Ant Colony Algorithms for Mobile Robot Path Planning: A State-of-the-Art Review

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Abstract

Mobile robots require path planning to move from start position toward the target position (end point). Along the movement, the mobile robot manipulates in static and/or dynamic condition of obstacles and collison avoidance. Path trajectories (path planning) are generated in the robot motion controller. Path trajectory is generated using exact or heuristic method. From the mobile robot point of view, there is local and global environment. Path planning that is generated encounter a problem in local optimum and slow convergence speed. Ant Colony algorithm is a metaheuristic search algorithm. In this paper, the path planning based on Ant Colony System is studied. The problem encountered using Ant Colony path planning is the decision of local and/or global planning to reach convergences. To solve that encountered problem, many researchers proposed novel additional methods to Ant Colony Algorithmto optimize. Futher, discussion of those method will be presented

Keywords: *Ant Colony, Algorithm, Mobile Robot, Path Planning, Simulation*

Abstrak

Mobile robot membutuhkan perencanaan jalur/lintasan untuk bergerak dari posisi awal menuju posisi target (titik akhir). Sepanjang pergerakannya, mobile robot melakukan manipulasi dalam kondisi statis dan/atau dinamis dari rintangan dan penghindaran tabrakan. Perencanaan lintasan (path planning) dihasilkan dari kendali pergerakan robot. Perencanaan lintasan dihasilkan menggunakan metode eksak atau heuristik. Dari sudut pandang mobile robot diketahui terdapat lingkungan lokal dan global. Perencanaa lintasan yang dihasilkan mengalami kendala pada lokal optimum dan konvergensi kecepatan yang lambat. Algoritma Koloni Semut (Ant Colony) adalah algoritma pencarian metaheuristik. Dalam makalah ini dipelajari perencanaan jalur berdasarkan Sistem Koloni Semut. Masalah yang dihadapi dengan menggunakan perencanaan jalur Koloni Semut adalah keputusan perencanaan lokal dan/atau global untuk mencapai konvergensi. Untuk mengatasi masalah yang dihadapi, banyak peneliti mengusulkan berbagai metode tambahan baru bagi Algoritma Koloni Semut untuk dioptimalkan. Selanjutnya, berbagai metoda tersebut akan diulas dalam makalah ini.

Kata kunci: *Koloni Semut, Algoritma, Mobile Robot, Perencanaan Lintasan, Simulasi*

1. Introduction

To wander in a space, a mobile robot requires path planning or trajectory planning to move from a start position to reach a target position. The path planning can be divided into two categories, namely, the global path planning and the local path planning [28,39]. The objective of executing a path planning is to find the shortest distance, the quickest time and the minimum cost to rearch the target point within a specific condition such as static and dynamic condition while avoiding obstacles. The local path planning enable the mobile robot to plan its path as it moves in the environment. While global path planning is required to gather information regarding the environment including the obstacles position. Figure 1 shows existing path planning approaches. The picture indicates how some approaches more inclined toward either global or local path planning [39]. In this paper, the work on path planning is focused into the soft-computing category, where the objective of local and global optimization with low computational cost [3-10, 12-20, 23-24, 26-33, 36-38]. The use of Ant Colony System (ACS) to optimize the path trajectory in achieving the movement toward the target point. Ant Colony Optimization (ACO) is a meta-heuristic method to solve NP-Hard problem [1,21,25], which the path planning of mobile robot is within this category.

Figure 1 clasify existing path planning approaches and the detail explained in [39]. The next paragrahs, an overview of mobile path planning is discussed in section 2. The approaches to generate path planning from exact method and heuristic method is overviewed. It includes the classical Ant Colony System and its improvement to the algorithm. In section 3, we discuss mainly on the result of tuning the parameter for local environment with preserving the processing time to be low. The issue of robustness, distributed computing, multi-robot, multi-task, among others, will be highligthed. Discussion of improved algorithm to Ant Colony Optimization will be presented in section 4.

