Pedestrian Safety Systems Using V2V Assisted Emergency Braking System

Abstract

This project explores the use of Vehicle-to-Vehicle (V2V) Communication technology to increase pedestrian safety by assisting the on-board emergency braking system of a vehicle with information about the environment from other vehicles, which otherwise cannot be obtained by the vehicle's own sensors. We build a V2V system that communicates the information necessary for the emergency braking system that is available in the PreScan Simulator, and then test it by building real-world scenarios where the use of V2V systems can help prevent vehicle collisions with pedestrians.

Abbreviations used: V2V – Vehicle-to-Vehicle Communication/Systems, TIS – Technology Independent Sensor (Radar/Laser), PPS – Pedestrian Protection System (Emergency Braking System), TTC – Time to Collision, TRX – Transceiver.

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Introduction

As vehicles become more technologically advanced, the opportunities for car manufacturers will continue to grow. Recent trends have seen virtual assistants, gesture controls, and facial recognition introduced into upcoming vehicles. One such technology that has emerged in the field is vehicle-to-vehicle (V2V) communication using Dedicated Short-Range Communications (DSRC). This two-way short range wireless technology provides local message transmission at near instantaneous network connectivity. DSRC is capable of providing secure, reliable communication while allowing for very high data transmission rates, even in vehicles traveling at high speeds, due to a designated licensed bandwidth [1]. The communications use the 5.850-5.925 GHz band, which has been allocated by the FCC. Due to its relatively clean operating environment and few preexisting users, this band allows for an interference-free zone of communication [2].

The DSRC technology borrows characteristics from ad hoc networks, such that the network created between the vehicles is decentralized, meaning it does not rely on any existing infrastructure to assist in communication [3]. This allows for vehicles to communicate by transmitting and receiving data from other vehicles in their local vicinity, which, in essence, creates a mobile distributed system.

Using V2V communication gives vehicles an advantage over systems that just use ultrasonic sensors, cameras, or radar. This advantage comes from a higher range of visibility and the ability to see objects, pedestrians, or vehicles that may not be detected without assistance from V2V communication. V2V equipped vehicles are able to transmit basic safety messages (BSM) on a vehicle's speed, heading direction, braking status, and location. In addition, vehicles can send data on objects or pedestrians that are detected to be potential crash hazards [2]. As messages are received by vehicles, the data is processed in order to determine if a crash could occur. Vehicles may also send warning message to vehicles if a collision is imminent.

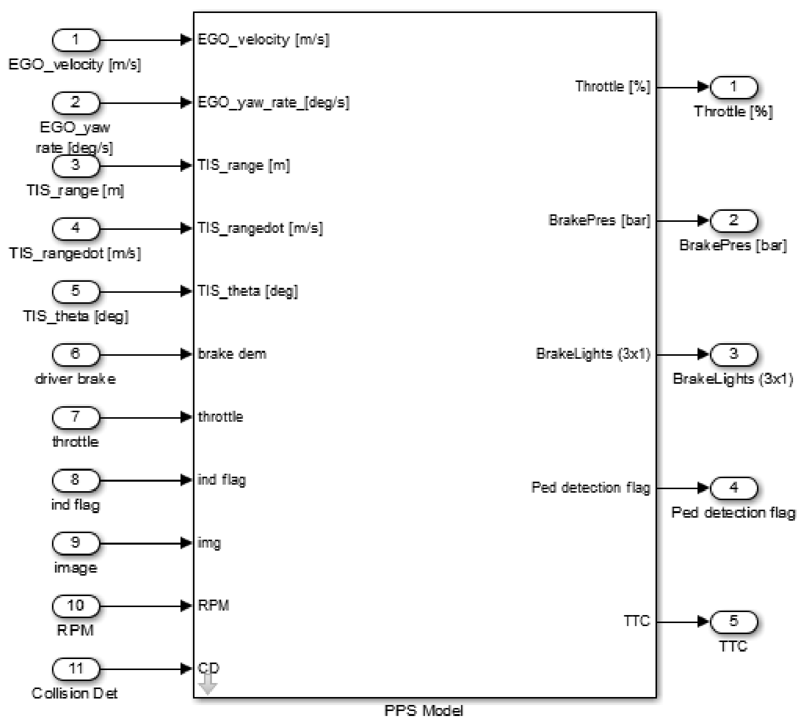
With DSRC, vehicles are able to utilize a number of applications with V2V communication that can assist in reducing crashes, and ultimately deaths. Two such applications that would not be possible without V2V communication are Intersection Movement Assist (IMA) and Left Turn Assist (LTA). In the National Highway Traffic Safety Administration's (NHTSA) analysis, just these two applications could reduce collisions, injuries and deaths by 50 percent, on average. This could mean up to 400,000 to 600,000 less crashes, 190,000 to 270,000 less injuries, and 780 to 1,080 less deaths each year [2]. Additional applications include Emergency Electronic Brake Light (EEBL), Forward Collision Warning (FCW), Blind Spot Warning and Lane Change Warning (BSW) and Do-Not-Pass Warning (DNPW).

