Optimal Trajectory Planning for Multiple Waypoint Path Planning using Tabu Search

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***Abstract*—A Tabu search algorithm associated with multiple waypoint real-time path planning and map building such as Traveling Salesman Problem is proposed in this paper. This application plays a major role in actual world scenarios just as the ones encountered by the robots functioning in disaster prone environments like service, rescue, mining robots, etc., where there is a need for the robot to travel to collective goals through the shortest distance possible. This paper examines the use of one such algorithm, Tabu search, for finding the shortest path possible. It basically does neighborhood search with a set of nodes termed as Tabu list, which comprises of nodes that have been previously evaluated, thereby avoiding getting stuck in the local minima. During every new iteration, the recent search candidates are compared with the best solution found so far, so that the best possible node is retained for later use. This strategy enables an autonomous robot to travel to multiple goals using the shortest possible path. As soon as a global route is generated by the Tabu search, a D*-Lite algorithm combined with VFH based local navigation is laid on to plan a collision less trajectory through a contour with simultaneous map building under unknown environments.**

***Index Terms*—Multiple waypoint path planning, Traveling Salesman Problem, Tabu Search ,Tabu list, D*-Lite, Vector Field Histogram**

I. INTRODUCTION

Robotics is one of the most important scientific areas where the relationship between perception and action is being carried out. A mobile robot platform comprises of a system with characteristics such as mobility, certain levels of autonomy, perception ability (sensing and reacting in a specified environment), etc. Mobile robots have immense potential application in areas ranging from entertainment to high-end applications such as planetary Rovers. To accomplish this, mobile robots need to incorporate optimal motion planning and mapping. The existing algorithms mainly focuses on collision avoidance of a mobile robot for a finite goal in a known or unknown environment. However, in actual scenarios multiple-goal seeking and path planning in addition to motion trajectory estimation is necessary. Multi-goal robot path planning has many applications in addition to rescue robots, such as lawn movers, window cleaners, mining robots, vacuum mobile robots, etc. where there requires a minimization of fuel and cost. The multi waypoint robot path planning approach in this work enables the robot to go to multiple specified goals along a collision-free path of the minimized total distance with suitable starting point which basically refers to optimization. A matching table is created for sequencing the waypoints as multiple goals with suitable starting point.

A variety of approaches have been contemplated in the area of mobile robot motion planning. A motion planning method based on elastic-band was designed by Gu et al, where the main focus for mobile robot navigation was based on tunability and stability [1]. Another approach was proposed by Raja et al. based on Genetic algorithm with a gradient function. This proposal had major resemblance to the conventional path planning method termed as potential field method [2]. Recently, there exists a great and enormous research at The University of South Florida at The Center of Robot Assisted Search and Rescue where the study focuses on the use of self governing mobile robots for exploration of the survivors in a collapsed building [3]. A modern research using Genetic Algorithm was done by Davies and Jnifene where the research focuses on generation of an optimal path with shortest distance for going to all the required goals or multiple way-points without collision [4]. The major steps needed for multiple way-point path planning are identification of coordinates of the way-points, the actions required to be accomplished at the way-points, identification of workspace dimension, obstacles which are known and the areas that are required to be refrained. The multiple way-point motion planning suitably uses this information about the coordinates to aim and decide the order of visiting each co-ordinates accordingly, with shortest distance possible avoiding the known obstacles. In addition, there may be cases where there occurs an unknown obstacle. This is dealt particularly by an on-line path planner. Computational Intelligence techniques also play an important role in path planning. Luo and Yang [5-6] contemplated a bio-inspired artificial neural network model to perform path planning [5] - [6]. Yang and Meng also developed a method for a dynamic environment by a bio-inspired ANN (Artificial Neural Network) to actual collision-less path planning of mobile robots [7]. The neurons are topologically arranged in the network with regional local connections. The non-stationary activity prospect of the network aids in real-time mobile robot path planning. However, there are very few path planning algorithms explaining multiple way-points. Luo et al. proposed another method using Particle Swarm Optimization for multiple way-points [8]. It incorporated a solution by hybrid algorithms for real-time gmapping and navigation for multiple goals where a D* - Lite algorithm that is closely associated with LIDAR based navigation was proposed. Faigl and Macak intelligently integrated SOP (Self-Organizing map) with potential field method for achieving shortest path with multi-target seeking behavior through a TSP toolkit [9]. The robot thus visits several points which are the corresponding targets in the presence of obstacles. A method was also discussed briefly in Spong's book with way-points which have attractive fields by potential field method thereby enabling full search of all the possible way-points in-order to create a trajectory for path planning [10].

