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A Vehicular Collision Warning Algorithm Based on the Time-to-collision Estimation under Connected Environment

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***Abstract*—Considering the traffic safety in the scenario of arterial road with on-ramp, this study proposes a time-to-collision (TTC) based vehicular collision warning algorithm under connected environment. In particular, the information of vehicles of interest, i.e., position, traveling direction and velocity, is assumed to be collected by the roadside device via the vehicle-to-infrastructure (V2I) communications. Then, the TTC of a pair of vehicles in arterial road and on-ramp is estimated based on the position, traveling direction and velocity difference of that pair of vehicles. Consequently, the TTC warning messages can be disseminated to vehicles within the communication range of the roadside device, so as to reduce the risk of collision. The proposed algorithm can be used in the cooperative vehicle infrastructure systems (CVIS) to improve the traffic safety.**

Keywords-collision warning algorithm; time to collision; connected environment; intelligent transportation systems

I. INTRODUCTION

Traffic problems, e.g., traffic safety, traffic congestion, and traffic pollution, have received much attention recently. According to the World Health Organization (WHO), about 1.2 million lives are lost each year worldwide due to the traffic accidents, and around 50 million people suffer vehicle accidents [1]. Hence, there is a research need to enhance the traffic safety using the advanced technologies. Recently, connected vehicles technologies, i.e., vehicle-to-vehicle/vehicle-to-infrastructure (V2V/V2I) communications, are popular in the field of transportation. In this context, vehicles can share the information, i.e., position, traveling direction and velocity, with other vehicles in their vicinity via the V2V/V2I communications [2-6]. Therefore, V2V/V2I communications can enable the following vehicles to respond to the potential risk of collision or accident in advance [7-8]. Consequently, the probability of collision will be reduced accordingly. The benefits of connected vehicles technology with respect to safety motive this study.

In previous studies, Lee [9] proposed a control strategy of following vehicles based on the information about time-to-collision (TTC) rather than distance, speed, or acceleration/deceleration to enhance the traffic safety. Winsum et al. [10-12] incorporated the kinematic characteristics and human factors into car-following model based on the relationship between the states of following vehicles and TTC. However, the above studies are restricted to the lane-discipline-based road system. They cannot be readily applied in a road with lateral gap. To address this scenario, Li et al. [13-14] proposed a generalized car-following model to capture the characteristics of traffic flow considering the effects of bilateral gaps. Recently, Jin et al. [15] proposed an extended general motor (GM)-based traffic flow model by incorporating the effects of lateral gap and visual angle into TTC estimation under non-lane-discipline road system. However, this model is restricted to the straight road without junction. Hence, there is a research need to propose a vehicular collision warning algorithm in the scenario of arterial road with on-ramp under the connected environment.

Motivated by the research need discussed above, unlike the existing studies only considering the visual characteristics of the drivers in a road under a common environment without V2V/V2I communications, this study focuses on the characteristics of the vehicles at the junction of arterial road with on-ramp under connected environment. To this end, this study proposes an extended TTC estimation incorporating the angle between the traveling direction and the center of vehicles in arterial road and on-ramp. In addition, considering that roadside device can judge whether the information, i.e., position, traveling direction and velocity, is from vehicles in arterial road or on-ramp, this study proposes a collision warning algorithm to identify the potential collision risk of vehicles at the junction by calculating TTC value based on the proposed TTC estimation. Finally, the TTC warning message can be disseminated to vehicles within the communication range of the roadside device, so as to reduce the risk of collision.

The rest of this paper is organized as follow: Section II proposes a two-level framework to illustrate the collision warning algorithm. Section III proposes an extended TTC estimation. Section IV proposes the collision warning algorithm based on the proposed TTC estimation. The final section concludes this study.

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II. FRAMEWORK

This study proposes a two-level framework to design the algorithm as shown in Fig. 1. The proposed framework includes two components. The first component is information collection including preprocessing, and the second component is information processing, which is comprised of vehicle matching, prediction and identification.

