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A dynamic priority based path planning for cooperation of multiple mobile robots in formation forming

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ABSTRACT

Robots that work in a proper formation show several advantages compared to a single complex robot, such as a reduced cost, robustness, efficiency and improved performance. Existing researches focused on the method of keeping the formation shape during the motion, but usually neglect collision constraints or assume a simplified model of obstacles. This paper investigates the path planning of forming a target robot formation in a clutter environment containing unknown obstacles. The contribution lies in proposing an efficient path planner for the multiple mobile robots to achieve their goals through the clutter environment and developing a dynamic priority strategy for cooperation of robots in forming the target formation. A multirobot system is set up to verify the proposed method of robot path planning. Simulations and experiments results demonstrate that the proposed method can successfully address the collision avoidance problem as well as the formation forming problem.

1. Introduction

Cooperation of multiple robots system has drawn great interest of robotic communication for recent two decades [1,2]. In many multirobot applications, robots are required to form specific formations to accomplish complex tasks such as transportation of large awkward objects, reconnaissance, pursuit task and assemble task, etc. In [3], a group of mobile robots form a specified formation to transport an object, which is overweight for a single one robot. In [4], a group of agents form a hybrid formation to pursue and capture a group of evaders. In [5], cooperative formations among multiple mobile robots are proposed for an inspection task. In [6], some interactive seats can quickly form several rows of seats for a seminar or a conference in library. In automated highway system (AHS) [7], the throughput of the transportation network can be greatly increased if vehicles can form a formation at a desired velocity while keeping a specified distance between vehicles.

Existing work in robot formation focuses on analyzing the formation behavior under certain control laws, along with stability analysis [8–10]. In [11], a decentralized formation controller is designed, and accordingly the associated formation stability is analyzed. In [12], a control law is developed to build and keep a desired formation, where prescribed reference paths are provided. In [13], a synchronization approach to maintain a time-varying formation of multiple mobile robots is proposed, but the collision constraint is neglected. Recently, a control scheme with obstacle avoidance is presented for mobile robot formation, where the obstacles are considered as rectangles [14]. These works mentioned above pay much attention to the control laws of formation forming and maintenance, but usually assume an ideal fully known environment or simplified models of obstacles. This paper aims to address the problem of forming a target formation in an unknown clutter environment. Since the robot does not fully know the motions of other robots in the group, a path planner should be designed properly for collision avoidance as well as formation forming.

Many existing planners can generate optimal smooth trajectory, but assume a fully known environment or known trajectories of the moving objects [15,16]. As a result, they cannot be directly applied in the situation of multiple robots, when the motions of other robots are not available. Some path planners can dynamically change the generated path to avoid moving obstacles in the environment, e.g. a biologically inspired neural network approach in [17,18], where the generated path can locally deform for collision avoidance. This mechanism is similar to the method of "elastic bands" [19], which considers the generated path as a spring and deforms it for collision avoidance and changing environment. These methods can be applied in the situation of multiple robots. However, kinematics of the robot is difficult to consider in these methods, so a model of mass point is usually used alternatively. As a result, the generated path sometimes cannot be easily used by real robots, especially for those robots with nonholonomic kinematics. In contrast, some path planners

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can directly generate feasible paths for nonholonomic robots [20], but they are usually limited by long runtime for multiple robots. Recently, a popular rapid path planner is developed based on the algorithm of rapidly exploring random trees (RRT) [21]. It can run fast enough to replan a new path when the robot detects obstacles, and consider complicated kinematics in the path generation. Their applications can be found in multiple robot system, such as robot soccer [22]. However, these RRT-based path planners are usually applied to holonomic robots that have similar model of a mass point, so that the generated paths can be directly used [23]. In this paper, a improved RRT based path planner is developed for multiple mobile robots to form a target robot formation in a clutter unknown environment. The contributions lie in the following perspectives.

First, an improved RRT based path planner is developed for multiple mobile robots. Compared to existing RRT based path planners, the proposed one considers the kinematics of the mobile robot in the path generation. As a result, a feasible path for nonholonomic mobile robot can be generated [24], so that it can be directly used by the practical mobile robot online. Second, the path planner is applied for forming a target formation of a group of mobile robots, where the goal positions of these robots are assigned to form a target formation for specific use. A dynamic priority strategy is introduced to avoid the mutual collisions of the robots and cooperate the motion of the robots in forming the target formation. Compared to existing priority strategies [25–27], the motion conflict among the robots in approaching the formation is investigated, and proper priorities can be calculated dynamically during the motion. Third, a multiple mobile robots system is set up to verify the proposed path planning of forming a target formation. Simulation and experiment results prove that the proposed path planning method can address the cooperative motion of formation forming more efficiently than existing methods.