In this paper a real-time optimal route for multiple way-point optimal trajectory path planning for an autonomous robot using Tabu search is proposed. The rest of the paper is organized as follows. The evolution of multiple goal visit using Tabu Search approach is explained in Section II, Section III addresses the simulation outputs of the multiple goal visit in detail, with the path optimization. Also, the fitness curve is plotted in Section III. The detailed strategy of navigation and map building is explained in Section IV to validate the efficiency of the simulation.

II. Tabu Search Based Multi-goal visit

Earlier proposed hill climbing methods are the basis of Tabu search approach. Hill climbing method basically take a move to the next node if it is better. But there are certain limitations when we explore the gradient using hill climbing approach. The algorithm gets stuck at the local minima. Thus, a more efficient algorithm to escape the local minimum point and go against the heuristic function is indeed necessary.

A. Related work

In this paper, Tabu search algorithm is utilized to solve multiple target exploration with numerous way points programmed in MATLAB. An allowable factor along with a termination criteria is necessary for further exploration. Data backup or storage is important here to find the best solution. The allowable factor prevents the algorithm from reaching back to the same node again. This is achieved by maintaining a closed list called circular queue of some finite size, which can be over written. Another way of achieving this is by keeping track of all the moves that were made in the recent past essentially. If a bit has been changed in the last 't' moves, then disallow the same. This is slightly different from maintaining a closed queue, because closed queue never returns back to the same node again, whereas a memory array is maintained in this case and the moves are done accordingly.

In path planning approach, this move is termed as Tabu (not allowed) move. If the isolated move happens to be the actual solution, an exception is made called aspiration criteria, where if all the allowed neighbors are not efficient, and a Tabu move leads to 'n' which is better than the best, the particular move is allowed, thereby optimizing the objective function. Thus, Tabu search is an efficient local search method, which is programmed from an already existing greedy algorithm based on Euclidean distance heuristics and iteratively exploring the neighborhood to improve the existing algorithm [11]. If stagnation occurs after a number of iterations, the diversification technique assists in driving the search to a new space [11]. This technique marks a straight line based on Euclidean distance between the starting point and the goal, which may have the possibility of even intersecting with the obstacles. Between all the cells, the algorithm selects a random cell which is used to generate a path between starting point and the goal. This new path which is generated helps to update the algorithm optimizing the distance. An optimized total route was thus obtained with Tabu search approach thereby visiting all the way points once. This plays a major role in rescue robot applications, where the robot needs to visit every way point by starting at a designated point and ending at the introductory co-ordinate.

Traveling Salesman Problem is one such trajectory enhancement issue where an optimum route has to be found out between the cities that are desired to be visited with minimum cost. The classical TSP basically concerns to multiple way point path planning problem where all the designated cities needs to be visited minimizing the effective distance travelled in the journey. The unique approach how TSP is related to the multi way point target seeking is how the search is done for finding an ordered pair of way points minimizing cost or distance for our autonomous mobile robot. Thus, the goals basically represent the way points with corresponding GPS coordinates in the latitude and longitude.