Our project delves into the use of V2V communication technology to enhance the capabilities of the on-board systems. We explore ways to use the data produced by the on-board sensor systems and process it in a way that is suitable for transmission through V2V communication, which the other vehicles can receive and use to alert themselves of dangers that lie out of their visibility range. We also explore how to adapt this data to be used by existing emergency braking systems for decision making. Finally, we test our system by simulating various real-world situations that would benefit from the use of V2V technology using PreScan Simulator.

PreScan is a simulation platform used for development of Advanced Driver Assistance Systems (ADAS) and active safety. It has built-in modules for radars, laser, cameras, and GPS, which are designed with real world specifications and working mechanisms of these technologies. The software is primarily used to simulate scenarios with a wide variety of vehicle-based technologies, such as Lane Keeping Assist, Emergency Braking Systems, and V2V communication systems. It provides an intuitive graphical user interface (GUI), which can be used to build and modify scenarios and upon parsing, creates a MATLAB Simulink module file which can be used to configure the lower level details [4] [5].

Design Details

Our scenarios are designed using PreScan and MATLAB Simulink. All active vehicles in our scenario are equipped with a TIS sensor (radar/laser), which is used to detect any objects within its Field-Of-Vision (FOV). We equip the vehicle, which is on-course to collide with the pedestrian, with a Pedestrian Protection System (PPS). The PPS takes in data from both the TIS sensor and the camera sensor, and determines if the car is going to collide with any of the objects detected. If the PPS finds that the vehicle is going to collide with an object, it then continuously calculates the Time-To-Collision (TTC) with the object and performs image processing on the camera input to determine if the object is a pedestrian. The PPS has two TTC thresholds defined. When the calculated TTC with the object falls below the first threshold the PPS sends out a driver warning to alert the driver to take action. If the TTC with the object falls below the second threshold, and the driver has not taken any action or the action taken has not resulted in avoiding the collision, then the PPS sends out a Full Braking Action signal, which causes the vehicle to apply 100% brake until it comes to a complete stop. Every vehicle that is actively involved in the scenario is equipped with a Vehicle-To-Vehicle Transceiver (V2V-TRX), which is used by the vehicle to transmit and receive any information from other vehicles nearby. While the PPS module, by design, is not configured to use V2V information, we have designed our V2V systems to parse the data to adapt to the input types of the PPS [4].



Pedestrian Protection System – MATLAB Simulink Module/Function Block

In addition to these modules provided by PreScan, we have designed some modules of our own to process the data being sent through the V2V-TRX and perform necessary transformations and calculations.

