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PROPOSED PASSING COLLISION WARNING SYSTEM FOR TWO-LANE HIGHWAYS

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Abstract: Passing collisions are one of the most dangerous traffic safety problems. These collisions occur when the driver of the passing vehicle is distracted or does not appropriately assess the passing situation. The purpose of this study is to develop a Passing Collision Warning System (PCWS) for drivers on two-lane highways in order to prevent passing collisions and improve road safety. This paper provides the framework and algorithm design for a passing collision warning system that assists unprotected passing drivers on two-lane highways. The system uses a radar sensor placed in the passing vehicle to detect opposing vehicles travelling in the left lane and determines their relative distance and speed to estimate the time to collision and compare it with the time required for the passing vehicle to clear the path. The realistic passing maneuver parameters were calculated using experimental field data collected with a Global Positioning System (GPS) data logger device that was installed in passing, impeding, and opposing vehicles to record their position and speed at 1 s intervals. Regression models were also provided to determine the necessary initial time, passing time, and acceleration required by the driver of passing vehicles using field data collected from 25 different drivers. The algorithm considers the time needed for the driver of the passing vehicle to notice the message displayed by the warning system and react to it. The MATLAB simulation was developed and used to replicate real-life passing maneuvers. The MATLAB Simulink model was also used to create the algorithm for the proposed warning system. The passing maneuver parameters were selected from a distribution curve based on the field data. The simulation model for two-lane highways determines the relative distance and speed of the opposing vehicle at four different time intervals. The different factors that impact system accuracy were also examined.
Keywords - Passing Collision Warning Systems; ITS; Vehicle Dynamics; Simulink Model.

1 Introduction

Passing collisions (head-on) on two-lane highways occur when a vehicle attempts to pass a slower moving vehicle by travelling in the left lane. In Canada, passing (head-on) collisions accounted for approximately 30% of all collisions reported in 2010 (Road Safety in Canada, 2010). In the USA, this value reached approximately 20% (Persaud et al, 2004). Safe driving requires drivers to be alert, constantly scanning their environment and properly responding to the movements of opposing vehicles. Numerous driver performance factors can contribute to passing collisions. These factors include incorrect driver reaction time, following too closely, and driver inattention (Brown et al, 2001). These factors could be eliminated with the aid of Passing Collision Warning Systems (PCWS), improving roadway safety.

Collision warning systems can be categorized as kinematics-based or perceptual-based. Kinematics-based collision warning systems use the principal laws of motion and then assume driver reaction times to activate the warnings. These systems generate the warnings when the subject vehicle is within the specified minimum distance. Perceptual-based systems activate the warnings using assumed driver reaction times along with the time-to-collision (TTC) tolerance (Nilsson et al., 1991). The warning algorithm is an important component of these systems. An insufficiently designed algorithm may initiate the warning too early or too late, affecting the reliability of the algorithms (Dabbour, 2009; Mehmood, 2010).

Warning Systems can be installed in vehicles to help prevent collisions. These systems measure the speed and distance of the closest vehicle in the oncoming direction and warn the driver of the target vehicle if there is any conflict between the paths of both vehicles. Some researchers have attempted to develop warning systems for intersections. The vehicle-mounted collision avoidance system was created by the Calspan Corporation (Pierowicz et al., 2000). This system makes use of an in-vehicle positioning system along with two 77 GHz (later replaced with 24 GHz) radar sensors with rotating antennae to identify the speed of the approaching vehicles (using the Doppler Effect) and warn the driver of any potential conflict.

A passing collision warning system (PCWS) can help drivers avoid passing collisions by reducing the chance of human errors. The purpose of this study was to develop a prototype of a passing collision warning system for drivers on two-lane straight highways to prevent passing collisions and improve road safety. Regression models were developed to determine the necessary initial time and passing time for passing vehicles using data collected in various field studies. The Simulink imitation was used to replicate real-life passing maneuvers. The passing maneuver parameters were selected from a distribution curve based on field data. The following section presents the proposed passing collision warning system. The Simulink model and application examples are then presented, followed by concluding remarks.

2 Proposed Collision Warning System

The algorithm is capable of recognizing various opposing vehicles involved in the passing maneuver and the same procedures are followed for each passing vehicle. Fig. 1 shows the procedure for the passing collision warning algorithm.

