Optimal Path Planning using Swarm Intelligence Techniques

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ABSTRACT-Optimal path planning is the way to plan a shortest & efficient path for the defined source to destination within the efficient time interval. Path planning is one of the core and extensively studied problems in robotics. The scope of path planning is not only limited to robotics, it has gained its pertinence in many of the application areas including simulations and gaming, computer graphics, very large scale integration (VLSI) and many more. In this research work, we have applied the concepts of swarm intelligence for the optimal path planning. We have used different swarm intelligence based cuckoo search, firefly algorithm, and bat algorithm for the path planning. For this experimentation, a real time dataset of Alwar region situated at Rajasthan (India) is used. From this Alwar region, urban area along with the dense vegetation area is considered for the testing. Results are evaluated and compared in terms of in terms of simulation time and minimum number of iteration required to achieve the optimal path from defined source to destination.

Keywords-*Optimal Path Planning, Cuckoo Search, Bat Algorithm, Firefly Algorithm, Swarm Intelligence, Meta-heuristic Algorithms*

1. INTRODUCTION

The problem of path planning is an intricate task which has been a motivating factor for researchers from several research domains including: simulation, very large scale integration system, geographic information system, computer graphics, animations and gaming [1]. A typical formulation of path planning problem could be considered as *"the piano-movers problem"* [2], where the task is to determine a collision-free path to move a piece of furniture say sofa from one room to other in a cluttered house. The simple version of path planning is to identify the shortest and safe path between two specified points say source point and destination point in a given workspace with obstacles [3]. There are various applications of path planning. Table 1 lists some interesting application areas of path planning.

Table 1: Path planning application areas

Application area	Description
Robotics	Path planning is a vital task for both industrial and service robots. In industrial applications, robots work in a predictable environment whereas service robots operate in an unstructured and unpredictable environment.
Simulation and Modelling	Virtual prototyping in designs, dynamics and kinematics leads to achieve realistic virtualization [4].
Computer Graphics and Animation	The integration of animation and graphics with artificial intelligence lead to the high-level usage of path planning techniques to achieve real time animation [5].
Biology	It is an unexpected application area of path planning. In biology and chemistry path planning techniques are used to identify protein folding gateways [6] and ligand docking [7].
Surveillance	For planning and surveillance of indoor environments, path planning techniques are used to identify the paths covering the entire workspace also called as "Watchman route problem" [8].

Moreover, there are various methods to solve different applications of path planning. In this research work, optimal path planning problem is resolved based on the swarm intelligence concepts. We have considered different swarm intelligence concepts of cuckoo search (CS), firefly algorithm (FA), and bat algorithm (BA). Bat Algorithm is nature inspired algorithm that work by imitating the echolocation behaviour of bats. Bat algorithm was proposed by Yang in

2010 [9][10]. Cuckoo Search algorithm is also a nature inspired algorithm that work based on the brood parasitic nature of laying their eggs in other bird's nest. CS algorithm was proposed by Yang and Deb in 2009 [11][12]. Firefly is a meta-heuristic based swarm intelligence algorithm developed by Yang [13]. The algorithm is inspired from the bioluminescent/flashing behaviour of the fireflies. All these concepts are proposed by Xin-She Yang. In these concepts, bat algorithm and cuckoo search are single agent based algorithms and firefly algorithm is multi-agent based algorithm.

Here, mentioned swarm intelligence approaches are compared and evaluated for path planning based on simulation time and minimum number of iteration required to achieve the optimal path from defined source to destination. Results are evaluated for path planning of the urban and vegetation regions of Alwar region situated at Rajasthan (India).

Further paper follows the structure as mentioned: Section 2 discusses the related work based on path planning. Section 3 elaborates the process of path planning. Section 4 discusses the result section along with comparison of considered algorithms. Section 5 concludes the research paper along with some future directions.

2. RELATED WORK

Wang et al. [14] introduced bat algorithm for path planning in unmanned combat air vehicles. Standard bat algorithm is modified with mutation property when the new solutions are updated and named as bat algorithm with mutation. A graph with nodes is considered and a global collision free optimal path is achieved by connecting the selected nodes. The nodes are selected on the basis of fitness function value. In this case, lower the fitness value, smaller the threat and higher the chances to select the node. The simulation results when compared to other meta-heuristic techniques, projects the viability of proposed algorithm.

