Reduction of Fuel Consumption and Emissions and Simulation on SUMO

Guiduan Li[1]

[1] School of Computer Science and Technology, Tiangong University, Tianjin, 300387, China

Abstract

Saving energy and reducing emissions is always the research focus in recent Internet of Vehicles study. Frequent braking and acceleration seriously affect the performance of vehicles' fuel consumption and leads to polluting the environment. A scenario of driving assistance where vehicles receive information about vehicle driving via Dedicated Short-Range Communications (DSRC) and Internet of Vehicles is difficult to evaluate by hardware, because of the current network state and cost of such experiment. Therefore, in this paper, based on the co-simulation platform developed by us to simulate the whole process of vehicle crossing through the intersection, we proposed Method Based on Threshold (MBT) to reduce fuel consumption and emissions in the condition of knowing the traffic lights state and the vehicle state, the simulation results show that the proposed method can improve fuel economy. Compared with the default way of passing through the intersection, the proposed method reduces fuel consumption by 16%.

Keywords: *Internet of Vehicles, Assisted Driving, Simulation of Urban Mobility(SUMO).*

1. Introduction

In American, traffic congestion has increased since the low point of the economic recession in 2009. In 2014, it consumed an extra 600 million hours and 700 million gallons of fuel more than in 2009 [1]. Travel delays caused by traffic jams lead to drivers wastes more than 3 billion gallons of fuel and kept travelers stuck in their cars for nearly 7 billion extra hours. On average, each commuter wastes 42 hours and 19 gallons of gasoline per year on the road. Most of the delays are caused by traffic congestion which frequently occur at intersections.

In the early days, intelligent transportation mainly focused on highway, while at present, the focus and pressure of traffic problems come from urban road congestion. The main problems facing the development of intelligent transportation in the future will be two problems: the hotspot area and the transfomation of vehicle-oriented management mode. In the case of the current road resources do not match the growth of the number of vehicles, resolving congestion problems mainly through the management and deployment of vehicles. Therefore, it is urgent to establish a system based on vehicles' information -- Internet of Vehicles (IoV) for intelligent transportation.

The Internet of vehicles platform collect and effectively utilize the information about vehicle driving through Vehicular ad-hoc networks (VANETs), and provide comprehensive services for different requirements. Internet of Vehicles will bring infinite development possibilities to the transportation field, and many applications based on IoV will emerge. In IoV, a vehicle can be connected to the Internet through a wireless LAN so that both the vehicle's internal and external devices can access to the Internet through the vehicle [2]. With the development of advanced computer, communication and sensor technology, which provide efficient traffic management and real-time traffic states for drivers. Driving behavior can be assessed through effective analysis and processing of real-time data. These real-time data are very important for reducing vehicle fuel consumption and traffic congestion. Therefore, a optimal driving inspiration can be obtained according to the evaluation situation.

"Simulation of Urban MObility" (SUMO) is an open source, highly portable, microscopic road traffic simulation package designed to handle large road networks [3]. The implementation of SUMO started in 2001, with a first open source release in 2002[4]. It is mainly developed by employees of the Institute of Transportation Systems at the German Aerospace Center. SUMO has applied in vehicle routing, vehicle fuel consumption analysis and traffic assessment. Vehicular Ad-Hoc Networks (VANETs) makes it possible to communicate between vehicles and vehicles as well as between vehicles and roadside infrastructures. In response to available software tools for VANETs research still lack the ability to evaluate the availability of vehicular applications. Axel Wegener et al. present Traffic Control Interface (TraCI) a technique for interlinking road traffic and network simulators [5]. TraCI is a flexible and extendable request-reply protocol for controlling road traffic simulators. TraCI uses a TCP based client/server architecture to provide access to SUMO [6]. At this time, SUMO acts as a server and listen on for incoming connections. TraCI send request connection command and SUMO reply a accept command. TCP connection is established and TraCI takes over the simulation.

This paper is organized as follows: We discuss the related work in Section 2. In section 3, we developed co-simulation platform and discuss the models. Section 4 shows our simulation results. Finally, we conclude and introduce our future work.

2. Related Work

The traditional traffic lights control system receives information about the vehicle through a fixed sensor and analyzes the information to set a fixed traffic lights phase. Fixed phase is not optimal for all vehicles, so we propose a solution that plan vehicles' speed based on real-time data without changing the existing infrastructure to reach the goal of reduce fuel consumption and emissions. Some researchers focus on reducing the travel time of vehicles but ignore the vehicles' fuel consumption.

