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Path Planning for Mobile Robots：A Review

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Abstract: Path planning of mobile robots is one of the core contents of intelligent control and robotics. Current research on mobile robots mainly solves the problem of path planning algorithm and Optimization in static and dynamic environments. This paper summarizes the main contents and development trends of the research on path planning methods for mobile robots. From the perspective of algorithm strategy, path planning methods are divided into classical methods and Intelligent Heuristic methods. Then the principles of various algorithms are analyzed concretely, and the advantages and disadvantages of various path planning methods are discussed. Finally, the future development trend of robot path planning technology in multi-robot coordinated operation, hybrid algorithm improvement, complex environment and high-dimensional environment is pointed out.

Keywords: Mobile Robot; Path Planning; Classical Approaches; Intelligence Heuristic Approaches.

1.Introduction

With the rapid development of modern science and technology, autonomous mobile robots are widely used in various fields, such as terrain detection, disaster relief, public services, factory operations and indoor cleaning. As a new tool for human beings, it effectively reduces labor intensity and improves productivity and safety. With the continuous improvement of social demand and the enhancement of intelligence, autonomous mobile robots are paid more and more attention. Autonomous navigation and mobile is one of the most basic and important functions of autonomous mobile robots. Path planning technology is an important guarantee for the autonomous and safe completion of tasks of autonomous mobile robots, and also a key technology in the navigation of autonomous mobile robots.

The path planning of mobile robot is that the robot collects the information of the

surrounding environment through its own sensors, and chooses a collision-free optimal path quickly and accurately through the planning algorithm, so that the robot can reach the target position efficiently and safely from the starting position. In many static and dynamic environments, mobile robots are used more and more. Normally, there are various feasible paths for a robot to reach the target from the start location, but in circumstance, the best feasible path is selected according to some guideline such as shortest distance, smoothness of the path, minimum energy consumption etc. At present, path planning can be divided into local planning and global planning. In local path planning, robots have limited (partly known or unknown) knowledge of the map environment. However, in the global path planning, the robot is fully aware of the map environment, so the robot can reach the target position through the planned path. However, due to the uncertainty of environment and terrain, the application of global path planning method is limited, while the local path planning method shows greater flexibility in some known/unknown environments and can plan an optimal path in real time [1]. Path planning methods can be further divided into classical methods and Intelligent Heuristic methods.

At present, the research of path planning technology is mainly in the following three aspects: (1) When a mobile robot walks in a given global environment, it must avoid all kinds of static (or dynamic) obstacles so as to reach the target safely；(2) In the course of the robot moving towards the target position, sensors and other devices are used to detect the uncertainties in the forward path, which can deal with the errors caused by various reasons in a short time and correct them；(3) According to people's specific requirements, an optimal path is planned.

2.Current Situation of Path Planning Methods

Path planning is an important aspect of mobile robot navigation control behavior design. The robot must reach the final target position in the shortest time, and the distance should be the smallest, and the computational complexity and power consumption should be low. According to the different characteristics of path planning principles, the planning methods are divided into traditional methods and Intelligent Heuristic methods, as shown in Figure 1. This section lists many planning methods proposed by many researchers, and lists and analyses the advantages and limitations of these methods.