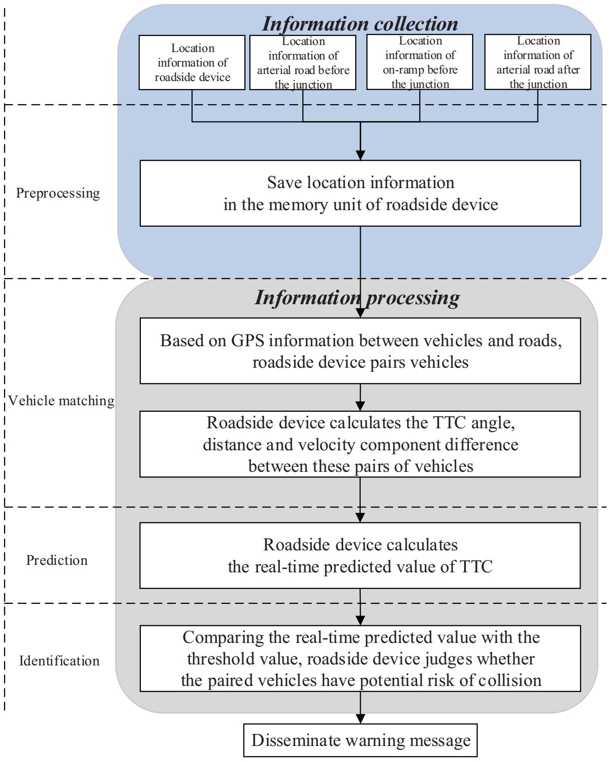

Figure 1. Proposed framework.

Following Fig. 1, the framework is described in detail as follows:

- **Preprocessing.** Collect location information of the roadside device and roads (i.e., arterial road, on-ramp). And then, store the information in the memory unit of the roadside device.
- **Vehicle matching.** Roadside device preliminarily processes the saved information in preprocessing phase and pairs those vehicles based on GPS information.
- **Prediction.** Roadside device can calculate the real-time predicted value of TTC based on the proposed TTC estimation.
- **Identification.** Roadside device can identify the potential collision risk of those pairs of vehicles according to the real-time predicted value of TTC.

III. TTC ESTIMATION

A. Scenario without on-ramp

Fig. 2 illustrates the scenario without on-ramp. According to the information between the leading vehicle and the following vehicle, the TTC value can be estimated by the following formula:

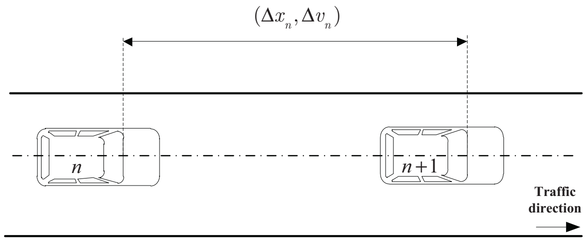

Figure 2. Scenario without on-ramp.

$$\mathrm{TTC}_n(t) = -\frac{\Delta x_n(t)}{\Delta v_n(t)} \tag{1}$$

where $\mathrm{TTC}_n(t)$, $\Delta x_n(t) = x_{n+1}(t) - x_n(t)$ and $\Delta v_n(t) = v_{n+1}(t) - v_n(t)$ denote the time to collision (in s), space headway (in m) and velocity difference (in m/s) between the leading vehicle $n+1$ and the following vehicle n at time t, respectively.

The TTC estimation in Eq. (1) is derived considering the visual characteristics of the drivers. It can analyze the potential risk of collision between vehicles in the same road. However, it is restricted to the straight road without junction. With the development of connected vehicles technologies, the V2I communication based roadside device enables to perceive the information of vehicles in its vicinity so as to enhance the accuracy and real-time of information acquisition. Consequently, it motivates to study the TTC estimation based on the characteristics of vehicles in complex road condition (i.e., junction) under connected environment.

B. Scenario with on-ramp

To address the issue mentioned above, Fig. 3 shows the scenario of arterial road with on-ramp. Hence, vehicles can travel in different roads and may collide at the junction. In this scenario, we suppose that a pair of vehicles ($\{N_{ai}, N_{rj}\}$) at the junction is matched by the vehicle N_{ai} in the arterial road and the vehicle N_{rj} in on-ramp. Therefore, the extended TTC estimation can be formulated as follows:

$$\mathrm{TTC}_{ij}(t) = -\frac{\Delta x_{ij}(t)}{\Delta v_{ij}(t)} \tag{2}$$

where $\mathrm{TTC}_{ij}(t)$, $\Delta x_{ij}(t)$ and $\Delta v_{ij}(t)$ denote the time to collision (in s), distance (in m) and velocity component difference (in m/s) between vehicle N_{ai} in arterial road and

