Waveguide Path Planning using Nearest Neighbor, Breadth First Search and Ant Colony Inspired Optimization Algorithms

Trushar Shah[a], Jay Patel[a], Vinod P Shingadiya[b], V.B. Patel[a]

[a]*Department of Mechanical & Mechatronics Engineering, U.V.Patel College of Engineering, Gujarat, India.*

[b]*Head of CMID Department, Space Applications Centre (ISRO), Gujarat, India*

Abstract: **- Waveguide is the device used as communication channel in Satellites. Waveguide path planning is essential for proper utilization of area and systematic arrangement. In this literature, three types of optimization algorithms have been discussed for waveguide path planning. These algorithms are compared for optimum area utilization and their advantages and disadvantages with respect to waveguide path planning are discussed.**

Keywords: **Path planning, Travelling salesman problem, ACO, BFS, NNA, Optimization, Artificial Intelligence.**

I. INTRODUCTION

Waveguide is a metallic tube structure which guides electromagnetic or sound waves. The original and most common meaning of waveguide is a hollow conductive metal pipe used for carrying high frequency radio waves, particularly microwaves. By means of waveguide, different panels on satellite can communicate with each other. Due to its bulky size compare to any other communication media, the need arises to minimize the floor area utilization occupied by waveguides. The major difficulties are: 1) The waveguide can be organized in 3D space rather than 2D space. 2) Geometric properties of waveguides like bent angle, minimum distance between two channels, its dimensions etc. may cause disturbance in communication between two panels. 3) In presence of random stationary obstacles, the path shall optimally be generated automatically.

This literature contains discussion on 2D area minimization for waveguide path planning and other limitations like geometric limitations are omitted for sake of simplicity. Literature related to optimum path planning has been referred. Marco Dorigo et. al. had introduced Ant Colony Optimization for industrial applications like vehicle routing and scheduling problems. They found that algorithm is efficient to solve many travelling salesman problems [1]. After his work, many researchers have resolved problems related to mobile robots or Automated guided vehicles applications[3,5,6,8,11,15,16,18], logistic applications[9, 12,14], circuit debugger[7] etc. In [2], ACO is improved using potential field method for faster convergence. In [4], hybrid method of ACO and NNA is used to overcome limitations of slow convergence and local minima problem and [17] discusses about combining ACO and GA for achieving better optimization results. For optimization, various optimization algorithms are compared. In [13] BFS, A* and Dijkstra algorithms are compared. NNA is also used for logistics applications[10] due to its simplicity.

Though many optimization algorithms have already been tested, there is a need to test them for waveguide path planning problem as it is more or less different than travelling salesman problem. The physical problem arises in case of waveguide is that waveguides must not intersect each other. Imposing this problem, there are some modifications needed in conventional algorithms.

In following section, Nearest neighbor, Breadth first search and Ant colony inspired algorithms are discussed. Section (3) presents results and discussions on each algorithm. Finally section (4) concludes the outcome of this research.

II. EXPERIMENTAL PROCEDURES

The map is passed as information in form of image which is considered to occupy binary value at each grid. Value ‘1’ indicates region of obstacle whereas value ‘0’ indicates free space. In image form, black color indicates free space whereas white indicates region of obstacle. The obstacle can beof any shape. The first step of process is extracting nodes for all obstacles. For any shape of obstacle, the bounding box is generated first whose four indices may serve as nodes or via points. These nodes will also enable us to avoid obstacle while generating waveguide path. Fig. 1 illustrates result of nodes extraction. White four dots around circle are nodes created for circular obstacle. Similarly, four dots surrounding rectangular obstacle shall be observed. Next step involves database generation in which distance between each node to other node has been stored. These data will serve as primary inputs for all three optimization technique. The Euclidean distance between any two nodes is given by,

$$d(n_1, n_2) = \sqrt{(x_1 - x_2)^2 + (y_1 - y_2)^2}$$

Where, d is distance between nodes n1 and n2 and tuples (xi,yi) indicates their co-ordinates from upper-left corner.

