Forecasting approach in VANET based on vehicle kinematics for road safety

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Abstract: This paper deals with the forecasting of collision events for road safety. Using significant parameters of each vehicle, such as position, speed and direction, it is possible to contribute to improving the road safety. We present a collaborative forecasting module in intersection scenario for collision avoidance. The proposed module is focused on the estimation of these parameters using a kinematic model of each vehicle to generate the trajectories estimation. The first simulation results show and assess that the vehicle trajectories estimated with the suggested kinematic modelling are realistic in all critical cases. The main goal of the suggested forecasting approach is to detect and avoid collision. On the basis of these trajectories estimation, the future occurrence of the collision event can be calculated, an alert must be generated and this will trigger the forecasting module in order to avoid collision. In addition, the second part of the simulation proves that the proposed forecast scenario is excellent for collision avoidance.

Keywords: vehicle kinematic; trajectories estimation; forecasting module; collision; detection; avoidance; road safety.

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1 Introduction

Faced with the growing development of Intelligent Transportation Systems (ITS) and with the arrival of the embedded telematics, vehicles are becoming more and more sophisticated. Thus to make the intelligent traffic road, i.e. communicative and interactive, we need to constitute a new concept in advanced driver support systems. The whole developed applications and conducted research in ITS intend to improve the road safety. In order to achieve the main objective which is road safety and collision avoidance, it is necessary to develop and design new collision detection systems with new communication protocol algorithms, so that vehicles can exchange their significant information namely: position, velocity, steering angle or next movement, etc. Mostly, the main problem facing the road users is caused by the deficiency of the communication between vehicles. The majority of accidents can be avoided if one of the drivers is alerted just-in-time before the occurrence of collision events. The question arises: how can the drivers detect and avoid, a priori, a possible danger? Some research works in this area do not deal really with the problem of the road safety. This is seen in the sent messages which are alarm for dangers either already sent or already occurred. Vehicle-to-vehicle communication is one of the solutions that enable vehicles to exchange the necessary information such as: position, velocity, acceleration and steering angle. It is worth noting that the estimation of the same parameters is one of the solutions which allow the vehicle to detect beforehand a possible risk.

Our work intends to propose a forecasting module embedded in vehicle that contributes to reduce the road traffic collision. We present the structure of conceptual scheme for communication model in Vehicle Ad hoc Networks (VANET) taking into account the forecasting module based on estimator part of this model. This structure is focused on the estimation of the necessary vehicle parameters that may imply the traffic collision. Each vehicle of this model introduces the technical alert to nearby vehicles in case the vehicle forecasts the occurrence of any risk (estimation, generation risk, decision and reaction). This does not mean that estimations should allow the prediction of accidents accurately, but the distinction between a high-risk situation 'collision' and a low risk situation 'no accident'. The rest of the paper is structured as follows: the related works and research projects are presented in Section 2. In Section 3, we explain in detail the kinematic modelling of vehicle type. The proposed conceptual scheme for a vehicular communication model is presented in Section 4. In Section 5, we show the first simulation results of the parameters to generate the estimated trajectories. The second simulation of the proposed forecast scenario is described in Section 6. In Section 7, we expose a comparative analysis table. Conclusion and future works are discussed in Section 8.

2 Related works

Many works have been carried out in this area, this section presents the related works realised about the collision warning systems and VANET communication protocols in interurban (motorway) or urban (intersection) vehicular traffic.

All scenarios revealed in these works allowing an exchange of alerts information between the vehicles in a dangerous situation (collusion). Yang et al. (2004) propose a vehicle-to-vehicle communication protocol for Cooperative Collision Warning (CCW). This protocol includes a differentiation mechanism of message to share a common channel for other non-safety applications and defines congestion control policies for Emergency Warning Messages (EWM). The task of proposed protocol is to achieve low-latency in delivering emergency warning in various road situations. The abnormal vehicle (AV) sends an EWM to all potentially endangered vehicles. Corresponding to their different requirements delay, authors defined three classes of messages: the first category is the EWM which has the highest priority to be transmitted, the second and the third categories are, respectively, reserved for forwarded EWM message and non-time-sensitive message that have a lower priority. The performance of protocol is evaluated by the transmission rate according to the delay of EWM, waiting time and retransmission delay using ns2 simulator. This protocol can satisfy emergency warning delivery requirements and support a large number of co-existing AVs at the low cost of channel bandwidth.

Tang and Yip (2010) present the warning strategies for collision avoidance based on timing analysis events. These strategies are constrained by some events such as the communication latency time, detection range, read condition, driver reaction and deceleration rate. Authors describe the design of the collision avoidance systems based on two collision avoidance timings: the critical and the preferred time to avoid collision. Sengupta et al. (2005) introduce the concept of CCW systems, this concept provides warnings or situation awareness displays to drivers based on information about the motions of neighbouring vehicles obtained by wireless communications from those vehicles, each vehicle needs to know about the locations and motions of the all neighbouring vehicles, representing the state of the vehicle neighbourhood. The proposed intersection warning algorithm shows two display icons used in CCW prototype. The 'No left turn' icon is triggered if the driver puts on the left turn signal at an intersection and the system detects a conflict. Otherwise, about the risk detection at an intersection, the system displays the 'STOP' icon. The intersection warning is based on two principal parameters: time and distance. Time to collision (TTC) and distance to collision (DTC) are the parameters used to trigger the warning. Before calculating TTC and DTC, it is necessary to determine a collision point. The collision point is a conflict point derived by projecting trajectories of vehicles in the neighbouring vehicle map assuming they will keep going straight. Authors explained the prototyping design and experimental evaluation of a CCW system by presentation of experimental results showing the performance of a first prototype CCW system (Sengupta et al., 2007). Salim et al. (2007) suggest a method for the knowledge acquisition of intersection accidents detection system and real-time collision detection to implement the ubiquitous intersection awareness that is based only on trajectory calculations. The developed intersection safety system should be able to adjust different types of crossroads via the acquisition patterns on a computer using data mining method. These patterns are used for matching vehicle pairs to be calculated for the possibility of route contention and future collision events. In this proposition, the algorithm of collision detection is embedded in each vehicle of network. This algorithm calculates a future collision point (X+, Y+) and the time at which the vehicle reaches the future collision point (TTX). The set of detected future collision events for the first time is recorded in a log file, with the following attributes: registration number of vehicles, collision point, time to collision, leg location of both vehicles, and collision type. The average detection time (time to collision) for each run is calculated. The really collision is evaluated when the prediction system gives the concurrence of the future collision event. Whenever the collision event is detected, it is counted as a true positive (valid detection). On the contrary, when a collision event is not predicted, it is counted as a false positive (invalid detection). In the case when a collision occurs without being predicted by the system, it is counted as false negative (undetected collision) (Salim et al., 2007). Rezaei et al. (2010) investigate four communication schemes for Cooperative Active Safety System (CASS) and compare their performance with application level reliability metrics.

