CHAPTER 9

V2I-Based Multi-Objective Driver Assistance System for Intersection Support

Jianqiang Wang, Jiaxi Liu, Xiaohui Qin, Keqiang Li

State Key Laboratory of Automotive Safety and Energy, Tsinghua University, Beijing, China

Chapter Outline

Advances in Intelligent Vehicles. http://dx.doi.org/10.1016/B978-0-12-397199-9.00009-4

9.1 Introduction

With the use of automobiles increasing over the years, traffic accidents have become an increasingly severe problem. Data from the MTPRC (Ministry of Transport of the People's Republic of China) shows that intersection crashes account for 20% of all the accidents happening in China annually [1], and have caused many casualties and property loss due to the high vehicle density at the intersections. Many efforts have been made to improve the situation through infrastructure construction and traffic light optimization, but these attempts still could not solve the problem completely [2–4]. In recent years, the emergence of ADAS (Advanced Driving Assistance Systems) based on VIC (Vehicle Infrastructure Cooperation) offers a new way to address this matter [5].

As an important branch of ADAS, IDAS (Intersection Driver Assistance System) can reduce traffic violations greatly, and can also reduce accidents or even prevent them from occurring at intersections, and has attracted much attention worldwide.

The main idea behind IDAS is to prevent drivers from incurring traffic violations, violating red lights, for instance, through indicators, warnings or auto-braking. Also, IDAS perceives the timing of traffic lights through communication with the infrastructure, thus recommending to drivers an optimal driving speed to go through the intersection without unnecessary stopping on the basis of safety. IDAS can also inform drivers in advance if the green light is going to time out, which will give drivers more time to take the proper action, and thus improve driving comfort [6,7].

Much work has been conducted on IDAS, and can be divided into three categories: (a) V2I (Vehicle to Infrastructure) wireless communication; (b) vehicle positioning; (c) IDAS safety algorithms.

9.1.1 V2I Wireless Communication

Two kinds of wireless communication methods are used in V2I systems: (a) DSRC (Dedicated Short Range Communication) [8]; (b) beacon-based wireless communication technology.

DSRC is developed based on "IEEE 802.11 Wi-Fi". The advantages of DSRC include a high data transfer rate, low time delay, high stability, strong anti-jamming capability, and concentrated signal coverage. Therefore, DSRC is suitable for V2I systems that require stable communication for a specific section only [9,10].

DSRC has become the first choice for Intelligent Transportation Systems (ITS) based on V2I in Europe and the USA. However, the technical standard for DSRC is still under discussion. Therefore, many researchers apply some wireless communication technology that can be easily replaced by DSRC. In INTERSAFE conducted in Europe and VII directed in America, "IEEE 802.11b" was used, and an update to DSRC was planned [11–15].

Japan selected a beacon-based wireless communication method in its ITS. The practical system VICS (Vehicle Information and Communication System) applied radio wave and infrared beacons [16,17].

DSRC and beacons are two main wireless communication approaches used in ITS. However, each has its own advantages and disadvantages. Compared with beacon-based wireless communication, DSRC has a higher transfer rate, larger data processing capability, and broader coverage. However, it has a more stringent requirement on the hardware and is more sensitive to jamming. Beacon-based wireless communication adopts a fixed operating region and emission direction, so many beacons have to be installed around interested sections and thus the cost is a weak point, but its requirement for hardware is lower.

9.1.2 Vehicle Positioning Technology

Since IDAS can only work at intersections, a relative small area, we have to utilize a precise positioning method to provide accurate information, otherwise the performance of the assistance system cannot be guaranteed. The positioning precision should be high enough to distinguish different lanes, e.g. 1 m [11].

E-map-aided GPS positioning is now the most common way for positioning in the automobile industry. However, stand-alone GPS positioning cannot satisfy the precision demand of IDAS. In order to settle the problem, the BMW platform in Europe (INTERSAFE) and the American ICAS (Intersection Collision Avoidance System) adopted DGPS (Differential Global Position System) [11,18]. DGPS can reach a precision of 1 cm [19], which is accurate enough for IDAS. However, a large number of base stations have to be deployed so as to apply DGPS, and an accurate E-map is required.

The test vehicle VW in Europe INTERSAFE combined radar, machine vision, and detailed E-map to achieve accurate positoning.

Toyota used infrared beacon-based wireless communication to develop its IDAS. The vehicle could receive messages from the infrared beacon only in a specific small area and this determined the relative position between the vehicle and the intersection. After the beacon, the remaining distance between the host vehicle and the intersection was short enough for INS (Inertial Navigation System) to guarantee the precision [7].

9.1.3 IDAS Control Algorithm

The American IDAS adopted a fixed acceleration bound. IDAS monitored the vehicle speed and the remaining distance up to the intersection, and the real-time acceleration needed to stop the vehicle right at the intersection was calculated. Once the acceleration exceeded $0.35g$, a warning was generated [18].

IDAS in the literature [6] can get the phase and timing of the intersection in advance, and TTI (Time to Intersection) was calculated according to the current speed and the remaining distance to the intersection. A comparison between the TTI and the timing at the intersection would then be made in order to tell the driver the phase of the traffic light when the host vehicle arrived at the intersection.

On the basis of statistical data about speed change at the intersection, Ref. [20] proposed a warning algorithm based on speed threshold. To keep a low false alarm rate, the trends of speed change 1 s before warning should be taken into consideration. If the vehicle was slowing down, then the warning would be canceled so as not to distract the driver. This algorithm included driver characteristics, which made it more acceptable to drivers. However, the author did not put it into practice.

The IDAS created in Europe, INTERSAFE, not only gave out a warning on traffic light violations, but also provided recommended driving speeds based on current vehicle status, environmental information, and traffic lights. For instance, if the green light was changing and there was no other vehicle in front, then the system would suggest that the driver accelerate to pass the intersection before the green light changed.

In Ref. [7], Toyota's IDAS provided TSVW (Traffic Signal Violation Warning) and GLDS (Green Light Driving Support).

IDAS should take enough driver characteristics into consideration in designing the IDAS algorithm to enhance the acceptability of the system. Similarly, the information fusion of vehicle status and driver operation can reduce false warnings and missed warnings. A well-defined IDAS algorithm should take full advantage of I2V. Besides providing warnings against potential traffic signal violations, IDAS should also offer assistance information in non-dangerous situations to help the driver pass intersections without stopping and therefore improve traffic efficiency.

9.2 Structure of IDAS

The functions of IDAS include violation warning and driving comfort promotion. The following section describes the basic functions of IDAS and then the architectural structure of IDAS.

9.2.1 Function Definition of IDAS

The primary function of IDAS is to prevent drivers from incurring traffic signal violations. The On-Board Unit (OBU) of IDAS can receive the phase and timing of traffic signals as well as vehicle position, and therefore can provide other helpful information in those situations that are not dangerous and help the driver pass intersections without having to stop. Furthermore, rear-end collisions are a frequent occurence at intersections, so a rear-end collision warning should also be merged into IDAS. Hence, the functions of IDAS can be defined as follows:

1. **Passing Support (PS).** PS provides speed recommendations in non-dangerous situations and helps the driver to pass intersections without stopping or even without decelerating. PS aims at increasing intersection passing rates and reducing unnecessary stops, and therefore improves driving smoothness and comfort at intersections.
2. **Traffic Light Violation Warning (TLVW).** TLVW avoids traffic light violations through informing, warning the driver, or even automatically braking. In another aspect, when a green signal is about to finish, TLVW can also inform the driver in advance and avoid the sudden amber phase surprise for the driver that can lead to hard, uncomfortable braking. Therefore, TLVW improves driving safety and comfort at intersections.
3. **Rear-End Collision Warning (REW).** REW warns the driver in cases of imminent crash danger to provide him/her with a sufficient time margin to react. The range sensor (Radar or Lidar) of IDAS can detect/assess the various target vehicles ahead of the host vehicle and measure the kinematic attributes of each target. The speed sensor (e.g. ABS sensor) can measure the speed of the host vehicle. Alerts will be given to the driver in anticipation of an existing potential rear-end collision based on a warning algorithm.

9.2.2 Architecture of IDAS

Based on the function definition, the architecture of IDAS is designed as shown in Figure 9.1. The hardware of IDAS includes a Road-Side Unit (RSU) and OBU. RSU is a traffic light equipped with a wireless communication device, which broadcasts the signal phase and timing information for the intersection area. Dedicated Short-Range Communication (DSRC) is investigated worldwide as a wireless communication technology used in ITS, and will be the best solution for this application.

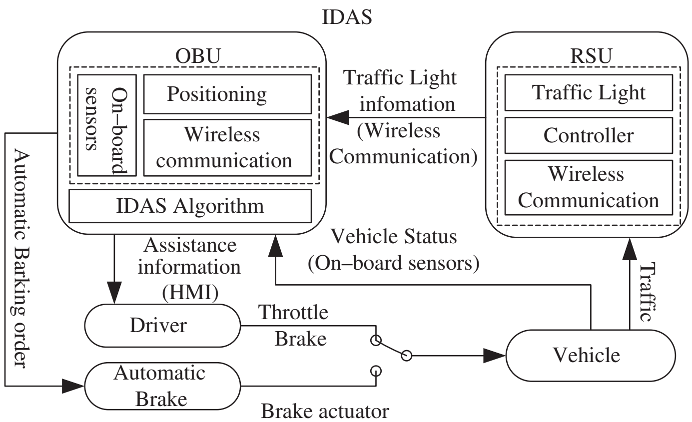

Figure 9.1: Architecture of IDAS.

In the OBU, the wireless receiver receives signals coming from the traffic light; positioning systems provide vehicle positioning at intersections; on-board sensors collect vehicle status information such as velocity, acceleration, and so on. According to the above information, the IDAS algorithm assesses the vehicle's situation, and determines the most suitable driving operation, whether to pass for driving smoothness and traffic efficiency or to yield to the signal and stop for safety.

In non-emergent situations, the OBU presents TLVW, PS or REW information to the driver through the Human—Machine Interface (HMI). When TLVW or REW is on, HMI gives multi-level visual and auditory warnings. When PS is on, HMI presents speed recommendations through a visual image and auditory information signal. In emergent situations when the driver fails to respond to the warning and the vehicle is going to violate the traffic signal, the OBU controls the vehicle to stop by automatic braking.

