

# **Software Requirements Specification (SRS)**

## **Pedestrian Backup Assist System (PBAS)**

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### **1 Introduction**

Every year, thousands of people are injured or killed in backup rollover accidents [11]. These tragedies disproportionately impact vulnerable populations like young children and the elderly [11]. We propose this Pedestrian Backup Assist System (PBAS) to enhance vehicle safety while backing in order to reduce serious backup collisions. Without PBAS, a driver may not see a small child behind the vehicle in the mirrors or out the windows, leading to a backup accident. Therefore, PBAS provides the driver with a video feed of the scene behind the vehicle, so he or she can better see behind the vehicle. PBAS also automatically detects pedestrians and obstacles behind the car and alerts the driver if the vehicle is close to something with aural and visual alarms, since a combination of both warning types were more effective than either one alone in studies [1, 8]. Additionally, PBAS provides similar auditory alarms outside the vehicle to alert pedestrians that the vehicle is backing, so the pedestrian has a warning that he or she should move to safety. PBAS also provides automatic mitigation if a backup collision is imminent. Instead of solely relying on the driver, who may be distracted, to brake, PBAS engages the vehicle's braking system to slow the vehicle if a collision is likely and the driver has not taken evasive action.

This document describes the project requirements and software specifications for the Pedestrian Backup Assist System (PBAS). The first section of the document provides a brief introduction to the project and documentation, followed by background information and the product description. Enumerated requirements are found in the third section, and those are modeled and cross-referenced in the fourth section. A demonstration of the system is provided in the fifth section, including the behavior for the scenarios modeled in the earlier section. Finally, references and contact information are provided in the sixth and seventh sections.

#### **1.1 Purpose**

This Software Requirements Specification, or SRS, document is intended to provide a high-level understanding of the PBAS project. It defines the underlying assumptions, constraints, and requirements for the system as the basis for development. This document

is intended to promote consensus among the project stakeholders including clients, customers, management, and the development teams. PBAS is a safety-critical system intended to prevent backup rollover collisions, so it is important that the stakeholders agree upon and understand the system requirements in order to build the desired system that prevents backup rollover accidents and protects those most vulnerable to such tragedies.

## **1.2 Scope**

The Pedestrian Backup Assist System is designed with the intent of preventing injuries and fatalities due to backup rollover collisions. PBAS is part of an embedded automotive system. As such, it is constrained to the onboard hardware and software capabilities of the intended vehicle(s).

PBAS includes obstacle detection, warning, and backup collision mitigation features whenever the vehicle is in reverse gear. However, the driver may manually override the Mitigation system if desired. Whenever the vehicle is in reverse, the surroundings behind the vehicle are displayed for the driver in order to help avoid obstacles, including children who may be difficult to see in the rearview or side mirrors. PBAS provides auditory and visual warnings if obstacles are detected behind the vehicle. If a collision is likely, the system will automatically engage the braking system to mitigate this risk. This system has security measures in place to ensure it is only activated by the driver in reverse gear and never by an external source in order to protect the safety of the vehicle occupants and their surroundings.

## **1.3 Definitions, acronyms, and abbreviations**

This section defines any keywords, acronyms, phrases, or abbreviations that are referenced throughout the rest of the document.

<b>Pedestrian Backup Assist System (PBAS)</b>	The safety-critical system defined in this document including the set of hardware and software components involved in detecting and mitigating rollover backup collisions.
<b>Infotainment System</b>	A subsystem with a touchscreen display in the center of the dashboard for the driver or passenger to interact with the vehicle software systems and hardware components.
<b>Software Requirements Specification (SRS)</b>	This document outlining requirements, assumptions, and constraints as interpreted by the development team.
<b>Braking System</b>	A subsystem of the vehicle that other subsystems can use that

	can control the vehicle's brakes, including the Anti-lock Braking System (ABS) to safely brake in various environments.
<b>Driver</b>	The user of the system, who is assumed to be legally authorized to operate the vehicle, but may not have any special knowledge of the system.
<b>Pedestrian</b>	A person (who may be walking, but need not be) who is behind the rear of the vehicle.
<b>Obstacle</b>	Any object (human, pedestrian, car, or otherwise) larger than $0.3 \text{ m}^3$ located behind the rear of the vehicle that can be moving or stable.
<b>Detection</b>	The first active stage of backup collision avoidance. In this stage, the camera and radar sensors collect data from the rear of the vehicle and pass the data to the onboard computer. The computer analyzes the data and calculates a risk assessment for whether or not an obstacle is present behind the vehicle. The result of the obstacle detection and risk assessment is either: <i>None</i> if no obstacle/pedestrian is detected or <i>low, medium, or high</i> if an obstacle (or pedestrian) is detected.
<b>Warning</b>	The second stage of backup collision avoidance. Warning occurs when an obstacle is detected behind the vehicle (the risk is <i>low, medium, or high</i> ). PBAS provides auditory and visual cues of the detected obstacle's proximity and direction inside the vehicle for the driver, so he or she can brake to prevent an accident. PBAS also provides auditory warnings outside the vehicle so pedestrians behind the vehicle know the car near them is reversing, to prompt them to move to safety.
<b>Mitigation</b>	When the system detects that a backup collision is imminent given the current trajectory and the obstacle detection, PBAS automatically engages the braking system to limit or prevent impact.

## **1.4 Organization**

After the introduction in Section 1, the rest of the document is organized as follows:

Section 2 provides an introduction to the PBAS project including background and context for the product. Section 2 also describes the major functionality of PBAS, assumptions about the intended product users, environment, and dependencies, hardware and software constraints, and a discussion of potential features to be added in the future, which are currently out of scope.

Section 3 provides a list of enumerated requirements. The first section describes desired high-level behavior and expected functionality with the functional requirements. The second section describes requirements for quality, security, and performance assurance, as well as constraints imposed by the vehicle with the non-functional requirements.

Section 4 models the requirements from the previous section. The models include a use case diagram, domain model, sequence diagrams, and a state diagram. The use case diagram and descriptions show the high-level services of the system. The domain model shows the key entities and how they are connected using class-diagram notation. Sequence diagrams show how objects interact with each other in the course of normal and abnormal scenarios the system will face. Finally, a state diagram shows the states of components and the overall system and their transitions between these states.

Section 5 shows a rapid prototype for how the system behaves in the scenarios described in the above section.

Section 6 provides credit to the resources referenced in making this system.

Section 7 provides a point of contact for further information about this project.

## 2 Overall Description

This section gives a high level description of the PBAS project. Next, we describe the components and system boundaries. This section also highlights the flow of the system with a Data Flow Diagram (DFD) and the functions and goals with a KAOS goal model. Finally we overview the assumptions made about the system user and constraints.

### 2.1 Product Perspective

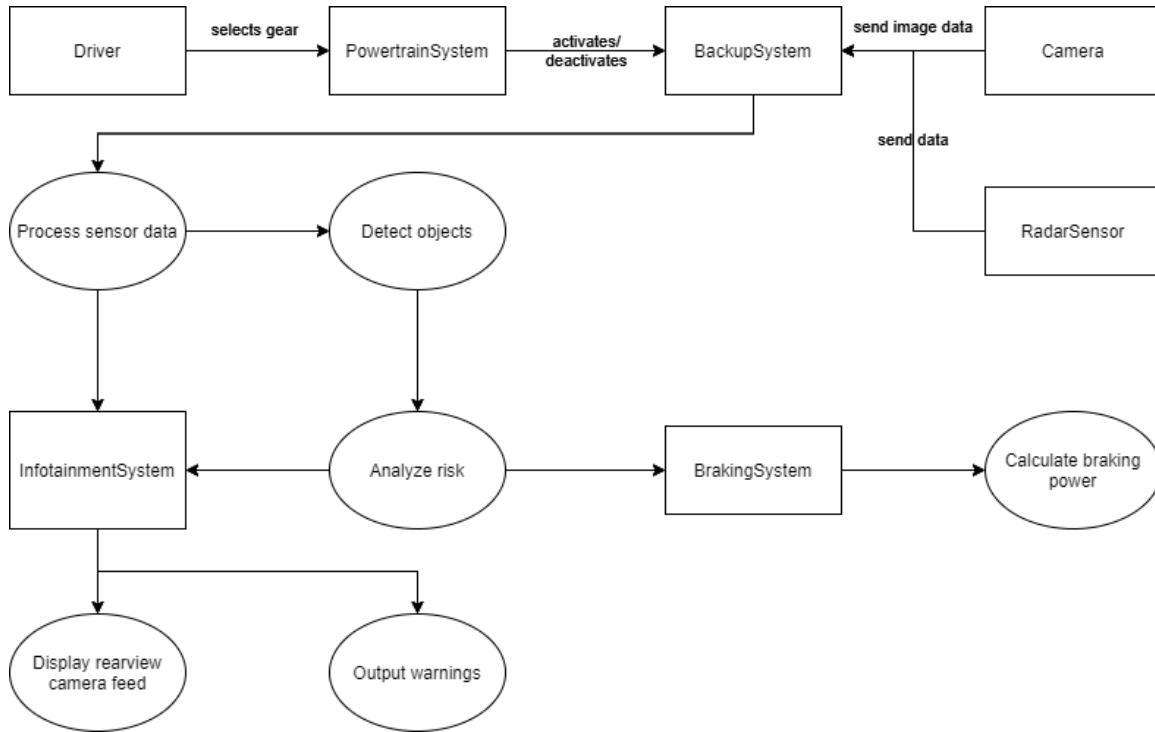
PBAS is designed to mitigate the thousands of annual injuries and deaths related to vehicles colliding with pedestrians [11]. The system refers to the set of camera and radar sensors, software and hardware components that process data and perform computations, infotainment display system, and braking system for mitigating backup collisions. PBAS works in three stages: detection, warning, and mitigation. Detection is the first active stage of backup collision avoidance. In this stage, the sensors pass data to be analyzed by

the onboard computer for obstacles behind the vehicle. Warning involves alerting the driver through audio and visual cues of the detected obstacle's proximity and direction. Mitigation occurs when the system detects that a backup collision is imminent given the current trajectory, therefore activating the braking system to limit or prevent impact. These mitigation measures are active as the default setting; however, we provide driver override to deactivate the Mitigation system.

As an overview, the sensors are found on the sides and rear of the vehicle, with an ultrawide-view camera in the middle of the rear tailgate, omni-directional cameras on the rear corners of the bumper, and directional cameras in the side mirrors as backup in case the primary cameras at the rear fail. Three radar sensors are spread throughout the rear bumper. More details of the sensors can be found in the use case descriptions and enumerated requirements.

An infotainment display system with a touchscreen and connected to the speakers is located in the center of the dashboard for the driver and passenger to view information and adjust vehicle settings. The infotainment display screen will show the composite video of the scene behind the vehicle from the cameras and any obstacles will be highlighted on this display. The driver can also enable or disable the backup-rollover Mitigation system through the vehicle settings using the settings screen of the infotainment display system. The auditory warnings provided by this system also use the infotainment system to play warning tones through the vehicle's speakers. The features of the system include collecting data from the sensors, processing and analyzing the data, providing appropriate visual and audible warnings based on the obstacle detection and analysis, and employing the braking system to mitigate collisions. The system is active if and only if the vehicle is in reverse gear.

The data flow diagram below in Figure 1 shows the DFD for the PBAS system. The DFD indicates how information flows throughout the onboard vehicle subsystems. In the DFD, the rectangles indicate actors or entities, the arrows denote the data and how data is transformed, and the ovals are processes that the data goes through.



**Figure 1:** The DFD depicts how information flows through the vehicle and PBAS subsystem. The rectangles represent actors/entities, the arrows represent data, and the ovals represent processes that transform the data. First, the driver puts the vehicle in reverse that activates PBAS. Once activated, the camera and radar sensors send data to PBAS. This data is processed for obstacle detection and risk assessment. If obstacles are detected, the infotainment system warns the driver and pedestrians behind the vehicle. At the same time, if the risk of backup collision is high, PBAS engages the braking system to mitigate the accident.

## 2.2 Product Functions

The high-level goal of PBAS is to avoid collisions and serious injuries while backing. PBAS is automatically activated when the driver puts the vehicle in reverse. This begins with activating the camera and radar sensors in order to detect obstacles behind the vehicle. If an obstacle is present, a backup collision can be avoided by the driver braking, the obstacle/pedestrian moving, or the system braking. Serious injury from backup collisions can be avoided by constraining the speed of the system while in reverse, as well as having automatic braking with the Mitigation system using the vehicle's braking system.

For the driver or pedestrian to take action, the system should carry out the goal of warning the driver about the obstacle or the pedestrian about the imminent, reversing

vehicle. This is the warning stage, where PBAS uses the infotainment system to provide auditory and visual cues to the driver and pedestrians.

If the driver or pedestrians do not take action to prevent a backup collision, PBAS mitigates the collision by automatically engaging the braking system.

The KAOS goal diagram below in Fig. 2 shows how the high level system goal breaks down to specific, achievable goals (parallelograms) to be conducted by the actors/entities/hardware components (hexagons). Arrows connected by the blue circles denote AND connections, and single arrows without blue circles denote OR connections.

The rest of the goals are broken down into smaller components until the sub-goals can be discharged to an agent to be accomplished (ex. a subsystem within the vehicle, like the BrakingSystem, or an actor, like the Driver).

**Driver:** The driver activates the PBAS by putting the vehicle in reverse gear with the PowertrainSystem. The driver deactivates PBAS by shifting out of reverse.

**PowertrainSystem:** The system shifts gears and activates PBAS if and only if the vehicle is in reverse gear.

**Sensors and Cameras:** The camera and sensors shall be turned on when the car is started and begin transmitting their signals to the backup system's processing unit for obstacle analysis and displaying the scene behind the vehicle.

**BackupSystem:** The system shall coordinate, process, and analyze the inputs from the Cameras and RadarSensors. The system shall analyze the risk of the obstacles. The risk assessment includes determining the location and proximity of the obstacle relative to the vehicle and the vehicle's trajectory and categorizing the obstacle as *none*, *low*, *medium*, or *high* risk.

