P2V and V2P Communication for Pedestrian Warning on the basis of Autonomous Vehicles

Ahmed Hussein[1], Fernando García[1] *Member, IEEE*,
José María Armingol[1] and Cristina Olaverri-Monreal[2,*] *Member, IEEE*

***Abstract*— The use of smartphones in a road context by drivers and Vulnerable Road Users (VRU) is rapidly increasing. To reduce the risks related to the influence of smartphone usage in a situation where traffic needs to be considered, a collision prediction algorithm is proposed based on Pedestrian to Vehicle (P2V) and Vehicle to Pedestrian (V2P) communication technologies, which increases the visual situational awareness of VRU regarding the nearby location of both autonomous and manually-controlled vehicles in a user-friendly form. The proposed application broadcasts the device's position to the vehicles nearby, and reciprocally, the vehicles nearby broadcast their position to the device in use, supporting pedestrians and other VRU to minimize potential dangers and increase the acceptance of autonomous vehicles on our roads. Results regarding the evaluation of the proposed approach showed a good performance and high detection rate, as well as a high user satisfaction derived from the interaction with the system.**

I. INTRODUCTION

The Association for Safe International Road Travel states that road crashes account for 2.2 per cent of all deaths globally and predicts that road injuries will become the fifth leading cause of death by 2030 [1]. According to the European Commission Report "Road Safety in the European Union" 22% of those killed on roads are pedestrians and the highest accident exposure occurs in urban areas [2].

There are multiple risk factors influencing crash involvement; primarily road user distraction, which leads to lack of road awareness and is fostered by the use of mobile devices that have not been designed specifically for use in a traffic environment. As a consequence, a great deal of research has been investigating appropriate warnings and location of functions for safety enhancement, mainly in an in-vehicle context [3]. The use of mobile devices not only by drivers but also by Vulnerable Road Users (VRU) is rapidly increasing, and most current mobile solutions tend to neglect the risks they entail in a context where traffic needs to be considered [4]. Therefore, safety related to the use of mobile devices is becoming a very prominent issue, particularly relevant in urban environments with high traffic density [5].

At the same time, as stated in [6], the introduction of fully autonomous vehicles on our roads represents an opportunity to reduce the rate of accidents due to human errors, as driver intervention will no longer be required. In this context, trust plays a decisive role in the adoption of the new self-driving car technology [5]. If the road users interacting with autonomous vehicles are not able to verify the reliability of the technology in terms of safety, a low social acceptance rate might follow.

Therefore, in this work we present a mobile application to support pedestrians and other VRU to minimize potential dangers and raise the acceptance of autonomous vehicles on our roads. Our application increases the visual situational awareness of VRU regarding the nearby location of both autonomous and manually-controlled vehicles in a user friendly form. Unsafe road situations in which pedestrians are involved are identified when the user is interacting with the device (i.e. speaking, entering information) and the mobile screen is active. In the event that such interaction is detected and relying on Pedestrian-to-Vehicle (P2V) communication, the proposed application broadcasts the device's position to the vehicles nearby, and reciprocally, the vehicles nearby broadcast their position to the device in use, thereby building on Vehicle-to-Pedestrian communication (V2P). Thusly, both pedestrians and vehicles can anticipate each others maneuvers and identify if there is a possibility of collision.

The remainder of this paper is organized accordingly: section II reports on related work in the areas of V2P, P2V communication technologies and related applications. Section III presents the collision prediction algorithm. Section IV describes the developed application. Sections V and VI show the evaluation process and the obtained results. Section VII concludes the paper.

II. RELATED WORK

Pedestrian protection and comfort are common topics in the Intelligent Transportation Systems (ITS) community [7]. With the development of Advanced Driver Assistance Systems (ADAS), several solutions to protect pedestrians in road environments have been presented over the years, whether based on computer vision, such as monocular-vision in [8] and [9]; stereo-vision in [10] and [11]; or far infrared approaches for night-light conditions in [12]. Other sensing devices, such as laser scanners or radar, were also presented in [13]. Recent advances fuse the information of these technologies and combine the capabilities of different sensing units for better perception [14] and [15].