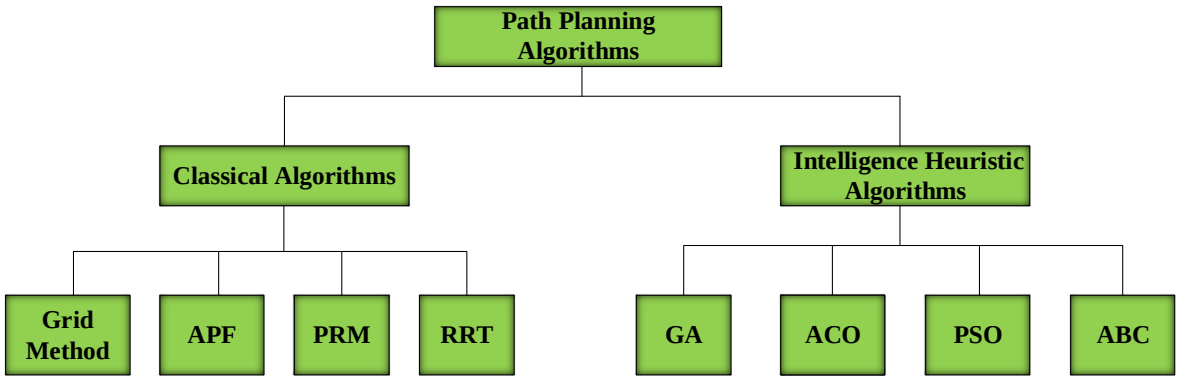

Fig 1. The classification of robot path planning algorithms

2.1 Classical Approaches

At first, classical methods were very popular in solving the problem of robot path planning, because artificial intelligence technology had not been developed at that time. In path planning, the classical method is relatively simple and easy to implement, but the calculation cost is high, and it can not respond to the uncertainty in the environment in real time. Classical planning methods include raster map method, artificial potential field method (APF), probability roadmap method (PRM), fast exploring random tree method (RRT), etc.

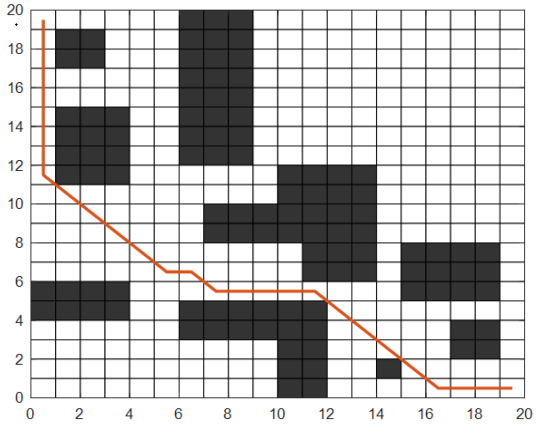

Fig 2. Grid Method

2.1.1 Grid Method

Grid Method (GM) is the most commonly used environmental modeling method in traditional path planning. This method was first proposed by W. E. Howde [2] in 1968. Now the grid method has been widely used in robot path planning. The grid map method divides the environment information of the robot into many small grids, and codes each grids. Then the grids are classified according to the corresponding environment information, and different values are given to the grids to indicate whether the grids are obstacle areas or free passage areas. This method is simple to

use and easy to implement, but it has high computational complexity, long running time and low search efficiency. It is only suitable for simple environment. As shown in Figure 2, the black grid represents the obstacle area, the white grid represents the free area, and the solid line represents the walking path of the robot.

2.1.2 Artificial potential field method (APF)

Artificial potential field method [3] is a virtual force field method proposed by Khatib in 1986. The principle is to create a virtual artificial potential field with gravity and repulsion in the working environment of the robot. The virtual attraction field is created at the target point, which increases with the decrease of the distance between the target point and the robot. The virtual repulsive force field is created near the obstacle, which increases with the decrease of the distance between the robot and the obstacle. In path planning, the robot is controlled by the combined force of gravity and repulsion, so as to avoid obstacles and reach the target point to find the path, as shown in Figure 3. This method has simple structure, small computation and good real-time performance, and can generate relatively smooth paths. It has been widely used in robot path planning. However, this method also has some drawbacks. When obstacles are near the target point, it is easy to cause the target to be unreachable and fall into local minimum. In recent years, in order to solve this problem, many scholars have made a lot of research improvements. Zhang et al. [4] proposed the evolutionary APF method. The feasibility and effectivity are verified by simulation. Zhou et al. [5] proposed an adaptive APF method for the path planning of robot obstacle avoidance. The results show the method can avoid falling into the local optimal solution. Zhang [6] combines chaotic optimization algorithm with artificial potential field, and proposes a new method of robot path planning based on chaotic artificial potential field method, which effectively solves the problem that traditional artificial potential field method will oscillate in trap area.

