Global path planning algorithm for mobile robots

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Abstract –**This research study presents a novel metaheuristic approach to solving the global path planning problem, which combines the search space separation capabilities of the Quad-tree method and optimization capabilities of the Harmony Search method. Results have shown that this approach is effective and gives accelerated convergence.**

Keywords – **metaheuristic algorithms, mobile robotics, optimization, global path planning.**

I. INTRODUCTION

The global path planning problem can be easily formulated as establishing a feasible route from a starting point to a destination point. On this route, a search agent might face obstacles in the searching environment, which need to be avoided, which leads to the fact that a collision-free path is crucial and necessary. This route, however, ought to be determined before the search agent has started it's travelling through this path. This means that one needs a certain effective algorithm to perform this task as fast as possible and it's recommended that the found solution is optimal. Since the nature of this problem is its NP-completeness, there have been several metaheuristic techniques applied to the global path planning. Although there were approaches that used completely metaheuristic algorithms, there were also research studies which utilized hybrid approaches, i.e. combination of deterministic and metaheuristic algorithms in order to obtain a technique which would provide desirable or near-optimal solutions.

The agents's navigation through the defined route can be divided into two sub-tasks, namely local and global path planning. This means that there's a part of the path planning approach, i.e. the local path planning, which deals with avoiding obstacles, acceleration, processing input data and other environmental dependent problems, whereas the global path planning issues the finding of an optimal route. The representation of the environment of interest for the search agent can be given as a real-world interpretation, or it can be discretized. There have been many researches that applied grid-based path planning, i.e. techniques that represented the search space as a two dimensional grid. This type of discretization is popular in path planning algorithms, as it can easily be manipulated by the algorithms utilized for its solving. Though this approach in real-world applications might not be satisfying, it is a crucial foundation for obtaining a path based on a priory provided data to the algorithm.

This paper presents a novel sophisticated approach to solving the path planning problem, namely the Quad Harmony Search algorithm. This metaheuristic algorithm has been accelerated by the popular quad-tree free space decomposition technique in order to divide the search space into smaller free space regions, which proved by our experimental results, gave great speed to the process of obtaining an optimal solution. In the end, we provide a detailed study of the effectiveness of the Quad Harmony Search algorithm.

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II. RELATED WORK

The global path planning problem is a popular topic that has been actively researched over the last several years. Most of these research studies involve using metaheuristic approaches, given they were purely metaheuristic or combined with other techniques as well. Also, one should emphasize that grid-based representations of the mobile robot's environment are explored thoroughly, so grid-based path planning plays a crucial role in solving today's real-world applications. Particular studies even use discretization of complex obstacles to a grid-based representation, which provided collision-free near optimal solutions as well [1].

Simulated annealing (SA) had been proposed as an algorithm in 1983. It is a well utilized metaheuristic algorithm which mimics the slow cooling appearing in the annealing process [2], analogous to the slow convergence and accepting more solutions. SA has been vastly used for path planning problems over the past years. Some research studies, referring to this algorithm, represented the robot's path by using a Voronoi diagram. A particular research used the Voronoi diagram to find a collision-free path by using Dijkstra's algorithm, thus utilizing this data to compute the best path by applying SA, satisfying the kinematic constraints [3]. Results have proved that this approach gives better results than the traditional SA algorithm [3]. SA has also been combined with other metaheuristic techniques in order to solve the path-planning problem for mobile robots. A concrete study used the genetic algorithm (GA) as an acceleration to the SA algorithm [4, 5]. Some researches presented that this hybrid approach of the GA and SA algorithms avoids premature convergence and gives better results [6]. In the end, there's a research paper stating that SA algorithm, used solely and compared to other metaheuristic techniques, was able to always find a solution and proved to be practical and effective, but compared to tabu search couldn't always find the shortest possible path [7].

