MOBILITY & VEHICLE
MECHANICS

https://doi.org/10.24874/mvm.2023.49.02.02
UDC: 629.3.021;608.4

# SIMULATION OF A PEDESTRIAN COLLISION AVOIDANCE USING THE PEDESTRIAN PROTECTION SYSTEM

*Ioana Alexandra Rosu [1]*, Ioana Diana Buzdugan[2], Laurentiu Carabulea[3], Csaba Antonya[4]*

*Received in August 2022* *Revised in September 2022* *Accepted in October 2022*
RESEARCH ARTICLE

**ABSTRACT:** Autonomous vehicles are a growing concern nowadays, therefore the knowledge and expectations regarding pedestrian safety have risen substantially. Additionally, ensuring pedestrian safety has become a crucial requirement for autonomous driving. The current research focuses on the contribution of the Pedestrian Protection System (PPS) in the prevention of pedestrian collision impact. The simulation technology that Simcenter Prescan and Simulink are providing, has been used to develop the virtual traffic scenario which highlights the performance of the main sensors: camera and RADAR (radio detection and ranging). The Simcenter Prescan simulation framework includes realistic vehicle dynamic models and virtual traffic infrastructure along with sensors that were placed in several locations on the vehicle to capture the position of the pedestrian. Three variations of speed were analysed in order to observe where the collision is avoided considering the safety conditions. The results of the considered speed were primarily observed using the visualization output of the sensors from the PPS system. To develop trustful autonomous vehicles, it is fundamental to incorporate efficient pedestrian crash avoidance systems that increase traffic safety.

**KEY WORDS**: *braking system, Prescan, autonomous vehicle*

---

[1] *Ioana Alexandra Rosu, Transilvania University of Brașov, Automotive and Transport Engineering, No. 1, Politehniciii st. Brasov, România, ioana.rosu@unitbv.ro, https://orcid.org/0000-0002-8398-2884, (*Corresponding author)*

[2] *Ioana Diana Buzdugan, Transilvania University of Brașov, Automotive and Transport Engineering, No. 1, Politehniciii st. Brasov, România, ioana.buzdugan@unitbv.ro, https://orcid.org/0000-0001-5769-0653*

[3] *Laurentiu Carabulea, Transylvania University of Braşov, Automotive and Transport Engineering, No. 1, Politehniciii st. Brasov, România, ionut.carabulea@unitbv.ro, https://orcid.org/0000-0002-4018-3150*

[4] *Csaba Antonya, Transilvania University of Brasov, Department of Automotive and Transport Engineering, No. 1, Politehniciii st. Brasov, România, antonya@unitbv.ro, https://orcid.org/0000-0002-0139-5425*

# SIMULACIJA IZBEGAVANJA SUDARA PEŠAKA PRIMENOM SISTEMA ZA ZAŠTITU PEŠAKA

**REZIME**: Autonomna vozila su danas sve veća briga, stoga su znanje i očekivanja u vezi sa bezbednošću pešaka značajno porasla. Pored toga, osiguranje bezbednosti pešaka postalo je ključni zahtev za autonomnu vožnju. Ovo istraživanje se fokusira na doprinos sistema za zaštitu pešaka (PPS) u prevenciji sudara. Tehnologija simulacije koju pružaju Simcenter Prescan i Simulink, korišćena je za razvoj scenarija virtuelnog saobraćaja koji naglašava performanse glavnih senzora: kamere i RADAR (radio detekcija i domet). Simulacioni ram Simcenter Prescan uključuje realne dinamičke modele vozila i virtuelnu saobraćajnu infrastrukturu zajedno sa senzorima koji su postavljeni na nekoliko lokacija na vozilu da bi locirali poziciju pešaka. Analizirane su tri varijacije brzine kako bi se uočilo gde se sudar izbegava s obzirom na uslove bezbednosti. Rezultati analiziranih brzina su prvenstveno posmatrani vizuelnim prikazom podataka senzora iz PPS sistema. Za razvoj pouzdanih autonomnih vozila, od suštinske je važnosti ugraditi efikasne sisteme za izbegavanje sudara pešaka koji povećavaju bezbednost u saobraćaju.

