Energy Efficiency Evaluation of Automatic Driving Control for Passing through Intersection

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Abstract

This paper reports on the energy saving effect of autonomous driving control at intersections. An intersection is defined as a point at which traffic lanes in several directions coexist. Intersections are prone to higher congestion and a higher incidence of traffic accidents because of heavy traffic. Therefore, the traffic flow at intersections is controlled by incidental equipment. On roads carrying a light amount of traffic, the flow is controlled by stop lines, whereas on roads carrying medium and heavy amounts of traffic, the traffic flow is controlled by traffic signals and overpasses, respectively. However, these incidental facilities are not always the most efficient way to control the traffic flow. These facilities would never be removed as long as vehicles are driven manually, and they would never be able to optimize traffic flow at an affordable cost. On the other hand, autonomous driving of vehicles would optimize the traffic flow by implementing vehicle-to-vehicle or vehicle-to-infrastructure cooperation. Currently, there is a need for the quantitative evaluation of the impact of advanced vehicle control in support of global developments in vehicle automation. This prompted our study, which involves a quantitative evaluation of the energy saving effect of automatic driving control for passing through intersections, which we have developed. This paper first provides background information surrounding vehicle automation. Related work on automatic driving control for passing through intersections and on vehicle control for energy conservation is introduced, after which relating technological issues are clarified. Subsequently, a vehicular behavior model designed to evaluate the extent to which automatic driving control for passing through intersections is able to save energy, is specified. Finally, we report the results of a simulation evaluation using the vehicular behavior

model. The experimental evaluation certifies that automatic driving control for passing through an intersection conserves more energy than traffic control signals.

Keywords: Automatic Driving System, Intelligent Transport Systems, Advanced Vehicle Control and Safety Systems, Intersection Traffic Management.

1. Introduction

Recent years have seen acceleration in the number of advances in the field of vehicular driving control. Miniaturization and ongoing reductions in the price of semiconductors have contributed to enhancing the performance of devices required for driving control, such as sensors, actuators, and electric control units (ECUs). Conventional driving control is accomplished by relying on drivers' cooperation in terms of recognition, judgment, and operation. Lately, however, driving control, which is able to substitute almost all the driving tasks, has been researched and developed, and some manufacturers aim to accomplish fully autonomous driving around 2020.

Advanced driving control not only lightens drivers' load, it also contributes to the efficiency of the whole traffic system. For example, communication and the use of sensors enable recognition using a wide range of high-resolution information. A high-performance computer accomplishes appropriate judgment with recognition information. In addition, a high-performance actuator enables operation at high speed and with high accuracy based on appropriate judgment. The implementation of these devices would accomplish a traffic system beyond the current system, which only consists of manual driving.

On the other hand, some people would prefer advanced driving control not to spread. In general, vehicles are said to have higher palatability than other forms of transport. This is

why drivers are concerned about a scenario in which their driving pleasure would be lost if advanced driving control were to prevail. These opinions cannot be ignored and they could disrupt attempts to accomplish advanced driving control.

One of the reasons for the above concerns is that the benefits derived from advanced driving control are not well understood. Although driving control fields have developed technologies for advanced driving control, the quantitative effect of these driving controls on society is not known. Thus, drivers cannot compare the driving pleasure they would forfeit by using driving control and the benefits they would derive from driving control. In addition, automated driving control has not reliably been implemented in the automotive market. In other words, we should proactively support the quantitative evaluation of the effect of advanced driving control to attempt to accomplish implementation of the control.

This study therefore focuses on the evaluation of the energy saving effect of advanced driving control systems on the traffic system. Specifically, this study evaluates the energy saving effect on traffic systems by comparing automatic driving control for passing through intersections developed as part of this study and manual driving.

Section 2 introduces related work on energy saving technologies of traffic systems and their technological issues are clarified. Details of the simulation models developed for the simulation evaluation of the energy saving effect on automatic driving control for passing through intersections, are described in Section 3. Section 4 reports the conditions and results of the simulation evaluation of the energy saving effect and the paper is concluded in Section 5. Fig. 1 shows the vehicles and the test site that were used for the experimental evaluation of the automatic driving control for passing through intersections.