The advances in the field of communication are increasingly enhancing the performance of detection systems, and as a consequence, the possibilities of these technologies are undergoing extensive investigation. For example by testing

[1] Intelligent Systems Lab (LSI) Research Group, Universidad Carlos III de Madrid, Spain.
{ahussein, fegarcia, armingol}@ing.uc3m.es
[2] University of Applied Sciences Technikum Wien, Department of Information Engineering and Security, Vienna, Austria.
olaverri@technikum-wien.at *corresponding author

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of dedicated networks relying on the vehicle communication 802.11p protocol [16] or on the IEEE 802.15.4 standard for low-rate wireless personal area networks [16].

In order to determine the most reliable communication protocol for a given scenario, the delay associated with the use of these protocols is crucial to evaluate the acceptable data packet reception time. To this end, different prototypes based on 3G and WLAN networks have been evaluated in different proposed approaches [17]. In this sense, it has been shown that the latency related to Wi-Fi communication [18] is lower than the one related to 3G networks [19]. On the other hand, novel 4G and 5G networks allow further advances towards efficient communication with low latency within devices, such as vehicles and smartphones [20].

Vehicle to Vehicle (V2V), V2P and P2V communication-based technologies send and receive information in different road situations. With this in mind, the works in [21] and [22] focused on receiving information from the vehicle and creating an ADAS application that retrieves localization information from mobile devices in order to identify pedestrians in immediate danger. In the work in [23], information regarding pedestrian detection is received from the vehicle's sensing devices and broadcast in real time. Other works focused on broadcasting information to pedestrians so that they were able to react to a certain event in time [24] and [25].

In this paper, we propose an approach to increase the visual situational awareness of all users sharing the road based in communication technologies already available in the market such as 4G and Wi-Fi networks. Through warnings regarding the nearby location of each other and based on the location of both vehicles and VRU, the users sharing the road can anticipate each others behavior and the possibility of a collision.

The proposed application intends to reduce the risks related to the use of mobile devices in a traffic context and thereby decrease the accident exposure of pedestrians and other VRU. To assess the performance of our approach, we test it using an autonomous vehicle, to prove the reliability of the upcoming automation to potential users and increase the social acceptance of autonomous vehicles on the roads. Additionally, the overall performance regarding the proposed application is compared with other object detection algorithms based on laser scanning and computer vision.

III. COLLISION PREDICTION ALGORITHM

As previously mentioned, this work aims at increasing the visual situational awareness of VRU and vehicles. Therefore, V2P and P2V communication technologies are selected to test their applicability in the field of autonomous and manually-controlled vehicles compared to other available sensing devices. The proposed collision prediction approach is based on the algorithm presented in [26], which retrieves information from two information sources and anticipates the possible collision point. To contribute to the enhancement of the system, we improve the calculation of the danger degree in equation 5. In addition to computing the collision point with reference to location coordinates, we also calculate the orientation angle of both the pedestrian and the vehicle. The calculations are performed using equations 1 and 2 [26].

$$x_c = \frac{(y_2 - y_1) - (x_2 \cdot tan(\theta_2) - x_1 \cdot tan(\theta_1))}{(tan(\theta_1) - tan(\theta_2))} \tag{1}$$

$$y_c = \frac{(x_2 - x_1) - (y_2 \cdot cot(\theta_2) - y_1 \cdot cot(\theta_1))}{(cot(\theta_1) - cot(\theta_2))} \tag{2}$$

where x_i,y_i and θ_i are the location coordinates and orientation angles of pedestrian (1), vehicle (2) and collision point (c), as shown in Figure 1.