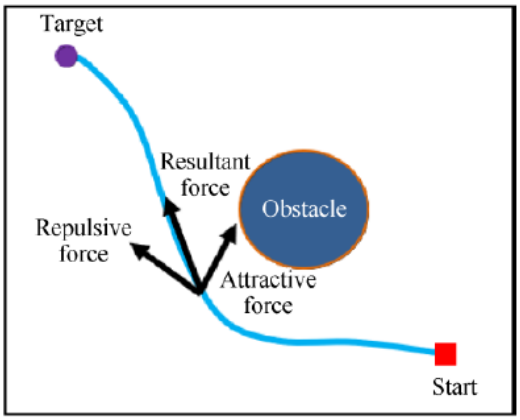

Fig3. Mobile robot navigation by APF approach

2.1.3 Probabilistic Road Map Method (PRM)

Kavraki et al. [7] proposed the probabilistic roadmap method in 1994. The main

principles of the probabilistic road map method are as follows. Based on random sampling, the undirected road map R= (N, E) is established, where N is the milestone node obtained by random sampling and E is the edge connecting these nodes. Given the starting point S and the end point G, the probabilistic roadmap method is to find two nodes S' and G' satisfying S and S' are directly connected, G and G' are directly connected. In undirected road map, an optimal path is obtained by continuously searching the edge sequence directly connected with S' and G'.

2.1.4 Rapidly Exploring Random Tree Method (RRT)

Rapidly-exploring Random Tree(RRT) is a sampling-based search algorithm, which can solve the problem of incompleteness constraints in multi-dimensional space, and provides a new idea for path planning in high-dimensional complex environment. The basic principle of this method is as follows: the starting point of path planning is defined as the root node of the search tree, and an existing node of the search tree is determined according to the prescribed criteria. Then, according to the constraints of path planning, a new node is extended and stored in the search tree, and the steps mentioned above are repeated until the destination is found. This method has the advantages of fast processing speed, strong search ability and no requirement for map preprocessing, so it has been widely used in path planning research in recent years. However, this method has some drawbacks, such as blindness, high computational complexity, easy to fall into dead zone and local minimum problems. Kalisiak et al. proposed a RRT-blossom algorithm [8], which generates new nodes by regression constraint function, thus reducing the probability of repetitive region search in the early stage of random tree and avoiding falling into the local optimum of search space. Frazzoli et al. [9] proposed a RRT* algorithm with asymptotic optimality. The core idea of this method is to apply random geometric graph and pruning optimization theory to the expansion of random number nodes, so as to ensure that the nodes of random tree can converge to the current optimal value. In 2017, Jia Lihong [10] proposed an improved method based on the combination of artificial potential field method and RRT algorithm. The basic idea of this method is that in the early stage of path planning, artificial potential field method is used to predict a path in the initial environment. If there are new obstacles in the path, RRT algorithm is used to plan the current local path, so as to achieve obstacle avoidance. This algorithm effectively solves the problem that RRT algorithm is easy to fall into local minimum, and improves the efficiency of path planning.

2.2 Intelligence Heuristic Approaches

In recent years, with the continuous development of technology, many intelligent heuristic methods have been widely applied in path planning. At present, commonly

used intelligent heuristic algorithms such as genetic algorithm, ant colony optimization, neural network, particle swarm optimization, artificial bee colony algorithm, etc. They have a strong ability to deal with uncertainties in the environment. This section will discuss various intelligent heuristics.