**Warning System:** The warning system shall notify both the driver and the pedestrian of a potential backup collision with auditory and visual alarms based on the risk assessment for the detected obstacle(s)/pedestrian(s). The composite video of the surroundings shall be displayed in the InfotainmentDisplay.

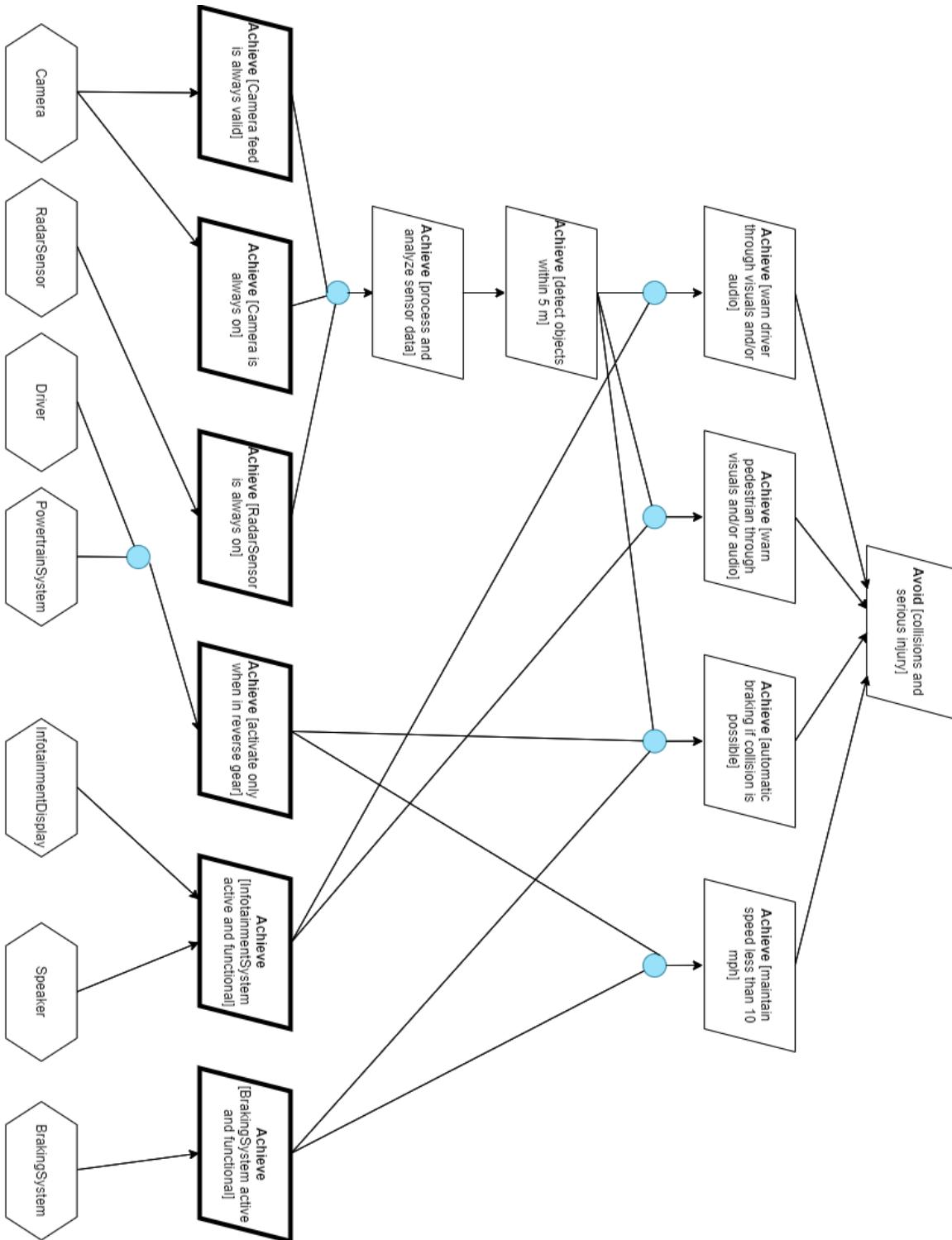
**Mitigation System:** Based on the risk assessment from the BackupSystem, if the risk of an obstacle being hit is high, then the Mitigation subsystem shall intervene to prevent the collision by engaging the braking system to automatically apply the brakes and bring the

vehicle to a halt. Once the backup system determines no risks are present the Mitigation subsystem releases the brakes.

**BrakingSystem:** The BrakingSystem slows the vehicle based on the driver pressing the brake pedal or signal from the Mitigation system.

**InfotainmentDisplay:** The infotainment display shows the scene of the rear of the vehicle and any warnings from the backup system.

**Speaker:** Internal and external speakers provide auditory warnings to the driver and pedestrians based on the risk assessment by the backup system.



**Figure 2:** A high-level KAOS goal diagram for the PBAS. This diagram shows the decomposition of the goal of avoiding collisions and serious injury while backing. The driver, pedestrian, or PBAS can act to prevent backup collisions and injuries. PBAS is active if and only if the driver shifts the vehicle into reverse gear. When the system is

active, PBAS uses the braking and powertrain systems to limit the speed of the vehicle to prevent serious injury. PBAS uses the camera and radar sensors to detect obstacles behind the vehicle and alert the driver and pedestrian through visual and auditory alarms with the InfotainmentDisplay and speakers. The driver could apply the brakes, or the pedestrian could move out of the way. Otherwise, PBAS automatically engages the braking system to prevent backup collision injury.

### **2.3 User Characteristics**

*The driver* refers to the user of the system, who is assumed to be legally authorized to operate the vehicle. The driver may not have any special knowledge of the system. It is assumed that the driver knows how to drive the vehicle and will respond to the warnings displayed on the InfotainmentDisplay screen and/or the auditory warnings played over the speakers. Any messages/warnings provided to the driver by the system should be clear such that anyone who drives the vehicle can understand them without any kind of training or knowledge of the system.

### **2.4 Constraints**

To ensure maximum safety, we define global, system invariants. Invariants must hold regardless of the environment, state of the system or other onboard system, these requirements must always hold. These requirements state that the system shall:

1. Operate in any weather condition (1.3).
2. Be active if and only if the vehicle is in reverse gear (1.8).
3. Be constrained to moving back with a speed of less than 10 mph (1.9).
4. Be activated any number of times within the 5-year warranty period (2.1.4).
5. Not be activated by any remote means (2.4.1).

Furthermore, the primary objective of the PBAS is to prevent injuries; therefore, requirements related to detecting obstacles, warning the driver of a potential collision, and braking to limit impact are the highest priority. Following the primary requirements directly related to injury prevention, our next highest priority is security and preventing unauthorized access of the system. Injuries may result if the system were to be hijacked by malicious actors; therefore, including security as a focus from the beginning is important for fulfilling the goal of preventing injuries. Our lowest priorities are the biometric-based awareness verification system and the self-cleaning mechanisms for the cameras, since the main function of the system of detecting and preventing backup collisions can be fulfilled without these additional functionalities. All other requirements are of medium priority.

## ***2.5 Assumptions and Dependencies***

We acknowledge the threat of uncertainty in this safety-critical system, including variable outdoor environments, hardware reliability, software reliability, and human unpredictability. The environment in which the vehicle operates varies, including changes in lighting, weather, and road conditions that the system must be able to handle to maintain acceptable behavior. The backup-rollover system must be able to operate during the day and at night with low light, which could diminish camera effectiveness. Additionally, poor weather including heavy fog or precipitation may also impede the cameras.

To accommodate changing lighting and weather conditions, we rely on a combination of self-cleaning cameras and radar sensors that are less impacted by lighting. Additionally, road conditions may change. For example, in cold climates, ice on the road may lessen the effectiveness of the braking system as our form of backup-rollover mitigation. The Mitigation subsystem should be able to account for this kind of traction loss to prevent injuries even in these adverse weather and road conditions. Success of this system also hinges on the dependability of hardware, including sensors, the display screen, and braking system. If the camera or radar sensors are to fail or break, then the system may not be able to reliably detect obstacles or mitigate collisions, which poses a safety risk. Therefore, we have redundant sensors and do not rely on a single sensor/failpoint for decision making to reduce this risk.

Other components of the hardware in this system are other parts of the vehicle including the InfotainmentSystem and BrakingSystem. For the purpose of warning the driver, it is possible that the InfotainmentDisplay may fail, which would make it more challenging for the driver to know of obstacles behind the vehicle without the video display. If the brakes fail, then the Mitigation system will fail since the Mitigation mechanism relies on working brakes. The other hardware involved with data transfer and processing in this system must also be sound to accurately detect obstacles, warn the driver (and pedestrians behind the vehicle, when possible), and mitigate collisions.

The software of the system must also be safe and reliable. Bugs in the code or in the obstacle detection and analysis algorithms or interactions with other onboard systems could cause the system to fail to identify obstacles, provide a warning, or prevent a collision. The software must remain safe and reliable throughout its lifetime, from implementation to patches and updates. Finally, humans continue to be a source of uncertainty, including the driver inside the vehicle and anyone behind the vehicle. The driver or vehicle owner may choose to disable the Mitigation system in the settings or errantly override the Mitigation system, presenting a safety risk. Other humans in the

vicinity may be passing behind the vehicle (walking, biking, etc.) suddenly or unexpectedly or change their trajectories unpredictably, but the system must still prevent a collision and injuries, regardless of what the pedestrian does.

## **2.6 Apportioning of Requirements**

To prevent the scope of this system from growing beyond a reasonable size, it has been determined that select features will be revisited in future versions of PBAS. Brief descriptions of such features are listed below:

- Camera overlays on the InfotainmentDisplay, such as lines to indicate direction of vehicle or grids to better indicate distance
- Overhead view of the vehicle with additional cameras for 365 degree view
- Autonomous backup by the system with control over the accelerator
- Heated camera lenses for automatic snow unblocking
- Additional indicators or displays in rear-view or side mirrors
- More specific warning messages such as “vehicle coming from left”

The merits of the above features require future discussion.

## **3 Specific Requirements**

Below are the enumerated functional and non-functional requirements for the PBAS. These correspond to the cross references provided in the above descriptions, and every requirement is covered by at least one use case.

### 1. Functional Requirements

- 1.1. The detection system shall take the radar sensor and camera inputs to analyze the scene behind the vehicle [8]. The scene refers to the composite video from the cameras ranging horizontally from 45° to either side of the rear bumper and 130° from the ground up.
  - 1.1.1. The system shall synchronize the radar and camera inputs for continuity among the various sensors [7].
  - 1.1.2. The scene shall be categorized into one of 4 groups: no risk, low risk, medium risk, or high risk.
  - 1.1.3. **No risk** indicates the system has detected no obstacles behind the vehicle.
  - 1.1.4. **Low risk** indicates the system has detected an obstacle, but it is over 5 m away from the rear of the vehicle.

- 1.1.5. **Medium risk** indicates the detected obstacle is between  $1.5\text{ m}$  and  $5\text{ m}$  away.
- 1.1.6. **High risk** indicates the detected obstacle is less than  $1.5\text{ m}$  away from the vehicle.
- 1.1.7. Obstacles of size larger than a  $0.3\text{ m}^3$  shall be detected whether they are moving or stationary.
- 1.1.8. The system shall be able to detect one or more obstacles at the same time.
- 1.1.9. The system shall detect movement of objects in the scene.
- 1.1.10. Objects moving into the path of the vehicle will be assigned a higher risk value.
- 1.2. The system shall notify the driver of the detected obstacle(s) depending on the risk assessment from the detection system similar to [8]. Auditory and visual cues have been shown to be effective in trials, so both indicators will be utilized in the system when an obstacle is detected [1, 8]. External auditory and visual warnings are also provided for the safety of pedestrians.
  - 1.2.1. If there is no risk, then the video display will be shown on the infotainment display screen in the center of the dashboard.
  - 1.2.2. If there is low risk, then the video will be displayed, highlighting the obstacle and its relative position on screen, and an auditory tone of 65 decibels ( $dB$ ) at 60 beats per minute ( $bpm$ ) shall be played over the speakers through the infotainment system inside the vehicle [14].
  - 1.2.3. If there is medium risk, then the video and obstacle detection will be displayed and the auditory tone shall increase to 90  $bpm$ .
  - 1.2.4. If there is a high risk, then the video and obstacle detection will be displayed, the auditory tone will be 120  $bpm$ , and the Mitigation (braking) system shall be activated along with the flashing of brake lights at the rear of the vehicle to notify pedestrians. The brake strength shall be determined by the braking system based on the risk assessment of the detected obstacle (or highest risk assessment if multiple obstacles are detected).
  - 1.2.5. If an obstacle is detected (risk is not *none*), then the auditory tone shall be played over any sound coming out of the vehicle stereo while the vehicle is in reverse.
  - 1.2.6. The system should have an external speaker which produces tones at a volume of 110 dB [16] and follows the same speed as the internal auditory tone (i.e., 60  $bpm$  for low risk, 90  $bpm$  for medium risk, and 120  $bpm$  for high risk).

- 1.3. The system shall operate in any weather condition.
  - 1.3.1. The primary central, ultra-wide camera and peripheral omni-directional cameras on the rear shall have self-cleaning mechanisms to help with performance in adverse weather conditions. Redundant cameras (in the side mirrors) and radar sensors (on the rear bumper) shall continue to operate even if the primary sensor is obfuscated [5]. The sensors are described in further detail under Hardware Constraints.
- 1.4. The cameras shall automatically clean themselves if particulates land on the lens.
- 1.5. The system shall display a warning message to the driver on the infotainment display screen that PBAS is deactivated if PBAS or the components it uses are not functional while in reverse gear, so the driver knows not to rely on PBAS to prevent a backup collision. This happens if the cameras cannot be cleared, the radar sensors are not functioning properly, or the backup system processing unit is malfunctioning.
- 1.6. The system shall compose the video streams from multiple cameras into a single, synchronized video display for the driver, compliant with NHTSA standards [10, 12].
- 1.7. The video stream shall always be active whenever the vehicle is in reverse, regardless of the self-cleaning cameras' states.
- 1.8. The system shall be active if and only if the vehicle is in reverse gear.
  - 1.8.1. By default, the braking Mitigation subsystem shall be activated along with the detection and warning subsystems upon the vehicle entering the reverse gear unless the system has been disabled by the driver in the vehicle settings (not driver override). See 1.11 for further details on driver override and the Mitigation system.
- 1.9. While the Mitigation subsystem is active, the vehicle is constrained to moving less than 10 *mph* to reduce the impact of unavoidable collisions [7].
- 1.10. By default, the system shall automatically apply the brakes when an obstacle is detected and its risk is *high*.
  - 1.10.1. The level of braking applied to prevent a collision shall be calculated by the braking system based on the speeds and trajectories of the vehicle and the obstacle, coming from the risk assessment to smoothly, but quickly halt the vehicle.
- 1.11. The driver shall have the ability to override the Mitigation system that automatically brakes to prevent a backup collision.
  - 1.11.1. Transition to manual driving through driver override shall be smooth and immediate.

