Curvilinear path generation for UGV with improved ant colony algorithm

Hub Ali [1], Dawei Gong [2], Xinyue Lan [3] and Anxu Li [4]

Abstract**—**To deal with the complexity of different maps considering safety and path consistency is a problem which has to be addressed in path planning of Unmanned Ground Vehicle (UGV). In this paper, an efficient approach is introduced through combining improved Ant Colony Optimization (ACO) algorithm with cubic spline parametrization to provide smooth global route. Firstly, grid map is constructed. Initial cost policy is introduced for ant to search and performance of ant colony algorithm is improved through adding A* heuristic search and MAX_MIN ant system characteristics to enhance global searching ability. To improve localization and path consistency in global path, an evaluation function based on novel cost policy is introduced to evaluate path candidates in order to improve the quality of global path. At last, arc-length parametrization is applied to achieve path consistency and smoothness. The simulation results show optimal performance of this approach in complex maps including common and tunnel maps as compared with other versions of ACO algorithm.

Keywords**—**Path planning, UGV, ACO.

I. Introduction

In recent era, the application of Unmanned Ground Vehicle (UGV) increases in different areas including disaster management, industry and functions ranging from the applications to assist human beings in daily lives, improve their safety and comfort. Path planning is a middle stage between perception and actuation. It is considered to be a key problem for mobile robots to assist UGV to arrive at destination in constraint areas. Therefore, it needs to be improved further to achieve an optimal path with precision from start to destination in various complex environments.

Global Path Planning (GPP) is a key technique to achieve optimal route from initial position to final destination. Many approaches have been introduced in order to achieve the optimal global path. However, with increasing complexity of map, the performance reduces due to limited functionalities. Most of GPP techniques use discrete search optimization and apply on grid-based environment. In grids-based environment, the obtained path is made of suboptimal grid points. Each grid point is connected with another in a sequence and shape a global route made of suboptimal straight lines, which consist of sharp bending. In contrast, a smooth route can deliver UGV a comfortable and safe drive. Given such scenarios, the sharp bending of global path may cause more braking and unpleasant change in acceleration. To ensure a safe and comfort drive, curvilinear global route has been regarded as a suitable choice for navigation and it is used in real-time scenarios, for example, in DAPRA autonomous challenge (2012), a vehicle used curvilinear route generated from predefined global waypoints [1].

Different path planning approaches has distinct advantages and drawbacks depending upon the complexity of problem. [2] simulated annealing, [3] potential function theory [4], fuzzy logic algorithm [5] and many other approaches have quite limited problem-solving ability than modern evolutionary optimization techniques, including ant colony algorithm [6], bee colony algorithm [7], genetic algorithm [8] and so on. This comparison is made upon the basis degree of intelligence. Ant colony algorithm have been seen as one of popular evolutionary approaches to solve optimization problem due to its advantages, such as good feedback information, strong robustness and better distributed computing [9] and it can be easily combined with other techniques to provide optimal solution. However, due to slow convergence and prematurity issues. it has to be enhanced further. In this regards, various methods have been developed to optimize performance of ACO with respect to path strategy and pheromone update. In [10] pheromones updated at every optimal iteration of ant to improve the convergence rate. In [11] global search ability of ant has improved through acclimatize volatilization rate and enhancing the pheromone update equation. In [12], to avoid initial blind search efficient algorithm has presented. From [13] many researchers presented various improved model of ACO to achieve optimal performance.

In this paper, initial constraints policy is introduced to ant for keeping offset distance from obstacle grids. An evaluation function of A* algorithm is utilized to accelerate convergence speed in search strategy of ant colony algorithm with better heuristic information. Global searching ability is improved by MAX_MIN ant system through updating path pheromone of optimal network information, along with bending suppression operator introduced to improve heuristic information, which aims to optimize the performance of ACO. The path obtained in grid-based environment consists of small number of suboptimal paths connected with heading angles (e.g., 0, $\pi/4$, $\pi/2$, etc.), which result in an unnatural path. To get smooth path, linear interpolation is applied on initial coordinates

[1]Hub Ali is the graduate student in School of Mechanical and Electrical Engineering, UESTC (e-mail: hubali49@outlook.com).

[2]Dawei Gong is the Associate Professor in School of Mechanical and Electrical Engineering, UESTC (e-mail: pzhzhx@126.com).

[3]Xinyue Lan is the undergraduate student in Glasgow College, UESTC (e-mail: xinyuelan@std.uestc.edu.cn).

