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Automatic Driving Control for Passing through Intersection by use of Feature of Electric Vehicle

Takeki Ogitsu¹, Manabu Omae¹, Hiroshi Shimizu²

¹ Graduate School of Media and Governance, Keio University, 5322 Endo, Fujisawa, Kanagawa, 252-8520, Japan,
ogitsu@sfc.keio.ac.jp

² Faculty of Environment and Information Studies, Keio University

Abstract

This study expects that the automatic driving control for passing through intersection has potential for energy saving and solving traffic jams. Therefore, first, this study calculates the predicted effect of the automatic driving control at intersection in simulations. Second, this study proposes the control method for vehicles to pass through an intersection by cooperating with each other on contact with the intersection-traffic control which manages the schedule of vehicles to enter the intersection. Third, a vehicle control algorithm for reaching the intersection on the scheduled time is also proposed. Last, the proposed vehicle control and intersection-traffic control are validated by experiments using electric light vehicles.

Keywords: Automatic Driving System, Intelligent Transport Systems (ITS), Electric Vehicle (EV), Intersection

1 Introduction

This paper proposes a control method for vehicles to pass through an intersection by cooperating with each other on contact with the intersection-traffic control which manages the schedule of vehicles to enter the intersection. There have been so many traffic jams and accidents in intersections, because traffics from various courses make heavy and complicated traffic at intersections. Therefore, traffic management of intersections has a potential to solve the traffic problem and there has been a lot of studies focusing on intersections from various aspects [1]-[5]. This study focuses on traffic control at intersection by automated electric vehicles and traffic management system.

Human-operated vehicles can safely pass through an intersection because the drivers decide when to proceed by visually confirming the movement of other vehicles, or because traffic signals control the sequence of vehicles entering the

intersection by stopping traffic. Meanwhile, when automated electric vehicles are on the road, multiple vehicles' paths may intersect at an intersection efficiently, smoothly and safely, because electric vehicles are highly-controllable.

This study proposes the intersection traffic control by the following procedure: An intersection is divided into several control sections considering the overlap of trajectories of automated vehicles; The controlled vehicles approaching the intersection send information of their states and path to the intersection-traffic-management system; The intersection-traffic-management system schedules the vehicles' times of entering and passing the intersection for vehicles approaching the intersection so that the vehicles might pass through the intersection without collision; The intersection-traffic-management system sends commands to each vehicle; And, the traction and braking forces of vehicles are controlled to reach the control sections on the

scheduled time. Figure 1 shows an automatic driving control for passing through intersection. The organization of this paper is as follows: Chapter 2 explains the predicted effect in the case of using the automatic driving control at intersection, Chapter 3 explains the details of the control method for automated electric vehicles to pass through an intersection; Chapter 4 describes an experimental for evaluation of the proposed vehicle control; Chapters 5 and 6 describe experimental for evaluations of the proposed intersection control at an intersection of one-way road and at an intersection of two-way roads, respectively; Chapter 7 describes the concluding remarks.



Figure 1: Automatic driving control at intersection

2 Predicted Effect of Automatic Driving Control at Intersection

This chapter describes the predicted effect in the case of using the automatic driving control at intersection. This study expects that the automatic driving control for passing through intersection has potential for energy saving and solving traffic jams. Before development of the automatic driving control for passing through intersection, this study calculates the predicted effect of the automatic driving control at intersection in simulations. In the following sections, the conditions and results of the simulations are explained.

2.1 Simulation Conditions

The simulations deal with the circumstance that has two cross one-way roads. The roads have a length of 2[km], a width of 2[m] and an intersection at the 1[km] mark. The roads are passed by a hundred vehicles each. The each vehicle comes in the start point of the road at intervals of 5[sec] sequentially. The difference in the time of coming in each road is 2.5[sec].

This study makes a comparison between the traffic flow management using only traffic signal and the traffic flow management using the automatic driving control without traffic signal. the vehicle model of the all vehicles bases on the Gipps' model which is car-following model [6].

In case of the traffic flow management using only traffic signal, the all vehicles work at keeping a time headway of 3[sec] and a velocity of 60[km/h] over the entire length of the roads.