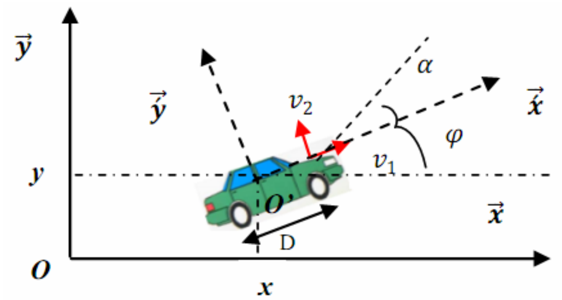
Currently, we quote some current projects in vehicular ad hoc networks such as: eCall (2011) is a project of the European Commission intended to bring rapid assistance to drivers involved in a collision anywhere in the European Union. In case of crash, an eCall equipped vehicle automatically calls the nearest emergency centre. Shortly after the accident, emergency services therefore know that there has been an accident, and where exactly. The severity of injuries could be considerably reduced in 15% of cases. The NOW 'Network on Wheels' (2011, see http://www.network-on-wheels.de/) project is a German project from the Federal education and research government, founded by automobile manufacturers, telecommunications operators and academia. NOW is the successor of FleetNet Project (2013) and supports and strongly cooperates with the Car2Car consortium (Communication Consortium, see http://www.car-to-car.org/). One of NOW's main objectives is the implementation of communication protocols and data security algorithms in vehicular network. Considering the wireless 802.11 technologies and location-based routing in a V2V or vehicle to infrastructure communication context, the goal is to implement a system of reference and to contribute to the standardisation of such a solution in Europe in collaboration with the Car2Car consortium (Communication Consortium, see http://www.car-to-car.org/). The project Cooperative Systems for Intelligent Road Safety (COOPERS, 2006, see http://www.coopers-ip.eu/) focuses on innovative telematic applications for cooperative traffic management. From a communication perspective, it therefore primarily addresses vehicle-to-roadside communication and makes use of CALM (Communication Architecture for Land Mobile) environment standards like the CALM infrared communication interface. The project Cooperative Vehicle-Infrastructure System (CVIS, 2006, see http://www.cvisproject.org/) is based on such real-time road and traffic information is a major European research and development project financed by the European Commission aiming to design, develop and test the technologies needed to allow cars to communicate with each other and with the nearby roadside infrastructure. The project SAFESPOT (2006, see http://www.safespot-eu.org/) aims at designing cooperative systems for road safety based on vehicle-to-vehicle and vehicle-to-infrastructure communication. The project PReVENT (2006, see http://www.prevent-ip.org/) consists of the development of preventive safety applications and technologies. Within the PReVENT Integrated Project as the subproject Willwarn, this project focused on the topic of vehicle-to-vehicle and vehicle-to-infrastructure communication. Integrated Vehicle-Based Safety Systems (IVBSS, 2010, see http://www.its.dot.gov/ivbss/) project explores human–machine interface issues when several safety applications, with potentially overlapping or contradictory advisories, are operated simultaneously. The Cooperative Intersection Collision Avoidance System (CICAS, 2006, see http://www.its.dot.gov/cicas/) project had three components: a violation warning project (demonstrated in Michigan), a stop sign assist project (demonstrated in Minnesota), and a signalised left turn assist project (demonstrated in California).

3 Kinematic model of the vehicle

The physical systems can be represented by a kinematic or dynamic model, the first considers only the movement applied to the system, whereas the second takes into account the forces of the masses appearing in the system (Marina and Marti, 2005). In this section, we present an outline on the kinematic modelling of the vehicle parameters, namely: position, velocity, steering and heading angle. Taking into account the notion of time, the kinematic model can be modelled in continuous or discrete time.

Assuming that the configuration of a mobile vehicle is represented in a fixed reference with two dimensions noted by $R\left(O,\vec{X},\vec{Y}\right)$ and a mobile reference related to the movement of vehicle noted by $R'\left(O',\vec{X}',\vec{Y}'\right)$. The vehicle state shown in Figure 1 can be represented in space of dimension M, chosen as follows: $((x,y), (v_1,v_2), (\varphi,\alpha))$.

Figure 1 Presentation of a vehicle parameters type (see online version for colours)



By developing the components of this speed on the x and the y axis, we obtain a longitudinal and lateral speed noted v_1, v_2, respectively, v_2 is equal to zero due to the rolling without slip on constraints non-holonomic and v_1 represents the velocity of the vehicle, in the remainder of the paper is noted by v (Abuhadrous, 2005).

$$\begin{cases} \dot{x}\cos\varphi + \dot{y}\sin\varphi = v_1 \\ -\dot{x}\sin\varphi + \dot{y}\cos\varphi = v_2 \\ \begin{cases} v_2 = 0 \\ v_1 = v \end{cases} \end{cases} \tag{1}$$

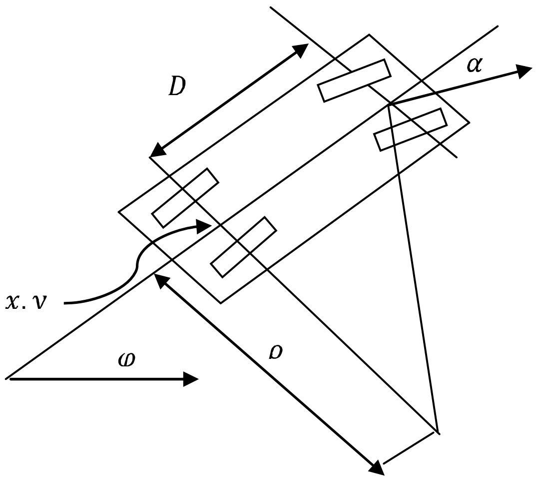
Table 1 Vehicle parameters identification

x	The lateral position of the vehicle
y	The longitudinal position of the vehicle
v_1	The longitudinal velocity of the vehicle
v_2	The lateral velocity of the vehicle
φ	The angle direction of the vehicle (heading angle)
α	The angle direction of the wheels (steering angle)
ω	The speed of rotation around the IRC
D	The distance between axle of the vehicle