2.2.1 Genetic Algorithm (GA)

Genetic Algorithms (GA) is an intelligent algorithm proposed to simulate biological evolution in nature. Its application to the field of computer science was presented first by Holland [11] in 1975. The basic process of this method is as follows. First, the path group is initialized, then the crossover, mutation and selection operations are carried out. Finally, after several generations of evolution, the solution space is searched and the current optimal solution is output according to the requirements of the planning objectives. The advantage of GA is that it is simple, robust, and has strong search capability and high search efficiency. However, it is prone to premature convergence. When it approaches the optimal solution of the problem, the convergence speed of the algorithm will decrease. It is usually used in the global path planning. In recent years, the path planning of mobile robot based on genetic algorithm has been widely studied by many scholars. Shi et al. [12] proposed a path planning algorithm based on genetic simulated annealing to solve the problem of premature convergence speed of traditional genetic algorithm. Xu et al. [13] presented adaptive GA to solve the path planning of unmanned aerial vehicle. Example simulation shows that the new algorithm satisfies the requirements in the computation efficiency and the precision of the solution. Wang et al. [14] proposed a Double global optimization method combining genetic algorithm and particle swarm optimization. This method improves the efficiency of the algorithm and solves the problem that it is difficult to obtain the optimal solution for path planning. Wang et al. [15] proposed a method based on adaptive crossover and mutation probability. The traditional genetic algorithm was optimized by hybrid selection, which effectively improved the convergence speed and evolution efficiency of the genetic algorithm.

2.2.2 Ant Colony Optimization (ACO)

The ACO is proposed by Marco Dorigo in 1992. The ACO algorithm originated from the behavior of ants and its ability to find the shortest path from their nest to a food source (Figure 4). The basic principle of the ACO is each ant will release a secretion on the path it walked as a reference and will also perceive the secretions released by other ants while it is searching for food.This secretion is usually called pheromone. Under the action of pheromones, the ant colony can communicate with each other and choose paths. When the pheromone on a path is more than other paths, the ant colony will spontaneously move to this path, and release more secretions during the movement, so that the concentration of the pheromone becomes higher to attract the

latter ants which forms a mechanism of positive feedback. After a period of time, the concentration of pheromone on the shorter path is getting higher and higher, then the ants that choose it are gradually increasing, while the pheromones on other paths are gradually reduced until there is no. Finally， the whole ant colony is concentrated in the optimal path. Nowadays, the ACO is used to handle the mobile robot navigation problem for obstacle avoidance and path planning. In path planning, ant colony algorithm has the advantages of good global search ability, good stability and easy integration with other algorithms, but in the early stage of the algorithm, its convergence speed is slow, and it is easy to fall into local optimum in more complex environment. In recent years, many scholars have studied the optimization and improvement of traditional ant colony algorithm. X. Chen et al. [16] proposed a two-stage ACO model which has ability to overcome the main inconsistency problem between premature convergence and the optimal path. In [17], an optimal path planning method is introduced based on Ant Colony Optimization Meta-Heuristic (ACO-MH). The algorithm has the adaptive capability of changing in the environment so that it can perform a global robot path planning with dynamic obstacles. Zhang et al. [18] initialize pheromones by random values and cross-operate pheromones, which improves the search ability, but reduces the convergence speed of the algorithm. Li et al. [19] combined the parameters of ant colony algorithm by bacterial foraging algorithm to improve the overall performance of the algorithm, but this method is limited to some fixed scenarios.