Fig. 1. Automatic driving control for passing through intersections.

2. Related Work

This section introduces related work on energy conservation in traffic systems.

Approaches to saving energy in traffic systems are largely classified into two categories: the influence on the infrastructure and that on the vehicles. Recent studies tend to assume that a wireless communication device is installed in each vehicle.

The main approach that is followed to achieve energy saving is designed to influence the infrastructure by way of controlling traffic signals. This has led to the development of an adaptive traffic signal control algorithm⁽¹⁾ based on a wireless Vehicular Ad-hoc NETwork (VANET), which was evaluated using actual traffic data in the city of Moncton.

On the other hand, methods that accomplish energy saving by influencing vehicles are largely classified into two groups: methods that offer information about traffic congestion or optimal routes and methods that use vehicle control. Collins and Muntean⁽²⁾ proposed an optimal route calculation algorithm named TraffCon to offer information to connected vehicles, whereas Gupte and Younis⁽³⁾ proposed a method to guide each vehicle along its optimal route by adaptively managing the traffic flow through communication with other vehicles. These two studies adopted methods to offer information regarding traffic congestion or optimal routing to drivers.

Driving control methods aimed at accomplishing energy saving can be classified into three groups: a) autonomous driving control specific to passing through intersections. Milanese et al.⁽⁴⁾ proposed driving control for passing through intersections using vehicle-to-vehicle (V2V) communication and fuzzy controllers. Our previous work also involved the development of an automatic driving control system for passing through intersections and certified the technological validity of the system by conducting the evaluation using several small electric vehicles (EVs). The vehicle control on which this study focuses also belongs to this classification;

b) Driving control that simulates energy saving during manual driving. Some studies aim to achieve efficient driving by considering the factors that influence energy consumption, such as the road slope, preceding vehicles, and traffic signals. These studies are not introduced in this paper because they are beyond the scope of this study;

c) A V2V distance control system that targets the expansion of traffic capacity or the smoothening of traffic flow. A representative V2V distance control system targeting expansion of the traffic capacity is platoon control. Some

large research projects on platoon control, such as CHAUFFEUR, SARTRE, KONVOI, OATH, and Energy ITS, are recently underway in countries around the world⁽⁵⁻⁸⁾. We also conducted studies focusing on the stability of platoon control and the transference sequence of the control⁽⁹⁻¹⁰⁾.

Thus, much related work attempting to improve energy saving of traffic systems has been conducted before. In these studies, autonomous driving control specific to passing through intersections is expected to accomplish a large energy saving effect. Control models for autonomous driving control specifically for passing through intersections have already been proposed, even though no studies have shown that these controls are able to accomplish energy saving. Therefore, this study aims to use simulation to clarify the energy saving effect of autonomous driving control specifically for passing through intersections.

3. Simulation Models

This section provides details of the driving behavior model for simulating the evaluation of energy saving. The design of the model is based on the automatic driving control system for passing through intersections, which we developed before. First, the design of a manual driving behavior model based on the Intelligent Driver Model (IDM), which is used for comparative evaluation purposes, is explained prior to describing the controlled vehicle behavior model of which the design is based on automatic driving control for passing through intersections.

3.1 Manual Vehicle Behavior Model

This model simulates the driving behavior of a typical driver with consideration for preceding vehicles and traffic signals, based on IDM. IDM is one of the continuous time vehicle following driver models, a well-known model used for traffic flow simulations⁽¹¹⁾. The IDM consists of a free road term and an interaction term. The manual vehicle behavior model developed in this study is based on IDM, although the interaction term is modified. The interaction term in this study simulates driver behavior in cases in which other vehicles or traffic signals are ahead of the vehicle. In situations where other vehicles are driving forward the vehicle, the interaction term in this study calculates target deceleration of the vehicle by considering the relative velocity and V2V distance of the vehicle and the nearest preceding vehicle. At the same time, when the vehicle is approaching traffic signals, which indicate a red light, the

interaction term calculates the target velocity of the vehicle to enable it to stop at the traffic signal. Finally, target deceleration of the vehicle in the interaction term of the manual vehicle behavior is set to a larger value to ensure two-target deceleration.