**KLJUČNE REČI**: *sistem za kočenje, Prescan, autonomna vozila*

# SIMULATION OF A PEDESTRIAN COLLISION AVOIDANCE USING THE PEDESTRIAN PROTECTION SYSTEM

*Ioana Alexandra Rosu, Ioana Diana Buzdugan, Laurentiu Carabulea, Csaba Antonya*

## INTRODUCTION

Traffic injuries remain a frequent root of human injuries, deterioration of goods and deaths of millions of people. The large expansion in the numbers of vehicles on the road has leaded to an intensification of research to find solutions regarding traffic congestion, pollution, and road safety. The adoption of automated cars is expected to provide an effective solution to this issue, since they are predicted to reduce the number of such accidents by 80%, by the year 2040 [1]. Regardless of their potential as life-saving vehicles, autonomous cars have yet to step forward into insuring as much as possible the safety of all the participants involved in the traffic system. Autonomous vehicles are in terms of safety accelerating fast. The potential to influence even more this category of intelligent system is of huge interest above all for pedestrian safety improvement. The capacity to accelerate pedestrian safety represents an important effort to prevent road traffic injuries. Pedestrian collision is both predictable and preventable, like other categories of road traffic accidents, and can be avoided using intelligent systems that are incorporated in nowadays vehicles. Ensuring that 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.

There are a large variety of systems implemented in autonomous vehicles like: pedestrian protection systems, advanced emergency braking system and many more that can make a significant difference in decreasing the number of lives that are being 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 deals with unpredicted situations in order to reach a high level of safety, especially in the nowadays situations. In order to provide advanced solutions for a major category of situations a large area of complex technology contributes to the performance of the autonomous vehicles from sensors, computer vision systems, vehicle control systems, navigation systems to human interaction setup. Simulation software can assist to overcome the challenges regarding the sensors, vehicle dynamics controls system and scenario creation and also support design and evaluation of different safety systems. One of such simulation software used in this study is Prescan, which is a leading software tool that can be used for designing and evaluating ADAS and IV systems that are based on sensor technologies such as radar, laser, camera, ultrasonic, GPS, and C2C/C2I communications (car to car/car to infrastructure) [2].

In the following sections, we outline our approach on how autonomous vehicles can increase their potential and contribute to a better and safer transportation. 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.

## 1. RESEARCH BACKGROUND

Transportation system has been constrained to improve substantially by many parts like manufacturers and researchers to handle the high numbers of vehicles and deficit of traffic law obedience by both drivers and pedestrians. The research and industry are expanding their struggle to enlarge the safety and automation competence of autonomous vehicle in order to create a secure road infrastructure and avoid road collisions.

There are several advantages of the implementation of autonomous vehicles: efficient usage of the road networks, comfort expansion of the passenger by eliminating the need of the driver to perform driving correlated tasks, opportunities for different categories of people who were not included in the transportation 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. Autonomous Vehicles (AVs) are widely anticipated to alleviate road congestion, improve road safety by eliminating human error, and free drivers from the burden of driving, allowing greater productivity and/or time for rest, along with a myriad of other foreseen benefits [3]. 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 [4].

The main stages of vehicle autonomy are called perception, localization, planning and control. Perception represents the stage where autonomous vehicles is collecting meaningful information using sensor data. The relative localization of an AV refers to vehicle referencing its coordinates in relation to the surrounding landmarks, while absolute localization refers to the vehicle referencing its position in relation to a global reference frame (world) [5]. Since the localization and perception of the vehicles help to determine its position, the system will further proceed with the planning of the trajectory. The planning includes more than moving from the initial point to the destination, it contains also the behavior planning which includes how the vehicle reacts to objects and the humans that it may meet along the way. The control of the vehicles refers to the generation of commands using sensor data in order to perform the required maneuvers of the vehicle.

Autonomous vehicles incorporate multiple navigations and sensing technologies (high-definition cameras, LiDAR, GPS), and rely on sophisticated artificial intelligence, as well as high-definition geospatial and street-level data [6]. Sensors represent an important 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 the systems of the vehicle. Since each type of sensor has advantages and disadvantages their choice and combination need to be done carefully.