[4]Anxu Li is the graduate student in School of Mechanical and Electrical Engineering, UESTC (e-mail: 15008491072@163.com).

generated by ACO for increasing number of path candidates, and a novel cost evaluation policy is applied on the set of optimal grid candidates, which removes poor candidates to increase smoothness of the path. In order to obtain path consistency and optimal trajectory of global path, parametric curves are frequently employed to model the geometry of a road and to determine the motion path trajectory [1]. In this way, a safe and comfortable global path achieved for mobile robot.

II. ENVIRONMENT MODEL.

The proposed path-planning approach is implemented in grid-based environment. The known superiorities of grid method are the simplicity and effectivity in creating and maintaining grid model. Furthermore, the grid method is adaptable to obstacles and it is convenient for computer to store and handle. In this approach, the working space is divided in to $N*N$ grids, as shown in Figure.1:

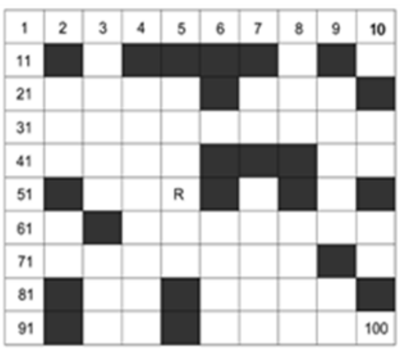

Figure.1 Grid Model

White grids are spaces where robot can move freely. In contrast, black grids represent the area of constraints. In order to identify constraint areas, the white grid cells are represented with 0, and black grid units are represented with 1. The position coordinates *(x, y)* corresponding to any grids with grid number R is as followed:

$$\begin{cases} x = \begin{cases} mod(R,N) - 0.5 & \text{if } mod(R,N) != 0 \\ N + \text{mod}(R,N) - 0.5 & \text{otherwise} \end{cases} \\ y = N + 0.5 - ceil(R/N) \end{cases} \tag{1}$$

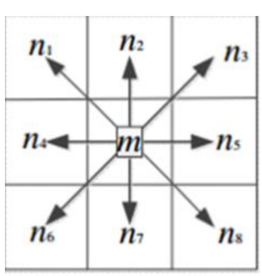

Figure.2 Possible Visiting Direction

Serial number method is applied to reduce computational complexity of ACO. The direction of each move from center point of grid with respect to neighbor grids has been simplified with arithmetic operation.In Figure.2, m represents number of central grid point and n is number of rows and columns of grid map. N represents all the possible direction. A set of arithmetic equations are presented in Table I.

Table I. Arithmetic equations for Direction

Direction	Arithmetic operation
n_1	m - (N+1)
n_2	m – N
n_3	m – (N-1)
n_4	m – 1
n_5	m + 1
n_6	m + (N-1)
n_7	m + N
n_8	m + (N + 1)

III. IMPROVED ACO WITH NOVEL COST POLICY

Ant Colony Optimization (ACO) algorithm [8] is improved to optimize the performance of global path planning. Initial cost policy has been introduced to guide ant to maintain an offset distance with obstacle grid. An ant has 8 probable directions and they are defined through set of equations presented in Table I. When the obstacle grid is found, ant has to move towards free grids according to the desired initial cost policy to maintain an offset distance with obstacle grid. The heuristic information assists ant in moving towards goal. In this paper, A* heuristic function characterization is used to improve the directing ability of ant instead of blind search. Additionally, MAX_MIN ant system is utilized to increase the efficiency of pheromone update and the ability of global search. At last, ant colony algorithm provides a sequence of grids in serial number method, which has been further refined according to novel cost policy to remove bending effect.

A. *Initial constraint Policy*

In ACO, ant has to search from one grid to another to arrive at the destination. When an ant found obstacle grids around it, it prefers to move towards the obstacle-free grids. Initial constraint policy is designed for ant to maintain offset distance with obstacle grids. It eliminates those grids which do not maintains offset distance with obstacle grid. In Table II, the directions of obstacle grids are referred as Obstacle direction and the grids without maintaining offset distance are represented as Eliminating grids according to the set of equations in Table I.