First, we consider the simple car model represented in Figure 2. This vehicle has two fixed wheels on the same rear axis and two other directional wheels placed on the longitudinal axis of the vehicle. We chose generally for O' a significant point of the platform, typically the centre of the axis of the driving wheels. The Instantaneous Rotation Centre (IRC) of the vehicle is located at the meeting of the fixed wheels axle and the directional wheels axle, where *x* and *y* give the central position of the rear axle, φ is the angle between the vehicle body and the horizontal *x*-axis, α is the direction angle (the steering angle). The movement is provided to the vehicle by two actions: the longitudinal speed v_1 and the orientation directional wheel ω (Bayle, 2010/2011). On the other hand, the rotation speed of the vehicle is equal to the speed of rotation around the IRC. This allows determining ω from the speeds of the wheels and can be determined from ρ and the longitudinal velocity, as shown in Figure 2: ρ can be determined geometrically from the orientation angle of the front wheel:

$$\begin{cases} \omega = v/D \tan\alpha \\ \rho = D/\tan\alpha \\ \dot{\varphi} = \omega \end{cases} \tag{2}$$

Figure 2 The kinematic modelling of vehicle type



This type of vehicle can move in straight line for α = 0 and theoretically turn about the point *O′* for α = π/2. However, the turning radius of the directional wheel, usually limited, requires values such as π/2 < α < π/2, prohibiting the vehicle rotation on itself (Abuhadrous, 2005). The kinematic model is described by:

$$\begin{pmatrix} \dot{x} \\ \dot{y} \\ \dot{v} \\ \dot{\varphi} \\ \dot{\alpha} \end{pmatrix} = \begin{pmatrix} \cos\varphi \\ \sin\varphi \\ 0 \\ \tan\alpha/D \\ 0 \end{pmatrix} v_1 + \begin{pmatrix} 0 \\ 0 \\ 0 \\ 0 \\ 1 \end{pmatrix} v_2 \tag{3}$$

These equations are inspired from the kinematic model shown in Figure 2, with a simple geometric reasoning, we establish the kinematic equations of this model, *x* and *y* are the estimations of lateral and longitudinal position of a vehicle, respectively, *v* is the vehicle velocity which is always constant and φ represents the steering angle of the vehicle contribution to the horizontal *x*-axis (Bayle, 2010/2011). The kinematic model equations in continuous time are described as follows:

$$\begin{cases} \dot{x} = v(t)\cos\varphi(t) \\ \dot{y} = v(t)\sin\varphi(t) \\ \dot{\varphi} = v(t)\dfrac{\tan\alpha(t)}{D} \\ \dot{v} = 0 \\ \dot{\alpha} = \begin{cases} 0, | \; if \;\; v_2 = 0 \\ \eta, | \; if \;\; v_2 \neq 0 \end{cases} \end{cases} \tag{4}$$

where η stands for the orientation speed v_2 imposed on the steered wheel.

The discrete form of the equations above is

$$\begin{cases} x_{k+1} = x_k + v_k \cos(\varphi_k)T \\ y_{k+1} = y_k + v_k \sin(\varphi_k)T \\ \varphi_{k+1} = \varphi_k + v_k \dfrac{\tan\alpha}{D}T \\ v_{k+1} = v_k; invariable \\ \begin{cases} \alpha_{k+1} = \alpha_k; invariable \\ \alpha_{k+1} = \alpha_k + \eta T; variable \end{cases} \end{cases} \tag{5}$$

where *T* denotes the sampling period.

4 The proposed communication model in VANET network

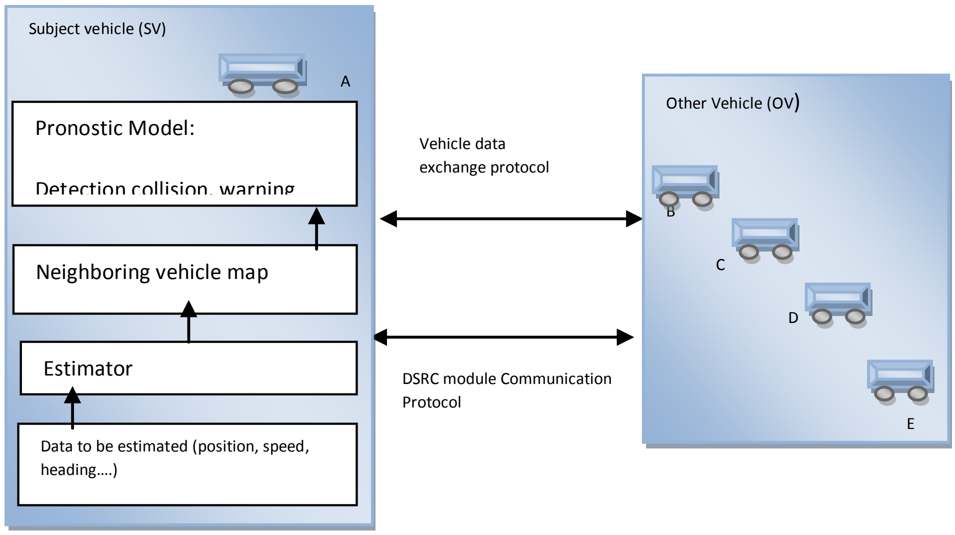
Assuming a communication network (VANET) is constituted by *N* vehicles divided into two groups: the first group contains just only one vehicle which is the subject vehicle (SV) and the second group contains the other vehicles or neighbour vehicles (OV) (Rezaei et al., 2010). In our model, each vehicle of the network is equipped by an estimator, and thus the vehicle could have a posterior global view of the dynamics of its network. The estimation of future state is carried out using an embedded forecasting system. This system estimates the parameters of its vehicle and those of its neighbours, such parameters are: position, velocity, steering angle and heading angle (Bektache et al., 2012).

The architecture has significant common elements useful to multiple warning applications. These elements include: the neighbouring vehicle map layer[1] in each vehicle that has several functions (Sengupta et al., 2007):

- It passes the GPS position, speed and heading information produced by its estimator to the Vehicle Data Exchange Protocol (VDEP) entity for transmission to other vehicles.
- It receives the GPS position, speed and heading messages sent by other vehicles from the VDEP entity.
- It transforms this information to relative coordinates and plots it on the neighbouring vehicle map.

Thus, our architecture requires the standardisation of two protocols, shown as the VDEP and communication protocol in Figure 3. Vehicles need to send position, speed, heading and possibly other data in a format understood by all vehicles. This is the VDEP. The VDEP messages need to be sent over a communication protocol and radio standardised across vehicles. In our case this is 802.11p dedicated short range communications (Sengupta et al., 2007).

Figure 3 The proposed architecture communication model in VANET (see online version for colours)



The position, speed and direction are important information in the inter-vehicle communication to avoid a possible collision. The estimation of the same parameters used beforehand to generate alerts to a potential risk, for this reason a forecasting module is integrated into the proposed communication model. The operation of this module is shown in Figure 4.

- Generator of risks: This generator is based on the exploitation of the estimated parameters of the subject vehicle and those of its neighbours then after analysis and comparison between these different estimations, one or more risks can be detected. Note also that there are situations where no risk can occur. Otherwise, each risk is evaluated and interpreted according to its danger degree (degree of risk), this information is transmitted to the decision maker (Bektache et al., 2012).