In case of the traffic flow management using the automatic driving control, the each vehicle switches some parameters of its vehicle model from the 500[m] mark to passing through the intersection to simulate the automatic driving control. First, the following target is switched to a preceding vehicle which cannot pass through control sections at the same time with the vehicle. Second, the time headway is switched to 1[sec]. Last, the limit speed at intersection may be provided by the automatic driving control for safety. the limit speed at intersection is switched from 60[km/h] to the pre-set speed (10-60[km/h]). The all vehicles are passenger vehicles which are categorized as D-segment car, and have the same parameters of the vehicle model. The all vehicles' initial velocity is 60[km] in the all simulations.

2.2 Simulation Results

Figure 2 shows the average of driving energy requirement of each simulation. Seeing Fig. 2, the result shows that the average of driving energy requirement using the automatic driving control is lower than using only traffic signal. Additionally, the more the limit speed is increased, the more the average of driving energy requirement is decreased. Meanwhile, figure 2 shows results in the case of using the vehicles which have regeneration brake because this study deals electric vehicles. In the case of using the vehicles which have regeneration brake, the effect of the automatic driving control is deteriorated. However, the traffic flow management using the automatic driving control consumes about 10[%] less energy than using only traffic signal at the least.

Figure 3 shows the average of driving time of each simulation. Seeing Fig. 3, the result shows that the almost average of the driving time using the automatic driving control is lower than using only traffic signal. However, in case of the limit speed of 10[km/h], the average of the driving time using the automatic driving control is lower than using only traffic signal. This reason is that there is a great difference between initial speed and limit

speed. The deference exceeds performance limitations of the control, causes a traffic jam. Meanwhile, the more the limit speed is increased, the more the average of the driving time is decreased. Except in case of the limit speed of 10[km/h], the traffic flow management using the automatic driving control consumes about 36[%] less time than using only traffic signal at the least. The above results prove that the automatic driving control for intersection is efficient and effective.

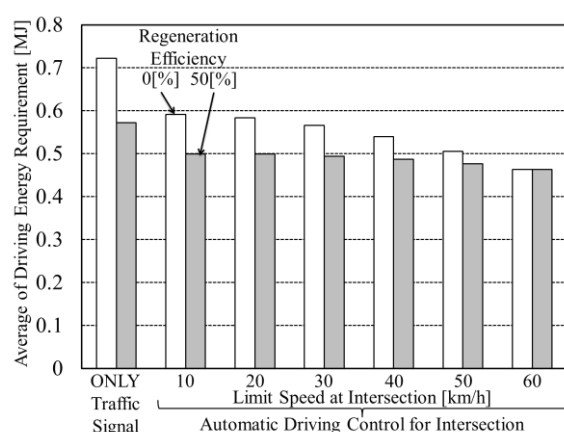


Figure 2: Average of driving energy requirement

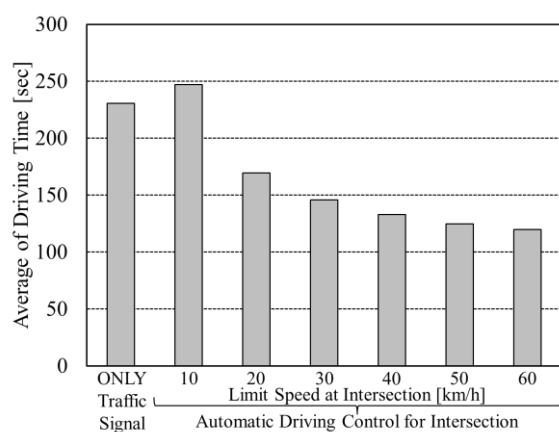


Figure 3: Average of driving time

3 Control Algorithms for Passing through Intersection

This chapter describes the proposed control method for passing through intersection by automated electric vehicles and a traffic management system. An intersection is divided into one or more control sections, and vehicle's schedule of entering and passing the intersection are controlled with respect to each control

section by the intersection-traffic-management algorithm. The vehicles are controlled by the vehicle control algorithm to reach the intersection on the scheduled times. In the following sections, the control section of the intersection-traffic management, the intersection-traffic-management algorithm, and the vehicle control algorithm are explained.