According to the system architecture, the layer configuration of OBU is shown in Figure 9.2. Except for the OBD described above, some infrastructure needs to be installed on the road side, such as a digital transceiver, traffic light equipped with wireless communication device, and a Radio-Frequency Identification (RFID) tag.

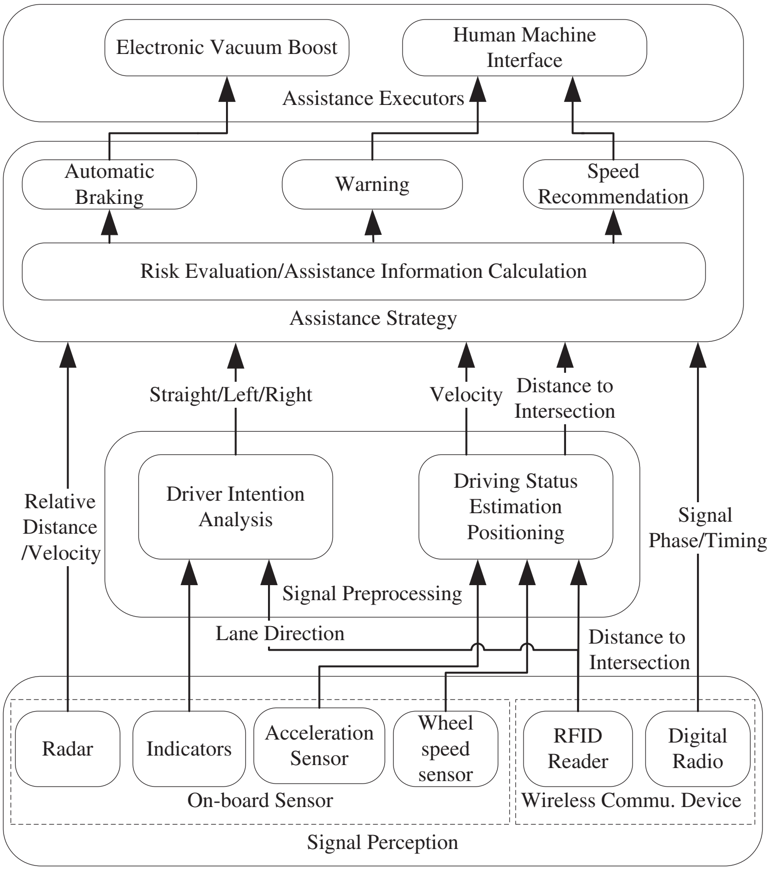

Figure 9.2: Layer Configuration of On-Board Unit.

Also, the following four key technologies are needed to develop a complete IDAS:

1. Accurate positioning with respect to intersection
2. Vehicle status estimation
3. IDAS algorithm fully accepted by drivers
4. Vehicle control technology.

9.3 IDAS Algorithm

Based on the architecture described above, the following section describes signal perception level algorithms of IDAS, including vehicle status estimation based on a Kalman filter, vehicle positioning technology based on RFID, and driver intention recognition. Then algorithms of PS and TLVW are demonstrated below.

9.3.1 IDAS Signal Perception Level Algorithms

Signal perception level algorithms process raw signals to determine vehicle speed, relative distance to the intersection, and driver's intention, which are necessary for core algorithms.

Vehicle Status Estimation

Vehicle status including vehicle speed and acceleration are important inputs to IDAS. The signal wheel speed sensor is not reliable in driving conditions due to tire slippage. Additionally, noise pollutes the signal from the accelerometer and renders it unusable.

Based on the literature [21−23], an algorithm is designed to estimate vehicle speed and filtered acceleration as shown in Figure 9.3 [24], where Bias Correction is used to compensate the zero drift of the accelerometer as shown in Eq. (9.1). Slip estimation is explained in Eq. (9.2) and the Kalman filter is depicted in Eq. (9.3):

$$a_{\mathrm{m}}^{*}(k) = a_{\mathrm{m}}(k) - a_{\mathrm{bias}} \tag{9.1}$$

$$\begin{aligned} &\lambda = f(F_x/F_z) \\ &F_z = M/L\cdot(l_{\mathrm{a}}\cdot g + H\cdot a) \\ &F_x = \begin{cases} M\cdot g\cdot f & F_{\mathrm{b}} = 0 \\ -a\cdot M\cdot \beta & F_{\mathrm{b}} > 0 \end{cases} \end{aligned} \tag{9.2}$$

$$\begin{aligned} \begin{bmatrix} v(k) \\ a(k+1) \end{bmatrix} &= \begin{bmatrix} 1 & \tau \\ 0 & 1 \end{bmatrix} \begin{bmatrix} v(k) \\ a(k) \end{bmatrix} + \begin{bmatrix} 0 \\ \tau \end{bmatrix} w_{\mathrm{at}} \\ \begin{bmatrix} v_{\mathrm{wm}}(k) \\ a_{\mathrm{m}}^{*}(k) \end{bmatrix} &= \begin{bmatrix} 1-\lambda & 0 \\ 0 & 1 \end{bmatrix} \begin{bmatrix} v(k) \\ a(k) \end{bmatrix} + V. \end{aligned} \tag{9.3}$$

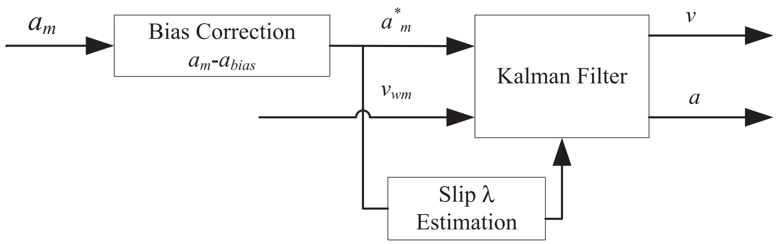

Figure 9.3: Kalman Filter for Velocity and Acceleration Estimation.

In Eq. (9.1), a_m is the raw signal from the accelerometer and a^*_m is the modified signal. K is time tag and a_bias represents the zero drift of the accelerometer.

In Eq. (9.2), λ stands for tire slip and F_z denotes the load on the driven axle, F_x represents the longitudinal force from the driven axle, L is the wheel base, l_a is the distance between the front axle and the mass center, H is the height of the mass center, M stands for the overall mass of the vehicle, f is the coefficient of rolling resistance, a represents vehicle acceleration, g is the acceleration of gravity, and β is the ratio of braking force on the rear axle, which accounts for the total braking force of the vehicle.

In Eq. (9.3), v represents the real velocity of the vehicle, v_wm stands for the rotation speed of the driven wheel, wat means system noise, V is the two-dimensional observation noise, and τ is the time step of calculation. The filtering results are shown in Figure 9.4.

Vehicle Positioning

Vehicle positioning method

RFID is a technology that uses radio waves to transfer data from an electronic tag, called an RFID tag or label, through a reader attached to an object for the purpose of identifying and tracking the object. Some RFID tags can be read from several meters away and beyond the line of sight of the reader. RFID has many applications. Logistics and transportation are major areas of implementation for RFID technology. For example, yard management, container shipping, and freight distribution use RFID tracking technology. Transportation companies around the world pay great attention to RFID technology due to its impact on business value and service efficiency.

Here, a real-time RFID-based vehicle positioning method is described. A series of passive RFID tags are mounted in the middle of lanes on the road surface, and store position information, distance information to intersection, lane number, lane direction and road curvature, gradient, etc. When the vehicle passes over an RFID beacon, the RFID reader and antenna carried by the vehicle activate the tag and read the information. Then the

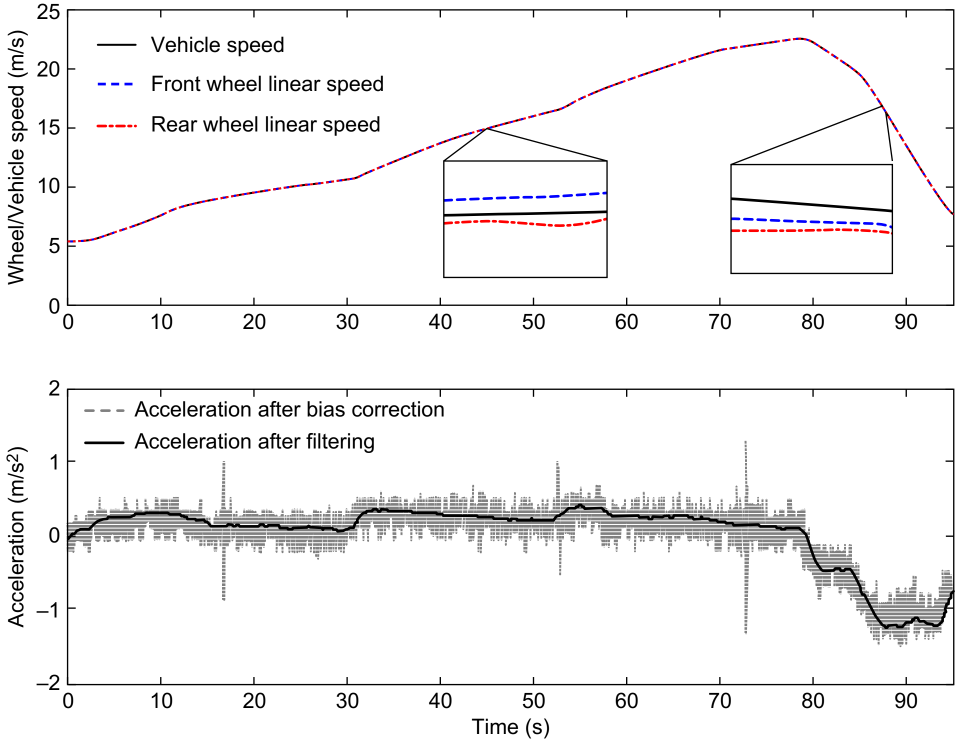

Figure 9.4: Filtering Results of Acceleration and Speed.