Fig. 1 Extraction of nodes

In addition to via points generated as nodes user is free to select source and destination nodes anywhere in an image map. Thus, the database will contain distance from one node to all other nodes.Total number of nodes will be given by,

$$n_n = 4n_o + 2$$

Where n_n is number of nodes generated and n_o is number of static obstacles present in map. Table 1 shows part of database created.

Table I Sample database for five nodes

		Node j				
		1	2	3	4	5
Node i	1	Infinite	158.71	Infinite	176.55	39.56
	2	158.71	Infinite	73	335.25	197.14
	3	Infinite	73	Infinite	Infinite	Infinite
	4	176.55	335.25	Infinite	Infinite	139
	5	39.56	197.14	Infinite	139	Infinite

Table 1 shall be interpreted as follows: First node and Last node are source and destination nodes respectively. The grid value indicates Euclidean distance between current node 'i' to next node 'j'. Thus, value at node i=2 and node j=4 indicates that distance between these two nodes is 335.25. Distance value for nodes which cannot be connected by line due to obstacle is considered infinite to show that those nodes cannot be connected directly. Similarly, considering the fact that current and next node cannot be same, distance between same nodes is also marked 'infinite'. This value causes cost function or heuristics function value very high which results in proper guidance for path planning. It shall also be observed that upper triangle and lower triangle of matrix are same which means that matrix is diagonally symmetric matrix.

After development of database matrix, next step involves development of Nearest Neighbor, Breadth First Search and Ant Colony Inspired Optimization algorithm for path planning. All three algorithms are briefly discussed here.

A. Nearest neighbor algorithm

The simplest and fastest algorithm out of all three is Nearest Neighbor Algorithm. This algorithm works based on heuristic function that the next node of travel is the one which is the most nearest to current one. The major limitation of nearest neighbor algorithm for finding optimal path is that the algorithm checks for local distance only and do not account for number of via nodes. This limitation comes from the fact that sometimes nodes far from current node may need very few via nodes and thus total distance is far less than travelling through many nodes which are nearer to each other. Thus, guarantee for optimal path cannot be achieved through Nearest neighbor search algorithm except source and destination nodes are too nearer to each other.

B. Breadth first search technique

Breadth first search technique is non-heuristic technique which searches for less number of nodes than for lesser distance. In this technique, all the possible solutions are explored simultaneously from given current nodes. If any of the explored nodes matches with destination node then process of exploring next level nodes stops and path is regained. If none of the explored nodes match with destination node then these nodes are explored simultaneously again. This process continues till either all solutions are checked or destination node is found. As it explores simultaneous solutions, there is guaranteed lesser number of stages if it exists. But, having lesser number of via nodes cannot guarantee optimal path.

C. Ant Colony Inspired Optimization algorithm

As already discussed, many researchers have used Ant Colony Optimization algorithm for mobile robots, logistics, and circuit testing etc. applications. Convergence of algorithm depends on many parameters like Ant move, pheromone update, varying control parameters etc. [2]. To overcome limitation of this parametric method, new non-parametric method is suggested in this literature. Effects of parameters are diminished by taking number of solutions in account. Based on probability theory, the number of solutions which may exist isgiven by

$$n_p = \sum_{i=0}^{n} \frac{n!}{(n-i)!}$$

Where n_p indicates total number of paths, n is number of stages or number of via nodes that may be allowed. The number of ants are needed will be equal to number of paths. Assuming that at none of the instance, number of ants will be less than predefined value; ants are allowed to move in different direction in order simultaneously. Number of ants that will be sent to particular node from current node will be equal in all the directions which mean that probability of number ants' distribution will be equal for all possible next nodes. If any ant has reached to the goal position, then it will not travel further and wait for ants to complete their journey. Finally as all ants complete their journey, maximum up to predefined 'n' stages, all ants will report distance travelled by each ant. The ant or group of ants which have reached to destination node and distance travelled by those ants is minimum compared to all other ants which have also reached to destination node, is considered winner. The path travelled by winner ants is optimum.

