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Time-to-collision for the Pedestrian Protection System simulation

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Abstract

The development of autonomous vehicles has increased significantly, with a high focus on driving safety. Pedestrian avoidance systems are a top priority for ensuring higher pedestrian safety. The Pedestrian Protection System (PPS) is mainly observed in current research to analyze the impact of the time-to-collision for collision avoidance with a pedestrian for different vehicle speed variations. The PPS is a critical system that prevents vehicle and pedestrian collisions based on multiple sensors such as camera and RADAR (radio detection and ranging). Time-to-collision value represents a reliable parameter for the PPS for classifying the traffic conflict between a vehicle and a pedestrian as an inevitable or avoidable event. Simcenter Prescan was used to simulate the traffic infrastructure, the vehicle dynamics of the models, and the sensors. This study aims to evaluate the potential impact of different values of the time-to-collision parameter on the avoidance of collision with the pedestrian. The results showed that Pedestrian Protection System could completely avoid a pedestrian collision.

Keywords: autonomous vehicle; collision avoidance; Simcenter Prescan; critical scenario; time-to-collision;

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1. Introduction

Pedestrian crash injuries and deaths have grown worldwide over the past decade. Automated vehicles expanded notably with a profound purpose of helping to improve safety policies and influence the safety of pedestrians.

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Regardless of their potential as life-saving vehicles, autonomous cars have yet to step forward to ensure the safety of all participants involved in the traffic system as much as possible. Autonomous vehicles could prevent 95% of pedestrian injury crashes in the United States if the pedestrian was visible more than one second before crossing the street (Detwiller & Gabler, 2017). Pedestrian collision is both predictable and preventable, like other categories of road traffic accidents, and can be avoided using intelligent systems incorporated in vehicles nowadays. The potential to influence this category of intelligent system even more, is of tremendous interest for pedestrian safety improvement. The capacity to accelerate pedestrian safety represents a substantial effort to prevent road traffic injuries. Autonomous vehicles are part of developing a road infrastructure where both driver and pedestrian safety is one of the top priorities and represents a must for researchers and industries.

A large variety of systems are implemented in autonomous vehicles like pedestrian protection systems, advanced emergency braking systems and many more that can make a significant difference in decreasing the number of lives lost on the world's roads. Therefore, developing pedestrian safety systems requires complex information about pre-crash data, risk estimation, and advanced vehicle dynamics control (steering and breaking).

The complex environment requires autonomous vehicles that deal with unpredicted situations to reach a high level of safety, especially in the nowadays situations. To provide advanced solutions for a significant category of situations, a large area of complex technology contributes to the performance of autonomous vehicles from sensors, computer vision systems, vehicle control systems, and navigation systems to human interaction setups. Simulation software can assist in overcoming the challenges regarding the sensors, vehicle dynamics control systems, scenario creation and support design, and evaluation of different safety systems.

In the following sections, we outline our approach on how autonomous vehicles can increase their potential and contribute to better and safer transportation. This study was built from a previous study which focuses on the contribution of the Pedestrian Protection System (PPS) in the prevention of pedestrian collision impact (Roșu et al., 2022). The main purpose of this study is to determine the effectiveness of the Pedestrian Protection System at a low, medium, and high speed under the presented testing condition, where the vehicle encounters a pedestrian crossing the street.

2. Research background

There are several advantages of implementing autonomous vehicles (AV): efficient usage of the road networks, comfort expansion of the passenger by eliminating the need for the driver to perform driving correlated tasks, opportunities for different categories of people who were not included in the vehicles due to mobility limitations. Increasing the number of autonomous vehicles will influence road disasters, protect a vast category of people, and decrease traffic congestion. There are growing research and development attempts to enhance the safety and automation capability of AVs, prevent traffic accidents and create a better road infrastructure. In particular, reduced traffic congestion and safety assurance are two significant promises of autonomous vehicles (Atakishiyev et al., 2021).