- Decision maker: After the generation of a potential risk, according to its degree, the risk will be sent to the decision maker which generates a type and an appropriate decision as shown in Table 2 (Bektache et al., 2012).

Figure 4 Operation of forecasting model (see online version for colours)

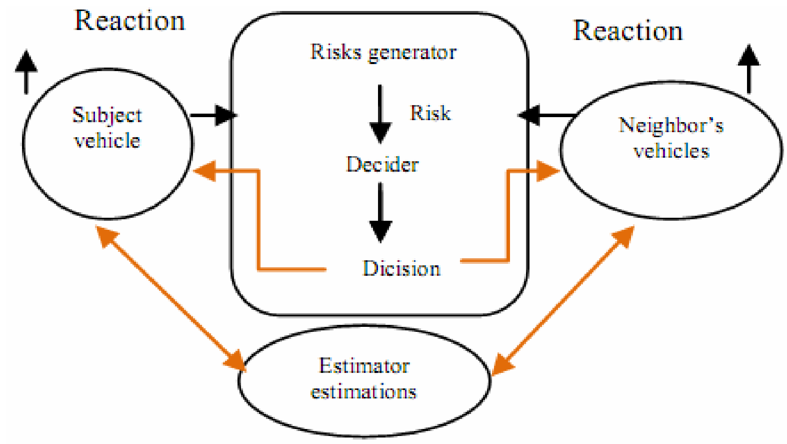


Table 2 Reference risk-decision

Risk number	*Risk degree*	*Decision*	
		Number	*Type*
1	High Risk (collision)	1	Alert urgently
2	Middle risk	2	Alert message
3	Weak Risk (no collision)	3	Information message

5 Simulation results of trajectory estimation

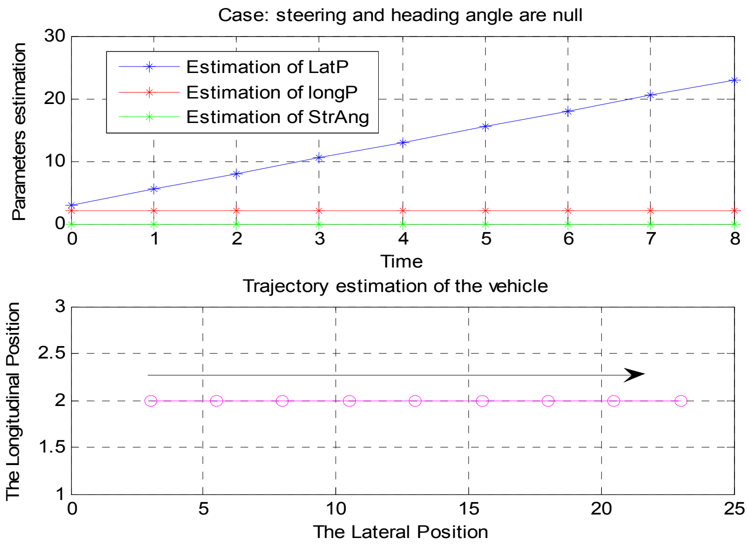
In this section, we present the first simulation results of the kinematic model equations presented previously in the discrete time [(see equation (5)]. Thereby, the main goal of this simulation is about the realistic evidence of the model equation to generate the accurate trajectories estimation. The kinematic model chosen is a vehicle type because the area research is VANET, so the node is a mobile vehicle.

If the steering angle of the wheels α is null (α = 0), i.e. the vehicle is moving in a straight line (there is no turning), according to the value given at the angle direction of the vehicle φ (heading angle), we distinguish five cases. Noting that the parameters estimated are represented as: LatP: lateral position; LongP: longitudinal position; StrAng: steering angle. This notation is valid in all Figures 5–10.

- *Case 1:* $\alpha = 0$ *and* $\varphi = 0$

The vehicle is moving in a straight line to the positive *x*-axis as in shown in Figure 5.

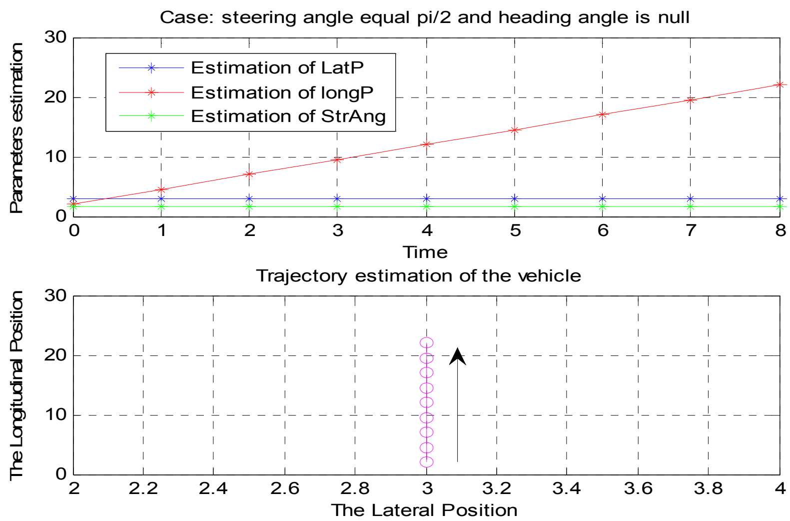
Figure 5 Estimation of parameters in the case: $\alpha = 0$ and $\varphi = 0$ (see online version for colours)



- *Case 2: $\alpha = 0$ and $\varphi = \pi/2$*

The vehicle moves in a straight line to the positive *y*-axis, as shown in Figure 6.

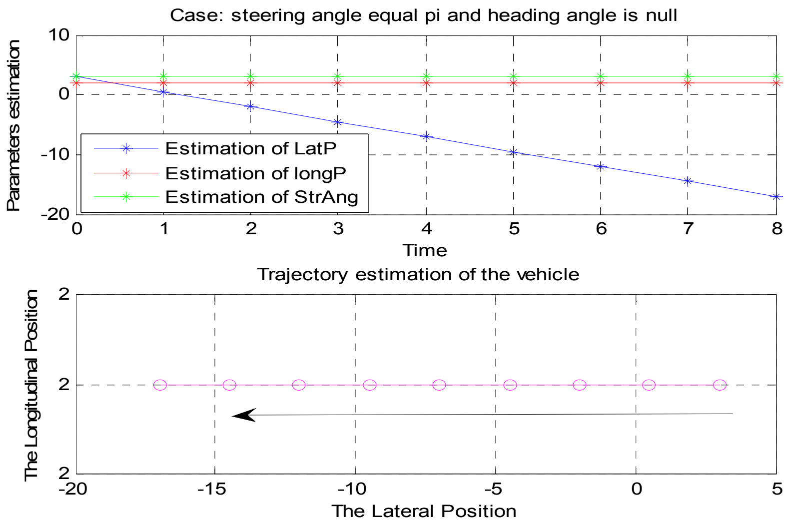
Figure 6 Estimation of parameters in the case: $\alpha = 0$ and $\varphi = \pi/2$ (see online version for colours)



- *Case 3: $\alpha = 0$ and $\varphi = \pi$*

The vehicle moves in a straight line to the negative *x*-axis, as shown in Figure 7.