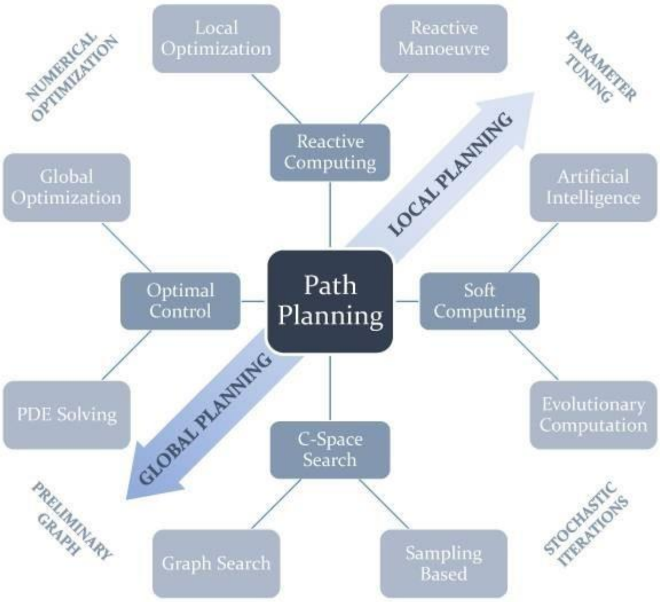

Figure 1. Proposed classification of existing path planning approaches [39]. Ant Colony approach is a sub-category of evolutionary computation (meta-heuristic) together with Genetic Algorihm, Memetic Algorithm, etc.

2. Mobile Robot Path Planning

In this paragraph, we discuss an overview of mobile robot path planning; the issue of mobile robot path planning and path planning classification, the basic Ant Colony Algorithm, and various improvement algorithms to Ant Colony Algorithm.

2.1 Mobile Robot Path Planning: an overview

In mobile robots, finding a path to move from a starting position to a goal safely is a serious problem. Many effort to find an effective and efficient path planning (trajectory planning) algorithm have been studied [11, 23,27,28]. Minimal traveling distance, minimal processing time and energy consumption are among others, the objective of most common research in mobile robot. Robot navigation is a fundamental aspect of a mobile robot systems. The function of navigation, respectively, could be shown as follows [28].

- Localization: It assists the robot to determine its location in the environment. The location can be specifiedas a local environment as expressed as topological coordinate or expressed in absolute coordinate using latitude, longitude and altitude.
- Mapping: The robot needs a map. A map is used to identify its robot location (position), direction, and its movement around. Usually, a map is located in the robot memory, and it is updated gradually when the robot discover a new environment.
- Trajetory Planning or Path Planning: A path planning is required to move from a starting position toward a target position. In a path planning, the movement of the robot is guided a long the path, whether the robot need to avoid static or dynamic obstacles and/or to keep moving in a staright path, or to re-route to a hasle free path. Figure 2 shows different issues of path planning with obstacle avoidance. In multi agent robot, coordination and communication of movement becoming a very major issues.

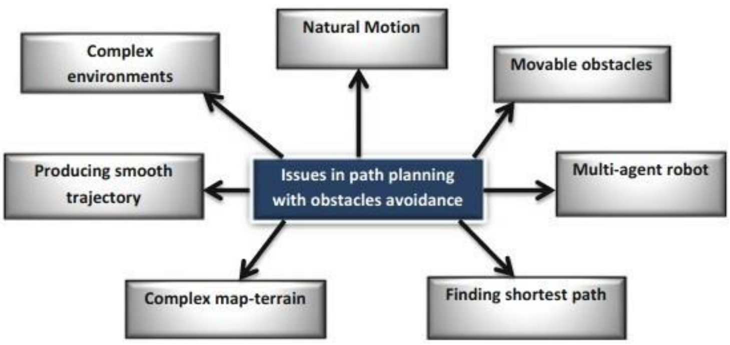

Figure 2. Different issues of mobile robot pathplanning [28]

Path planning for mobile robot can be classify as based on environment, based on algorithm, and based on completeness. Figure 2 shows this classification further.

