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Parameterized Dynamic Routing of a Fleet of Cybercars ⋆

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Abstract: Due to the nonlinearity of the dynamics of vehicles and the discrete nature of the route decision variables, the dynamic routing problem for a large number of vehicles is computationally very hard to solve. In this paper, two efficient parameterized control methods are proposed for the dynamic routing of a fleet of cybercars in a road network only open to cybercars. With the proposed parameterized control methods, the updates of the routes of cybercars are parameterized and then optimized over the parameters with respect to the overall performance of the cybercar system for a representative set of scenarios. After tuning the parameters, the proposed parameterized control methods are implemented online with fixed parameters. Moreover, the two proposed parameterized control methods are well-structured and scalable, and therefore can be applied to road networks with arbitrary topologies. The effectiveness of the proposed parameterized control methods is shown in a numerical simulation study.

Keywords: Dynamic routing; Transportation Control; Intelligent transportation systems.

1. INTRODUCTION

In recent years, the numbers of private cars in many big cities all around the world have greatly increased. Although much effort has been spent on improving the infrastructure, such as building more roads and installing more advanced traffic information systems, the highly disorganized behaviors of the human drivers are still causing severe problems, such as frequent congestion, high numbers of accidents, increasing energy consumption and pollution, and high levels of noise, etc. Due to these severe problems, the quality of life and the environment in big cities has been degraded.

Although public transportation systems (e.g., buses, trams and subways) have been considered capable of solving these problems, due to prefixed time schedules and routes, public transportation systems inherently cannot offer the same level of personal mobility to passengers as private cars. Therefore, even though public transportation systems have been continuously improved, people that are in favor of personal mobility still prefer using private cars. As a result, the problems caused by the increasing use of private cars in big cities are still largely unsolved.

A novel and promising approach for personal mobility, emerging as an alternative solution to the use of private cars, is to use a cybernetic transportation system, which is an intelligent transportation system providing on-demand and door-to-door service, see e.g., Parent and Texier (1993); Parent (1997, 2007); Naranjo et al. (2009). More specifically, a cybernetic transportation system is exclusively formed by cybercars, which are small-sized and automated vehicles typically accommodating 3 to 6 seated passengers. Cybercars have a high flexibility and reactivity, providing on-demand and door-to-door transportation service. Hence, a cybernetic transportation system offers better urban mobility than conventional public transportation systems, see Parent (2010). Besides, cybercars are powered by electricity, which is more efficient and less polluting than fossil fuels. Actually, according to Awasthi et al. (2011), cybercars are even competitive on a per passenger-km basis compared with public transportation in terms of energy consumption. In addition, since electric motors generate much less noise than gasoline motors, using a cybernetic transportation system will greatly reduce the noise levels in the urban environment. So far, several projects, such as CyberCars see Parent et al. (2003), CyberCars2, CyberC3 see Yang et al. (2006), have been dedicated to the development and dissemination of a cybernetic transportation system.

According to Bishop (2005), the fast development of automated driving technologies, such as adaptive cruise control, automated lane change and path following, etc, has enabled individual vehicles to drive autonomously. However, due to the absence of efficient strategies for the control of a fleet of cybercars, cybernetic transportation systems are still not widely used on a large scale basis.

Actually, the fleet control problem of cybercars has already been considered in the literature. More specifically, in Awasthi et al. (2011), the problem was considered conceptually from a centralized point of view and then a centralized fleet management system of cybercars was proposed. In Berger et al. (2011), a new concept of control that merges centralized and decentralized control approaches, was proposed for the fleet control problem of cybercars. However, that paper just discussed how the new concept can help in dealing with disturbances from the environment, but it did not introduce a specific control algorithm. In our previous work, see Luo et al. (2014), we proposed a discrete-time model for the dynamics and the energy consumption of cybercars and we formulated a specific instance of the fleet control problem of cybercars, i.e., the dynamic routing problem. However, we did not propose an efficient control

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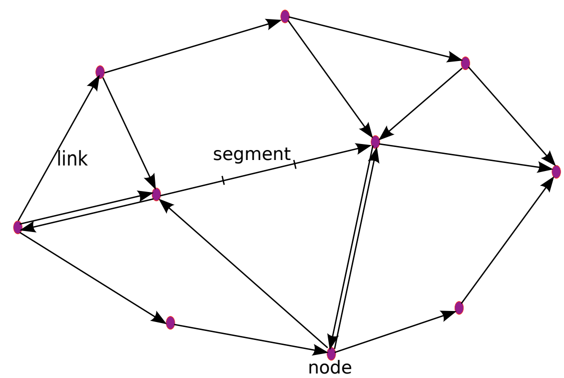

Fig. 1. Cybernetic transportation network

method to solve the problem. With respect to the literature, in this paper, we propose efficient control methods for the dynamic routing problem of cybercars.

