Extension of the 3DCoAutoSim to Simulate Vehicle and Pedestrian Interaction based on SUMO and Unity 3D

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***Abstract*— The protection of vulnerable road users (VRUs) has been an active research topic in recent years. In this context, P2V (Pedestrian-to-Vehicle) and V2P (Vehicle-to-Pedestrian) communication systems have become crucial technologies to minimize potential dangers, due to the high detection rates and the high user-satisfaction levels they achieve. The recent release of the latest versions of SUMO (Simulation of Urban Mobility) and TraaS (TraCI as a Service) reveals the possibility of developing both P2V and V2P communications in a simulated 3D environment with microscopic modeling of vehicles and pedestrians, as well as the possibility of testing the efficiency of the proposed system. To this end, we implemented a 3D driving simulator with pedestrian integration, using a powerful game engine (Unity 3D) that accessed data from the SUMO open source traffic simulator and was therefore capable of simulating vehicle-pedestrian interaction through Transmission Control Protocol (TCP) connection. Results from a defined use case validated the presented approach.**

I. Introduction

Even if the number of accidents in the European Union has decreased significantly in recent years, traffic accidents are still one of the major causes of death. In 2017, both passenger car and pedestrian road accident fatalities were the major causes of death in European Union [1]. Recently, some steps have been taken in the field of Intelligent Transportation Systems (ITS) to reduce these accidents.

For instance, authors in [2] sought to identify the most effective ITS approach for improving safety in certain intersections by using Vehicle-to-Pedestrian (V2P) and Pedestrian-to-Infrastructure (P2I)-based communication technologies in Automated Pedestrian Detection (APD) and Countdown Pedestrian Signal (CPS) as traffic signal adjustments. In another instance, contributors in [3] analyzed a set of ITS applications for pedestrian safety to find the most suitable one for a particular city.

There are also some works that investigate pedestrian detection for ITS [4]. In particular, authors in [5] developed an application based on a collision prediction algorithm using P2V and V2P communication at the same time, an approach that they chose in order to promote the acceptance of autonomous vehicles on the roads. Authors in [6] presented a method for detecting and tracking pedestrians from a moving vehicle using both the Histogram of Oriented Gradients (HOG) and the Kalman-based filter. Further research on pedestrian detection with mobile phones is found in [7], [8], which used image processing techniques for pedestrians captured by the phone rear-camera. An additional function of the program applied driver facial recognition through the front camera to detect their readiness for a potential Take Over Request (TOR).

At the present time, few open source, adaptable tools that aid research on pedestrian safety exist, as far as including realistic modeling based on actual traffic models and integrating upcoming communication technologies. This fact motivated the development of a platform to investigate the effect of V2P and P2V communication on safety by linking a Unity 3D-game-engine-based simulator with the SUMO traffic simulator. Simulation of transportation systems remains a necessary and important area of development today to manage transportation networks and ensure road safety.

The SUMO Traffic Control Interface (TraCI) makes it possible to access a traffic simulation during runtime. By using its TraCI as a Service (TraaS) library a remote-controlled realistic 3D traffic scenario that includes pedestrians can be implemented [9].

Such a framework was modeled in [10] as the foundation for the Simulator for Cooperative Advanced Driving Assistance Systems (CO-ADAS) and Automated Vehicles (3DCoAutoSim) [11], and for which the 3D Driving Simulator with VANET Capabilities to Assess Cooperative Systems (3DSimVanet) [12] and the work based on Traffic Lights and V2I communication in [13], [14] as well as the previous pedestrians integration in [15] are integral parts.
We extend here the mentioned tailored simulation platform and include both pedestrian- and driver-centric perspectives at the same time to acquire more realistic and optimized data for further research, contributing thus to the research in the field.

The remainder of the paper is organized as follows: section II delineates the proposed work over the simulator to introduce the pedestrians and communication schemes; section III presents the experimental setup to assess the system; section IV describes the data acquisition and analysis; sections V and VI describe and discuss the obtained results respectively; and finally, section VII concludes the work.

II. Simulation Framework Implementation

In this work we present a pedestrian detection system in a simulated environment that mimics bidirectional communica-

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tion between vehicles (V2P) and pedestrians (P2V) equipped with a smart device through a connection between SUMO and Unity. An application is required to run in the background of the smart device that uses the GPS localization and magnetometer sensors to access the pedestrian current location and orientation angles and to access any vehicle that is broadcasting its location information nearby in a manner similar to the one described in [5]. The system is able to estimate a collision point between pedestrians and simulated vehicles in the scenario.

