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A hybridization of an improved particle swarm optimization and gravitational search algorithm for multi-robot path planning

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ABSTRACT

This paper proposed a new methodology to determine the optimal trajectory of the path for multi-robot in a clutter environment using hybridization of improved particle swarm optimization (IPSO) with an improved gravitational search algorithm (IGSA). The proposed approach embedded the social essence of IPSO with motion mechanism of IGSA. The proposed hybridization IPSO–IGSA maintain the efficient balance between exploration and exploitation because of adopting co-evolutionary techniques to update the IGSA acceleration and particle positions with IPSO velocity simultaneously. The objective of the algorithm is to minimize the maximum path length that corresponds to minimize the arrival time of all robots to their respective destination in the environment. The robot on the team make independent decisions, coordinate, and cooperate with each other to determine the next positions from their current position in the world map using proposed hybrid IPSO–IGSA. Finally the analytical and experimental results of the multi-robot path planning were compared to those obtained by IPSO–IGSA, IPSO, IGSA in a similar environment. The Simulation and the Khepera environment result show outperforms of IPSO–IGSA as compared with IPSO and IGSA with respect to optimize the path length from predefine initial position to designation position ,energy optimization in the terms of number of turn and arrival time.

1. Introduction

The Path planning problem in mobile robotics is considered as a complex task. It has studied from the paper [8] that work determines a path for the robot to reach in predefined goal location from a specified starting location without hitting with various obstacles in the given Environment. The path planning problem has been classified into different categories. One of the classifications is static and dynamic path planning based on the environmental information. In the static path planning, the obstacles and goals are motionless. But, in the dynamic path planning the obstacles and goals are moving in the environment in each time and also the environment is changing in every time. Another classification is local and global path planning. Robot navigates through the obstacles by steps and determines its next position to reach at the goal by satisfying constraints like path, time and energy-optimality [1–7] with the help of the local path planning scheme. In global planning, the robot decides the entire collision free path before its movement towards the goal from a specified initial position. The above mentioned global planning is termed as *offline planning* [32]. Local path-planning, which includes navigation and online planning, sometimes referred to as navigation only in the literature. The phrase motion planning that includes the notion of time with the position of a robot on a planned trajectory, is often used in the context of path-planning. Motion planning thus takes care of planning the path with some resource management or constraints over time. In the last decades, Significant progress has been made on a single robot and multi-robot in motion planning [11,13,15] by using of some traditional and heuristic approaches such as potential field method [14], visibility graph-based, Voronoi-diagram [31], real time A* algorithm [8,9,19], Simulated Annealing and neural network [10] and evolutionary [16,17] algorithms. But, in the classical approach needs more time complexity in large problem space and trapping in local optimum are drawbacks. Therefore, solving these problems using classical approach is impractical. Hence heuristic algorithms have become more popular to solve optimization problem. Heuristic algorithms maintain a good balance between diversification and intensification to achieve both efficient global and local search. Therefore, authors have consented on solving multi-robot optimization problem using heuristic algorithms. In a multi-robot path planning problem, each robot has a specified initial and goal position in a given environment and each robot have to plan their

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collision free path without hitting any of the colleagues or obstacles present in the map through offline or online approach. The obstacles present in the environment may be static or dynamic. However, in this paper we have considered static obstacles in the given environment for the robots and robot is treated as dynamic obstacles for other robots. The path planning problem for multi-robot can be solved by two different approaches such as centralized or distributed approach. The cost or objective function and the constraints for computing the path for all the robots are considered together in the centralized approach [16,17]. Whereas, in the distributed planning [22], each robot determined its collision free trajectory path towards the goal independently without making collision with static obstacles or colleagues. The multi-robot navigational problem has divided into two smaller problems such as velocity planning and path planning. In the first phase, each robot constructs the individual path by satisfying the optimum path for each robot. In the velocity planning, each robot avoids the collision with obstacles and the teammates. In our study, we have proposed a novel meta-heuristic optimization approach to carry out the multi-robot navigational problem. Different meta-heuristic optimization algorithms have been used to generate the optimum trajectory collision free for each robot.