The main stages of vehicle autonomy are perception, localization, planning, and control. Perception represents the stage where autonomous vehicles collect meaningful information using sensor data. Since the localization and perception of the vehicles help to determine their position, the system will proceed further with the trajectory planning. This includes more than moving from the initial point to the destination, it also contains behavior planning which describes how the vehicle reacts to objects and humans it may meet along the way. Control of the vehicles refers to the generation of commands using sensor data to perform the required maneuvers of the vehicle.

Autonomous vehicles incorporate multiple navigation and sensing technologies (high-definition cameras, LiDAR, GPS) and rely on sophisticated artificial intelligence and high-definition geospatial and street-level data (Alvarez León & Aoyama, 2022). Sensors represent an essential category of elements in the overall autonomous vehicle system; their capabilities and performance determine the contribution to higher or lower safety for the participants in the traffic. The choice of the right sensors represents a challenge that will highly influence all vehicle systems. Since each type of sensor has advantages and disadvantages, their choice and combination must be made carefully. Cameras can detect moving and static obstacles within their field of view and provide high-resolution images of the surroundings. These capabilities allow the vehicle's perception system to identify road signs, traffic lights, road lane markings and barriers in the case of road traffic vehicles and a host of other articles in the case of off-road vehicles (Yeong et al., 2021). LiDAR or Light Detection and Ranging sensors use light pulse to create a three-dimensional map of the surrounding environment. The output from the LIDAR is the sparse 3D points reflected from the objects, with each point representing an object's surface location in 3D with respect to the LIDAR (Asvadi et al., 2016). This type of sensor, along with the camera, is the central core of the perception stage to determine the objects position of existing obstacles along the way. Radar (radio detection and ranging) sensors transmit high-frequency electromagnetic waves and receive the reflection of that wave to estimate the position and velocity of present objects. The distance to a target is determined using the time delay between the transmitted and the received signal (Steinbaeck et al., 2017).

3. Virtual testing

Driving in urban environments is one of the biggest roadblocks for autonomous vehicles to reach full autonomy. To make vehicles fully autonomous, they require the ability to communicate with other road users (pedestrian, vehicles, and other road users) and understand their intentions (Pandey & Aghav, 2020). Covering a large range of situations is a key element of providing autonomous vehicles qualified to sustain a safe environment for pedestrians.

Virtual testing of automated vehicles using simulations is essential during their development. When it comes to testing motion planning algorithms, one is mainly interested in challenging critical scenarios for which it is hard to find a feasible solution. However, these situations are rare under usual traffic conditions, demanding an automatic generation of critical test scenarios (Klischat & Althoff, 2019). Virtual prototyping supports complex situations to investigate autonomous vehicle features as a part of a development plan to encourage a safe traffic environment.

One important system that has massive importance in the life of people and it is of interest to researchers and industry is the pedestrian protection system which is used mainly for avoiding collisions between the vehicle and a pedestrian. In advance of a certain frontal collision, the pedestrian protection system is activated by the sensors' feedback, which warns the driver and changes the vehicle's behavior.

3.1 Pedestrian Protection System

Pedestrian Protection System is a forward-looking, predictive safety system that aims to avoid or reduce the severity of a collision with pedestrians. The common use of radar and camera sensors allows for automated recognition of the pedestrian and evaluation of the risk or the inevitability of an accident (Simcenter Prescan User Manual, 2021).

Several sensors are used to capture the changes in the traffic environment and protect the pedestrian by avoiding collision. Protection System uses the sensors with the primary purpose of automating the recognition of the pedestrian and evaluation of the exposure to a crash accident. The camera and radar are the primary sensors that send the information to the PPS. The radar sensor captures the data to obtain the relative speed between the host vehicle and the obstacle and calculates the obstacle's absolute velocity vector. Both values are calculated based on the presumption that the vehicle is moving forward at the same speed to establish the point where the collision occurs. Based on the pedestrian detection algorithm, the camera sensor determines if the identified obstacle is a pedestrian. The PPS uses the information provided by the camera and the radar to rate the severity of the conflict and determine if the collision is inevitable or could be avoided. A warning to the driver indicated that urgent action needs to be taken to avoid the possible danger.