3.1 Making Control Section Algorithm

This study proposes the intersection traffic control dividing an intersection into several control sections considering the overlap of trajectories of automated vehicles. It should be noted that the proposed intersection traffic control is based on the premise that automated vehicles can trace provided target trajectories precisely by automatic steering control. The automatic steering control to trace target trajectories has danger to collide against other vehicles which driving on the overlap point of target trajectories including intersection. Therefore, this study divides an intersection into several control sections considering the overlap of trajectories of automated vehicles. In the previous study, authors extracted the interference condition of passing through intersections [7]. This study divides an intersection into several control sections based on the study which extracted interference condition of passing through intersection.

In the following subsections illustrate a method for dividing intersection into several control sections by examples.

3.1.1 Intersection of two one-way roads (no left/right)

In this case, control section is the whole intersection as shown in A of Figure 4. In Fig.4, areas which are bounded by dashed lines are control sections. If an intersection architects two one-way roads without left/right turning, one control section is enough for the proposed passing through intersection control because that overlap point of target trajectories in intersection is only one.

3.1.2 Intersection of two one-way roads (with left/right)

In this case, control sections shown in B of Fig. 4. If an intersection is the crossing point of two one-way roads with left/right turning, the number of control sections is determined by the size of

intersection. As shown in case1 of Fig. 4, if the size of intersection is a relatively small scale, such as road of intersection with an overlap between straight lane and turning lane, one control section is enough for the proposed intersection control. As shown in case2 of Fig. 4, if the size of intersection is a relatively large scale, such as road of intersection without an overlap between straight lane and turning lane, an intersection should be divided into several control sections. Increasing the number of control sections increase traffic capacity of intersection because many vehicles can pass through intersection at one time. On the contrary, if an intersection is relatively small traffic, the traffic of the intersection can be controlled by one control section. Definition of coverage of control section must keep on the safe side with consideration for width of passing through intersection and accuracy of lateral control of automated vehicles.

3.1.3 Intersection of two two-way roads

In this case, control sections shown in C of Fig. 4. C of Fig. 4 shows definition of control sections in an intersection of relatively small traffic if size of intersection is a relatively large scale, the intersection can divide several control sections. In every case, definition of coverage of control section must keep on the safe side with consideration for width of passing through intersection and accuracy of lateral control of automated vehicles.

By the above method, an intersection is divided into several control sections considering size, traffic, and other configuration of intersection, and is controlled with respect to each control section by the intersection-traffic-management algorithm.

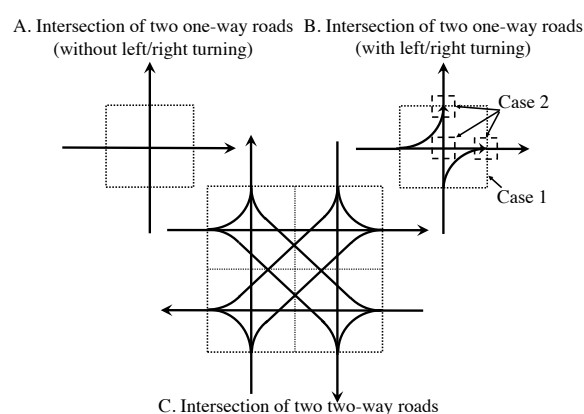


Figure 4: Control sections of intersection

3.2 Intersection-Traffic-Management Algorithm

This section explains the algorithm for the intersection-traffic-management. The proposed intersection-traffic-management algorithm schedules the vehicles' times of entering and passing the intersection for vehicles approaching the intersection so that the vehicles might pass through the intersection without collision. The vehicle's times of entering and passing the intersection are scheduled by the intersection-traffic-management system because intersection-traffic-management system can monitor states of the controlled vehicles approaching the intersection clearly and can make traffic flow more easily if several intersections are controlled.

The proposed intersection-traffic-management algorithm needs to synchronize the clock times of the intersection-traffic-management system and the vehicles approaching the intersection. Therefore, an intersection-traffic-management area for monitoring vehicles approaching the intersection previously set. And, the vehicles in the intersection-traffic-management area are classified into the following four states:

- State1: the vehicle is out of synchronization with the intersection-traffic-management system;
- State2: there is the preceding vehicle which cannot pass through the control sections at the same time with the vehicle;
- State3: there is NO preceding vehicle with which cannot pass through control sections at the same time with the vehicle; and
- State4: the vehicle has passed through intersection.