III. RESULTS AND DISCUSSIONS

All three algorithms were successfully developed and tested for achieving optimal waveguide path planning. The Ant Inspired Optimization algorithm is developed which do not require any iterative procedure and non-parametric in nature. The advantage gain is that it uses search technique till scope of solution exists.

Figures (2), (3) and (4) demonstrate result obtained for Nearest neighbor, Breadth first search and Ant Colony Inspired optimization algorithm.

Fig. 2 Path developed by Nearest Neighbor Algorithm.

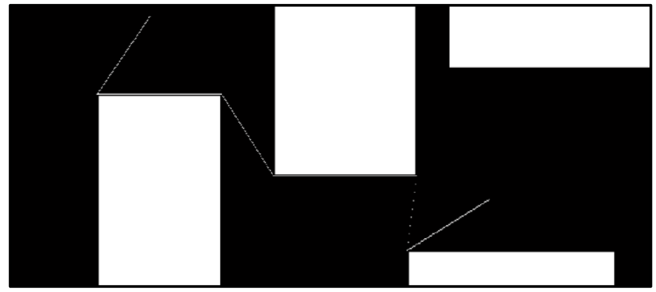


Fig. 3 Path developed by BFS Search algorithm.

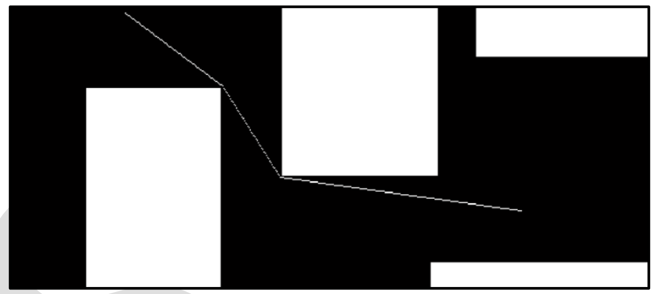


Fig. 4 Path developed by ACIO algorithm

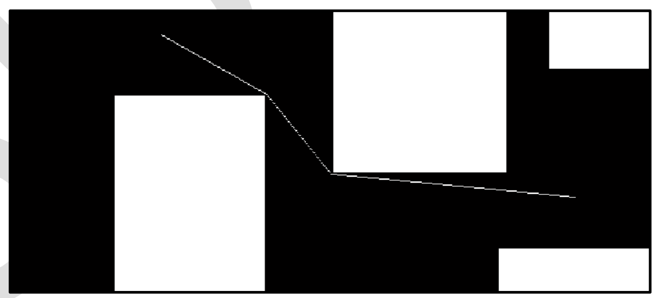


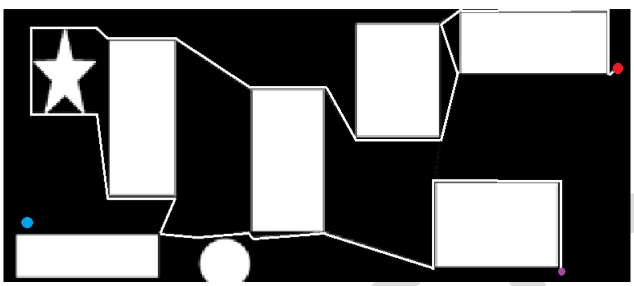
Table II Comparison of Nearest neighbor, Ant Colony Inspired Optimization algorithm and Breadth first search technique.