3.2 Simulation framework

The simulations used for this study were realized using Simcenter Prescan, which is a lead software for developing realistic traffic scenarios, to analyze and design autonomous vehicles environments. Simcenter Prescan was also used to virtually observe the performance of autonomous vehicle algorithms and sensors.

Simcenter Prescan relates to Matlab and Simulink during the simulation. In Simulink are visualized the block diagrams of the different libraries of the automated systems. Simulink provides methods to design and simulate different automated systems integrated into autonomous vehicles and allows the exploration of reusable components from different libraries and algorithm development before moving to hardware experiments. The simulation development using Simcenter Prescan and Simulink has three main stages: pre-processing, calculation and post-processing. The first stage is accomplished in Simcenter Prescan, where the visualization elements were adopted like environment, the infrastructure of the traffic scenario, actors or participants to the traffic, vehicles' trajectories, and parametrization of the selected systems. The second stage is the calculation, where the parameters, the vehicle system, the actors, and the associated trajectories from Simcenter Prescan are translated and calculated in Simulink using specific blocks. Regarding the third stage, the post-processing or visualization of the results is done using both Simulink and Simcenter Prescan. In Simulink, we can visualize the parameters of specific systems, plot different graphs, and check different algorithm results, and in Simcenter Prescan, the animation of the driving scenario can be viewed along with different sensors output and warning checks.

3.3 Scenario construction

In this study, the scenario was created with common urban roads, and it is simplified to understand the purpose of this research and to observe the pedestrian protection system. The scenario shown in Fig. 1 consists of a road with a 2-lane highway with a roundabout, an actor also called a vehicle, and a pedestrian. A black Audi A8 is moving forward at different speeds (30 km/h, 60 km/h, 90 km/h), enters a roundabout and encounters a pedestrian crossing in an unmarked location, the vehicle tries to avoid the collision with a pedestrian.

Fig. 1. Overview of the driving scenario.

To avoid any possible encounter with a pedestrian along the way, in the presented scenario, the vehicle includes a pedestrian protection system (PPS) design to understand the pedestrian intention in various situations and to avoid possible collisions. The PPS, as shown in Fig. 2, is built based on the Technology Independent Sensor and a camera. The TIS (1) increases the overall knowledge and validates the performance specification of the radar sensor (2). The TIS scans the target geometries of the obstacles by performing a discretization of the scene using a number of beams from the radar. The radar sensor in the PPS is a mid-range radar (MRR) with a range of 40 m and a beam width of 60 degrees. The data taken from the mid-range radar sensor is used to regulate the speed between the vehicle and the pedestrian and used to calculate the velocity of the pedestrian.

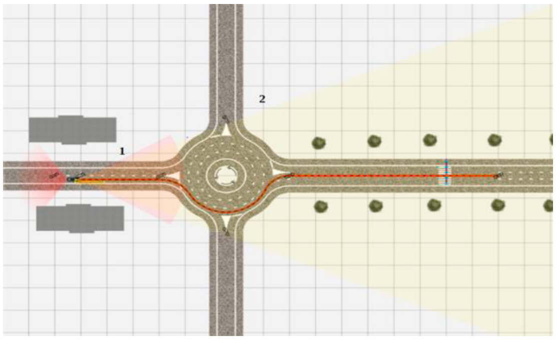


Fig. 2. TIS and camera representation of the autonomous vehicle in Simcenter Prescan.

The fundamental value used by the PPS algorithm is the time-to-collision (TTC) calculated based on the data required from the radar sensor. The time to collision value is calculated and compared with set values to hit the signal information to the driver. A lower TTC value implies extreme collision exposure of the pedestrian. The value of TTC below 2s suggests that the crash is considered inevitable. The warning for the driver is turned on if the TTC drops below 1.6s in case the collision object is identified as a pedestrian. The additional time allows the driver to react to the event and avoid contact with the pedestrian. In case the TTC is below 0.6 which means that the impact with the pedestrian is considered unavoidable, full braking is applied to reduce the impact speed. In Simcenter Prescan an animation representation of the braking light and warning was added in the simulation viewer to represent the PPS work and how the driver will get informed about the emergency braking. Also, the driver has the option of turning the indicator on, which automatically deactivates the system.