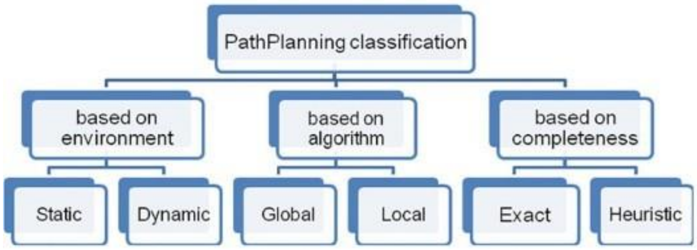

Figure 3. Path Planning Classification [28]

In this paper, we focuse on global and local path planning of mobile robot. Table 1 indicate the difference of both. In global path planning, the mobile robot has an a priori knowledge about the environment as a map. In local path planning, the mobile robot has no knowledge about the environment (no information of map). The robot has to construct an estimated (dynamic) map based on its searching process of the target position while avoiding obstacles during its movement forward. Based on sensory feedback (e.g. vision and proximity sensors), the movement and map creation are updated.

Tabel 1. Local Path Planning and Global Path Planning [28]

Local Path Planning	Global Path Planning
Sensor-based	Map-based
Reactive navigation	Deliberate navigation
Fast response	Relatively slower response
Suppose that the workspace area is incomplete or partially incomplete	The workspace area is known
Generate the path and moving towardtarget while avoiding obstacles or objects	Generate a feasible path before moving toward thegoal
Done online	Done offline

2.2 Path Planning Generation Methods

Robot path planning can be achieved by several methods [38], among others, Lagrange's Principle [10,18], Bezier curve [7], Genetic Algorithm [5], and Ant Colony Optimization [2-4, 6, 8-15, 19-26, 28-34, 36]. Lagrange's Polynomial path planner use to derive the non-linear equation of the system. In reaching the destination location, a set of piecewise Lagrange trajectory path is prepared. This trajectory is updated depend on the situation found during the movement of the mobile robot. During mobile robot movement in dynamic environment, avoiding moving obstacle requires re- calculating the trajectory. The processing time will increase significatly in preparing the path plan. The path smoothed is by employing polynomial equation.

Song et.al. [7] perform smoothing to mobile robot path planning. His work resulted on path smoothing algorithm. He compared several path plan generation such as using Hermite interpolation, Cubic Spline interpolation, Bezier curve interpolation and B-Spline interpolation based on Voronoi diagram and Djikstra algorithm. In conclusion, Bezier curve has booth shorter path and few fluctuation of curvature.

Genetic Algorithm [5,35] starting from a random initial individual solution. Multiple the number of individual into population using cross-over and mutation. Fomulating a fitness function to filter out generated proposed population solutions. A new generation of individual subset is generated. With fitness function select the superior individual according to "survival of the fittest" Darwin's natural law. Eventually the solution converge to an optimal ones for the actual problem

2.3 The Classical Algorithm of Ant Colcny System

Ant Colony Optimization was firstly introduced by Dorigo & Gambardella [1, 25] as a method introduced to Travelling Salesman Problem. Real ants can find food by finding the shortest path from its nest toward the target position. When the ant wander, pheromone is deposite on the ground and follow by other ants. The algorithm of Ant Colony is a heuristic search algorithm [22] that mimicking the behaviour of ants to find the optimal path between the nest and the food source. Along the path, ant's pheromone is released. By using this pheromone, the ants communicate each other and iteratively finding the pseudo shortest path to the food source. If the ant reaches an intersection at the first time, it chooses randomly a motion direction forward. The more ants follow a given path, the more pheromone left on the path, and it becomes the more attractive the path to be followed by others. The path probability to be selected by other ant is increased. When an ant find an obstacle on the path, it will find a new reroute path quickly. This process is shown as a loop of positive feedback. The transition probability of the ant k moving from the grid i to j is defined as follows:

$$p_{ij}^{k}(t) = \begin{Bmatrix} \frac{[\tau_{ij}(t)]^{\alpha}[\eta_{ij}(t)]^{\beta}}{\sum_{s \epsilon allowed_k}[\tau_{ij}(t)]^{\alpha}[\eta_{ij}(t)]^{\beta}} & j \epsilon allowed_k \\ 0 & otherwise \end{Bmatrix} \quad (1)$$

