Software Requirements Specification (SRS)
Hands Free Driving System (HFDS)

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1 Introduction

Hands-Free Driving System (HFDS) is a system that is used in coordination with Adaptive Cruise Control to lessen the strain of driving for vehicle operators. The HFDS is a complex system composed of interconnecting subsystems; these subsystems are defined in Section 1.3. HFDS enables a vehicle to safely control itself, with requirements such as the driver being attentive, sufficient road data available, and more seen in Section 3. The advantages of the HFDS system allows the driver to relax while driving, taking away the stress of travel. Section 1 summarizes the Software Requirements Specifications (SRS) document, including the intent of the document, different components of the system, acronyms that will be used throughout the document, and include information on different sections within the document.

1.1 Purpose

The purpose of the SRS is to explain and model the HFDS and all the subsystems that allow it to function. The SRS aids the customer in understanding the team's interpretation of the HFDS through descriptions, diagrams, and an interactive prototype. Outlined in the SRS are a variety of different diagrams, including use case diagrams, sequence diagrams, state diagrams, and a domain model (class diagram). The diagrams work in coordination with descriptions, explanations, and a prototype (seen in Section 5) to provide details on how the HFDS functions and ensures safety.

1.2 Scope

The HFDS allows a vehicle to control itself, adjusting speed, steering, and accelerating when necessary. To achieve this goal, the HFDS contains subsystems that monitor driver attentiveness, monitor the environment surrounding the vehicle, validate road conditions in real time, and communicate with one another to ensure vehicle and driver safety. The benefits of the HFDS include making driving more enjoyable, lessening the strain of driving for the driver, and ensuring safety. When HFDS is active, the driver is no longer required to steer and accelerate the vehicle – the driver is only required to be attentive in the case of warnings. The HFDS is not a self-driving system. Similarities exist between self-driving and HFDS, however, HFDS requires driver attentiveness.

1.3 Definitions, acronyms, and abbreviations

<u>Hands Free Driving System (HFDS)</u>

- This is the name of the system that encompasses and manages all other subsystems in the HFDS. The system will ensure the car remains within its lane and will allow for seamless transitions between HFDS and Hands-On Driving.
- Once activated, the driver can remove their hands from the steering wheel and the system will steer and accelerate. If an anomalous situation is detected that necessitates the driver's input, warnings will be issued for the driver to regain control [4].

<u>Driver Assist System</u>

- The Driver Assist System is responsible for validating road conditions, current trajectory, sensor input, and predicted path. It also maintains, updates and validates the outside systems that autonomously control the vehicle, including Lane Change on Demand and Adaptive Cruise Control [4].
- If any of the autonomous systems are deemed non-functional, it will communicate that to the Conditions Validator, which will then send a warning to the Warning System.

<u>Driver Attention System</u>

- This system will monitor the attentiveness of the driver by using data collected from internal cameras and sensors. If the driver is deemed to be inattentive, the Driver Attention System will issue a warning to the Warning Subsystem [4].

Driver Interaction System

- This system will validate that all systems used to convey information to the driver are functional [4].
- If any of the systems used to convey information to the driver are non-functional, a warning will be issued to the dashboard indicating that other warning systems are not working.

Warning Subsystem

- This system will take in warnings from the conditions validator and issue them to the different systems that communicate the warning to the user. It is also responsible for the escalation of warnings if the user does not take actions to correct the warning.

Path Prediction Subsystem

- This system will take in data from LiDAR (road mappings) and GPS (projected route) to validate that the driver is on a pre-approved highway [4].
- If the driver is on a preapproved highway, the HFDS will be able to be activated.

Vehicle Control System

- A system used to control the steering wheel and takes in input from the steering wheel, brakes, and accelerator to let the driver regain control of the vehicle [4].

LiDAR

- Light Detection and Ranging, is a remote sensing method that uses a pulsed laser to measure ranges and map roads.

Global Positioning System (GPS)

- A navigational system using satellite signals to fix the location of a receiver on or above the earth's surface.

Radar

- A method of detecting distant objects and determining their position, velocity, or other characteristics by analysis of very high frequency radio waves reflected from their surfaces.

Adaptive Cruise Control

- An advanced variant of cruise control that automatically adjusts the acceleration of a vehicle to keep pace with the cars in front of the vehicle.

1.4 Organization

Section 2 will define the HFDS being modeled, the functions of the HFDS, the characteristics of the users of the HFDS and the constraints of the HFDS. Section 3 will be an enumerated list of all requirements of the system. Section 4 will feature models of the system requirements and use cases. Section 5 will detail the system prototype. Section

6 will list all references used to create this document. Section 7 contains contact information.