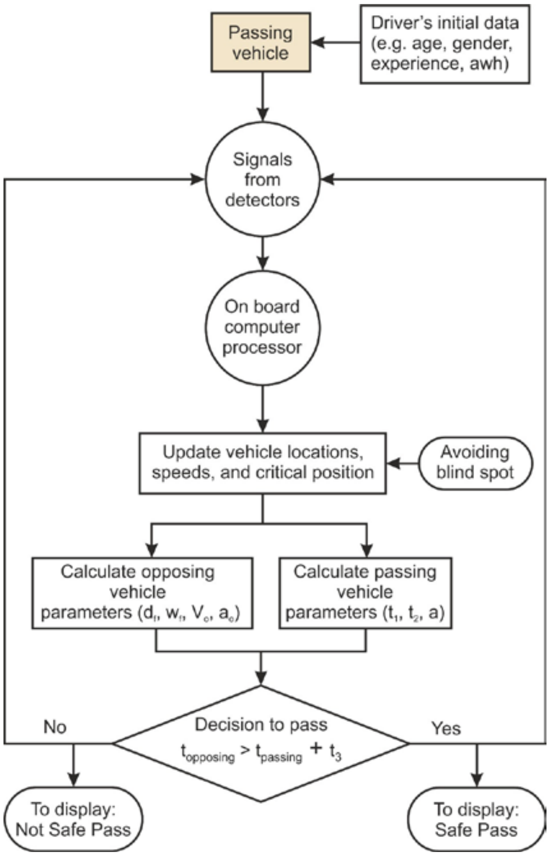

Fig. 1: Flow chart of the passing collision warning algorithm

If the system detects a vehicle in the opposing lane, the message ‘Not Safe to Pass’ will be displayed for the driver. The message can be in text format or an arrow symbol with different colours for each message (e.g. green for ‘safe’ and red for ‘not-safe’). The message stays on until the algorithm confirms that a safe passing maneuver is available.

2.1 General Description of Algorithm

The algorithm involves the following procedures:
1. The driver characteristics are entered in the system (e.g., age, gender, experience).
2. The system takes four successive measurements of both the location and speed of the nearest vehicle detected in the left lane and the time interval between two measurements equals to the inverse of the detector’s frequency.
3. Using these measurements, the system estimates the relative distance and speed of the vehicle that has been detected.
4. The system then determines the time needed for the opposing vehicle to reach the safe point, $t_{opposing}$.
5. This information is then used to determine the time ($t_{passing}$) needed for the passing vehicle to complete the pass which is equal to the sum of t_1 (the perception-reaction time and initial acceleration of the passing driver) and t_2 (passing time) as shown in Fig. 2.
6. The system compares times $t_{opposing}$, to (the sum of $t_{passing}$ and t_3) where t_3 represents a safety margin of 2 s, and makes a decision according to the following criteria:
(a) If $t_{opposing}$ is greater than, the ‘Safe to Pass’ message is turned on and the driver is free to begin the passing maneuver; or
(b) If $t_{opposing}$ is smaller than, the ‘Not Safe to Pass’ message stays on and the system replicates the algorithm to find a safe time gap.

2.2 Geometric Consideration

A GPS data logger device installed on-board the passing, impeding, and opposing vehicles was used to record the position and speed of the vehicles at 1 s intervals. The GPS data logger used in this study (Holux RCV-3000) measures speed with a precision level of 0.1 m/s (0.36 km/h) (Holux Technology Inc., 2014). Since this system is normally applied to passing zones on two-lane highways with speed limits of 80 km/h, the relative error is expected to be insignificant. The analysis included a total of 105 passing maneuvers (acceleration profiles) obtained from 25 different drivers and vehicles. This data was then loaded onto a computer. The sample was randomly selected from each group of passing drivers and included 17 male and 8 female drivers between the ages of 20 and 63 years. The mean age was 34 years and the standard deviation was 13 years.