In order to evaluate the proposed system we defined the following research question: Does the proposed pedestrian detection system assist the driver in recognizing a potentially unsafe situation in which vulnerable road users (VRU) are involved?

In this section, the simulator used for integrating the proposed work is explained, followed by a description of the environment, and, finally, the proposed V2P and P2V communication schemes.

A. 3DCoAutoSim

As previously mentioned, the proposed framework in this paper extends the 3DCoAutoSim simulator [11], which integrates the capabilities presented in the following works:

- Driver-centric driving platform that, through TraCI protocol, allowed communication between Unity 3D and the microscopic traffic simulator Simulation of Urban MObility (SUMO) to visualize the mobility behavior of surrounding vehicles [10].
- Driving simulator platform to evaluate advanced driving assistance systems based on vehicle-to-vehicle (V2V) communication [12].
- Platform to test vehicle-to-infrastructure (V2I) communication using a Traffic Light Assistance System that calculated the optimal speed when approaching an intersection by retrieving the traffic light timing program from the road infrastructure [14], [13].
- Method that combines the Robot Operating System (ROS) and Unity 3D as a powerful visualization tool [16].

B. SUMO Environment

SUMO makes it possible to establish a bidirectional communication to access information between different elements in the environment through its TraCI application programming interface (API). The Transmission Control Protocol (TCP) is applied after the road network information from Open Street Maps (OSM) data is accessed in the SUMO configuration file and loaded into Unity to display the 3D scenario.

A parent Game-Object is created for the roads which contains many children Game-Objects obtained by successively instantiating a prefab that represents a single road-section. For each game loop, a new simulation step is performed in the micro-simulator through the API, asking for the position of the System-Controlled Vehicles (SCV) and communicating the current position of the User-Controlled Vehicle (UCV).

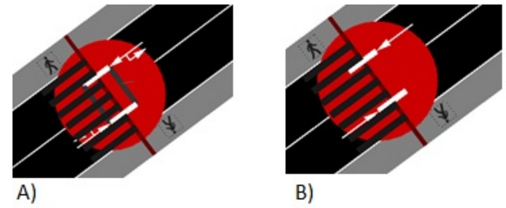

Fig. 1. Connections in the Netedit graphical network editor for SUMO before correction (A) and after (B).

1) Network Edition: The errors contained in the network file obtained from the OSM data were improved manually using the Netedit graphical network editor or Netconvert tool for SUMO, together with certain parameters. The errors were:

- Asynchronous Traffic Light System (TLS) programs, which resulted in traffic jams and inconsistencies.
- Invalid connections that made the vehicles move in an unrealistic manner as shown in Figure 1.
- Invalid pedestrian topologies.

After obtaining a cleaner version the network was further edited using the Netconvert tool with a variety of attributes, such as sidewalks that are lanes which only permits the vClass *pedestrian* in the simulation. Although some sidewalks were already generated, due to the current pedestrian models used by SUMO it was necessary to ensure that at least a sidewalk was present in each edge. To this end we used the attribute `sidewalks.guess`, which guess pedestrian sidewalks based on edge speed.

2) Classification of Roads Retrieved by SUMO: The method iterated the lanes retrieved from SUMO and analyzed the permissions of each lane. Depending on the permissions, a first classification was made that separated the lanes in two groups: pedestrian lanes and vehicle lanes. Further, in order to classify a current lane as sidewalk or as pedestrian crossing, all the function values of the edges in the simulation were examined to see if their type was crossing. The code in Listing 1 depicts the process to classify roads. The overall road classification was then updated as depicted in Figure 2 containing the configuration file after the process of all necessary information (roads, vehicles, pedestrians and routes) for a complete simulation.

Listing 1. Roads Classification

```
if (linkedLane.getType().Equals("walk"))
{Vector3 roadSectionCenterPosition =
new Vector3((currentVertexX +
previousVertexX)/ 2, 0.05f,
(currentVertexZ + previousVertexZ) / 2);
//instantiate new road section as game
//object, with walking road section prefab,
//location, and orientation
```

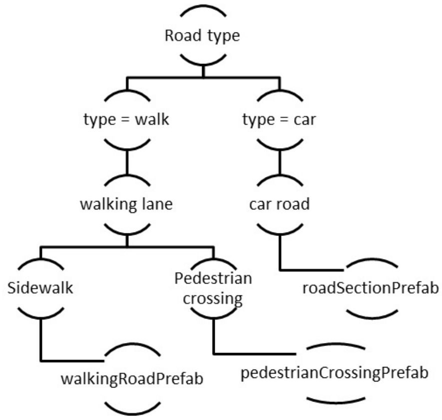

Fig. 2. Road classification scheme for visualization in Unity.