Table II. Initial constraints policy for ant

Obstacle direction	Eliminating grids
n_2	n_1 & n_3
n_4	n_1 & n_6
n_7	n_6 & n_8
n_5	n_3 & n_8

B. *Heuristic function to improve direction*

In [10] and [9], the researchers used A* heuristic function in order to improve the direction information for initial ant search to avoid blind search. After applying initial constraints policy, heuristic function assists the ant to choose an optimal grid. The cost of heuristic function is obtained through equation (2).

$$f(n) = g(n) + h(n) \tag{2}$$

In this function, the minimum cost from the source grid to the present grid is represented by $g(n)$. $h(n)$represents the minimum cost from the present grid to the destination. The estimated function of A* algorithm is applied as heuristic information to search for global optimal path in ant colony algorithm with the bending suppression operator added to the heuristic value of it. The improved heuristic information formula is as followed:

$$\eta_{ij}(t) = \frac{Q_2}{h(n) + g(n) + \mathrm{cost}(bend)} \tag{3}$$
$$\mathrm{cost}(bend) = \varphi * turn + \psi * \theta$$

Q_2 is constant greater than 1. The bending suppression operator is $cost(bend)$. $turn$ is the number of turns from grid $n-1$(previous grid) to grid $n+1$ (next grid). θ is the angle between the line segment from the center of grid $n-1$ to grid n (current grid) and the line segment from the center of grid n to grid $n+1$. φ is cost of converting bending into length between the centers of two grids. In a similar way, ψ is the cost of converting angle into length between the centers of two grids.

C. *Max_Min Ant System (MMAS)*

Pheromone trail updating: after each iteration trial, the distribution of pheromone is submitted into update history in conventional ant colony algorithm. Nevertheless, in the MMAS, only the path pheromone of the optimal network is updated after the iteration is completed. The method used here is similar to [10] and [14].

D. *Removing bending effect*

Improved ant colony algorithm gives a sequence of optimal grids, which are represented in serial number method and transformed into Cartesian coordinates. Each grid is represented with a grid point on map and connected with each other to draw global route from initial position to final destination. To increase the visibility of global path, Linear Interpolation (LI) is implemented. In this paper, a novel cost policy is introduced to evaluate each grid point with respect to its neighbor grid point.

a. Linear Interpolation (LI)

LI has a broad area of applications. Many path-planning approaches make a use of LI for path smoothing. LI is a technique applied to generate new data points between two given points. The derived global path points have been passed through LI to produce extra point between each original pair. In [15] similar procedure is used.

b. Novel cost policy

In order to remove the bending effect in global path, an efficient cost policy is introduced. The improved Ant Colony Optimization (ACO) has been able to produce a sequence of grids. Each grid has a number according to serial number method and has to be evaluated with respect to first two neighbors. In Table III, a desired cost policy is presented, which is based on the condition and cost. For each condition there is a cost value. If the cost value is 0 for a grid, it would be eliminated from the set of optimal path grids.

Table III. Cost policy

Conditions	Annotations	Cost
n_5 && n_2	If evaluating grid has given directions with neighbor grids	0
n_4 && n_2	If evaluating grid has given directions with neighbor grids	0
n_4 && n_7	If evaluating grid has given directions with neighbor grids	0
n_5 && n_7	If evaluating grid has given directions with neighbor grids	0
n_3 && n_7	If evaluating grid has given directions with neighbor grids	0
n_1 && n_7	If evaluating grid has given directions with neighbor grids	0
n_2 && n_8	If evaluating grid has given directions with neighbor grids	0
n_2 && n_6	If evaluating grid has given directions with neighbor grids	0
n_5 && n_6	If evaluating grid has given directions with neighbor grids	0
n_4 && n_8	If evaluating grid has given directions with neighbor grids	0
n_1 && n_5	If evaluating grid has given directions with neighbor grids	0
n_3 && n_4	If evaluating grid has given directions with neighbor grids	0

IV. Smooth Optimal Path

In order to get optimal route from initial position to destination, many state-of-art approaches used arc-length parametrization technique in predefined global waypoints to generate a reference road map. In grid-based environment, the obtained global path does not maintain consistency. In [1] parametric equations are given to drive smooth curvilinear path.

V. Simulations

In order to verify the efficiency of derived approach, a series of simulations have been performed on MATLAB. In Figure.3 a) and c), the initially optimized path is derived in common map and Baffle map through improved. In Figure.3

b) and d), the novel cost evaluation policy is applied and the arc-length parametrization smoothness, path consistency and safety has been achieved. In Table IV details are given.