In the field of energy saving at intersection, there are two main methods to save vehicles' fuel consumption. On the one hand, it is to improve the signal control strategy according to the actual traffic situation and the situation of adjacent traffic lights. A large amount of literatures has been studied in this area [7][8]. M Tubaishat et al. proposed a WSN-based traffic signal control system dedicated to reducing vehicles' average waiting time [9]. M Collotta et al. proposed a dynamic traffic signal control system based on WSN and fuzzy logic [10]. Y. Hou et al proposed a two-level approach (CIVIC-E^2) for all vehicles passing through an isolated intersection [11]. The method jointly optimizes the traffic lights phase and vehicles' speed with the objective of minimizing total energy consumption. These researchers are focused on traffic control system but ignore current situation about intersections. At present, most traffic lights at intersections are fixed phase.

On the other hand, by obtaining the current traffic lights phase through wireless communication (the communication between the signal controller and the vehicle control system) and planed speed based on that information, a more energy saving driving scheme can be obtained. B. Asadi and A. Vahidi designed an automatic cruise control method to reduce the overall travel time based on multiple traffic lights in the multiple intersections to be reached [12]. Mandava S, Boriboonsomsin K et al. proposed a speed planning algorithm based on traffic lights, considering the effects of acceleration on fuel consumption and CO2 emissions, as well as vehicle output power [13].

Giving access to a running road traffic simulation, it allows to retrieve values of simulated objects and to manipulate their behavior "on-line". As a highly versatile Application Programming Interface (API), TraCI can connect to multi-language clients for data reading and writing. TraCI provides a number of commands for different user requirements, including control process commands, vehicles' data read and write, traffic lights data read and write, etc. In the experiment of this paper, the commands in TraCI are mainly used to collect the vehicle data and traffic lights data, and based on the obtained data, the ideal assisted driving strategy is made, and then the data is written into the simulator.

In the energy-saving control of intersections, the traffic lights and other infrastructure are communicated with the vehicle to achieve the purpose of reducing fuel consumption and emissions of the vehicle. In terms of hardware, the basic technology for the realization of Internet of vehicles' equipment is already available. By installing Dedicated Short Range Communications (DSRC) equipment to connect the traffic lights and the vehicle and displaying it to the driver through a client, a simple auxiliary driving device with prompt message can be basically realized. In terms of software, it is feasible for SUMO and Python to evaluate various data of vehicles passing the intersection through Traci co-simulation.

3. Co-Simulation Platform and Models

To build a simulation platform for energy saving assessment of intersection requires not only an accurate model, but also powerful data analysis and presentation ability, it is necessary to consider various problems. Simply using Python or Traci for simulation will face difficulties in car following models and fuel consumption model. When SUMO is used alone, it is difficult to extract data and difficult to analyze data. Therefore, after studying the literature and official documents, choose the way to use SUMO and TraCI together. In this way, the corresponding data can be obtained by TraCI using Python, meanwhile, reliable car-following models and fuel consumption model can also be obtained. In this paper, we built a co-simulation platform using SUMO, TraCI and Python (see Fig.1).

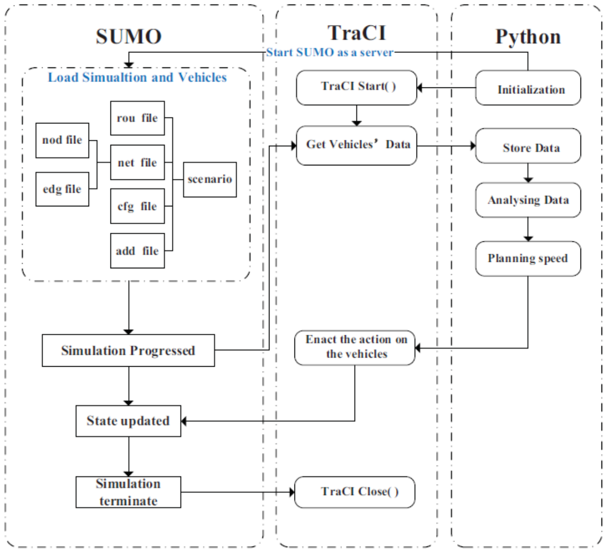

Fig. 1 Co-simulation platform process and structure.

3.1 Car-Following Models (CFMs)

The CFMs is a method of using dynamics to describe the driving state of the following vehicle when the following vehicle follows the leading vehicle in a single lane. It is a microscopic model that studies the traveling characteristics of non-free running state motorcade. The aim is to comprehend the characteristics of the single lane traffic flow by observing the way each car follows each other.