After the construction of the scenario in Simcenter Prescan, a Simulink model of the experiment elements are available on the compilation sheet, this includes the dynamics models, automated systems, the vehicle trajectory, chosen standard sensor models, actors, and visualization setup. In Fig. 3 is presented the PPS block, as exposed in the compilation sheet with the overview block from the entire scenario. Along with the overview blocks of the entire scenario in the compilation sheet, the PPS block uses the data coming from the vehicle (velocity and yaw rate), the TIS sensor (range, derivative of range, angular position of the detected object), the camera sensor (captured monochrome image), the driver (indicator lights on/off, applied braking pressure and throttle percentage).

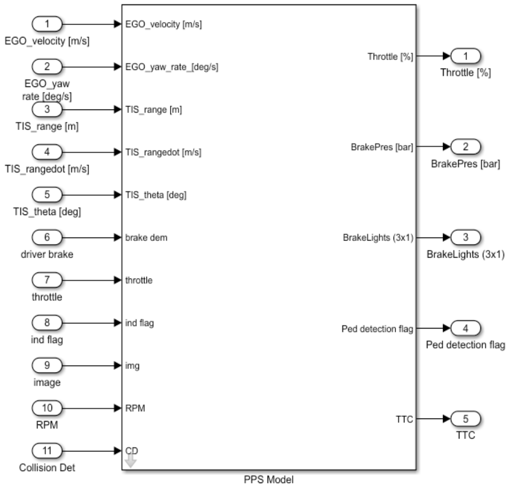


Fig. 3. Pedestrian protection system Simulink block.

The input and output parameters of the PPS block are presented in Table 1 and Table 2.

Table 1. Input parameter of the PPS.

Description	Parameter	Unit
Host vehicle actual velocity	EGO_velocity	[m/s]
Host vehicle actual yaw rate	EGO_yaw_rate	[deg/s]
TIS sensor range	TIS_range	[m]
TIS sensor Doppler velocity	TIS_dopplervelocity	[m/s]
TIS sensor azimuth	TIS_theta	[deg]
Brake pressure. Input from Path Follower	Driver Brake	[bar]
Throttle percentage. Input from Path Follower	Throttle	[%]
Binary input activating (1) or deactivating (0) the indicators and, hence, deactivating (1) or activating (0) the PPS	Ind flag	[-]
Output from Camera Sensor Block	Image	[-]

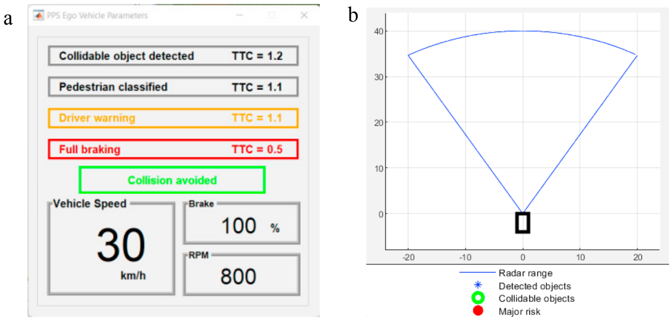
Engine angular speed	RPM	[rpm]
Binary flag indicating a collision between actors	Collision Det	[-]

Table 2. Output parameter of the PPS.

Description	Parameter	Unit
Percentage of maximum throttle	Throttle	[%]
Brake pressure	Brake Pres	[bar]
Brake Light, which can be connected with Light Source Animation [3x]	Brake Lights	[-]
Output high level when the pedestrian is detected as collidable object	Ped detection flag	[-]
Actual time to collision (TTC) of the closest collidable object	TTC	[s]

4. Results

The results have been defined using Prescan and Matlab for several visualization outputs. The main parameters of the system operation are displayed in the driver console, as presented in Fig. 4 (a). The TTC value for object detection, TTC value for pedestrian detection, TTC for driver warning, TTC for full braking, the status and speed of the collision (if not avoided) and driving parameters like speed, engine RPM, percentage of braking pressure. Also, it displays the status of the collision, after the full stop of the vehicle, the collision avoidance is green, meaning that the pedestrian avoidance was successful.