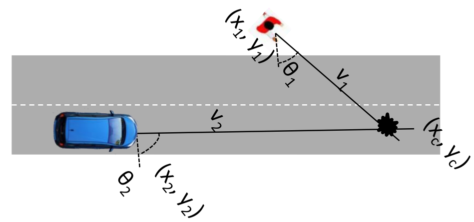

Fig. 1. Collision prediction algorithm modeling [26]

The period of time to collision point (TTC) from the perspective of the pedestrian differs from the one of the vehicle. However if the difference is less than a specific threshold, the situation is considered potentially unsafe, as a collision might occur. This case is calculated in equation 3, where TTC_i denotes the TTC for the pedestrian (1), the vehicle is represented by (2), (d) is the difference between them, and δ denotes the preset threshold, which determines if the road situation can be considered dangerous.

$$TTC_d = |TTC_1 - TTC_2| < \delta \tag{3}$$

The value of the δ parameter can be calculated based on the information of the driver reaction time t_r and braking time of the vehicle t_b, as shown in equation 4 [14].

$$\delta = t_r + t_b \tag{4}$$

As the difference in the TTC is not the only factor that determines a potentially dangerous road situation, the d_i danger index was also considered in the calculations, as shown in equation 5. This index is calculated for collision and no-collision trajectories, where λ is a parameter that is adjusted.

$$d_i(TTC_d, d) = \begin{cases} e^{-\frac{\lambda TTC_d^2}{2\delta^2}}, \text{ for collision trajectories} \\ e^{-d\gamma}, \text{ for none collision trajectories} \end{cases} \tag{5}$$

where the value of λ parameter is chosen to provide a danger index d_i of 0.7. When the value of TTC_d is equal to δ, the value of λ is set to 0.713. The value of γ parameter is adjusted for no-collision trajectories to ensure a specific safety distance, therefore for a desired d_i of 0.7 and safety distance of 3 meters, the value of γ is set to 0.119.

IV. SYSTEM DESCRIPTION

The proposed algorithm required the use of a system for both pedestrians and vehicle that is described in detail below.

A. Smartphone Application

The collision prediction algorithm is implemented as a mobile application, which runs in the background when the mobile phone is active. It uses the onboard smartphone GPS localization sensor to access the pedestrian's current location and uses the magnetometer sensor to access the pedestrian's current orientation angle. Based on these data, the application updates the algorithm with pedestrian location information, then it waits for a nearby vehicle that broadcasts the vehicle location information.

Thereafter, the application processes the information in order to calculate and predict the location of the collision point, with respect to the pedestrian location. Moreover, it calculates distance and time to the collision point for both pedestrian and vehicle. Last but not least, the system calculates the collision time and danger indexes to display the warning message accordingly. In the event that the application detects a situation that could jeopardize the safety for the pedestrian, it displays a warning and vibration message on the screen to inform the pedestrian about an approaching vehicle. In order to foster a quick reaction time to the message displayed, the user interface indicates the direction of the oncoming vehicle. Figure 2 shows an example of the calculations in the debugger and the user interface of the application.

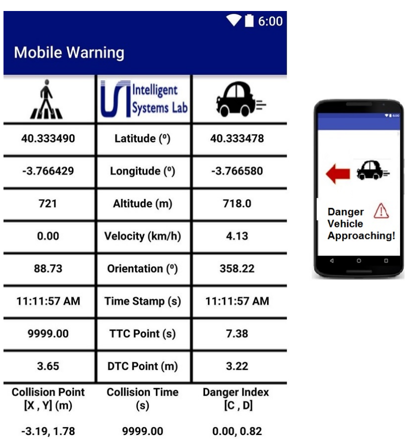

Fig. 2. Calculated information to debug the application that runs in the background (left) and user interface indicating the direction of the oncoming vehicle (right)

To increase the awareness and acceptance of autonomous vehicles on our roads, an alternative message indicated whether an autonomous vehicle was approaching. Furthermore, in case of a potential safety issue, the application sent the vehicle a collision warning.

An alert control system is responsible for automatically triggering an alarm when a situation is deemed unsafe, i.e. when the values are lower than a specific threshold. This threshold is calculated in equation 4, taking into account the minimum estimated reaction time of 0.66 seconds as defined in [27] and corroborated in a more recent work in [28]. When the time to collision is shorter than this value, the alarm is triggered according to the specific required reaction time determined by the type of vehicle involved and the road situation.

B. Vehicle Description

As previously mentioned, the proposed algorithm requires a vehicle equipped with sensors to localize its current location and orientation, in addition to a communication module to send and receive the information to and from the pedestrian smartphone. To this end, we used an electric golf cart autonomous vehicle, which had been designed within the iCab project [29]. Although we performed the proposed system's evaluation with an autonomous vehicle, the application was designed to be incorporated in any vehicle with any location system.