Where, $p_{ij}^{k}(t)$ is the transition probability in which the ant *k* moves from grid *i* to *j* at time *t*; $\tau_{ij}(t)$ is the pheromone intensity between grid *i* and *j* at time *t*; $\eta_{ij}(t)$ is the heuristic function between grid *i* and *j* at time *t; α* is information inspiration factor and *β* is hope inspiration factor, $allowed_k$ *is* a set of grids; the ant *k* selecting in next step.

$$\eta_{ij} = \frac{i}{d_{ij}} \quad (2)$$

$$d_{ij} = \sqrt{(x_i - x_j)^2 + (y_i - y_j)^2} \quad (3)$$

Where d_{ij} is the distance between two neighbour grids. The pheromone level on the arcs will be updated by volatizing the old pheromone and adding the pheromone deposited by each ant. The pheromone updating formula is given by

$$\tau_{IJ}(t+1) = (1-\rho)\tau_{ij}(t) + \sum_{k=1}^{m} \Delta\tau_{ij}^{k} \quad (4)$$

Where ρ is the pheromone evaporating rate, *m* is the number of ants and $\Delta\tau^{k}$ represents the amount of pheromone left by the ant *k* at the current iteration, which can be expressed as follows

$$\Delta\tau_{ij}^{k} = \begin{Bmatrix} \frac{Q}{L_k} & edge\ (i,j) is used\ \epsilon\ tour \\ 0 & otherwise \end{Bmatrix} \quad (5)$$

Where L_k is the length of the path that was found by the ant *k* and *Q* is a constant. Detail of the equations could be found in [23].

Ant colony robot path planning is divided into optimization and stagnation stages. The algorithm of optimization stage is stronger capability of global search and converge rapidly while at stagnation stage, the algorithm is able to automatically shift to local optimal search and thereafter continue to global solution. The algorithm steps is following.

- Step 1: initialization: start and target position, max number of cycles k_{max}, number of ant colony, and other parameters (*α, β,* etc.);
- Step 2: put all ants on the start position, for each ant determine path according to the transition probability equation $p_{ij}^{k}(t)$;
- Step 3: for each ants and each cycle save the path and the path length;
- Step 4: for a cycle completed, update pheromone quantity based on pheromone strategies;
- Step 5: loop step 2 to 4 until optimal and max. number of cycles.

Ant Colony Optimization algorithms are stochastic search procedure. The pheromone update prevent to reach optimum. Two different convergence are considered: (a) convergence in value, (b) convergence in solution. Convergence in value is the probability of generating an optimal solution. Convergence in solution is the probability that the algorithm reaches a state that keep generating the same optimal solution. The detail of convergence proof either in values or in solution, both can be found in Dorigo & Stützle [25].

3. Hybrid Algorithms

A lot of improvement to Ant Cology Optimization algorithm has been done. This paragraph highlights some selected work on solving path planning problem related with mobile robots. The following table shows our findings.