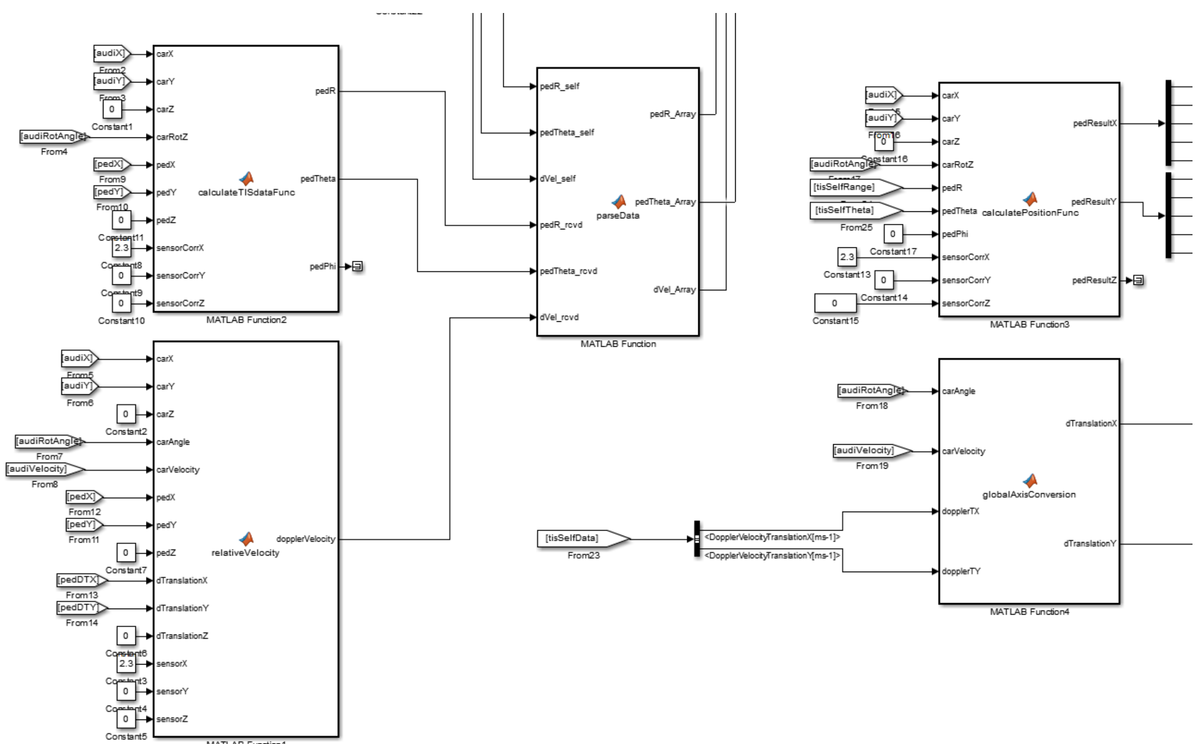
1. **calculatePositionFunc** – This function block takes input from the vehicle's TIS sensor, specifically the distance and angles of the objects detected and also takes the vehicle's position data as input to calculate the position of the objects in a global coordinate system. The output of this block is fed to the transmitter part of the vehicle's V2V-TRX.

2. **globalAxisConversionFunc** – This function block takes input from the vehicle's TIS sensor, specifically the Doppler translations in the X and Y axes of the objects detected, and also takes the vehicle's orientation angle and velocity as input to convert the local coordinate system values to the global coordinate system. The output of this block is fed to the transmitter part of the vehicle's V2V-TRX.

3. **calculateTISdataFunc** – This function block takes input from the receiver part of the V2V-TRX, specifically the global object position data, and also takes the vehicle's position data as input to calculate the position of the objects in the car's own local orthogonal coordinate system (local reference frame).

4. **relativeVelocityFunc** – This function block takes input from the receiver part of the V2V-TRX, specifically the global doppler translation data of the objects, and also takes the vehicle's position, orientation angle, and velocity as input to calculate the relative velocity of the objects detected in the car's own local orthogonal coordinate system (local reference frame).

5. **parseDataFunc** – This block takes the output from calculateTISdataFunc and relativeVelocityFunc and converts it to suitable format which is then fed as input to the PPS block.