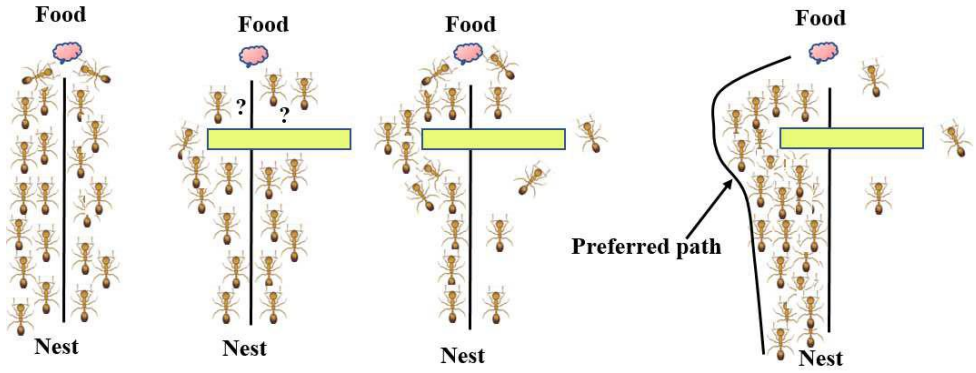

Fig4. The behavior of ants while searching the food

2.2.3 Particle Swarm Optimization (PSO)

Particle Swarm Optimization (PSO) is a nature-based metaheuristic algorithm which adopts the social behavior of creatures. It is proposed by Eberhart and Kennedy [20] in 1995. Basically, PSO is initialized with a set of random solutions and then updated each generation based on optimal schema. Then, the global optimum is achieved by changing the collection of particles in a search space toward a promising area. The particle position updating process of the algorithm is shown in Fig. 5. Nowadays, this

algorithm is widely used to solve the robotic path planning with the advantages of easy implementation, high precision and fast convergence. Gong et al. [21] proposed a global path planning method based on multi objective PSO. This method effectively improves the efficiency of global path planning. Tang X. et al. [22] addressed the mapping and localization issues of mobile robot navigation in the unknown environment by using a multi-agent particle filter. This method reduces the computational complexity and accelerates the convergence speed. Cheng et al. [23] proposed an improved chaos PSO to solve the path planning for unmanned aerial vehicle. The efficiency of this algorithm was superior to the traditional PSO, especially in the three-dimensional environment. Yusof et al. [24] proposed a predetermined waypoints method. The algorithm is fast and efficient, but it is easy to fall into local optimum.

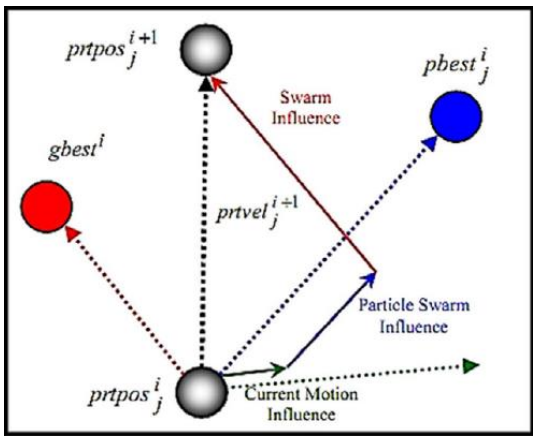

Fig5. Depiction of a particles position update in PSO

2.2.4 Artificial Bee Colony Algorithm(ABC)

The artificial bee colony (ABC) algorithm was presented by D. Karaboga [25]. It is a swarm based meta-heuristic algorithm utilized for enhancing numerical issues. The food search cycle of ABC consists of the following three rules: First, sending the employed bees to a food source and evaluating the nectar quality; Second, onlookers choosing the food sources after obtaining information from employed bees and calculating the nectar quality; Third, determining the scout bees and sending them onto possible food sources. The algorithm is simple, easy to implement and has strong robustness, but its development ability is poor, and it may fall into local optimal solution, especially in dealing with complex problems, which takes a long time and has low precision. In recent years, a large number of researchers have optimized and improved the traditional bee colony algorithm. Luo et al. [26] proposed a chaotic artificial bee colony algorithm, which combines chaotic mechanism with bee colony algorithm to find the optimal parameters, effectively improving the local optimal solution of traditional bee colony algorithm. Contreras-Cruz et al. [27] proposed a path planning method based on improved bee colony algorithm. This method uses artificial bee

colony algorithm for local search, and uses evolutionary programming algorithm to refine the local solution, so as to obtain the optimal solution. Moreover, the method has high accuracy and fast speed, and effectively improves the efficiency of path planning. Ma et al. [28] proposed a hybridized approach by combining the ABC algorithm with a time rolling window strategy. Thus the path planning of mobile robot in real-time dynamic environment is realized.

3.Development Trend of Path Planning

With the continuous development of science and technology, mobile robot path planning technology research has achieved a lot of research results, but in the specific path planning algorithm design, each algorithm still has certain limitations, there are many theories and methods need to be improved. From the current development direction, the future development direction of path planning technology for autonomous mobile robots includes the following aspects:

(1) Multi-robot coordinated operation. With the increasing complexity of task and working environment, it is very difficult for a single robot to complete the task. At this time, multiple robots need to coordinate and cooperate to complete the task. Multi-robot coordination operation has good security, reliability and coordination.