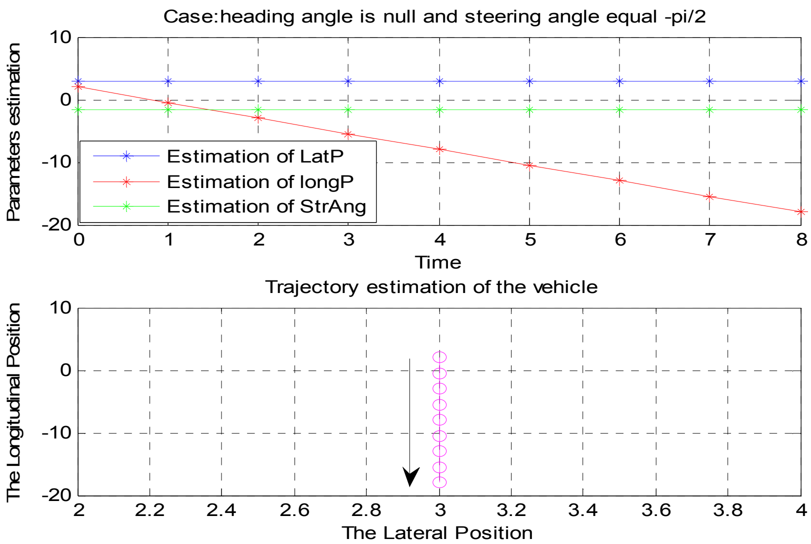
Figure 7 Estimation of parameters in the case: α = 0 and φ = π (see online version for colours)



- *Case 4 : α = 0 and φ = –π/2*

The vehicle moves in a straight line to the negative y-axis, as shown in Figure 8.

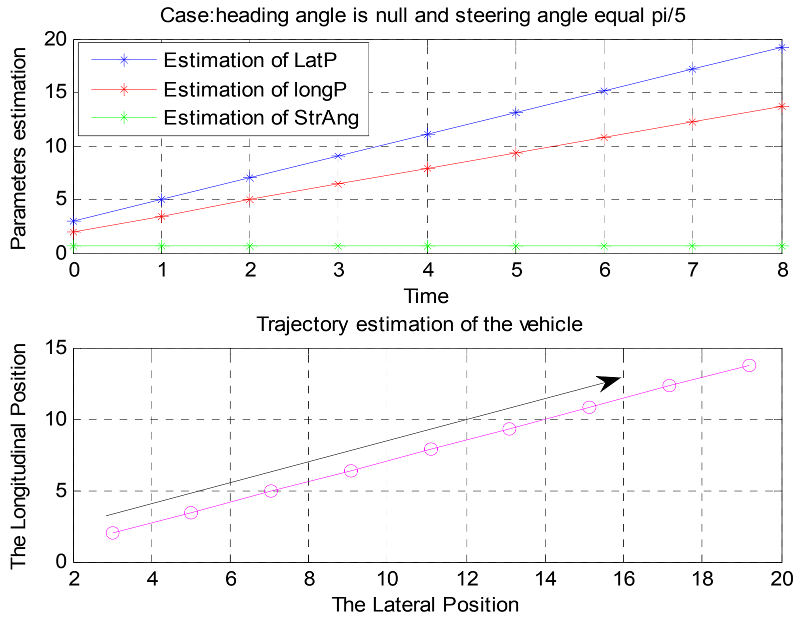
Figure 8 Estimation of parameters in the case: α = 0 and φ = –π/2 (see online version for colours)



- *Case 5: α = 0 and φ = π/5*

The vehicle moves in straight line with fixed steering *φ* equal to 36°, as shown in Figure 9.

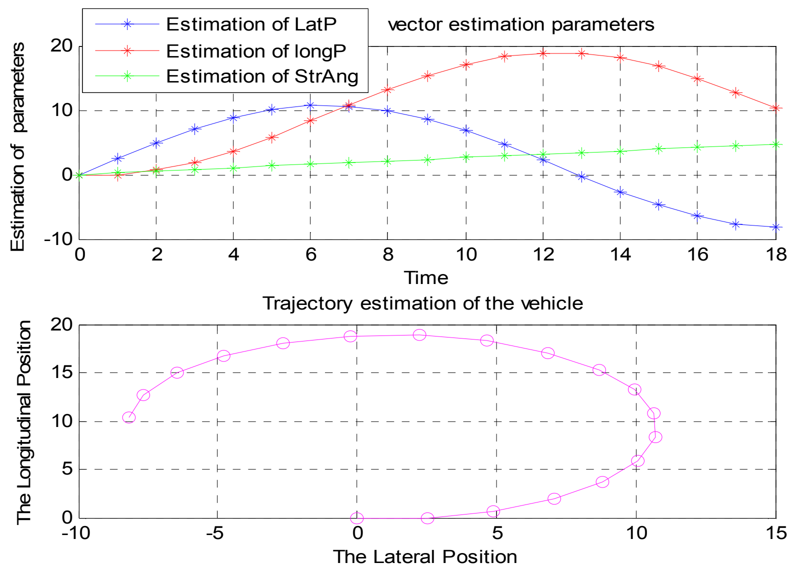
Figure 9 Estimation of parameters in the case: α = 0 and φ = π/5 (see online version for colours)



If α is not null, the steering of the wheel influences on the angle and thus influence also on displacement of the vehicle, we will take α as a fixed constant.

- *Case 1: X = 0, Y = 0, α = π/20, φ = 0 and v = 25*

Figure 10 Vehicle trajectory estimation using the kinematic model (α is fixed) (see online version for colours)



6 Simulation of the proposed intersection scenario

6.1 Assumption

We consider that each vehicle is equipped with sensors, communication hardware and wireless protocols, such as: GPS and DSRC, broadcasting GPS position, speed and heading estimators, and collision warning algorithms. Such tools are necessary to develop and demonstrate the concept of realistic forecasting scenario. Thereby each vehicle may use the alerts messages in order to detect possible collisions and warn its driver for collision avoidance. In case when the vehicle knows its own GPS position, speed and other key metrics, such as heading and steering angle, the estimation of its future trajectory becomes possible using the estimator based on kinematic model presented previously. The estimated trajectory is broadcast to other vehicles through the communication protocol DSRC.