At the first stage, entering the intersection-traffic-management area, all vehicles are classified into the State1. If a vehicle is classified into the state 1, the clock time of the vehicle is synchronized with that of intersection-traffic-management system. The clock time of vehicle must be synchronized with that of intersection-traffic-management system because vehicles are controlled to reach and pass the control sections at the specified times which are scheduled by the intersection-traffic-management system. The intersection-traffic-management system receives information of passage route of the vehicles from the vehicles approaching the intersection, and decides of the control sections which control the vehicles approaching the intersection.

At the second stage, the state of the vehicle whose clock times are synchronized with that of the intersection-traffic-management system changes

into the states 2 or 3. If there is a preceding vehicle which cannot pass through control sections at the same time with the vehicle, the vehicle's state is the state 2. If there is no preceding vehicle which cannot pass through control sections at the same time with the vehicle, the vehicle's state is the State3. If the vehicle's state is the state 2, the vehicle's time of entering has to set posterior to the preceding vehicle's time of passing. If the vehicle's state is the State 3, the vehicle's times of entering and passing can be scheduled as convenient time for the vehicle. If traffic in the intersection is crowded, the vehicles' times of entering and passing set convenient times for the traffic. At the states 2 and 3, the vehicle's traction and braking forces are controlled to reach the control section at the time specified by the intersection-traffic-management system.

At third stage, the state of the vehicle which passed through the intersection changes to the state 4. And the vehicle gets out of the intersection control.

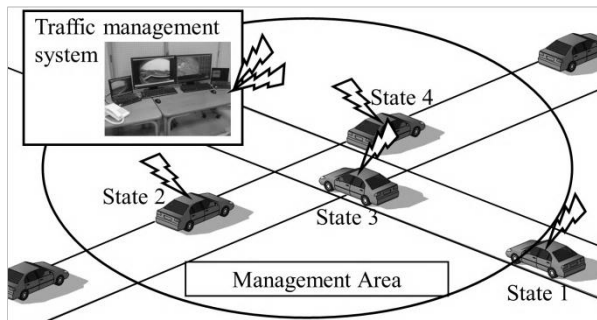


Figure 5: Intersection management algorithm

3.3 Vehicle Control Algorithm

This section explains the algorithm for vehicle control. The purpose of the algorithm is determining the desired acceleration of the vehicle to reach the intersection at the time specified by the intersection-traffic-management system. This study proposes the control algorithm using a virtual leading vehicle. The virtual leading vehicle is a numerical model calculated in a computer on the vehicle. It travels at a constant velocity to reach the intersection at the specified time. The vehicle is controlled to follow the virtual leading vehicle by comparing a velocity and position of the vehicle with those of the virtual leading vehicle. The desired acceleration of the vehicle is given as follows:

$$u = K_d(V_v - V_r) + K_p L \quad (1)$$

where,

V_v : Velocity of the virtual leading vehicle derived from the time to reach the intersection specified by the intersection-traffic-management system;

V_r : Velocity of the controlled vehicle;

L : Distance error of the controlled vehicle to the virtual leading vehicle; and

K_d and K_p : Feedback gains.

Distance error of the controlled vehicle to the virtual leading vehicle (L) is given as follows:

$$L = V_v(\tau_{arr} - \tau_n) - D \quad (2)$$

where,

τ_{arr} : Specified time to reach the intersection;

τ_n : Current time; and

D : Distance between the controlled vehicle and the intersection.

It is possible that a large acceleration or deceleration command is given by the above equations, if the calculated position of the virtual leading vehicle is very far from the current position of the controlled vehicle. Thus, acceleration and deceleration are limited to certain values for smooth movement, and a procedure to prevent reverse movement is added in the controller. By controlling the vehicle to follow the virtual leading vehicle, a velocity and position of the controlled vehicle are accorded with those of the virtual leading vehicles, resulting in reaching the intersection at the time specified by the intersection-traffic-management system.

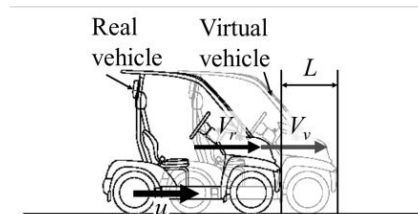


Figure 6: Vehicle control algorithm

4 Experimental for Evaluation of Vehicle Control

This chapter explains the experiments conducted for evaluating the proposed vehicle control algorithm. The purpose of the experiment is evaluating accuracy of time for a vehicle to reach an intersection at the time specified by the intersection-traffic-management system. The following explains the experimental condition and reports the experimental results.