Fig. 3. Visualization of connectivity through red colored pedestrians. (A) Bird's-eye view of a zebra crossing with a pedestrian. (B) Driver-centric perspective of two pedestrians in the surroundings on the left and right sides of the road respectively.

```
GameObject walkRoadSection =
Instantiate(walkingRoadPrefab,
roadSectionCenterPosition,
Quaternion.identity) as GameObject;
walkRoadSection.transform.rotation =
Quaternion.AngleAxis((float)
roadSectionOreintationAngle, Vector3.up);
// scale the new road section
walkRoadSection.transform.localScale =
new Vector3((float)(0.33 * laneWidth/
3.2),1,(float)(0.105*roadSectionLength));
//set new road section name to lane ID
walkRoadSection.name = laneID;
//set the parent of the new road section
// to lanes game object
walkRoadSection.transform.SetParent
(lanesParent.transform, false);
//see if the current lane is a pedestrian
//crossing
if(linkedLane.getID().Contains("_c")){
//setting the position where the pedestrian
//crossing will be instantiated
Vector3 roadzebraPosition = new Vector3
((currentVertexX + previousVertexX)
/ 2, 0.065f, (currentVertexZ +
previousVertexZ) / 2);
//instantiating the pedestrian crossing as
//game object in Unity
GameObject zebra = Instantiate
(pedestrianCrossingPrefab,
roadzebraPosition, Quaternion.identity)
as GameObject;
//Adding a rotation which is equal to
//the angle of that road
zebra.transform.rotation =
Quaternion.AngleAxis
(roadSectionOreintationAngle,
Vector3.up);
//Setting the width of the pedestrian
//crossing
zebra.transform.localScale = new Vector3
((float)(0.33 * (laneWidth) / 3.2), 1,
(float)(0.105 * roadSectionLength));}}
```

The works in [14] and [13] show in detail how roads are classified for vehicle traffic. Similarly, pedestrian objects are created in Unity for each simulated pedestrian in SUMO and added to the list of pedestrians in the last position. The attributes of position, ID, speed and angle are set to the SUMO attributes. With each game loop update, the position of each pedestrian is updated using the move function, which takes the local coordinates as a vector and two other additional flags that allowed the created object to walk in a realistic manner (a boolean flag for the crouch feature and a boolean flag for the jump feature (both always set to "false")). The final outcome for the pedestrian simulation in the 3DCoAutoSim is depicted in Figure 3.

C. Bi-directional Communication System

The purpose of the implementation of the framework described in this paper was to have a tailored platform to be able to evaluate P2V and V2P communication-based driving assistant systems and related technologies. We validated the adequacy of the developed system by performing the experiments described in the next section. The characteristics of both communication paradigms are as follows:

1) V2P-based communication system: warns pedestrian when a vehicle is nearby relying on the work in [7] and [8], with the purpose of increasing the visual situational awareness of VRU regarding the nearby location of both SCV and UCV.
   In order to evaluate if the V2P communication had been achieved in the simulated 3D environment the pedestrians to which information was broadcasted were visualized in the 3D environment in a different color (red) than the white regular one. As a threshold for establishing communication we set a maximum distance of $40m$ from the UCV.
2) P2V-based communication system: warns the driver when a pedestrian is nearby. The system is in charge

Fig. 4. Driver-centric perspective of a pedestrian in the surroundings to the left.

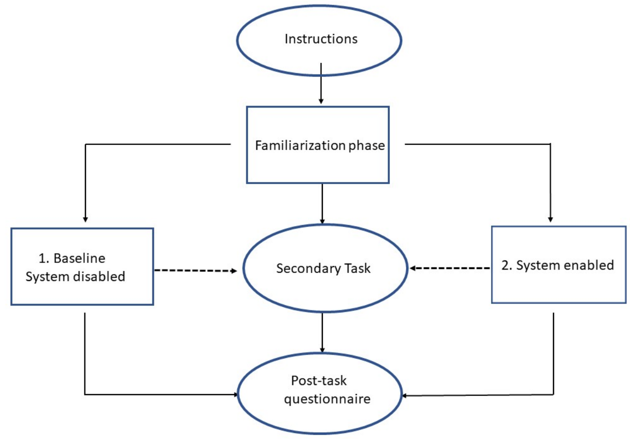

Fig. 5. Flowchart of the experimental procedure to test the proposed system.

of estimating a collision point between the UCV and the nearby pedestrian based on the work in [5]. The driver response to this pedestrian detection system was evaluated as described in the next section.