B. D*-Lite integration with Vector Field Histogram

The navigation strategy integrates D*-Lite with Vector Field Histogram for Obstacle avoidance and local map building. D*-Lite serves as the base for global path planning and VFH as the local planner for multi-way point navigation.D*-Lite is basically an improvisation to A* path planning algorithm which takes into the account the antecedent inspection or search for successive executions to generate productive trajectories. Koenig et al. introduced the improvisation to A* Lite which was termed as Lifelong A* (LPA*) [12]. LPA* takes into consideration the previous runs or searches for finding the optimal route between two co-ordinates D*-Lite is applied to a bounded graph traversal issues which incorporates the expansion or reduction of cost function with respect to time [12]. D*-Lite efficiently discovers the optimal trajectory between two co-ordinates (a start point and a target) with a clear knowledge about the graphs and cost function by using proper heuristics. This paper adopts D*-Lite algorithm for the development of global trajectory under unknown terrain.

VFH(Vector Field Histogram) serves as the local navigation strategy for path planning [13]. VFH is an obstacle avoidance technique that generates a histogram for finding the candidate valleys in order for the robot to steer towards the goal. This navigation technique locally outputs the linear and angular velocity commands for the robot based on the position of the obstacles in the histogram. The LIDAR outputs the distances based on the range and these readings are divided into sectors for obstacle density calculation. The LIDAR data serves as the base for the creation of polar histogram for estimating the wheel velocities and steering direction. This paper utilizes VFH as the local navigation strategy. The multi waypoint navigation requires the effective usage of parallel map construction simultaneously navigating to find a way to multiple goals through Tabu Search approach. The current pose of the mobile robot is determined by the roll, pitch and yaw readings from the map that is built. The block diagram for procedural analysis of the adopted technique is shown in Fig. 1. The multiple target navigation strategy is extremely useful and plays a major role for navigation in unknown surroundings by carefully analyzing the optimal trajectory by taking advantage of the path planning techniques (local and global).

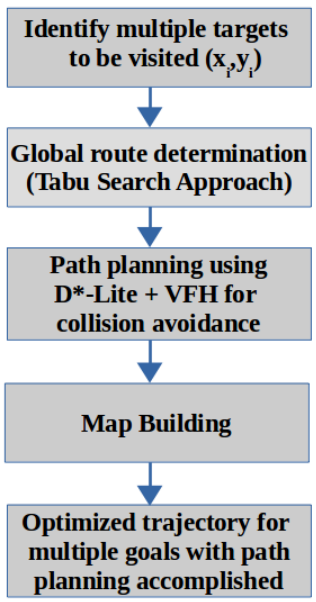

Fig. 1: Block diagram for Optimized trajectory planning

III. Simulation Results

This paper utilizes the Tabu search algorithm for resolving multiple goal navigation scenarios such as TSP with multi way points programmed in MATLAB. After execution of this Tabu Search based multiple way point path planning technique, the optimized route for the way points were successfully obtained. Initially, there were a total of 10 waypoints in the workspace that needs an autonomous robot to reach every way point. The Tabu search based multiple way point trajectory and path planning algorithm is applied to this application to determine the optimized shortest route by evaluating all possible routes between the coordinates, and finding the minimal route as shown in Fig. 2. After finding all the possible routes, the shortest optimized distance was found to be 32.0099 units with an execution time of 3.99 seconds which says that the proposed algorithm has faster execution time which is a greater advantage. Table I shows all the possible route distances that were calculated for estimating the final optimized path length.

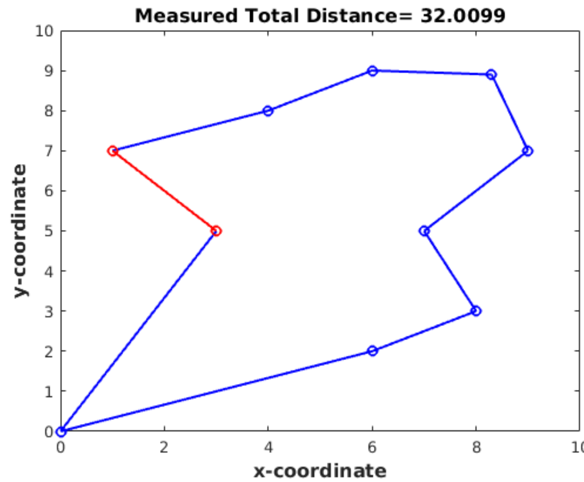

Fig. 2: Final Optimized Distance for 10 waypoints

TABLE I: Possible route distances estimated by simulation for optimization

Possible Route	Measured Distance
Route 1	49.6221 units
Route 2	47.6101 units
Route 3	44.6080 units
Route 4	41.0226 units
Route 5	34.4913 units
Route 6	32.0099 units