The car following models defined the longitudinal dynamics [14]. Standard car following models are of the form:

$$a_i = \dot{v}_i = f(h_i, \dot{h}_i, v_i) \tag{1}$$

Where the acceleration a_i of vehicle i is some typically nonlinear function of h_i, $\dot{h}_i$, v_i, which denotes the headway, relative velocity, and velocity for vehicle i, respectively. The distance from bumper to bumper is called headway. In this paper, the headway is calculated according to the following formula:

$$h_i(t) = p_{i-1}(t) - p_i(t) - l \tag{2}$$

Where $h_i(t)$ denotes the i-th vehicle's headway in time t, $p_{i-1}(t)$, $p_i(t)$ are respectively the position of vehicle i-1 and vehicle i, is the length of vehicle.

In this paper, two car-following models are selected to verify our method: Krauss CFMs and Intelligent Driver Model (IDM). Krauss car-following models is a modification of the model defined by Stefan KrauB in 1998[15]. The intelligent driver model is a time-continuous car following model developed by Martin Treiber, Ansgar Hennecke and Dirk Helbing in 2000[16]. In this paper, we approximate the velocity as a liner function between the simulation time step.

3.2 Emissions Model

Passenger Car and Heavy-Duty Emission Model (PHEM) is an instantaneous vehicle emission model developed by the TU Graz since 1999[17]. PHEM provides emission factors for the Handbook Emission Factors for Road Transport (HBEA). In this paper, we use gasoline powered Euro norm 4 passenger car modeled using the HBEFA3 based model. We can get the total fuel consumption by adding the instantaneous fuel consumption for each time step.

$$F = \sum_{t=1}^{T} f_t \tag{3}$$

Where F denotes the total fuel consumption, T represents total simulation time, f_t denotes instantaneous fuel consumption per time step.

3.3 Assisted Driving System

The distance from the sensor position to the intersection can be divided into two parts: constant speed section and deceleration section. We are committed to making the sum of the time of constant speed and the time of slowdown equal to the time of switching to the green phase. The vehicle dynamic characteristics of these two parts can be expressed as formula 4.

$$\begin{cases} l_1 + l_2 = L \\ \dfrac{l_1}{v_c} + \dfrac{v_c}{|a_s|} = T_s \\ {v_c}^2 = 2|a_s| * l_2 \end{cases} \tag{4}$$

Where l_1 and l_2 respectively represent the distance traveled at a constant speed and the distance traveled at a deceleration, L represent the distance between sensor and intersection, v_c denotes the constant velocity, a_s represent the deceleration and T_s denotes the time switch to green phase. Formula 4 is used as the constraint condition to seek the optimal velocity planning.

The fuel consumption of the vehicle at intersection mainly comes from the sudden acceleration, the high acceleration caused by the speed increase, and the engine idle state over a long period of time. Therefore, when designing the optimization algorithm, it is mainly desirable to reduce the time that the vehicle is stationary before the intersection. We proposed Method Based on Threshold (MBT) to reduce vehicles' fuel consumption and emissions.

4. Simulation and Results

In this paper, we mainly refer to the environmental settings in [18][19] to design the simulator. The assisted driving area is 500 meters before the traffic lights. Vehicle data, traffic lights data and sensor data can be transmitted to the data processing center via vehicles. The scenario is shown in Fig. 2, and the specific parameters are shown in Table. 1.

We designed the simulation experiment with reference to the classification method in the paper [19]. First of all, we carried out simulation experiments on the roads with and without traffic lights on the 1000 meters road. The data shows that the appearance of the traffic lights not only increases the total travel time, but also increases fuel consumption and emissions.

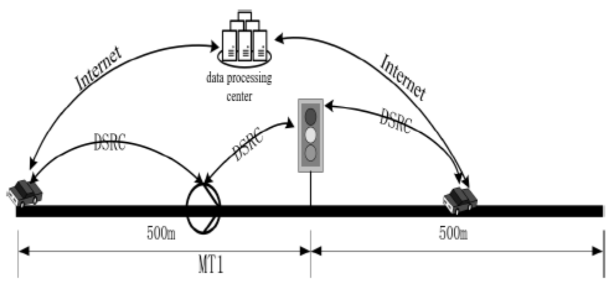

Fig. 2 Single lane experiment scenario.

Table 1: The detailed road parameters.