Cameras can detect both moving and static obstacles within their field of view and provides high-resolution images of the surroundings. These capabilities allow the perception system of the vehicle 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 [7]. LiDAR or Light Detection and Ranging sensor use light pulse to create a three-dimensional map with 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 [8]. This type of sensors along with the camera is the main core of the perception stage to determine the object position of the 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 a received signal [9]. The Global Navigation Satellite System, also known as Global Positioning System, has a well-defined purpose inside the structure of the autonomous vehicles, providing real-time vehicle localization. GPS can be used for both localization and perception submitting an accurate position of the vehicle [10].

## 2. VIRTUAL TESTING

When automated vehicles are deployed in the real world, they are subjected to an unforeseeable number of situations. This requires extensive testing during their development to ensure safety, especially with regard to motion planning [11]. Vehicles that have a high level of performance must assure and operate within the limits of safety without affecting the good well-being of the participants in the road traffic. The development of the autonomous vehicle systems relies on the conception of a large range of critical scenarios that can cover a highly possible situation that can occur in real life. Critical scenarios are an important milestone in terms of safety for the automated vehicle system in order to strengthen the design but also to the verification and validation stages. As autonomous vehicle performance has increased in a vast range of scenarios, it is crucial to find events where the systems are likely to drop to cover even the most unfeasible events.

Virtual testing of automated vehicles using simulations is essential during their development. When it comes to the testing of 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 [12].

Several systems like ADAS (Advanced Driving-Assistance Systems), AEBS (Advanced Emergency Braking System) system, PPS (Pedestrian Protection) contribute to the high performance of autonomous vehicles in order to ensure safety, comfort and to face the challenges of real unpredictable events. The complexity and uncertainty of the driving environment, and the complexity of the driving task itself, imply that the number of possible scenarios that an Automated Driving Systems (ADS) or Advanced Driving-Assistance Systems (ADAS) may encounter is virtually infinite [13]. Automated Driver Assistance Systems (ADAS) focus on increasing the comfort, support and safety while driving. ADAS performance is relying on the overall system performance, on the driver behaviour and on the driving context. The implementation of ADAS is significantly lowering the number of vehicle crashes. Advanced Emergency Braking System (AEBS) is based on a controller algorithm that detects the object or the pedestrian and checks the well-established distance and warns the driver and activates the braking. The AEBS control algorithm consists of two parts: obstacle detection part and main controller part. In the obstacle detection part, front obstacle information was measured and collected for the main controller's decision [14].

One important system that has huge importance in people’s live and it is of very interest to researchers as well as to industries is the pedestrian protection system which is used mainly for avoiding the collision between the vehicle and a pedestrian. In advance of a certain frontal collision, the pedestrian protection system is activated by the feedback of the sensors which is sending a warning to the driver and changing the behavior of the vehicle.

### 2.1 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 joint use of radar and camera sensors allows for automated recognition of the pedestrian and evaluation of the risk or the inevitability of an accident [15]. PPS is based on a combination of sensors, primarily camera and radar which offers a high potential for eliminating fatalities and detecting the pedestrian and its position. The PPS relies on multiple advanced technologies like brake assistance, driver caution and control collision avoidance which are in high demand in the automotive industry and in continuous need of improvement. Therefore, a safe automated vehicle is required to have a robust algorithm whose performance is capable of dealing with all types of events, especially in critical situations. This study presents an approach to increase the knowledge about the weak and strong points of the pedestrian protection system and investigate the response in a critical situation where a pedestrian is crossing the street in an unmarked space.

### 2.2Simulation architecture

The simulations in this research have been carried out by using Simcenter Prescan and one of Matlab’s modules, Simulink, to design and simulate autonomous vehicles which were exposed in critical safety scenarios and analysed from a safety point of view.

Simcenter Prescan is a software that focuses on solving a large variety of automated vehicles functionality based on real-world traffic scenarios (roads, infrastructure, weather, road signs, pedestrians). Also, it has a substantial number of automated systems that contains sensors along with algorithms for data processing, decision making and control, used to design a more realistic simulation that can be later compared with results from physical experiments.