4.1 Experimental Conditions

This section explains the experimental conditions. The experiments are conducted using an electric vehicle with automatic control devices. An optical gyro sensor, RTK-GPS and velocity sensor are fixed for measurement of vehicle information. An AC servo motor is mounted for controlling the steering angle. Traction and brake forces are generated by controlling the inverters of the traction motors of the vehicle.

The experiments are carried out on a straight course without gradient. The steering angle of the vehicle is automatically controlled for tracking the target trajectory stored as absolute position information [8]. The vehicle approaches the control section of intersection-traffic management system at a constant velocity of 10[km/h]. When a distance between the vehicle and the control section of traffic management system is less than 30[m], the vehicle is controlled to reach the control section of the intersection at the specified time. In the following, the specified time to reach the control section at constant velocity of 10[km/h] is defined as zero. In the experiments, performances of the vehicle control at the specified time from -3[sec] to +3[sec] are evaluated.

4.2 Experimental Results

Figure 7 shows the experimental results. The results show errors of time to reach the control section at each specified time. The vehicle is controlled to accelerate when the specified time is less than zero because vehicle must reach the control section earlier than time of reaching at constant speed. On the other hand, the vehicle is controlled to decelerate when the specified time is more than zero. The results show that the maximum error of time is 200[ms], which means that the vehicle can be controlled to reach the control section at the specified time with accuracy of 200[ms] by the proposed vehicle control algorithm, and that the intersection-traffic-management system can prevent collisions at the intersection by specifying the time for the vehicle to enter the intersection by adding the margin of more than 200[ms] to the time for the preceding vehicles to pass the intersection. The experimental results clarify the validity of the proposed vehicle control.

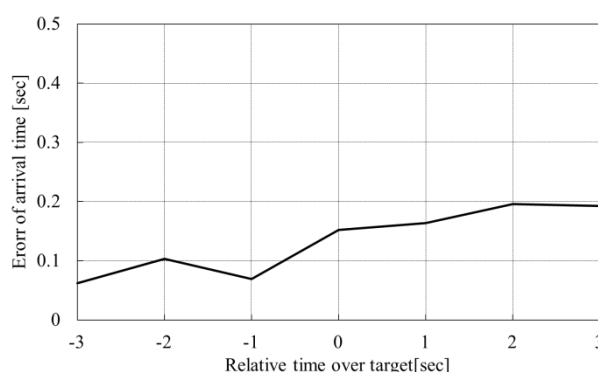


Figure 7: Experimental result of vehicle control algorithm

5 Experimental Evaluation of One-Way Roads

This chapter describes the experiment of passing through intersection of one-way roads without turning. In the experiment, the four experimental vehicles with the proposed vehicle controller and a computer for the traffic management of the intersection are used. The following explains the experimental conditions and reports the experimental results.

5.1 Experimental Conditions

This section explains the experimental conditions. In this experiment, an intersection of one-way roads is evaluated. Four experimental vehicles whose configurations are the same as those explained in the previous chapter and one personal computer for intersection-traffic management based on the proposed intersection-traffic-management algorithm are used. Wireless LAN is used for communication between the vehicle and the intersection-traffic-management system.

The four vehicles travel along the 8-shaped trajectory and the cross point is the intersection of one-way roads. One control section is placed on the intersection for the intersection-traffic management. The steering angles of the vehicles are automatically controlled to track the 8-shaped trajectory. The four vehicles are called as vehicle A, vehicle B, vehicle C and vehicle D, respectively. In the experiments, vehicles' behaviors from the following three patterns of initial locations of vehicles are evaluated:

- Pattern1: the vehicle D enters the intersection after the vehicle C on the cross lane passes through the intersection as shown in the upper part of Fig. 8;

- Pattern2: the vehicle D enters the intersection after the vehicle B on the cross lane passes through the intersection as shown in the middle part of Fig. 8; and
- Pattern3: the vehicle D enters the intersection after the vehicle A on the cross lane passes through the intersection as shown in the lower part of Fig. 8.