- 1.11.2. Driver override shall deactivate the Mitigation system for the remainder of the duration in reverse gear.

In addition to listing the expected behaviors of the system, we also define the non-functional requirements. As this pedestrian backup system is critical for safety, we detail these requirements for quality and performance assurance. We also outline security requirements since this automotive system requires communication throughout the vehicle, and this system is able to change vehicle's behavior, so employing cyber security measures is critical for the safety of the vehicle and its surroundings. Furthermore, the system is integrated as part of the larger onboard system; therefore, it must conform to the hardware and resource constraints of the vehicle.

## 2. Non-functional Requirements

### 2.1. Quality Measures

- 2.1.1. The video display should occur in real time at at least 30 frames per second so that the driver sees an accurate view of the current scene behind the vehicle. There should be no noticeable lag or flickering on screen [3].
  - 2.1.2. The system should provide a crisp, well-lit composite video stream with a resolution of at least 720p of the scene behind the vehicle from the combined cameras; therefore, the system should perform any necessary photometric and geometric transformations to the original video data to correct for lighting issues and warping due to the camera and environmental characteristics [3].
  - 2.1.3. The system shall perform routine checks to determine if a failure state is ever entered. Upon entering a failure state, the system shall determine whether detection, warning, and mitigation are possible and safe. The system is safe for detection if the cameras can pick up the entire scene behind the vehicle, the radar sensors are working, and the backup system processing unit is functioning. The system is safe for warning if the sound system and infotainment display systems are working. The system is safe for Mitigation if the braking system is working. If it is safe to proceed, then the system shall continue to operate as normal, however an indicator should alert the driver of an issue. If any of the states would not be safe, then the system shall stop before entering that or any downstream states and indicate the issue to the driver.
  - 2.1.4. The system can be activated any number of times within a 5-year warranty period, and the mean time to failure for the system

(including all components such as sensors and hardware) shall be at least 5 years.

## 2.2. Software Requirements

- 2.2.1. The system design shall be as simple and modular as possible.
- 2.2.2. The system shall work efficiently, utilizing as few shared resources as possible.
- 2.2.3. The system shall meet industry programming standards [13].

## 2.3. Hardware Constraints

- 2.3.1. Radar sensors and an ultra-wide camera shall be affixed to the rear bumper [3, 10].
  - 2.3.1.1. The ultra-wide view camera shall be mounted to the middle rear of the vehicle, exact location depending on the vehicle model, but must cover at least 130° vertically from the ground below the rear bumper upward.
  - 2.3.1.2. The ultra-wide camera shall have a field of view of at least 180° horizontally to capture the view along and behind the rear bumper.
  - 2.3.1.3. The ultra-wide camera shall have a self-cleaning mechanism to improve obstacle detection performance in poor weather (i.e., mitigate challenges of poor image quality due to rain/snow/dirt on the camera).
  - 2.3.1.4. The radar sensors shall detect objects in at least a 270° field of view behind the vehicle with a range of at least 5 m.
  - 2.3.1.5. Omni-directional cameras located on the corners of the rear bumper to augment the field of view offered by the central, ultra-wide camera with greater peripheral view and provide additional security if the ultra-wide camera fails, so there is not a single sensor or point of failure in the obstacle detection [5]. These cameras shall be able to display the same field of view, resolution, and frame rate as the primary camera, and add a 45° field of view on either side of the vehicle.
- 2.3.2. Cameras in the side mirrors shall provide additional rear side views [10].
  - 2.3.2.1. These cameras should operate with the same resolution and speed as the ultra-wide view camera for continuity throughout the composite video.
  - 2.3.2.2. These cameras should provide at least a 45° field of view from the side of the vehicle.

## 2.4. Security Requirements

2.4.1. The system shall be activated if and only if the driver inside the vehicle manually shifts into reverse gear and not be activated by any remote means.

2.4.1.1. If an external or unauthorized activation attempt is detected, then the entire system, including the Mitigation subsystem, shall be temporarily deactivated until the driver overrides the system, and the driver should be notified that the system is inactive through the infotainment display system. The powertrain system shall enforce this with a mechanical failsafe.

2.4.2. The system shall be independent from other cars so that there is no interference among nearby vehicles [7].

2.4.3. In vehicles where biometric authentication is available, the system shall coordinate with the facial recognition system to evaluate the driver's awareness to make sure the driver is awake and not yawning, and looking at either the infotainment display with the reverse scene or at the rearview mirrors. If the driver has disabled Mitigation, but the biometric system determines the driver is not aware based on facial cues and eye movements, the system shall re-activate the Mitigation system.

## 2.5. Testing Requirements

2.5.1. Each of the subsystems shall be tested independently and through integration and system testing to ensure efficacy.

2.5.1.1. Subsystems include sensors and cameras, the detection and risk analysis system, visual and auditory warning system, and braking Mitigation system.

## 2.6. Cyber security Requirements

2.6.1. The system shall detect any anomalies regarding the communication on the CAN bus.

2.6.2. The system shall maintain transparency, to notify the driver when it detects any irregularity.

2.6.3. The system shall detect any external access to the user's private data.

2.6.3.1. User's private data can include login details of the system, drive destination.

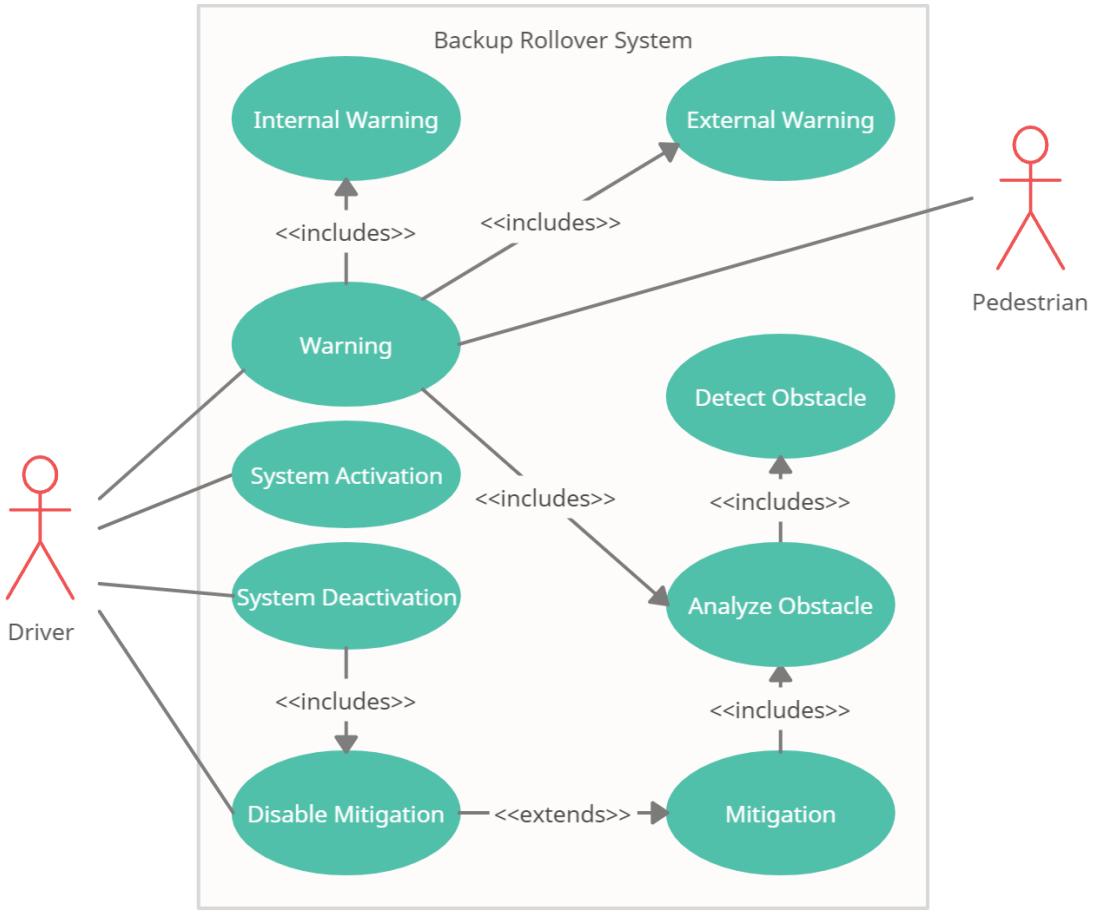
2.6.4. The system shall detect fake obstacles and consider them as false alarms and notify the driver.

## 4 Modeling Requirements

The figures below model the requirements enumerated above in 3. The models are intended to visually represent the team's interpretation of the system's functionality, from its high-level desired behavior with the use case diagram, key entities and their relationships with the domain model, behavior over time in specified scenarios with the sequence diagrams, and the system's states and transitions with the state diagram. These models are cross-referenced to the above requirements, and are consistent with respect to each other and the requirements.

### 4.1 Use Case Diagram

Figure 3 below is the use case diagram for the PBAS. The purpose of the use case diagram is to show the desired observable system behavior or high-level services. The gray rectangle in the use case diagram in Fig. 3 denotes the system boundary. The use cases are denoted in green ovals. Any external actors on the system are denoted by the red figures outside the system boundary, connected to the use cases with which they interact. Following the diagram, we describe the use cases in further detail in Table 1 below, cross referencing the enumerated requirements with the use cases. These listed requirements can be found in Section 3. The use case diagram shows the driver interacting with PBAS by activating and deactivating the PBAS, possibly deactivating the PBAS Mitigation system, and receiving warnings from PBAS when the system detects obstacles. Pedestrians can receive warnings from PBAS.



**Figure 3:** Use case diagram for our backup rollover system. The system boundary is denoted by the gray rectangle, use cases are denoted in green ovals, and external actors on the system are denoted by the figures in red outside the system boundary. PBAS is activated by the driver by shifting into reverse gear. The system begins detecting obstacles and assessing their risk. PBAS provides internal and external warnings to the driver and pedestrian, respectively if an obstacle is detected. PBAS will mitigate a collision if the risk of collision is high and Mitigation is enabled (the default), although the driver can disable or override Mitigation if he or she chooses. The driver ultimately deactivates the system by shifting out of reverse gear.

**Table 1:** Use case descriptions for our backup rollover system. These elaborate on the use case diagram above and cross-reference the corresponding requirements covered by each use case, as well as its actors and dependencies to other use cases.

Use Case:	System Activation
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Actors:	Driver
Description:	<p>Whenever the vehicle is in reverse, the system will be activated. The system shall be active if and only if the vehicle is in reverse gear, must not be remotely activated, and must not interfere with systems onboard other vehicles in close proximity. The sensors will be turned on and begin transmitting their signals to the processing unit for analysis and display via secured CAN buses. These sensors include a self-cleaning ultra-wide camera, omni-directional cameras, and radar sensors. Upon being activated, the system shall perform checks to see if the sensors are working properly (i.e., not in a fail state, the visuals are adequate) along with hardware and software failsafes to make sure the system is in a valid state in order to safely detect obstacles and mitigate collisions. If the system fails to pass these checks and deems it unsafe to autonomously mitigate a collision, the Mitigation system shall be deactivated, alerting the Driver of this system change to manual braking.</p> <p>The ultra-wide camera is located in the center of the rear of the vehicle. Exact placement depends on the vehicle model for maximum visibility, but must have at least 180° field of view left-to-right. An omni-directional camera is located in each of the rear tail lights for added peripheral view. Backup camera feeds from cameras in the side mirrors (typically used for blind spot detection) will be activated only if there is an issue detected with the primary video feeds. Radar sensors are located in the center and sides of the rear bumper. The vehicle's infotainment display located in the center of the dashboard shall be activated (if it is not already). The composite video stream from the cameras shall be displayed to the driver through this infotainment system.</p> <p>This system shall be implemented with simplicity and modularity as a focus in the design for possible reuse with further obstacle avoidance and autonomous driving features, following industry standards, and limiting use of shared resources. The system must also undergo a battery of unit, system, and integration tests to demonstrate its safety and reliability in many conditions. If the vehicle is equipped with biometric authentication and facial recognition, then the system shall use the onboard biometric system to evaluate the driver's awareness while backing and enable the Mitigation system if the Mitigation is disabled and biometric system deems the driver unaware (i.e., sleeping or not paying attention to the surroundings behind the vehicle).</p>
Type:	Primary

Includes:	N/A
Extends:	N/A
Cross-refs:	1.7, 1.8 (1.8.1), 2.1.3, 2.1.4, 2.2 (2.2.1-3), 2.3 (2.3.1, 2.3.1.1-5, 2.3.2, 2.3.2.1-2), 2.4, (2.4.1, 2.4.1.1, 2.4.2, 2.4.3), 2.5 (2.5.1, 2.5.1.1), 2.6 (2.6.1, 2.6.2, 2.6.3 (2.6.3.1))
Use Cases:	Detect Obstacle, Analyze Obstacle, Warning, Mitigation, Disable Mitigation, System Deactivation

