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The Path-Based Control Method

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Abstract

In this article, recent advances in the path-based control method will be reviewed. The path-based control method is not a systematic structuring method but is the focus of research in many field, especially in artificial intelligence, information communication, and graphics. This article starts with a historical review, and then discusses some typical problems. The recent advances in the path-based control method are reviewed and it has recognized the application of path planning method as the core proposition. Finally, future work is also discussed to explore the possible basic framework system.

Keywords

Path-based control method, path planning.

1. Introduction

Countless lines together form the three-dimensional world. In complex experimental environments, the introduction of the definition of line often makes the results of the experiment more specific. Therefore, path-based control method is always the focus of research in many fields, especially in artificial intelligence, information communication, and graphics. The purpose of this article is to provide an overview of the recent research advances of the path-based control method and explore the possible basic framework system of it. Although it is a method dating back to the early nineties, which was designed to guide the robot, with the need to address growing environmental information, it is widely applied, especially for the problems needing path planning.

This review article will describe a brief history of the path-based control method first. And then, a considerably complete description of typical problem and research trends of the path-based control method will be provided. Finally, we shall discuss the future possible research directions and technologies for it.

2. Background of the Path-Based Control Method

In the early 1990s, many scholars began to study the path planning of robot motion. In particular, Dahl proposed a path tracking method for flexible robots in 1991 [1] and realized its path constraint control in the second year [2]. Inspired by him, Tarn [3] proposed a path-based approach and then provided a natural reference frame for integrating robot planning and control system with the sensory information. However, Tarn's approach is essentially to achieve planning and control through event triggering and feedback mechanisms, and does not use the path-based control as the core research object. In 2006, Cao [4] applied the path pattern and host patch to build a access control model based on the paths of history, but his definition of the path was still a virtual data value and did not take any control strategies on the path information. It was not until 2007 that the path-based control method was first applied with visible effect by Kim [5]. Kim introduced a novel path manifold into the study of motion

controller for wheeled mobile robots. It asymptotically converged the robot to an arbitrarily small neighborhood of the path manifold and provided precise regional path control.

The path-based control method is not in fact a systematic structuring method. In different fields of research, its form of expression is also very different. In general, the path-based control method is the method that directly or indirectly influence the trend of the model object based on the trend of the directed path or the trend of the value of the undirected path attribute.

3. The Typical Path-Based Control Problems

There are many problems related to path-based control. In general, the main research focuses on artificial intelligence, network topology constraints and fluid simulation in the field of computer graphics. The following article will be discussed based on some of the existing topics, such as robot motion control, network information transmission topology optimization and fluid control simulation. However, these problems do not exist in isolation. For example, the motion signal transmission of robots also involves the problem of network topology.

3.1. Robot Motion Control

The robot motion control problem may be the most intuitive one of the path-based control problems, because every constraint added to the motion path can be reflected in the real scene. Although the most basic path control has been gradually improved in early research, it is still the most classic case for our research on path-based control methods [5].

3.2. Network Information Transmission Topology Optimization

The shortest path problem is the most common research object of network topology constraints, which is the solution of the minimum transmission distance between different network nodes. When the network changes from a tree structure to a mesh structure, the transmission path changes from undirected to directed, and the node attribute changes from no weight to weight, the difficulty of solving the shortest path problem will increase exponentially. At this time, how to make information transmission on each node of the network in complex logical constraints is the research content of the path control method. Berggren [6] first proposed a path-gain-based constraint for power control to solve the weight problem in ALOHA networks. And the energy-saving topology control algorithms named LSP (local shortest path) and RLSP (restricted local shortest path) proposed by Shen [7, 8] have effectively reduced the transmission power and the energy consumption during transmission.

Another important research object of network topology constraints is the multi-path routing algorithm. It implements the path control from the routing perspective to reduce network congestion. A typical representative is the application of ACMRA (admission control and multi-path routing algorithm) proposed by Farooq [9].

3.3. Fluid Deformation Control

The idea of using paths to control fluid simulation was first proposed by Kim [10]. By using a linear feedback loop to control the path, the velocity field obtained from the 3D flow simulation matched the target velocity field and the smoke was driven to move following with the default 3D curve. The particle-based target-driven control method proposed by Madill [11] has been widely concerned, and the relationship between the source control example and the target control particle also tends to correspond spatially. According to this correspondence, the point-to-point path constraint becomes a possibility. It may be a new research direction to indirectly control the fluid deformation by forming the force field by the path constraint.

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4. Research Trends of the Path-Based Control Method

In recent years, as people's understanding and research on path-based control method deepen, path planning has been recognized as the core proposition. Path planning is one of the main research contents of motion planning. The sequence points or curves connecting the starting point and the ending position are called paths, and path planning is the strategy that constitutes the path [12]. In short, any planning problem that can be topologically a point-line network can basically be solved by path planning.

According to the retrieval ability of the surrounding environmental information, scholars divided the path planning into two categories: global path planning and local path planning. Global path planning needs to master and configure all the environmental information, while the local path planning need not. It selectively acquires certain environmental information in a neighborhood by sensors, and then gives specific path constraints based on the location of the local map and its local obstacles. It should be noted that many methods suitable for global path planning can be improved for local path planning, and the methods applicable to the research of local path planning can also be promoted to the study of global path planning.