On-Board Unit (OBU) uses the information acquired from the RFID beacon to identify the vehicle's current position. Such a configuration is opposite to what is commonly used — the reader is fixed and the beacon is on the vehicle. It is this new configuration that brings significant advantages for much more accurate vehicle positioning that many other sensor technologies cannot provide.

The layout of the RFID beacons and the reader in the vehicle is depicted in Figure 9.5. Although more tags in the road will improve the positioning accuracy, only two RFID tags in each lane near the intersection are assumed to reduce costs (e.g. one is at the stop line and the other one is 150 m upstream).

Positioning data read and distance estimate

RFID beacons are distributed discretely in lanes. As a result, the input data acquired from RFID beacons are discontinuous. IDAS should provide the driver with continuous and reliable assistance information. To generate continuous positioning data with adequate accuracy, vehicle kinematics is fused with the RFID beacons data, as depicted in Figure 9.6.

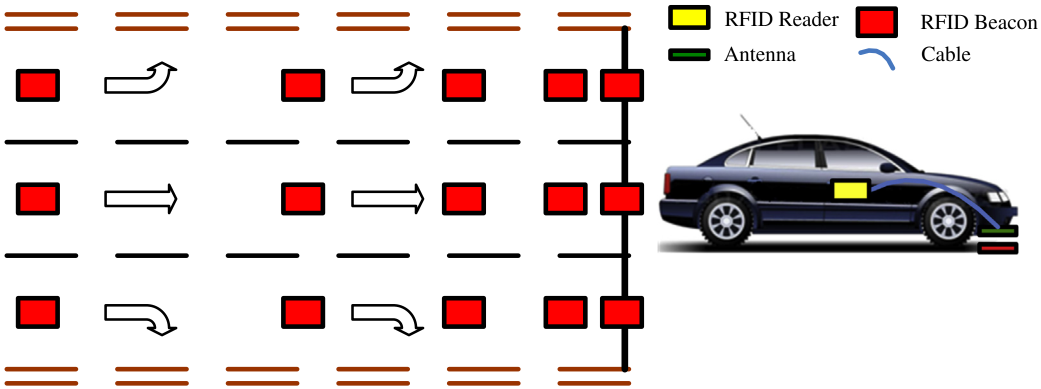

Figure 9.5: Layout of RFID Beacons and Reader.

The vehicle position can then be calculated by

$$d_{\text{2inter}} = d_{\text{tag}} - d_{\text{integration}}$$
$$d_{\text{integration}} = \begin{cases} 0 & \left|F_{\text{tag}}\right| = 1 \\ \sum\limits_{k=0} v(k)\cdot\tau + \frac{1}{2}\sum\limits_{k=0} a(k)\cdot\tau^2 & F_{\text{tag}} = 0, \end{cases} \tag{9.4}$$

where d_{2inter} is the current distance to the intersection; d_{tag} is the stored distance information obtained from the RFID tag at the last time; $d_{\text{integration}}$ is the driving distance integrated from the speed; F_{tag} is the road position flag with value 1 when the system can get the information from the RFID tag, and 0 otherwise; k is the data sequence number, starting the count when the system reads the tag and reset to 0 before reading the next tag; and v and a are vehicle speed and acceleration respectively.

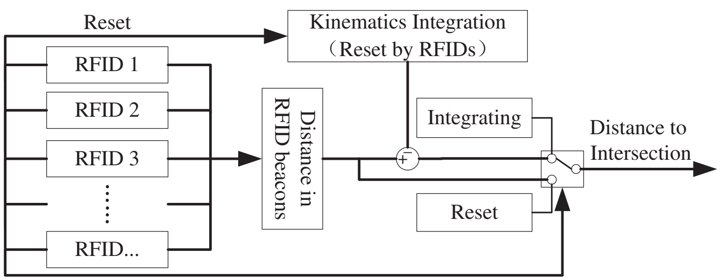

Figure 9.6: Algorithm of Vehicle Positioning.

On going a step further, position methods based on GPS and RFID can be fused. When the signal is of good quality, GPS is used to yield the accurate position, and thus fewer RFID beacons need to be installed. When the signal quality is limited, RFID is applied to calculate the accurate position. Fusion of these applications will make it possible to achieve better results.

Experimental verification

As mentioned above, the vehicle positioning approach is based on RFID. When the vehicle is passing over the tag, the vehicle position is given by the accurate position information previously stored in the tag (ground truth). Otherwise the vehicle position is estimated by kinematics integration. The lane information can also be obtained by the tag.

The position accuracy can be ensured by two aspects. (1) RFID is a short-range-oriented wireless communication set. The RFID readers on the vehicle can only receive the tag's information within 2 m. Also, the antenna facing direction would prevent the reader from receiving strong signals from the tag further away, which the antenna is not directed to. (2) Although the cumulative error of the distance estimation from the speed may increase with the moving distance, the known distance between two adjacent tags is relatively short and can be used to correct the error. In order to validate the method and the accuracy of the positioning, one test method is proposed by radar measurement below.

The main idea of this experiment is to use the calibrated radar distance measure to check the accuracy of the proposed positioning approach. The experimental vehicle and the test yard are shown in Figure 9.7. The experimental vehicle is equipped with a millimeter-wave radar set and an RFID reader. The radar is installed on the vehicle's front bumper. The radar wave beam faces the vehicle's running direction. The antenna is installed below the front bumper facing the ground. The tags installed on the test road have the same configuration as at an intersection (one at the stop line and the other at a certain distance, such as 100 m upstream). A fixed target is mounted on the driveway of the vehicle, via which the on-board radar can detect its distance.

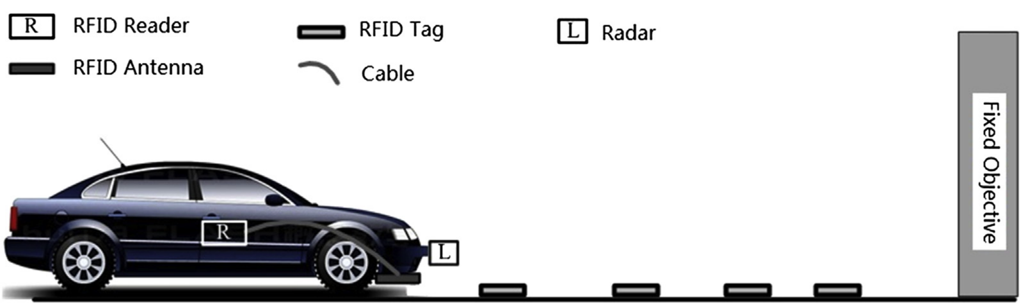

Figure 9.7: Position Approach Experimental Validation.

As is shown, the accuracy of the radar is within 1 meter, which is adequate for the validation. The radar measured distance and the distance estimated from the RFID are compared to check the accuracy, which can be conducted either online or offline.

The experimental scenarios include different vehicle speeds: constant, acceleration, and deceleration over several periods of time. The on-board computer estimates the distance between the test vehicle and the tag at the stop line. Meanwhile, the radar measures the distance between the vehicle and the fixed target. The data are recorded by CANoe through the CAN Bus. CANoe is a development and test software tool for a single ECU or for ECU networks. One of the test results is shown in Figure 9.8.

From the figure, the continuous curved line is obtained based on the position information stored in the first tag (top left of Figure 9.8) and the kinematics integration from the speed. It coincides with the dashed curved line obtained by radar detection, which shows that the estimated distance to the stop line using the proposed approach is equivalent to the radar measured distance. Similarly, the '×' marks on the continuous curved line mean that the estimated distance is equivalent to the accurate distance at tag locations. The experimental results demonstrate the feasibility of the proposed vehicle positioning approach.

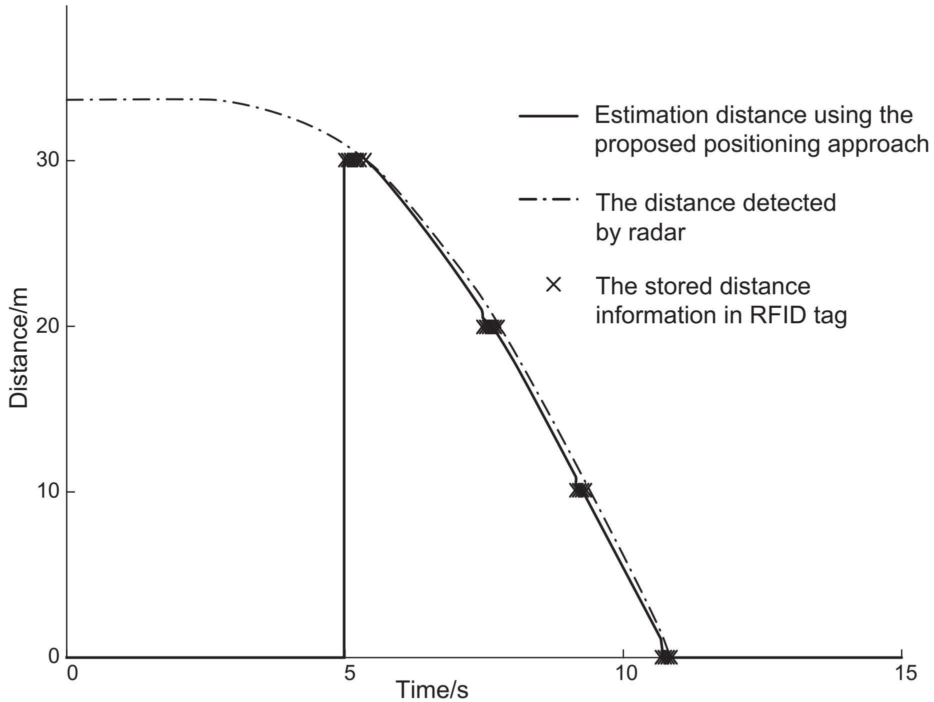

Figure 9.8: Positioning Test Result.

9.3.2 Driver Intention Recognition

The driver's intention is the driver's choice at an intersection, i.e. in which direction they are about to go, including straight ahead, left turn, and right turn.

Two messages can be used to judge the driver's intention when approaching an intersection: (a) steering light; (b) the lane in which the host vehicle is in now. The judging law can be explained using Table 9.1.