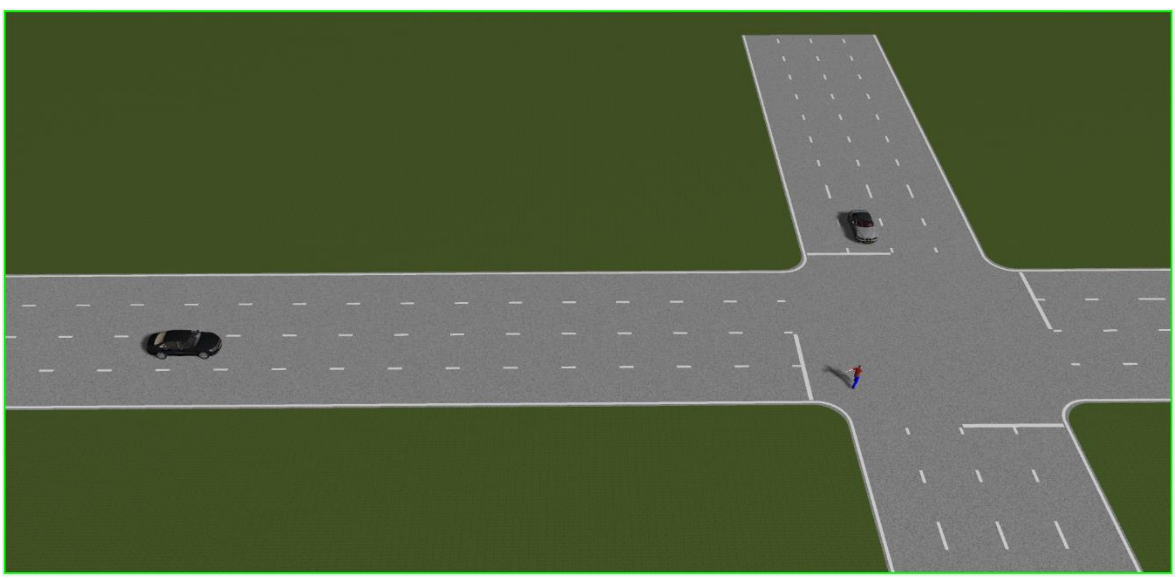
Function Blocks Designed for Our Application

Implementation Details

For our experiments, we have added a few constraints to either limit random behavior or for simplicity. Through many experiments we noticed that the image processing of the PPS that determines whether the object that the vehicle is about to collide with is a pedestrian, is not consistent with its outcome when subjected to small changes in the scenario. Due to a lack of proper explanation as to why this occurs in the documentation, we have modified the PPS module to bypass the pedestrian detection stage and treat every object that the vehicle is going to collide with in the same way. For position related data, we have chosen to ignore vertical angle and axis values in our calculations as all our scenarios take place at a level surface, with no irregular changes in the height. This also helps us in reducing the data being sent through the V2V-TRX as the module has limitations placed on how much data can be sent in one signal transmission. With the configuration we designed for our scenarios, we are able to send all the required data to calculate position of 5 objects. Thus, our scenarios are designed to make sure that any single TIS sensor does not pick up more than 5 objects in its FOV.

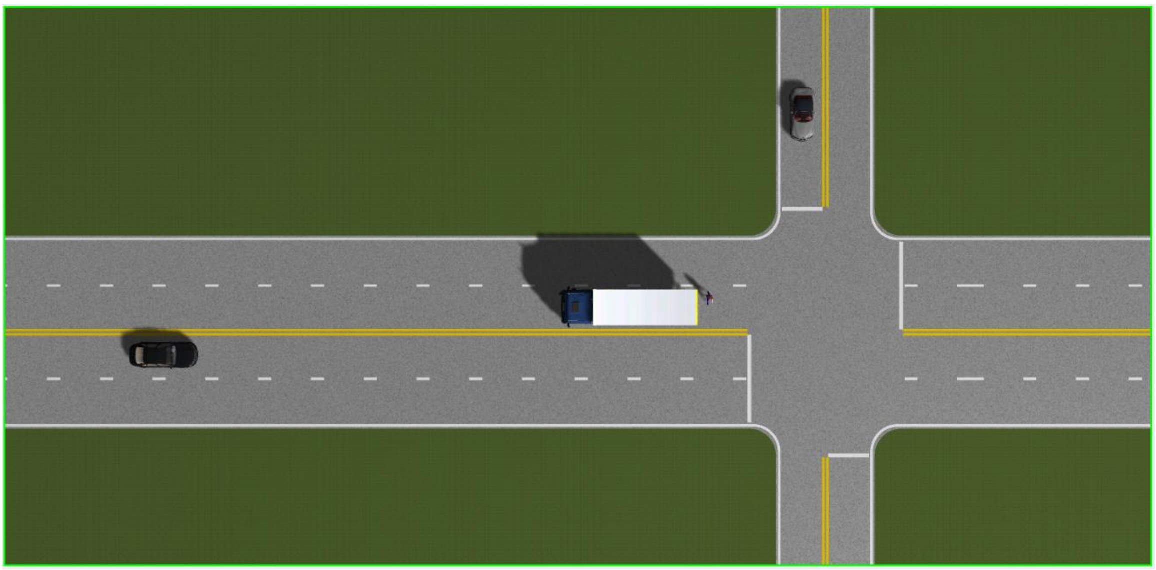
We have designed four scenarios for our project, with each scenario having its own objective, and some scenarios split into multiple cases.