Further, Mohanty and Parhi [15] proposed a cuckoo search based optimization concept for the robotic path planning in an unknown environment with multiple obstacles. The objective function of the cuckoo search is formulated to identify the best path without any collisions. The best solution results are obtained by cuckoo search and are sequentially visited by mobile robot. The robot keeps on moving on the particular path until an obstacle is detected. The comparative results of cuckoo search with genetic algorithm and Particle Swarm Optimization (PSO) witnessed the effectiveness of cuckoo search for path planning. The authors further continued their work and proposed a new variant of cuckoo search algorithm for path planning problem in mobile robot navigation [16]. The information about the obstacles is obtained with the help of obstacles. The mobile robot moves sequentially on every path identified by cuckoo search algorithm in the form of best solution. The robot moves towards the destination until an obstacle is detected. The mobile robot uses the sensor information to detect the nearby obstacle and then cuckoo search is implemented to avoid collisions. Different scenarios are considered to compare the simulation results of cuckoo search with genetic algorithm and PSO and in every scenario cuckoo search outperforms all.

Liu et al. [17] designed an adaptive firefly algorithm for path planning in a known environment. The author attempted to improve the performance of standard firefly algorithm by adjusting its parameter values with number of iterations. Initially, the environment information along with the start and destination points is attained. The firefly population is generated and the brightness value of each firefly is obtained. The fireflies are compared in terms of brightness with the neighboring fireflies and the values of random & absorption parameters are updated. The brightest firefly indicates the best path belongs to the brightest firefly. The simulation results are obtained in a workspace region of 450*350 with 9 static obstacles. Further, Wang et al. [18] modified the standard firefly algorithm for path planning in uninhabited combat air vehicle (UCAV). In the proposed algorithm fireflies communicate with top fireflies and exchange information with them while updating the light intensity information. For the random movement of the fireflies, another modification is the addition of levy flight property. In the proposed algorithm, the brightest fireflies are categorized as top fireflies. For each top firefly, another firefly of same category is randomly picked and the path connecting these two fireflies results into the generation of a new firefly. In case the two top fireflies have same intensity values then the new firefly is generated at the middle of the other two fireflies. The value of absorption coefficient is updated after each iteration. The modified firefly algorithm produced the best results with absorption coefficient value of 1.0.

3. SWARM INTELLIGENCE CONCEPTS FOR PATH PLANNING

This section presents the considered swarm intelligence concepts of BA, CS, and FA to find the optimal path from source to destination. The main goal to use the swarm intelligence based FA, BA and CS is to obtain the optimized path with minimum possible iteration and simulation time. The considered concepts use their own properties to handle the present obstacles and to find the optimal path from source point to destination point in a static and unknown environment. The behavioural property of fireflies of getting attracted towards brighter firefly is considered to identify optimal path in defined workspace. The obstacles are detected based on the light intensity value. The workspace is considered as set of values varying according to the light intensity value at particular point. On the other hand, CS algorithm works with an assumption of considering obstacle as worst nest for cuckoo egg to handle the obstacles. BA uses the frequency based echolocation system to detect the obstacles and handle those obstacles. In this research work, the workspace region is considered as collection of binary pixels values: 0 and 1 where value 1 indicates obstacle free white pixel and value 0 is black pixel with obstacle. The considered input image, obtained path are shown in figure 1. The step by step algorithm is discussed here.

Algorithm

Step 1: Consider the input classified Alwar image and define the source s_p and destination d_p for the path planning.

Step 2: Apply Morphological operation to reduce the blocked paths and unnecessary area gaps between the source to destination.

Step 3: Initialize the parameters of swarm intelligence algorithms for n-agents possessing random position x_i in d-dimensional search space.

Step 4: Evaluate the size g_{best_i} and position x_{best_i} for the minimum fitness function value.

Step 5: Handle the obstacles based on the different properties of different swarm based algorithms.

Step 6: When the obstacle is detected then the Euclidian distance of the neighbour pixels from destination point is calculated to find the next point for the movement of swarm agents. If p_i and dp_j are pixel point and destination point respectively then the Euclidean distance between them can be evaluated by using equation (1).

$$d_{ij} = \|p_i - dp_j\| = \sqrt{\sum_{k=1}^{n}(p_{ik} - dp_{jk})^2}$$

… Equation (1)

After, handling the obstacle, swarm concepts again proceed towards the destination by calculating the Euclidean distance from the neighboring pixels to destination point.

Step 7: Evaluate the swarm intelligence based global optimum solution for all the pixel points in the way from source to destination.

Step 8: Obtain the final shortest optimum path from source to destination.

In this research work, optimal path is planned from source to destination in the dataset image of Alwar region. Dataset Red band satellite image of Alwar region with 203*258 pixel size is considered as input image and it is converted into binary image for the experimentation and is presented in figure 1(a) and (b) respectively. The binary image contains large number of minor obstacles. These minor neighbouring obstacles are transformed into one bigger obstacle by applying morphological operation which reduces the complexity of algorithm as presented in figure 1(c). The final optimal path image obtained using different swarm intelligence concepts is shown in figure 1 (d). The same optimal path using all the algorithms is obtained but the simulation time and minimum number of iterations required to obtain that path differs.