Use Case:	Detect Obstacle
Actors:	N/A
Description:	<p>The system shall evaluate the data from each of the sensors to identify possible obstacles behind the reversing vehicle. The sensors shall cover the entire area horizontally behind the vehicle plus at least 45° to either side from the rear bumper. Vertically, the area covered for obstacle detection shall be from the ground (let this be 0°) up to at least 130°. The sensors shall detect obstacles within 5 m of the rear of the vehicle.</p> <p>The primary goal of the system is to prevent injuries to pedestrians, including children and the elderly, so the system must identify human obstacles. We define an <i>obstacle</i> as any object greater than 0.3 m<sup>3</sup>. The system shall identify any number of obstacles that occur concurrently.</p>
Type:	Primary
Includes:	N/A
Extends:	N/A
Cross-refs:	1.1 (1.1.1 - 1.1.8), 1.3 (1.3.1), 1.4, 1.5, 1.7
Use Cases:	Analyze Obstacle, Warning, Mitigation

Use Case:	Analyze Obstacle
Actors:	N/A

Description:	The system shall coordinate, process, and analyze the inputs from the camera and radar sensors; this includes temporal synchronization of the data streams, compositing the three video streams into a seamless singular scene, pruning redundancies in the detected obstacles from any given data stream, and matching obstacles among the various data streams. The system shall also analyse the potential obstacles for false positives and remove them from the set of obstacles to consider. The system shall analyze the risk of the remaining obstacles. The risk assessment includes determining the location and proximity of the obstacle relative to the vehicle and the vehicle's trajectory and categorizing the obstacle as no, low, medium, or high risk. No risk ( <i>none</i> ) means no obstacle was detected behind the vehicle. <i>Low</i> risk indicates an obstacle is detected, but over $5\text{ m}$ away from the rear. <i>Medium</i> risk indicates the detected obstacle is within $1.5\text{ m}$ to $5\text{ m}$ . <i>High</i> risk indicates the obstacle is less than $1.5\text{ m}$ from the rear of the vehicle. The system shall detect motion of objects, and assign objects which appear to be moving into the path of the vehicle a higher risk level.
Type:	Primary
Includes:	Detect Obstacle
Extends:	N/A
Cross-refs:	1.1 (1.1.1 - 1.1.10), 1.6, 1.10.1, 2.6.4
Use Cases:	Warning, Mitigation

Use Case:	Warning
Actors:	Driver, Pedestrian
Description:	The system shall display the composite video from Analyze Obstacle on the infotainment display for the driver to see the scene behind and around the rear of the vehicle. The video display shall remain active the entire time the vehicle is in reverse gear, even if the driver has disabled Mitigation. Based on the risk assessment from Analyze Obstacle, additional warnings besides the video display shall be provided to the driver (see Internal Warning) and for actors, such as a pedestrian outside the vehicle (see External Warning).
Type:	Primary

Includes:	Analyze Obstacle, Internal Warning, External Warning
Extends:	N/A
Cross-refs:	1.2 (1.2.1-1.2.6), 2.1.1, 2.1.2
Use Cases:	N/A

Use Case:	Internal Warning
Actors:	Driver
Description:	In addition to the behavior mentioned in Warning, additional notifications to the Driver are present inside the vehicle based on the risk assessment for detected obstacles. In the no risk case, the video stream is the only warning mechanism. For any risk level, whenever an obstacle is detected, the system shall highlight the obstacle on the video display. For low risk, a tone of 65 decibels ( <i>dB</i> ) shall also be played over the vehicle's speakers at a rate of 60 beats per minute ( <i>bpm</i> ). For medium risk, the tone shall be played with a rate of 90 <i>bpm</i> . For high risk, the tone shall be played at a rate of 120 <i>bpm</i> , and the Mitigation subsystem shall be activated to avoid a collision unless it has been disabled by the driver. If multiple obstacles are present, then the system shall play the tone corresponding to the highest risk.
Type:	Primary
Includes:	N/A
Extends:	N/A
Cross-refs:	1.2 (1.2.1-1.2.5), 2.1.1, 2.1.2
Use Cases:	Warning

Use Case:	External Warning
Actors:	Pedestrian
Description:	When the system detects pedestrians in the path of the vehicle an alarm of 110 decibels should sound outside the vehicle using the external speaker following the same scheme for speed as the internal speaker (i.e., 60 <i>bpm</i> for low risk, 90

	<i>bpm</i> for medium risk, and 120 <i>bpm</i> for high risk). If the risk is high and Mitigation is enabled and active, illumination of the brake lights provides a visual warning to the pedestrian when the braking system is engaged. The brake lights always illuminate as part of the braking system, whether the braking system is engaged by the driver or automatically by the Mitigation system. These external warnings are intended to alert pedestrians behind the vehicle that the vehicle near them is reversing; however, this is always active with Mitigation regardless of whether the system detected a human or different obstacle.
Type:	Primary
Includes:	N/A
Extends:	N/A
Cross-refs:	1.2 (1.2.1-1.2.6), 2.1.1, 2.1.2
Use Cases:	Warning

Use Case:	Mitigation
Actors:	N/A
Description:	<p>The Mitigation subsystem shall be activated by default, along with the detection and warning subsystems whenever the car is in reverse, unless it has been disabled by the driver in the video settings in the display which is located in the center of the dashboard (<i>note</i>: this is different from driver override).</p> <p>The vehicle is constrained to move less than 10 <i>mph</i> when the Mitigation is activated. Based on the risk assessment from Analyze Obstacle, if the risk of an obstacle being hit is high, then the Mitigation subsystem shall engage the braking system to automatically apply the brakes to bring the vehicle to a halt. The level of braking applied to prevent a collision shall be calculated based on the speeds and trajectories of the vehicle and the obstacle. Even after the braking, the sensors shall still be active and continue to detect any obstacle and send the information to the analyzer. Once the Analyze Obstacle determines there is no more risk, the Mitigation subsystem then releases the brakes, stops the warnings for both driver and pedestrian, and smoothly transitions from the autonomous braking to manual reversing by the driver, with the vehicle</p>

	constrained to less than 10 mph.
Type:	Primary
Includes:	Analyze Obstacle
Extends:	N/A
Cross-refs:	1.9, 1.10 (1.10.1)
Use Cases:	Disable Mitigation, Warning

Use Case:	Disable Mitigation
Actors:	Driver
Description:	<p>The driver has the ability to disable the Mitigation subsystem. One way to disable is to turn off the Mitigation setting in the video display that is located at the center of the dashboard once the vehicle is started. If the Driver has disabled Mitigation through the display settings, then Mitigation is disabled when the vehicle is in reverse gear unless the Driver re-enables Mitigation through the display settings. The infotainment display must warn the driver that Mitigation is disabled. Disabling Mitigation does not disable the entirety of PBAS. Detection and warning are always active, regardless of the driver's preferences for Mitigation.</p> <p>Another way to disable is to override the automatic braking which is initiated by the Mitigation subsystem by pressing on either of the pedals (i.e., if the warning is false positive and the driver wants to override the brake, he can press the gas pedal or the brake pedal to disable the Mitigation system).</p> <p>In both ways, the Mitigation subsystem shall be disabled for the remainder of the duration in reverse gear and can be enabled by turning on the setting in the video display. Even when the Mitigation system is off, sensors shall still continue to detect any obstacles, and the Analyze Obstacle analyzes the risk of pedestrians being hit and warning subsystem notifies both the driver and pedestrian of the risk.</p>
Type:	Primary

Includes:	N/A
Extends:	Mitigation
Cross-refs:	1.11 (1.11.1, 1.11.2)
Use Cases:	System Deactivation

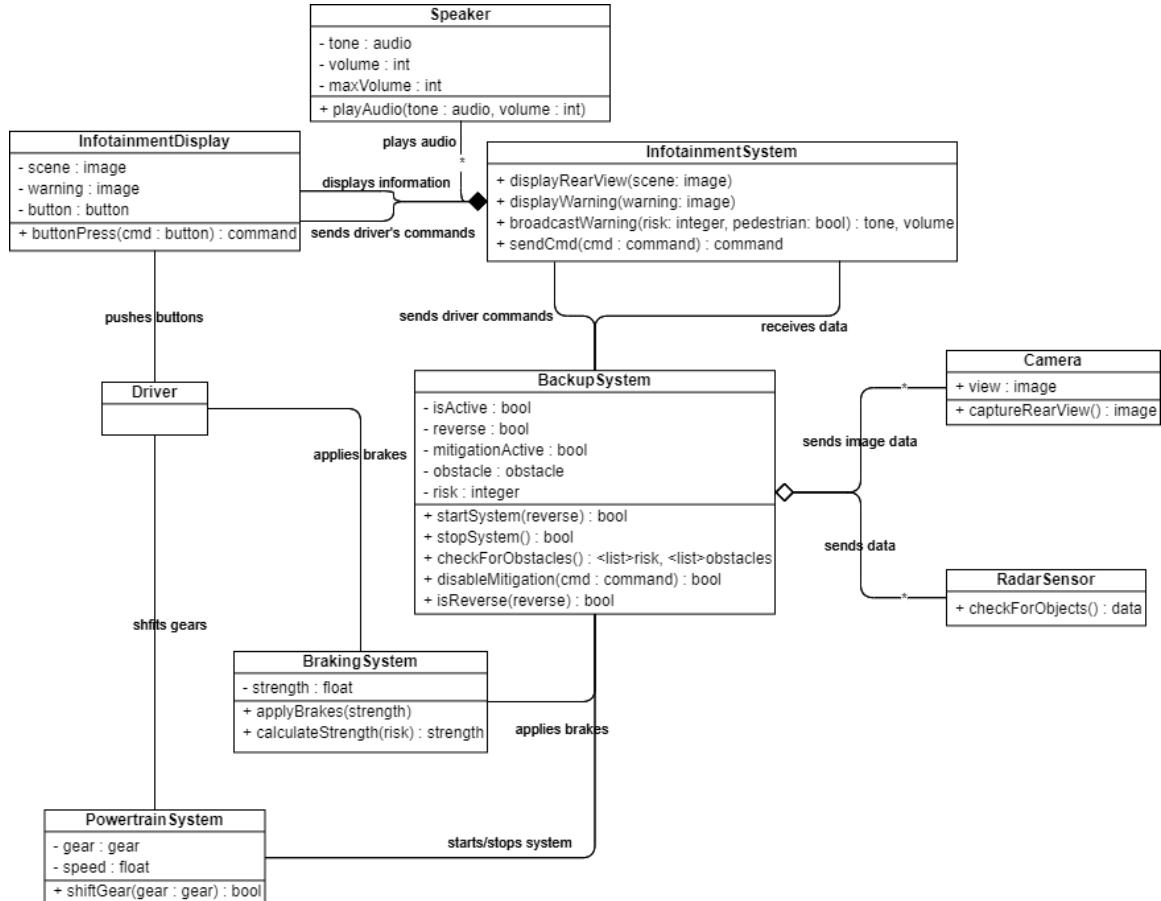
Use Case:	System Deactivation
Actors:	Driver
Description:	System shall only be active when the vehicle is in reverse gear. It shall be deactivated once the Driver changes the mode to drive, park, or any other gear besides reverse that the vehicle may have (such as a low gear), or once the Driver turns off a setting in the video display which corresponds to the entire system. For the later option, the driver can activate the system back by just turning the setting on.
Type:	Primary
Includes:	Disable Mitigation
Extends:	N/A
Cross-refs:	1.8, 1.11 (1.11.1, 1.11.2)
Use Cases:	N/A

## 4.2 Domain Model

The domain model below in Fig. 4 shows the key entities in the system and their relationships with other entities using class diagram notation. The boxes represent the key entities with their attributes and operations. The lines connecting the boxes represent the relationships among entities. The classes can be related through associations (plain lines) indicating a generic connection. Aggregation connections have diamond connections indicating a part-of relationship.

The major components include the Driver who activates the system, the BackupSystem that controls the other components, the sensors including any Camera and RadarSensor which send data to the BackupSystem, the vehicle's BrakingSystem that PBAS uses (it is not specific to the BackupSystem, but rather a generic braking subsystem that can be

used by other subsystems in the vehicle), and other actuators including the InfotainmentDisplay and Speakers to provide visual and auditory warnings to the Driver or pedestrians behind the vehicle. A data dictionary follows below the diagram to elaborate on the attributes and operations of the major components.



**Figure 4:** Domain model showing the key entities (boxes) of the system and their relationships (lines) using class diagram notation. The BackupSystem is the overall controller/coordinator of PBAS. This includes the camera and radar sensors. PBAS works with the InfotainmentSystem to display the rearview video scene and warnings (auditory and visual alarms, since the InfotainmentSystem includes the display screen and speakers).

The InfotainmentSystem also sends commands from the driver to PBAS (for enabling/disabling Mitigation). PBAS interacts with the BrakingSystem to automatically mitigate backup collisions. The driver (de)activates PBAS through the PowertrainSystem by manually shifting gears.