The fitness function is basically an objective function that summarizes a single figure of merit, that represents how accurate the solution is compared to the basic objective. It helps to guide the project simulations to more optimally designed solutions. The worst solutions are deleted after every round of simulation. Therefore, every design solution needs a figure of merit for indicating its closeness to the overall specification by applying the fitness function. It evaluates the probability of all possible results within the existing sample that is the parent which is basically chosen to create new offspring.The fitness value is calculated mathematically as follows :

$Fitness\_value = (length\_opt * assigned\_weights)+(prob\_in * (1-assigned\_weights))$

where $length\_opt$ denotes the probability that a solution is being chosen on the best possible path, $prob\_in$ denotes the probability that a solution is being chosen depending on intersection with the obstacles and $assigned\_weights$ is the weight that is assigned for obtaining the best possible solution with optimized path and time. The fitness evolution curve for ten waypoints is depicted in Fig. 3. It basically explains the variation of Fitness function with respect to number of iterations. The x-axis represent the number of iterations and the y-axis represents the value of objective function. Further testing of the algorithm was done for 9 waypoints, 20 waypoints and 30 waypoints and the results obtained were promising. Fig. 4 shows the optimized route for a 9 waypoint problem.

The simulated final optimized path route was a great improvement over other techniques like Particle Swarm Optimization(PSO) algorithm for multi waypoint navigation approach with 17 points to navigate [8]. In this, the robot also builds a map with the help of a 270 degree range LIDAR. The local navigator is based on Vector Field Histogram. For providing the VFH with intermediate goals, a D*-Lite algorithm was employed. The PSO when replaced by Tabu search shows greater performance characteristics. Therefore, the autonomous robot is fully capable of visiting every waypoint based on the sequence of the optimization found out based on the proposed multiple waypoint navigation approach using Tabu search.

