Computers and Electrical Engineering 43 (2015) 218–237

Contents lists available at ScienceDirect

Computers and Electrical Engineering

journal homepage: www.elsevier.com/locate/compeleceng

Data-driven multi-stage multi-objective motion planning of mobile robots, application to near minimum power fuzzy parking ☆

Amar Khoukhi

Department of Mechanical Engineering and Industrial Design, New York City College of Technology, 164 Jay St., Brooklyn, NY 11201, United States

A R T I C L E   I N F O

Article history:
Received 16 March 2014
Received in revised form 7 December 2014
Accepted 8 December 2014
Available online 7 March 2015

Keywords:
Wheeled mobile robot
Multi-objective offline planning
Gradient projection
Augmented Lagrangian
Genetic-enhanced sub-clustering
Data-driven adaptive-neuro-fuzzy inference system

A B S T R A C T

In this paper, the problem of multi-objective trajectory planning is studied for a wheeled mobile robot (WMR) in a crowded environment using a hybrid data-driven neuro-fuzzy system. This approach is composed of two basic stages involving a hard computing through a state space detailed modeling of the system and then a data driven evolutionary neuro-fuzzy system is used for online planning. Typically, a first pre-processing step involves an offline planning generating a large dataset of multi-objective trajectories, optimizing a time-power criterion while including robot, task, and workspace constraints. The discrete augmented Lagrangian is implemented on a decoupled form of the robot dynamics to solve for the resulting non-linear multi-objective optimal control problem. The final state constraint is satisfied with a gradient projection technique. The outcomes of this pre-processing step allow building a genetic neuro-fuzzy inference system to learn and capture the robot multi-objective dynamic behavior. Once this system is trained and optimized, it is used in a generalization phase to achieve online planning. The approach was also applied to the near optimal power fuzzy parking problem. Simulation results showing the effectiveness of the proposal are presented and discussed.

1. Introduction

THE pioneering work of Dubins [1] who set the problem of characterizing the shortest path for a particle moving forward with a constant linear velocity and simple kinematic model had opened the way for many researchers on trajectory planning problem of robotic systems. Reeds and Shepp considered the same problem, where backward motions were allowable [2]. A shortest path synthesis of Dubins' car has been determined according to Pontryagin's Maximum principle [3]. These results have been extended by Bacchi et al. [4]; to the case where obstacles are present. Clothoid like-approaches have been proposed by many researchers for path preserving curvature continuity. This approach has especially been used as a CAD tool [5,6]. In strongly non-linear, coupled mechanical structures, obstacle avoidance, and high velocity and precision tasks, these approaches fail to give acceptable results [7,8]. Furthermore, for the efficient use of the robot capacity, it is desirable to execute a task as quickly as possible. To this end, there have been many proposed methods for the minimum time control including robot's dynamic parameters and effects, such as inertia, Coriolis and centrifugal forces. However, the major drawback of this control criterion is its bang–bang character as it produces non-smooth trajectories [6,9]. Moreover, tracking

☆ Reviews processed and recommended for publication to the Editor-in-Chief by Guest Editor Dr. Ankit Chaudhary.

E-mail address: Akhoukhi@citytech.cuny.edu

http://dx.doi.org/10.1016/j.compeleceng.2014.12.008

a planned minimum-time trajectory had shown to lead to overshoot of motor torque limits. In addition, as robot tasks are demanding in precision and diversity, these tasks execution might be difficult to achieve because of the strong non-linearities of the robot dynamics involving components such as Coriolis and centrifugal wrenches, inertia parameters, and gravity forces [10,11]. Indeed, conventional fixed gain, linear feedback controllers are not capable of effectively controlling the movements of the WMR under different velocity, and obstacle avoidance requirements. Through the use of non-linear feedback, approaches like computed torque and robust H_{Infinity} methods provide better compensation for the robot dynamics [12,13]. But, these approaches require complete non-linear dynamic models describing the robot, which are difficult to be accurately modeled and implemented in real-time. To overcome these difficulties, several researchers have used neuro-fuzzy techniques for trajectory design of complex robot systems [14]. Some of them involve the use of a conventional control algorithm, e.g., PD or PID. The conventional control brings the system close to the desired state and the neuro-fuzzy mechanism then compensates for the remaining error. Other systems use only learning algorithms to execute the control. These learning controllers are computationally efficient after training and they have very good generalization capabilities, provided that a large enough dataset-based trajectories is provided.