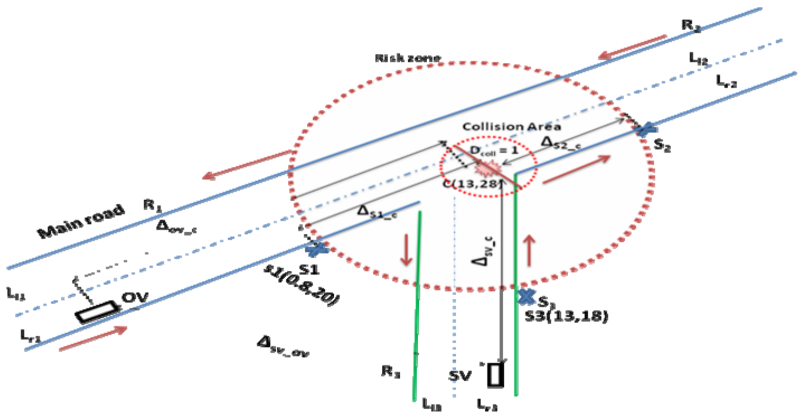
6.2 Challenge and problem statement

The crash rate in roads intersection increases more and more. The extent of this phenomenon justifies the need for using fast and accurate collision detection system. The most intersections safety system should be able to detect collision in real time. Then, the collision warning must be delivered a priori and just-in-time before collision occurs. An early and accurate detection should allow to detection system the necessary time to warn a potential collision. In our studies we have selected the critical scenario of Y-type intersection, when the visibility is almost zero and the communication must be made in real times. After having proved the realism degree of the kinematic model used in the trajectories estimations of vehicles, we can then apply it in our simulation scenario.

6.3 Scenario description

The main goal of the proposed scenario is the application of the suggested forecasting approach on intersection scenario (Figure 11) to detect and avoid collision. The estimated trajectories are used to simulate an intersection of k vehicles. Firstly, it is necessary to select among all vehicles of network a subject and other vehicles called, respectively, *SV* (i.e. carries the forecast module and *OV* (i.e. the neighbour of *SV*). The intersection topology is characterised by the number of legs crossing in the crossroad point. The number of crossroad legs defines the point of intersection degree. In our scenario, we use intersection with a multiple junction; this zone represents the intersection of three roads: R_1, R_2, and R_3 each road is composed of two lanes: the left and right lane noted as L_{lj} and L_{rj}, respectively, here j is the road number. In the presented simulation, we suppose that the two vehicles selected previously *SV* and *OV* are located, respectively, on L_{r3}, i.e. on the right lane of R_3, and on L_{r1}, i.e. on the right lane of R_1 (see Figure 11). In order to supervise the crossroad, the junction is partitioned into two principal regions: the first region $Z(D_{coll})$ stands for the collision area where vehicles probably crashed, its diameter is limited to 1 ($D_{coll} = 1$) that explained the cell road able to contain one vehicle. The size of this cell varies between 5 m and 7.5 m. The second region describes the risk zone, where the collision can occur. The communication between *SV* and *OV* must be started when the collision is estimated. This region is limited by threshold points defined on each road limited by a circular surface of radius r denoted by $Z(r)$. The activation of forecasting module depends on the estimated position of vehicle approaching to the circumference of $Z(r)$.

Figure 11 Presentation and description of the intersection scenario (see online version for colours)



Followings are the concept of the proposed forecasting approach:

1 Collision prediction and detection: Principally based on computing of the estimated trajectories as following: at any time the vehicle can estimate the eventual collision. This last occurs if at least two vehicles calculate their next positions in the red zone (collision region) at the same time t. the collision point noted C(.) is defined by two components C_x and C_y (lateral and longitudinal coordinates, respectively). The distance between the next positions of SV and OV vehicles noted as Δ_{sv}^{ov}, it is calculated using Euclidean formula. The computing collision condition must be started when the estimated vehicle positions of SV and OV are belong in the collision region $Z(D_{coll})$, on the other words:

$$\Delta_{sv}^{ov}(i) \geq D_{coll} \equiv \left\{\left(SV\left(\hat{X},\hat{Y}\right)\right)\wedge\left(OV\left(\hat{X},\hat{Y}\right)\right)\in Z\left(D_{coll}\right)\exists C\left(C_x,C_y\right)\right\}$$

2 Warning generation and reaction for collision avoidance: Where one of the vehicles is near to the risk region, the collision coordinates C_x and C_y must be communicated as a warning message to the concerned neighbour vehicle. For this reason, we need to define a threshold point on each road noted S_j, this point constitutes with the collision point a threshold distance noted Δ_{sj}^{c}. These distances coordinates and estimated trajectories are used by the SV in order to define the parameters of the collision avoidance procedure. This procedure is based on Forecasting Collision Avoidance Algorithm (FCAA) that compares the two input parameters, namely the residual instantaneous distance of each vehicle k relatively to the collision point noted by Δ_{k}^{c} and the threshold distance Δ_{sj}^{c}.

$$if\left(\Delta_{k}^{c} <= \Delta_{sj}^{c}\right) \textit{trigger the forecast module}.$$

where *j* and *k* stand, respectively, for the number of road and the index of vehicle in road.

The obtained results after using FCAA are summarised in two main calculated parameters which are: the critical time for collision avoidance and the expected distance for triggering the forecasting approach. These parameters are essentially used in the triggering of the collision avoidance procedure. Ultimately, new safety vector $\left(\hat{X},\hat{Y},\hat{V},\hat{\varphi},\hat{\alpha}\right)$ is generated for collision avoidance.

Algorithm 1 Forecasting Collision Avoidance Algorithm (FCAA)

Step 1: Declaration and Initialisation

Each vehicle k has a parameters *vector* such as: $\{X, Y, V, \varphi, \alpha\}$

Indicate the subject and other vehicles (*SV*, *OV*)

D_{coll} = 1//the diameter of the collision area

X_{Sj}, Y_{sj} //Threshold coordinates in the road$_j$

Δ_{sj}^{c} // the distance between road threshold S_j and the collision point

Δ_{sv}^{c} , Δ_{ov}^{c} //the distance between *SV vehicle* or *OV vehicle* and the collision point

N: number of iterations

Step 2: **foreach** *vehicle k* **do**

//Trajectory Estimation Procedure

for each *iteration i = 0* to *N*

calculate $\{\varphi_k(i+1); V_k(i+1); X_k(i+1); Y_k(i+1)\}$

end_for

end_for

Step 3: **foreach** vehicle SV and OV **do**

//Collision Detection Procedure

for each iteration $i = 0$ to N

$\Delta_{sv}^{ov}(i) = \sqrt{(X_{ov}(i) - X_{sv}(i))^2 + (Y_{ov}(i) - Y_{sv}(i))^2}$