Simulink is a MATLAB-based graphical programming environment for modelling, simulating, and analysing multidomain dynamical systems. Its primary interface is a graphical block diagramming tool and a customizable set of block libraries. It offers tight integration with the rest of the MATLAB environment and can either drive MATLAB or be scripted from it. Simulink is widely used in automatic control and digital signal processing for multidomain simulation and model-based design [16][17]. Simulink provides methods to design and simulated different automated systems that are integrated in autonomous vehicles and allows the exploration of reusable components from different libraries and algorithm development before moving to hardware experiments.

The development of the simulation using Simcenter Prescan and Simulink has three main stages: pre-processing, calculation and post-processing. The first stage is realized in Simcenter Prescan, where the elements of the visualization were adopted like environment, infrastructure of the traffic scenario, actors or participants to the traffic, trajectories of the vehicles along with parametrization of the selected systems. The second stage is the calculation one the parameters, vehicle system, the systems along with the actors and the associated trajectories, from Simcenter Prescan were translated and calculated in the Simulink using specific blocks. Related with the third stage, the post-processing or visualization of the results, this 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, in Simcenter Prescan the animation of the driving scenario can be viewed along with different sensors output and warning checks.

### 2. 3 Scenario construction

The current study presents an automated vehicle which avoids a collision with a pedestrian. The focus is on the effectiveness of the pedestrian protection system (PPS) with the main purpose of assuring the avoidance of collision with the pedestrian and contributing to a highly safe automated system traffic environment.

The scenario presents an Audi A8 which is entering a roundabout, moving forward, and avoiding a pedestrian walking across the street in an unmarked location.

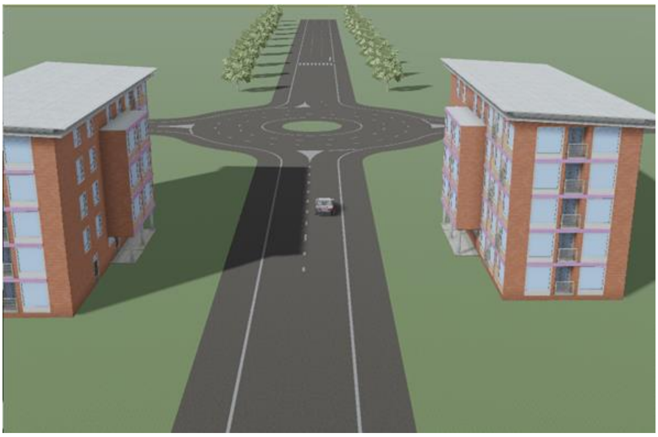


*Figure 1. Overview of the driving scenario*

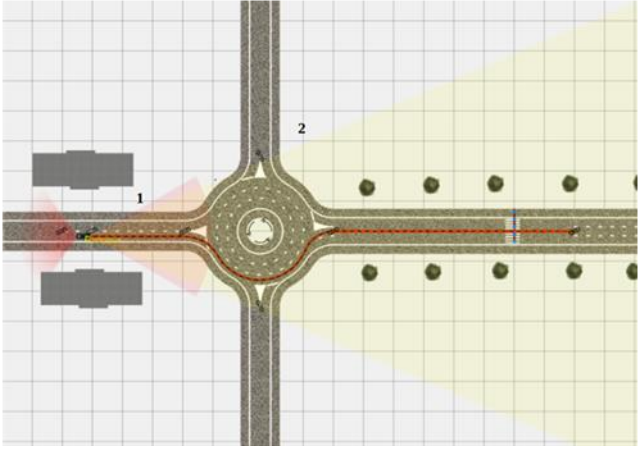


*Figure 2. TIS and camera representation of the autonomous vehicle in Prescan*

The vehicle has a Technology Independent Sensor (1) or TIS, which is used to increase the performance of the radar (2) sensor at a system level. This sensor has a great impact on the performance of the tracking and tracing algorithms by validating the standard specifications of the active scanning sensors. Together with the TIS is attached a camera on the front part of the vehicle in order to capture the object along the road.