Table 9.1: Driver Intention Judgment Table

Lane Direction	Steering Light	Driver's Intention
Straight ahead	–	Straight ahead
Left turn	–	Left turn
Right turn	–	Right turn
Straight ahead or left turn	Off	Straight ahead
	Left turn light	Left turn
Straight ahead or right turn	Off	Straight ahead
	Right turn light	Right turn light
All directions	Off	Straight ahead
	Left turn light	Left turn light
	Right turn light	Right turn light

9.3.3 IDAS Assistance Algorithm

When driving at intersections, vehicles may be in various scenarios and situations that can be classified into 19 typical types according to three factors: traffic control signal (green, amber, red or stop sign); driver's intended direction (straight ahead, right turn or left turn); presence of leading vehicle (LV; present or not).

These 19 typical scenarios have one thing in common, that the final behavior of the vehicle will be either passing or stopping. An algorithm of Passing Support (PS) is designed for scenarios in which the vehicle can pass the intersection, whereas the algorithm of Traffic Light Violation Warning (TLVW) is designed for scenarios in which the vehicle has to stop at the stop bar. The additional Rear-End collision Warning (REW) algorithm is for the possibility of potential rear-end collisions. The final hybrid IDAS algorithm is formed by matching the three algorithms with every typical scenario.

Overall Structure of IDAS Assistance Algorithm

The overall structure of the IDAS assistance algorithm is shown in Figure 9.9. The assistance algorithm is composed of two modules: Assistance Function 1 and Assistance Function 2. Input signals determine which module will be executed.

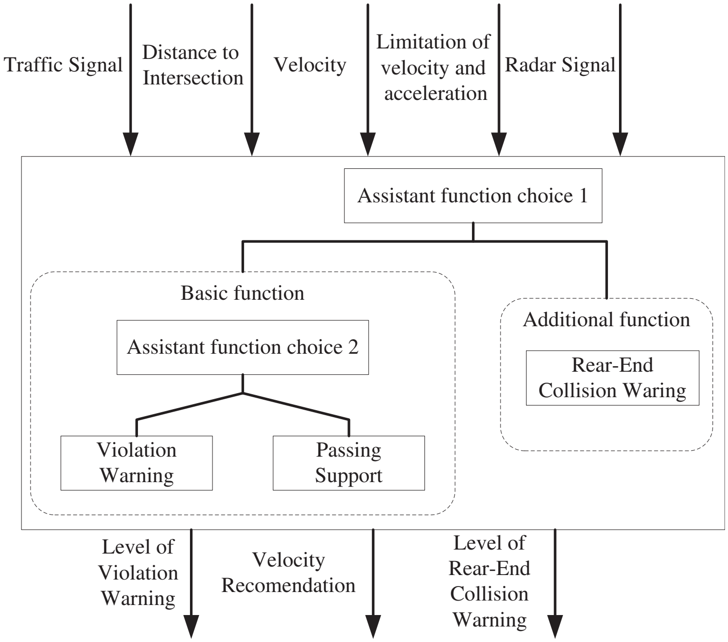

Figure 9.9: Structure of IDAS Assistance Algorithm.

RCW has a higher priority in Assistance Function 1. Whenever there is a possibility of a rear-end collision, a warning will be released first. Assistance Function 2 is based on critical speed. Critical speed is defined as the lowest final speed the host vehicle must reach in order to go through the intersection under the condition of a comfortable acceleration or deceleration. If the critical speed does not violate the traffic laws, then PS will be carried out. Otherwise, TLVW will be applied.

Rear-End Collision Warning Algorithm

REW is an additional function of IDAS. Currently, much research work has been done about rear-end collision warning. According to a literature review and field tests, an algorithm with multiple levels based on Time to Collision (TTC) has the advantages of simple architecture and variable sensitivity for different types of drivers. Therefore, it possesses a higher level of practicability and driver acceptance.

TTC is defined as the ratio of relative distance and velocity between the leading vehicle and host vehicle as shown in Eq. (9.5), and two warning thresholds are designated as TTC_{warn1} and TTC_{warn2}:

$$TTC = \frac{d_{2lead}}{v_{rel}}, \quad (9.5)$$

where d_{2lead} is the relative distance between the leading vehicle and host vehicle, and v_{rel} is the relative speed.

The REW algorithm is designed as follows:

1. $TTC > TTC_{warn1}$: No danger of collision, inform the driver of the leading vehicle's existence.
2. $TTC_{warn2} < TTC < TTC_{warn1}$: Certain danger of collision exists, issue warning level 1.
3. $TTC < TTC_{warn2}$: Great danger of collision exists, issue warning level 2.

The values of TTC_{warn1} and TTC_{warn2} represent the sensibility of the algorithm and can be adjusted by the driver as shown in Table 9.2. The more aggressive the driver, the smaller the values.

Table 9.2: REW Threshold

Sensibility Level	Speed <50 km/h	Speed >50 km/h
1	1.5 s	2 s
2	2.5 s	6 s
3	4 s	6 s
4	6 s	8 s
5	8 s	10 s

PS Control Algorithm based on Critical Speed

The PS algorithm calculates the speed recommendation and at the same time forms a reference for switching between the two functions of PS and TLVW. A PS algorithm is proposed based on a Critical Passing Speed (CPS), which is defined as the speed to which the vehicle should adapt at a limited acceleration that is comfortable for the driver, if the vehicle passes the stop bar at the very time point in which the traffic light changes from green to amber or from red to green. The two main parts of the PS algorithm are the calculation of CPS and the feasibility evaluation of CPS respectively, as described in Figure 9.10.

Three questions should be considered in the calculation of CPS. (1) If the CPS is presented to the driver as a speed recommendation, the driver needs a reaction time to interpret and respond. After the driver's response, the vehicle powertrain system also needs a certain amount of time to react to the driver's operation. (2) The vehicle will experience a speed-changing process from its current speed to the recommended one. (3) After the speed-changing process, the vehicle may still need to drive a distance to pass the stop bar.

Calculation of critical speed and its feasibility in green light and red light situations are discussed separately.

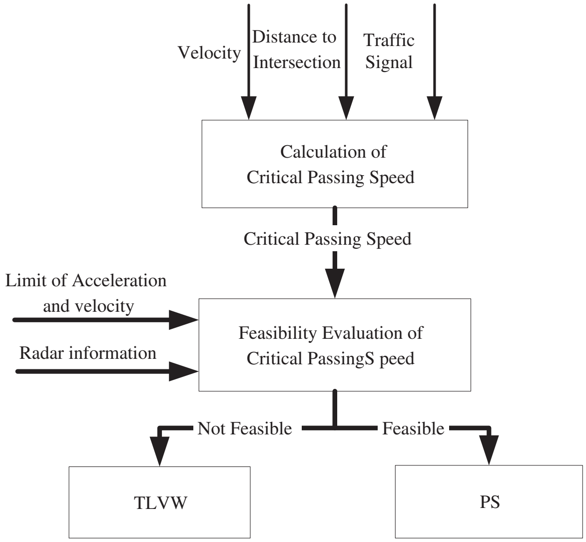

Figure 9.10: Structure of PS Algorithm.

For a green light, ignoring the previous motion state, suppose that the host vehicle will maintain a constant speed from the current position. Then the critical speed to get through the intersection in the remaining time of the green light can be calculated by

$$v_{\text{threshold,app}} = \frac{d_{2\text{inter}}}{t_{\text{left,g}}}, \tag{9.6}$$

where $d_{2\text{inter}}$ is the distance between the vehicle and the stop bar, $t_{\text{left,g}}$ stands for the remaining time of the green light, and $v_{\text{threshold,app}}$ represents the critical speed.

If $v_{\text{threshold,app}}$ satisfies inequality (9.7), then no further calculation is needed:

$$v_{\text{threshold,app}} \le v_{\text{cur}}. \tag{9.7}$$

If the inequality (9.7) is not satisfied, it means more acceleration to get through the intersection is required, and we have to re-calculate the critical speed.

Three hypotheses were proposed in order to simplify the calculation: (1) During the reaction time for the driver and powertrain, the vehicle speed is constant. (2) In the speed-changing process, the vehicle speeds up or slows down at a constant acceleration whose value is the upper or lower limit from the driver's comfort perspective. (3) After the speed-changing process, the vehicle drives constantly at the recommended speed. According to the hypothesis above, the calculation of CPS can be expressed as

$$\begin{cases} d_{\text{re}} = v_{\text{cur}} \cdot t_{\text{re}} \\ t_{\text{acc}} = \dfrac{v_{\text{threshold}} - v_{\text{cur}}}{a_{\max}} \\ d_{\text{acc}} = \dfrac{v_{\text{threshold}}^2 - v_{\text{cur}}^2}{2a_{\max}} \\ d_{\text{const}} = v_{\text{threshold}}\left(t_{\text{left,g}} - t_{\text{re}} - t_{\text{acc}}\right) \\ d_{2\text{inter}} = d_{\text{re}} + d_{\text{acc}} + d_{\text{const}}, \end{cases} \tag{9.8}$$

where t_{re} is the sum of driver and vehicle powertrain reaction time; v_{cur} is the current vehicle speed; d_{re} is driving distance under hypothesis (1); $v_{\text{threshold}}$ is the CPS; $a_{\max}$ is the maximum acceleration or minimum deceleration; t_{acc} is the acceleration or deceleration time under hypothesis (2) and d_{acc} is the driving distance under hypothesis (2); $t_{\text{left,g}}$ is the traffic light expected changing time; d_{const} is the driving distance under hypothesis (3); and $d_{2\text{inter}}$ is the current distance to intersection.

Equation (9.8) is a quadratic formula that is not easy to solve by a controller in practice. Numerical methods are better solutions.

After yielding $v_{\text{threshold}}$, its feasibility will be checked based on two limits:

1. $v_{\text{threshold}}$ does not violate traffic laws. If $v_{\text{threshold}}$ exceeds the limit of the traffic laws, then it is unfeasible and TLVW algorithms should be applied.
2. There is a possibility of rear-end collision. The situation can be divided into two sub-situations: (a) the leading vehicle cannot get through the intersection; (b) the leading vehicle can pass the intersection, but the host vehicle will be too close to it after acceleration in order to go through the intersection. These two situations will be discussed separately below.

