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DEVELOPMENT OF A PASSING COLLISION WARNING SYSTEM PROTOTYPE FOR OVERTAKING TRUCKS ON TWO-LANE HIGHWAYS

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Abstract: Passing collisions are one of the most serious traffic safety problems on two-lane highways. These collisions occur when the driver cannot correctly assess the situation. This paper provides the framework design for a passing collision warning system (PCWS) that assists drivers, avoiding passing collisions on two-lane highways by reducing the probability of human error. The system uses sensors to identify the impeding vehicle type and to detect opposing vehicles travelling in on the oncoming lane. The objectives of this research are: (1) to design driving simulator experiments for data collection to calculate passing parameters, (2) to develop the PCWS algorithm based on camera and radar sensors' signals for the detection of a truck (impeding vehicle), (3) to develop a the driver handling model that describes situations, in which steering wheel action is necessary for lane changes and maneuver interruptions, and (4) to develop SUV and articulated vehicle dynamic models which are represented as universal Simulink blocks combined in one simulation scenario. The simulation series were carried out to confirm the effectiveness of the PCWS algorithm. This study involved the investigation of the effect of driver behaviour on passing maneuvers, and the development of the algorithms for a PCWS that assists drivers in the selection of proper passing gaps during passing maneuvers. Certain techniques, such as mathematical and imitation models, were enhanced in order to replicate real-life driving situations in Simulink. The different factors that affect system accuracy were also examined.

1 Introduction

Passing collisions occur when a fast-moving vehicle tries to pass a slow-moving vehicle by travelling in the opposing lane on a two-lane highway. These collisions are often caused by driving errors and lead to the loss of human lives and costly property damages. The development of a Collision Warning System (CWS) makes a significant contribution to the field of vehicle transportation. These systems help to prevent accidents and save human lives, while avoiding the potential expenses involved in collisions and road infrastructure damage, benefiting the economy. The most important outcome from the implementation of these systems is expected to be autonomous vehicles and intelligent traffic, which help optimize vehicle flow and reduce erroneous human influences.

The evolution of CWS technology began with the study of the overtaking process. Using statistical estimation, researchers tried to distinguish certain zones (according to AASHTO, 2011) in the overtaking path and mathematically describe regressions for the corresponding times (Granet et al., 2003). The bicycle model (in the form of a state-space system) was often used to represent vehicles (Kretschmer et al., 2005). Using this approach, driver behaviour, which depends on different parameters such as age, gender, experience, etc., can be studied to reflect deviations in various time components (Hassein et al., 2017, Mehmood, 2010). The next step in the evolution of CWS technology included the study of vehicle handling and acceleration models using simulations. When automotive radar sensing technology was developed, CWS systems, which assist in the prevention of collisions, were considered in studies

(Dabbour et al., 2014). In approximately 2005, the new computer vision technology became affordable for implementation. By means of installed video camera and special image analysis techniques, the measurement of distances and object dimensions became an option for road object recognition (Isermann et al., 2012). The latest technology combination provides multi-sensor fusion and fully automatic handling to reach a zero-tolerance accident strategy.

The purpose of this paper was to develop a Passing Collision Warning System (PCWS) for driving on two-lane highways to avoid passing collisions and to improve road safety. Regression models were provided to determine the initial time, passing time, and acceleration needed by the driver of the passing vehicle using driving simulator data collected from 63 different drivers (Hassein, 2017). Mathworks Simulink was used to replicate real-life passing situations. The following section presents the proposed PCWS, driver model, and mathematical basis of the handling model. The Simulink model and application example are then presented, followed by the conclusion.

2 Proposed Collision Warning System

The algorithm is capable of detecting various opposing vehicles in the passing maneuver and the same procedures are followed for each impeding vehicle. Fig. 1 shows the procedure of the passing collision warning algorithm. When the system detects a vehicle in the opposing lane, a message regarding passing safety is 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.