The main system which is required to react in this study to avoid the collision with the upcoming pedestrian is the PPS. The pedestrian protection system uses two essential sensors in order to reduce the severity of the collision or to completely avoid: the camera and a radar. The radar sensors present in the PPS is a mid-range radar (MRR) whose range is 40 m and a beam width of 60 degrees. The data taken from the mid radar sensor is used to regulate the speed between the vehicle and the pedestrian and also used to calculate the velocity of the pedestrian.

The PPS algorithm based on the data received till the moment the object appears in the range of the camera will consider that the vehicle is moving strictly forward to determine the point where the collision will take place. The time to collision (TTC) is used in this situation as a core value to be calculated and the results are compared with the set values. TTC is defined as the time needed for two vehicles to collide if these two vehicles meet. The minimum value of TTC is an indicator for the severity of the encounter and a lower value of TTC indicates a higher risk of collision. If the time of the collision between the vehicle and the object is below 2s the contact is considered dangerous. Certainly, there is a difference between an object and a pedestrian, and therefore the pedestrian detection algorithm relays on the camera sensors in order to determine whether the object is a pedestrian. 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 that the TTC is below 0.6 which means that the impact with the pedestrian is considered unavoidable, the full braking is applied to reduce the impact speed. In Prescan an animation representation of the braking light and warning was added in the 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 Prescan, a Simulink models 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. The PPS block (Figure3) is 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 is the PPS block which is using 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).

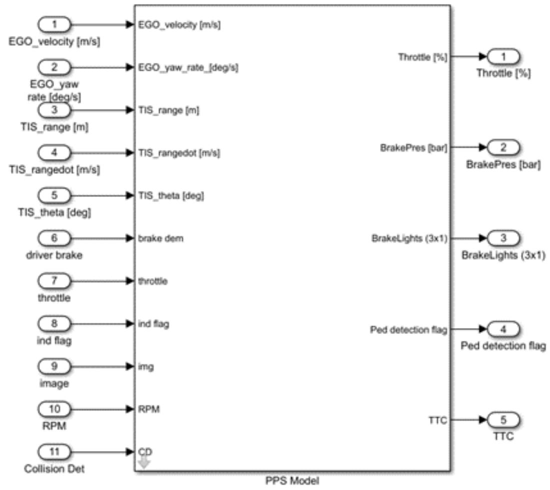


*Figure 2. Pedestrian protection system Simulink block.*

Regarding the input and the output of the pedestrian protection system block, these are presented in Table 1 and Table 2.

**Table 1.** Input parameters of the PPS.

| Parameter | Description | Unit |
|---|---|---|
| EGO_velocity | Host vehicle actual velocity | [m/s] |
| EGO_yaw_rate | Host vehicle actual yaw rate | [deg/s] |
| TIS_range | TIS sensor range | [m] |
| TIS_dopplervelocity | TIS sensor Doppler velocity | [m/s] |
| TIS_theta | TIS sensor azimuth | [deg] |
| Driver Brake | Brake pressure. Input from Path Follower (or given directly) | [bar] |
| Throttle | Throttle percentage. Input from Path Follower | [%] |
| Ind flag | Binary input activating (1) or deactivating (0) the indicators and, hence, deactivating (1) or activating (0) the PPS | [-] |
| Image | Output from Camera Sensor Block | [-] |
| RPM | Engine angular speed (input from Vehicle Dynamics block) | [rpm] |
| Collision Det | Binary flag indicating a collision between actors | [-] |

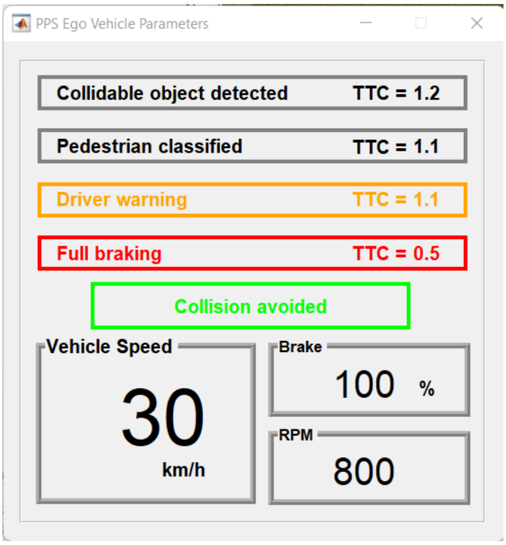
**Table 2.** Output parameters of the PPS.

