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# A Vehicle-pedestrian Two-way Collision Alert System Under Coordinated Vehicle Infrastructure Environment

## INTRODUCTION

### Vehicle-pedestrian safety problem

- Nowadays, vehicle-pedestrian collisions are common to see and threaten the safety of traffic participants, especially pedestrians, a vulnerable group of people. The number of pedestrians fatal and injured are 6,205 and 76,000 all around the U.S. in 2019.
- Under CVIS environment, real-time states of traffic participants can be obtained and real-time driver-assist strategies or collision alerts can be sent to the connected devices. However, few of these studies try to design a vehicle-pedestrian collision identification method that is suitable to the constructed system.
- How to deal with the system time delay problem when designing vehicle-pedestrian collision identification methods still needs to be studied.

### Purpose of this paper

- To proposes a vehicle-pedestrian two-way collision alert system under CVIS environment to provide timely collision alerts to the vehicles and the pedestrians
- To offset the system time delay

## PROBLEM DESCRIPTION

### Scope

- The task is to alert both the vehicle driver and the pedestrian that are about to collide by predicting their future trajectories, calculating their collision risks, and then sending the alerts via CVIS environment with the predefined data structure and system communications.

### Assumptions

- The location, speed, heading direction, and acceleration can be obtained in real-time. Under CVIS environment, sensing devices such as radar and cameras are able to obtain real-time location information of different participants. Moreover, their speeds, heading direction, and acceleration rates can be calculated based on historic location information.
- The acceleration rate of vehicles does not change when approaching the intersection. It is reasonable because the acceleration rates of vehicles seldom go up for safety reasons at intersections. On the other hand, if they get the acceleration rates down, the predicted vehicle trajectory based on the current acceleration rate is the most dangerous one and the collision alerts are still valid.

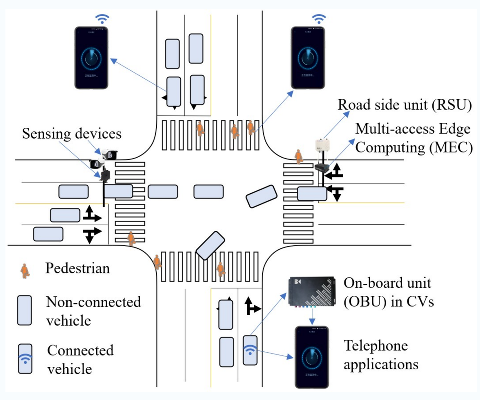


**Figure 1 Vehicle-pedestrian collision scenario at an intersection under CVIS environment.**

## PROBLEM FORMULATION

### Prediction Module

- The prediction is for all the vehicles and pedestrians in the control area in order to offset the system time delay. The system time is known in advance which is also the time length of the prediction. Kinematic formulations are used to predict the location and heading directions of vehicles and pedestrians. The prediction formulations are the same for both vehicles and pedestrians.
- The state prediction function at timestamp is shown in Equation (1); Equation (2) shows the posterior covariance matrix prediction function; Equation (3) represents the revision function of the state vector at timestamp ; The revision function of the posterior covariance matrix is shown in Equation (4).
- The state transfer function matrix is defined according to the kinematic functions, as shown in Equation (5). The measurement function is shown in Equation (6). It affects the measurement matrix. Therefore, it is defined as the state value itself and the measurement matrix is a unit diagonal matrix (see Equation (7)).

### Collision Risk Calculation

- After the prediction module, the collision risks of the vehicle-pedestrian pairs are calculated based on the predicted states. The collision risk of a vehicle and a pedestrian is measured by TTC, which is defined as the difference of the time to the collision point of the vehicle and that of the pedestrian. If TTC is smaller than the risk range, the risk of collision is high and both of them should be alerted.
- Whether the vehicle and the pedestrian have a collision point is based on their location and their heading direction. One location point and one heading direction form a radial. Therefore, the collision point should be the intersection of the two radials. Then, the intersection of the two lines is found by solving linear equations. To be more realistic, if their collision point is not inside the intersection, the vehicle-pedestrian pair will be removed and they will have no collision risks.
- For any vehicle-pedestrian pair that has a collision point, the time to the collision point of the vehicle and that of the pedestrian need to be calculated. Suppose that both the vehicle and the pedestrian are moving towards the collision point in a uniform linear motion. Consequently, the time to the collision point can be calculated with kinematic formulations, shown in Equation (8).
- Consequently, the difference of and , which is the collision risk indicator, TTC, can be calculated in Equation (9).