The vehicle was equipped with optical wheel encoders, stereo-vision camera, laser-rangefinder, compass and GPS sensor modules, as shown in Figure 3, to allow autonomous behavior and detection of obstacles [30]. It was controlled via an on-board embedded computer, which operates using Robotic Operating System (ROS) architecture, but which could also be manually controlled. The advantages of the proposed system are described as follows:

Fig. 3. Autonomous vehicles as part of the assessment platform

- Alert to foster road attentiveness. The mobile application urges the user to quickly pay attention to the road and it sends a notification to the vehicle involved.
- Road safety and battery conservation. The application avoids the trigger of an alarm if the mobile phone is inactive.
- Verification of reliability of autonomous vehicles. Information about the nearby location of an autonomous vehicle might help familiarize users with new technology and increase perceived safety of autonomous vehicles.

V. SYSTEM EVALUATION

A. System Performance

In order to assess the functionality and performance of the proposed algorithms, several experiments were performed in the scenarios described below. These scenarios and use cases were selected in order to evaluate smartphone performance and potential limitations in terms of accuracy of the collision prediction algorithms. Moreover, we aimed at assessing the viability of the system based on the available communication capabilities and evaluate the advantages of the proposed algorithms compared to the other sensing technologies. We also performed a user evaluation to assess user satisfaction with the developed system, and which can provide insight in terms of supporting the "discovery" and acceptance of autonomous vehicles. In order to evaluate the algorithm, the following metrics were analyzed: a) distance to collision point and b) collision danger index against time. System performance was tested based on two use cases:

- Basic performance test to prove the basic performance of the collision detection algorithm: VRU crossing the road while using the smartphone without paying attention to traffic. Figure 4 depicts this scenario showing 2 use cases: (a) pedestrian crosses the road and (b) pedestrian stands in the vehicle's way.

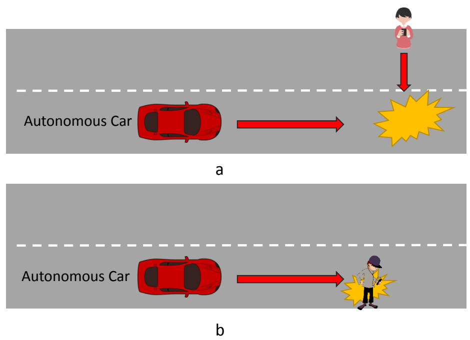

Fig. 4. Application evaluation scenarios: (a) pedestrian crosses the road and (b) pedestrian stands in vehicle's way.

- Test to measure the degree of improvement in relation to other collision avoidance technologies based on on-board sensors (i.e. laser scanner and cameras): VRU crossing road in the same conditions and without a clear view of an approaching vehicle. The sensor detection times were compared to the collision detection algorithm. Figure 5 shows two different use cases: (a) pedestrian crosses the road behind another vehicle obstructing the view of an oncoming vehicle; and (b) pedestrian crosses the road at an intersection behind an object obstructing their field of view. A collision point with the vehicle is calculated.

B. User Study

As described in section I, the safe introduction of fully autonomous vehicles on our roads is related to trust in the upcoming technology. To test the reaction of other road users to an autonomous vehicle and evaluate if our application supported them in the verification process of trusting autonomous vehicles as a reliable safe technology, a subjective evaluation was performed with a data sample of 10 test subjects (60% males, 40% females, mean age = 26 (SD = 3.5)). The representative sample was designated by selecting users randomly from a mailing list. The heterogeneity of subjects was therefore guaranteed.