In the first situation, the leading vehicle cannot pass the intersection in the remaining time of the green light. So the host vehicle must stop as well to avoid collision. Suppose the leading vehicle maintains a constant speed, then if Eq. (9.9) is met, the leading vehicle will have to stop, which makes PS unfeasible. Then the assistance algorithm should turn to TLVW.

$$\begin{aligned} & d_{2\text{inter,lead}} = d_{2\text{inter}} - d_{\text{rel}} \\ & v_{\text{cur,lead}} = v_{\text{cur}} - v_{\text{rel}} \\ & \frac{d_{2\text{inter,lead}}}{v_{\text{cur,lead}}} > t_{\text{left,g}}, \end{aligned} \tag{9.9}$$

where $d_{2\text{inter,lead}}$ is the distance between the leading vehicle and intersection, d_{rel} is the relative distance between the host vehicle and leading vehicle, $v_{\text{cur,lead}}$ stands for the speed of the leading vehicle, and v_{rel} represents the relative speed with respect to the leading vehicle.

In the second situation, although the leading vehicle is able to pass the intersection, the host vehicle has to accelerate to a high speed in order to get through the intersection too. Thus, the relative distance between the two vehicles may be too small considering the safety factors. Here, we define a Critical Dangerous Relative Distance (CDRD) as explained by Eq. (9.10). Whenever CDRD is reached, the situation is classified as dangerous.

$$d_{\text{danger}} = \begin{cases} \text{TTC}_{\text{limit}} \cdot \left(v_{\text{threshold}} - v_{\text{cur,lead}}\right) + d_{\text{offset}} & v_{\text{threshold}} > v_{\text{cur,lead}} \\ d_{\text{offset}} & v_{\text{threshold}} < v_{\text{cur,lead}} \end{cases}, \tag{9.10}$$

where d_{danger} is the CDRD defined above and d_{offset} is introduced into the equation to make the algorithm more conservative.

If critical speed is smaller than the speed of the leading vehicle, a rear-end collision will not be possible, then the critical speed can be recommended to drivers. Otherwise, a further calculation is needed.

Acceleration is needed to reach the critical speed. Whether there will be a possible collision or not depends on the relative distance. If the CDRD is reached, it is considered as a dangerous situation. Displacement of the host vehicle during the acceleration process can be calculated using Eq. (9.11), and the danger criterion is expressed by the inequality (9.12). If the relative distance between the two vehicles after acceleration is smaller than CDRD, i.e. inequality (9.12) is satisfied (collision may happen), the critical speed calculated above should not be applied.

$$d_{\text{acc}} = \begin{cases} \dfrac{v_{\text{threshold}}^2 - v_{\text{cur}}^2}{a_{\max}} & v_{\text{threshold}} > v_{\text{cur}} \\ 0 & v_{\text{threshold}} < v_{\text{cur}} \end{cases} \tag{9.11}$$

$$d_{\text{lead,acc}} = v_{\text{cur,lead}} \cdot t_{\text{acc}}$$

$$d_{\text{rel}} + d_{\text{lead,acc}} - d_{\text{acc}} < d_{\text{danger}}. \tag{9.12}$$

If inequality (9.12) is not satisfied, further judgment is needed.

If the critical speed is larger than the speed of the leading vehicle, there is still a potential danger of collision. The possibility of collision is determined by t_{danger}, the time during which the host vehicle accelerates from its original position till the moment its relative distance reaches CDRD. The relationship between t_{danger} and CDRD can be represented by

$$d_{\text{danger}} = d_{\text{rel}} + v_{\text{cur,lead}} t_{\text{danger}} - \left[d_{\text{acc}} + v_{\text{want}}\left(t_{\text{danger}} - t_{\text{acc}}\right)\right]. \tag{9.13}$$

If inequality (9.14) is satisfied, the danger will occur before the stop bar and therefore the critical speed should not be applied. Otherwise, collision avoidance can be achieved after the intersection.

$$t_{\text{danger}} = \frac{d_{\text{rel}} - d_{\text{acc}} + v_{\text{want}} t_{\text{acc}} - d_{\text{danger}}}{v_{\text{want}} - v_{\text{cur,lead}}} < t_{\text{left,g}}. \tag{9.14}$$

The PS problem is addressed while the traffic light is red. Again, there are two situations. (a) Critical speed is larger than the current vehicle speed. This means that when the vehicle reaches the stop bar, the traffic light is already green. So there is no need to pause at the stop bar. (b) Critical speed is smaller than the current vehicle speed. The vehicle should decelerate so as to avoid stopping before the stop bar when the traffic light changes from red to green. Suppose the host vehicle maintains a constant speed and arrives at the stop bar when the traffic light turns green, then we have an equation as expressed by

$$v_{\text{threshold,app}} = \frac{d_{\text{2inter}}}{t_{\text{left,r}}}, \tag{9.15}$$

where d_{2inter} is the distance between the host vehicle and stop bar, $t_{\text{left,r}}$ is the remaining time of the red light, and $v_{\text{threshold,app}}$ denotes an initial calculated critical speed.

If $v_{\text{threshold,app}}$ satisfies inequality (9.16), in that the CPS $v_{\text{threshold}}$ equals $v_{\text{threshold,app}}$, the calculation of critical speed is terminated. Otherwise, more calculations are necessary to yield a new useful critical speed.

$$v_{\text{threshold,app}} \geq v_{\text{cur}}. \tag{9.16}$$

In order to simplify the calculation of critical speed, three hypotheses are proposed:

1. The vehicle maintains a constant speed during the reaction time of the driver and powertrain.
2. The vehicle adopts a constant deceleration in order to decelerate to a recommended speed, and the deceleration is within the range in which the driver feels comfortable.
3. After reaching the recommended speed, the vehicle will maintain that speed.

Based on these hypotheses, we have the following formulae to calculate critical speed:

$$\begin{cases} d_{\text{re}} = v_{\text{cur}} \cdot t_{\text{re}} \\ t_{\text{decc}} = \dfrac{v_{\text{cur}} - v_{\text{threshold}}}{d_{\text{max}}} \\ d_{\text{decc}} = \dfrac{v_{\text{cur}}^2 - v_{\text{threshold}}^2}{2d_{\text{max}}} \\ d_{\text{const}} = v_{\text{threshold}} \left(t_{\text{left,r}} - t_{\text{decc}} - t_{\text{re}} \right) \\ d_{\text{2inter}} = d_{\text{re}} + d_{\text{decc}} + d_{\text{const}}, \end{cases} \tag{9.17}$$

where d_{re} is the displacement of the host vehicle in reaction time, d_{max} is the maximum deceleration that makes the driver feel comfortable, t_{decc} is the time it takes for the host vehicle to decelerate to the recommended speed from its original speed, d_{decc} is the corresponding displacement, and $t_{left,r}$ is the remaining time of the red light.

If the real root of Eq. (9.17) does not exist, it means the host vehicle cannot pass the intersection without pausing, and TLVW should be applied.

The feasibility should be checked after yielding $v_{threshold}$, and two factors are worthy of consideration:

1. If the $v_{threshold}$ obtained from Eq. (9.17) is too low, the host vehicle may cause a negative effect on other vehicles. Also, it would not make any sense if the critical speed is too low. Therefore, TLVW should be applied in this situation.
2. If LV exists, the motion of the host vehicle will be limited, and under such conditions TLVW should be applied.

Algorithm of TLVW

When critical speed is not feasible and the vehicle has to stop at the intersection, the TLVW is active. When the TLVW perceives that the driver is about to violate the traffic signal, it gives visual and auditory warnings, or automatically brakes the vehicle when necessary. Furthermore, TLVW informs the driver about the upcoming signal change in advance, and avoids the situation where a sudden change surprises the driver, which results in hard braking.

A dynamic TLVW algorithm with many levels is proposed based on velocity thresholds, which are defined as velocity profiles of the vehicle when it stops at the stop bar with constant decelerations of -1.5, -3, and -5 m/s^2. These deceleration values are selected based on driver behavior characteristics such as stop behavior at intersections [20], traffic light violation possibility [18], and comfortable acceleration [25,26]. The velocity vs. distance-to-intersection coordinate is divided into four warning zones, as described in Figure 9.11.

According to Figure 9.11, a static TLVW is defined as follows:

1. $v < v_{thre,warn1}$: Informing
2. $v_{thre,warn1} < v\ v_{thre,warn2}$: TLVW warning level 1
3. $v_{thre,warn2} < v < v_{thre,inter}$: TLVW warning level 2
4. $v > v_{thre,inter}$: Automatic braking.

According to statistics of velocity profiles of vehicles that stop at intersections, even though drivers yield to the traffic signal and stop, more than 50% of velocity profiles will exceed the warning threshold during deceleration [20]. Therefore, a static algorithm will result in a high false warning rate. To solve this drawback, the history of velocity profiles should be taken into account when designing TLVW algorithms. A TLVW algorithm checks vehicle

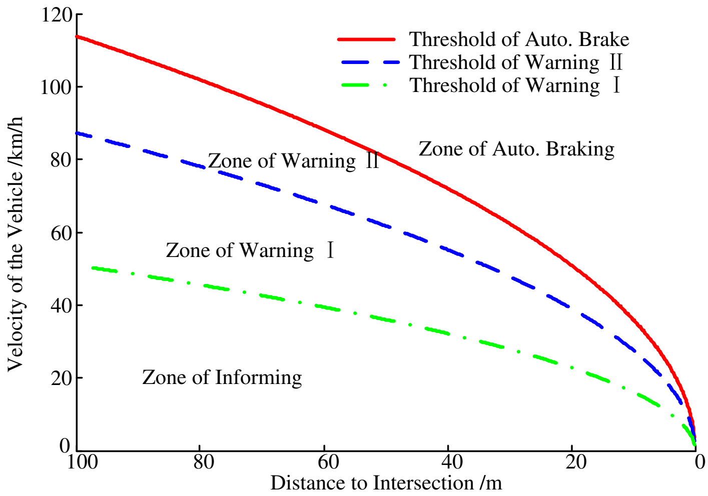

Figure 9.11: Warning Zones of TLVW.

acceleration at the last second before the velocity crosses the warning thresholds. If vehicle acceleration shows that the driver has already yielded to the traffic light, the warning will be canceled. Otherwise TLVW gives a warning according to the current warning zone.