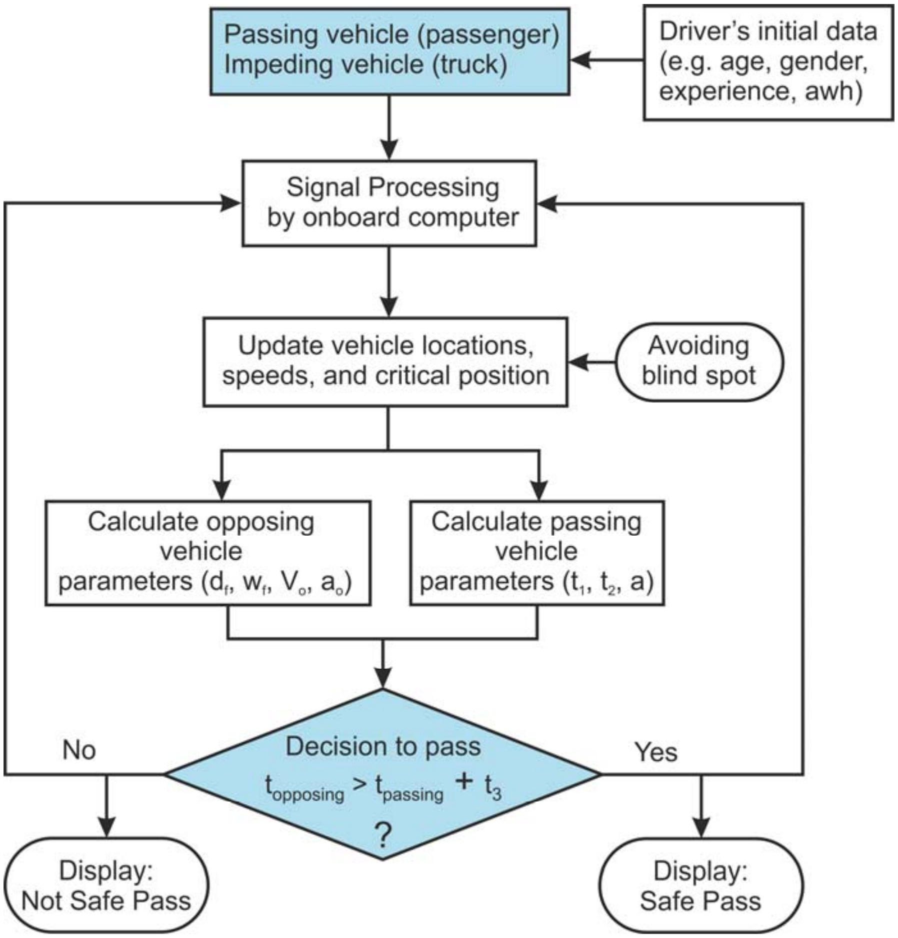


Figure 1: Passing collision warning algorithm

2.1 General Algorithm Description

1. The driver characteristics are entered in the system (e.g., age, gender, experience).

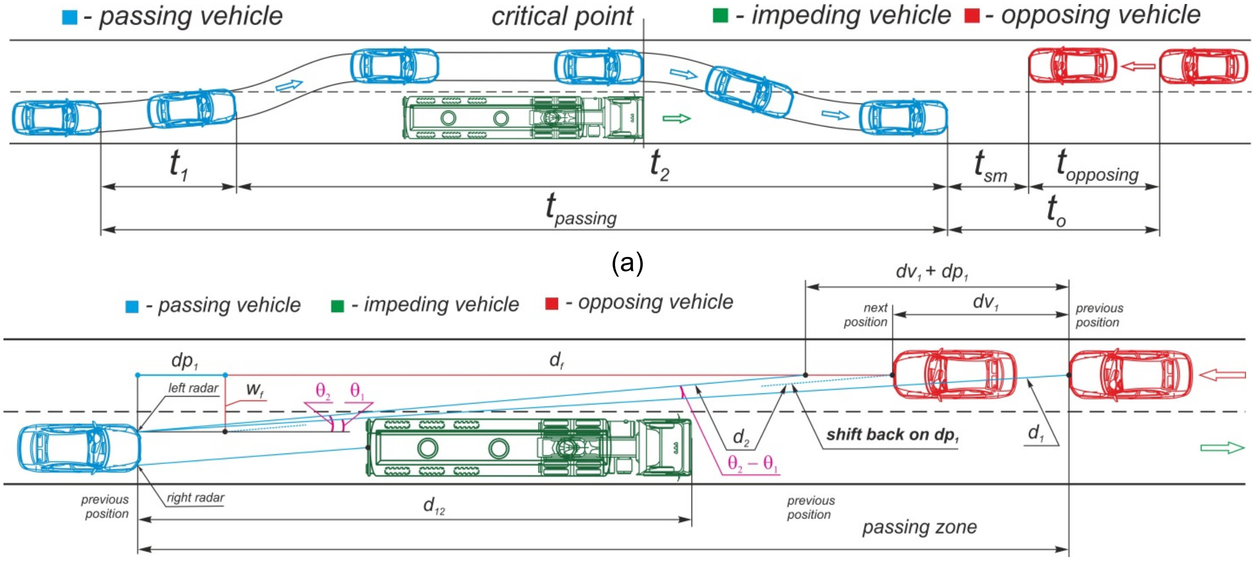
2. The system takes two successive measurements of both the location and speed of the nearest vehicle detected in the closest lane on the left side and the time interval between the two measurements equals the inverse of the detector's frequency.