1. **Scenario 1** – This is a Blind Test Scenario. To test our systems, we needed to come up with a scenario where the vehicle's on-board sensor does not influence the outcome of the situation in any way. From a theoretical point of view, if our systems are designed properly then the vehicle that is on-course to collide with an object, or pedestrian, should be able to stop itself using PPS and the object data from the other vehicles without having any kind of object detecting sensors on-board. Therefore, we designed a situation where the vehicle that is on-course to collide with the pedestrian is "blinded", meaning it has no TIS sensor on-board to detect any objects, and is entirely reliant on the object detection data sent from the vehicles in its vicinity. To keep things simple, we have only one other vehicle in this scenario, which is equipped with a TIS sensor and sends the object position data through a V2V message. We tested the outcome of this scenario and found the maximum delay that is possible in receiving and processing the message before the collision becomes unavoidable.



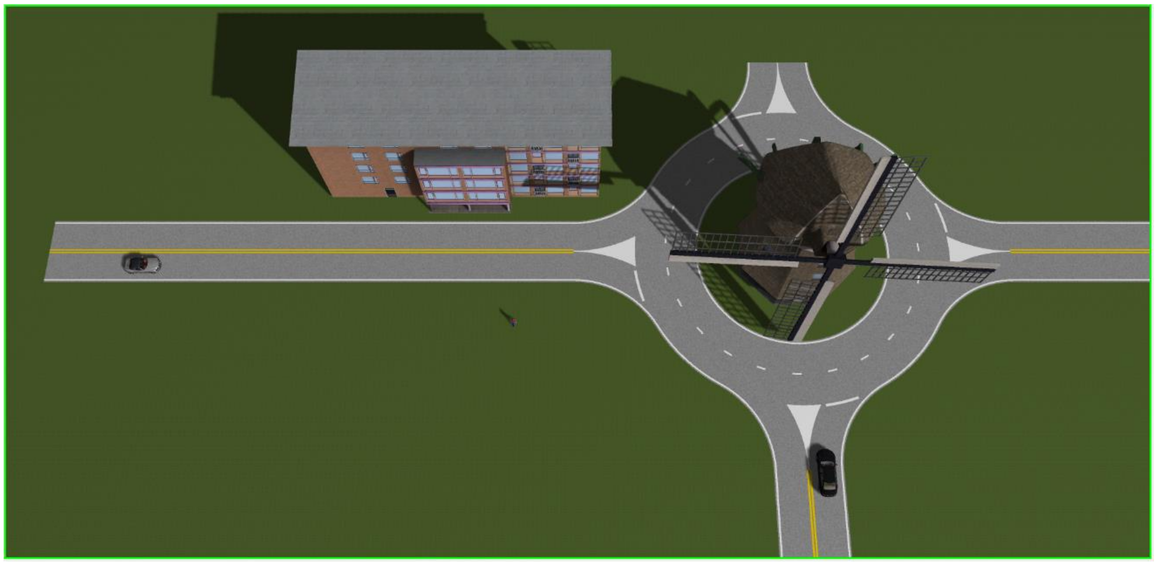
Scenario 1: Blind Test

2. **Scenario 2** – This is a Blocked Vision Test scenario. In this scenario, the vehicle on-course to collide with the object has all on-board sensors required by PPS, and in-addition, it also uses the data sent from the vehicle stopped at the intersection. The pedestrian (object) walks into the path of the vehicle from behind a broken-down truck, which is blocking the on-board sensors of the vehicle from detecting the pedestrian. The vehicle that is stopped at the intersection can pick up the pedestrian's position and movement through its TIS sensor and transmit the data. The scenario is configured, such that, by the time the on-coming vehicle picks up the pedestrian on its own sensors it is too late for it to avoid the collision, and thus is reliant on the data sent from vehicles around it. We test this scenario to see the difference between the vehicle relying on the data from its own sensors vs. the vehicle using data both from its own sensors as well as from other vehicles. We then test the scenario to see how much delay in transmission is accommodable before the collision becomes unavoidable.