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

The vehicle which possessing a PPS system is running at different speed (30 km/h, 60km/h, 90km/h) and encounters a pedestrian crossing the road on an unmarked area.

## 3. RESULTS

The results have been defined using Prescan and Matlab several visualization outputs. The main parameters of the system operation are displayed in the driver console (Figure 4). 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 showing 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

*Figure 4. PPS of the driver console.*

The radar output graph as part of the PPS is showing the top radar view (Figure 5), which helps identifying 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 reduce risk and the ones highlighted in red are the objects of major risk (pedestrian).

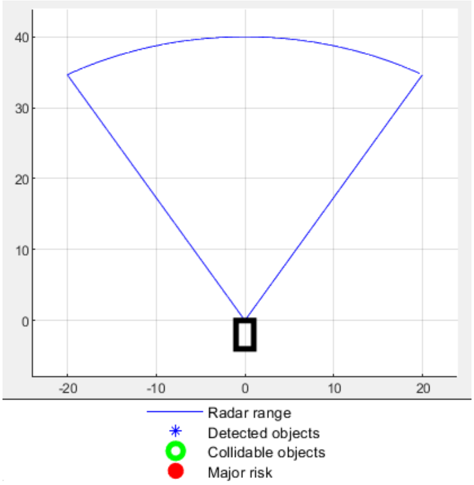


*Figure 5. PPS Radar Display.*

Another output measurement is the camera (Figure 6), 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 if the object is a pedestrian or not (Figure 7).

At a speed of 30km/h, the vehicle stops, assuring the safety conditions for the pedestrian.

At a speed of 60 km/h, the radar still detects the pedestrian (Figure 8) at all the stages of the object detection using the TTC, the PPS determines that the moving object is a pedestrian and starts decreasing the speed, managing to avoid the collision.