**Table 2:** Data dictionary describing the attributes and operations of the major components in the domain model.

Name	Driver
------	--------

Description	The Driver can control whether the Mitigation subsystem and backup system is active. The Driver is crucial to the system and will be informed of potential collisions with pedestrians.
Relationships	Associations: Display - Driver pushes buttons on the display to interact with various vehicle systems PowertrainSystem - driver shifts gears BrakingSystem - driver applies brakes
Attributes	
Operations	
Public	

Name	Backup System
Description	The Backup System is the hub of information and connects all components of the overall system. This system is also responsible for processing data and performing computations.
Relationships	Associations: InfotainmentSystem - sends driver commands and broadcasts information from the system, Speaker - broadcasts warnings, BrakingSystem - Used by the system to stop the vehicle, Aggregations: The Camera and RadarSensor classes are part of the BackupSystem

Attributes	<p>isActive: boolean - whether or not the overall system is active</p> <p>mitigationActive: boolean - whether or not the Mitigation subsystem is enabled, true by default</p> <p>reverse: boolean - whether the vehicle is currently in reverse</p> <p>obstacle: obstacle - currently detected obstacle or none</p> <p>risk: integer - risk level assessed by the system</p>
Operations	<p>startSystem() - enables system</p> <p>stopSystem() - disables system</p> <p>checkForObstacles() - called periodically to check sensors for obstacles</p> <p>disableMitigation() - called to disable Mitigation and update appropriate attributes</p> <p>isReverse() - getter for reverse</p>
Public	

Name	Braking System
Description	This system applies the brakes to stop the vehicle when triggered by the Driver or BackupSystem.
Relationships	Association: BackupSystem, Driver both the driver and the BackupSystem use the braking system to apply brakes and stop the vehicle.
Attributes	strength: float - strength of the braking force
Operations	<p>applyBrakes(strength : float) - activates vehicles brakes at a specified strength</p> <p>calculateStrength(risk : int) - calculates correct strength of brakes based on risk</p>
Public	

Name	Camera
Description	The various cameras in the system operate as sensors and provide data to the system to make calculated decisions.
Relationships	Association - BackupSystem: sends image data to backup system
Attributes	view : Image - the image currently being seen by the camera
Operations	captureRearView() - Captures a single frame of video from the camera and returns the data
Public	

Name	RadarSensor
Description	Radar sensors are located on the rear bumper and detect objects in at least a 270° field of view behind the vehicle with a range of at least 5 m.
Relationships	Association: BackupSystem - sends data to backup system
Attributes	
Operations	checkForObjects() - returns whether the radar sensor is currently detecting objects.
Public	

Name	Speaker
Description	A speaker that can be used to present a warning tone. For low risk, a tone of 65 decibels ( <i>dB</i> ) shall also be played over the speaker at a rate of 60 beats per minute ( <i>bpm</i> ). For medium risk, the tone shall be played with

	a rate of 90 <i>bpm</i> . For high risk, the tone shall be played at a rate of 120 <i>bpm</i> .
Relationships	<p>Generalization: Parent of InternalSpeaker and ExternalSpeaker</p> <p>Aggregation: InfotainmentSystem - The infotainment system is made up of the various speakers and the display as well as its computing core.</p>
Attributes	<p>tone : audio - the audio being played by the speaker</p> <p>volume : int - the current volume of the speaker from 1 to 100 as a ratio of its maximum</p> <p>maxVolume : int - the maximum volume of a speaker in decibels.</p>
Operations	playAudio( tone: audio , volume: int) - plays specified audio track at a certain volume.
Public	

Name	InfotainmentDisplay
Description	The infotainment display is a screen located in the center of the vehicles dashboard between the driver and passenger. It is used for a wide variety of interactions but for purposes of the PBAS is used to manually enable and disable parts of the system. It also displays video feed from the cameras while reversing and shows warnings in the event of an imminent collision.
Relationships	<p>Aggregation: InfotainmentSystem - The infotainment system is made up of the various speakers and the display as well as its computing core.</p> <p>Association: Driver- Driver pushes buttons on the display to interact with various vehicle systems</p>

Attributes	screen : image - currently displayed image warning : image - pop up warning in the event of an imminent collision button : button - used by the driver to interact with the system
Operations	buttonPress(cmd : button) : command - sends a command to the infotainmentSystem to be processed.
Public	

Name	InfotainmentSystem
Description	An infotainment display system with a touchscreen and connected to the speakers is located in the center of the dashboard for the driver and passenger to view information and adjust vehicle settings. This screen will display the composite video of the scene behind the vehicle from the cameras and any obstacles will be highlighted on this display. The driver can also enable or disable the backup-rollover Mitigation system through the vehicle settings using the settings screen of the infotainment display system.
Relationships	Aggregation: Display, Speakers- The infotainment system is made up of the various speakers and the display as well as its computing core. Association: BackupSystem - The infotainmentSystem sends driver commands to the BackupSystem and receives data such as risk, warnings, and the rearview feed.
Attributes	
Operations	displayWarning(warning :image) - displays collision warning on the screen displayRearview(scene: image) - displays

	composite video from cameras broadcastWarning(risk : Integer, pedestrian : boolean): tone, volume - uses the speakers to broadcast a warning about a potential collision sendCmd(cmd : command): command - sends a command from the driver to the BackupSystem.
Public	

Name	PowertrainSystem
Description	This system encompasses the components that convert the engine's power into movement. The PBAS is primarily concerned with the gear of the vehicle as well as the speed of the vehicle.
Relationships	Association: BackupSystem - The powertrain system engages the BackupSystem when the vehicle is placed in reverse. , Driver - The driver changes the gear of the vehicle.
Attributes	gear: gear- current gear of the vehicle speed: float - current speed of the vehicle
Operations	shiftGear(gear : gear):bool - shifts the gear of the vehicle.
Public	

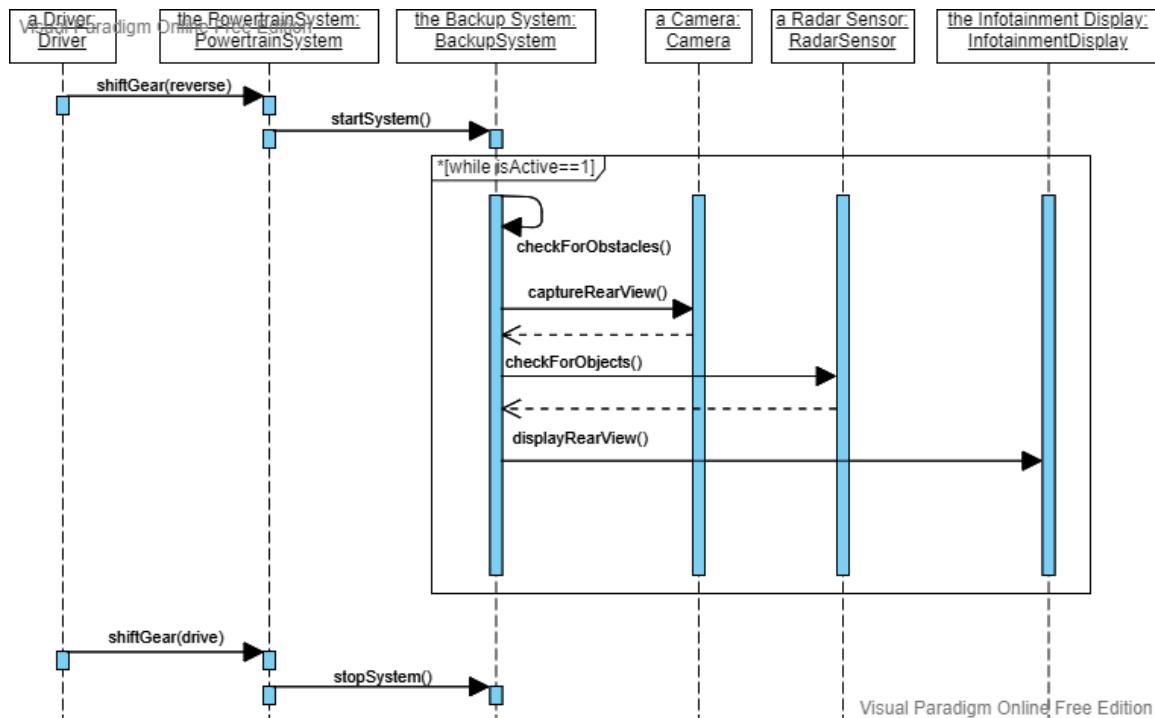
### 4.3 Sequence Diagrams

This section provides the sequence diagram used to illustrate how various components of the system interact over time, given a particular scenario the system may encounter. Various scenarios are described in the following figures to capture both normal and abnormal situations and to illustrate the corresponding system behavior. Sequence diagrams show objects as boxes, the object lifelines as the dotted lines descending from

the boxed object, and messages between objects are passed as arrows along the object lifelines to show the sequence of events for a given scenario.

#### 4.3.1 Normal, Unobstructed Backing

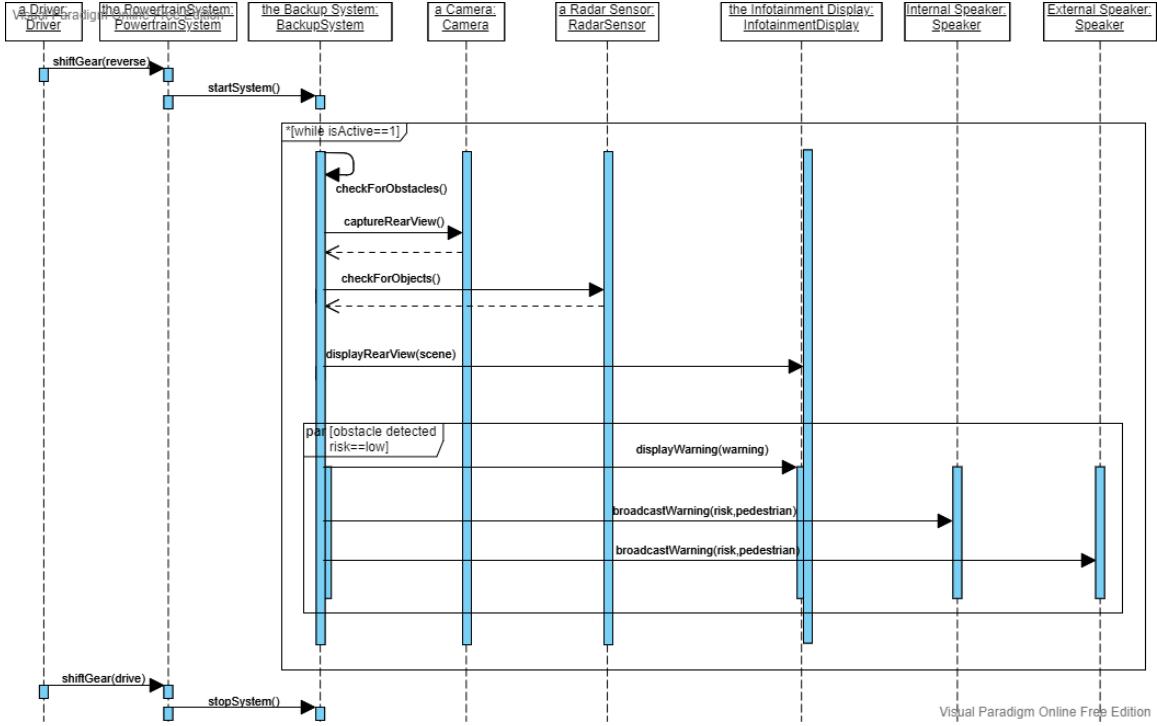
Figure 5 shows the sequence diagram for a normal scenario when backing. There are no obstacles behind the vehicle obstructing the vehicle's trajectory, so the driver can proceed to reverse as usual.



**Figure 5:** Normal, unobstructed backing scenario. The driver starts the PBAS system, which continuously checks for obstacles based on data from the camera and radar sensors. The scene behind the vehicle is displayed to the driver. Once the driver finishes backing, he stops the system.

#### 4.3.2 Object/Pedestrian Detected, No Imminent Collision (No Mitigation)

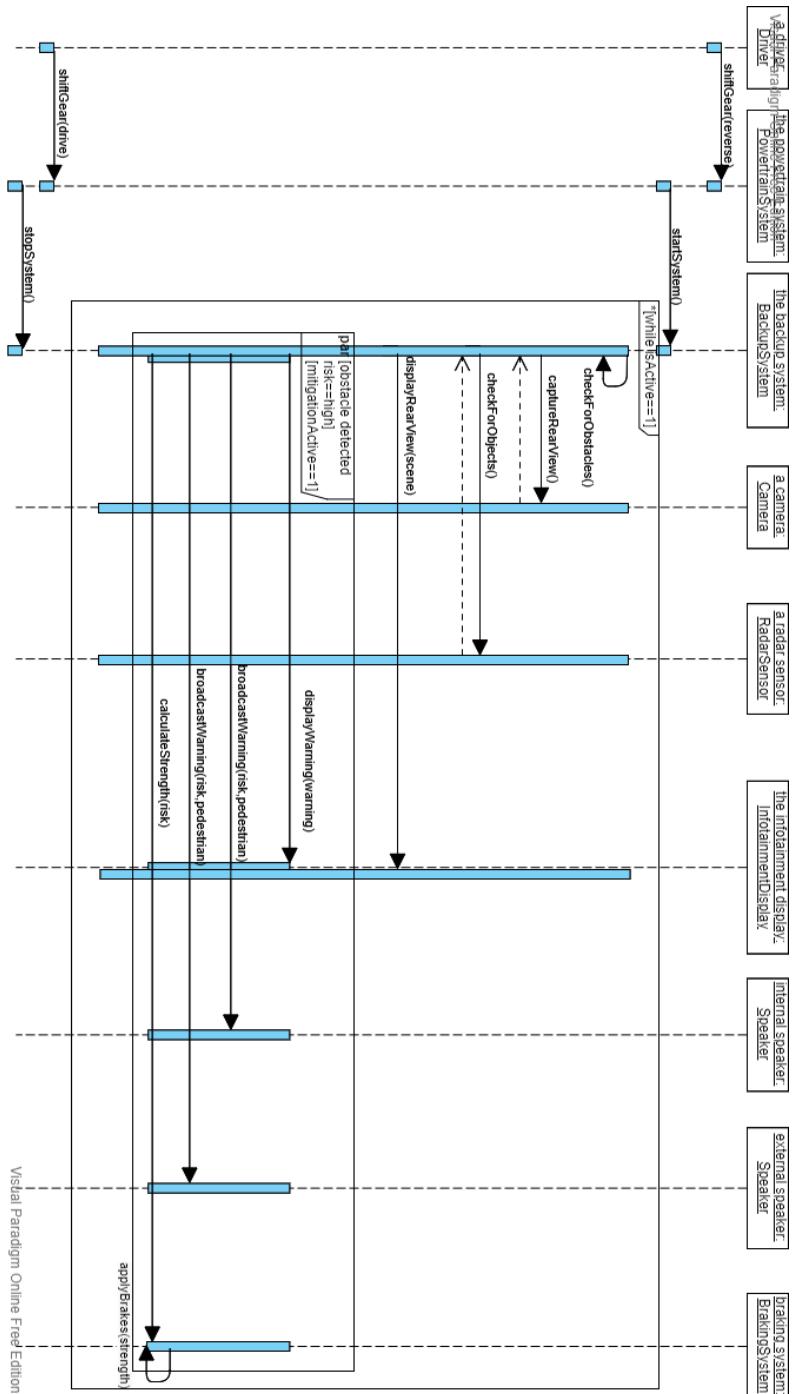
Figure 6 shows the scenario where an obstacle is detected behind the rear of the vehicle; however, the risk of collision is low, so the driver can proceed to reverse as usual, and Mitigation does not become necessary. Either the obstacle is moving away from the vehicle or is too far away for the vehicle to collide with it in this case.



