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Proposed collision warning system for right-turning vehicles at two-way stop-controlled rural intersections

Essam Dabbour [a,*], Said Easa [b]

[a] Department of Civil Engineering, Abu Dhabi University, P.O. Box 59911, Abu Dhabi, United Arab Emirates
[b] Department of Civil Engineering, Ryerson University, Toronto, Canada

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ABSTRACT

At two-way stop-controlled (TWSC) rural intersections, a right-turning driver who is departing the minor road may select an improper gap and subsequently may be involved in a rear-end collision with another vehicle approaching on the rightmost lane on the major road. This paper provides perceptual framework and algorithm design of a proposed infrastructure-based collision warning system that has the potential to aid unprotected right-turning drivers at TWSC rural intersections. The proposed system utilizes a radar sensor that measures the location, speed, and acceleration of the approaching vehicle on the major road. Based on these measurements, the system's algorithm determines if there will be any potential conflict between the approaching and the turning vehicles and warns the driver of the latter vehicle if such a conflict is found. The algorithm is based on realistic acceleration profile of the turning vehicle to estimate its acceleration rates at different times so that the system can accurately estimate the time and distance needed for the departing vehicle to accelerate to the same speed as for the approaching vehicle. That realistic acceleration profile is established using actual experimental data collected by a Global Positioning System (GPS) data logger device that was used to record the positions and instantaneous speeds of different right-turning vehicles at 1-s intervals. The algorithm also gives consideration to the time needed by the driver of the departing vehicle to perceive the message displayed by the system and react to it (to start departure) where it was found that 95% of drivers have a perception–reaction time of 1.89 s or less. A methodology is also illustrated to select the maximum measurement errors suggested for the detectors in measuring the locations of the approaching vehicle on the major road where it was found that the accuracy of the system significantly deteriorates if the errors in measuring the distance and the azimuth angle exceed 0.1 m and 0.2°, respectively. An application example is provided to illustrate the algorithm used by the proposed system.

1. Introduction

At two-way stop-controlled (TWSC) rural intersections, the traffic on the non-controlled major road usually moves at relatively high speeds while the drivers on the stop-controlled minor road should rely on their judgement to perceive the speed and acceleration of the oncoming cross-traffic vehicles in order to estimate the available time gaps and select the ones that can be safely used to make their right-turning departures. However, many drivers may select improper time gaps for their

* Corresponding author. Tel.: +97125015634
E-mail addresses: essam.dabbour@adu.ac.ae (E. Dabbour), seasa@ryerson.ca (S. Easa).

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departures, which usually lead to serious collisions. This inadequacy in selecting proper time gaps may be explained by the fact that the perception of the human visual system to the speed and acceleration of in-depth moving objects is usually inadequate (López-Moliner et al., 2003; Watamaniuk and Duchon, 1992; Gottsdanker, 1956; Werkhoven et al., 1992; Watamaniuk and Heinen, 2003). Installing a traffic signal may theoretically have the potential to mitigate this problem, but this solution is not usually warranted (or desired) since traffic signals at rural intersections may lead to an increase in rear-end crashes (given that vehicles on the major road usually travel at relatively high speeds).

Another innovative solution to the above problem is to install an intersection collision warning system that measures the distance and speed of the nearest vehicle on the rightmost lane to warn the right-turning driver if there will be a potential conflict between the approaching and turnin vehicles. There were some attempts to propose intersection collision warning systems that meet this objective. Calspan Corporation developed the vehicle-mounted Intersection Collision Avoidance system (Pierowicz et al., 2000), which utilized an in-vehicle positioning system along with two 77 GHz (later replaced with 24 GHz) radar sensors with rotating antennae to detect the speeds of the vehicles approaching the intersection (using Doppler Effect) and warn the driver of the equipped vehicle in case of a potential conflict. The system's algorithm was based on the assumption that all approaching vehicles, as well as the equipped vehicle, are moving on constant speeds. The program also did not give any consideration for the time required for the driver of the equipped vehicle to perceive the warning message and react to it. Furthermore, the use of rotating antennae led to technical challenges in synchronizing the rotating speed of the antennae with the update rate of the radar beam, which may also compromise the precision in measuring both the distance and the speed. Additionally, using rotating antennae may be difficult to be implemented for commercial use.