Table 2. Hybrid Algorithm to Ant Colony Optimization Optimization

Problem & Finding	Authors	Reference
Tuning parameter optimization with Fuzzy, Memetic, Genetic Algorithm	Li. et.al. Garcia, et.al, Castilo, et.al, Chih-Ta, et.al, Al Taharwa, et.al, Chen, et.al.	[5][6][16][17][24]
Task Allocation & multi-robot coordination	Wang, et.al, Zhang, et.al, Zitoumi, et.al	[11][27][34]
A* heuristic, enhanced heuristic	Long, et.al, Gao, et.al	[29][33]
3D path plan	Wang, et.al	[30]
Population entropy	Zang, et.al	[37]
Adaptive, indoor	Changwei, et.al	[36]
Static & dynamic → obstacle avoidance	Ajeil, et.al, Chih-Ta, et.al	[32][17]
Dynamic	Dehui, et.al, Mei, et.al	[3][31]
Omnidirectional	Hsu-Chih	[14]
Point-to-point	Nazemizadeh, et.al	[10]
Improved algorithm	Xiangyang, et.al, Castilo, et.al,, Rashid, et.al, Akka, et.al,	[13][16][19][23]
Precise trajectory	Li, et.al	[18]
Global path plan	Buniyamin, et.al	[8]
Path smoothing → local path	Song, et.al	[7]

Finding the optimal (or shortest) path toward the target position with minimal energy is the main objective of mobile robots path planner. The autonomy shows by the path planner function inside the mobile robot to make decision to the reach the goal while avoid obstacles [28]. The algorithm discussed is to address the exploration in search space and the exploitation of knowledge in optimization progress. They are some limitation of ant colony algorithm, namely, the stagnation phase, exploration and exploitation rate and convergence speed [7]. To recover from those limitation, novel results from various research are shown at Table 2. The application is not only apply for a single mobile robot, but multi-robots or AGVs as well. Consequently, for multi-robot, a task allocation and communication need to be distributed [11,27, 34].

The hybrid algorithm to Ant Colony for optimization may use Fuzzy Logic for tuning parameter [6,16,17], memetic [24], and A* algorithm [29]. Those additional algorithm are implemented onto static environment where the single mobile robot recovers of facing static obstacles [5,32]. However, from the reality, mobile robots will encounter other mobile robots, human/operator, and any object that is moving in the shopfloor. For this case, the mobile robot moves based on map, the environment is dynamic, and it should have the capability to avoid either static and dynamic obstacles, avoiding collison. The path planning generated must have this capability [3,16,32,17]. The path planning trajectory is optimized either for local [7] or global [4,8,20].

4. Concluding Remarks

In this paper, we give an overview of the path planning problem of mobile robot, giving some method of generating path plan. Finding the optimum method to traverse from starting position to target position either in local and/or global environment. Navigating mobile robots requires the knowledge/information regarding the environment (static and/or dynamic). To navigate efficiently, safely, with minimum energy, intelligent-based methods are introduced and discussed to achieve target objectives and overcome some conditions such as obstacles and collision avoidance either in static or dynamic environment. Solution to generating mobile robot path planning is exact and heuristics. Ant Colony Optimisation is chosen. It is a metaheuristics searching algorithm which is suitable to be embedded into a mobile robot motion planner or controller. Slow convergency or local optimum are among other are the problem mostly addressed. Additional novel methods to Ant Colony Optimization are discussed. They are, amongst others, Genetic Algorithm, Fuzzy Logic, Memetic Algorithm, A* Heuristic Algorithm, Rapid Random Tree, etc. Combination with exact solution such as B-Spline, Lagrange's principle, Bezier curve are included. The most add-in methods to Ant Colony Optimization addressed are solving local optimum problem, slow convergence response, exploitation and exploration, shortest path to avoid obstacles, and the issue of static and dynanic condition while the mobile robot traverse that increase the complexity toward NP-Hard problem. Most of the result claimed of imporving the Ant Colony Optimisation algorithms. They are shown with the metrics, the performance graphs. However, to justify which is the near best of those novel additional algorithm still need to be explored with a standard of simulation test-bed and test cases. Most of improved Ant Colony Optiomization are simulated for a smooth terain.

References

[1] Dorigo, M., & Gambardella, L. M. (1997). Ant colony system: a cooperative learning approach to the traveling salesman problem. IEEE Transactions on evolutionary computation, 1(1), 53-66.

[2] Blum, C. (2005). Ant colony optimization: Introduction and recent trends. Physics of Life reviews, 2(4), 353-373.