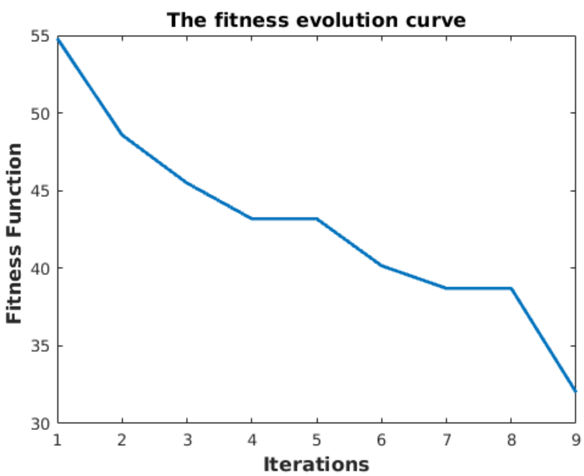

Fig. 3: Fitness evolution curve for 10 waypoints

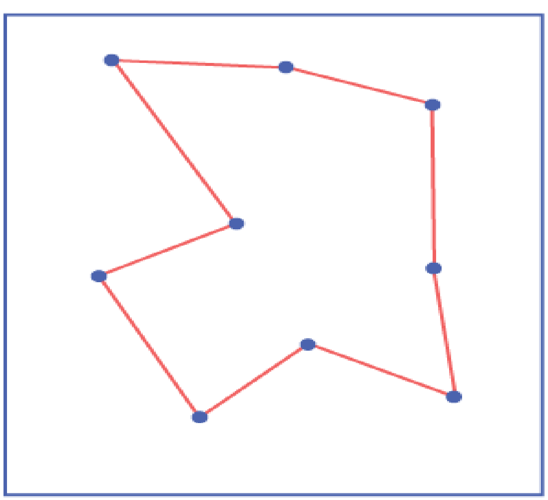

Fig. 4: Tabu search algorithm for TSP applied in a 9-waypoint

IV. Navigation and Map Building

The designed model is tested with real-time concurrent multiple waypoint navigation and map building of a mobile robot for validating the effectiveness in an unknown environment (for the 9 waypoint problem). The initial path that is noted by the markers between the pair of targets is provided by the D* - Lite algorithm. The Vector Field Histogram algorithm helps in driving the robot along those markers. D*- Lite helps in path planning, thereby providing the best route between the waypoints. The 9 waypoint problem statement which was simulated as shown in Fig. 5 is inhabited and populated with obstacles such as barrels, fences and barricades. Once the optimized route has been generated using the Tabu search approach, the GPS coordinates of the respective targets in latitude and longitude in a proper sequence of goals are then acquired by the global path planner as shown in Fig. 6. The autonomous vehicle finally returns to the starting point after it travels from the initial coordinate to each and every target, thereby generating a collision-less path by connecting the required number of waypoints with minimized distance. Thus, the multiple goal visit is accomplished successfully via the efficient Tabu search algorithm.

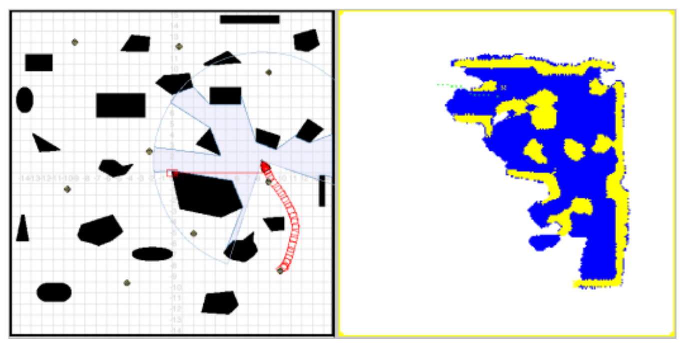

Fig. 5: Simulation of robot in an unknown environment with 9 waypoints accomplished by Tabu Search based TSP model (depicts early stage of traversal). (Left): The environment with obstacles and 9 waypoints; (Right): Constructed map.

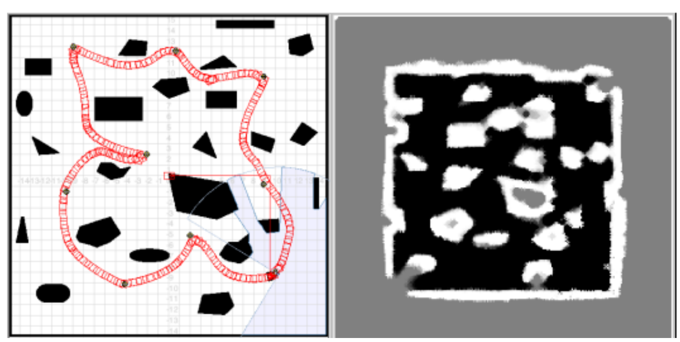

Fig. 6: Simulation of robot in an unknown environment with 9 waypoints accomplished by Tabu Search based TSP model (depicts final stage of traversal). (Left): The environment with obstacles and 9 waypoints; (Right): Constructed map.

V. Conclusions

A solution by Tabu Search approach for multiple waypoint motion path planning is presented in this paper for real time map construction and navigation. This paper incorporates an effective approach using D*-Lite algorithm that is integrated with local LIDAR - based navigation methodology (VFH) for multiple way point path planning. The D*-Lite algorithm provided VFH with necessary intermediate goals. The multi-goal optimized route was thus calculated and planned by the proposed Tabu Search based multi-way point path planning approach. Results from simulation techniques and experimental study demonstrated effectively the benefits of local navigator in conjunction with a path planner to reach multiple goals with optimized distance.

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