Collidable object detected TTC = 1.2

Pedestrian classified TTC = 1.1

Driver warning TTC = 1.1

Full braking TTC = 0.5

Collision avoided

Vehicle Speed 30 km/h

Brake 100 %

RPM 800

Fig. 4. (a) PPS of the driver console; (b) PPS Radar Display

The radar output graph as part of the PPS shows the top radar view, as shown in Fig. 4 (b), helps identify the pedestrians along the way. The objects detected by the radar that are highlighted in green are the objects with which a collision is possible but of reduced risk and the ones highlighted in red are the objects of significant risk (pedestrian).

In Fig. 5 is presented the output measurement of the camera, which marks the area around the objects detected by the systems. The camera is making a classification of the processed image, which is used as an input to be decoded by the Pedestrian Classification Algorithm to detect whether the object is a pedestrian, as shown in Fig. 6.

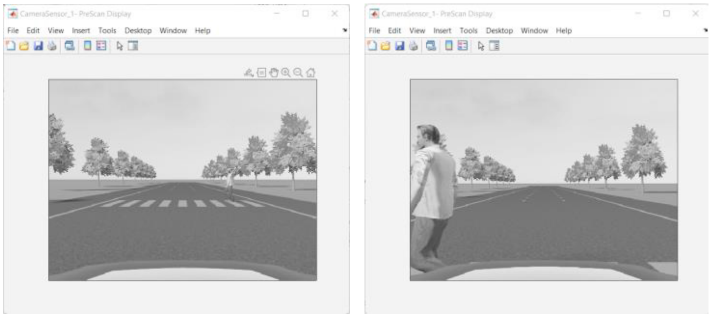


Fig. 5. Camera output (video).

Fig. 6. Input to the Pedestrian Classification Algorithm.

When the vehicle runs at a speed of 30km/h, the vehicle can entirely stop, assuring the safety conditions for the pedestrian. Similarly, at a speed of 60 km/h, the radar still detects the pedestrian at all the stages of object detection using the TTC, as presented in Fig.7. The PPS determines that the moving object is a pedestrian and starts decreasing the speed, managing to avoid the collision.

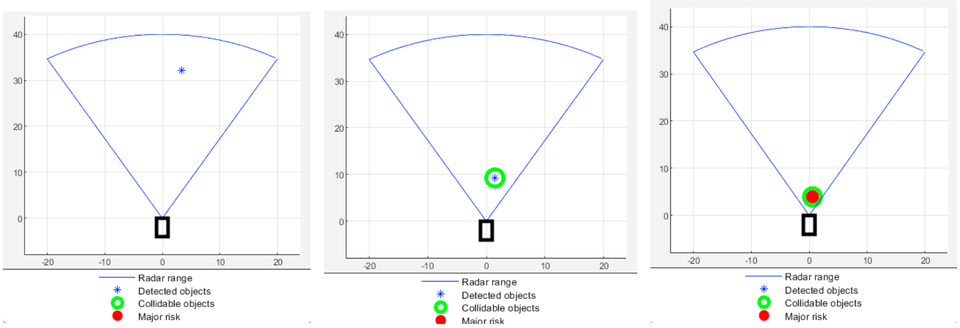
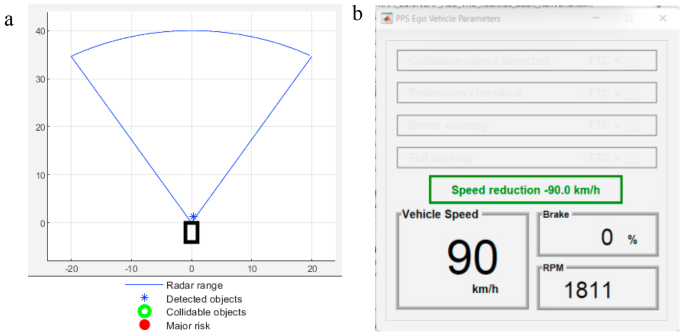


Fig. 7. Stages of the radar detection of the vehicle with 60 km/h speed.