The responses of the participants to the warnings shown in the application were then analyzed according to the

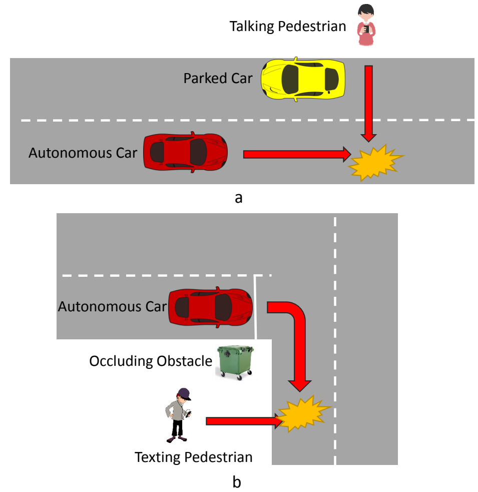

Fig. 5. Application evaluation scenarios: (a) pedestrian is crossing being behind an obstacle obstructing their field of view, and (b) pedestrian is crossing the road at an intersection

potential increase of visual situational awareness regarding the nearby location of other vehicles. The warnings related to the specific unsafe road situation in which they were involved (i.e. interacting with the mobile phone while crossing the road). To this end the participants tried the system in two scenarios in the vicinity of the university campus while interacting with their phones. To make sure that the attention of the user while crossing the road was on the phone and not on the road, we let the pedestrian watching a video:

- an autonomous vehicle was approaching
- a manually-controlled vehicle was approaching

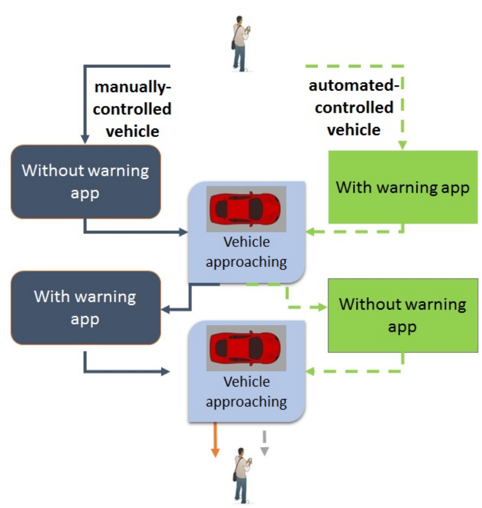

Fig. 6. Usability Evaluation Procedure

In both cases the order of showing a warning message and showing no message was alternated. The procedure for the experiment is depicted in Figure 6. It consisted of two scenarios specifying if the experiment started with the warning application activated or deactivated. As a consequence, we avoided bias that could affect the results by any eventual advantage caused by the order. We observed the reaction of the mobile phone users to these warnings and asked them to complete a post-task questionnaire related to their impression. To this end we developed a 5-point Likert scale questionnaire with 14 items relying on the perceived usefulness and ease of use by [31]. Additional questions related to demographic information and a field to enter comments completed the survey. We then analyzed the responses to measure the extent of the person's agreement with the set of questions from our survey.

VI. Results

A. Collision Prediction

In this section we selected some representative results of the viability of the application. Figure 7 depicts the performance of both the proximity index (for non-collision trajectories) and collision index in the use case corresponding to Figure 4a. The collision is detected up to 5 seconds and 9 meters in advance: time and distance enough to allow the vehicle to correct the trajectory.

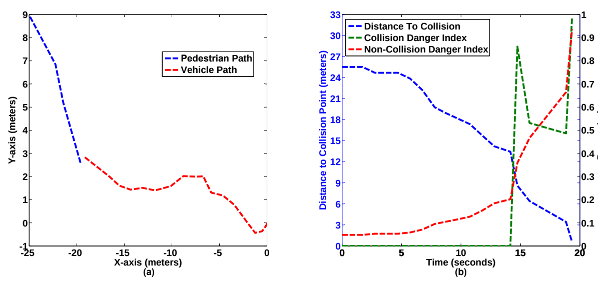

Fig. 7. Reconstruction of the movement of the vehicles (left). Results given by the app, with the collision detection index in green and the proximity in red. The distance between vehicles is shown in blue (right).

Figure 8 shows the results of the tests in the vehicle obstacle detection scenario also regarding the comparison with the on-board sensing devices (5). Due to the obstruction, these sensors were not able to detect the vehicle with the anticipation of our developed system. In this example, our system detected the vehicle approaching 5 seconds earlier than the in-vehicle sensing devices, thusly proving the advantages of the technology and the viability of the application proposed in this paper. Both indices were included in the figures to allow full understanding of the results. Results of Figure 8 also show that once the trajectories are not colliding, at the 20th second, the proximity index is still high, although there is no risk of collision as stated by the collision index.