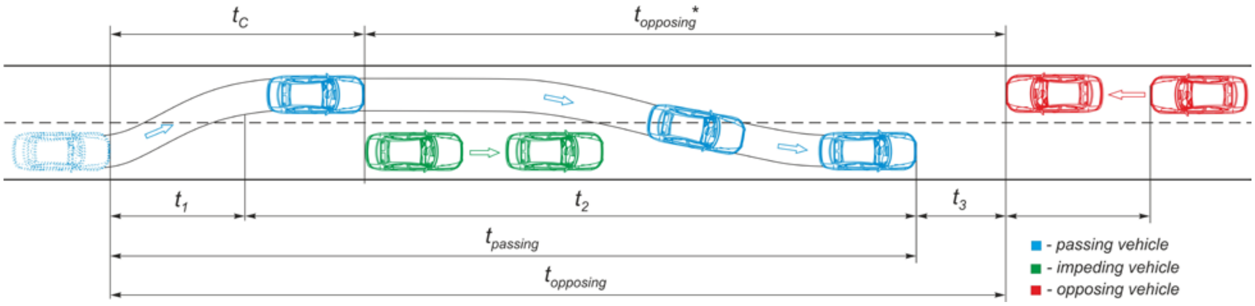

Fig. 2: Times definition

2.3 Passing Vehicle Location

It is not realistic to assume a constant acceleration rate when creating a vehicle acceleration profile (Rakha et al, 2004; Wang et al, 2004). Instead, an acceleration profile should be created for each individual case. In this study, the linear decreasing acceleration model was used in order to create the acceleration profiles. This method was used in several other studies (e.g. Dabbour & Easa, 2014; Drew, 1968; Fuerstenberg & Chen, 2007; Long, 2000). According to this model, the acceleration rate can be computed using the following equation:

[1] $$a = dv/dt = \boldsymbol{\alpha} - \boldsymbol{\beta} \cdot v \pm \boldsymbol{G} \cdot g$$

where a represents the acceleration rate for a particular speed ***v*** (m/s^2); v represents the speed (m/s); ***α*** represents the acceleration rate at the initiation of acceleration (m/s^2); ***β*** represents the rate of decrease in acceleration with increases in speed; ***G*** represents the grade (m/m); and ***g*** represents gravity (approximately 9.81 m/s^2).

As previously discussed, the total time needed for the driver of a passing vehicle to complete the pass, $t_{passing}$, is the sum of the following:

1) The driver's perception-reaction time and initial acceleration (t_1), which is the time needed by the driver to notice the 'safe' signal and then take the necessary action (to activate throttle);
2) The vehicle's travel time (t_2), which is the time needed to accelerate the vehicle and clear the path for the oncoming opposing vehicle. This deals with the time needed to cross the offset distance involving the passing vehicle and the opposing vehicle, along with the length of the passing vehicle itself.

The total time required for the passing vehicle to complete the pass, $t_{passing}$, is calculated using the following formula (see Fig. 2):

[2] $$t_{passing} = t_1 + t_2$$

2.4 Opposing Vehicle Location

Fig. 3 provides an illustration of the calculating distance and angle at each time interval. The radar sensor detectors produce the detection beams at time T to scan the left lane of the two lane highway. If nothing is detected, a 'safe' message is displayed. Otherwise, the closest detected object is measured at distance d_1 and azimuth angle θ_1 where the polar coordinates used with the origin point coexist with the detector's location. At time $T+\Delta t$, the detector produces another detection beam. The Δt represents the detector's time interval (at 25 Hz frequency, the inverse of the frequency = 0.04 s). The new location of vehicle A is recorded at distance d_2 and azimuth angle θ_2. Similarly obtained: d_3, θ_3 and d_4, θ_4. Next step requires a shift on one sample time forward keeping in memory four last measured values.

The distance that is crossed by the vehicle after four time intervals can be calculated using the following generalized equation, where i = {1, 2…n}:

[3] $$dv_i = \sqrt{d_i^2 + d_{i+1}^2 - 2 \cdot d_i \cdot d_{i+1} cos(\theta_i - \theta_{i+1})} - dp_i$$

The speed v_{opp} is calculated using the well-known 4-point numerical first derivative formula revised for line segments instead of function values (where dv_{k-2}, dv_{k-1} and dv_k are calculated using the preceding equation and $k = i + 2$):

[4] $$v_{opp} = \left(1/3 \cdot dv_{k-2} - 7/6 \cdot dv_{k-1} + 11/6 \cdot dv_k\right) / \Delta t$$

The side offset between the opposing vehicle and the passing vehicle, w_f is obtained using:

[5] $$w_f = s_l + d_{i+1} \cdot sin\left(\theta_{i+1}\right)$$

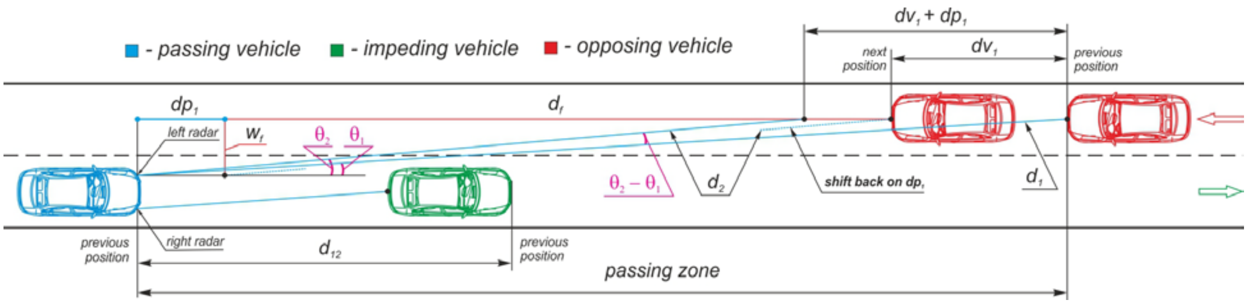

Fig. 3: Calculating distance and angle at each time interval

The offset may be used as a gauge in order to ascertain whether the opposing vehicle is travelling in the left lane. This is accomplished by comparing the calculated value with the sum of the setback distance (between the detector and the edge of the left lane) and the width of the left lane, where s_l represents the location of the left radar sensor on the passing vehicle, which is equal to 0.618 (m). The distance between the opposing vehicle and the detector, d_f, is obtained using:

[6] $$d_f = d_{i+1} \cdot \cos\left(\theta_{i+1}\right)$$

The time needed for the opposing vehicle to reach the end of its part of the distance to the critical point is calculated using the following formula:

[7] $$t_{opposing} = d_f \Big/ \left(v_{opp} + v_p\right)$$

where d_f can be calculated from Eq. (6); v_p represents the passing vehicle speed; v_{opp} represents the instantaneous velocity of an opposing vehicle, which is determined for each value of the time interval Δt, and v_{opp} can be calculated from the speed of an opposing vehicle Eq. (4).

The blind spot is detected using the following procedure. First, the coordinates of the intersection of the point of two lines is determined: one line is defined by the segment joining a passing vehicle's left sensor point and an opposing vehicle's front bumper midpoint and the other line is defined as perpendicular to the longitudinal axis of an impending vehicle and passing through the outermost point of its rear bumper. If the point is within the boundaries of the impending vehicle's width (Fig. 3), it follows that the signal does not pass and two sensors measure the distance to a slow vehicle. Moreover, the rapprochement of passing and slow cars, when moving strictly in track, enhances the blind spot effect. The primary maneuver towards the separating dash line is thus provided by the simulation control algorithm. After that the intersection point of ray and bumper goes out of impending vehicle width and passing car's left sensor can see an opposing vehicle. The algorithm then turns on the warning system.

2.5 The Decision-Making Process

The last step in the algorithm (see Fig. 1) compares the time needed for the opposing vehicle to reach a conflict point, $t_{opposing}$, with the time needed for a passing vehicle to complete the passing maneuver, $t_{passing}$ (see Fig. 2). The following condition is used for the initial decision:

[8] $$t_{opposing} > t_{passing} + t_3$$

where $t_{opposing}$ can be calculated from Eq. (7), $t_{passing}$ can be calculated from Eq. (2), and t_3 is the safety margin (s). If the above condition is met for the opposing vehicle detected, a 'safe to pass' message is displayed for the driver. If not, a 'not safe to pass' message will be displayed until the above condition is met. The subsequent timing of the passing and opposing vehicles will be updated at each time interval during the passing maneuver (see Fig. 2). The algorithm keeps track of these times for subsequent decision making. The time needed by the passing vehicle to complete the passing maneuver can be calculated using the following formula:

[9] $$t_{passing}^{*} = t_1 + t_2 - t_C$$

where $t_{passing}$* = the actual passing time during the passing maneuver (s), t_1 = initial time (s), t_2 is the passing time (s), and t_C is the current sensor's signal processing time (s). The t_C value is zero before the initial decision. During $t_{passing}$*, the data processing continues using the radar sensor and the measurement of the distance between the passing and opposing vehicles is provided. The system continuously monitors overtaking safety until the passing maneuver is complete (see Fig. 2). The following condition is used for subsequent decisions:

[10] $$t_{opposing}^{*} > t_{passing}^{*} + t_3$$

where $t_{opposing}$* = the opposing vehicle time during the passing maneuver that can be calculated from Eq. (7), $t_{passing}$* can be calculated from Eq. (9), and t_3 is the safety margin (s). If the above condition is met for the opposing vehicle detected, a 'safe to continue to pass' message is displayed for the driver. If not, a 'not safe to continue to pass' message will be displayed until the above condition is met.

3 Passing Vehicle Parameter Estimation

Linear regression models for the initiation of passing time (t_1), passing time (t_2), and average acceleration (***a***) were developed using SAS software (SAS, 2015) using the field data collected for the development of the proposed model. Twenty five drivers participated in this study and a total of 105 observations were collected.

3.1 Initiate Passing Time (t1)

The linear model was developed as follows:

[11] $$t_1 = 4.4409 + 0.0552 \cdot Gender + 0.0164 \cdot Age - 0.0233 \cdot Exp - 0.0179 \cdot Awh - 0.0358 \cdot Vp$$

where t_1 = initial passing time (s), *Age* = passing vehicle driver age (years), *Gender* = passing vehicle driver gender (0 for males and 1 for females), *Exp* = passing driver driving experience (years), *Awh* = passing vehicle driver weekly driving hours (hours), and *Vp* = passing vehicle speed (m/s). The results indicated that, at a 95% confidence level, the passing vehicle speed before reaching the critical point (*Vp*) explained a suitable amount of the passing vehicle speed decrease (F = 1.91). The estimated slope of the linear regression line was considerably significant (t = -1.31, p-value = 0.1939). The mean of the initial time was 3.572 s and the standard deviation was 0.634 s. 95% of the observations were less than 4.5 s. The second value (4.5 s) could therefore be used for design purposes.

3.2 Passing Time (t_2)

The linear model was developed as follows:

[12] $$t_2 = 8.968 + 3.515 \cdot Gender + 0.223 \cdot Age - 0.303 \cdot Exp - 0.166 \cdot Awh - 0.111 \cdot Vp$$

where t_2 = passing vehicle time when occupying the left lane (s). The results indicated that, at a 95% confidence level, the passing vehicle speed (*Vp*) explained a suitable amount of the difference in the speed decrease (F = 1.60). The estimated slope of the linear regression line was considerably significant (t = -1.26, p-value = 0.2091). The mean of the initial time was 9.597 s and the standard deviation was 2.452 s. 95% of the observations were less than 14.58 s. The second value (14.58 s) could therefore be used for design purposes.

3.3 Acceleration Profile (*a*)

A linear regression model for acceleration was developed using experimental data in order to provide more accurate values of parameters *α* and *β*. The speed of the passing vehicle was used as the predictor variable. The acceleration model was then developed. The linear model was developed as follows:

[13] $$a = 0.72569 - 0.00649 \cdot Vp$$

where ***a*** represents the acceleration rate (m/s^2) and *Vp* represents the speed (m/s). The results indicated that the coefficients of the independent variable (speed) were significant at the 95% confidence level (F = 0.21838). The estimated slope of the linear regression line was considerably significant (t = 2.61338, p-value = 0.0105).

4 Simulink Model Description

The use of the powerful imitation environment Simulink allows researchers to simultaneously watch an object, the structure of its constituent systems, and to monitor behaviour and control algorithms (by Stateflow), summing up the basis for rapid prototyping of mechatronics systems. The proposed model can be customized for any vehicle and takes into account the design, physical properties, and geometric properties of the vehicle. The simplest object is shown in Fig. 4, which allows for the combination of several car-models in one simulation scenario to reflect overtaking processes on two-lane highways.

The basis of a single vehicle model, shown in Fig. 4, is block 1, where all necessary 2D-steerability components are implemented via the Simulink library. Blocks 2 and 3 are vectors that transmit initial positions (plane location and yaw rotation) and velocities (longitudinal, lateral, and yaw rate) according to degrees of freedom.