$$¿ T = \frac{\sqrt{(x_u - x_c)^2 + (y_u - y_c)^2}}{v_u} ¿ (8)$$

$$¿ TTC = |T_v - T_p| (9)$$

- With TTC representing the collision risks, a collision alert range of TTC needs to be determined. According to Baek et al. (2020), (0, 2.6) s of TTC range is a suitable alert range. Besides, the alert range of TTC should consider the time that a pedestrian passes through the width of a vehicle.
- Therefore, the results are calculated within a second, and this vehicle-pedestrian collision alert algorithm can be utilized online with real-time information. The complexity of the collision alert algorithm is , where and denote the numbers of vehicles and pedestrians in the sensing area, respectively.

## SYSTEM STRUCTURE

### Hardware structure

- To realize the previous vehicle-pedestrian collision alert algorithm, a CVIS control system needs to be constructed and the structure of the system should meet the requirements of the algorithm realization. The hardware structure of the CVIS control system is composed of six devices, which are sensing devices, MEC, the cloud center, RSU, OBU, and APP.
- MEC obtains information and data from the sensing devices and the cloud center as inputs to the collision alert algorithm. The output alerts are sent to RSU via Ethernet and then from RSU to OBU via the C-V2X communication protocol. After that, the output alerts are sent to the APP for CV drivers. In terms of the pedestrian ends, the alerts are sent to the cloud center via 4G/5G and then to the telephone via 4G/5G for pedestrians. The communication ways are different for CV drivers and pedestrians. For non-CV drivers, they receive alerts the same way as the pedestrians do.

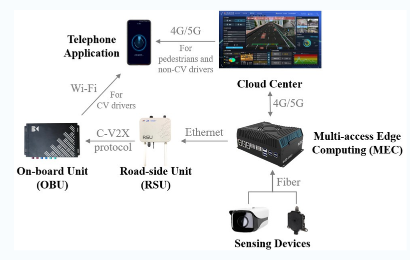


**Figure 2. Hardware structure.**

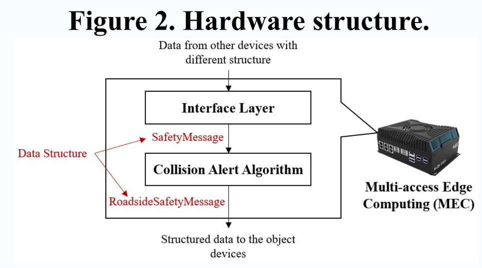


**Figure 3. Role of the data structure.**

### Data structure

- The data structure refers to the definition of the data used in the communication of the devices in the system. SafetyMessage is defined as the input data structure of the alert algorithm and RoadsideSafetyMessage is defined as the output of the algorithm. Data from other devices, such as the sensing devices, needs to be structured in the interface layer before inputting to the algorithm. The output data is structured to send to the object devices, such as RSU and the cloud center in this paper.

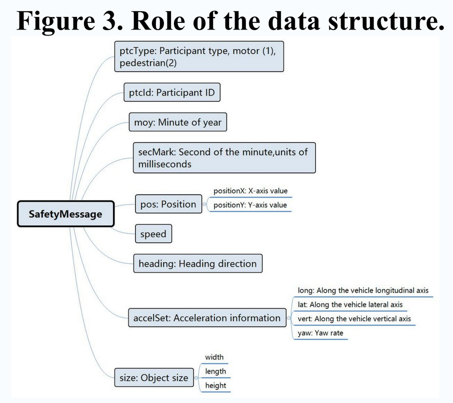


**Figure 4. Data structure of**

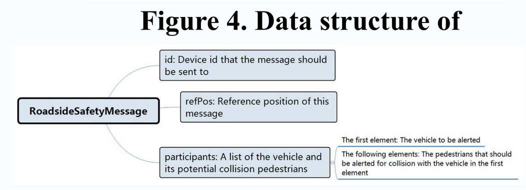


**Figure 5. Data structure of RoadsideSafetyMessage.**

## RESULTS AND ANALYSIS

### Numerical Studies

- In general, the four figures share a similar ladder-shaped area of the alert scenarios. Comparing the four figures, the collision alerts are generated when the vehicle is further away from the stop line with the increase in vehicle speeds.
- The vehicle-pedestrian collision alert algorithm is effective under different location and speed conditions.