Particle Swarm Optimization (PSO) [8] is an algorithm that is also one of the well utilized metaheuristic approaches, and it's based on imitating the social behaviors, where individual's capabilities are less valued than the global social interactions [9]. Global path planning has been previously solved by utilizing a quantum-behaved PSO algorithm (QPSO). Here, the robot's map between the initial and the end point is represented with coordinate system transferring. The algorithm has performed with accelerated convergence having no restrictions regarding the shapes of the obstacles [10]. In the past several years, there have been also many hybrid approaches which combined the PSO algorithm with other metaheuristic algorithms. These approaches have proven their efficiency through several experimental studies. One of them is the hybrid GA-PSO algorithm, which used the genetic algorithm as an acceleration to the existing PSO algorithm. This algorithm applied the mutations and crossover operators on the generated results from the particles. After finding a feasible route, a cubic B-spline technique is utilized to produce a smoother and better solution. This method has avoided the drawbacks of an early convergence, which is typical for these metaheuristic algorithms when used separately [11]. There had been also an orthogonal PSO algorithm, which included the orthogonal design operator to the simple PSO algorithm in order to avoid falling into local optima. Compared to the traditional PSO algorithm, this approach also gave more effective solutions [12]. When the path space model of the mobile robot is transformed by decomposition of the two-dimensional representation of the route, pairs of particles are capable of exchanging information for the crossover operator. This led to avoiding falling into local optima and giving feasible and reasonable solutions [13]. Very recent approaches took the path planning problem to four dimensions, thus defining the problem as a calculus of variation problem (CVP). Then, the solution to the CVP is effectively provided by applying the PSO algorithm [14].

The Ant Colony Optimization (ACO) algorithm is also a metaheuristic algorithm, which is inspired by the behavior of ants and their process of seeking food [15]. Hybrid approaches and implementations have been very popular, one of them being a combination of ACO and genetic algorithm (GA), referred to as smartPATH [16]. This concrete hybrid algorithm includes improvements of the ACO algorithm and modified crossover operator for the GA part of the algorithm, thus avoiding the inclination towards local minima. Results have shown that this algorithm performs much better that the standard ACO algorithm and also the Bellman-Ford method [16]. A Two-way ACO algorithm has been applied to the global path planning problem in a static environment, such that there are two ant tribes walking in opposite directions from starting and ending point [17]. The heuristic information was then gathered by the initial point, destination point and ants' movements [17]. An endpoint approximation method proved to give efficient results, which consisted of constantly moving the starting and ending point of the grid towards each other, so the convergence obtained an accelerated speed [18]. A type of ant colony system with potential field heuristics provided effective construction of the robot's path planning and avoidance of environmental obstacles [19]. In a late research study, cellular ant colony algorithm consisted of two ant colonies running with different strategies [20]. Then, these paths were evolved by using cellular rules, so the ants could jump to the region which leaded to the solution, thus resulting in a more stable algorithm [20]. A Best-Worst ant colony method also improved the searching processes significantly, and a Max-Min system for limiting the global pheromone intensity provided applicable solutions to the path planning problem [21].

Genetic algorithms (GA) is a technique which makes the best use of the search by implementing the concepts of natural evolution [22]. A combination of the Anytime Planning criteria and multi-resolution search spaces in the genetic algorithm resulted with several parallel evolutions, thus exchanging information between these parallel search threads about the low-cost solutions in the environment and improving the overall convergence [23]. Recent improved GA constituted of several optimizations to this algorithm. A hill-climbing method was firstly used to improve the mutation of the algorithm. Then, particle swarm optimization (PSO) was utilized to speed up convergence, and in the end an emulation takes place with float-point coding involved in the improved GA [24]. A dual population evolution with proportion threshold adaptation when having a fixed length binary path improved the capability of the algorithm to gravitate towards global optimal solutions and accelerated the convergence speed as well [25]. Introducing an adaptive local search operator and applying an orthogonal design method in the process of the initialization of the population and including intergenerational elite mechanism, also gave great accelerations compared to the original GA [26]. There have been research studies that implemented a hybrid of Artificial Potential Fields (APF) and GA, which uses the APF method to determine the collision-free area and avoid the environmental obstacles, and then it applies the fitness function of the GA accelerated by least-square curve fitting [27]. This combination has been applied to soccer robots' path planning and obtained effective results in terms of finding an optimal route [27].