The vehicles A, B and C travel at a velocity of 6[km/h] and the vehicle D travels at a velocity of 8[km/h], when they are out of the intersection-traffic-management area. The range of intersection-traffic-management area is 5[m] from the intersection. The interval of entering the control section of two vehicles for the intersection-traffic-management system is 2[sec].

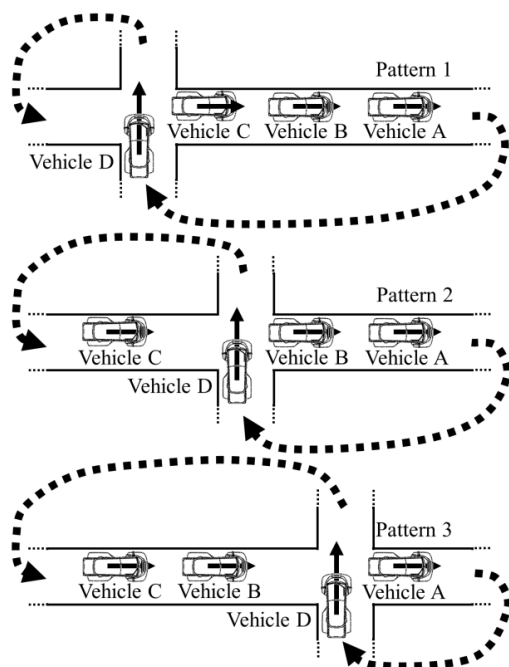


Figure 8: Experimental pattern

5.2 Experimental Results

Figure 9 shows the trajectory of the vehicles and Figs 10, 11 and 12 shows the distances between the intersection and each vehicle at the patterns 1, 2 and 3, respectively. Seeing Fig. 10, the vehicles are located as the pattern 1 at 7[sec] and after that the vehicle D passes through the intersection after the vehicle B on the cross lane passes through the intersection. Seeing Fig. 11, the vehicles are located as the pattern 2 at 5[sec] and after that the vehicle D passes through the intersection after the vehicle A on the cross lane passes through the intersection. Seeing Fig. 12, the vehicles are located as the pattern 3 at 6[sec]

and after that the vehicle D passes through the intersection before the vehicle A on the cross lane passes through the intersection.

At each pattern, a collision at the intersection might occur if the vehicles are not controlled. In the experiment, the proposed intersection-traffic-management system schedules the timing of the vehicles to enter the intersection, and the vehicles are controlled to reach the intersection at the specified time sent from the intersection-traffic-management system. Thus, the vehicles successfully pass through the intersection without collisions. The experimental results clarify the validity of the proposed control at the intersection of one-way roads.