[3] Mei, H., Tian, Y., & Zu, L. (2006). A hybrid ant colony optimization algorithm for path planning of robot in dynamic environment. International Journal of Information Technology, 12(3), 78-88.

[4] Guan-Zheng, T. A. N., Huan, H. E., & Sloman, A. (2007). Ant colony system algorithm for real-time globally optimal path planning of mobile robots. Acta automatica sinica, 33(3), 279-285.

[5] Ismail, A. T., Sheta, A., & Al-Weshah, M. (2008). A mobile robot path planning using genetic algorithm in static environment. Journal of Computer Science, 4(4), 341-344.

[6] Garcia, M. P., Montiel, O., Castillo, O., Sepulveda, R., & Melin, P. (2009). Path planning for autonomous mobile robot navigation with ant colony optimization and fuzzy cost function evaluation. Applied Soft Computing, 9(3), 1102-1110.

[7] Song, B., Tian, G., & Zhou, F. (2010). A comparison study on path smoothing algorithms for laser robot navigated mobile robot path planning in intelligent space. Journal of Information and Computational Science, 7(1), 2943-2950.

[8] Buniyamin, N., Sariff, N., Wan Ngah, W. A. J., & Mohamad, Z. (2011). Robot global path planning overview and a variation of ant colony system algorithm. International journal of mathematics and computers in simulation, 5(1), 9-16.

[9] Zhangqi, W., Xiaoguang, Z., & Qingyao, H. (2011). Mobile robot path planning based on parameter optimization ant colony algorithm. Procedia Engineering, 15, 2738-2741.

[10] Nazemizadeh, M., Rahimi, H. N., & Amini Khoiy, K. (2012). Trajectory planning of mobile robots using indirect solution of optimal control method in generalized point-to-point task. Frontiers of Mechanical Engineering, 7(1), 23-28.

[11] Wang, J., Gu, Y., & Li, X. (2012). Multi-robot task allocation based on ant colony algorithm. J. Comput., 7(9), 2160-2167.

[12] Reshamwala, A., & Vinchurkar, D. P. (2013). Robot path planning using an ant colony optimization approach: a survey. International Journal of Advanced Research in Artificial Intelligence, 2(3), 65-71.

[13] Deng, X., Zhang, L., & Luo, L. (2013). An Improved Ant Colony Optimization Applied in Robot Path Planning Problem. J. Comput., 8(3), 585-593.

[14] Huang, H. C. (2013). Intelligent motion control for omnidirectional mobile robots using ant colony optimization. Applied Artificial Intelligence, 27(3), 151-169.

[15] Mohanraj, T., Arunkumar, S., Raghunath, M., & Anand, M. (2014). Mobile robot path planning using ant colony optimization. International Journal of Research in Engineering and Technology, 3(11), 1-6.

[16] Castillo, O., Neyoy, H., Soria, J., Melin, P., & Valdez, F. (2015). A new approach for dynamic fuzzy logic parameter tuning in ant colony optimization and its application in fuzzy control of a mobile robot. Applied soft computing, 28, 150-159.

[17] Yen, C. T., & Cheng, M. F. (2018). A study of fuzzy control with ant colony algorithm used in mobile robot for shortest path planning and obstacle avoidance. Microsystem Technologies, 24(1), 125-135.

[18] Li, B., & Shao, Z. (2016). Precise trajectory optimization for articulated wheeled vehicles in cluttered environments. Advances in Engineering Software, 92, 40-47.

[19] Rashid, R., Perumal, N., Elamvazuthi, I., Tageldeen, M. K., Khan, M. A., & Parasuraman, S. (2016, September). Mobile robot path planning using Ant Colony Optimization. In 2016 2nd IEEE International Symposium on Robotics and Manufacturing Automation (ROMA) (pp. 1-6). IEEE.

[20] Cao, J. (2016). Robot global path planning based on an improved ant colony algorithm. Journal of Computer and Communications, 4(02), 11.

[21] Pizzo, J. (2015). Ant colony optimization. Clanrye International.