III. Experimental Setup to Assess the Pedestrian Detection System

Two visualization paradigms for the detection of pedestrians were implemented in order to measure driver response to the implemented P2V communication-based system as follows:

- If the pedestrian was visible from the vehicle and the time to reach the collision point was inferior to a defined threshold of $5s$, an object-bounding box was displayed on the head-up-display of the vehicle as marker. The estimated time to reach the collision point was also conveyed.
- In the event that the pedestrian was not visible the system displayed an arrow pointing to the pedestrian's location, as shown in Figure 4.

In both cases an additional warning message was conveyed to the driver through an acoustic signal once the pedestrian collision detection conditions were met.

The testing sample consisted of 20 subjects, 80% males and 20% females and a mean age of 26.4 (SD=6.5). Each experiment consisted of two sets of driving sessions:

1) under baseline conditions, the system disabled;
2) with the pedestrian detection system enabled.

The order of the sets was alternated to avoid bias. As collisions with pedestrians are rare in a simulation environment, we added a distracting visual-manual secondary task during the driving task relying on [17] to increase the probability of accidents. It was not the goal of this work to assess the effect of the secondary task on the driving performance. The flowchart in Figure 5 illustrates the procedure.

After being welcomed, instructions regarding the experimental procedure were given to each participant. They were asked to drive according to the traffic rules without exceeding speed limits on a given path in which the way to follow was signaled by arrows. After a 3-minute familiarization phase with the simulator, during which no data was logged, the participants then performed the two driving sets (baseline and system enabled) for 5 minutes each until they reached three stop signals. The secondary task consisted of extracting a pen from a bag that contained a variety of items that was located on the passenger seat. This task started when the driver reached the area of interest, in which pedestrians were present as defined in Section IV. The participants performed the task until they reached the end of the scenario.

As the last phase of the experiment, each participant was required to complete a post-task questionnaire. The purpose of this phase was to perform a subjective evaluation of certain parameters. The participants were asked to answer questions in order to know if they were satisfied with the P2V system. To this end a 5-points Likert-type scale ranging from "1-strongly disagree or very bad" to "5-strongly agree or very good" was implemented.

IV. Data Acquisition and Analysis

To study the effect of the system on driving performance, several metrics were measured by logging and analyzing the data retrieved from the devices included in the simulator logging tool [11]: CAN-bus-reader, UCV, GPS, pedestrians GPS, lidar pointcloud and front camera images. That is, for each driver, information related to the speed, position, braking and acceleration patterns was logged every 0.1 s ($f_{logging}$ = 10Hz). Furthermore, a camera took photos of the simulation with the purpose of rebuilding the entire experiment and performing a further analysis of each frame. The metrics retrieved from the lidar were not evaluated within this work.

To log the position of every pedestrian using GPS devices a boolean argument was added to the function which is in charge of enabling the devices that the user has selected. This makes it possible to recognize if the GPS is attached to a pedestrian or if it is part of the user-controlled car. Driving performance was calculated by the following parameters (areas) of interest when the drivers entered a straight road section with pedestrian crossings or pedestrians nearby:

A. Deceleration Change Rate

The deceleration is calculated based on the ratio of deceleration within two successive frames [18] when the driver starts braking in the area of interest.

$$DCR = \frac{a}{tf} = \frac{V_{f-1} - V_{ftf}}{tf} \tag{1}$$

Where:

- V_{f-1} = Velocity of the vehicle during the previous frame while braking
- V_f = Velocity of the vehicle during the current frame while braking
- t_f = Duration of the frame

As the duration of each frame was not available, the acceleration was computed as the difference between the speed in two timestamps of the simulation to ensure consistency with results from other works [19]. Since the area of interest is a straight road section, the deceleration change rate (DCR) represents the amount of reduction in speed by the driver due to the sudden appearance of a pedestrian. To analyze the data we first established the null and alternative hypotheses to test if the activation of the system increased the average DCR.

- H_0: μ_D = 0
- H_1: $\mu_D > 0$

where μ_D = μ_x - μ_y and μ_x = $E[X]$, μ_y = $E[Y]$

X being the speed variable observed while the pedestrian detection system was enabled (2) and Y being the speed observed under baseline conditions with the system disabled (1).

For the comparison of the parameters of interest between 1) and 2), the paired t-test for means was applied with $\alpha = 0.05$. The performance of the same driver in a certain environment was measured twice and the net change from the first condition to the next was computed, thereby showing whether the mean change score was significantly different for each condition.