No.	Actual minimum distance	NNA Algorithm	Error (NNA)	ACIO algorithm	Error (ACIO)	BFS Technique	Error (BFS)
1	637.95	2049.15	1411.2	637.95	0	653.4	15.45
2	298.88	1411.12	1112.24	298.88	0	410.69	111.81
3	844.37	2903.33	2058.96	847.99	3.62	844.37	0
4	297.02	333.17	36.15	297.02	0	312.65	15.63
5	1111.07	3642.17	2531.1	1111.07	0	1142.92	31.85
6	610.4	2511.51	1901.11	610.4	0	610.4	0
7	1298.93	3683.97	2385.04	1298.93	0	1353.6	54.67
8	1254	4365.69	3111.69	1254	0	1462.77	208.77
9	324.71	405.41	80.7	324.71	0	324.71	0
10	535.38	2618.27	2082.89	741.91	206.53	982.2	446.82
RMS Error			**1928.88**	**-**	**65.321**	-	**161.314**

While testing nearest neighbor algorithm, it has been observed that nearest neighbor algorithm gives optimal results in case of only when source node and destination nodes are comparatively very nearer to each other. The reason is nearest neighbor algorithm searches for nodes which are near in local region. In case if any path exist which is the shortest but do not contain any nearest nodes in their sequence consecutively then algorithm fails to find optimum path. From figure (2), such cases can be observed.

Nearest neighbor algorithm has an additional limitation for case like waveguide path planning. In case of waveguide path planning, waveguide itself work as an obstacle for next waveguide. In such case, nearest neighbor algorithm will get trapped as no other path exist which can avoid existing waveguide path. Figure (5) illustrates the case in which nearest neighbor failed to find any path from source to destination locations.

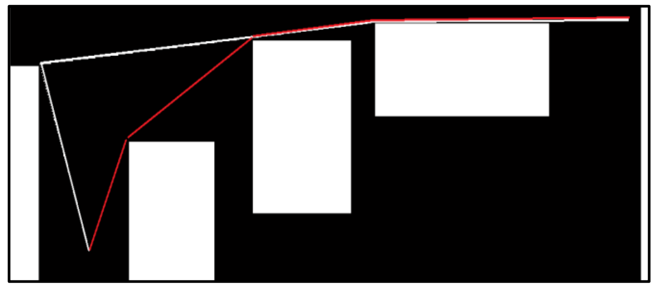
Fig. 5 Nearest neighbor algorithm fails to find path between source and destination nodes. Source node is highlighted in red color whereas cyan colored circle indicates destination. Magenta colored circle shows node where path searching process stopped.



As stated earlier, breadth first search technique has advantage that it finds stage optimal path. Because it is not only confined to local nearest node search, it has capability to guarantee solution if it exists. None of the selection has resulted in failure for both Ant Colony Inspired Optimization algorithm and Breadth first search technique. Though BFS technique finds acceptable result in many cases, it cannot guarantee optimal solution. Examples include a case when shorter distance contains many node few distance apart. Figure (6) demonstrates non-optimal path finding solution by BFS technique. The optimal solution had three via node points whereas solution found through BFS technique had only two via node points.

The main contribution of this paper is in development of new Ant Inspired Optimization algorithm which overcomes the limitation of parametric ACO technique. It has been successfully developed and the result demonstrated in table 2 reveals its success. It can be seen that ACIO has resulted in very less RMS error for 10 experiments. ACIO technique has less error compared to other two techniques. The error exists due to the fact that ACIO consumes more memory which restricts total number of via points. If numbers of via points are fixed due to memory limitation, capability of ACIO algorithm will be restricted and result obtained will be minimum for limited via points only.

Fig. 6 Non-optimal solution resulted in case of BFS technique. The white solid line indicated solution found using BFS technique whereas red solid line indicates optimal path. It shall be observed that BFS technique has found solution in 3 stages whereas optimal solution needs 4 stages.



IV. CONCLUSIONS

Optimizing waveguide path is crucial in order to utilize space properly. Three techniques were suggested in this literature: Nearest neighbor search algorithm, Breadth first search technique and Ant Colony Inspired Optimization technique. Nearest neighbor search technique has resulted in 1928.88 distance error than manually measured optimal distance whereas the same for Breadth first search and Ant Colony Inspired non-parametric technique had resulted in 161.31 and 65.32 distance error respectively. Therefore, ACIO technique is better to find shortest path compared to BFS technique and NNA algorithm. The limitation of ACIO technique is that it consumes more memory than other two techniques. So, its application for 3D space planning shall be tested with some modifications.