In this context, we develop a two-stage multi-objective trajectory-planning approach to mobile robot systems (Fig. 1). Criteria to be optimized are time and power necessary for a task execution while satisfying safety, and task constraints (e.g. visiting recharging areas, obstacle avoidance, and reaching the goal pose). The optimal power criterion is highly desirable for mobile robots since the robot has to be stopped to recharge its batteries. This allows for also achieving smoother trajectories as compared to those realized by minimum time based-planners. Hence, the power criterion gives as a result an important influence on the overall time.

In the first part of the proposed system, an offline pre-processing step is performed using an Projected Augmented Lagrangian with Decoupling (PALD) technique [15,16]. This step is done as many times as possible to cover most of the robot workspace and tasks, generating an input/output dataset. The inputs are the WMR Cartesian positions and velocities, and orientations and variations on the orientations. The outputs are the corresponding motor torques and sampling periods. A genetic enhanced subtractive clustering algorithm is implemented to partition the generated dataset into clusters.

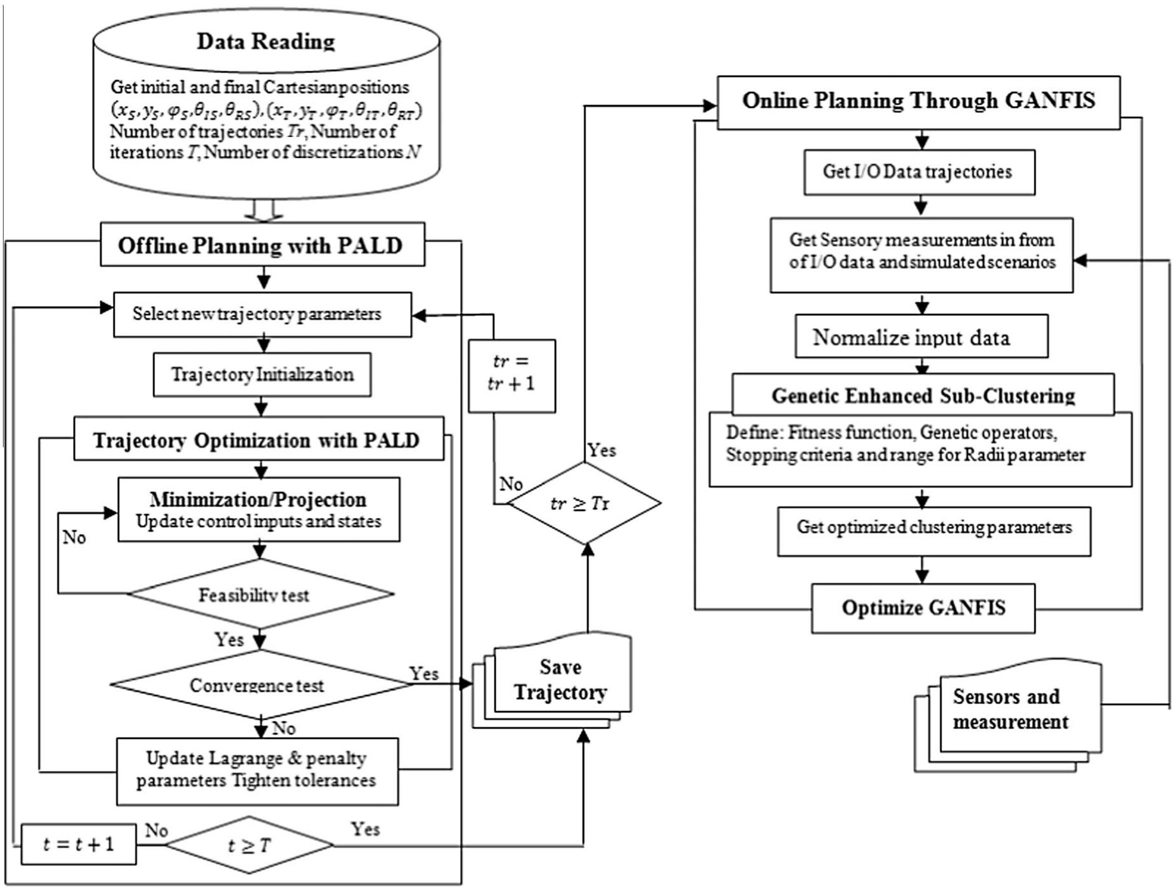

Fig. 1. The proposed approach to motion planning of a robot system.