B. Maximum and Minimum Steering Wheel Angles

The information conveyed by this parameter provides similar cues to the ones derived from the lateral deviation metric due to the lack of curves in the desired region. Thus, these values are used to identify cognitive distraction as in related literature [20]. The null and alternative hypotheses to test if the activation of the system increased the average maximum and minimum steering wheel angles was defined similarly to the previous parameter.

As with the previous DCR, the paired t-test for mean was applied with $\alpha = 0.05$ to test whether the average number of the respective measurements in both conditions was significantly different.

C. Number of Collisions

This parameter is a boolean number (0 for no-collision and 1 for collision), which is obtained after the frame-to-frame analysis of the experiments and indicates the number of collisions between the participant and the simulated pedestrians. For the comparison of the number of collisions between scenarios a McNemar χ^2 two-tailed test for each of the variables was applied. Also, as we are using contingency tables with low frequency numbers, we considered the potential for biased data and applied the Yates correction.

The null and alternative hypotheses to test whether the proportion of collisions when the P2V system was activated was lower than when it was disabled were defined as follows:

- H_0: π_x = π_y
- H_1: $\pi_x < \pi_y$

π_x = $E[X]$, π_y = $E[Y]$

X being the number of collisions observed when the P2V system is activated and Y being the number of collisions observed when the P2V system is disabled.

V. Results

A. Quantitative Results

Results regarding deceleration change rate from both driving sessions indicated a non-significant trending in reducing the speed when the system was enabled (see Table I).

Furthermore, the analysis of the retrieved values from the steering wheel sensor indicated a non-significant difference for both conditions.

TABLE I

Driving performance measured by the deceleration change rate (DCR) and the steering wheel angle

	System 1 Baseline		**System 2 Enabled**		**System 1 vs. System 2**	
	M	*SD*	*M*	*SD*	$t(19)$	p
DCR	0.08	0.24	0.11	0.48	1.02	0.160
Steering Wheel	0.36	0.33	0.26	0.30	0.91	0.187

The percentage of collisions in the baseline condition was with 25% significantly higher than the percentage in the system activated condition with 5% ($\chi^2(1, N = 20) = 7.04$, p = 0.0079). As a consequence we rejected H_0: π_x = π_y and accepted that the number of collisions observed when the P2V system is activated is lower than the number of collisions observed when the P2V system is disabled.

B. Questionnaire Results

Results regarding the qualitative evaluation of the questionnaire showed that almost all participants considered the pedestrian detection system to be useful and 95% of the participants found the bounding box displayed in the head-up-display around the pedestrians not obstructive for scenario visibility. 15% of the participants did not notice the alarm included in the pedestrian detection system.

VI. Discussion

In order to have a collision between a vehicle and a pedestrian, an unexpected event involving pedestrians had to occur. 32 pedestrians from a total of 40 appeared unexpectedly in the scenario in the N=40 trials being the probability of having a potentially hazardous road situation involving pedestrians 0.8 for each participant regardless of the activation of the system. Although the probability of encountering a pedestrian was considerably increased in our experiment there was still a 20% probability that it did not occur. This is due to the SUMO implementation: the file generated from SUMO that defines the routes for every pedestrian is the same for every participant but the walking speed of each participant might vary, which leads to encountering different pedestrians at the same instant.

After analyzing the speed of participant 14 (the one who had an accident while the system was activated), it was found out that the driver was not respecting the speed limits, a potential cause for the accidents.

Taking into account the limitations of this study regarding the available data and that the experiment was designed to cause accidents, the behavior of the driver has been shown to be positively affected by the proposed system, since the proportion of accidents that have happened with the system enabled was significantly lower than when the system was disabled i.e. under baseline conditions. Even if the DCR decrease was not statistically significant a tendency to reduce the speed could be identified that affected positively the driving behavior resulting in less accidents. Furthermore, both subjective and objective results show that the proposed system was not intrusive to drivers, did not interfere with their task and was therefore safe. In conclusion, there is enough evidence to state that the proposed system with the features explained in this paper could assist the driver improving the safety of road users by reducing accidents.

VII. Conclusion and Future Work

The results from the described use case validated the presented approach of a 3D driving simulator with pedestrian integration, as a tool capable of simulating vehicle-pedestrian interaction through TCP connection. P2V and V2P communication-based driving assistant systems could be assessed with the simulation platform as a proof of concept to test new in-vehicle technology.

In future work the vehicle detection system will be tested by using mobile devices connected to the simulation. The acoustic signal and hardware related to the simulation will be also improved.

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