**Figure 6:** Obstacle detected, but no imminent collision scenario. The driver starts the system, which continuously checks for obstacles based on data from the camera and radar sensors, and the scene behind the vehicle is displayed to the driver on the screen. PBAS detects an obstacle, but the risk assessment is low, so the corresponding visual warning is displayed on screen and an auditory alarm is sounded on the internal and external speakers for a low risk obstacle. The driver finishes backing and stops the system.

#### 4.3.3 Object/Pedestrian Detected, Collision Imminent (Mitigation)

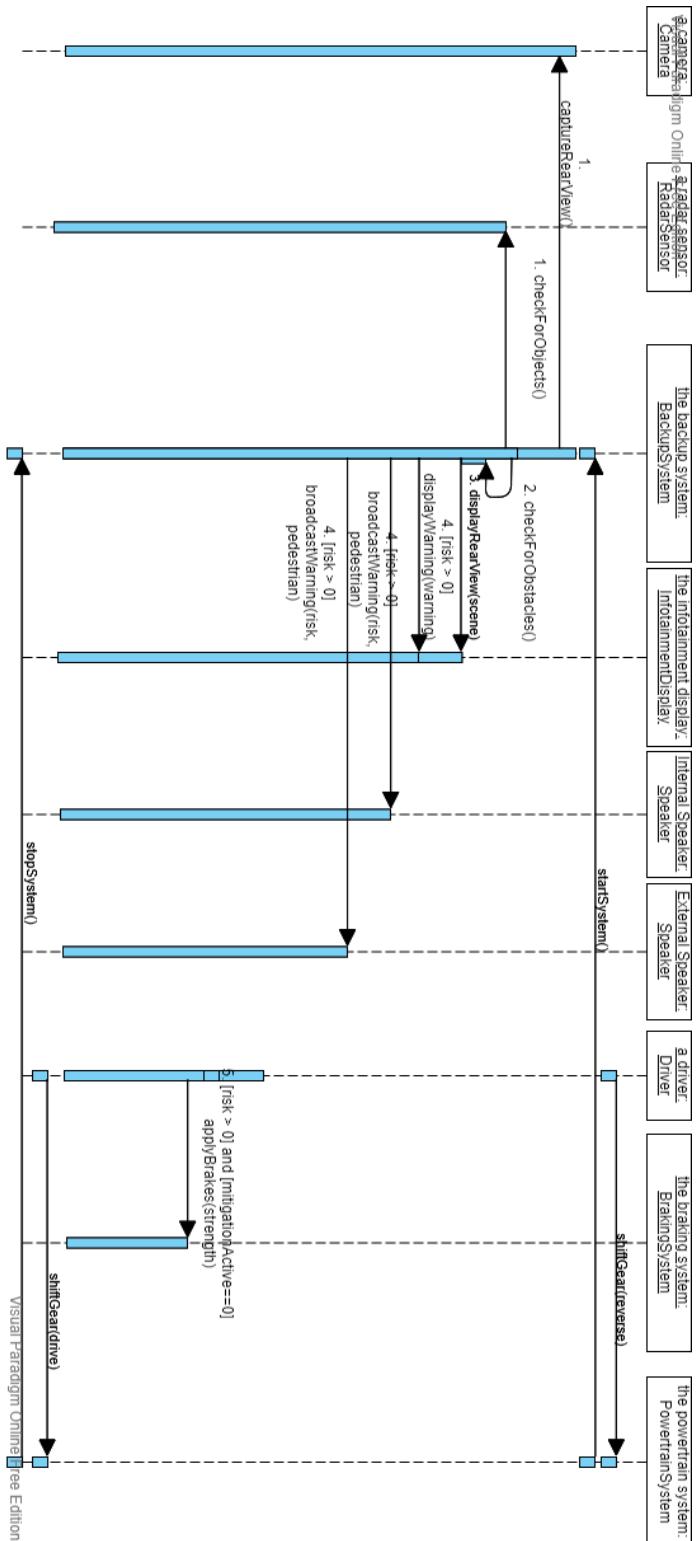
Figure 7 shows an obstacle or pedestrian is detected behind the vehicle in this scenario, and the risk of collision is high, so a collision is likely to occur. Mitigation has been enabled, so the braking system is engaged to prevent a serious accident.



**Figure 7:** The driver starts the system. PBAS detects an obstacle and imminent collision (the risk assessment is high). PBAS displays a visual and auditory warning to the driver and pedestrian. Since Mitigation is enabled, PBAS automatically mitigated the potential collision by engaging the braking system. The driver finishes braking and stops PBAS.

#### ***4.3.4 Object/Pedestrian Detected, Collision Imminent (No Mitigation)***

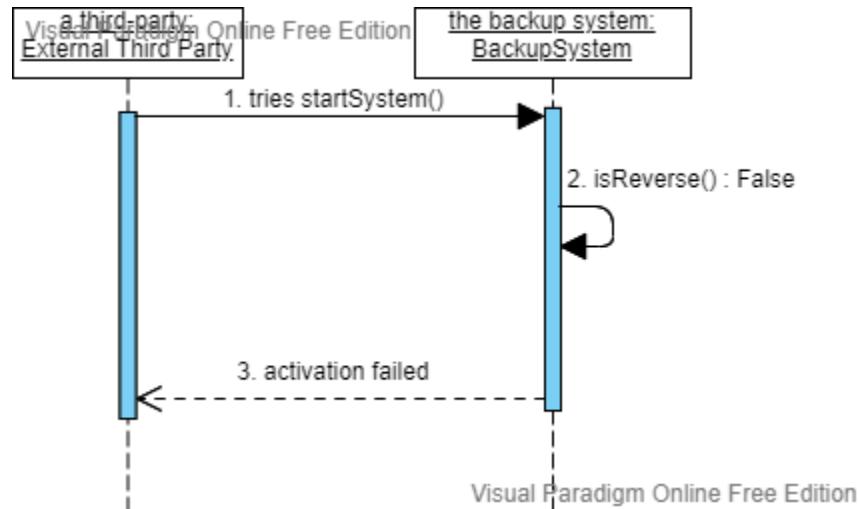
An obstacle or pedestrian is detected behind the vehicle in this scenario, and the risk of collision is high, so a collision is likely to occur. Mitigation has been disabled by the driver, so the driver must manually apply the brakes, change gears, or steer away from the obstacle to prevent a collision, otherwise a serious accident may occur.



**Figure 8:** In this scenario, PBAS detects an obstacle with a high risk of collision, but Mitigation is disabled. In this case, the driver must apply the brakes since PBAS cannot engage the braking system to automatically prevent a collision.

#### **4.3.5 External Entities Tries to Remotely Activate PBAS**

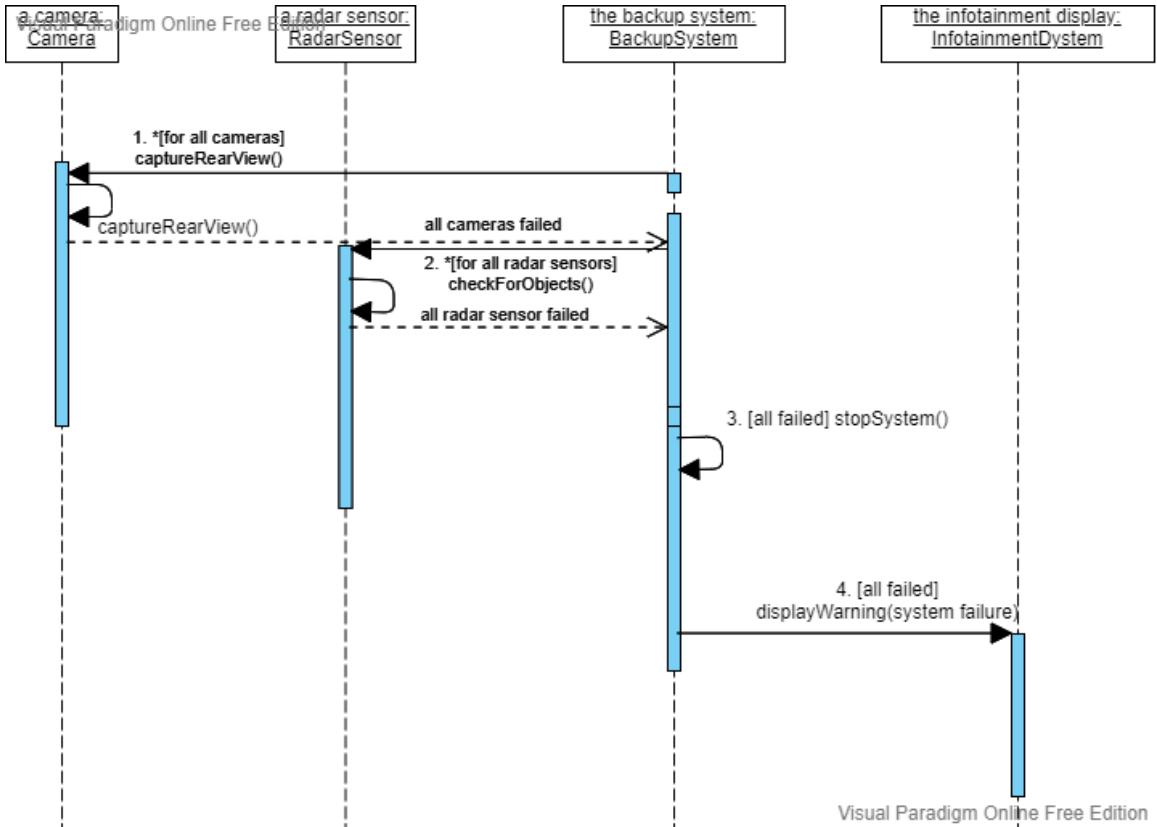
In this scenario, an external third-party attempts to activate PBAS remotely, but fails since the system can only be activated by shifting into reverse from inside the vehicle, and is active if and only if the vehicle is in reverse gear.



**Figure 9:** In this security scenario, a remote third-party attempts to hijack the PBAS system, however the attempt is denied because of mechanical failsafes and software security measures to prevent cyberattacks.

#### **4.3.6 System Cannot Safely Operate (Sensors Broken/Obfuscated And Cannot Be Cleared)**

In this scenario, the system cannot safely operate to mitigate backup rollover accidents. This may be due to broken or obfuscated sensors (including their redundancies), so the system cannot safely or accurately detect obstacles and avoid backup collisions. The driver must manually mitigate if an obstacle is present and a collision is possible.



**Figure 10:** The system is broken and cannot safely operate in this scenario, so a warning is displayed to the driver to make him or her aware that obstacle detection and Mitigation while reversing are not currently possible.

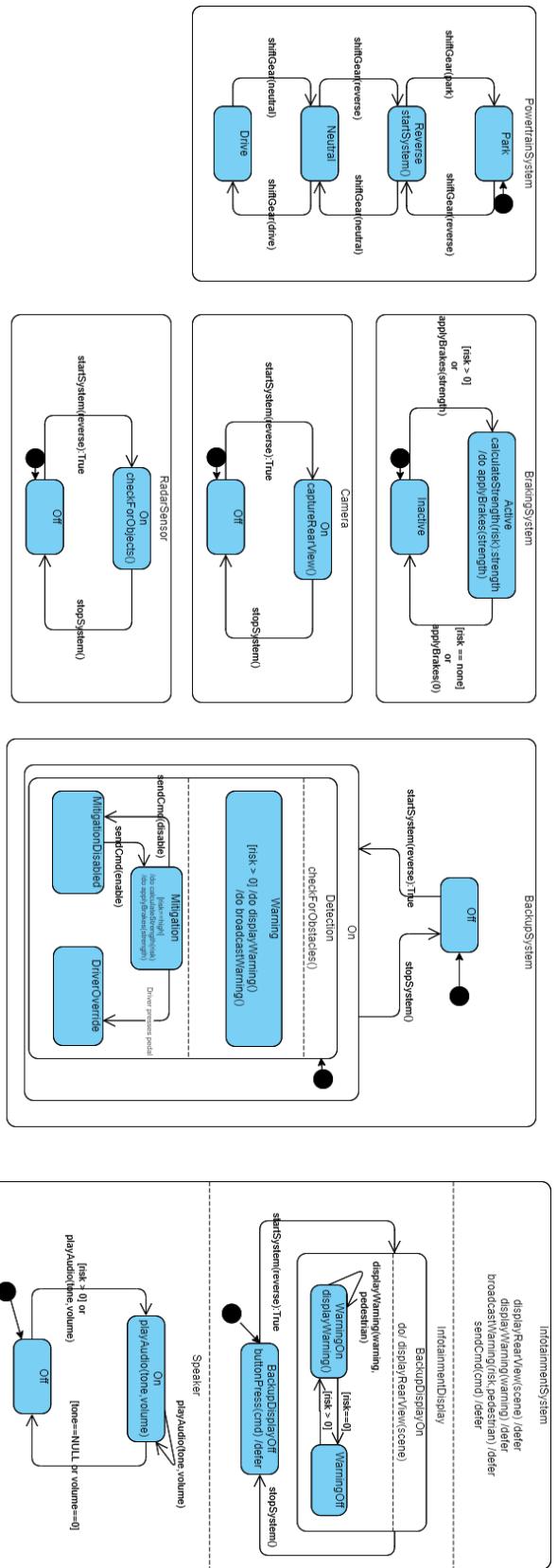
#### 4.4 State Diagram

This section introduces and describes the state diagram for the PBAS system. The state diagram is shown in the following figure. The state diagram illustrates the various states or conditions the system components can assume, and how these components transition between their states. The state diagram is analogous to the sequence diagrams if each component is considered across all scenarios it could encounter. The states are shown as rectangles. Substates are shown as smaller boxes inside another state. The initial state is indicated by a dot with an arrow pointing to the first state. Transitions between states are shown with arrows with text describing conditions for transitioning, and may include events that occur during the transition. Concurrent states are shown with a dashed line between the simultaneous events.

