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Technical Paper

Dual hierarchical genetic-optimal control: A new global optimal path planning method for robots

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ABSTRACT

A new two-stage analytical-evolutionary algorithm considering dynamic equations is presented to find global optimal path. The analytical method is based on the indirect open loop optimal control problem and the evolutionary method is based on genetic algorithm (GA). Initial solutions, as start points of optimal control problem, are generated by GA to be used by optimal control. Then, a new sub-optimal path is generated through optimal control. The cost function is calculated for every optimal solution and the best solutions are chosen for the next step. The obtained path is used by GA to produce new generation of start points. This process continues until the minimum cost value is achieved. In addition, a new GA operator is introduced to be compatible with optimal control. It is used to select the pair chromosomes for crossover. The proposed method eliminates the problem of optimal control (being trapped in locally optimal point) and problem of GA (lack of compatibility with analytical dynamic equations). Hence problem is formulated and verification is done by comparing the results with a recent work in this area. Furthermore effectiveness of the method is approved by a simulation study for spatial non-holonomic mobile manipulators through conventional optimal control and the new proposed algorithm.

1. Introduction

Although optimal path planning of robots has been developed recently, but still there is not a comprehensive algorithm for finding the global optimal path. Optimal path planning algorithms are classified as below: evolutionary and analytical, but both of them have some problems. In the first group, there is no need for gradients of cost function. The optimal path is found by generating random points all over the possible search area, comparing value of cost function in these points and then selecting the best set of points. Random search techniques like annealing simulated, genetic algorithm and neural network methods [1,2] are in this category. In the second group, the analytical gradients of cost function are used for the optimization process. The dynamic programming [3], direct optimal control [4,5], Taylor series complex expansion [6] and indirect open loop optimal control [7,8] are at this category. In these methods, optimal values are obtained after calculating derivatives of the cost function using a first- or second order algorithm. derivatives of the cost function are calculated according to the design variables. In the first-order algorithms, only first derivative of the cost function is necessary with respect to design variables. For example, the fastest gradient-based algorithm is a first-order algorithm method. In this algorithm, the search is performed in the negative gradient vector direction. Second-order algorithms need both the cost function first derivative and second derivative values. Algorithms of pseudo Newton [9] are of this type.

Wang et al. have solved the optimal control problem using the B-Spline functions in order to determine the maximum payload of a fixed-base manipulator [12]. The basic idea of this work is to parameterize the joint trajectories by the use of B-Spline functions, and tuning the parameters in a nonlinear optimization until a local minimum that satisfies the constraints is achieved. A weak point of this method is limiting the solution to a fixed-order polynomial. Another difficulty arises from the complexity of differentiating torques with respect to joint parameters and payload due to their constraints and discontinuity. Constantinescu and Croft [10] introduced a method to determine smooth and time-optimal path constrained trajectories for robotic manipulators using the third derivatives of path parameters. The desired smoothness of the trajectory is obtained through imposing limits on the torque rates. The optimization problem is solved using the flexible tolerance method. But, the method may return a local minimum and it is not applicable for holonomic or non-holonomic systems. A method for trajectory planning using the notion of kinematic controllability for second-order underactuated mechanical systems is presented in [11], that it obtains an optimal time solution and the others

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