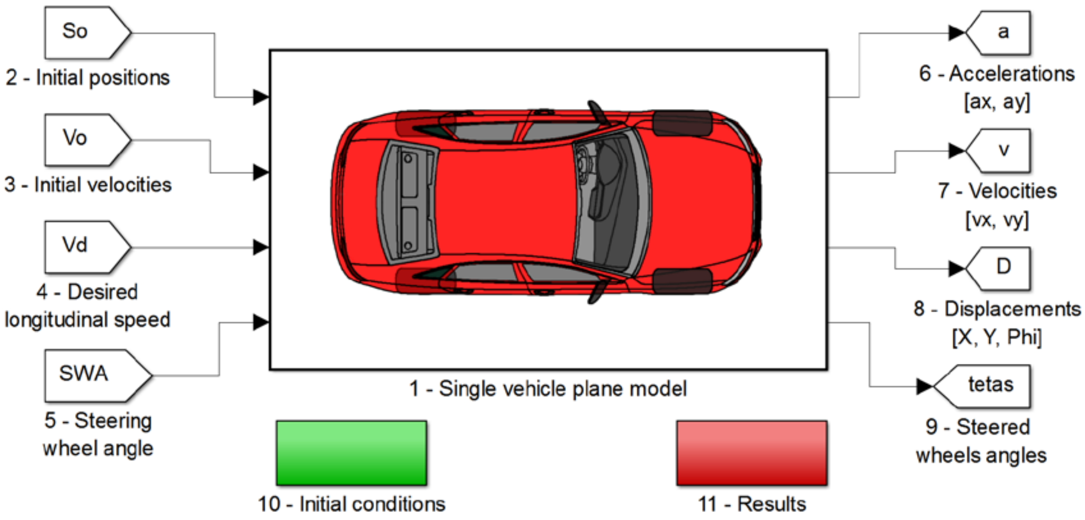

Fig. 4: Calculating distance and angle at each time interval

Block 4 allows for the adjustment of the traction dynamics by means of the desired course velocity, and the current steering wheel angle is provided through input port 5. The outputs of block 1 are as follows: into port 6 - accelerations (longitudinal and lateral) in the vehicle's local coordinate system; into port 7 - velocities (longitudinal and lateral); into port 8 - all absolute displacements relative to the global coordinate system; into port 9 - steering wheel turning angles. Subsystem 10 sets the initial conditions of motion and control laws, and subsystem 11 obtains graphical representations of solutions. The model makes it possible to start an animation script that visually reflects the realism of the simulation.

The equation system of dynamics [14] is represented in the vehicle's local coordinate system by longitudinal, lateral, and rotational dynamics around axis OZ. $\boldsymbol{m}$ represents the vehicle mass, $\boldsymbol{I}$ represents the moment of inertia relative to the *OZ* axis, V_{Cx} and V_{Cy} represent the velocities along the axes of the local coordinate system associated with mass center *C*, δ_r represents the coefficient that takes into account the inertia of the transmission's rotating masses, $\boldsymbol{\phi}$ represents the angle of the vehicle's rotation around the *OZ* axis, and $\boldsymbol{F}^{(e)}_x$, $\boldsymbol{F}^{(e)}_y$, $\boldsymbol{M}_z$ signify the generalized external force factors along the x and y axes and around *z* (respectively). The vehicle control is carried out through the change of power factors by magnitude and direction, that is, traction and the lateral reactions of the tires.

$$[14] \qquad \begin{cases} m\cdot\delta_r\cdot\left(\dfrac{dV_{Cx}}{dt}-\dfrac{d\phi}{dt}\cdot V_{Cy}\right)=\sum \boldsymbol{F}_x^{(e)}, \\ m\cdot\left(\dfrac{dV_{Cy}}{dt}+\dfrac{d\phi}{dt}\cdot V_{Cx}\right)=\sum \boldsymbol{F}_y^{(e)} \\ I\cdot\dfrac{d^2\phi}{dt^2}=\sum \boldsymbol{M}_z \end{cases} \qquad \begin{pmatrix} \dfrac{dV_{Cx}}{dt} \\ \dfrac{dV_{Cy}}{dt} \\ \dfrac{d\omega}{dt} \end{pmatrix} = \begin{pmatrix} \dfrac{1}{m\cdot\delta_r} & 0 & 0 \\ 0 & \dfrac{1}{m} & 0 \\ 0 & 0 & \dfrac{1}{I} \end{pmatrix} \cdot \begin{pmatrix} \sum \boldsymbol{F}_x^{(e)} \\ \sum \boldsymbol{F}_y^{(e)} \\ \sum \boldsymbol{M}_C \end{pmatrix} + \underbrace{\frac{d\phi}{dt}}_{\omega} \cdot \begin{pmatrix} V_{Cy} \\ -V_{Cx} \\ 0 \end{pmatrix}$$

