FORMATION DRIVING USING PARTICLE SWARM OPTIMIZATION AND REACTIVE OBSTACLE AVOIDANCE

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Abstract:
This paper presents a new leader following approach for a formation of carlike robots. The path planning problem is solved for the leader with optimized spline functions, which are generated by an evolutionary technique called particle swarm optimization. Because of the expansion of the formation, a collision free path is not guaranteed for the following vehicles. In our approach the followers reactively avoid collisions with path-blocking obstacles and also with other robots within the formation. The developed algorithms have been tested intensively in various simulations.

Keywords: multi robot, formation driving, leader following, carlike robots, obstacle avoidance, path planning, particle swarm optimization

1. INTRODUCTION

Formation driving is one of the big topics related to cooperating mobile robots and has been well studied during the last years. It can be used i.e. for cooperative search tasks, collective agrarian harvesting or military maneuvers. Due to the restriction of their steering angle which prevents carlike robots from being able to turn on the spot, only very few results can be effectively used for this group of robots. This paper introduces a method which allows the coordination of a group of carlike robots that maintain a predefined formation and move through an obstacle filled environment. Literature mentions mainly three approaches which are used to coordinate a formation of mobile robots: *Virtual Structures* (Kar-Han and Lewis, 1996; Belta and Kumar, 2004), *Behavioral* (Balch and Arkin, 1998; Reynolds, 1987; Elkaim and Siegel, 2005) and *Leader-Following* (Desai *et al.*, 2001; Barfoot and Clark, 2004).

In the Leader Following approach, one robot normally is dedicated to be the leading vehicle of the formation and the remaining form the group of followers. During the formation driving the control inputs of these robots are usually based on the position and the orientation of a reference point which can be for example the leading vehicle (Desai *et al.*, 2001; Gustavi *et al.*, 2005). The needed information is often transferred from the leader or a control center to the followers (Das *et al.*, 2002; Barfoot and Clark, 2004) or it is estimated via obtained sensor data (Fredslund and Mataric, 2002; Fujimori *et al.*, 2005). In contrast to the other approaches, Leader Following provides easy control of the overall group behavior of the formation and thus is well suited for obstacle avoiding formation driving of carlike robots in simulation and in real environments (Hess, 2005).

In this paper an approach based on leader following is presented which allows a group of mobile robots to move in formation through an environment that includes nearly arbitrary obstacles. It is assumed that the leading vehicle is driving on an obstacle free trajectory which is achieved by pre-planning an optimized trajectory with the help of evolutionary methods. Many different algorithms for obstacle avoidance previously have been mentioned in literature (Latombe, 1996; Borenstein and Koren, 1991; Meng and Picton, 1992). Unfortunately, most of the methods cannot be used for formation driving, because in this special case new problems arise: The optimal path needs to be smooth (the minimal radius depends on the shape of the formation) and the distance to the obstacles must be big enough for the formation. Therefore a novel approach was developed, which uses Particle Swarm Optimization (PSO) (Macas *et al.*, 2006) of splines.

In Section 2 it is explained how an optimized trajectory is computed with the help of PSO. Section 3 contains the main aspects of our novel formation driving approach for carlike robots in an obstacle containing environment. After this in Section 4 the results of various accomplished simulations are presented followed by concluding words and plans for future work in Section 5.

2. TRAJECTORY PLANNING

2.1 Particle Swarm Optimization

The PSO is an optimization method developed for finding a global optima of some nonlinear functions (Kennedy and Eberhart, 1995). It has been inspired by the social behavior of birds and fish. Thus the method applies the problem solving in groups. Each solution consists of a set of parameters and represents a point in the multidimensional space. The solution is called a "particle" and the group of particles (population) is called a "swarm".

Two kinds of information are available to the particles. The first one is their own experience, which results out of the assessed possibilities - they know which state has been best so far and also how good it was. The other information is social knowledge - the particles know how the individuals in their neighborhood have performed.

Each particle i is represented as a D-dimensional position vector $\vec{x}_i(t)$, which has a corresponding instantaneous velocity vector $\vec{v}_i(t)$. Furthermore, it remembers it's individual best value of the fitness function and also the position $\vec{p}_i$ where this value results from.

During each iteration t, the velocity update rule (1) is applied on each particle in the swarm. p_g represents the social knowledge as it is the best position of the entire swarm.

$$\begin{aligned}\vec{v}_i(t) = w\vec{v}_i(t-1) \\ + \Phi_1(\vec{p}_i - \vec{x}_i(t-1)) \\ + \Phi_2(\vec{p}_g - \vec{x}_i(t-1))\end{aligned} \qquad (1)$$

The parameter w is called the inertia weight, which decreases linearly from w_{start} to w_{end} during the whole iteration process. Φ_1 and Φ_2 are diagonal matrices weighted φ_i, which consist of random numbers drawn from a uniform distribution between 0 and 1.

In the next step the position update rule (2) is applied.

$$\vec{x}_i(t) = \vec{x}_i(t-1) + \vec{v}_i(t) \qquad (2)$$

If any component of $\vec{v}_i$ is less than $-V_{max}$ or greater than $+V_{max}$, the corresponding value is replaced by $-V_{max}$ or $+V_{max}$ respectively. So V_{max} is the maximum velocity parameter.

The update formulas (1) and (2) are applied during each iteration and p_i and p_g are updated simultaneously. The algorithm stops if the maximum number of iterations is achieved or any other stopping criterion is satisfied.

2.2 Particle description

The problem of path planning for a carlike robot can be realized through a search in the space of functions. This space is reduced to a subspace, which only contains strings of cubic splines. Splines are natural for robot movements (Ye and Qu, 1999), they are easy to implement and could be smoothly connected together. The mathematical notation of a spline in 2D space could be:

$$\begin{aligned}f(t) = a_x t^3 - b_x t^2 + c_x t + d_x \\ g(t) = a_y t^3 - b_y t^2 + c_y t + d_y\end{aligned} \qquad (3)$$

where a, b, c, d are constants defined by

$$\begin{aligned}a &= 2P_0 - 2P_1 + P_0' + P_1' \\ b &= -3P_0 + 32P_1 - 2P_0' - P_1' \\ c &= P_0' \\ d &= P_1' \quad .\end{aligned} \qquad (4)$$

Parameter t is in interval $(0, 1)$. P_i and P_i' are vectors that define the spline in space. According to these equations each spline is defined only by points P_0 (starting point), P_1 (final point) and the tangent vectors P_0', P_1'. To guarantee continuity in the whole path, every two neighboring splines in the string share one of their terminal points. The total number of variables that define the whole trajectory in 2D is therefore only $4(n-1)$, where n is the number of splines in the string. The structure of the particles that were used for the optimization process is shown in Fig. 1.

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