3. Using these measurements, the system estimates the acceleration rate 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.a.

6. The system compares times $t_{passing}$, t_o (the sum of $t_{opposing}$ and t_{sm}) where t_{sm} represents a safety margin of 2 s and makes a decision according to the following criteria: (a) If $t_{passing}$ is greater than t_o, the "Not safe to pass" message stays on and the system replicates the algorithm to find a safe time gap; or (b) If $t_{passing}$ is smaller than t_o, the "Safe to pass" message is turned on and the driver is free to begin the passing maneuver.



(a)

(b)

Figure 2: (a) Time definitions; (b) Calculating distance and angle at each time interval

2.2 Passing Vehicle Location

The total time required 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); and

2. The vehicle's travel time (t_2), which is the time needed to accelerate the vehicle and clear the path for the oncoming vehicle. This involves the time needed to cross the offset distance between the passing and opposing vehicles, along with the length of the passing vehicle itself.

Finally, the total time required for the passing vehicle to complete the pass, $t_{passing}$, is calculated using the following formula:

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

Linear regression models for initiating the passing time (t_1), and passing time (t_2) were developed (see Fig. 2.a) using the field data collected using SAS software (SAS, 2015). The new parameter developments are presented in the following sections.

2.3 Opposing Vehicle Location

Fig. 2.b provides an illustration of the distance and angle calculations at each time interval. The radar sensor detectors produce the detection beams at time T in order to scan the left lane of the two-lane highway. If nothing is detected, a "Safe" message is displayed. Otherwise, the closest object detected 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. The algorithm (see Fig. 1) assumes that the opposing vehicle is approaching from the east and the azimuth angle is measured counter clockwise from the north meridian located at the detector's location. At time $T + \Delta t$, the detector produces another radar beam. The Δt represents the detector's time interval (the inverse of the frequency = 0.01). The new location of vehicle A is recorded at distance d_2 and azimuth angle θ_2 (Fig. 2.b).

The speeds v_1 and v_2 of the opposing vehicle are also measured at time interval Δt. If d_1 and d_2 are equal (v_1 and v_2 are both zero), the algorithm infers that the object is stationary (e.g., a tree or a post) and the "Safe" message is displayed. If d_2 is greater than d_1, the algorithm infers that the object is moving in the opposite direction (away) and a "Safe" message is displayed. If d_2 is smaller than d_1, the distance crossed by the vehicle during the time interval at time $T+\Delta t$ (dv_1) is obtained using:

[2] $dv_1 = \sqrt{d_1^2 + d_2^2 - 2 \cdot d_1 \cdot d_2 \cos(\theta_2 - \theta_i)} - dp_1$

A third radar signal is produced at time $T+2\Delta t$ and records the information for vehicle A at distance d_3 and azimuth angle θ_3. The distance that is crossed by the vehicle in the second time interval, dv_2, can be calculated in a similar way as dv_1 using the following formula:

[3] $dv_2 = \sqrt{d_2^2 + d_3^2 - 2 \cdot d_2 \cdot d_3 \cos(\theta_3 - \theta_2)} - dp_2$

The speed, $v_{T+2\Delta t}$, and acceleration, $a_{T+2\Delta t}$, were determined using the following formulas:

[4] $V_{T+2\cdot\Delta t} = \left(3 \cdot dv_2 - dv_1\right) / \left(2 \cdot \Delta t\right)$

[5] $a_{T+2\cdot\Delta t} = \left(dv_2 - dv_1\right) / \Delta t^2$

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

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

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 0.618 (m). The distance between the opposing vehicle and the detector, d_f, at time $T+2\Delta t$ is obtained using:

[7] $d_f = d_3 \cdot cos(\theta_3)$

Based on conflict types involving the opposing vehicle and the passing vehicle (travelling in the opposing lane or along the same lane), an opposing time, $t_{opposing}$, with a passing time, $t_{passing}$, are calculated in one of the two ways described below. The formula obtained using regression analysis to determine the time t_2 only contains passing vehicle speed as the main unknown variable. This means that the influence of the acceleration mode is neglected in this case. In a real-life situation, the acceleration at the start of overtaking reduces the estimated runtime of the maneuver. In this case, some of the imperfections of the model represented by the formulas for t_2 may be considered as a factor for the tightening of conditions.

