, many researchers have been in a relatively mature research stage for ant colony algorithm.

3.3 Investigator profile

In this paper, we use cite space software to perform visual analysis on a dataset containing 2000 records, and set the node type as author. We obtain the research results. The “n=260, e=228” in the results summarizes the key statistical data, in which “n” identifies the number of author nodes, a total of 260 bits. The size of the node text directly reflects the frequency of mention of each author in the data sample - the larger the font, the higher the author’s activity and influence. “E” represents the number of edges or connecting lines, totaling 228. Each connecting line symbolizes the cooperative relationship between the two authors, and its width directly reflects the frequency of their joint publications, which means a closer cooperation mode. The result includes a network of 260 author nodes and 228 cooperation edges. Obviously, the dense connections between some nodes highlight the close cooperation group. In particular, the results highlight two teams of authors who work closely together: the first team includes you Xiaoming, Liu Sheng, Li Juan, zhanghainan, liuzhongqiang and others. Their research results are concentrated in a relatively new time period, namely, 2018-2020, and the number of papers issued by members is large; The other team is composed of Zhaohui, Xujun, wanghongjun, yueyoujun, etc. Although the overall number of papers issued by this team is relatively small, they were active earlier, mainly in 2017. These observations not only reveal the mode of cooperation among authors, but also reflect the dynamic changes in the field of academic research and the potential cooperative network structure.

With the help of the analysis data about authors displayed in cite space, the data of the top 10 high-yielding authors are intercepted and tabulated, and the results shown in Table 1 can be obtained. Among them, Liusheng, youxiaoming, liushichang and Zhang Zheng published more articles. The number of articles published by the top two was 22, while the number of articles published by the last two was 7 and 5. The vast majority of the papers published by the authors other than the 10 authors are 1-4. According to figure 5, the domestic research on the subject of ant colony algorithm presents a single core development mode. A few core members occupy an important position and play a decisive role, while the rest of the authors have few papers and have little connection.

Table 1 .Top 10 authors

serial number	Author	Number of publications	Year of initial publication
1	Liu Sheng	22	2018
2	You Xiaoming	22	2018
3	Liu Changshi	7	2019
4	Zhang Zheng	5	2020
5	Nie Qingbin	4	2017
6	Wan Zhiping	4	2013
7	Unopen a position	4	2014
8	Wang Xin	4	2017
9	Liu Chunnian	4	2013
10	Zhao Kaixin	4	2017

3.4 Overview of the research institution

In the cite space operation interface, select the node type as institution for visual analysis, and get the map. Similarly, the larger the font size of the organization name, the higher the frequency of the organization in 2000 data, "e" represents the connection, and the connection between nodes represents the connection between organizations. The thicker the connection, the higher the frequency of their occurrence in the same document. According to the "n=80, e=0" in the results, there is basically no connection between various institutions, indicating that there is no cooperation. In order to develop the academic frontier, cooperation among research institutions needs to be strengthened.

In order to more clearly show the important relevant research institutions, this paper draws Table 2 with the help of the relevant data in cite space, listing the top 10 institutions with a large number of published articles. The institutions in the table are all major institutions of higher learning. Among them, Shanghai University of engineering and technology has issued many papers, and its research year is relatively recent in 2018. The number of papers issued by Dalian Maritime University and Dalian University of technology is the same as 6. The number of papers issued by Dalian Maritime University is relatively recent in 2019. The number of papers issued by Shanghai University of technology is relatively old in 2013. The number of papers issued by Northeast University and Shanghai Maritime University is the same as 5. The number of papers issued by Northeast University is earlier, which is 2013, while the number of papers issued by Shanghai Maritime University is relatively recent, which is 2018.

Table 2 Research information of important institutions

serial number	institution	Number of posts	Start year
1	Shanghai University of Engineering Science	15	2018
2	Dalian Maritime University	6	2019
3	University of Shanghai for Science and Technology	6	2013
4	Shanghai Maritime University	5	2018
5	Northeastern University	5	2013
6	Air Force Engineering University	4	2014
7	Hefei University of Technology	4	2018
8	Henan Institute of Technology	3	2017
9	Xinxiang College	3	2014
10	Suihua College	3	2022

3.5 Research Interests

In order to clarify the application scope of ant colony algorithm, this study explores the method of keyword analysis. In terms of specific operation, in the interface of cite space software, we set the node type as “keyword”, and then generate a visual display of the scientific map. On this basis, through the implementation of algorithmic clustering analysis on these keywords, and summarizing, we get the clustering map of keywords, which focuses on the architectural characteristics of different clusters, highlights the core nodes and key links, and provides visual clues for understanding the focus of research.