The system is in an off state until the driver shifts into reverse gear, which activates the system. When the system is activated, the cameras and radar sensors turn on in order to display the rearview scene to the driver through the InfotainmentDisplay and detect obstacles behind the vehicle. If obstacles are detected, then the system warns the driver

through visuals on the InfotainmentDisplay and internal speakers, and plays a warning through external speakers to notify the pedestrians behind the vehicle. If the risk is high and Mitigation is enabled, then the system will utilize the BrakingSystem to apply the brakes to mitigate the collision/reduce the impact.

The driver can enable or disable Mitigation through pressing buttons on the InfotainmentDisplay. The driver can also override the Mitigation system by pressing either pedal (accelerator or brake), in which case Mitigation will be deactivated for the remainder of the session in reverse gear and a warning that Mitigation is deactivated is displayed on screen for the driver. The entire system is deactivated when the driver shifts into any other gear besides reverse (park, drive, neutral, low, etc.).



Template based on IEEE Std 830-1998 for SRS. Modifications (content and ordering of information) have been made by Betty H.C. Cheng, Michigan State University (chengb at msu.edu)

**Figure 11:** State diagram showing the various states and conditions of the system and its components. This diagram is composed of state diagrams for the modules: PowertrainSystem, BrakingSystem, Camera, RadarSensor, BackupSystem, and InfotainmentSystem which consists of the InfotainmentDisplay and Speaker.

## 5 Prototype

The intention of this section is to visually illustrate the system requirements and its behavior in various scenarios (outlined above in 4.3) through an interactive prototype. The rapid prototype below was developed in Unity for online interaction. This is *not* intended to be used as a basis for actually developing the system. Instructions for how to use the prototype are provided below, followed by walkthroughs of the prototype in sample scenarios.

### 5.1 How to Run Prototype

The PBAS prototype is accessible through standard web browsers by following this link: <https://loukotaj.github.io/870Prototype/>. The blue button at the bottom right corner of the page opens the prototype in full screen. The figure below shows the prototype start screen.

Click on any of the buttons to initiate that scenario. The system activates upon entering reverse gear, so until *Reverse* is clicked, the vehicle will drive as it would without PBAS.

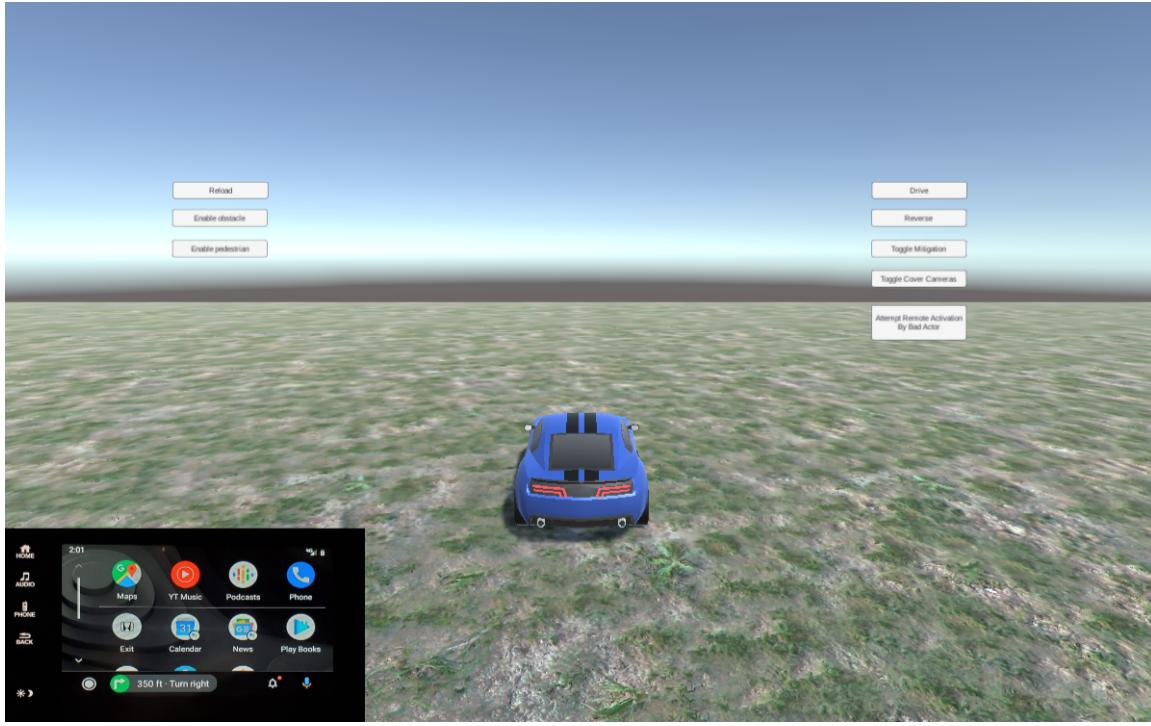
To accelerate, press *W*. To brake, press *S*. *Reload* resets the prototype.

*Enable obstacle* and *Enable pedestrian* populate an obstacle/pedestrian behind the vehicle. As the vehicle reverses toward an object, a warning is displayed on the InfotainmentDisplay (lower left corner) and the warning alarm plays based on the vehicle's proximity to the object.

Mitigation can be enabled or disabled by clicking *Toggle Mitigation*. For ease of use, the prototype always displays whether Mitigation is enabled or disabled on the InfotainmentDisplay.

Scenario 5 (system fault - in this case due to camera failures) can be activated by *Toggle Cover Cameras*.

Scenario 6 (cyber security) can be activated by *Attempt Remote Activation by Bad Actor*.



**Figure 12:** Prototype start screen

## 5.2 Sample Scenarios

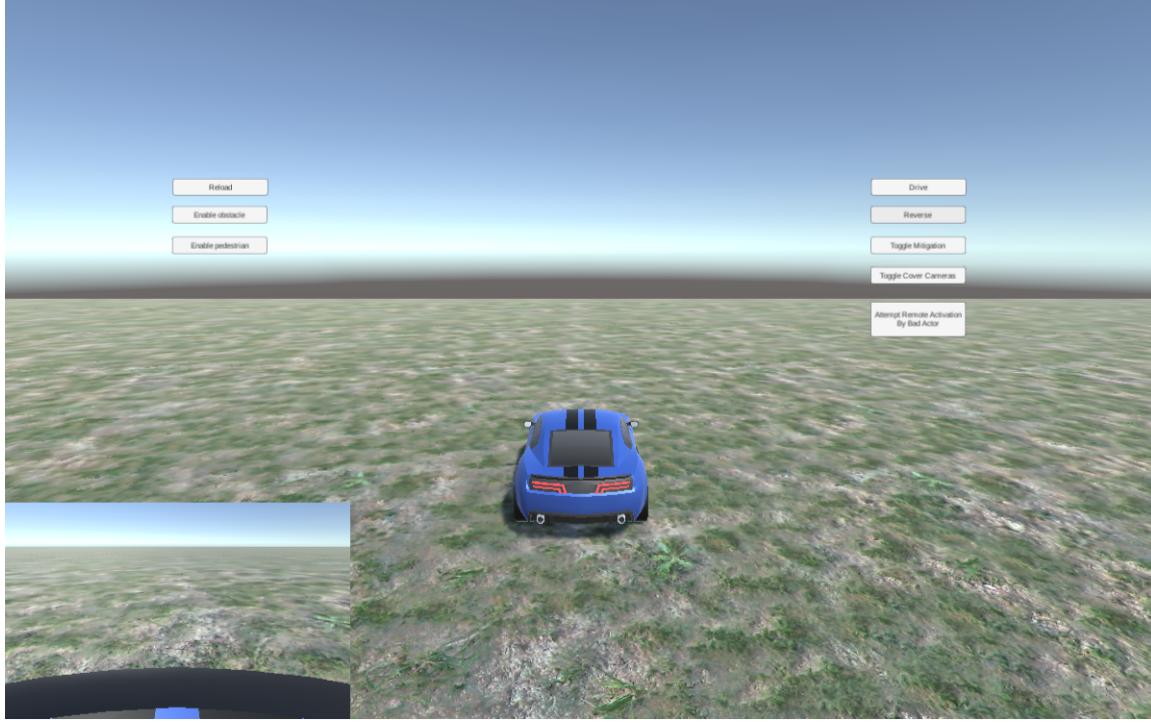
The following figures show how the prototype operates when the scenarios described in 4.3 are played. In some cases, there are several figures in the sequence to show changes over time. In other cases, the behavior is captured by a single image. These scenarios and more can all be played using the link above.

### 5.2.1 Scenario 1: Normal, unobstructed backing

Figure 13 below shows a normal backing scenario where there are no obstructions. This is the base scenario loaded by the prototype whenever *Reload* is clicked. This scenario begins with Mitigation enabled, although that is not necessary for this unobstructed situation. The driver shifts into reverse gear and begins backing. After some time, the driver shifts into drive, and PBAS is turned off.

To run this scenario on the prototype:

1. Click: *Reload*
2. Click: *Reverse*
3. Press: *W* to accelerate backward
4. Press: *E* to brake as desired
5. Click: *Drive* to switch go forward and exit PBAS



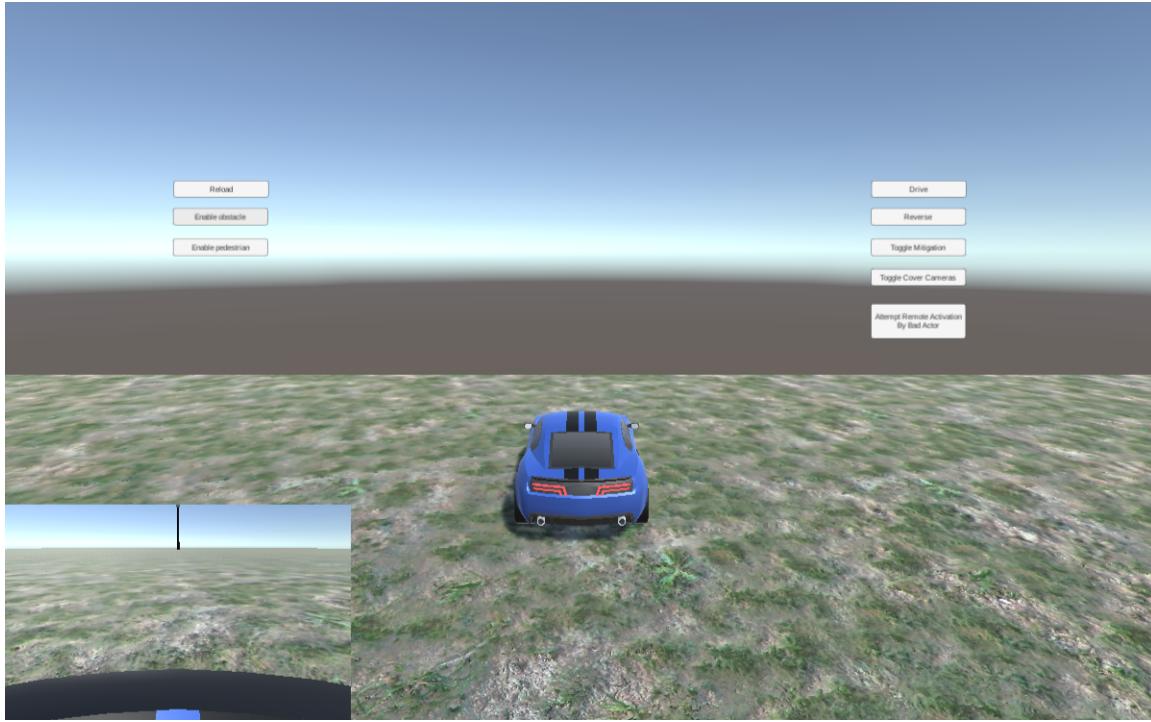
**Figure 13:** Scenario 1 - normal, unobstructed backing.

### 5.2.2 Scenario 2: Low risk obstacle detected

In Fig. 12, the vehicle begins backing toward an obstacle. PBAS detects the obstacle, but no collision is imminent because the vehicle is not in close proximity to the obstacle. The driver returns to driving forward. Since the prototype reloads the same base scenario, this low risk scenario is achieved by backing only a short distance toward the obstacle to simulate backing toward a lower risk obstacle farther away from the vehicle.

To run this scenario on the prototype:

6. Click: *Reload*
7. Click: *Enable obstacle*
8. Click: *Reverse*
9. Tap: *W* to accelerate backward toward the obstacle.
  - a. Note: Tapping *W* 5 times brings the vehicle into PBAS's obstacle detection range with a low risk.
10. Click: *Drive* to switch go forward and exit PBAS



**Figure 14:** Scenario 2 - object detected, but no collision imminent.

### 5.2.3 Scenario 3: High risk collision automatically mitigated

In this scenario, the vehicle begins approaching the pedestrian. PBAS detects the pedestrian and warns the driver who is coasting backward. Mitigation is enabled in this case, so when the risk becomes high, PBAS applies the brakes to halt the vehicle before colliding with the pedestrian. With Mitigation is applying the brakes, the vehicle stops more quickly than if the vehicle simply coasted, since the brakes are applied in addition to the forces that would eventually stop the vehicle by coasting.