Obviously, the formula is more suitable for the flying pass, when the speed is reached in advance and is kept constant while overtaking the impeding vehicle. The necessary linear space for the complete passage is therefore calculated using $v_p \cdot t_{passing}$, where $t_{passing} = t_1 + t_2 - t_C$. Here, t_C represents the current time from the start of sensor data processing, providing the measurement of the distance between the opposing vehicles. Since t_1 and t_2 were determined during the initiation of the warning system, t_C allows for the calculation of the remaining time for the maneuver and ensures the continued monitoring of the safety of the overtaking maneuver. Thus, assuming that the probability of a significant positive change in the speed of an opposing car is small (leading to increased danger), the time required for the opposing vehicle to overcome its portion of the distance to the critical point is calculated using the following formula:

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

where d_f can be calculated from Eq. (7); 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 the opposing vehicle Eq. (5).

2.4 Decision-Making Process

The last step in the algorithm compares the time needed for the opposing vehicle to reach a conflict point, $t_{opposing}$, with the time needed for the passing vehicle to complete the passing maneuver, $t_{passing}$. If the time needed to complete the passing maneuver, $t_{passing}$, is less than the time needed for the opposing vehicle to reach a conflict point, t_o, a "Safe" message is displayed for the driver. Otherwise, a "Not safe" message will be displayed (see Fig. 1).

3 Proposed Steering Control Model

The development of adequate driver models is critical for vehicle dynamics simulations and for the development of control algorithms that can be added to autonomous vehicle technologies. It should be noted that a driver has a much broader range of parameters characterizing his/her behaviour than a robotic analogue. The various vehicle handling models can be categorized into the following two approaches, which have been successfully used in researchs of overtaking research. Isermann et al. (2012) described the coincidence between the vehicle's mass center trajectory and a hypothetical trajectory. Kretschmer et al. (2005) described a steering controller, which used a current lateral vehicle offset from a determined overtaking trajectory. The controller uses the virtual guidance point, when the look-ahead distance depends on many vehicle properties, including the vehicle speed.

The proposed driver model is illustrated in the Fig. 3.a. A hypothetical curve is shown by the blue line that represents a driver's guide for visual reference starting from point ***0*** to point ***G***, used when it is necessary to change direction. That is, the guidance point in the process of vehicle motion slips along this conditional trajectory. Consider a generalized variant, when the vehicle mass center has current displacements ΔX, ΔY in this curve's fixated coordinate system, and a current course angle ϕ (Yaw Angle) is determined by the rotation of the local coordinate system $\xi C \mu$ around the coordinate system $x'Cy'$, which slides parallel to the global coordinate system (Fig. 3.a). In addition, assume that the driver intuitively holds a certain area in his/her field of vision, which is limited by the sight angles and radius ***R***, thus forming the circle sector. If the hypothetical trace of the guidance point ***G*** is given by function *y = f(x)*, then taking into account the equation of circle, the required value *x* can be derived from the following equation:

[9] $$\sqrt{R^2-\left(x-\Delta X\right)^2}-\Delta Y-f\left(x\right)=0$$

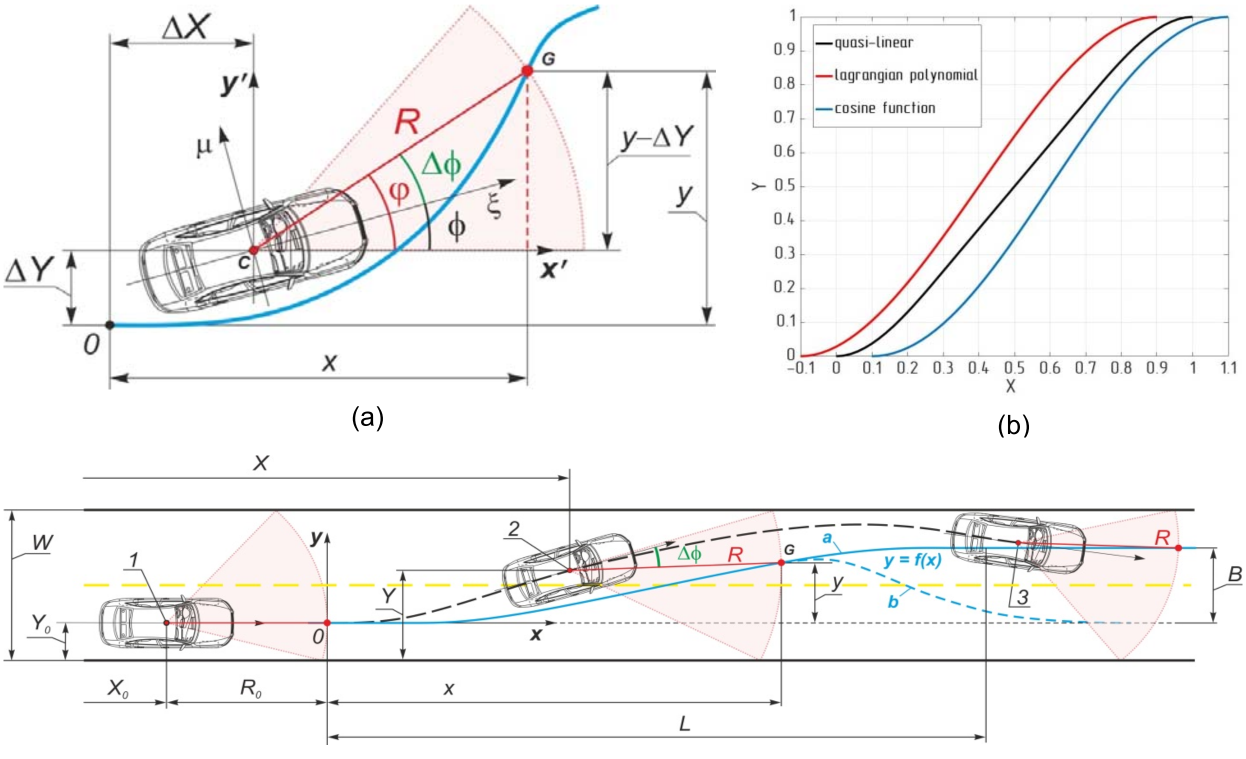
The line segment that combines the mass center ***C*** and the point of intersection of an arc with a hypothetical track of the guidance point sets the angle ***φ*** relative to the ***x′*** axis, which is defined as:

[10] $$\varphi = \arcsin\left(\left(y-\Delta Y\right)/R\right)$$

The difference between the angles ***ϕ*** and ***φ*** is ***Δϕ***, which must be compensated by a feedback circuit with a PID (proportional-integral-derivative) controller. Fig. 3.b depicts the main functions reduced to a normalized scale, which are proposed for the guidance spot trace. The *x*-axis is a longitudinal coordinate, which varies from ***0*** to ***L***, and the *y*-axis is a side offset of point ***G*** from ***0*** to ***B***. The primary requirement for these functions is a continuous derivative. The simplest option in this regard is the inverted and vertically shifted trigonometric cosine function, which has a zero *y* value and a zero derivative at the zero point.

[11] $$y\left(x\right) = B\cdot\left(1-\cos\left(x\cdot\pi/L\right)\right)/2$$

Another function, which provides smoothness and smooth curvature changes, is a cubic polynomial with zero derivatives at the boundary points. Function y(x) in Eqs. (11) and (12) are closely adjoined.



(a)

(b)

(c)

Figure 3: Elements of the proposed driving strategy: (a) Scheme for creating the desired course relative to the current direction of movement; (b) Typical normalized tracking curves for guidance spot; (c) Scheme of the formation of the vehicle mass center trajectory during the lane change

[12] $y(x) = B \cdot \left(3 \cdot L \cdot x^2 - 2 \cdot x^3\right) / L^3$

The last function is composed of three parts: a cubic polynomial, Eq. (12), with a zero-value function and a zero derivative for the left boundary point; a value of the function, and a derivative at the right boundary point matching the corresponding left boundary parameters of the following linear component function. The steps are then repeated in the opposite direction using polynomial Eq. (13) instead of Eq. (12).

