Research on trajectory optimization of control robot

Jun Wang, Weijuan Li, Rui Guo,Tong Wang, Huatao Zhang

Shandong Vocational College of Information Technology, Weifang 261041, China

Abstract: With the rapid development of robot technology, trajectory optimization has become an important research direction in the field of robot control. The aim of trajectory optimization is to find an optimal path that meets certain constraints to achieve efficient, safe and accurate robot movement. This paper first introduces the importance of trajectory optimization and its basic concepts, and then elaborates the main methods and technologies of trajectory optimization, including interpolation, search algorithm, optimization algorithm based on mathematical model, intelligent optimization algorithm and real-time trajectory optimization. Then, through the concrete case analysis and experimental verification, the effects and challenges of trajectory optimization in practical application are discussed. Finally, the practical application of trajectory optimization in robot control is demonstrated through case analysis, the research status and development trend of trajectory optimization are summarized, and the future research direction is prospected.

Keywords: Trajectory Optimization; Interpolation; Search Algorithm; Mathematical Model; Intelligent Optimization Algorithm

1. Introduction

Robot trajectory optimization is one of the important research directions in the field of robot control, which is of great significance for improving robot motion efficiency, reducing energy consumption and ensuring motion safety. With the continuous expansion and complexity of robot application scenarios, the importance of trajectory optimization technology is becoming increasingly prominent. In industrial automation, logistics and transportation, medical rehabilitation and other fields, robots need to carryout accurate and efficient trajectory planning and control. Therefore, trajectory optimization technology has become an important support for the development of robot technology. [1]

2. The basic concept and importance of trajectory optimization

2.1. Basic concept of trajectory optimization

Trajectory optimization refers to finding an optimal path that satisfies certain constraints through optimization algorithm in the case of given robot movement space and target position. Among them, the constraint conditions include the robot's dynamic characteristics, environmental obstacles, task requirements, etc. The goal of trajectory optimization is to make the robot have higher efficiency, lower energy consumption and better safety during movement.

Trajectory optimization usually involves the following key steps:

① Modeling: Establish the kinematics model and dynamics model of the robot to describe the motion law of the robot in three-dimensional space. [2]

② Set goals: according to the task requirements, set optimization goals, such as the shortest path, minimum energy consumption, highest efficiency, etc.

③ Constraint conditions: considering environmental obstacles, robot kinematics and dynamics constraints and other factors, set the constraints of the optimization problem.

2.2. Trajectory optimization has extremely important significance in the field of robot control, mainly reflected in the following aspects:

① Improve motion efficiency: By optimizing the motion trajectory of the robot, unnecessary paths and redundant actions can be reduced, thus improve the motion efficiency of the robot. In the fields of industrial automation, logistics and transportation, trajectory optimization can significantly improve production efficiency and reduce operating costs.

② Reduce energy consumption: The optimized trajectory can make the robot more energy efficient and reduce energy consumption during movement. This is especially important for robots that need to work continuously for a long time, which can effectively reduce maintenance costs and extend service life. The optimized trajectory can avoid obstacles and dangerous areas to ensure the safety of the robot during movement. In fields such as driverless cars and medical rehabilitation, trajectory optimization can significantly improve the safety and reliability of the system.

3. The main methods and technologies of trajectory optimization

3.1. Interpolation method

Interpolation method is a simple and intuitive trajectory optimization method, its basic idea is to obtain a smooth trajectory through interpolation operation when the starting point and end point are known. The characteristic of this algorithm is that it can complete the movement of elements while finding the insertion position. Because the movement of the element must be from back to front, the two operations can be combined to improve the efficiency of the algorithm. The performance of the insertion method depends on the choice of the initial path and the insertion strategy. Different initial paths and insertion strategies may lead to different optimization results. Interpolation is suitable for low speed, low precision control applications.

3.2. Search algorithms

Search algorithm is a trajectory optimization method based on heuristic search, is the key component of trajectory optimization, they are based on a certain search strategy and rules, in the solution space to find the trajectory that satisfies the specific objective function and constraints. Search algorithms usually have an explicit objective function for evaluating the quality of the solution. [3] The search algorithm gradually approximates the optimal solution through iterative steps. In each iteration, the algorithm updates the state of the solution based on the state of the current solution and the search strategy. The search algorithm can adapt to different application scenarios and constraints.