3.2 Controlled Vehicle Behavior Model

This model simulates the automatic driving control method, which we previously developed for passing through intersections. This work proposes two types of approach: a control system type and VANET type. The control system type uses a control center to control the arrival time and passing time of vehicles passing through the intersection. This type also ensures that vehicles pass through the intersection on time. On the other hand, the VANET type shares the distance to and velocity of each vehicle in relation to the intersection. This type also controls each vehicle to form an artificial platoon. Both types of automatic driving control for passing through intersections have common points: they need no traffic signals, adjust timing to pass through the intersection by driving control before entering, and target the efficient use of occupancy time of the vehicles in the intersection.

This study therefore shares the distance to the intersection and the current velocity of each vehicle before entering the intersection similar to the VANET type and then reproduces driving behavior which simulates the artificial platoon formed by each vehicle. IDM and the platoon control algorithm⁽⁹⁾ are used in the controlled vehicle behavior model. This behavior model adopts the free road term of IDM in cases where no other vehicles are ahead of the vehicle. The interaction term of IDM is adopted in cases where other vehicles are driving in front of the vehicle. However, in cases where the vehicle is driving between the control activation point and the end of the intersection, platoon control is added to the vehicle control by considering other vehicles in the intersection. The platoon control is applied only if there is another vehicle which is about to enter the intersection and is driving at almost the same distance to the intersection. By controlling the vehicle to form an artificial platoon with another vehicle, collision in the intersection can be avoided.

The effect of control on the traffic flow was evaluated by using these simulation models to simulate automatic driving control for passing through intersections.

4. Simulation Evaluation

The simulation assumed a one-way intersection in which right/left turning is prohibited. Each road connecting to the intersection is 2 km in length and crosses in the point after 1 km. One hundred vehicles are prepared on each road and each vehicle starts to drive in turn at intervals of 2 s to 10 s, which are randomly selected. Each vehicle starts from the endpoint of the road at 40 km/h.

The energy saving effect of the automatic driving control for passing through intersections is evaluated by specifying that all vehicles drive according to either the manual vehicle behavior model or the controlled vehicle behavior model. Target velocity in the simulation s_d is set to 60km/h, which is the limiting velocity on a standard highway. The target V2V time T is set to 2 s, which is the standard V2V time, and the target V2V distance s_d is set to 4 m, using a recent research project as a reference. Moreover, in case all the vehicles drive according to the manual vehicle behavior model, traffic signals are placed at the intersection. The traffic signal at the intersection changes from red to green and vice versa every 60 s and indicates different signals to the two intersecting roads. The minimum required energy model of all the vehicles simulated a D segment vehicle.

The result shows that the controlled vehicle behavior model performs at 92% higher average velocity than the manual vehicle behavior model. This is because the controlled vehicle behavior model does not require the vehicle to stop for traffic signals. Moreover, the result shows that the controlled vehicle behavior model requires 30 % less average minimum energy than the manual vehicle behavior model.

The above results certified the energy saving efficiency of automatic driving control for passing through intersections.

5. Conclusions

This paper reported on the energy saving effect provided by driving control for passing through intersections in automated driving control.

Specifically, the introduction explained that quantitative evaluation for benefit of the driving control to users is required for accomplishing automated driving control of vehicles. Then related works on vehicle control for saving energy is introduced. Many related works on the driving control model have been conducted, however no other works have been there. Details of the manual vehicle behavior

model based on IDM and the controlled vehicle behavior model, which are developed for evaluation of the energy saving effect of the automatic driving control for passing through intersection, are described. Finally, the simulation evaluation on energy saving effect of the automatic driving control for passing through intersection using the simulation models is reported.

In future we plan to evaluate the energy saving effect of automatic driving control for passing through intersections in more complex situations.

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