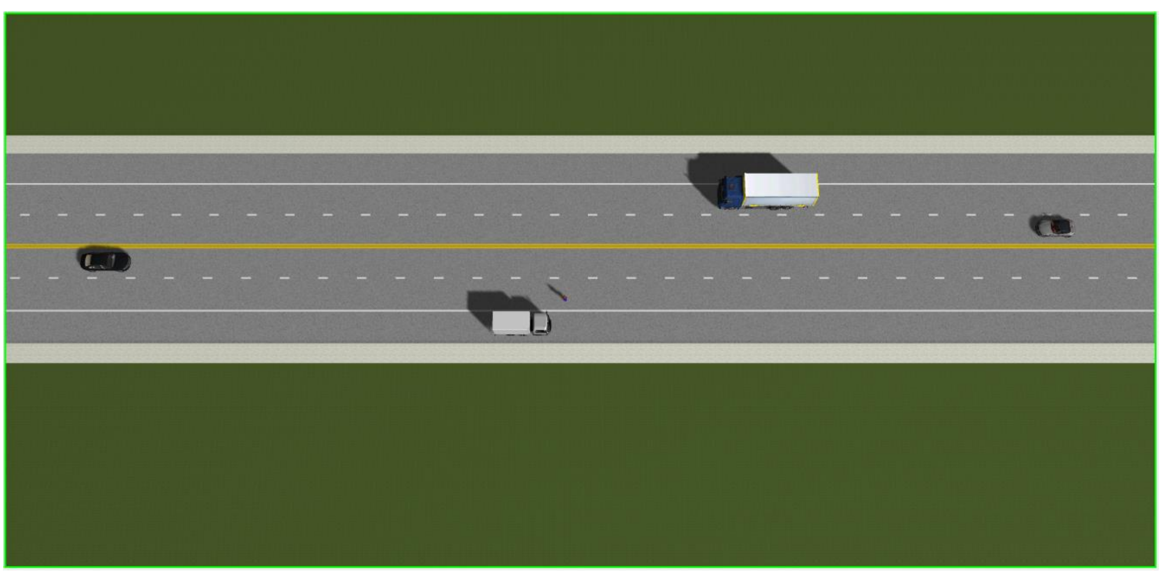
Scenario 2: Blocked Vision Test

3. **Scenario 3** – This is a Roundabout scenario, where we test the vehicles ability to use the data sent through V2V messages to determine if a collision is imminent while making a turn. This is an important situation to test, as determining a possible collision while the vehicle is making a turn involves considering an extra parameter, which is the yaw-rate (turn rate of the vehicle in degrees/sec), as compared to the standard straight path collision determination. We test this scenario with the vehicle relying only on its on-board sensors vs. using the V2V message data sent by other vehicles.



Scenario 3: Roundabout Scenario

4. **Scenario 4** – This is a Faulty On-Board Sensor scenario, where the vehicle that is on-course to collide with the pedestrian has a faulty on-board TIS sensor and is calculating the position and other data associated with the detected objects with an impermissible error. Thus, the PPS of the vehicle is reliant on information received through V2V message sent by cars in the vicinity to detect any potential collisions. While any end-product released to the market is built with redundancies and fault-tolerance to disable the on-board systems in such a scenario, erroneous values can occur due to visibility and other environmental factors, sensor tampering, or simply some dust on the sensor hardware. In this case, the sensor output is similar to but not necessarily the same as a faulty on-board sensor. Thus, it is important to simulate and test such a scenario. In our experiment, we test this scenario to see if the vehicle is capable of avoiding the collision and also test the delay accommodable in the scenario before the collision becomes unavoidable.