The mathematical model and derivative equations via the vectors shown in Eq. (14) are easy to implement using Simulink tools, making it simple and obtainable without requiring any special commercial software. Computational procedures are performed almost instantly, making this a promising model for the simulation of traffic situations involving several vehicles. The main feature of the proposed model is its four-point (all wheel) road contact instead of the bicycle models that are still widely used. The distribution of the vertical forces on the wheels, which is the most influential factor in the tire slip process, is provided. This distribution takes into account the effect of the inertia pseudo-forces at the vehicle's mass center. The model takes into account non-linear tire-road contact and degree of adhesion with the road surface. The distribution of steering angles is represented functionally as a result of the steering trapezoid's design optimization.

The basic functional idea behind this warning system is the preventive forecasting of the relative location of approaching vehicles. Two radar sensors are used as detectors and are mounted symmetrically on the vehicle's front bumper. These detectors operate using the Doppler Effect. This allows the warning system to monitor the simultaneous positions of two vehicles. This paper does not cover device simulation and signal processing due to the complicated nature of the general model. The calculation of the distance from the sensor to the opposing vehicle is obtained geometrically from the solutions of differential equations.

The State Flow (Mathworks, 2016) chart was used for computational procedures and the arrangement of the warning system. The sample time of the sensors is provided at the interval of $\Delta t = 0.04$ s and new vehicle route distances are defined after each assessment. After that, the measurement data from the first four measurements is stored and the finite difference formulas are used to determine the kinematic characteristics of the opposing vehicles. The kinematics of an overtaking vehicle are determined by in-vehicle reading devices that allow for the use of these parameters directly from the solution of motion equations.

5 Application Example

The application example in this section is provided to illustrate the methodology used in this investigation. The input data for the passing vehicle from field studies for Passing Collision Warning Systems (PCWSs) included the following: (1) initial speed of 18 (m/s); (2) initial distance of 460 (m); (3) initial acceleration rate of the opposing vehicle of 0.68 (m/s^2); (4) detection sensor angle of 90^o; (5) gender 0 (male = 0), age of 27 (years), driving experience of 10 (years) and average weekly driving hours of 30 (hours) for the passing vehicle driver; and (6) the number of lanes of 2, lane width of 3.75 (m), and design speed of 22.22 (m/s), which is equal to 80 (km/h) in highway geometric design. The proposed system uses a radar sensor range of 1,000 m (see for example Symeo, 2016). The example assumes that the advisory system is using a detector with a frequency of 25 Hz and a precision level of 0.1 m for the reading distance. The first detector is installed on the right side of the front bumper of the passing vehicle. The setback distance (d_{12}) was approximately 26.4 m from the front bumper of the passing vehicle to the front bumper of the impeding vehicle.

Fig. 5 illustrates the numerical data processing. The initial detection measurements for the opposing vehicle were obtained at a distance (d_1) of 440.6 m, a sensor ray angle (θ_1) of 0.372°, and a speed of approximately 21.76 m/s. The second detection measurements for the same vehicle were obtained at a distance (d_2) of 439 m, a sensor ray angle (θ_2) of 0.372°, and a speed of 21.73 m/s. The third detection measurements for the same vehicle were obtained at a distance (d_3) of 437.4 m, a sensor ray angle (θ_3) of 0.372°, and a speed of 21.7 m/s. The final distance between the opposing vehicle and the detector (d_f), calculated using [6], was 435.8 m and the distance between the opposing vehicle and the conflict point was 195.4 m. Since the impeding vehicle was travelling at a near-constant speed, the time required for the passing vehicle to overtake the impeding vehicle ($t_{passing} = t_1 + t_2$), computed using Eq. (11) and Eq. (12) was 8.35 s. The time required for the opposing vehicle to reach the conflict point ($t_{opposing}$) computed using Eq. (7) was 11.9 s. The difference between $t_{opposing}$ and $t_{passing}$, the 2.39 s safety margin was larger than the critical 2.0 s (95% confidence interval). This safety margin was significantly larger than the measurement error associated with the precision level (0.02 s). The warning message displayed to the passing driver can therefore be deactivated.