If $(\Delta_{sv}^{ov}(i) \le D_{coll})$

Calculate the collision point C(X,Y)

end_if

end_for

end_for

Step 4: foreach selected *SV* **do**

//Avoidance Collision Procedure

foreach iteration $i = 0$ to N

calculate the distance to collision; $\Delta_{sv}^{c}(i)$;

if $(\Delta_{sv}^{c}(i) \le \Delta_{sj}^{c})$

update the collision coordinates

trigger alerts to Neighbour OV;

trigger the forecasting approach;

else

go to step 2.: estimation trajectory of SV

end_if

end_for

end_for

6.4 Simulation: case study

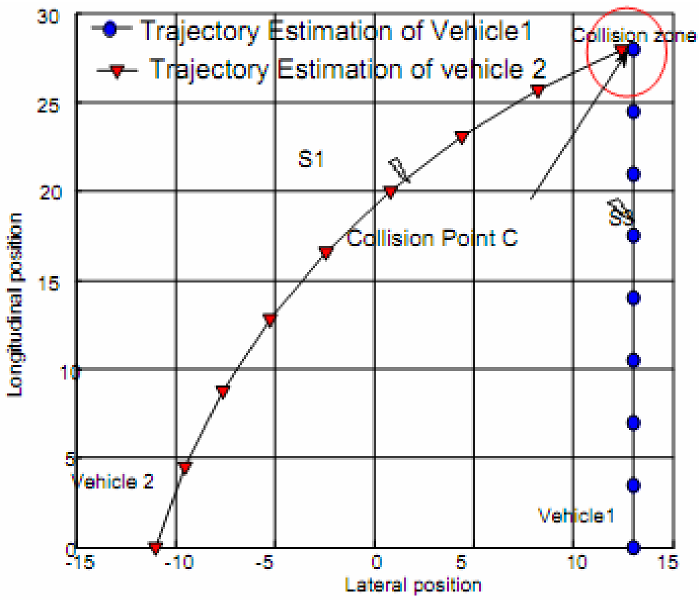
The case study is aiming at getting realistic simulation results; the kinematic model equation simulated in Section 5 is re-used. Table 3 illustrates the coordinates of each vehicle in its initial and final statements; it shows the simulation data used in this case study.

Table 3 The initial and final coordinates

	SV					*OV*				
	X	*Y*	*V*	*α*	*φ*	*X*	*Y*	*V*	*α*	*φ*
T0	13	0	35	0	π/2	–11	0	47	π/90	2π/5
T8	13	28	35	0	π/2	12.39	27.9	47	–π/90	0.5

In the 8th iteration *SV* (13, 28) and *OV* (12.39, 27.9) $\in Z(D_{coll})$ implies existence of collision, the collision at the point (12.9, 28) is unavoidable if both vehicles continue to circulate with same velocity. The simulation of this model will generate the trace files that describe exchanged requests and the estimated displacements of the mobile nodes in the intersection scenario without using the forecasting approach as shown in Figure 12.

Figure 12 Estimation of the collision in intersection scenario without forecasting approach (see online version for colours)



The selected vehicles *SV* and *OV* belong to the risk zone. Firstly, we chose *Veh*1 as a subject vehicle, i.e. the one which carries the forecasting module to avoid collisions, we define a threshold point S_3 (13, 18) on the road R_3. The distances Δ_{s3}^{c}, Δ_{sv}^{c} can be calculated at any time. These distances and the estimated trajectories are used by the vehicle to define the parameters of the collision avoidance procedure. The efficiency of the proposed approach is explicitly shown by the vehicle reaction, this reaction is interpreted by the deceleration rate of the vehicle velocity since the 6th iteration (where *SV* coordinates has exceeded the threshold S_3). The 6th iteration coordinates are (13, 21) $\in \Delta_{s3}^{c}$ implies that the forecast module is triggered, it was started before the 6th iteration and the subject vehicle decreases its velocity (see Figure 13).

Figure 13 Avoid collision in intersection scenario with FCAA (see online version for colours)

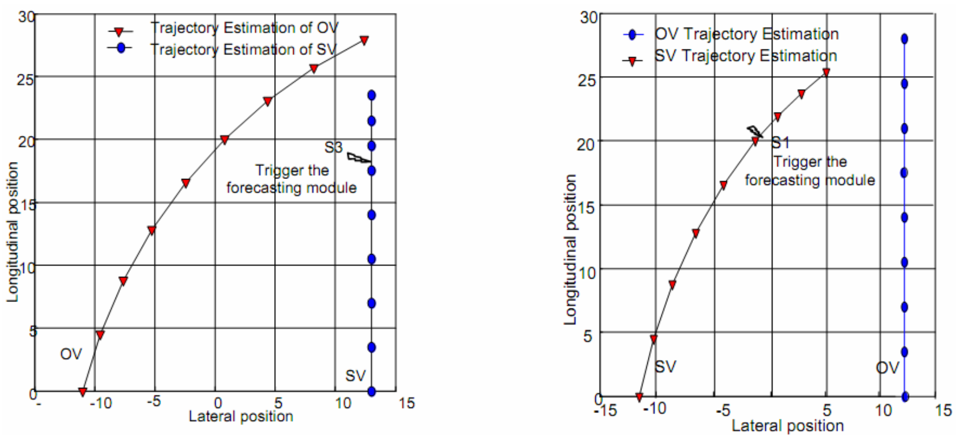


Table 4 SV coordinates with and without forecasting approach

Iteration number	*SV coordinates without FCAA*		*SV coordinates with FCAA*	
	X	*Y*	*X*	*Y*
5	13	17.5	13	17.5
6	13	21	13	19.5
7	13	24.5	13	21.5
8	13	28	13	23.5

Secondly, we chose *Veh*2 as the subject vehicle, i.e. that one carries the forecast module to avoid collision, the threshold point S_1 (0.8, 20) is defined on the road R_1. The effect of this approach is interpreted by the deceleration rate of the vehicle velocity since the 6th iteration. From the collision and the threshold pointes coordinates $C(13, 28)$, $S_1(0.8, 20)$, we can calculate Δ^c_{s1}, Δ^c_{sv} distances at any time. In the 6th iteration, the vehicle coordinates are $(4.36, 23.06) \in \Delta^c_{s1}$ implies that the forecasting approach was started before the 6th iteration where the vehicle coordinates has exceeded the threshold S_1 (see Figure13). The distances $(\Delta^c_{s1}, \Delta^c_{sv})$ and the estimated trajectories are used by the vehicle to define the parameters of the collision avoidance procedure.