In addition, Fig. 8 (a) indicates that at a speed of 90 km/h, the radar detects the object, but it does not classify it as a pedestrian, due to the high speed. The PPS systems do not have time to react and to apply 100 % of the brake, this happens only in a later stage and the collision is not avoided even if the brake is applied in Fig. 8 (b).



Speed reduction -90.0 km/h

Vehicle Speed 90 km/h

Brake 0 %

RPM 1811

Fig. 8. (a) Radar detection of vehicles at 90 km/h speed; (b) Driver console for a vehicle speed of 90 km/h.

The driver console in Fig. 8 (b) indicates that the speed has been reduced but the collision was not avoided showing that at a higher speed, the PPS system needs to have a TTC with a higher value so that the time in which the vehicle react is larger.

5. Conclusions

The contribution of this study is to enhance the understanding of the PPS to support the challenges of real unpredictable events that the autonomous vehicle might encounter. When the vehicle moves at 30 km/h and 60 km/h, it can entirely stop in safety conditions and ensure the avoidance of the collision with the pedestrian proving that the TTC value is appropriately selected to ensure safety conditions even in unpredictable events like a pedestrian encounter. At 90 km/h, the PPS is not able to determine the classification of the object as a pedestrian in the defined TTC to avoid the pedestrian, the vehicle does stop but too late to avoid the collision. This proves that for a higher speed of the vehicle, the PPS needs to increase the time of the TTC since the reaction time needs to be longer when the speed is higher. In further works, we will expand the proposed scenario and observe the PPS system with a more complex driving condition to improve the system's efficiency.

References

Alvarez León, L. F., & Aoyama, Y. 2022. Industry emergence and market capture: The rise of autonomous vehicles. Technological Forecasting and Social Change, 180, 121661.

Asvadi, A., Premebida, C., Peixoto, P., & Nunes, U. 2016. 3D Lidar-based static and moving obstacle detection in driving environments: An approach based on voxels and multi-region ground planes. Robotics and Autonomous Systems, 83, 299–311.

Atakishiyev, S., Salameh, M., Yao, H., & Goebel, R. 2021. Explainable artificial intelligence for autonomous driving: An overview and guide for future research directions.

Detwiller, M., & Gabler, H. C. 2017. Potential Reduction in Pedestrian Collisions with an Autonomous Vehicle. 25th International Technical Conference on the Enhanced Safety of Vehicles (ESV)National Highway Traffic Safety Administration.

Klischat, M., & Althoff, M. 2019. Generating Critical Test Scenarios for Automated Vehicles with Evolutionary Algorithms. 2019 IEEE Intelligent Vehicles Symposium (IV), 2352–2358.

Pandey, P., & Aghav, J. 2020. Pedestrian–Autonomous Vehicles Interaction Challenges: A Survey and a Solution to Pedestrian Intent Identification (pp. 283–292).

Roşu, I.-A., Buzdugan, I.-D., Carabulea, L., & Antonya, C. 2022. Simulation of a pedestrian collision avoidance using the Pedestrian Protection System. 9th International Congress Motor Vehicles & Motors 2022.

Simcenter Prescan User manual. 2021.

Steinbaeck, J., Steger, C., Holweg, G., & Druml, N. 2017. Next generation radar sensors in automotive sensor fusion systems. 2017 Sensor Data Fusion: Trends, Solutions, Applications (SDF), 1–6.

Yeong, D. J., Velasco-Hernandez, G., Barry, J., & Walsh, J. (2021). Sensor and Sensor Fusion Technology in Autonomous Vehicles: A Review. Sensors, 21(6), Article 6.