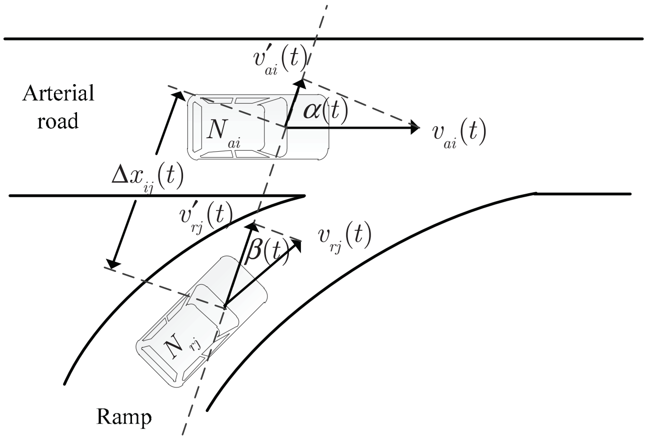

Figure 3. Scenario with on-ramp.

vehicle N_{rj} in on-ramp at time t, respectively. $\Delta v_{ij}(t)$ is defined as:

$$\Delta v_{ij}(t) = v'_{ai}(t) - v'_{rj}(t) \tag{3}$$

where $v'_{ai}(t)$ denotes the velocity component of vehicle N_{ai} in the direction of N_{ai} to N_{rj}; $v'_{rj}(t)$ denotes the velocity component of vehicle N_{rj} in the direction of N_{ai} to N_{rj}. Hence, $v'_{ai}(t)$ and $v'_{rj}(t)$ can be re-written as follows:

$$v'_{ai}(t) = v_{ai}(t)\cos\alpha(t) \tag{4}$$

$$v'_{rj}(t) = v_{rj}(t)\cos\beta(t) \tag{5}$$

where $\alpha(t)$ is the angle between the center of vehicle N_{ai} to vehicle N_{rj} and the direction of the velocity of vehicle N_{ai}, $\beta(t)$ is the angle between the center of vehicle N_{ai} to vehicle N_{rj} and the direction of the velocity of vehicle N_{rj}. Here, $\alpha(t)$ and $\beta(t)$ are named TTC angle.

IV. Collision Warning Algorithm

Based on the proposed TTC estimation, the purpose of this section is to propose a collision warning algorithm applied to the junction under connected environment. The algorithm includes the preprocessing of road data and process of vehicle data, which are shown in Fig. 4 and Fig. 5, respectively.

A. Preprocessing of Road Data

The purpose of this stage is to save road data in the memory unit of roadside device. The data includes the location information of roads (i.e., arterial road and on-ramp) before the

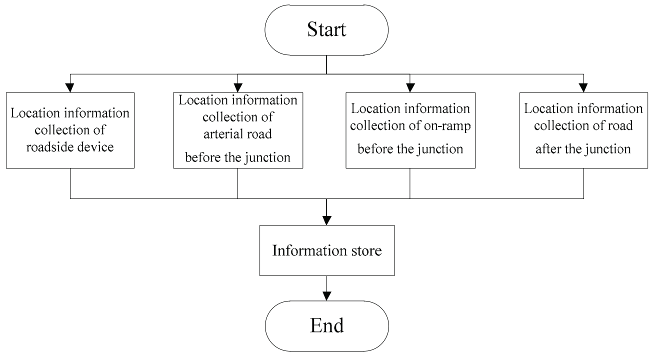

Figure 4. Preprocessing of road data.

junction, the location information of roadside device at the junction, and the location information of arterial road after the junction. The saved data associated with road will be used to pair vehicles in different roads (i.e., arterial road and on-ramp).

B. Process of Vehicle Data

- **Step 1:** V2I communication establishment. When vehicles move into the communication range (R) of the roadside device, vehicles will send the GPS information (i.e., longitude and latitude, traveling direction and velocity) to the roadside device via the V2I-based communication. Then, the roadside device will judge whether the vehicles are in the prediction area. The prediction area is defined as follows:

$$0 < \Delta x < r \tag{6}$$

where Δx is the distance between the vehicle and roadside device, r is the radius of prediction area ($r < R$). It means the distance between the boundary of prediction area and roadside device.