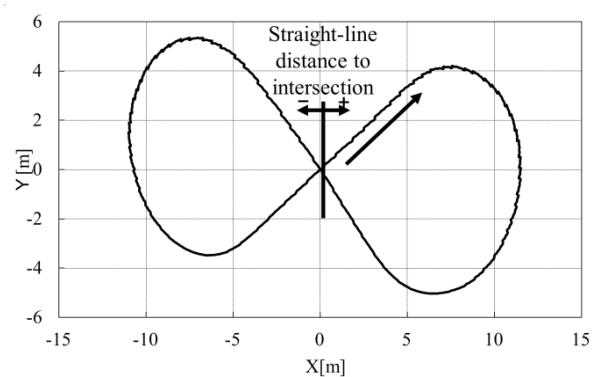


Figure 9: Target trajectory

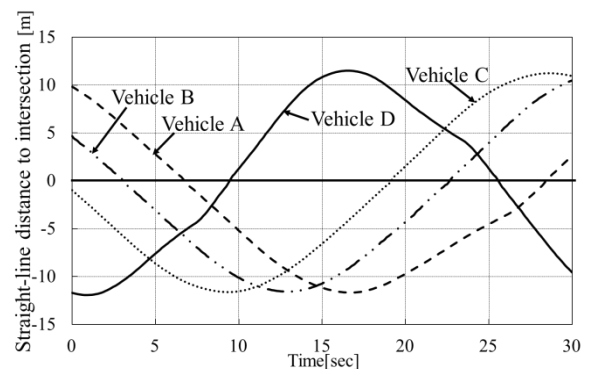


Figure 10: Experimental result of pattern 1

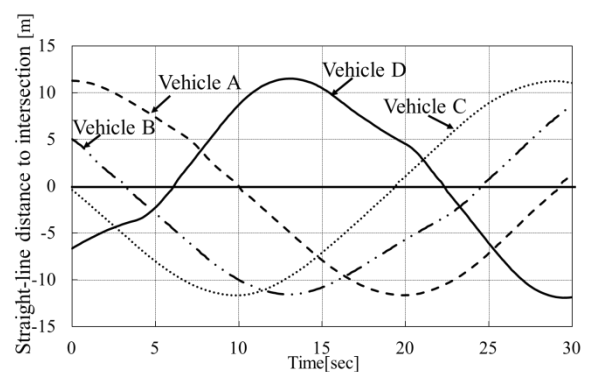


Figure 11: Experimental result of pattern 2

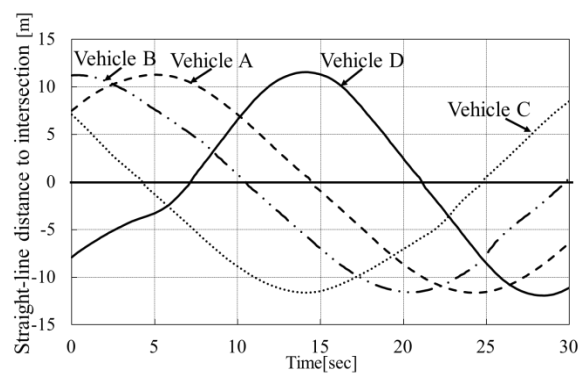


Figure 12: Experimental result of pattern 3

6 Experimental Evaluation (Intersection of Two-Way Roads)

This chapter describes the experiment of passing through intersection of two-way roads with left and right turns. In the experiment, the three experimental vehicles explained in the previous chapter are used. The following describes the experimental conditions and reports the experimental result.

6.1 Experimental Conditions

This section explains the experimental conditions. In this experiment, an intersection of two-way roads is evaluated. The configurations of intersection-traffic-management system and experimental vehicles are the same as those explained in the previous chapter. Figure 13 shows the experimental course and control sections of the traffic management system. Three vehicles are used and called as vehicle A, vehicle B and vehicle C, respectively. As shown in Figure 13, experimental course is T-shaped intersection of two-way roads and the intersection-traffic-management system control the flow of the vehicles by dividing the intersection into three control sections of the control section A, control section B and control section C as shown in Figure 14. The three vehicles approach the intersection from the different directions along the target trajectories set on each vehicle and pass through the intersection by turning to the left or right as shown in Figure 15. In the experiment, the vehicles approach the intersection with the same timing by passing the points located 30[m] far from the intersection at speeds of 8[km/h] at the same time. The steering angles of the vehicles are automatically controlled to track the target

trajectories. Traction and braking forces of the vehicles are controlled by the proposed control. The target velocity for passing through intersection is 8[km/h] and the interval of entering the control section of two vehicles is 4[sec].