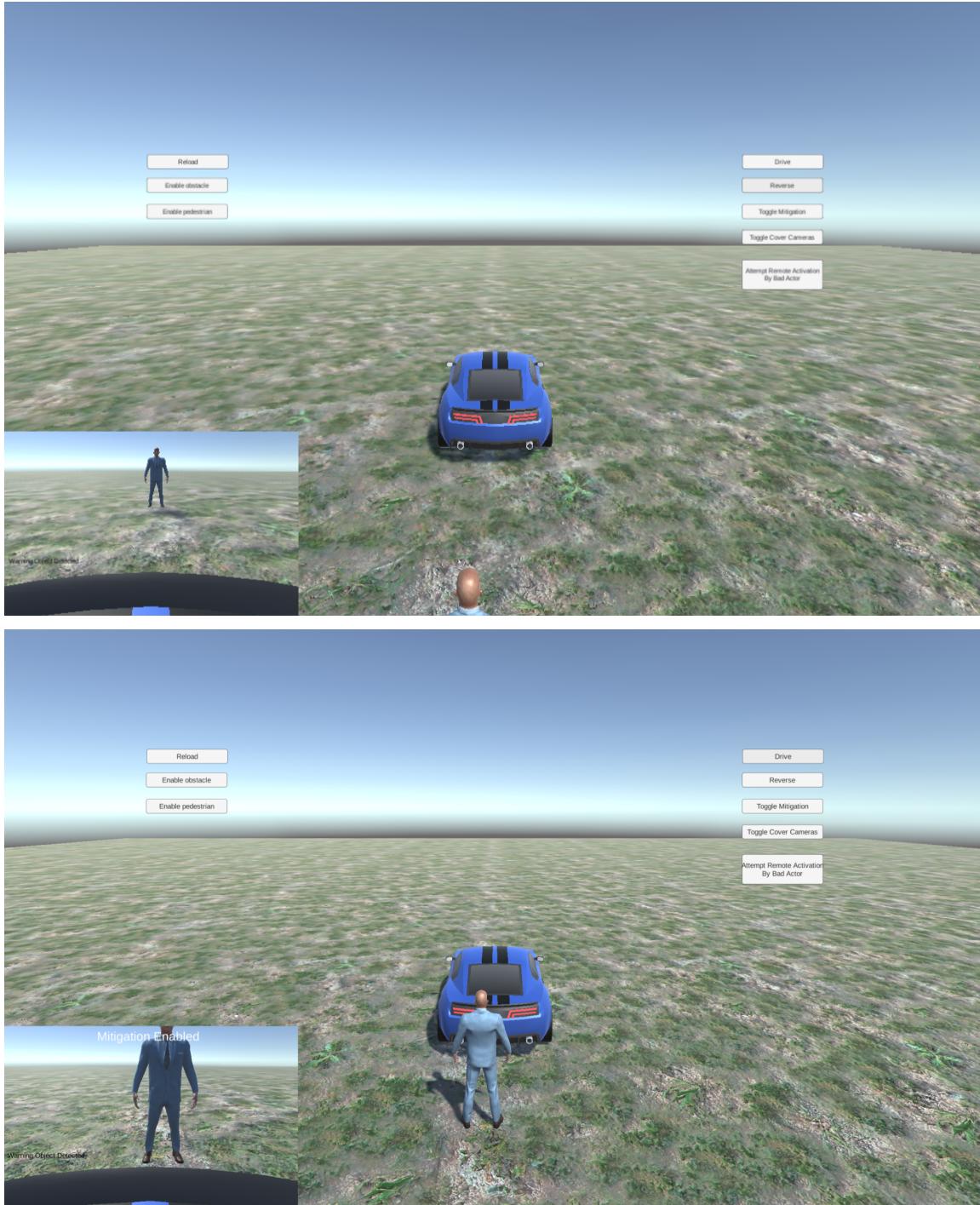
To run this scenario on the prototype:

11. Click: *Reload*
  - a. Note: the InfotainmentDisplay should say that Mitigation is enabled for the user's convenience. If the user starts from a different scenario without reloading and Mitigation is disabled on the InfotainmentDisplay, click *Toggle Mitigation*.
12. Click: *Enable pedestrian*
13. Click: *Reverse*
14. Tap: *W* to accelerate backward toward the obstacle
15. Release: *W* when the vehicle is close to the pedestrian and the auditory warnings have increased to rapid beeps for PBAS to automatically brake. Based on the spacing of this scenario, tapping *W* 12 times and then releasing the key brings the

vehicle close to the pedestrian. Another option is to hold  $W$  until the vehicle is about a car length away from the pedestrian and then release  $W$ .

- a. Note: Holding down  $W$  while the collision risk is high is equivalent to the driver pressing the accelerator pedal to override Mitigation.

16. Click: *Drive* to switch go forward and exit PBAS



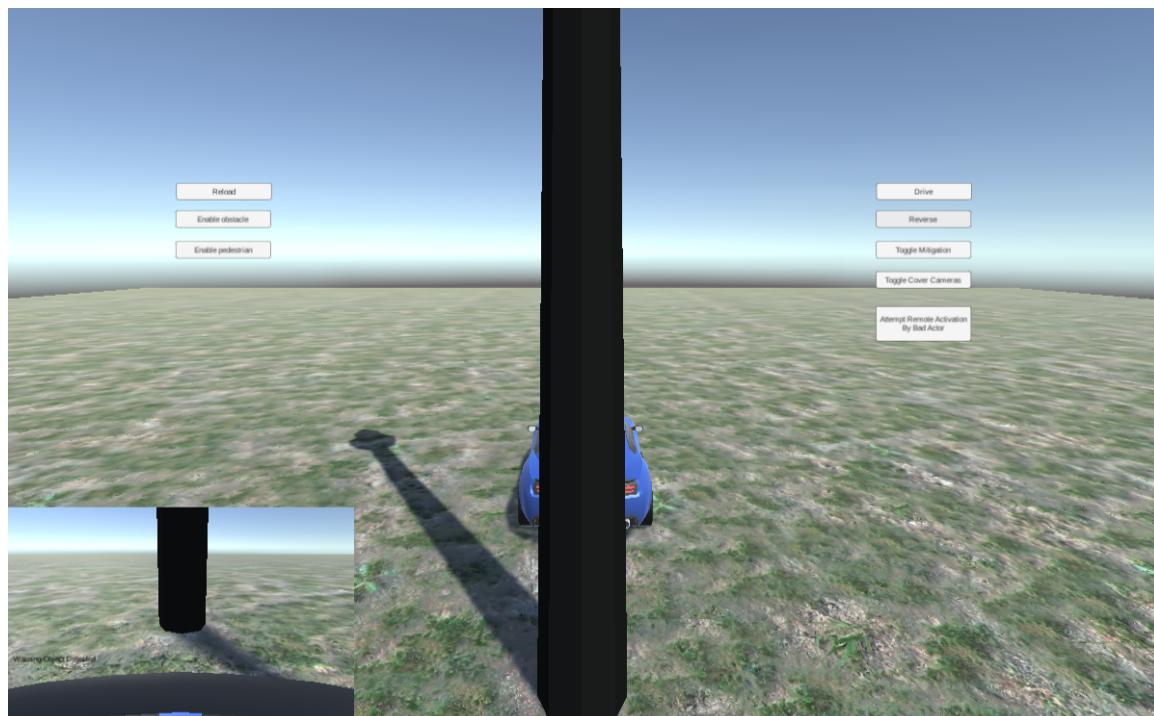
**Figure 15:** Scenario 3 - collision with pedestrian automatically mitigated.

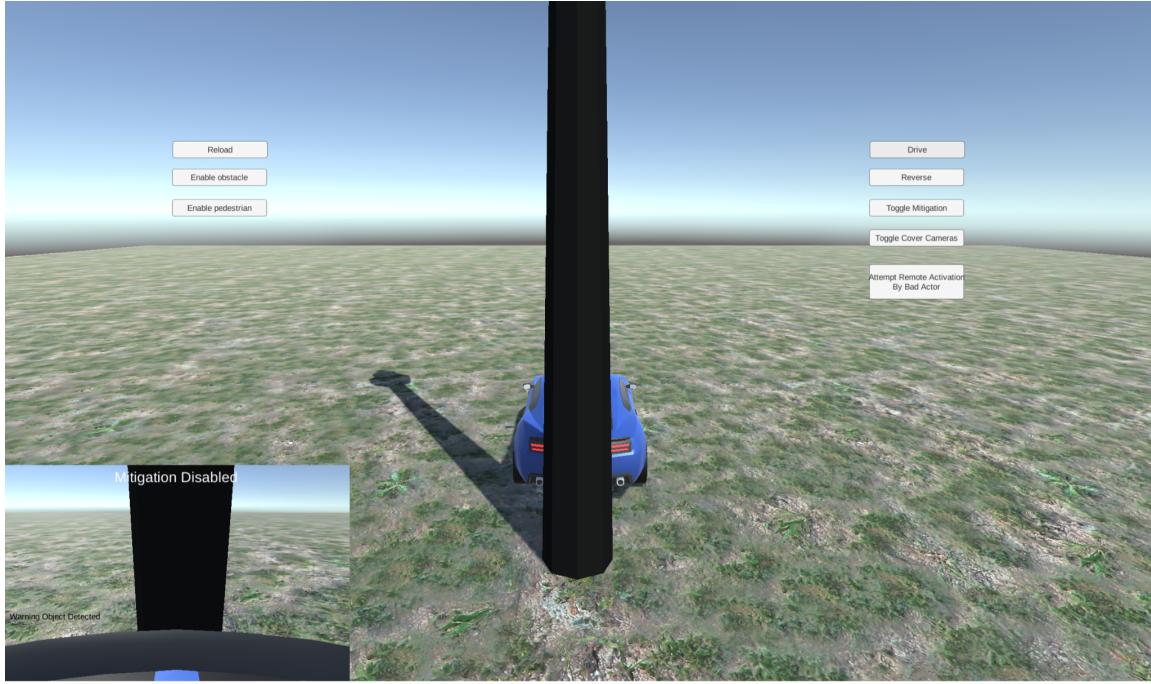
### 5.2.4 Scenario 4: Driver avoids high risk collision

In Fig. 16 below, the driver has disabled Mitigation. The system still detects the obstacle and provides warnings as the vehicle approaches the obstacle, but PBAS does not automatically apply the brakes to prevent a collision. The driver must manually press the brakes in order to stop before colliding with the obstacle.

To run this scenario on the prototype:

17. Click: *Reload*
18. Click: *Enable obstacle*
19. Click: *Reverse*
20. Press: *W* to accelerate backward toward the obstacle
21. Press: *E* to brake as needed when getting close to the obstacle
22. Click: *Drive* to switch go forward and exit PBAS





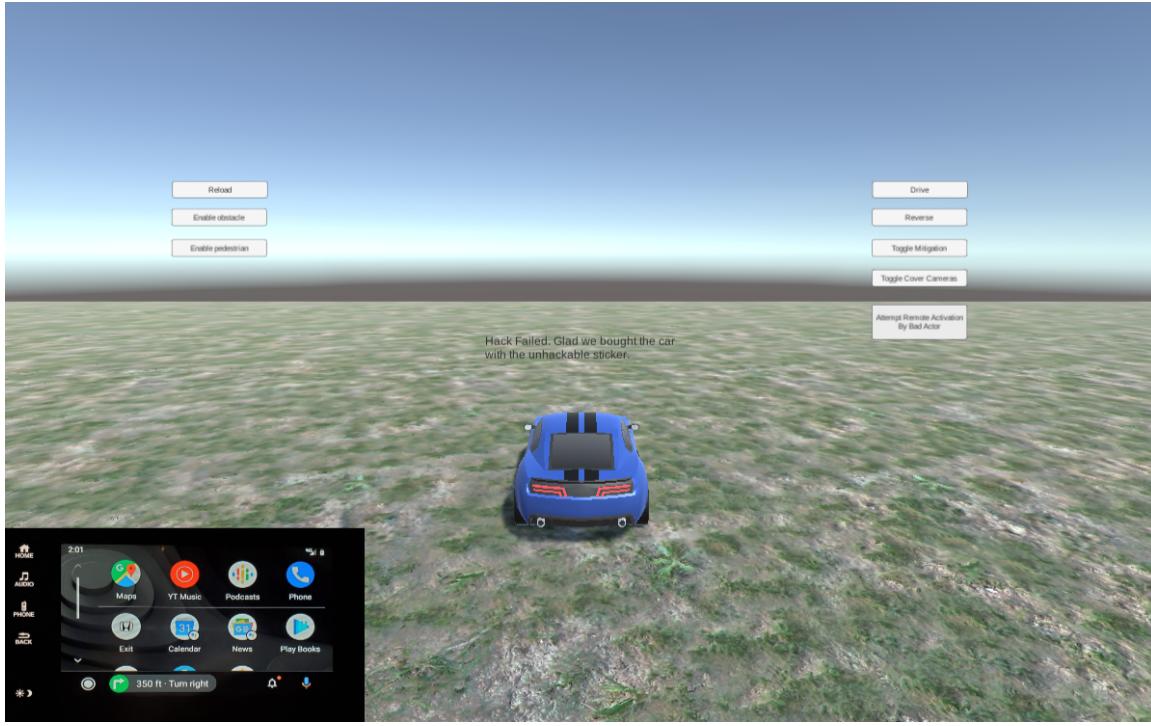
**Figure 16:** Scenario 4 - Driver brakes to manually avoid imminent collision since Mitigation is disabled (press *E*).

### 5.2.5 Scenario 5: Cyber attack prevented

In Fig. 17 below, an external bad actor attempts to remotely access PBAS to take control of the vehicle. The attempt is thwarted due to onboard security measures and mechanical failsafes.

To run this scenario on the prototype:

23. Click: *Reload*
24. Click: *Attempt Remote Activation By Bad Actor*



**Figure 17:** Scenario 5 - Cyber attack prevented, so the current behavior of the vehicle does not change.

### 5.2.6 Scenario 6: System malfunction

In Fig. 18 below, PBAS is unable to function properly. In this case, the system malfunction is due to catastrophic camera failure. Both the primary and backup sets are not providing sufficient information for PBAS to detect obstacles, so detection, warning, and Mitigation do not work. A warning that this system is not operational is provided on the InfotainmentDisplay for the driver.

To run this scenario on the prototype:

25. Click: *Reload*
26. Click: *Toggle Cover Cameras*



**Figure 18:** Scenario 6 - System failure due to exhaustive camera failure, so the driver is alerted the system is unavailable.

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## 7 Point of Contact

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