Parameters of Road	Value	Parameters of Road	Value
Road Length	1000 m	Yellow Phase	3 s
DSRC Communication Distance	500 m	Position of Traffic Lights	500 m
Green Phase	35 s	Speed Limit	50 km/h
Red Phase	20 s	Signal Control Mode	Stationary

In the second place, we analyzed the driving data of vehicles with traffic lights. When the car is 100m away from the intersection, the vehicle will change speed according to the state of the traffic lights. However, due to the inaccuracy of the information, when the vehicle reaches the intersection, it will still wait for a while. The change of vehicle speed with time and distance is shown in Fig. 3. From the figure we can see that the velocity of vehicle is 0 for some time. This time is the time to wait at the intersection. The driver reached a lower speed because the driver failed to take a reasonable deceleration mode. We hope to do our best to avoid such situations through assisted driving.
Finally, we used the method of multiple experiments to select the assisted driving plan and selected different deceleration times in multiple experiments to obtain the best fuel consumption performance in each experiment. Because TraCI can only set velocities, not deceleration, we assume that the change of the velocity is linear. we convert the deceleration into $\Delta v = a * \Delta t$, where Δv is the change in speed, a is the deceleration and Δt is the deceleration time.

Fig. 3 shows the changes of the optimized speed, fuel consumption, carbon dioxide emission with time and the change of the optimized speed with distance. Optimized fuel consumption, CO_2 emissions and unoptimized detailed figures are shown in Table 2. Simulation results have validated fuel economy improved and emissions reducing capability of the proposed method based on threshold. The simulation results show that fuel consumption using the proposed method is improved by up to 16.5% compared with no use of assisted driving. At the same time, it also reduces carbon dioxide emissions by 16%.

Table 2:Detial Simulation Results

	Fuel Consumption	CO_2 Emissions(g)
Not Optimized	109.694	2550143
Optimized IDM	91.552	212.938
Optimized Krauss	91.867	213.67

5.Conclusions

In this paper, through the co-simulation platform built by SUMO, TraCI and Python, the real-time data acquisition and analysis of vehicles at intersections are realized. And verified the validity of the MBT proposed in this paper. The simulation results show that the method proposed by us can reduce fuel consumption and CO_2 emission by more than 15%. It effectively improves fuel economy and reduces environmental pollution. However, the proposed method cannot deal with multiple intersections, which should be considered in our future work. In addition, the co-optimization of routing plan and signal intersection will also be studied in the future.