The remainder of this paper is organized as follows. Section 2 introduces the improved RRT based path planner for multiple mobile robots. In Section 3, a dynamic priority strategy is incorporated into the path planning of multiple robots to form a target robot formation. Simulations and experiments are performed in Sections 4 and 5, to demonstrate the effectiveness of the proposed path planning for forming a target formation. Finally, conclusions of this work are given in Section 6.

2. An improved RRT path planner for multiple mobile robots

Consider a group of mobile robots in an environment cluttered with obstacles, where only local surrounding information is available to each robot. The objective is to plan a collision-free path for each robot to reach its goal position to form a target formation, as shown in Fig. 1. Denote $A_1, A_2, \ldots, A_n$ as n mobile robots each with two driven wheels. The state of robot A_i is represented by $[x_i, y_i, \theta_i]^T$, where $i = 1, \ldots, n$ is the index of the robots, x_i and y_i denote the translational position coordinates of robot A_i, and θ_i denotes the orientation of robot A_i. Denote v_i as the linear velocity and w_i the angular velocity with respect to the mass center. The kinematics of robot A_i can be represented by a unicycle model as follows:

$$\dot{x}_i = v_i \cos\theta_i, \quad \dot{y}_i = v_i \sin\theta_i, \quad \dot{\theta}_i = w_i \tag{1}$$

where v_i and w_i are subjects to constraints of the velocity boundaries, denoted by V_{max} and W_{max}, respectively.

In the following, an improved rapidly exploring random trees (RRT) based path planner will be proposed for path planning of each robot online. RRT provides a single-shot, probabilistically complete planning method with fast runtime in searching high-dimensional configuration spaces, which can be well generalized to path planning of mobile robot.

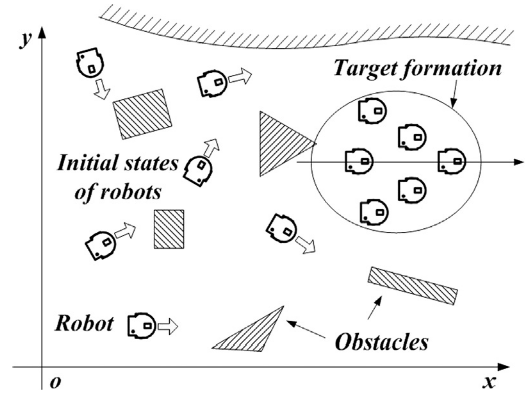

Fig. 1. Path planning for multiple robots in forming a target formation.

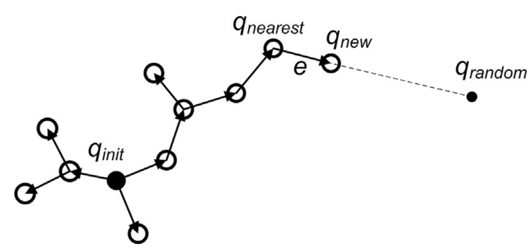

Fig. 2. Growth of a RRT tree.

2.1. Basic RRT

A basic RRT planning algorithm, starting from q_{init}, is shown in Fig. 2. The following steps are repeated until a valid path is found or the termination criterion is met. Consider a random point $q_{random} \in C$, where C denotes the configuration space. Its nearest neighbor, denoted by $q_{nearest}$, is selected according to a scalar metric $\rho(q_1, q_2) \rightarrow \Re$ defined on C, where $\rho(q_1, q_2)$ specifies the distance between two general points q_1 and q_2, and $\Re$ denotes the distance based on C. Then, an edge denoted by e is generated, which extends from $q_{nearest}$ towards q_{random}. If e lies in the free configuration space denoted by C_{free}, add the edge e into the tree and also, insert the terminal point of the edge, denoted by q_{new}, into the tree as a child of $q_{nearest}$, as shown in Fig. 2. The basic RRT algorithm chooses $q_{random} \in C$ uniformly throughout the space, which builds a tree T to explore the free configuration space C_{free}. To reach a goal position q_{goal} in the path planning, RRT-GoalBias [19] modifies the basic RRT algorithm by making the selection of q_{random} bimodal. That is, choose the goal location q_{goal} with probability p, and choose a point uniformly from the configuration space with probability $1-p$.

2.2. Improved RRT path planner

Most of existing RRT path planners consider a mass point model of the robot for short runtime. Therefore, the generated path can only be directly used by a holonomic mobile robot. In the following, an improved RRT path planner will be proposed that considers kinematics model of the robot.

In the RRT algorithm, the path segment from $q_{nearest} = [x_{near}, y_{near}, \theta_{near}]^T$ to $q_{new} = [x_{new}, y_{new}, \theta_{new}]$ is generated, when the RRT tree is extended from $q_{nearest}$ towards the random position $q_{random} = [x_{random}, y_{random}]^T$, as shown in Fig. 2. Consider the kinematics in (1), the state q_{new} should be achieved from the state $q_{nearest}$ by the mobile robot. Denote v_{extend} and w_{extend} as velocities