Matching IDAS Algorithms with Driving Scenarios at Intersections

As described above, a vehicle may be in 19 typical scenarios when driving toward an intersection. For each scenario, the traffic control signal and detail regulation will be different, so the above three algorithms cannot simply be combined, and certain adjustments should be made to match the algorithms to each scenario, as described in Table 9.3.

Table 9.3: Matching ITLAS algorithm with driving scenarios at intersections

			REW	PS	TLVW
Green	Straight	LV	×	√	No braking
		Non-LV	√	√	No braking
	Left turn	LV	×	×	No braking
		Non-LV	√	×	No braking
	Right turn	LV	×	×	Only inform
		Non-LV	√	×	Only inform
Amber	Straight and left turn	LV	×	×	√
		Non-LV	√	×	√
	Right turn	LV	×	×	Only inform
		Non-LV	√	×	Only inform
Red	Straight and left turn	LV	×	√	√
		Non-LV	√	×	√
	Right turn	LV	×	×	Only inform
		Non-LV	√	×	Only inform
Stop sign			√	×	√

9.4 Simulation of IDAS

9.4.1 Simulation Model based on Simulink

In order to verify the IDAS algorithm and access its effect on intersection driving, a micro-simulation model of intersection traffic is built based on Simulink. This simulation model includes a model of OBU and a model of the intersection environment, which includes models of road, traffic light, Subjective Vehicle (SV), Leading Vehicle (LV), and drivers of SV, as described in Figure 9.12.

The intersection environment model includes:

1. **Driver Decision Model.** To simulate the driver's perception, decision, and operation.
2. **SV Model.** To simulate the kinematic motion of SV.
3. **LV Model.** To simulate the kinematic motion of LV.
4. **Model of Traffic Light and Wireless Communication.** To simulate the traffic light and its communication with vehicles.

An OBD Model is used to simulate the real IDAS controller mounted on the SV, including data acquisition and assistance algorithm.

9.4.2 Simulation and Results

Two kinds of simulations are designed: (a) Fixed Initial Condition Simulation (FICS); (b) Random Condition Simulation (RCS). The difference between the two types of simulation models is based on whether the initial conditions of the simulation are fixed or random.

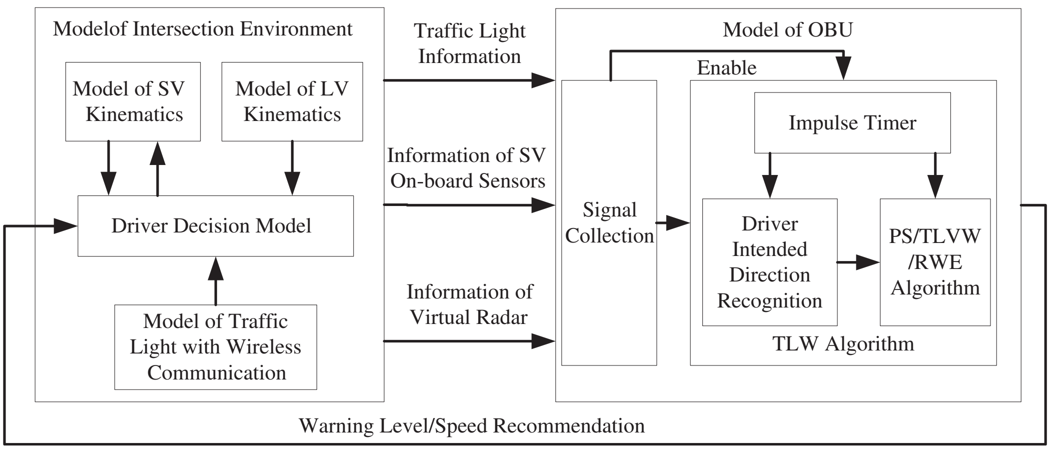

Figure 9.12: Architecture of Simulation Model.

FICS is designed to verify the rationality and function of IDAS. Such typical initial traffic conditions as initial position and initial speed are configured. IDAS should cope with these conditions. The simulation results show that the IDAS algorithm is working properly.

RCS aims at accessing the impact of this IDAS algorithm on intersection driving. The initial velocity of the SV and initial time point of the traffic signal is random. The velocity of the SV is distributed normally around a mean value, and the initial time point of the traffic signal is distributed evenly in its cycle. For every mean velocity of 30, 40, and 50 km/h, 10,000 simulations are conducted, and four statistical indices are used to compare the behavior of vehicles with and without IDAS, and to access the effect of IDAS on intersection driving. The results are shown in Figure 9.13.

Unintended traffic light violation is a scenario in which it is not possible for the driver to brake the vehicle to a full stop in the limited distance to the stop bar when the traffic light suddenly turns to amber from green. Large deceleration means the deceleration of the vehicle exceeds a value of -1.5 m/s^2. The rate of unintended violation represents driving safety at the intersection, and the rate of large deceleration reveals riding comfort. As described in Figure 9.13, when the vehicle is not equipped with IDAS, i.e Traffic Light

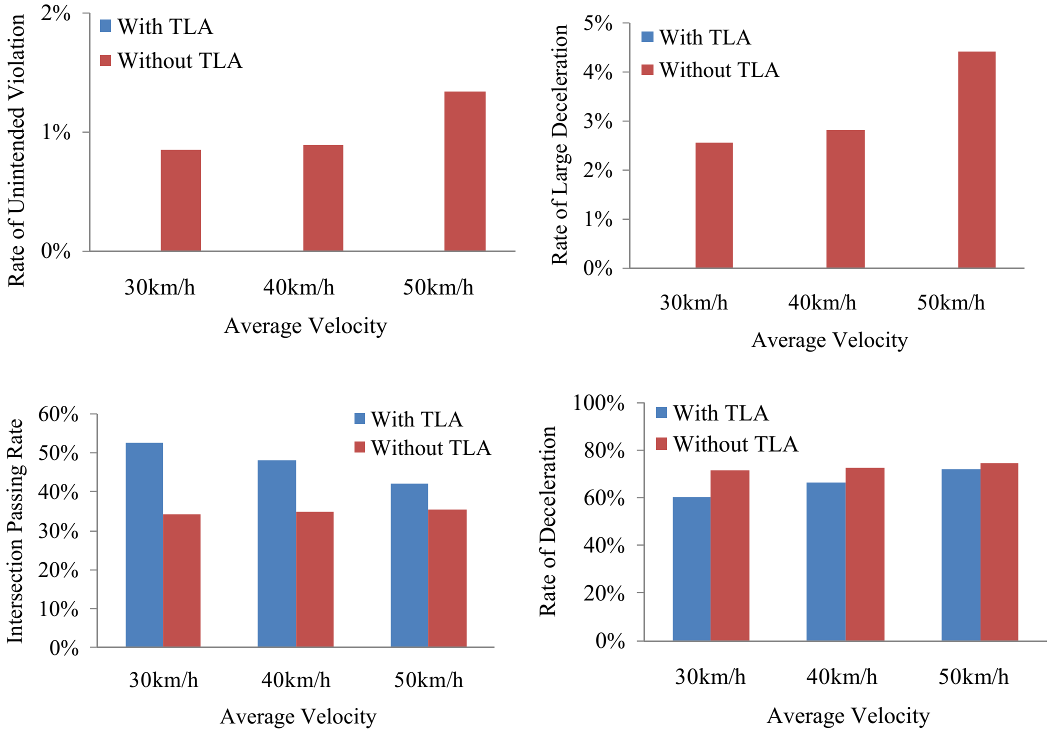

Figure 9.13: Results of Random Condition Simulation.

Assistance (TLA), the rates of unintended traffic light violations and large deceleration increase with velocity, but IDAS can avoid these two situations. Intersection passing rate is the ratio of the times that a vehicle passes the intersection without stopping to overall simulation times; rate of deceleration is the ratio of times that a vehicle experiences deceleration resulting in a traffic light to overall simulation times. These two indices reveal driving smoothness at the intersection. From Figure 9.13, it can be seen that IDAS increases the passing rate and reduces the rate of deceleration, and therefore IDAS improves driving smoothness.

9.5 Real Vehicle Test

In order to further test the performance of IDAS, a real vehicle test is needed. Here, the IDAS platform is composed of OBD and RSU, and a wireless communication is required to transmit data between the two parts. OBD is based on xPC technology [27]. Many experiments have been carried out concerning intersection assistance. Results show that IDAS is beneficial to drivers and can improve safety.

9.5.1 Design of IDAS Prototype

Architecture of an IDAS Prototype

The prototype consists of RSU and OBU, as shown in Figure 9.14. RSU is composed of a traffic light with a wireless communication device and RFID beacons, and the OBU contains an RFID reader, radio receiver, xPC-based controller and assistance executors, including HMI and Electronic Vacuum Boost (EVB).

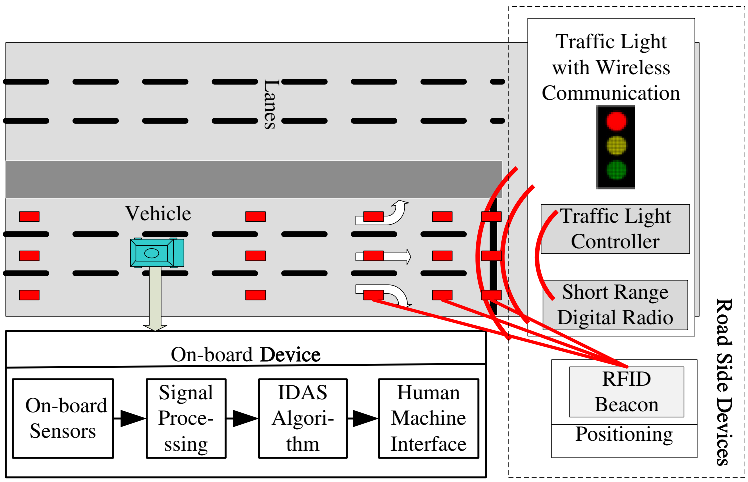

Figure 9.14: Architecture of IDAS Prototype.