4.1. Local Path Planning

Local path planning is sometimes called path following (different from the path tracking in Graphics). The concept of path following was originally proposed by Willard [13] in 1981, but he only used it as a way to build a dynamic equilibrium model. In local path planning, the target point, which follows the control process, is on the path of the object's motion, and its distance from the object is usually a constant.

In the path following control process, it needs to be updated the path in real time with the intra-domain control strategy and the obstacle avoidance strategy. Typical local path planning algorithms include artificial potential field method, fuzzy logic algorithm, etc. Different algorithms of path following are applied according to the physical characteristics of the moving object and the environmental characteristics of the moving process. For example, Low [14] introduced GPS to map the robot's motion path to assist in stability adjustment for slip. This method does not directly apply environmental information to the forward path control, but used the back-stepping controller to compensate for the path following error. What’s more, the inverse optimal path-following control and the PID (proportional-integral-derivative) control in the wind’s reference frame were introduced into the traditional hovering method by Saiki [15], which inspired people's thinking about the coordinate system of path following. In addition, the bio-inspired neurodynamics are also used to provide environmental information for path control [16].

There are also some path following studies based on classical mechanics. For example, Syamsuddin [17] controlled the dynamic particles under the force field constructed by Bezier curve. With the steering force that best approximates the pre-set path, a large number of particles can be controlled to follow the desired path and form target model. Sun [18] introduced the angular velocity constraints into a fuzzy path planning algorithm and Wang [19] applied the vector field to the curved path following control process by combining the Lyapunov method and the BIBO (bounded input bounded output) stability.

Since the path following is essentially the processing and processing of environmental information, the classification, management and comprehensive application of data are important components of such research. Numerical methods such as integrals and differences are the most widely used. For example, Francis [20] applied the covariance matrix as the input of un-observability index in observability-based path-planning research. Satoh [21] applied the path integral analysis to the convergence analysis of SHJB (stochastic Hamilton-Jacobi-Bellman)

equation. The suboptimal feedback controller replaced the particular assumption necessary for the conventional method by iteratively obtained weighted path.

Another classic question in path following research is about autonomous driving. By combining the two common path planning methods for autonomous driving problems: artificial potential fields and optimal controllers, Rasekhipour [22] developed a predictive path-planning controller based on the potential field. In this method, different PFs can be flexibly considered for different obstacles and road structures. Recently, Wu [23] combined the strategies of NTSM (nonsingular terminal sliding mode) and ADRC (active disturbance rejection control) to solve the AGV (autonomous ground vehicle) path following control problem. It provided a new idea of using coordinate transformation to simplify path following problem.

4.2. Global Path Planning

The general path planning method includes at least three aspects: environment modeling, path search and path smoothing. But for the global path planning, there are more factors to consider. For example, Macek [24] presented a new navigation framework that not only had the process of a collision avoidance scheme but also applied the both global path planning and path following. In essence, global path planning is to promote the research method of local path planning from a single body to multiple bodies, and increase the contents and influence scope of environmental information. Therefore, the research object of global path planning is often related to local path planning. For example, based on the fuzzy logic control method, Zhang [25] proposed a formation path control method to expand the perception scope of individual unmanned ship and complete the collaborative tasks. Recently, Dirik [26] proposed a mobile robot path planning method based on IT2FIS (interval type-2 fuzzy inference system). Comparing with other information collection method, it showed using an overhead camera than traditional information collection method can provide higher efficiency when generating the path for a mobile robot.

There are also some algorithms specific for the global path planning problem. Such as ant colony algorithm, neural network algorithm and genetic algorithm. In past research, Wu [27] applied the GA (genetic algorithm) to achieve coordinated path planning for multiple AUVs (autonomous underwater vehicles) through simulations similar to Darwin's evolution. For the self-assembly path planning of swarm robots, Wei [28] proposed an intelligent control algorithm based on the CVT (centroidal Voronoi tessellation). It simplified each robot as a particle and neglected the collision among these particles for more precise path control. Recently, to solve the path planning problems of rescuing and coal exploring robot in three-dimensional space environment, a path planning method of rescuing and coal exploring robot based on the improved ant colony algorithm was proposed. After the simulation and test with MATLAB software, it showed the great improvement in search efficiency, decision-making ability and convergence performance [29].

5. Conclusion

In the above, we introduced the main research directions of the path-based control method. Because the types and quantities of environmental information of the research objects are very different, people often need to apply different path selection strategies and control algorithms. Although this is a professional manifestation, people always hope to achieve the integration of the basic methods to the greatest extent, which also reflects the current situation of the path-based control method is not systematic. To initiate this discussion, four main attributes are considered to constitute the basic framework of the path-based control method:

1. Independent coordinate system;
2. Parameterized extraction of obstacle data;

3. Global or local optimal solution selection strategy system;
4. Objects can be extended.

It is suspected that no many existing codes have considered these four attributes. The path-based method, as described in this article, have not as yet. But with further research on deep learning and adaptive methods, we can foresee it being able to do so in the relatively near future.

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