In fact, the dynamics of cybercars are highly nonlinear and the routes of cybercars are discrete. This leads to the fact that the dynamical routing problem of a fleet of cybercars is actually a mixed integer nonlinear programming problem, which is computationally very hard to solve. For this reason, instead of computing the optimal routes of cybercars directly, we propose to use efficient control methods in which the route selection process is parameterized, and then optimize the parameters of the control methods with respect to the performance, e.g., total time spent and total energy consumption, of cybercars.

This paper is organized as follows. In Section 2, we present the general description of the dynamic routing problem of a fleet of cybercars. In Section 3, the discrete-time model of the dynamics and the energy consumption of cybercars used in this paper is described. In Section 4, two parameterized control methods are proposed for the dynamic routing of cybercars. In Section 5, a simple numerical case study is presented to demonstrate the effectiveness of the proposed control methods. Finally, in Section 6, we summarize the results of this paper and present some ideas for future work.

2. THE DYNAMIC ROUTING PROBLEM OF CYBERCARS

A cybernetic transportation network is a road network only open to cybercars. Conceptually, a cybernetic transportation network can be represented by a graph like the one shown in Figure 1, where each road is represented by a directed link and each intersection is represented by a node. In addition, we consider that each link is divided into a number of segments and each segment has a length typically in the range of 50 to 100 m.

We assume that there are higher-level controllers deciding schedules (including starting time, departure point and destination) for all cybercars and only focus on the dynamic routing problem of all cybercars from their departure points to their destinations. We assume that, at any time, the traffic density (i.e. the number of cybercars per unit of length) in each segment determines the speeds of all the cybercars running in that segment. We also assume each segment has a maximum capacity, which is the maximum allowed number of cybercars in the segment at the same time. Note that at any time, if the number of cybercars in a segment reaches or exceeds the maximum capacity, that segment will be blocked and no more cybercars are allowed to enter the blocked segment. In addition, we assume that all cybercars have the same length and the same mass. Finally, we assume that within a simulation time interval, no cybercar can cover a distance longer than the length of a segment.

By taking the real-time conditions (i.e., the positions of cybercars, the number of cybercars in each segment and the blocked or unblocked state of each segment) of the network into account, we aim to update the routes of cybercars dynamically so that the overall system performance, i.e., a weighted sum of the total time spent and the total energy consumption of all cybercars in the network, is optimized.

3. DISCRETE-TIME MODELING

Given the current states of the cybercars and the network, a model of the dynamics of cybercars the network can be used to predict the future states of the cybercars and the network, which can then be used in the route selection process for cybercars.

When the departure time for a cybercar arrives, the cybercar will enter the network. After that, at each simulation time step, with the current states of all cybercars and the current conditions of the network given, the states of the cybercars and the conditions of the network at the next step need to be updated, and the energy consumption of cybercars at this step need to be calculated. In this paper, the discrete-time model for the dynamics and the energy consumption of cybercars presented in Luo et al. (2014) is used. Summarily, this model consists of three parts:

- update of states of a single cybercar
- update of states of the network
- computation of energy consumption of a single cybercar

Given the routes of all cybercars, the discrete-time model can be used to compute the total time spent and the total energy consumption by all cybercars in the network.

4. PARAMETERIZED CONTROL METHODS

The main idea of a parameterized control method is to parameterizing the control decision-making process and then tune the parameters off-line by solving an optimization problem considering the performance of the control method on a number of representative scenarios, see Oung and D'Andrea (2012) and Tarău et al. (2010). After that, for any specific scenario, the control decisions are made on-line by using the parameterized control method with fixed parameters.

In the dynamic routing of cybercars, at each control cycle, the parameterized control methods update the route of each cybercar by selecting a route using a parameterized control law from a limited set of possible routes. More specifically, a finite set of possible routes for each cybercar from its current position to its destination can be generated by using shortest route algorithms, e.g., *Dijkstra's Algorithm* presented in Dijkstra (1959). Besides, the whole network is divided into a set G of subnetworks and in different subnetworks the parameterized control law uses different values of parameters.

4.1 Generating a limited set of possible routes from one node to another

Given a static network with a fixed cost on each link, a shortest route algorithm is able to find a predefined number of minimal