(2) Multi-sensor information fusion technology. The stability and accuracy of robot path planning can be improved by utilizing multiple sensors to collect and process information reasonably.

(3) Improvement of new intelligent heuristic algorithm or hybrid algorithm. Path planning method requires good real-time and responsiveness, and can be suitable for different environments. At present, any single algorithm will have some shortcomings, such as weak global search ability, easy to fall into local optimal solution and so on. Therefore, a variety of algorithms are effectively integrated, which can produce a better kind of algorithm and improve the effect of path planning by learning from each other's strengths and weaknesses. In addition, exploring new intelligent algorithms is one of the directions of the development of path planning technology.

(4) Path planning technology in complex environment and high-dimensional environment. Path planning of mobile robots is mostly to solve the path planning research of intelligent robots in terrestrial working environment, such as logistics robots, service robots, explosion-proof robots, etc. However, there are relatively few studies on flying robots and underwater robots in three-dimensional space. With the need of future space exploration, the research of path planning technology in high-dimensional space and more complex environment will gradually become an important direction. To sum up, enhancing the research and development of robot path planning in real environment is an inevitable problem for practical application, and it is also an

important development direction of path planning technology in the future.

4.Conclusion

Path planning technology of mobile robots has always been one of the key contents of robotics research at home and abroad. The path planning problem is an important research field of the mobile robot which has aroused the interest of many researchers both at home and abroad. Good path planning technology of mobile robot can not only save a lot of time, but also reduce the wear and capital investment of mobile robot. In this paper, the research status of path planning for mobile robots is briefly described. Path planning methods are divided into traditional methods and Intelligent Heuristic methods. The advantages and disadvantages of various methods are described, as well as the main research results. Finally, the future research direction of path planning algorithm is prospected, which has a certain reference significance for the research and development of mobile robot path planning technology.

References

[1] P.K. Mohanty and D.R. Parhi. (2014) "Journal of Experimental & Theoretical Optimal path planning for a mobile robot using cuckoo search algorithm." December:37–41.
[2] Howden W E. The sofa problem[J]. Computer Journal, 1968, 11(3):299-301.
[3] Khatib O. Real-Time Obstacle Avoidance for Manipulators and Mobile Robots[J]. International Journal of Robotics Research, 1986, 5(1):90-98.
[4] Zhang, Q.S.; Chen, D.D.; Chen, T. An obstacle avoidance method of soccer robot based on evolutionary artificial potential field. Energy Procedia 2012, 16, 1792–1798.
[5] Zhou, L.; Li, W. Adaptive Artificial Potential Field Approach for Obstacle Avoidance Path Planning. In Proceedings of the 7th International Symposium on Computational Intelligence and Design, Hangzhou, China, 13–14 December 2014; pp. 429–432.
[6]ZHANG Cheng.Path Planning for Robot Based on Chaotic Artificial Potential Field Method ［J］.IOP Conference Series: Materials Science and Engineering，2018，317(1): 12-56.
[7] Kavraki, L.; Latombe, J. Randomized preprocessing of configuration space for fast path planning. In Proceedings of the 1994 IEEE International Conference on Robotics and Automation, San Diego, CA, USA,8–13 May 1994; pp. 2138–2145.
[8] Kalisiak M, Panne M V D. RRT-blossom: RRT with a local flood-fill behavior[C]//IEEE International Conference on Robotics and Automation. IEEE, 2006: 1237-1242.
[9] Karaman, S, Frazzoli E. (2011). Sampling-based algorithms for optimal motion planning[J]. The International Journal of Robotics Research, 2011, 30(7): 846-894.
[10] JIA Lihong. Research on Two-Way Search Path Based on GPS［D］.Huainan: College of Computer Science and Engineering，Anhui University of Science ＆ Technology，2017.
[11] J. H. Holland, "Adaptation in natural and artificial systems. Ann Aebor," MI: University of Michigan Press.
[12] SHI Tiefeng. Application of Improved Genetic Algorithm in Path Planning of Mobile Robots ［J］.Computer Simulation，2011，28(4) : 193-195，303.
[13] Xu, Z.; Tang, S. UAV path planning based on adaptive genetic algorithm. J. Syst. Simul. 2008, 20, 5411–5414.
[14] WANG Xuewu，SHI Yingpan，DING Dongyan，et al. Double Global Optimum Genetic Algorithm-Particle Swarm Optimization-Based Welding Robot Path Planning ［J］.Engineering Optimization，2016，48(2) : 299-316.