Particle swarm optimization (PSO) with mutation operator [49] has been used to develop an algorithm for path planning for a mobile robot. Multi-objective optimization problem has formulated for obstacle avoidance in a dynamic environment and solved it by PSO [50]. An algorithm for robot path planning has developed using PSO of Ferguson Splines [51]. A smooth path planning of a mobile robot has solved using stochastic PSO [52]. In [21] multi-objective PSO-and NPSO based algorithms for robot path planning. In [57] PSO is used in an obstacle avoidance scenario in which robots are meant to navigate between static and dynamic obstacles. In [53–56] Area Extension PSO (AEPSO) and Cooperative AEPSO (CAEPSO) are employed as navigators of a swarm of robots in dynamic and static environments. AEPSO and CAEPSO take advantage from macro scoping modelling of PSO in addition to extra heuristics that utilize concepts such as reinforcement learning and cooperative learning. Multi-objective particle swarm optimization (MPSO) has been used to solve the path planning problem under uncertainty to minimize the path length and risk degree [20]. In [43] used two multi-objective path planning models to find a safe path by minimizing the energy consumption. A stochastic path planning scheme has been proposed [44] for a mobile robot to find safety and smooth path. Multi-objective PSO with self-adaptive mutation operation has been proposed [45] to solve the path planning problem in an environment with obstacles and danger source. A PSO used endocrine regulation mechanism [46] to update the particle behaviors by the interaction of neural and endocrine systems and reduced the local convergence with help of momentum factor has been utilized to plan a robot path. Binary PSO [47] has been proposed to find the global optimal path and a path is encoded with some vertices of the polygon type's obstacle present in the environment. Similarly, a PSO has embedded with potential field's approach [48] to update particles and avoid the obstacles with the help of potential field method. Gravitational search algorithm (GSA) and on a particle swarm optimization (PSO) algorithm applied to multiple mobile robot on holonomic wheeled platforms [58]. Dijkstra algorithm and bat algorithm [68] has been proposed to find the global optimal path. Cuckoo search (CS) algorithm has been applied for mobile robot path planning in an unknown or partially known environment with variety of static obstacles [69]. The different intelligent algorithm had also been used to solve robot path planning such as memetic algorithm [63,70], culture algorithms [64], biogeography particle swarm optimization algorithm (BPSO) [65]. Glowworm Swarm Optimisation (GSO) [66] has been used to solve multiple source localisation tasks through real robot experiments and GSO [67] has also been used for pursuing multiple mobile targets using single and two source cases. Firefly algorithm (FA) [71] has been proposed for solving the path planning problem by improving the solution quality and convergence speed. Multi-robot path planning problem is well known for optimisation problem, recently, so many swarm intelligence algorithms have been proposed to solve multi-constrained problem such as grey wolf optimizer (GWO) [72], chicken swarm optimisation (CSO) [73], krill herd (KH) [74], monarch butterfly algorithm (MBA) [75]. These algorithms are inspired by swarm behaviour of grey wolves, chicken, krill, and butterfly, respectively. Gravitational search algorithm (GSA) based approach has been applied for generating an optimal path for a robot travelling in partially unknown environments in the presence of multiple (static or dynamic) obstacles [30]. Path planning of Uninhabited Aerial Vehicle has been solved using improved GSA [59]. Differential Evolution (DE) [17] has used for multi-robot navigation in a static environment and performance of the algorithm has used for minimizing the path length. Hybridization of meta-heuristic algorithms such as ACO-GA [32], PSO–GSA [33], and Hybrid Evolutionary Algorithm Based on Tree Structure Encoding [34] has been solved for multi-robot path planning. However, we have hybridized improved PSO (IPSO) and IGSA for better performance with respect to IPSO [24,27] and IGSA.

However, PSO suffers from premature convergence in the evolutionary process while dealing with complex problems such as some real world navigation based optimization problem like the solution of path planning in multi-robot. PSO also depends on users to tune control parameters such as inertia weight, social and cognitive coefficients and velocity clamping in order to achieve the required solution. For instance, as iteration increase the initial weight in PSO is mostly decreasing linearly from 0.9 to 0.4 in order to emphasize on the exploitation. However, there is no mechanism for significant hasty movements in the search space for PSO and this makes the poor performance of PSO [61]. Therefore, the structure of PSO algorithm needs further improvement for achieving an optimal solution to the real world problems. GSA is one of the meta-heuristic algorithms, which is based on the law of gravity and mass interaction, and implements law of motion and Newtonian gravity. The advantages of GSA are (1) easy to implement with higher computational efficiency; (2) few parameters to adjust, but the disadvantages of this algorithm as follow (1) if premature convergence occurs, there will not be any recovery for this algorithm; (2) the algorithm loses its ability to explore and then becomes inactive only after becoming convergence [62]. Due to the above difficulties in GSA, further improvements are required for the optimal solution to the complex problem. The main idea of hybridizing of improved PSO and GSA to integrate the ability of exploitation in PSO and exploration in GSA to produce both algorithms' strength [60]. Therefore, authors motivated to hybrid the improved PSO and GSA for maintaining a good balance between diversification and intensification to achieve global optima.

The above proposed work has been focused on the minimizing the path length of the mobile robot and not considered the path deviation and energy consumption as a key factor. In this work, we have focused on the minimizing the path cost, path deviation and energy consumption for each robot with the help of the proposed algorithm. This paper contributes to establish a novel optimization algorithm by a hybrid of IPSO and IGSA. The main idea of this hybridization is to embed the social and cognitive behavior of IPSO with the Newtonian gravity concept of IGSA by co-evolutionary techniques. Then, this novel hybrid improved particle swarm optimization and improved gravitational search algorithm (IPSO–IGSA) is proposed to solve the multi-robot path planning in a cluster environment, where some of the obstacles are static and