[13] $y(x) = B \cdot \left(2 \cdot x^3 - 3 \cdot L \cdot x^2 + L^3\right) / L^3$

We then obtain a quasi-linear function with smoothed conjugation. The description of the formation of the vehicle mass center trajectory is based on Fig. 3.c, where the lane change process is shown according to the handling strategy on a two-lane highway. The proposed glide function *y = f(x)* of the virtual guidance point ***G*** has a longitudinal basis ***L*** and a transversal basis ***B***. In order to immediately change the direction of spot ***G*** without a sharp transition between the virtual curves ***a*** and ***b***, the condition of derivative continuity in the current ***G*** point must be satisfied. Consequently, both the guidance track curve *y = f(x)* and its derivative *dy/dx* should be calculated simultaneously. Thus, the driver's decision to continue or to abort an overtaking maneuver would be possible at any moment within curve basis ***L***. The expression for curve b is as follows:

[14] $y(x) = y_0 \cdot \left(2 \cdot x^3 - 3 \cdot L \cdot x^2 + L^3\right) / L^3 + dy_0 \cdot \left(x^3 - 2 \cdot L \cdot x^2 + L^2 \cdot x\right) / L^2$

where $\boldsymbol{y_0}$ and $\boldsymbol{dy_0}$ represent the function and its derivative for the left end of the base L, respectively. It is assumed that the function and derivative of the right end are equal to zero. This indicates a return to the initial location within the lane.

4 Simulink Model Description

4.1 Collision Warning System: Simulink Model for Overtaking Cases Involving Trucks

The general Simulink model for overtaking scenarios involving a truck as the impeding vehicle consists of three components which are combined by data exchange buses (Fig. 4.a). Blocks 1, 5 (Single Unit Vehicle) and 9 (Articulated vehicle (truck + semitrailer)) represent the 2D-dynamic steerability models for passenger cars and articulated vehicles. These blocks implement the mathematical models that describe the vehicle plane dynamics. Each vehicle block-model has an extended inner hierarchy of subsystems that are based on the Simulink library elements. This can be adapted for any vehicle configuration, taking into account geometric, physical, and technical characteristics. Each unit has one input and one output complex port for more compact data transfer. The input data are generated using blocks 4, 8, 13 - bus creator. Each vehicle model has a block with initial conditions (positions 2, 6, 11), which specify the initial kinematic parameters (displacements, velocities) of the vehicle movement.

The control models (positions 3, 7, 12) form the signals corresponding to the vehicle speed modes and the steering wheel angles, allow for independent control of the vehicle models. In Block 10 - Road Cond, the general parameters of the road conditions, such as the rolling resistance coefficient and the maximum coefficient of the road adhesion, can be specified. All the kinematic output data from each particular vehicle block (displacements, velocities, accelerations) are combined in block 14 - Results. From this block, the parameters involved in the functioning of the proposed collision avoidance system are directly selected along with data that affect the control algorithm (driver behaviour) for a passing vehicle. The output variables associated with the activation buttons for creating visualizations or filming can be found in block 15 - Vis log.

4.2 Control-model Development

Fig. 4.b shows a block structure of the control signal formation, which sets the direction of vehicle movement. Longitudinal displacement signals are received in input port 1, marked by block *1 - X*; Transverse displacement signals are received in port 2 of block *2 - Y*; The longitudinal velocity signal of

the local vehicle coordinates is received in input port 3 of block *3 - Vx*. Port 4 (block *4 - Yaw*) transmits the course angle.

All of these parameters are the numerical solution results of the SUV's motion differential equation system. In block 5 - Driving strategy, the lane changing algorithm is implemented using Stateflow. This algorithm also contains the scheme in Fig. 4.d. The output parameter of the Stateflow chart is the desired direction angle DesYaw (output port 2). The error between the angle that was predicted by the driving strategy and the actual yaw angle is evaluated in block 6 - Sum. The PID-controller (block *7 - PID Controller*, see Fig. 4.c) generates a deviation compensative signal. Block 8 - Transport Delay, allows for the avoidance of the occurrence of the detrimental algebraic circuit, and simulates the delay associated with the driver's reaction time. The Limitation 9 - Saturation restricts the steering wheel rotation angle within rational boundaries. Output port 1 (block *10 - StAng*) transmits the steering wheel angle to outside, where it is converted into driver wheel rotational angles by corresponding subsystems in the vehicle model structure.

4.3 Simulink-function solver to search the guidance track point

Fig. 4.d illustrates the Simulink-function, which is part of the Stateflow chart, for the determination of the current guidance point coordinates. The input parameters are as follows: ports 1, 2 (blocks 1 - DX, 2 - DY) receive the vehicle mass center's relative displacements in the guidance point function coordinate system; input ports 3 - L, 4 - B – receive the corresponding values that parameterize the virtual track function in the space (on the highway lanes); the input ports 5 - R_{min}, 6 - R_{max} receive the values of the minimum and maximum radii, which form the changing sight distance range; input port 7 – Vmax, is the signal of a vehicle's maximum conditional speed corresponding to the most outlying guidance point in the space ahead of the vehicle.