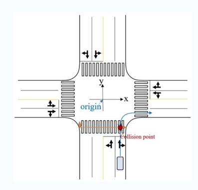

**Figure 6. Scenarios in numerical studies.**

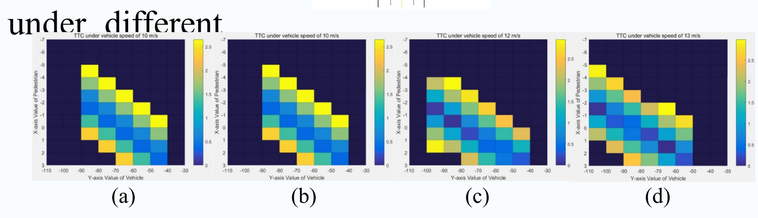


**Figure 7. Collision alert results under different vehicle speeds: (a) 10 m/s; (b) 11 m/s; (c) 12 m/s; and (d) 13 m/s.**

**Figure 8. Testing intersection in the map.**


**Figure 9. APP interface.**

### Field Test

- The testing intersection is a T-shape intersection in Jiading District, Shanghai.
- In the field test, not only the algorithm but also system architecture and communications are also tested. The validation tests are successful in all the scenarios.
- The sensing time, the data input time, the alert generation time, and the APP alert time are recorded. The average system time delay is 1.66 s, and the can be offset by the prediction module in the algorithm.

**Table 2 Time Delay in Field Tests**

| Timestamp 1 (ms) | Timestamp 2 (ms) | Timestamp 3 (ms) | Timestamp 4 (ms) |
|---|---|---|---|
| 1632882437347 | 1632882438723 | 1632882438829 | 1632882438849 |
| 1632882437447 | 1632882438893 | 1632882439029 | 1632882439059 |
| 1632882437747 | 1632882439079 | 1632882439231 | 1632882439271 |
| 1632882437847 | 1632882439547 | 1632882439632 | 1632882439662 |
| 1632882438047 | 1632882439731 | 1632882439834 | 1632882439874 |
| **Delay between Timestamp 1 and 2 (s)** | **Delay between Timestamp 2 and 3 (s)** | **Delay between Timestamp 3 and 4 (s)** | **Total time delay (s)** |
| 1.38 | 0.11 | 0.02 | 1.50 |
| 1.45 | 0.14 | 0.03 | 1.61 |
| 1.33 | 0.15 | 0.04 | 1.52 |
| 1.70 | 0.09 | 0.03 | 1.82 |
| 1.68 | 0.10 | 0.04 | 1.83 |

## CONCLUSION

### Contributions of this study

- This study proposes a vehicle-pedestrian two-way collision alert system under CVIS environment to provide timely collision alerts to both vehicle drivers and pedestrians to enhance traffic safety.
- Time delay problem in reality is suitably coped with, which is by establishing a prediction module using Kalman Filtering to predict the states of the vehicles and the pedestrians to offset the system time delay.
- To realize the vehicle-pedestrian two-way collision alert, a system composed of six types of hardware devices is constructed. The data structure is also designed for information communications in the system.
- Numerical studies and field tests validate the collision alert algorithm and the vehicle-pedestrian two-way collision alert system..

### Future work

- The prediction module can be replaced by other better state prediction methods for higher precision.
- Intersection signal control can be added as input information to improve the accuracy of the prediction and collision identification.

## ACKNOWLEDGMENTS

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**Table 1 Notations**

| Notations | Variable description | Notations | Variable description |
|---|---|---|---|
| | Current state of the object, including x-coordinate (m), y-coordinate (m), speed (m/s), heading direction (degrees), angular speed (degrees/s), and acceleration rate (m/s²). | | Predicted posterior covariance matrix at timestamp with the information at timestamp . |
| | Predicted state of the object, including the same contents of the current state. | | Covariance matrix of the multivariate normal distribution function of the state transfer noise. |
| | Coordinate values of the collision point, m. | | Measurement matrix. |
| | Predicted state vector at timestamp with the information at timestamp . | | Measurement function. |
| | State transfer function matrix. | | Covariance matrix of the multivariate normal distribution function of the measurement noise. |
| | Control matrix. | | Measurement vector. |
| | Controller input vector. | | Time to the collision point of an object, s. |
| | | | Time to the collision point of the vehicle (pedestrian), s. |
| | | | Time to collision indicator, s. |