The traffic light with a wireless communication device is modified from an ordinary mobile one. The controller can control the traffic light shift cycle and simultaneously broadcast its phase and timing through a wireless communication transmitter. The wireless communication device in this prototype is a digital radio, which can easily be replaced by a DSRC when it becomes available.

The RFID beacons used in this prototype are passive RFID tags with high reading speed.

Design of Test Vehicle

Architecture of test vehicle

The overall architecture of the IDAS test vehicle is shown in Figure 9.15. The features of this test vehicle are as follows:

1. Most of the information such as vehicle status, which is acquired by an intersection driving assistance system, can be obtained from the original CAN bus of the vehicle. Therefore, a complex signal collection network is avoided.
2. The original CAN bus and added CAN bus are connected through a CAN gate. This design ensures that the added system can obtain information from the original CAN bus and avoid possible influence on the vehicle's original system.
3. The testbed is designed based on modularization and is convenient for extensions.
4. To meet the requirements of IDAS, some devices are added and connected to the CAN bus, which includes the receiver of a short-range communication radio and its ECU, the reader and antenna of the RFID and its ECU, and the central controller of the IDAS OBU.

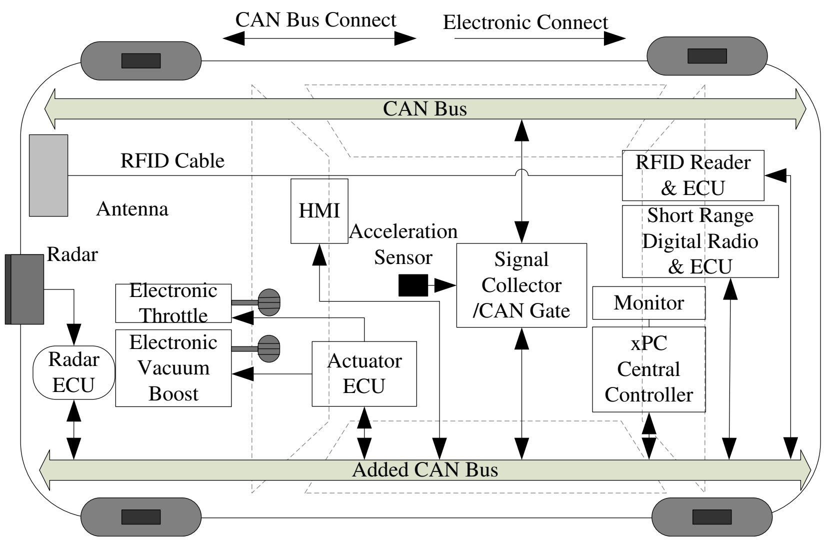

Figure 9.15: Architecture of IDAS Test Vehicle.

Electronic vacuum booster

Based on a normal vacuum booster, EVB is developed. The additional electromagnetic coil makes it possible for the booster to achieve braking via an electronic signal [28].

In order to build a dynamic model of the vehicle, the performance of the EVB has to be taken into consideration. In fact, what is really interesting is how the actual brake pressure will respond to the desired braking pressure. The controller adopts a PID algorithm to control EVB.

We utilize a sinusoidal scanning method to acquire the frequency response characteristics of EVB. Also, we determine the yield of the transfer function of EVB, as expressed by

$$G(s) = \frac{bs + 1}{a_1 s^2 + a_2 s + 1}. \tag{9.18}$$

Double-Mode Electronic Throttle (DMET)

Based on a normal electronic throttle system, a Double-Mode Electronic Throttle (DMET) system was designed as shown in Figure 9.16 [29]. Compared with the normal electronic throttle system, the DMET controller is a unique additional hardware. The acceleration pedal position sensor is connected to the DMET controller rather than the engine ECU. The output terminal of the DMET controller is linked to the engine ECU. Also, in order to carry out closed-loop control, the actual throttle angle must be accessible for the DMET controller.

Figure 9.17 shows the electric schematic diagram of the DMET controller. The DMET controller gets the throttle angle demand from the upper controller via a CAN bus and gets the actual throttle angle signal from the throttle angle sensor via an AD conversion module. Then the control variable will be figured out by the DMET controller with suitable control software. A DA conversion module is set to convert the control variable into an analog voltage signal that is equivalent to the output of the acceleration pedal position sensor. We mark the former as U1 and the latter as U2. Then U1 and U2 are in proportion to the desired throttle angle of the upper controller and driver respectively.

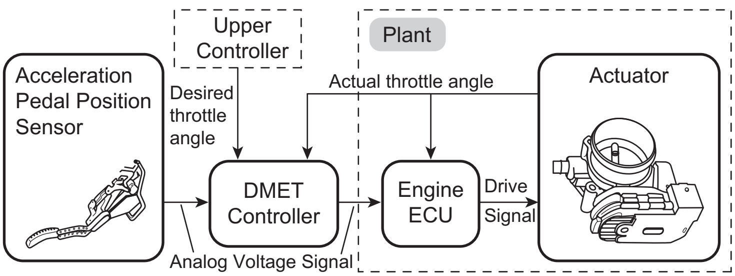

Figure 9.16: Double-Mode Electronic Throttle.

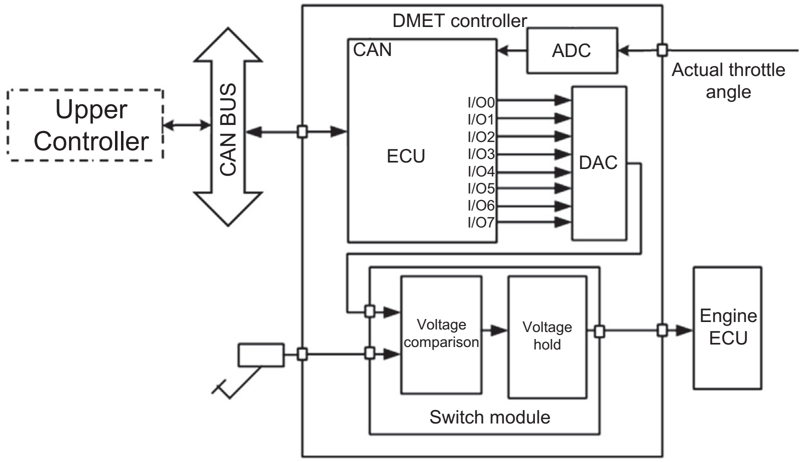

Figure 9.17: Structure of DMET Controller.

The DMET controller achieves seamless switching of the throttle angle demands between upper controller and driver via a switch module. The switch module compares U1 and U2 via a voltage comparison module and the output of the larger one. That is, the larger of the two voltage values determines the resulting throttle angle.

Because of the difficulty in establishing an accurate mathematical model, a PID control algorithm is used to design the feedback controller. The design of such a controller is independent of exact mathematical models and the controller parameters can be adjusted by experience to a certain extent.

In addition, hysteresis of the system results in some fluctuations of the controlled throttle angle, so a feedforward algorithm is added to the controller. This means that a controller is designed to carry out the command of the upper controller. Its diagram is shown in Figure 9.18.

In order to achieve seamless switching between the driver operating mode and automatic brake mode, a dead zone is also introduced into the PID controller.

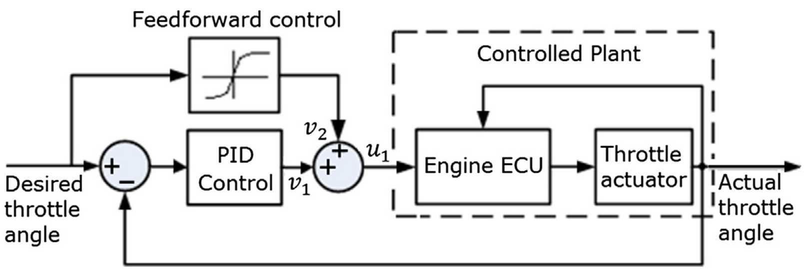

Figure 9.18: Architecture of the Software of DMET.

9.6 Field Test and Results

9.6.1 Test Scenario

In order to further test IDAS, three kinds of tests are carried out:

1. PS in green light
2. PS in red light
3. TLVW.

9.6.2 Results and Analysis

Field tests in a private intersection are conducted based on the developed prototype. The system function under conditions of PS and TLVW is verified. The test results are shown in Figure 9.19.

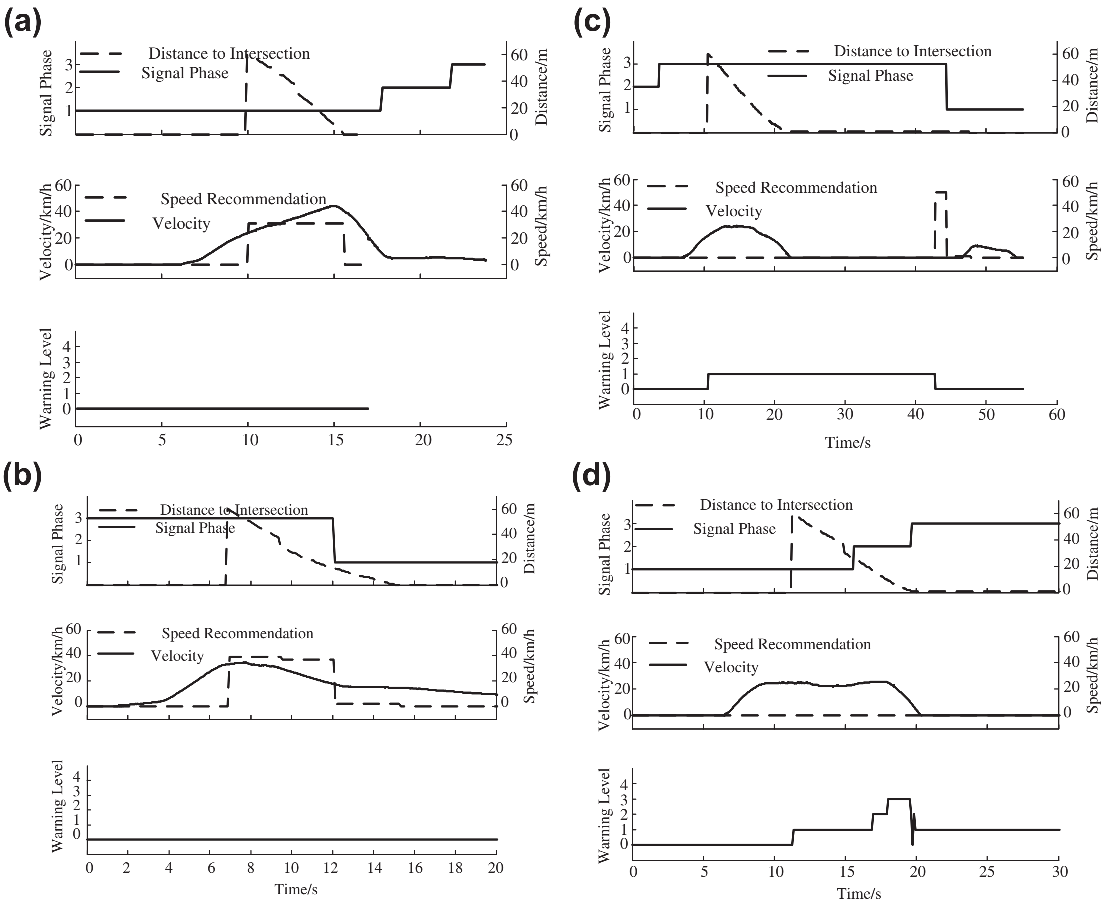

Figure 9.19: Results of Field Test.
(a) PS in green light. (b) PS in red light. (c) TLVW — informing. (d) TLVW — warning.