III. Quad-Harmony Search Algorithm

This research paper presents a novel Quad-Harmony Search (QHS) algorithm which is effectively applied to the global path-planning problem. By using the Quad-tree free space decomposition algorithm, this algorithm splits the environmental data of the agent into four equally sized subgrids in a recursive manner, until it finds a single cell or an obstacle-free subgrid. In this phase, all of the free regions are labelled with proper numbers and treated as a single node later in the Harmony Search (HS) stage of the algorithm. The HS stage consists of applying the Harmony Search method [28] to find an optimal route, given the data provided from the Quad-tree stage of the algorithm. The search space of the agent is static and the agent is able to move in four different directions, namely labelled as up, right, down and left.

The QT stage of the algorithm used for the QHS is executed in the following manner:

1. Give the necessary discretized environmental data to the mobile robot as input.
2. Check if there is a single cell. If this is the case, determine whether it's a free rectangle or an obstacle. If it's empty, label it with a unique number. Otherwise, label it with -1.
3. Separate the current examined part of the environment into four equally sized regions.
4. Explore these regions and check if they are obstacle-free.

a. When all of the regions are obstacle-free, label them with the same unique number.

b. When two adjacent regions are obstacle free, label them with the same unique number and repeat the recursion steps from Step 2.

c. When 4.a) and 4.b) result with a false outcome, repeat the recursion steps for all of the regions from Step 2.

The results from the QT stage of the algorithm are fed as input to the Harmony Search stage of the QHS algorithm. Here, the input is used to construct an adjacency list which should be used for the graph search of the algorithm. Then, these data are utilized for the purposes of the fitness function of the HS algorithm. The value of the fitness function is then computed as follows:

1. **Initialization.** Set the start node of the algorithm to the initial point of search of the mobile robot. Set this node as the current node.

2. **Adjacent nodes search.** Examine the current node and check for its label:

a. When the current node is the final node, terminate and exit with success. Otherwise, continue to step 2.b.

b. Examine the adjacent nodes of the current node. The next node to be selected is the node generated as the random value by the one present in the current value (member) of the candidate vector, modulus the maximum number of labelled rectangle areas. This number is the index of the node in the adjacency list of the current node and it belongs to the domain of numbers given by [1; *maxRectangles*], where *maxRectangles* is the largest unique number generated by the QT stage of the algorithm.

c. Set the randomly selected node as the current node. Increase the returning value of the fitness function by a predefined value. Repeat Step 2 for this particular node.

Hence, the mathematical formulation of the fitness function would be interpreted as follows:

$$f(.) = \sum_{g \in G} NodeCost(g)\,, \tag{1}$$

where g is the current examined node, G is the domain set of the g node, and *NodeCost(g)* stands for the cost of the g node related to its position compared to the destination point, defined in the following manner:

$$NodeCost(g) = \begin{cases} 1, & g \text{ is before the destination node} \\ 0, & g \text{ is a destination node, or is after the destination node} \end{cases} . \tag{2}$$

For the purposes of our research, several types of grids were tested by using the QHS technique. These grids had sizes of 32x32, 64x64 and 128x128, and they had 10%-90% percentage of obstacles. These results from the QHS algorithm were then compared to other two metaheuristic approaches, namely the Ant Colony Optimization (ACO) and Genetic Algorithm (GA). Results from this research are detailed and presented in Fig. 1, Fig. 2 and Fig. 3 for the grid sizes of 32x32, 64x64 and 128x128 respectively. As it can be clearly seen, the QHS algorithm has performed with great acceleration in convergence compared to other metaheuristic approaches. The GA needed a lot more iterations to converge, and always found only a local optima, i.e. it always found little variations of the first obtained feasible path, whereas the ACO algorithm always found a global optima, but needed more iterations to provide an optimal solution. This makes QHS algorithm the right choice for the global path planning problem of a search agent.