Comprehensive analysis of keyword data in keyword co-occurrence map and keyword clustering map can identify the core areas of ant colony algorithm research. The keyword co-occurrence map and keyword clustering map include keywords such as “ant colony algorithm”, “improved ant colony algorithm”, “path planning”, “cloud computing”, “pheromone”, “multi-objective optimization”, “path optimization”, “wireless sensor network”, “UAV” and “cloud computing”, which reveal that they have a high-frequency trend in the 2000 literatures covered, reflecting the popularity and importance of these topics. At the same time, there are also some smaller keywords in the figure, such as “parameter optimization”, “pheromone update”, “heuristic function”, implying that the research community also maintains a certain degree of attention and Exploration on other specific aspects and details of ant colony algorithm.

Because there are many keywords in the keyword clustering map, in order to improve the accuracy of summarizing the research field, this paper uses the keyword clustering function of cite space to summarize the closely related keywords to form a cluster and get the keyword clustering map. There are two Q values and s values in the city space software, one is Q value (quality) and s value (significance), and the other is modular Q and mean silhouette. The first pair of Q-values and S-values are used to evaluate the relevance and importance of the literature.

The second pair of Q values and s values are mainly used in this paper. According to the network structure and the clarity of clustering, city space provides two indicators: module value (Q value, i.e. modular q) and average contour value (s value, i.e. mean silhouette). In the city space software, it is used to evaluate the network structure and clustering results.

Modular Q value and mean silhouette value are important indicators for evaluating network structure and clustering results in city space. They provide quantitative measurement methods to help users understand the community structure of keyword co-occurrence network and the quality of clustering results, and then reveal the knowledge structure and relevance in the field of academic research. When Q value>0.3, the clustering structure is significant; When the s value reaches 0.7, it can be considered that the clustering is convincing.

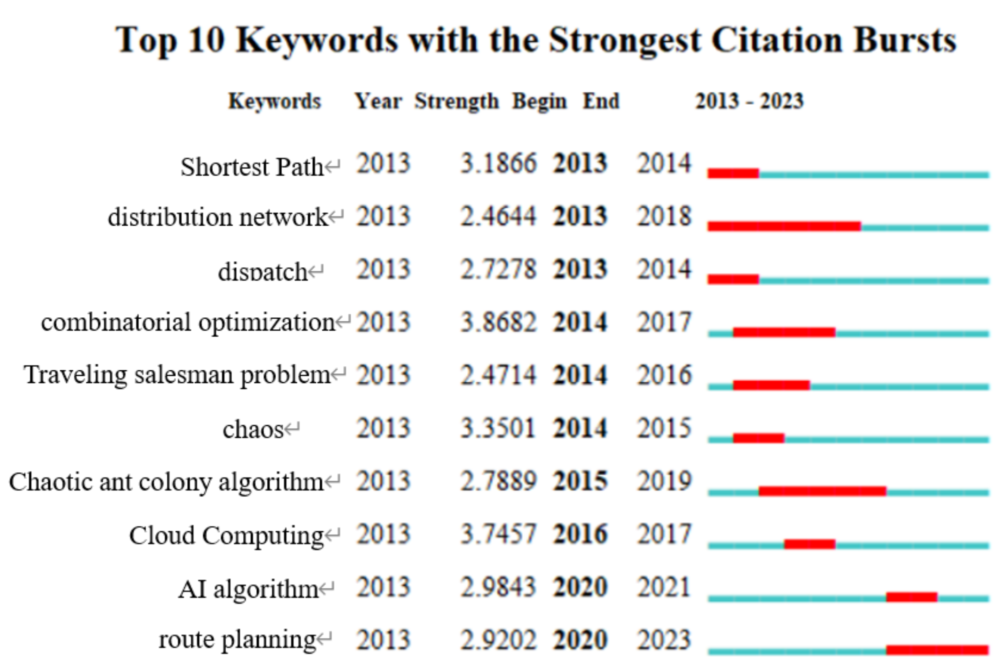
The data of keyword cluster Tupu shows that Q value=0.4619, S value=0.3752, which shows that the clustering structure of clustering Tupu is significant, but the clustering is not convincing, but it is in a reasonable range.