B. User Evaluation

Figure 9 shows the results regarding the use of the system for visual road awareness with notifications about A) Autonomous Driving (AD) and about B) Vehicle Approaching (VA). The answers ranged from 1 (not at all) to 5 (absolutely). Results indicated that perceived road safety and awareness of a potential dangerous situation was considered high when the user was notified by the system. The majority

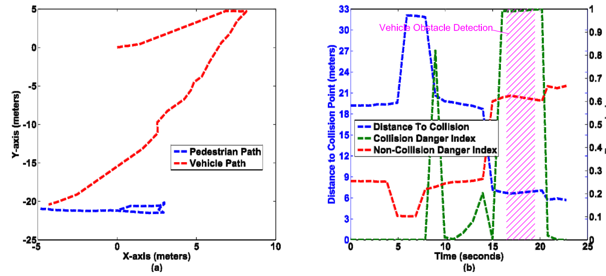

Fig. 8. Reconstruction of the movement of the vehicles (left). Results regarding the detection of the sensors (camera and laser) highlighted in pink (right).

of the participants perceived the application as very useful and agreed that a message notifying that an autonomous vehicle was present in the road could help them to develop a trust in the autonomous vehicle technology as they realized it was as safe as a conventional vehicle. One user stated that "if he had the application, he would always be interacting with his phone without paying attention at all to the road".

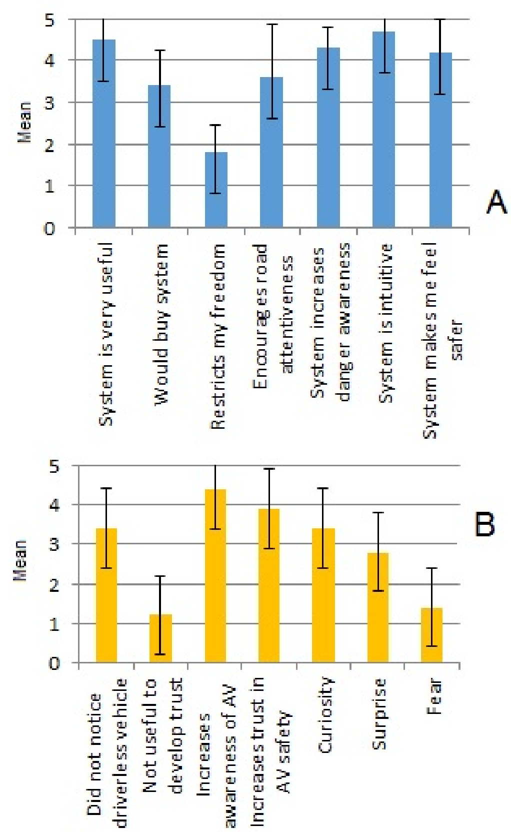

Fig. 9. Answers ranging from 1 (not at all) to 5 (absolutely) regarding the subjective evaluation of the proposed system with A) manually-controlled vehicle approaching and B) autonomous vehicle approaching

VII. Conclusion and Future Work

This paper presented a collision prediction warning algorithm based on P2V and V2P communication technologies.

The obtained results showed a good performance and high detection rate, as well as high user satisfaction derived from the interaction with the system. The provided tests proved the advantages given by the approach from three different perspectives. First, the viability of the application for vulnerable road user protection. Second, the advantage for the driver in the vehicle as the collision prediction algorithm detects an approaching vehicle in advance. Finally, the high usability and user satisfaction provided by the application. We found it particularly remarkable that some subjects stated that they would ignore the traffic risks and rely completely on the warnings of a mobile application. Considering these responses, and because our tool aims at fostering road safety, in future work we will address research questions regarding a potential counterproductive use of the application.

An unfavorable characteristic of the application is its dependence on GPS technologies. Therefore, future approaches will address the localization enhancement of both pedestrians and vehicles by means of estimation filters to ensure a more accurate estimation of the localization through a higher calculation frequency.

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