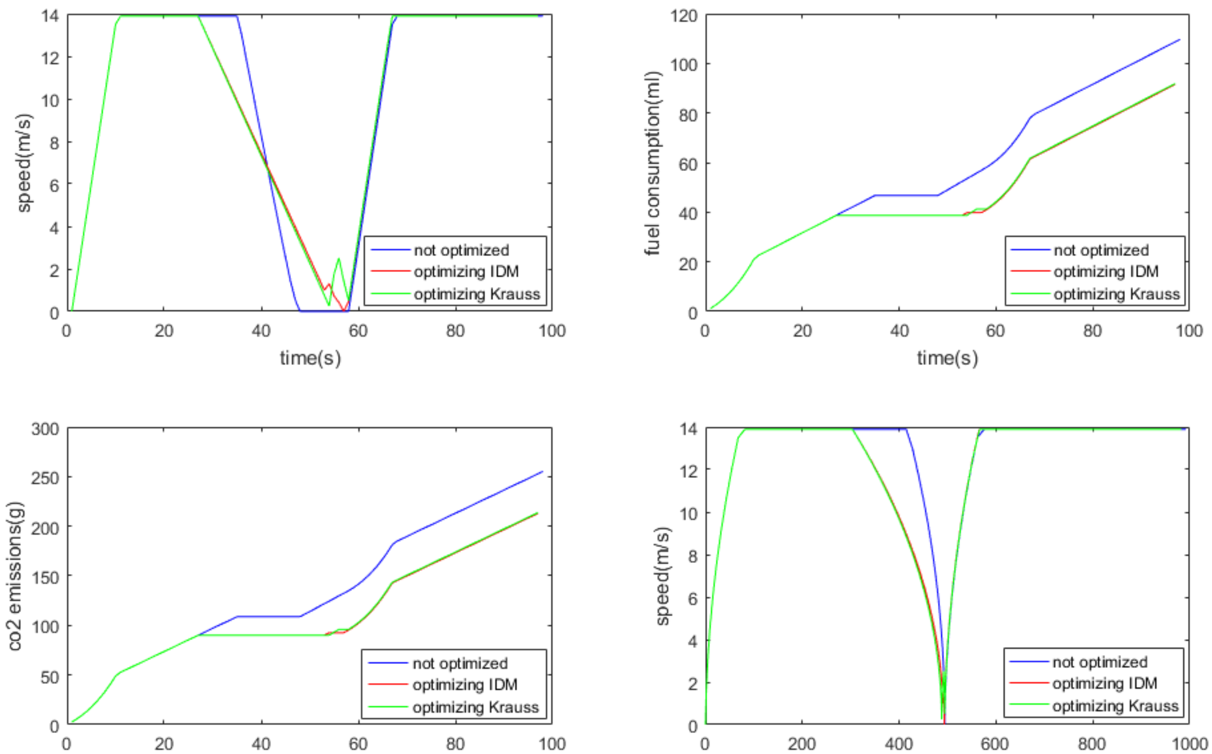

Fig.3 (a) comparison of speed varies with time; (b) comparison of fuel consumption varies with time; (c)comparison of co2 emissions varies with time; (d)comparison of speed varies with distance.

References

[1] Schrank D, Eisele B, Lomax T, et al. 2015 urban mobility scorecard[J]. (2015)

[2] Gerla, Mario, et al. "Internet of vehicles: From intelligent grid to autonomous cars and vehicular clouds." 2014 IEEE world forum on internet of things (WF-IoT). IEEE, (2014)

[3] SUMO User Documentation Homepage, https://sumo.dlr.de/docs/, last accessed 1 Sep 2020

[4] Krajzewicz, Daniel, et al. "Recent development and applications of SUMO-Simulation of Urban MObility." International Journal On Advances in Systems and Measurements 5.3\&4 (2012)

[5] Wegener, Axel, et al. "TraCI: an interface for coupling road traffic and network simulators." Proceedings of the 11th communications and networking simulation symposium. ACM, 2008

[6] SUMO User Documentation TraCI page, https://sumo.dlr.de/docs/TraCI/Interfacing_TraCI_from_Python.html last accessed 1 Sep 2019

[7] Papageorgiou, Markos. "Overview of road traffic control strategies." Ifac Proceedings Volumes 37.19 (2004): 29-40.

[8] Brockfeld, Elmar, et al. "Optimizing traffic lights in a cellular automaton model for city traffic." Physical Review E 64.5 (2001): 056132.

[9] Tubaishat, Malik, et al. "Wireless sensor-based traffic light control." 2008 5th IEEE Consumer Communications and Networking Conference. IEEE, 2008.

[10] Collotta, Mario, Lucia Lo Bello, and Giovanni Pau. "A novel approach for dynamic traffic lights management based on Wireless Sensor Networks and multiple fuzzy logic controllers." Expert Systems with Applications 42.13 (2015): 5403-5415.

[11] Hou, Yunfei, et al. "Cooperative and integrated vehicle and intersection control for energy efficiency (CIVIC-E 2)." IEEE Transactions on Intelligent Transportation Systems 19.7 (2018): 2325-2337.

[12] Asadi, Behrang, and Ardalan Vahidi. "Predictive cruise control: Utilizing upcoming traffic signal information for improving fuel economy and reducing trip time." IEEE transactions on control systems technology 19.3 (2010): 707-714.

[13] Mandava, Sindhura, Kanok Boriboonsomsin, and Matthew Barth. "Arterial velocity planning based on traffic signal information under light traffic conditions." 2009 12th International IEEE Conference on Intelligent Transportation Systems. IEEE, 2009.

[14] Orosz, Gábor, R. Eddie Wilson, and Gábor Stépán. "Traffic jams: dynamics and control." (2010): 4455-4479.

[15] Lopez, Pablo Alvarez, et al. "Microscopic traffic simulation using sumo." 2018 21st International Conference on Intelligent Transportation Systems (ITSC). IEEE, 2018.

[16] Treiber, Martin, Ansgar Hennecke, and Dirk Helbing. "Congested traffic states in empirical observations and microscopic simulations." Physical review E 62.2 (2000): 1805.

[17] Hausberger, Stefan. "Simulation of Real World Vehicle Exhaust Emission." (2003).

[18] Mandava, Sindhura, Kanok Boriboonsomsin, and Matthew Barth. "Arterial velocity planning based on traffic signal information under light traffic conditions." 2009 12th International IEEE Conference on Intelligent Transportation Systems. IEEE, 2009.

[19] Schuricht P, Michler O et al. Efficiency-increasing driver assistance at signalized intersections using predictive traffic state estimation[C]//2011 14th International IEEE Conference on Intelligent Transportation Systems (ITSC). IEEE, 2011: 347-352.

First Author Guiduan Li received the B.E. degree in network engineering from Liaocheng University, Liaocheng, China, in 2018. He is currently pursuing the M.S. degree in software engineering with Tiangong University, Tianjin, China. His research interests include intersection management, and intelligent transportation systems.