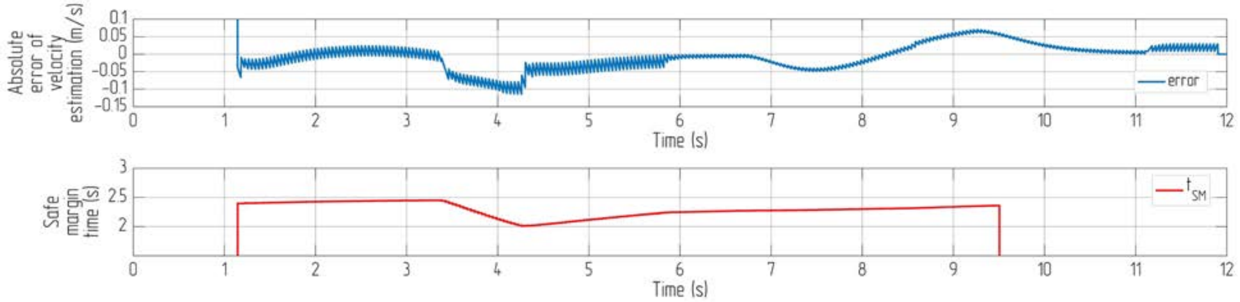

Fig. 5: Example of numerical data processing

For a design speed of 22.22 (m/s), it is important to note that the warning message would not have been deactivated if the opposing vehicle was detected at a shorter distance (less than 400 m) from the passing vehicle or if it was travelling at a higher speed (higher than 25 m/s). It is also important to note that the warning message would not have been deactivated if a higher confidence level had been used (higher than 99%) or if the precision levels of the detector were above 0.1 m and 0.1 when measuring the distance and the angle, respectively. Furthermore, during the 1.5 s of computation time, the pre-steer maneuver arrangement compensates for the effect of the blind spot. The following sample time points are spent obtaining the first couple of measured values illustrated on the graph of the distance to the opposing vehicle. After the information has been accumulated, the warning system will be ready to begin the forecasting assessment. This occurs around the 1.145 s mark. The comparison of the impeding vehicle's actual speed and the speed obtained from numerical estimation shows a good convergence between the results with some delay. It is apparent that the sharp change in the movement mode of approaching vehicles has a negative impact on the accuracy of distance estimations. The absolute error, which is mostly positive with an average value below 0.15 m/s, compensates for the delay, slightly reducing the estimated safety time. At around 12 s, the maneuver is almost over and this time corresponds to a specified time $t_{opposing}$. The warning signal reflects that the remaining distance is not sufficient to stay in the opposing lane.

6 Conclusions

This paper presents the framework and algorithm design of a collision warning system intended to help drivers conduct safe passing maneuvers on two-lane highways.

1. The system makes use of a detector (radar sensor) to measure the relative distance and speed of the closest opposing vehicle on a two-lane highway at four successive time intervals in order to discern the distance to the conflict point, as well as the speed.
2. The algorithm used in this system calculates the time required for the passing vehicle to complete the pass. The algorithm then ascertains whether or not there is any possible conflict between the opposing and passing vehicles and displays a warning message if a conflict is detected. An in-vehicle detector (placed in the passing vehicle) is used to activate the system and launch the algorithm.
3. The algorithm considers the time required for the driver to notice the warning message displayed by the system and react to it (to start or abort the passing maneuver).
4. Mathematical models were developed to estimate the reaction time of perception. The initial time, passing time, and acceleration rate of passing drivers were obtained using data collected from field experiments in which a GPS data logger device recorded the position and speed of various vehicles at 1 s intervals.
5. The results revealed that 95% of drivers have a safety margin time of 2 s or more. The inclusion of the safety margin time in the system's algorithm may increase the reliability of the system by decreasing the amount of mistimed warnings.

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