Scenario 4: Faulty On-Board Sensor Scenario

Note that in most of the scenarios described above we have tested for delay. This delay may be associated with a number of factors, including preprocessing, transmission, or processing/decision making. Preprocessing and processing delays can be reduced to a certain extent by using algorithms that make the most efficient use of data and resources. Transmission delay has many factors, such as distance of separation between source and destination of message, obstacles in the path of transmission blocking/absorbing or reflecting the signals, or signal attenuation, which are unavoidable. However, predictive algorithms can be designed to compensate for the delay by predicting the position of the pedestrian using known trajectory of pedestrian and vehicle. For the scope of our project, we have grouped the different kinds of delays to one overall delay, which is realistic in most cases, and then tested our scenarios to determine the maximum accommodable delay before collision becomes unavoidable.

Results and Discussion

1. **Scenario 1 – Blind Test:** Vehicle Speed: 68 kmph

Case 1: No V2V message	
Collision	Yes
Speed at the time of Collision	66 kmph
Case 2: V2V message with no delay	
Collision	No
PPS Ego Vehicle Parameters	
Collidable Object Detected – TTC	1.1 secs
Driver Warning – TTC	1.1 secs
Full Braking – TTC	0.9 secs
Case 3: V2V message with added delay	
Collision	Yes
Delay added	0.25 secs
Speed at the time of Collision	26 kmph
PPS Ego Vehicle Parameters	
Collidable Object Detected – TTC	0.8 secs
Driver Warning – TTC	0.8 secs
Full Braking – TTC	0.8 secs

In this scenario the on-coming vehicle has no TIS sensor of its own. In case 1, the vehicle has no information about the pedestrian, and thus collides with him at a high speed. In case 2, the vehicle gets information about the pedestrian from the other vehicle in the vicinity and uses the information to brake and avoid the collision. Thus, we have demonstrated that the system we have developed is successfully carrying out its intended functions. In case 3, we find that the overall delay in decision making process has to be less than 0.25 secs or 250 ms to avoid the collision.

2. **Scenario 2 – Blocked Vision Test**: Vehicle Speed: 54 kmph

Case 1: No V2V message	
Collision	Yes
Speed at the time of Collision	38 kmph
PPS Ego Vehicle Parameters	
Collidable Object Detected – TTC	0.4 secs
Driver Warning – TTC	0.4 secs
Full Braking – TTC	0.4 secs

Case 2: V2V message with no delay	
Collision	No
PPS Ego Vehicle Parameters	
Collidable Object Detected – TTC	1.3 secs
Driver Warning – TTC	1.3 secs
Full Braking – TTC	0.9 secs
Case 3: V2V message with added delay	
Collision	Yes
Delay added	0.75 secs
Speed at the time of Collision	16 kmph
PPS Ego Vehicle Parameters	
Collidable Object Detected – TTC	0.6 secs
Driver Warning – TTC	0.6 secs
Full Braking – TTC	0.6 secs

In this scenario, we have all the required sensors and systems in the on-coming vehicle. In case 1, the vehicle detects the pedestrian 0.4 secs before collision and is unable to avoid the collision at this point. In case 2, the vehicle uses the V2V information and detects an impending collision and takes preventive measures much earlier, avoiding the collision. Comparing the TTC in the two cases, we can clearly see that the message through V2V makes the difference in saving the pedestrian from being hit by the vehicle. In case 3, we find that the delay in decision making process has to be less than 0.75 secs in order to avoid the collision. We also observe that the speed of collision is much less even if the delay is 0.75 secs, which in real world could make the difference of the collision being non-fatal.