[22] Abdel-Basset, M., Abdel-Fatah, L., & Sangaiah, A. K. (2018). Metaheuristic algorithms: A comprehensive review. Computational intelligence for multimedia big data on the cloud with engineering applications, 185-231.

[23] Akka, K., & Khaber, F. (2018). Mobile robot path planning using an improved ant colony optimization. International Journal of Advanced Robotic Systems, 15(3), 1729881418774673.

[24] Chen, X., Zhang, P., Du, G., & Li, F. (2018). Ant colony optimization based memetic algorithm to solve bi-objective multiple traveling salesmen problem for multi-robot systems. IEEE Access, 6, 21745-21757.

[25] Dorigo, M., & Stützle, T. (2019). Ant colony optimization: overview and recent advances. Handbook of metaheuristics, 311-351.Mulani, M., Desai, V., (2018). Design and Implementation Issues in Ant Colony Optimization, *International Journal of Applied Engineering Research,* Vol. 13, No. 16, 12877-12882

[26] Zhang, Y., Wang, F., Fu, F., & Su, Z. (2018). Multi-AGV Path Planning for Indoor Factory by Using Prioritized Planning and Improved Ant Algorithm. Journal of Engineering & Technological Sciences, 50(4).

[27] Koubaa, A., Bennaceur, H., Chaari, I., Trigui, S., Ammar, A., Sriti, M. F., ... & Javed, Y. (2018). Introduction to mobile robot path planning. In Robot Path Planning and Cooperation (pp. 3-12). Springer, Cham.

[28] Dai, X., Long, S., Zhang, Z., & Gong, D. (2019). Mobile robot path planning based on ant colony algorithm with A* heuristic method. Frontiers in neurorobotics, 13, 15.

[29] Wang, L., Kan, J., Guo, J., & Wang, C. (2019). 3D path planning for the ground robot with improved ant colony optimization. Sensors, 19(4), 815.

[30] Zhang, D., You, X., Liu, S., & Pan, H. (2020). Dynamic multi-role adaptive collaborative ant colony optimization for robot path planning. IEEE Access, 8, 129958-129974.

[31] Ajeil, F. H., Ibraheem, I. K., Azar, A. T., & Humaidi, A. J. (2020). Grid-based mobile robot path planning using aging-based ant colony optimization algorithm in static and dynamic environments. Sensors, 20(7), 1880.

[32] Gao, W., Tang, Q., Ye, B., Yang, Y., & Yao, J. (2020). An enhanced heuristic ant colony optimization for mobile robot path planning. Soft Computing, 24(8), 6139-6150.

[33] Zitouni, F., Harous, S., & Maamri, R. (2020). A distributed approach to the multi-robot task allocation problem using the consensus-based bundle algorithm and ant colony system. IEEE Access, 8, 27479-27494.

[34] Li, Y., Huang, Z., & Xie, Y. (2020, May). Research status of mobile robot path planning based on genetic algorithm. In Journal of Physics: Conference Series (Vol. 1544, No. 1, p. 012021). IOP Publishing.

[35] Miao, C., Chen, G., Yan, C., & Wu, Y. (2021). Path planning optimization of indoor mobile robot based on adaptive ant colony algorithm. Computers & Industrial Engineering, 156, 107230.

[36] Zhang, S., Pu, J., & Si, Y. (2021). An adaptive improved ant colony system based on population information entropy for path planning of mobile robot. IEEE Access, 9, 24933-24945.

[37] Song, Q., Li, S., Yang, J., Bai, Q., Hu, J., Zhang, X., & Zhang, A. (2021). Intelligent Optimization Algorithm-Based Path Planning for a Mobile Robot. Computational Intelligence and Neuroscience, 2021.

[38] Sánchez-Ibáñez, J. R., Pérez-del-Pulgar, C. J., & García-Cerezo, A. (2021). Path Planning for Autonomous Mobile Robots: A Review. Sensors, 21(23), 7898.