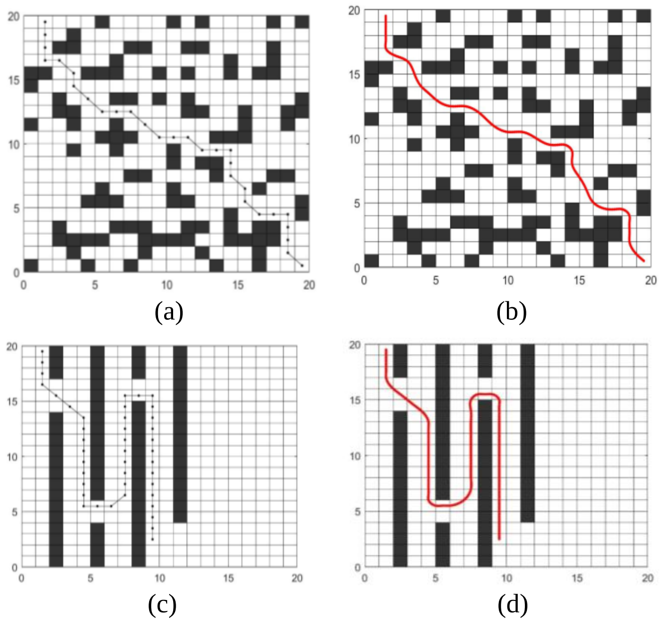

Figure.3. Simulation in common and Baffle map

Table IV. Simulation results

Map	General map	Baffle map
Iteration	15	18
Actual length	32.34	52.7
Sharp corners	14	17
Sharp corners after Evaluation function	0	0
Average time (s)	5	8.7
Length after evaluation	29.23	50.2

VI. Concluding Remarks

This paper concludes an efficient approach to deal with path planning problem for unmanned ground vehicle. Which provides a curvilinear shortest path for UGV in order to consider path smoothness and consistency. It can also be upgraded to deal with dynamic constraints.

.

VII. Acknowledgment

This work has been supported by School Mechanical and Electrical Engineering, UESTC.

References

[1] K. Chu, M. Lee, and M. Sunwoo, "Local path planning for offroad autonomous driving with avoidance of static obstacles," *IEEE Trans. Intell. Transp. Syst.*, vol. 13, no. 4, pp. 1599–1616, Dec.

[2] Zhiping Zhou， Yunfeng Nie， Min Gao． Enhanced ant colony optimization algorithm for global path planning of mobile robots［C］‖2013 5th International Conference on Computational and Information Sciences，2013: 698－701.

[3] Miao H, Tian Y C. Dynamic robot path planning using an enhanced simulated annealing approach [J]. Applied Mathematics & Computation, 2013, 222(5):420-437.

[4] Bakdi A, Hentout A, Boutami H, et al. Optimal path planning and execution for mobile robots using genetic algorithm and adaptive fuzzy-logic control[J]. Robotics & Autonomous Systems, 2016, 89(1):95–109.

[5] Song B, Wang Z, Zou L. On Global Smooth Path Planning for Mobile Robots using a Novel Multimodal Delayed PSO Algorithm [J]. Cognitive Computation, 2017, 9(1):1-13.

[6] B. Smith, "An approach to graphs of linear forms (Unpublished work style)," unpublished.

[7] Jovanovic R, Tuba M, Voß S. An ant colony optimization algorithm for partitioning graphs with supply and demand [J]. Applied Soft Computing, 2016, 41(3):317-330.

[8] Contreras-Cruz, Marco A., Victor Ayala-Ramirez, and Uriel H. Hernandez-Belmonte. "Mobile robot path planning using artificial bee colony and evolutionary programming." Applied Soft Computing 30 (2015): 319-328.

[9] František Duchoň, Andrej Babinec, Martin Kajan, et al. Path Planning with Modified a Star Algorithm for a Mobile Robot [J]. Procedia Engineering, 2014, 96(96):59-69.

[10] Long, Shuai, et al. "Mobile Robot Path Planning Based on Ant Colony Algorithm with A* Heuristic Method." *Frontiers in Neurorobotics* 13 (2019): 15.M. Young, *The Techincal Writers Handbook.* Mill Valley, CA: University Science, 1989.

[11] Liu J, Yang J, Liu H, et al. An improved ant colony algorithm for robot path planning [J]. Soft Computing, 2016, 1(11):1-11.

[12] Zhao J, Cheng D, Hao C. An Improved Ant Colony Algorithm for Solving the Path Planning Problem of the Omnidirectional Mobile Vehicle [J]. Mathematical Problems in Engineering, 2016, (2016-9-19), 2016, 2016(12).

[13] Zeng M R, Xi L, Xiao A M. The free step length ant colony algorithm in mobile robot path planning [J]. Advanced Robotics, 2016, 30(23):1509-1514.

[14] Wang D S, Yu H F. Path planning of mobile robot in dynamic environments[C]// International Conference on Intelligent Control and Information Processing. IEEE, 2011:691-696.

[15] Blu, Thierry, Philippe Thévenaz, and Michael Unser. "Linear interpolation revitalized." *IEEE Transactions on Image Processing* 13.5 (2004): 710-719.