- **Step 2:** Vehicle data calculation. Matching the stored GPS information of roads (i.e., arterial road and on-ramp) in Section IV.A with GPS information of vehicles in the prediction area, after that, the roadside device can pair vehicles before the junction. Then, the roadside device can calculate the TTC angle, distance and velocity component difference between those pairs of vehicles based on Eqs. (3)-(5).
- **Step 3:** Potential risk prediction. Based on the proposed TTC estimation in Eq. (2), the roadside device can calculate the real-time predicted value of TTC. Then, the roadside device can judge whether the pair of vehicles in Step 2 has potential risk of collision by comparing the real-time predicted value of TTC with the threshold value (T). According to different T, the potential risk of collision can be classified as different warning levels. Note that the T depends on the level of road, average velocity, etc.
- **Step 4:** Real-time warning output. Based on the results of potential risk prediction in Step 3, the roadside device can disseminate the warning messages to the

paired vehicles with risk of collision in Step 2 via the V2I-based communication. It implies that necessary and immediately operations (e.g., braking) should be taken to reduce the risk of collision.

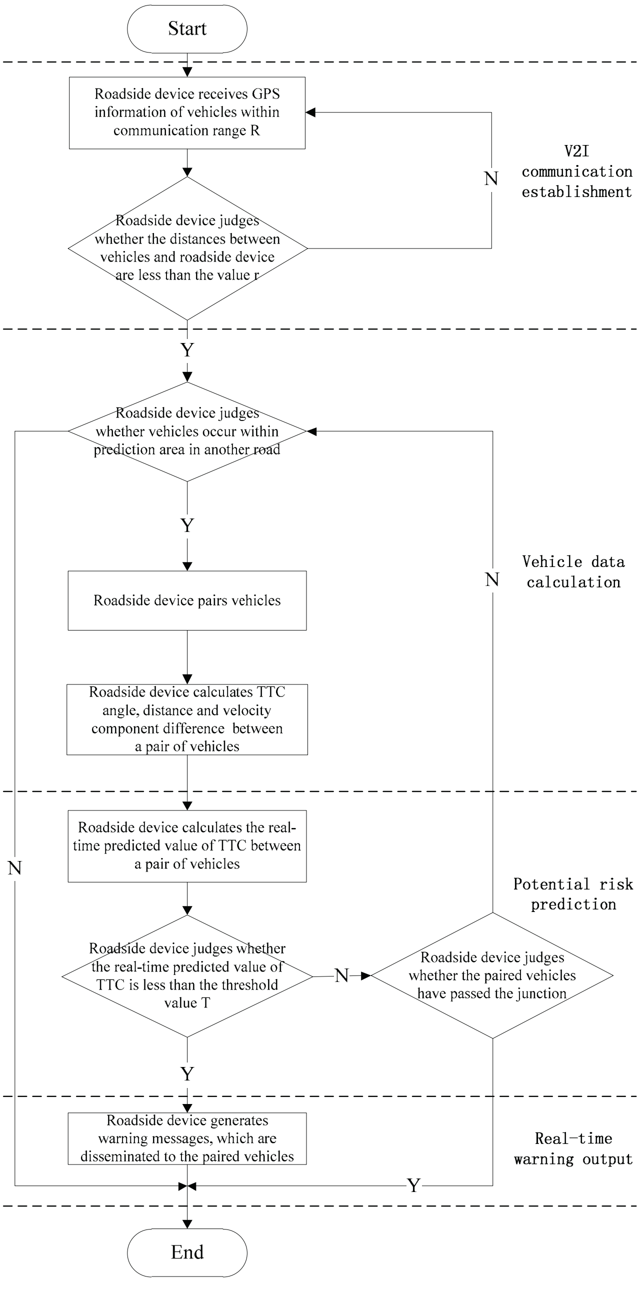

Figure 5. Process of vehicle data.

V. CONCLUSIONS

Considering the scenario of arterial road with on-ramp, this study proposes an extended TTC estimation based on the characteristics of vehicles. And consequently, a vehicular collision warning algorithm is proposed based on this extended TTC estimation under connected environment. The process of the proposed algorithm is discussed in detail.

The proposed algorithm can identify the risk of collision according to the real-time TTC value prediction and disseminate the corresponding warning messages to the paired vehicles within the communication range of the roadside device. Hence, the safety of vehicle movement near the junction can be improved accordingly. In addition, the proposed algorithm can enhance the road network capacity as it can smooth the vehicular traffic flow based on the different warning levels in the road network.

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