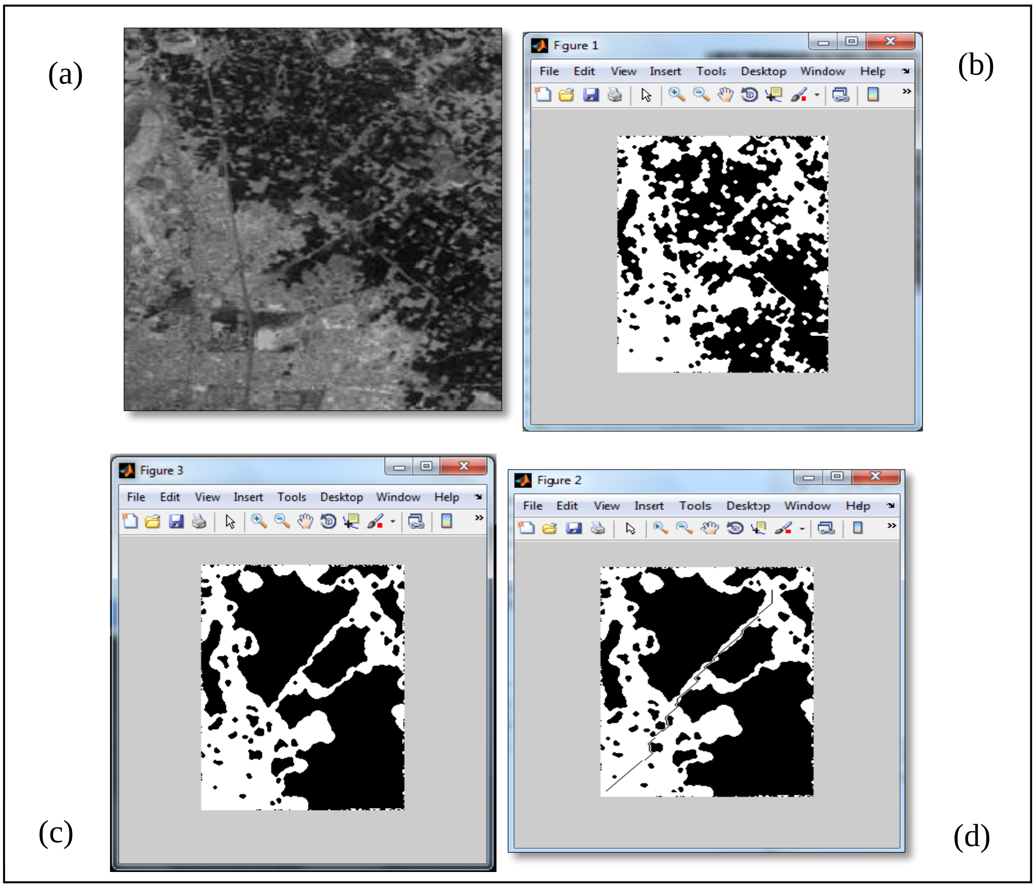

Figure 1: (a) Satellite input image of Alwar region (b) the binary conversion of Satellite image (c) Image after morphological operation (d) Obtained Optimal Path Length

4. RESULTS AND DISCUSSION

This section presents the evaluated results in terms of evaluation parameters. The experiment is performed on MATLAB version 8.3.0.532 and system configuration of window 7 operating system, 8 GB RAM, Intel i3 Processor. The evaluated path length obtained using all the swarm intelligence concepts is 246 pixels. The path length using FA, BA and CS are also same but the simulation time and minimum numbers of iterations that are required to obtain the optimal path vary as per the obstacles handling and path finding properties of different algorithms. The comparison of considered swarm intelligence based on the minimum number of iteration and simulation time is presented in table 2.

Table 2: Comparison of FA, BA & CS concepts

	Minimum No. of Iterations	Simulation Time (in sec)	
		Minimum	Maximum
CS	49	179	230
BA	61	198	264
FA	56	151	195

From evaluated results values in terms of minimum number of iterations and simulation time, it can be noticed that CS algorithm is efficient enough to find the optimal path length of 246 pixels in comparison with other considered concepts of BA and FA. The minimum numbers of iterations consumed by CS are 49 which are lesser as compared to BA and FA. On the other hand, simulation time of FA is lesser in comparison with CS and BA.