Table 5 SV coordinates with and without forecasting approach

Iteration number	*SV coordinates without FCAA*		*SV coordinates with FCAA*	
	X	*Y*	*X*	*Y*
5	0.8	20	0.8	20
6	4.36	23.06	3.07	21.95
7	8.24	25.72	5.48	23.74
8	12.39	27.93	8	25.36

The simulation of this model generates the trace files that describe the requested exchanges and the estimated displacements of the mobile nodes in the intersection scenario using the forecasting approach (FCAA):

7 A comparative analysis

In this section, we present a comparative and a qualitative analysis of the existing intersection collision warning systems. The existing collision warning systems are not efficient because they are based only on the collision detection and the exchange between them of the generated alerts. Nevertheless, the proposed FCAA (Forecasting Collision Avoidance Approach) is based on the detection, the prediction and the avoidance of such collision. The originality of FCAA is compared with the previous methods for starting the forecasting approach in order to avoid the predicted collision. We have identified the advantages and disadvantages of our approach as well as the other methods suggested beforehand. Table 6 presents the comparative analysis of different approaches with our method.

Table 6 A comparative analysis of different approaches

Approach	*Description*	*Disadvantages*	*Advantages*	*C*	*D*	*W*	*A*
VCWC Protocol (2004)	Vehicular Collision Warning Communication protocol is to provide Emergency Warnings Messages (EWM) to all potentially endangered vehicles when a vehicle acts abnormally. This task is to achieve low-latency in delivering EWMs in various road situations.	• The protocol supposes the existence of AV but does not treat how this vehicle becomes AV. • The vehicle starts the emergency warning messages if become the abnormal vehicle (AV) but the vehicle must begin emergency before it is become the abnormal vehicle. • The protocol did not deal the avoidance collision, it based just on the EWM.	• The VCWC protocol can still support low EWM delivery delays at the time of emergency in very stressful scenarios with many AV. • All vehicles affected by an emergency event will receive the emergency warning in time trough emergency warning dissemination • The protocol can indeed support the messages differentiation mechanism and safety.	×			×
U&I (Aware Framework) (2007)	Suggest a method for the knowledge acquisition of intersection accidents detection system and real-time collision detection to implement the ubiquitous intersection.	• The collision prediction method is not efficient. • There is not the avoidance collision approach.	• Collision prediction algorithm used. • Intersection warning systems. • The best precision to collision detection.	×			×

Table 6 A comparative analysis of different approaches (continued)

Approach	*Description*	*Disadvantages*	*Advantages*	*C*	*D*	*W*	*A*
CCW protocol (2007)	The concept of cooperative collision warning (CCW) systems provides warnings or situation awareness displays to drivers based on information about the motions of neighbouring vehicles obtained by wireless communications from those vehicles.	• The system displays the collisions detection and warning but not how avoidance collisions.	• The cooperation concept aid to calculate the collision estimation point. • Time to collision (TTC) and distance to collision (DTC) are the parameters used to trigger the warning.				×
CAAS protocol (2010)	Collision avoidance analysis strategies protocol presents the warning strategies for collision avoidance based on timing analysis events. The design of the collision avoidance systems based on two collision avoidance timing the critical and the preferred time to avoid collision.	• The collision occurrence is not estimated or analysed, but it is just assumed. • To avoid such collision the timing modelling is not satisfied; we must added outer parameters such as the distance to collision.	• The CAAS protocol modelling the collision events to avoidance a potential risk by the timing analysis collision (TAC) to evaluate the various attenuation strategies. • The CAAS system envisages a collision and informs the driver before it detects the danger and determines how long can provide a warning in advance to give the driver and the vehicle sufficient time to react.	×	×		

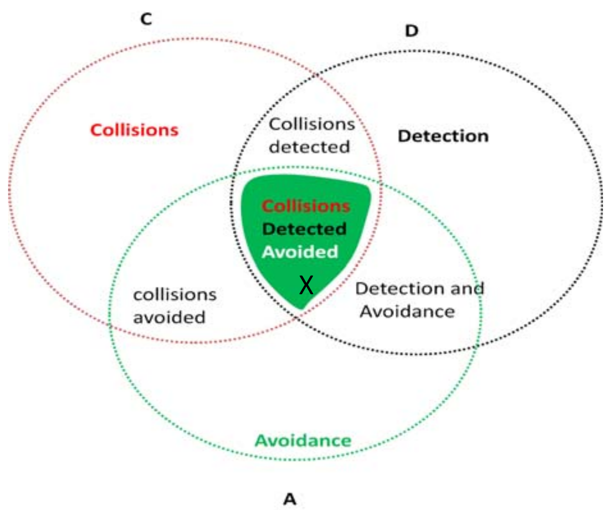
Table 6 A comparative analysis of different approaches (continued)

Approach	*Description*	*Disadvantages*	*Advantages*	*C*	*D*	*W*	*A*
FCAA (2013)	Forecasting Collision Avoidance Approach (FCAA). The main goal of our approach is to estimate or detects a possible collision using the kinematic modelling and warns its neighbours about how to react to avoid this collision.	• The collision avoidance approach does not support an important number of vehicles. • The suggested forecasting approach is designed for scenarios of Y-type intersections.	• Forecasting approach for the collision prediction used by the kinematic model algorithm. • Intersection warning system for collision detection is designed. • Collision avoidance approach is implemented and proved in our realistic scenario				

The difference between the FCAA and the others is summarised in the reaction or decision of the vehicle when the alert is received. The question that dealt it is: how to avoid the collision and which is the good moment for starting the forecasting collision avoidance approach? One of the main approach objectives is to avoid the maximum of detected collision (subject to maximise the X set), i.e. each estimated collision must be detected and avoided. $C \cap D \cap A = X =$ {set of the Collision Detected and Avoided}

$$\text{The precision} = \frac{\text{number of the collision detected and avoided}}{\text{number of the estimated collision}}.$$

Figure14 FCAA presentation set (see online version for colours)



8 Conclusion and perspective

In this paper, we present a new approach for the collision detection and avoidance called FCAA. We have detailed kinematic modelling of vehicle type, and then we have focused on its movement estimation using the kinematic model programming. Our contribution deals with the suggested scheme; this scheme is based on the estimation of some essential parameters in the inter-vehicle communication such as: position, velocity and direction. This model allows the estimation of the future trajectory for each vehicle that is calculated by an embedded estimator. The estimator output becomes an input of the forecasting module that detects the potential collision presence and transmits it to the nearby vehicles as warning. Then the subject vehicle triggers the collision avoidance procedure. In the beginning we have simulated the trajectories estimations vehicles and then we have applied the proposed FCAA in a realistic intersection scenario. Our next work is to extend our simulation approach for other scenario types such as highways and test FCAA performance in the dense VANET when we can estimate some collisions for maximising the X set.

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Note

1 This layer is seen as a bridge between the subject vehicle and the other vehicles; it transmits and receives the estimates of the vehicles, then translates the generated risk on a display board.