When the vehicle is driving in a normal situation at intersections, the hybrid IDAS algorithm is the function of PS and provides the driver with speed recommendations through HMI. Figure 9.19(a) describes PS under green light. The driver follows the speed recommendation and speeds up the vehicle, and then the vehicle passes the intersection without stopping. Figure 9.19(b) describes PS under red light. The driver follows the speed recommendation and slows down the vehicle, and then the vehicle passes the intersection without stopping after the signal changes.

The hybrid algorithm of IDAS shifts to the function of TLVW when the vehicle has the potential to violate the traffic light. Figure 9.19(c) describes the situation where the driver follows the traffic light and the TLVW informing signal. If the driver does not respond to the traffic light and informing signal, TLVW gives a stronger warning, as shown in Figure 9.19(d).

9.7 Conclusion and Discussion

In this chapter, an infrastructure–vehicle communication-based intersection driving assistance system is designed and developed. It is effective in solving problems of safety and congestion at intersections. In the field tests, the validity of the system is demonstrated and the following conclusions can be drawn:

1. The proposed IDAS system can make full use of the capability of infrastructure–vehicle communication systems in the way that it not only maintains the driving safety, but also simultaneously improves driving comfort and traffic efficiency at intersections.
2. The proposed hybrid IDAS algorithm can deal with various scenarios and presents appropriate speed recommendations, warnings or automatic braking.
3. The developed IDAS prototype can realize the designed functions of passing support, traffic light violation warning and rear-end collision warning, and demonstrate the advanced assistance system at intersections.

At level intersections where each lane only has one direction, i.e. straight ahead, right turn or left turn, the driver's intended direction can be determined from the lane direction and on-board indicator. However, as for intersections where some of the lanes have two or three possible directions, the driver's intention cannot be identified because the lane may have more than one possible direction and some drivers may not turn on the indicators until their vehicles are very close to the stop bars. Similar problems also exist when the intersection is a ring type or cloverleaf. Therefore, in the future, the IDAS algorithm should contain a module to identify the driver's intended direction by fusing multiple information such as lane direction, indicator, navigation, and driver operating sequences.

In addition, there are some special driver behavior characteristics at intersections, especially at the onset of the amber phase. However, these have not been fully considered in the proposed IDAS algorithm. In the future research, the IDAS system should be improved not only according to theoretical calculations, but also by taking the driver's behavior characteristics into account.

Acknowledgments

This work was supported by the National High Technology Research and Development Program of China ("863" Project, No. 2011AA110402).

References

[1] Transportation Department of the Ministry of Public Security of the People's Republic of China, The Annals of Road Traffic Accident Statistics of PRC (2010), Traffic Management Research Institute of the Ministry of Public Security, Wuxi, Jiangsu, 2010 (in Chinese).
[2] R.A. Retting, M.A. Greene, Influence of traffic signal timing on red-light running and potential vehicle conflicts at urban intersections. Transportation Research Record 1295 TRB, Nation Research Council, Washington, DC, 1998, pp. 23–26.
[3] P.T. Martin, V.C. Kalyani, A. Stevanovic, Evaluation of Advance Warning Signals on High Speed Signalized Intersection, University of Utah Traffic Lab, 2003, pp. 39–40.
[4] T.J. Smith, C. Hammond, M.G. Wade, Investigating the Effect on Driver Performance of Advanced Warning Flashers at Signalized Intersections. Human Factors Research Laboratory, University of Minnesota, Minneapolis, MN, 2001, pp. 101–114.
[5] M. Nekoui, H. Pishro-Nik, The effect of VII market penetration on safety and efficiency of transportation networks, in: Proceedings of the IEEE International Conference, 2009, pp. 1–5.
[6] I. Iglesias, L. Isasi, M. Larburu, et al., I2V communication driving assistance system: On-board traffic light assistant, in: Proceedings of the IEEE 68th Vehicular Technology Conference, 2008, pp. 1–5.
[7] IT and ITS Planning Division, Toyota Motor Corporation, Toyota's Approaches to ITS,: Toyota Motor Corporation, Toyota-Shi, Aichi, 2008, pp. 7–11.
[8] C.-Y. Chen, et al., California Intersection Decision Support: A Systems Approach to Achieve Nationally Interoperation Solutions, University of California, Berkeley, 2005, pp. 125–130.
[9] H. Oh, C. Yae, D. Ahn, et al., 5.8 GHz DSRC packet communication system for ITS services, vol. 4, Vehicular Technology Conference, 1999, 2223–2227.
[10] F. Bai, H. Krishnan, Reliability analysis of DSRC wireless communication for vehicle safety applications, in: Proceedings of the IEEE Intelligent Transportation Systems Conference, Toronto, 2006, pp. 355–362.
[11] K. Fuerstenburg, et al., Project Evaluation and Effectiveness of the Intersection Safety System, Sixth Framework Program, Hamburg, 2007, pp. 21–65.
[12] K.C. Fuersternburg, A new European approach for intersection safety – The EC-Project INTERSAFE, in: Proceedings of the 8th International IEEE Conference on Intelligent Transportation Systems, Vienna, 2005, pp. 343–347.
[13] J. Chen, S. Deutschle, K. Fuerstenburg, Evaluation methods and results of the INTERSAFE intersection assistants. Proceedings of the 2007 IEEE Intelligent Vehicles Symposium, Istanbul, 2007, pp. 142–147.
[14] C. Shooter, J. Reeve, INTERSAFE-2 architecture and specification, in: Proceedings of IEEE 5th International Conference on Intelligent Computer Communication and Processing, 2009, pp. 379–386.
[15] M. Nekoui, D. Ni, H. Pishro-Nik, et al., Development of a VII-enabled prototype intersection collision warning system. Proceedings of International Conference on Testbeds and Research Infrastructure for Development of Networks and Communities, 2009, pp. 1–8.
[16] K. Tamura, M. Hirayama, Toward realization of VICS – Vehicle Information and Communication System, in: Proceedings of the IEEE–IEE Vehicle Navigation and Information Systems Conference, 1993, pp. 72–77.

[17] S. Yamada, The strategy and deployment plan for VICS, Communications Magazine 34 (10) (1996) 94–97.
[18] J. Pierowicz, E. Jocoy, M. Lloyd, et al., Intersection Collision Avoidance Using ITS Countermeasures, US Department of Transportation, Washington, DC, 2000, pp. 5–46–5-48.
[19] G. Wang, DGPS Technology and Application, Electronic Industry Press, Beijing, 1996 (in Chinese).
[20] H. Berndt, S. Wender, K. Dietmayer, Driver braking behavior during intersection approaches and implications for warning strategies for driver assistant systems, in: Proceedings of the 2007 IEEE Intelligent Vehicles Symposium. Istanbul, Turkey, 2007, pp. 245–251.
[21] K. Kobayashi, K.C. Cheok, K. Watanabe, Estimation of absolute vehicle speed using fuzzy logic rule-based Kalman filter, in: Proceedings of the American Control Conference, Seattle, WA, 1995, pp. 3086–3090.
[22] C.K. Song, M. Uchanski, J.K. Hedrick, Vehicle speed estimation using accelerometer and wheel speed measurements, in: Proceedings of the 2002 SAE International Body Engineering Conference and Automotive and Transportation Technology Conference, Paris, SAE 2002-02-2229.
[23] K. Wantanabe, K. Kobayashi, Absolute speed measurement of automobile from noisy acceleration and erroneous wheel speed information, in: International Congress and Exposition, Detroit, MI, SAE 920644.
[24] J. Liu, S. Li, J. Wang, K. Li, A fast identification method of vehicle longitudinal dynamic parameters for intelligent cruise control, Transactions of the Chinese Society of Agricultural Machinery 41 (10) (2010) 6–10 (in Chinese).
[25] M. Canale, S. Malan, Analysis and classification of human driving behaviour in an urban environment, Cognition, Technology and Work 4 (3) (2002) 197–206.
[26] L. Zhang, A Vehicle Longitudinal Driving Assistance System Based on Self-Learning Method of Driver Characteristics. Doctoral dissertation, Tsinghua University, Beijing, 2009.
[27] L. Shengbo, W. Jianqiang, L. Keqiang, xPC technique based hardware-in-the-loop simulator for driver assistance systems, China Mechanical Engineering 18 (16) (2007) 2012–2015.
[28] J. Wang, D. Zhang, K. Li, J. Xu, L. Zhang, Design of vehicular integrated electronic vacuum booster systems, China Journal of Highway and Transport 24 (1) (2011) 115–121.
[29] D. Zhang, J. Wang, S. Li, L. Zhang, K. Li, Double-mode vehicular electronic throttle for driver assistance systems, 2009 IEEE Intelligent Vehicles Symposium, Xi'an, China, 3–5 June 2009.