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REFERENCES

[1]. Marco Dorigo, Mauro Birattari, and Thomas Stutzle (2006), "*Ant colony optimization: Artificial ants as a computational intelligence technique*." IEEE Computational intelligence magazine. Pp. 28-39.

[2]. Joon-Woo Lee, Jeong-Jung Kim, Byoung-Suk Choi and Ju-Jang Lee (2008), "*Improved ant colony optimization algorithm by potential field concept for optimal path planning*". IEEE-RAS International conference on humanoid robots. Pp. 662-667.

[3]. Farnood Gholami, M. J. Mahjoob (2007), "An investigation of parameters in ant colony optimization for a path optimization algorithm". Proceedings of the IEEE International Conference on Mechatronics and Automation. Pp. 463-468.

[4]. Shu Yunxing , Guo Junen , Ge Bo.(2008), "An Ant colony optimization algorithm based on the nearest neighbor node choosing rules and the crossover operator". IEEE International Conference on Computer Science and Software Engineering. Pp. 110-114.

[5]. Zhao Juan-ping, Gao Xian-wen, Liu Jin-gang, Fu Xiu-hui. (2010). "Improved ant colony optimization algorithm and its application

for path planning of mobile robot in 3-d space". IEEE. Pp. 194-198.

[6]. Zhao Shaogang, Li Ming. (2010). "Path panning of inspection robot based on ant colony optimization algorithm". 2010 International conference on electrical and control engineering. IEEE. Pp. 1474-1477.

[7]. Liu Xinmei, Liu Peng, Yin Junling, Hou Wen. (2012). "The application of ant colony algorithm on automatic testing path optimization in complex circuits". 2012 Third global congress on intelligent systems. IEEE. Pp. 84-87.

[8]. Yuwan Cen, Choingzhi Song, Nenggang Xie, Lu Wang. (2008). "Path planning method for mobile robot based on Ant Colony Optimization Algorithm". IEEE. Pp 298-301.

[9]. Sandeep Dhakal and Raymond Chiong. (2008). "A hybrid nearest neighbor and progressive improvement approach for travelling salesmen problem". IEEE.

[10]. Yoonho Hwang, Bohyung Han, Hee-Kap Ahn (2012). "A fast nearest neighbor search algorithm by nonlinear embedding". IEEE. Pp 3053-3060.

[11]. M.A. Porta Garcia, Oscar Montiel, Oscar Castillo, Roberto Sepu lveda, Patricia Melin. (2009). "Path planning for autonomous mobile robot navigation with ant colony optimization and fuzzy cost function evaluation". Applied soft computing. Elsevier. Pp 1102-1110.

[12]. Lijie Li, Shangyou Ju, Ying Zhang. (2008). "Improved ant colony optimization for the traveling salesman problem". International Conference on Intelligent Computation Technology and Automation. IEEE. Pp. 76-80.

[13]. Tolga Yuksel, Abdullah Sezgin. "An implementation of path planning algorithms for mobile robots on a grid based map".

[14]. Ying-Tung Hsiao, Cheng-Long Chnang, Cheng-Chih Chien. (2004), "Ant colony optimization for best path planning". International Symposium on Communications and Information Technologies. Pp. 109-113.

[15]. 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. Pp. 9-16.

[16]. Michael Brand, Michael Masuda, Nicole Wehner, Xiao-Hua Yu. (2010, May). "Ant colony optimization algorithm for robot path planning". International Conference on Computer Design and Applications. IEEE. Volume-3, Pp. 436-440.

[17]. Minjie Yi. (2012). "The Research of path-oriented test data generation based on a mixed ant colony system algorithm and genetic algorithm". IEEE.

[18]. Wang Zhangqi, Zhu Xiaoguang, Han Qingyao. (2011). "Mobile robot path planning based on parameter optimization ant colony algorithm". Advanced in Control Engineering and Information Science. Elsevier. Pp. 2738-2741.