3.3. Optimization algorithm based on mathematical model

The optimization algorithm based on mathematical model is the traditional method of trajectory optimization. It converts the trajectory optimization problem into a mathematical optimization problem by establishing the kinematics model and the dynamics model of the robot, and then uses the mathematical optimization algorithm to solve the optimal trajectory. Common mathematical optimization algorithms include gradient descent method, Newton method, conjugate gradient method and soon. This kind of method has high accuracy and stability, but the calculation amount is large, and the ability to deal with complex environment and constraints is limited.

3.4. Intelligent optimization algorithm

Intelligent optimization algorithm is a research hotspot in the field of trajectory optimization in recent years. It uses artificial intelligence and machine learning technology to realize trajectory optimization by simulating evolution, learning and other processes in nature. [4] Common intelligent optimization algorithms include genetic algorithm, particle swarm algorithm, ant colony algorithm, etc. This kind of algorithm has strong global search ability and robustness, and is suitable for trajectory optimization problems under complex environment and constraints.

3.5. Real-time trajectory optimization

Real-time trajectory optimization refers to real-time trajectory optimization in the process of robot movement. It needs to constantly adjust and optimize the trajectory according to the real- time status and environmental changes of the robot. Real-time trajectory optimization is of great significance to improve the autonomy and adaptability of the robot. Common methods of real-time trajectory optimization include model predictive control, reinforcement learning, etc. This method can respond to the environment change in real time and realize the autonomous optimization and control of the robot. [5]

4. The research status and development trend of trajectory optimization

4.1. Research status

At present, the trajectory optimization technology has made remarkable progress. In terms of algorithms, a variety of efficient trajectory optimization algorithms have emerged, such as genetic algorithm, ant colony algorithm, simulated annealing algorithm and soon. In terms of application, trajectory optimization technology has been widely used in driverless cars, industrial automation, aerospace and other fields.

4.2. Development trend

In the future, trajectory optimization technology will show the following development trends:

① Application of deep learning in trajectory optimization: With the continuous development of deep learning technology, its application to trajectory optimization will become a research hotspot.

② Multi-robot collaborative trajectory optimization: With the wide application of multi-robot system, how to realize the collaborative trajectory optimization among multi-robots will become the focus of research. Through collaborative trajectory optimization technology, multi-robots can cooperate efficiently and accomplish tasks cooperatively.

5. The practical application of trajectory optimization in robot control

Trajectory optimization technology has a wide range of application prospects in the field of robot control. The following are some practical application cases:

① Driverless car: In the path planning of a driverless car, trajectory optimization technology can help the car avoid obstacles, reduce energy consumption and improve driving efficiency.

② Industrial automation: on the industrial automation production line, trajectory optimization technology can realize the rapid and accurate grasp and placement of the workpiece by the robot, and improve production efficiency. [6]

③ Medical rehabilitation: In the field of medical rehabilitation, trajectory optimization technology can help robots achieve accurate and smooth motion trajectories, and provide patients with safer and more comfortable rehabilitation services.

6. Conclusion

This paper introduces the basic concept, importance, main methods and techniques of trajectory optimization. The practical application of trajectory optimization in robot control is demonstrated through case analysis. In the future, with the continuous development of robot technology and the continuous expansion of application fields, trajectory optimization technology will face more challenges and opportunities. Future research will focus on improving the real-time and adaptive performance of trajectory optimization algorithms to meet the needs of more complex and diversified application scenarios.

References

[1] Kober, J., Bagnell, J. A., & Peters, J. (2013). Reinforcement learning in robotics: A survey. The International Journal of Robotics Research, 32(11), 1238-1274.

[2] Wang, L., & Li, J. (2020). An improved particle swarm optimization algorithm for robot trajectory planning with multiple objectives. Robotics and Autonomous Systems, 126, 103455.

[3] Betts, J. T. (2010). Practical methods for optimal control and estimation using nonlinear programming. SIAM.

[4] Betts, J. T. (1998). Survey of numerical methods for trajectory optimization. Journal of Guidance, Control, and Dynamics, 21(2), 193-207.

[5] Li, Z., & Wang, B. (2018). Trajectory optimization and control of Delta robots. Robotics and Computer-Integrated Manufacturing, 24(6), 1250-1262.

[6] Van den Berg, J., Patil, S., & Alterovitz, R. (2012). Motion planning under uncertainty using iterative local optimization in belief space. The International Journal of Robotics Research, 31(11-12), 1368-1382.

Project source:

This article is one of the phased research results of the 2023 Shandong Province Education Development Research Micro Project “Experimental Teaching Research on Unmanned Aerial Vehicle Majors Based on ‘Online+Offline’ and ‘Virtual+Reality’” (Project ID: FJ012).