Input block 8 - V is the vehicle's current longitudinal velocity. Block 9 - Variant function, offers one of the three guidance curves defined in Fig. 3.b, and block 10 - Circle function, determines the arc of a ring with a moving center coinciding with the vehicle's mass center. In block 11 – Subtract, the difference between these two functions is computed. Block 12 - Algebraic Constraint, uses iterations to find the value of the output parameter (which is the current *x* to be found), which provides a zero function subtract at the input of this block. The current distance to the guidance spot is recalculated repeatedly in block 13 - Current Radius. The determination of the desired angular position value is carried out in block 14 - Required Angle, and is transmitted to the output port 1 of the 15 - ang block. Lastly, the output port 2 of block 16 - D transmits the derivative of the virtual curve track to the outside, and the output port 3 of block 17 - r sends the current radius R.

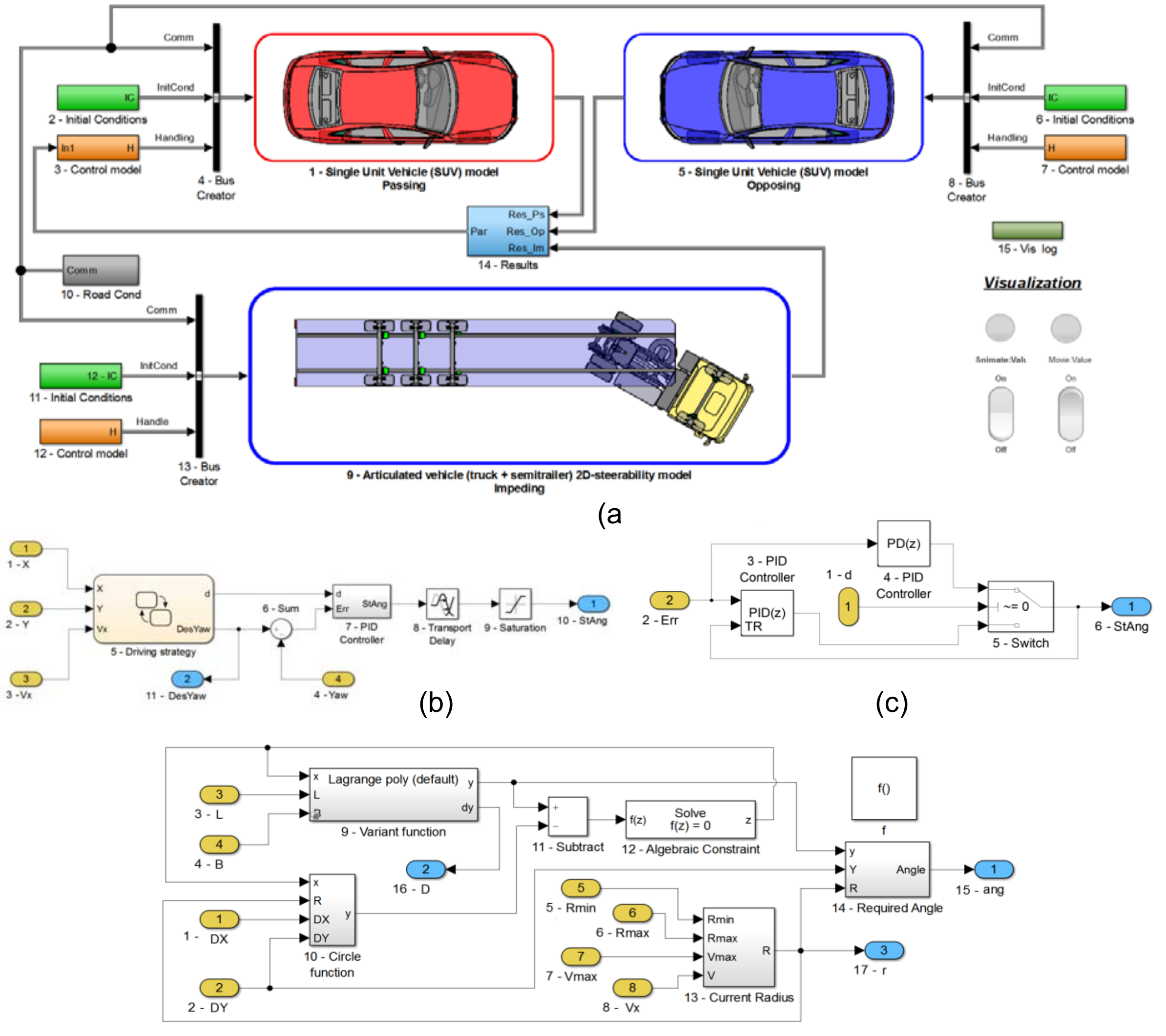


Figure 4: Simulink-model of overtaking scenario: (a) Simulink model structure of a truck overtaking scenario on a two-lane highway; (b) Structural Simulink-model of automatic steering angle control; (c) Internal structure of the PID-controller; (d) The structure of the Simulink-function solver for intersection point search between the arc and the guidance point functions