5. CONCLUSIONS

Path planning is one of the core and extensively studied problems in robotics. In this research work, optimal path is determined based on the workspace environment having static obstacles and unknown environment area. Different swarm intelligence algorithms of Bat Algorithm (BA), Firefly Algorithm (FA), and Cuckoo Search (CS) are used to determine the optimal path from defined source to destination. Different algorithm uses their respective properties to find the optimal path and handles the obstacles. Results of these concepts are compared with each other in terms of simulation time and minimum number of iteration required to achieve the optimal path from defined source to destination. The optimal path length of 246 pixels is obtained by all the swarm intelligence concepts but the simulation time and minimum numbers of iterations vary in different algorithms. The obtained results indicates the superiority of CS in terms of optimal path planning with minimum number of iterations and FA in terms of optimal path planning with lesser simulation time.

For future directions, the concept CS and FA can be hybridized to obtain the better results as compared to individual concepts of CS and FA.

REFERENCES

[1] Bhattacharya, P. and Gavrilova, M.L., 2008. Roadmap-based path planning-using the voronoi diagram for a clearance-based shortest path. *IEEE Robotics & Automation Magazine*, *15*(2).

[2] Weisstein, Eric W, 1999. Piano Mover's Problem. From *MathWorld* -- A Wolfram Web Resource. http://mathworld.wolfram.com/PianoMoversProblem.html

[3] Davoodi, M., 2017. Bi-objective path planning using deterministic algorithms. *Robotics and Autonomous Systems*, *93*, pp.105-115.

[4] Sundaram, S., Remmler, I. and Amato, N.M., 2001. Disassembly sequencing using a motion planning approach. In *Robotics and Automation, 2001. Proceedings 2001 ICRA. IEEE International Conference on* (Vol. 2, pp. 1475-1480). IEEE.

[5] Pettré, J., Siméon, T. and Laumond, J.P., 2002. Planning human walk in virtual environments. In *Intelligent Robots and Systems, 2002. IEEE/RSJ International Conference on* (Vol. 3, pp. 3048-3053). IEEE.

[6] Amato, N.M. and Song, G., 2002. Using motion planning to study protein folding pathways. *Journal of Computational Biology*, *9*(2), pp.149-168.

[7] Bayazit, O.B., Song, G. and Amato, N.M., 2001. Ligand binding with OBPRM and user input. In *Robotics and Automation, 2001. Proceedings 2001 ICRA. IEEE International Conference on* (Vol. 1, pp. 954-959). IEEE.

[8] Danner, T. and Kavraki, L.E., 2000, April. Randomized planning for short inspection paths. In *Robotics and Automation, 2000. Proceedings. ICRA'00. IEEE International Conference on* (Vol. 2, pp. 971-976). IEEE.

[9] Yang, X.S., 2010. A new metaheuristic bat-inspired algorithm. In *Nature inspired cooperative strategies for optimization (NICSO 2010)* (pp. 65-74). Springer, Berlin, Heidelberg.

[10] Yang, X.S. and Hossein Gandomi, A., 2012. Bat algorithm: a novel approach for global engineering optimization. *Engineering Computations*, *29*(5), pp.464-483.

[11] Yang, X.S. and Deb, S., 2009, December. Cuckoo search via Lévy flights. In *Nature & Biologically Inspired Computing, 2009. NaBIC 2009. World Congress on* (pp. 210-214). IEEE.

[12] Yang, X.S. and Deb, S., 2010. Engineering optimisation by cuckoo search. *International Journal of Mathematical Modelling and Numerical Optimisation*, *1*(4), pp.330-343.

[13] Yang, X.S., 2010. *Nature-inspired metaheuristic algorithms*. Luniver press.

[14] Wang, G., Guo, L., Duan, H., Liu, L. and Wang, H., 2012. A bat algorithm with mutation for UCAV path planning. *The Scientific World Journal*, *2012*.

[15] Mohanty, P.K. and Parhi, D.R., 2013, December. Cuckoo search algorithm for the mobile robot navigation. In *International Conference on Swarm, Evolutionary, and Memetic Computing* (pp. 527-536). Springer, Cham.

[16] Mohanty, P.K. and Parhi, D.R., 2016. Optimal path planning for a mobile robot using cuckoo search algorithm. *Journal of Experimental & Theoretical Artificial Intelligence*, *28*(1-2), pp.35-52.

[17] Liu, C., Gao, Z. and Zhao, W., 2012, June. A new path planning method based on firefly algorithm. In *Computational Sciences and Optimization (CSO), 2012 Fifth International Joint Conference on* (pp. 775-778). IEEE.

[18] Wang, G., Guo, L., Duan, H., Liu, L. and Wang, H., 2012. A modified firefly algorithm for UCAV path planning. *International Journal of Hybrid Information Technology*, *5*(3), pp.123-144.