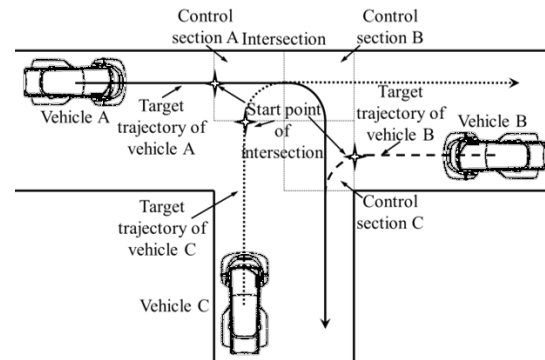


Figure 13: Outline figure of experiment

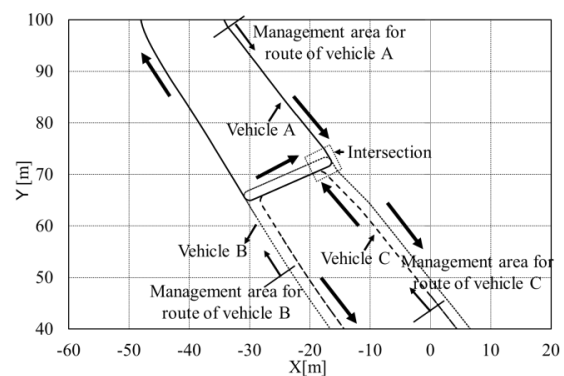


Figure 14: Target trajectories

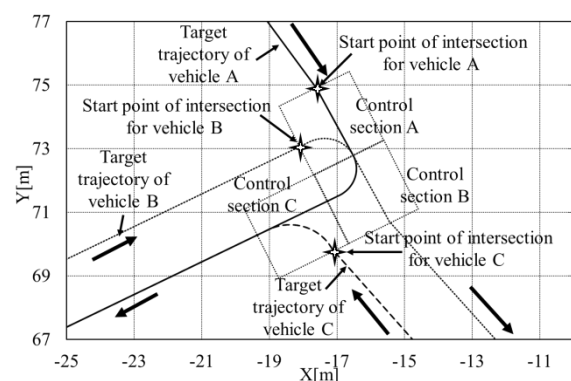


Figure 15: Position of control sections

6.2 Experimental Results

Figure 16 shows the experimental result. The result shows distances between the intersection and each vehicle. Seeing the initial conditions, the vehicle might collide with the other vehicles if they are not controlled. The result shows that the vehicles successfully pass through the intersection by the

proposed control. The vehicles B and C enter at the same time but do not collide with each other because the trajectories of the vehicles B and C do not overlap, which means that efficient traffic flow is realized. The efficient traffic flow control is realized by conducting the intersection-traffic management dividing the intersection into several control sections. The experimental result clarifies that the proposed control is applicable to the traffic management of the practical intersections such as intersections of two-way roads.

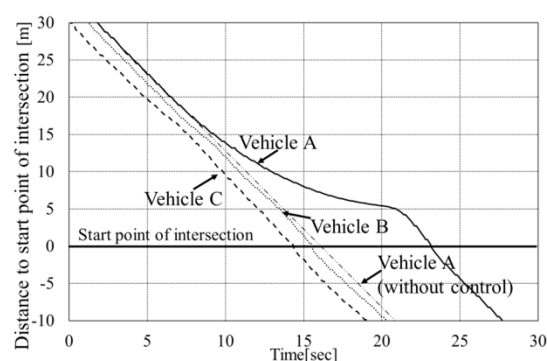


Figure 16: Experimental result

7 Conclusion

This paper explains the predicted effect of the automatic driving control at intersection in simulations, and proves that the automatic driving control for intersection is efficient and effective. Furthermore, this paper proposed the automatic driving control for passing through an intersection using the intersection-traffic-management system. The control is constructed making the most use of the feature of electric vehicles, that traction and braking forces can be accurately and quickly controlled. The procedure of control for passing through intersection and control algorithms for the intersection-traffic-management system and vehicles are proposed. In the proposed procedure, the vehicles approaching the intersection are controlled to enter the intersection at the scheduled times assigned by the traffic management system. For realizing the proposed procedure, this study designed the intersection-traffic-management algorithm for determining the vehicles' times of entering and passing the intersection. And the vehicle control algorithm for entering the intersection at the scheduled time was designed and it was clarified by experiments that the experimental vehicle can enter the intersection at

the scheduled time with accuracy of 0.2[s]. The proposed intersection control was validated by experiments using electric light vehicles. The fruit of this study shows the electric vehicle's advantage towards future vehicle systems.

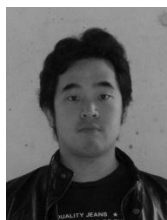
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Authors



Takeki Ogitsu

Graduate School of Media and
Governance, Keio University
5322,Endo, Fujisawa, Kanagawa 252-
8520, Japan
Tel: +81-0446-49-3501
Fax: +81-044-580-1435
Email: ogitsu@sfc.keio.ac.jp



Manabu Omae, Prof. Dr. Eng.

Graduate School of Media and
Governance, Keio University
5322,Endo, Fujisawa, Kanagawa 252-
8520, Japan
Tel: +81-0446-49-3501
Fax: +81-044-580-1435
Email: omae@sfc.keio.ac.jp



Hiroshi Shimizu, Prof. Dr. Eng.

Faculty of Environment and Information
Studies, Keio University
5322,Endo, Fujisawa, Kanagawa 252-
8520, Japan
Tel: +81-44-580-1565
Fax: +81-44-580-1435
Email: hiros@sfc.keio.ac.jp