3. **Scenario 3 – Roundabout Test:** Vehicle Speed: 32.5 kmph

Case 1: No V2V message and Case 2: With V2V message	
Collision	No
PPS Ego Vehicle Parameters	
Collidable Object Detected – TTC	0.4 secs
Driver Warning – TTC	0.4 secs
Full Braking – TTC	0.4 secs

In this scenario, we observe that the cases both with and without the V2V message have the same readings. Due to the low speed of the vehicle in the roundabout, and while making the exit turn, there is enough time for the vehicle to use its own sensors to avoid the collision. This outcome remained the same in multiple configurations of placements of vehicle and pedestrians, meaning either the vehicle could avoid the collision using its on-board sensors or the vehicle would collide despite having the information about the pedestrian through V2V message. We determined that this is due to the difference in decision making mechanism of PPS between when the vehicle is on a straight path vs. when the vehicle is making a turn and has nothing to do with the system of sending information using V2V. We did not measure delay in this scenario as the response of the on-board mechanism was on-par with V2V being included.

4. **Scenario 4 – Faulty On-Board Sensor:** Vehicle Speed: 54 kmph

Case 1: No V2V message	
Collision	Yes
Speed at the time of Collision	52 kmph

Case 2: V2V message with no delay	
Collision	No
PPS Ego Vehicle Parameters	
Collidable Object Detected – TTC	1.3 secs
Driver Warning – TTC	1.3 secs
Full Braking – TTC	0.9 secs
Case 3: V2V message with added delay	
Collision	Yes
Delay added	0.75 secs
Speed at the time of Collision	9 kmph
PPS Ego Vehicle Parameters	
Collidable Object Detected – TTC	0.6 secs
Driver Warning – TTC	0.6 secs
Full Braking – TTC	0.6 secs

In this scenario, as demonstrated in case 1, the vehicle on-course to collide cannot rely on its on-board sensor systems due to faulty values which we have simulated by adding random values to the TIS data. In case 2, the vehicle on-course to collide uses the information sent by the other vehicles to avoid hitting the pedestrian. Through this scenario we have demonstrated that even if the vehicle has faulty or skewed data from on-board sensors, we can still use the values sent by other cars. Finally, we find the delay that can be accommodated before the collision becomes unavoidable in case 3. Besides the three scenarios tabulated above, we also tested the same scenario with multiple pedestrians walking into the path of the vehicle in close proximity to each other. While the results did not differ in this particular scenario, it is yet to be tested in other scenarios. The data being sent in a situation such as this would increase due to the TIS creating a different dataset for each pedestrian, which can result in an unnecessary increase in data packet size sent through V2V communication.

Conclusion and Future Work

Through the scenarios simulated in this project, we have demonstrated the effectiveness of having V2V communication systems assisting the on-board emergency braking systems of a vehicle in detecting and avoiding potential collisions. We've also demonstrated that in cases where the V2V messages are delayed to the point where the collision becomes unavoidable, it can still serve to reduce the speed of the vehicle changing the situation from becoming a fatal one. We believe this work serves as proof to NHTSA's analysis that integration of V2V technology can help drastically reduce the number of collisions, injuries and deaths.

While this project sets up a good baseline for use of V2V communication assisted emergency braking system, there is room for improvement and future work using this. As we've noted in the design details section of this report, the PPS system, by design, cannot use V2V data. We believe that developing a new emergency braking system with in-built capabilities to use V2V data can improve the end results significantly. In regard to the Roundabout scenario, the system had issues with predicting collisions when making turns. Integration of path data into emergency systems can help improve the outcome of such scenarios. We've also noted that the data that would potentially be sent through V2V messages could be unnecessarily large in cases where the pedestrians are in close proximity. Adapting existing clustering algorithms, or other grouping algorithms, to such situations can help treat these pedestrians as one big entity rather than multiple individual entities, thus reducing the size of the data being transmitted, and also reduce processing time. Another observation we've made is the matter of trusting the data sent by other vehicles. Since the V2V communication system is an extension of distributed systems and ad-hoc network systems, we can test the different trust models that can be found in such systems and evaluate its application in V2V systems.

Critique

This project has been a great opportunity to work in a new and upcoming field where, relatively speaking, not much work has been done. But, in hindsight, there are a few things we would've done differently. We wish we hadn't spent as much time trying to understand the project work done by TASI and instead focused on building the system on our own as we ended up doing anyways. We've also had a couple of weeks where we did not coordinate with each other's schedule very well which led to very less work being done in those weeks. Other than that, we believe we have carried out this project to the best of our abilities given the challenges we've faced with obtaining and learning the new software from scratch.

References

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