5 Application Example

An application example is provided in this section in order to illustrate the methodology used in this study. The input data for the passing vehicle from field studies for Passing Collision Warning Systems (PCWSs) included the following: (1) initial speed of 20.83 (m/s); (2) initial distance of 480 (m); (3) initial acceleration rate of the opposing vehicle of 0.0 (m/s^2); (4) detection sensor angle of 90º; (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 is 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 example assumes that the advisory system is using a detector with a frequency of 100 Hz and precision levels of 0.1 m and 0.1 for the reading distance and azimuth angle, respectively. The first detector was installed on the right side of the front bumper of the passing vehicle. The setback distance (d_{12}) was approximately 31.5 m from the front bumper of the passing vehicle to the front bumper of the impeding vehicle. The second detector was installed on the left side of the front bumper of the passing vehicle and the setback distance was approximately 475 m from the front bumper of the passing vehicle to the front bumper of the opposing vehicle.

The initial detection measurements for the opposing vehicle were obtained at a distance (d_1) of 475.3 m, a sensor ray angle (θ_1) of 0.375°, and a speed of approximately 20.83 m/s. The second detection measurements: d_2 = 474.9 m, θ_2 = 0.3752°, speed = 20.82 m/s. The third detection measurements: d_3 = 474.5 m, θ_3 = 0.3755°, speed = 20.8 m/s. The final distance between the opposing vehicle and the detector: d_f = 474.1 m, θ_4 = 0.3759°, and the speed was 20.79 m/s. The distance between the opposing vehicle and the conflict point was 220.3 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. (1), was 9.6 s. The time required for the opposing vehicle to reach the conflict point ($t_{opposing}$), computed using Eq. (8), was 11.4 s. The difference between $t_{opposing}$ and $t_{passing}$, the 1.8 s safety margin, was larger than the critical 1.4 s (95% confidence interval). This safety margin was significantly larger than the measurement error associated with the precision level (0.002 s). The warning message displayed to the passing driver can therefore be deactivated.

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 460 m) from the passing vehicle or if it was travelling at a higher speed (higher than 22.22 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. Fig. 5 shows the example of numerical safety margin time processing.

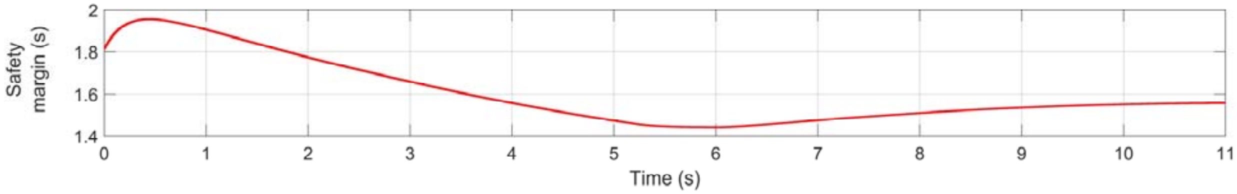


Figure 5: Example of numerical safety margin time processing

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 or laser scanner) to measure the speed and location of the closest opposing vehicle on a two-lane highway at two successive time intervals in order to discern the distance to the conflict point, as well as the speed and rate of acceleration.

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 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 displayed by the system and react to it (to start or abort the passing maneuver).

4. Mathematical models were developed in order to estimate the perception reaction time. The initial acceleration, 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 1s intervals.

5. The results revealed that 95% of drivers have a safety margin time of 1.5 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.

This study presents the development of a Matlab Simulink model that simulates passing scenarios in order to evaluate the performance of the system when different reading error levels are present. This mathematical model can be used in any similar passing collision warning systems as they are independent of technology. The results of this study are also applicable to detectors with reading errors that exceed those suggested in this study, although the proper safety margin threshold should be utilized (see Fig. 5). Further research will be required in order to identify various hardware components that meet the minimum requirements of the proposed system.

Acknowledgements

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