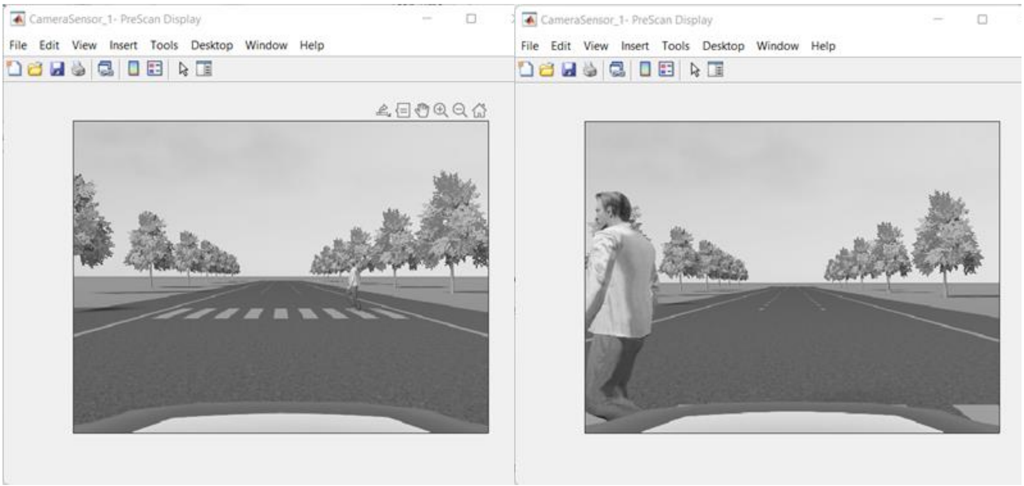


*Figure 6. Camera output (video).*

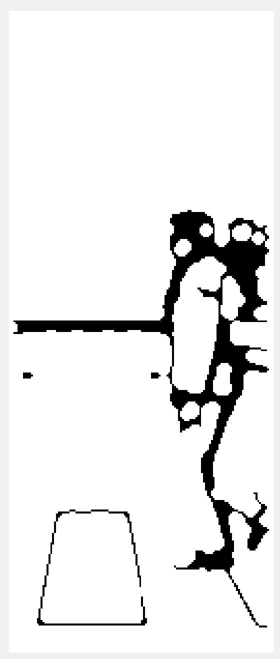


*Figure 7. Input to the Pedestrian Classification Algorithm.*

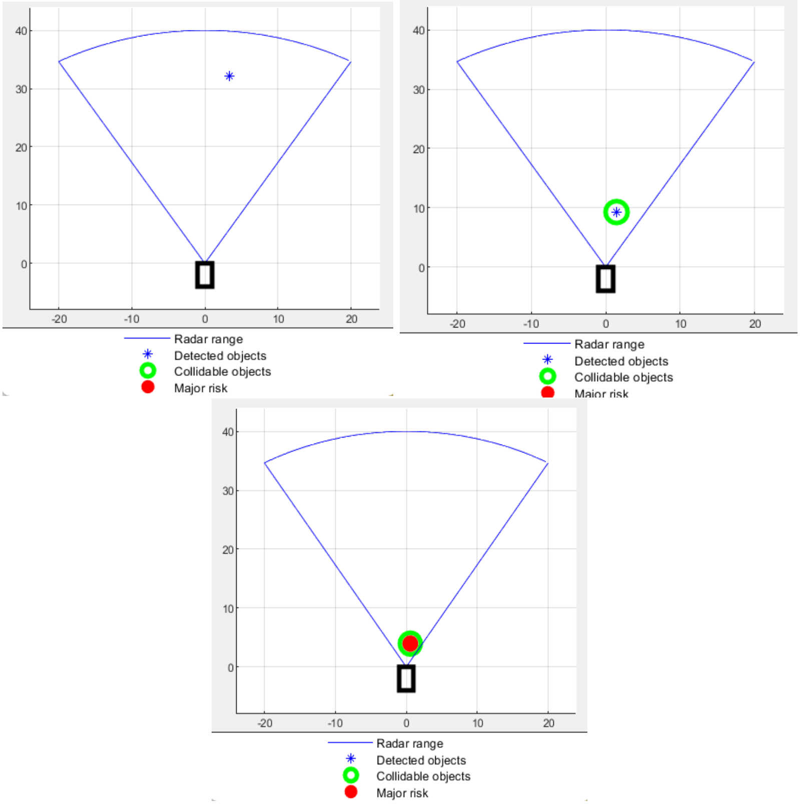


*Figure 8. Radar detection of the vehicle with 60 km/h speed.*

At a speed of 90 km/h, the radar is detecting the object but it does not classify it as a pedestrian (Figure 9) due to the high speed, the PPS systems does 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 hit, it is too late (Figure 10).

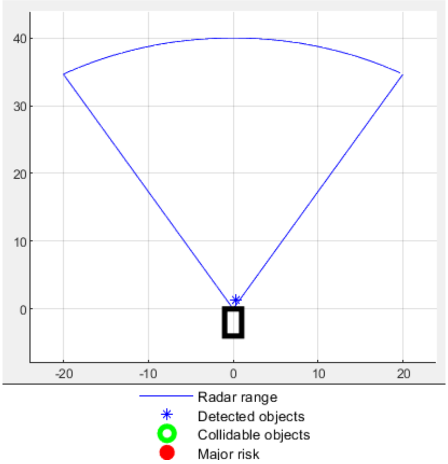
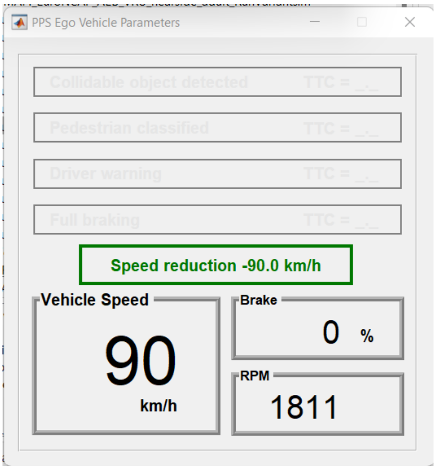