3.6 Research hotspots

In this paper, the keyword co-occurrence map in Figure 6 is transformed into a keyword time zone view. Combined with the research breakout points from 2013 to 2023 summarized by cite space software, it is helpful to find the research hotspots in different stages. The keyword time zone graph shows that the initial research focused on the basic category of ant colony algorithm. Since the research on ant colony algorithm was very mature in 2013, there were research directions and application directions such as improved ant colony algorithm, pheromone, ant colony optimization, road strength optimization, and path planning, especially the application of ant colony algorithm in path planning problems, with a large number of research articles; From 2017 to 2018, the research content mainly focused on the application of ant colony algorithm in heuristic function and artificial potential field; From 2020 to 2021, the research content at this stage mainly focuses on the application of ant colony algorithm in three-dimensional path planning; In 2022, the academic research content and direction are still constantly adjusted and changing, and the research focuses on heuristic functions.

According to the mutation keyword graph (Fig. 2) in the literature related to ant colony algorithm, it can be seen that the shortest path, distribution network and dispatching in the application field of ant colony algorithm appeared in 2013, and the shortest path and dispatching ended in 2014, because ant colony algorithm was first used to solve the problem of finding the optimal path and scheduling, and the ant colony algorithm was mature in 2013, so it ended in 2014, and the distribution network ended in 2018, with a long life. Combinatorial optimization, traveling salesman problem, and chaos all appeared in 2014. Keyword combinatorial optimization ended in 2017, keyword traveling salesman problem ended in 2016, and keyword chaos ended in 2015. Then chaotic ant colony algorithm was proposed, and keyword chaotic ant colony algorithm appeared and disappeared in 2019. Chaotic ant colony algorithm (CaCO) combines ant colony algorithm and chaos theory, enhances the search diversity and optimizes the global optimization ability through the nonlinear dynamic characteristics of chaotic sequence. Its core is to dynamically adjust the ant path selection and pheromone update mechanism by using the random sensitivity of chaos, and combine the volatilization and enhancement strategy to balance exploration and development, so as to improve the convergence speed and avoid local optimization. The algorithm supports flexible parameter adaptation to adapt to different scenarios, but it still needs to be optimized in terms of initial value sensitivity, selection of chaos generation strategy and convergence efficiency of complex problems, and needs targeted debugging to play its potential in combinatorial optimization problems. Cloud computing appeared in 2016 and disappeared in 2017. AI algorithm appeared in 2020 and disappeared in 2021. Keyword path planning appeared in 2020, and it will continue until 2023. It is a new hot field in the application of ant colony algorithm.

Fig.2 Mutation keywords



Top 10 Keywords with the Strongest Citation Bursts

Keywords	Year	Strength	Begin	End	2013 - 2023
Shortest Path	2013	3.1866	**2013**	2014	
distribution network	2013	2.4644	**2013**	2018	
dispatch	2013	2.7278	**2013**	2014	
combinatorial optimization	2013	3.8682	**2014**	2017	
Traveling salesman problem	2013	2.4714	**2014**	2016	
chaos	2013	3.3501	**2014**	2015	
Chaotic ant colony algorithm	2013	2.7889	**2015**	2019	
Cloud Computing	2013	3.7457	**2016**	2017	
AI algorithm	2013	2.9843	**2020**	2021	
route planning	2013	2.9202	**2020**	2023	

4.Summary

In this paper, the process and principle of ant colony algorithm are expounded, and the researchers, research institutions, and related literature publication time and application fields of ant colony algorithm are reviewed and analyzed by using CiteSpace software. Through bibliometric methods, this paper reviews the application of ant colony algorithm in many fields, including combinatorial optimization, path planning, waterway planning, task scheduling, etc. In the bibliometric analysis, we introduce the profile of researchers and research institutions, reveal the research hotspots and trends of ant colony algorithm through citation network and keyword co-occurrence analysis, and summarize some research hotspots of ant colony algorithm through keyword time zone and mutation keywords, such as chaotic ant colony algorithm, track planning, search strategy improvement, cloud computing and combination with other algorithms.

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Conflict of Interests

The author(s)declare(s) that there is no conflict of interest regarding the publication of this paper.

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