[15] WANG Lei，LI Ming. Application of Improved Adaptive Genetic Algorithm in Path Planning of Mobile Robots［J］.Journal of Nanjing University of Science and Technology: Natural Science，2017，41(5) : 627-633.
[16] X. Chen, Y. Kong, X. Fang, Q. Wu, A fast two–stage ACO algorithm for robotic path planning, Neural Comput. Appl. 22 (2013) 313–319.
[17] M.A.P. Garcia, O. Montiel, O. Castillo, R. Sepulveda, Optimal path planning for autonomous mobile robot navigation using ant colony optimization and a fuzzy cost function evaluation, Adv. Soft Comput. 41 (2007) 790–798.
[18] Zhang Y, Wang F L, Fu F K, et al. Multi-AGV Path Planning for Indoor Factory by Using Prioritized Planning and Improved Ant Algorithm[J]. Journal of Engineering and Technological Sciences. 2018, 50: 534-547.
[19] Li P, Zhu H. Parameter Selection for Ant Colony Algorithm Based on Bacterial Foraging Algorithm[J]. Mathematical Problems in Engineering, 2016: 1-12.
[20] R. C. Eberhart and J. A. Kennedy, "A new optimizer using particle swarm theory", Proceedings of the sixth international symposium on micro machine and human science, IEEE service center, Piscataway, NJ, NAGOYA, Japan, pp. 39-43, 1995.
[21] Gong, D.W.; Zhang, J.H.; Zhang, Y. Multi-objective Particle Swarm Optimization for Robot Path Planning in Environment with Danger Sources. J. Comput. 2011, 6, 1554–1561.
[22] X. Tang, L. Li and B. Jiang, "Mobile robot SLAM method based on multi-agent particle swarm optimized particle filter," The Journal of China Universities of Posts and Telecommunications, vol. 21, no. 6, pp.78-86, 2014.
[23] Cheng, Z.; Tang, Y.X.; Liu, Y.L. 3-D Path Planning for UAV Based on Chaos Particle Swarm Optimization. Appl. Mech. Mater. 2012, 232, 625–630.
[24] Yusof, T.S.T.; Toha, S.F.; Yusof, H. Path Planning for Visually Impaired People in an Unfamiliar Environment Using Particle Swarm Optimization. Procedia Comput. Sci. 2015, 76, 80–86.
[25] Karaboga, D, (2005). "An idea based on honey bee swarm for numerical optimization." Technical Report TR06, Erciyes University, Engineering Faculty, Computer Engineering Department.
[26] LUO Qinan，DUAN Haibin. Chaotic Artificial Bee Colony Approach to Step Planning of Maintaining Balance for Quadruped Robot［J］.International Journal of Intelligent Computing and Cybernetics，2014，7(2) : 175-191.
[27] CONTRERAS-CRUZ M A，AYALA-RAMIREZ V HERNANDEZ-BELMONTE U H. Mobile Robot Path Planning Using Artificial Bee Colony and Evolutionary Programming［J］.Applied Soft Computing Journal，2015，30: 319-328.
[28] Q. Ma, and X. Lei, "Dynamic path planning of mobile robots based on ABC algorithm", In International Conference on Artificial Intelligence and Computational Intelligence, pp. 267-274, Springer, Berlin, Heidelberg, 2010.