Another vehicle-mounted intersection collision warning system was proposed by the INTERSAFE research project (Fuerstenberg and Chen, 2007; Fuerstenberg and Roessler, 2008), which utilized different technologies that include laser scanners, video camera, GPS and digital mapping. The video camera was used to recognize the lane marking, while the laser scanners were used to measure the distances and speeds of the approaching vehicles. The algorithm used in the system was designed to identify all possible conflicts between the equipped vehicle and all detected vehicles using data from high-level digital map. The system triggers a warning if the path of the equipped vehicle conflicts with the path of any of the detected vehicles. A probabilistic model for the behavior of all vehicles was deployed to determine the behavior of the drivers of detected vehicles.

In addition to the above vehicle-mounted intersection collision warning systems, there were some other attempts to develop cooperative and/or infrastructure-based warning systems. The INTERSAFE-2 system (Roessler and Westhoff, 2010) was an enhancement of the former INTERSAFE system that combined on-board sensing with infrastructure sensing in addition to vehicle-to-infrastructure (V2I) communications. The INTERSAFE-2 had the ability to automatically apply brakes in risky situations. This is in contrast with the former INTERSAFE system that only provided warnings to the drivers. In the United States, the Federal Highway Administration sponsored an Infrastructure Consortium, which consists of state Department of Transportations and Universities from Minnesota, Virginia, and California. Based on that, the University of Minnesota developed the Intersection Decision Support (IDS) system (Donath et al., 2007). The system utilized infrastructure-based sensing and communication technology to determine safe gaps in traffic and then communicates the information to the driver for safe departure. The system utilized an algorithm loaded on a central processor to determine available departure gaps at 10 Hz frequency. The system also utilized vehicle/driver classification system and weather/road condition sensing system.

This paper proposes an infrastructure-based intersection collision warning system for rural intersections. The proposed system has the objective of aiding unprotected right-turning drivers at high-speed rural intersections in selecting a proper gap for their departures. The system includes a detector (either a radar sensor or a laser scanner) that detects the nearest approaching vehicle on the rightmost lane along the major road and the system measures the positions and speeds of that nearest detected vehicle at two consecutive time intervals to determine its acceleration rate. The system's algorithm also estimates the distance and the time needed for the right-turning vehicle to accelerate to the same speed as for the approaching vehicle. Based on that, the system's algorithm warns the driver of the turning vehicle if any potential conflict is found between the approaching and turning vehicles. The system is actuated (and the algorithm is initiated) by utilizing a vehicle-presence detector (either another radar sensor or a simple loop detector) that detects vehicle presence on the minor road approach. The proposed system's algorithm gives consideration to the time needed by the driver of the right-turning vehicle to perceive the message displayed by the system and react to it (to start departure). This paper provides mathematical models to estimate the perception reaction time needed by the driver of the departing vehicle. That estimate is based on data collected from driving simulation by 60 different drivers. Since the departing vehicle typically starts from a stop position, the parameters related to its acceleration profile are needed to estimate the time and distance needed to accelerate to the same speed of the approaching vehicle. This paper also provides details on the regression models that were developed to establish the acceleration profile of the turning vehicle. These regression models are based on actual data collected from field experiments by utilizing a Global Positioning System (GPS) data logger device that recorded the positions (including latitudes, longitudes and altitudes) and the instantaneous speeds of different experimental vehicles at 1-s intervals. This paper also provides a methodology to select the maximum measurement errors allowed for the detector in measuring the locations (including the distances and the azimuth angles) of the approaching vehicle on the major road. The methodology is based on utilizing two different Matlab codes that were created to assess the performance of the proposed system under different levels of precision in measuring the distance and the azimuth angle so that optimal practical precision levels can be selected to ensure acceptable performance under different conditions. An application example is provided to illustrate