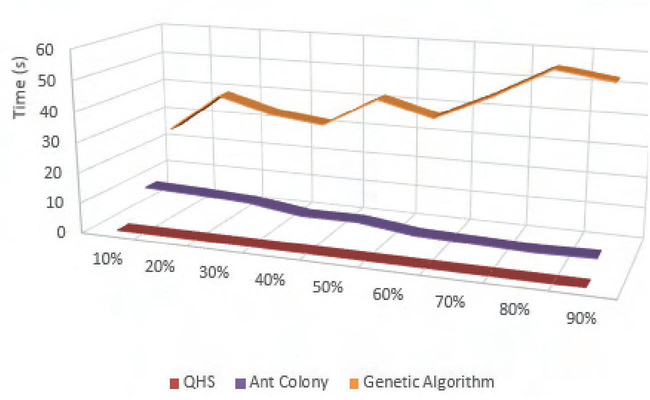

Fig. 1. Comparison of QHS, Ant Colony and Genetic Algorithm for 32x32 grid sizes.

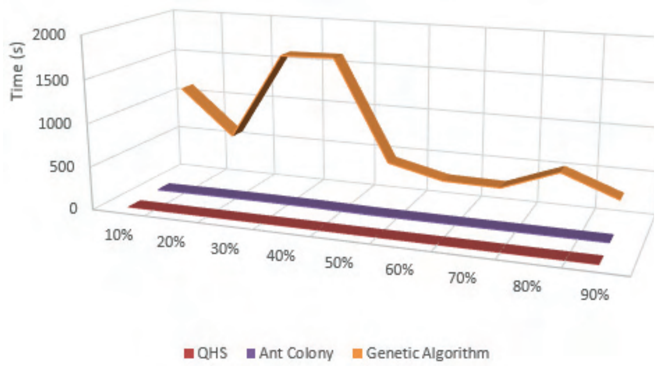

Fig. 2. Comparison of QHS, Ant Colony and Genetic Algorithm for 64x64 grid sizes.

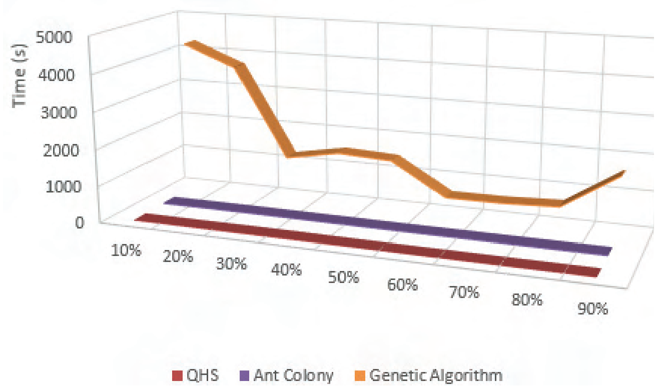

Fig. 3. Comparison of QHS, Ant Colony and Genetic Algorithm for 128x128 grid sizes.

IV. Conclusion

This paper presented a novel metaheuristic approach to solving the global path planning problem, namely the QHS algorithm. This algorithm was founded on the effective search space division capabilities of the Quad-tree algorithm and the optimization capabilities of the Harmony Search algorithm. Different grid sizes and different percentages of obstacles have been examined and experimental results have been elaborated. This research has shown that this algorithm performs better than other metaheuristic methods, namely the ACO and GA algorithms in terms of time and acceleration of convergence. Hence, this algorithm is a great foundation for further researches in the field of metaheuristic algorithms applied to NP-complete problems, such as the global path planning problem detailed in this paper.

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