*Figure 9. Radar detection of the vehicle with 90 km/h speed.*



Collidable object detected TTC = _._

Pedestrian classified TTC = _._

Driver warning TTC = _._

Full braking TTC = _._

Speed reduction -90.0 km/h

Vehicle Speed: 90 km/h

Brake: 0 %

RPM: 1811

*Figure 10. Driver console for a vehicle speed of 90 km/h.*

The driver console (Figure 10) is indicating 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.

## 4. CONCLUSIONS

In this paper, a critical scenario is presented where a vehicle runs at various speed (30 km/h, 60 km/h, 90 km/h) and encounters a pedestrian crossing the street. The vehicle is analysing the object and determining if the object is a pedestrian using the Pedestrian Protection System. At 30 km/h and 60 km/h, the vehicle is able to fully stop in safety conditions and assures the avoidance of the collision with the pedestrian proving that the TTC value is properly selected to assuring 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 in order 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 enlarge the time of the TTC since the reaction time needs to be bigger 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 in order to improve the efficiency of the system.

## ACKNOWLEDGMENTS

This work was supported by a grant of the Romanian Ministry of Research, Innovation and Digitization, CNCS/CCCDI – UEFISCDI, project number PN-III-P2-2.1-PED-2019-4366 within PNCDI III (431PED).

## REFERENCES

[1] Bertoncello M and Wee D 2015 Ten Ways Autonomous Driving Could Redefine the Automotive World (McKinsey & Company)

[2] Zhang Q, Chen D, Yusheng L and Keqiang L 2015 Research on Performance Test Method of Lane Departure Warning System with PreScan

[3] Pendleton SD, Andersen H, Du X, Shen X, Meghjani M, Eng YH, Rus D and Ang Jr MH 2017 Perception, Planning, Control, and Coordination for Autonomous Vehicles

[4] Atakishiyev S, Salameh M, Yao H and Goebel R 2022 Explainable artificial intelligence for autonomous driving: An overview and guide for future research directions

[5] Guo X 2017 Feature-Based Localization Methods for Autonomous Vehicles. Ph.D. Thesis (Freien Universität Berlin, Berlin, Germany)

[6] Luis F, Leon A and Aoyama Y 2022 Industry emergence and market capture: The rise of autonomous vehicles

[7] Yeong D Y, Velasco-Hernandez G, Barry J and Walsh J 2021 Sensor and Sensor Fusion Technology in Autonomous Vehicles: A Review

[8] Asvadi A, Premebida C, Peixoto P and 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

[9] Steinbaeck J, Steger C, Holweg G and Druml N 2017 Next Generation Radar Sensors in Automotive Sensor Fusion Systems

[10] Shahian Jahromi B, Tulabandhula T and Cetin S 2019 Real-Time Hybrid Multi-Sensor Fusion Framework for Perception in Autonomous Vehicles

[11] Kalra N and Paddock S M 2016 How many miles of driving would it take to demonstrate autonomous vehicle reliability? (RAND Corporation, Santa Monica, CA, Tech. Rep.)

[12] Klischat M and Althoff M 2019 Generating Critical Test Scenarios for Automated Vehicles with Evolutionary Algorithms IEEE

[13] Zhang W, Tan K, Torngren M, Sanchez J M G , Ramli M R, Tao X, Gyllenhammar M, Wotawa F, Mohan N, Nica M and Felbinger H 2021 Finding Critical Scenarios for Automated Driving Systems: A Systematic Literature Review

[14] Taeyoung L, Kyongsu Y, Jangseop K and Jaewan L Development and Evaluations of Advanced Emergency Braking System Algorithm for the Commercial Vehicle

[15] Simcenter Prescan Help 2022

[16] Bodemann C D and De Rose F 2011 The successful development process with matlab Simulink in the framework of ESA’s ATV project

[17] Reedy J and Lunzman S 2010 Model Based Design Accelerates the Development of Mechanical Locomotive Controls