2 Overall Description

The following sections will analyze the functionality and characteristics of the Hands-Free Driving system. Included throughout Section 2 are reasons to use the HFDS, who the HFDS is marketed towards, and functions/constraints of the HFDS. Section 2.1 will describe the context and constraints of the system. Section 2.2 outlines the functionality of the system. Section 2.3 describes the expectations of the user. Section 2.4 explains the constraints of the system. Section 2.5 goes over assumptions and Section 2.6 lists the requirements beyond the scope of the project.

2.1 Product Perspective

The Hands-Free Driving (HFDS) is an advanced automotive technology designed for a semi-autonomous driving experience, particularly tailored for highway conditions. The HFDS allows users to activate an assisted driving feature, taking control of steering, acceleration, and braking while ensuring the vehicle stays within its lane. Operating within the framework of existing lane detection and adaptive cruise control features, the system assumes its role with reliance on precise LiDAR mapping of highways.

There are several constraints that can arise within the use of this system. There are many subsystems involved in the HFDS, and each of them must be compatible with one another. Failure of communication between subsystems could have disastrous consequences.

The user of the HFDS is also a constraint, as the user's attention and communication of system information is essential for a safe experience for those in the vehicle. Interfaces the user interacts with should be clear and intuitive.

Hardware and software should always be working properly. There are sensors, cameras, GPS, and other pieces of hardware that all work in parallel with the software to support the HFDS. For example, without proper data from GPS and sensors, the Path Prediction Subsystem would be useless and perhaps even dangerous. Communication between all these parts of the HFDS is essential to ensure safety.

2.2 Product Functions

According to the customer specification document for the HFDS by Andrew Davenport [4], the HFDS enables automatic steering, acceleration, and braking in specific highway conditions. Once activated, the system continually monitors the driver to ensure active engagement with the road. Warnings are issued in cases where the system requires driver intervention or detects distraction.

Before entering hands-free mode, the driver must be on a highway enabled by the Path Prediction Subsystem. The Driver Assist System validates road conditions, trajectory, sensor input, and predicted path. If the trajectory is deemed safe, the user can choose hands-free mode. In this state, the user can remove their hands from the steering wheel, and the vehicle enters adaptive cruise control, staying within its lane for the session.

During hands-free mode, the Driver Attention System monitors the driver's eyes and head movements, functioning effectively in all lighting conditions. Warnings are issued if the system detects improper driver engagement, with a final warning sending vibrations to prompt reengagement. If the system identifies the driver as inactive, it aborts hands-free mode, bringing the vehicle to a stop if necessary.

Apart from maintaining attentive eyes and head placement, the driver is not required to interact actively. However, the driver can regain control by manipulating the steering wheel, brakes, or throttle with any interaction.

2.3 User Characteristics

The user of the HFDS should, first and foremost, be a legal and licensed driver of the location they reside in. The user should be informed on how the system operates and be familiar with the user interfaces available. The user should also be able to see, hear, and understand warnings that are issued to them. Finally, the user should be attentive and ready to take back control of the vehicle if necessary.

2.4 Constraints

Besides the hardware and software constraints stated in section 2.1, there are other constraints from the “IEEE Recommended Practice for Software Requirements Specifications” to consider.

Performance is essential for the HFDS. Given that the system operates within a motor vehicle it is intrinsically safety critical. The system should be fast, responsive, and reliable to ensure the user of the system is safe and not taking any risk with the HFDS activated.

The HFDS should be immune to attacks targeting its software. A third party outside the user should not be able to assume control of any part of the HFDS. This could result in potential for malicious use with deadly consequences. The HFDS’s status as a safety critical system makes it extremely important that it is completely secure.

The environment is a constraint considered by the HFDS. The Driver Assist System ensures that the current trajectory that the user is on course with has all factors considered. This includes potential weather hazards, construction, or any other less than ideal driving conditions.

Above all else, as stated in section 2.1, the HFDS should always be communicating with all its supporting systems and interfaces to ensure that the user has everything they need to keep themselves safe and to create a fully functional experience. If the HFDS deems the experience unsafe or non-functional through either a high warning level or system/subsystem failure, the HFDS will relinquish control back to the driver.

2.5 Assumptions and Dependencies

It is assumed that the HFDS is implemented on a fully functional vehicle with proper steering, braking, and acceleration. It is also assumed that the hardware and software required for supporting the HFDS are fully functional as well. In cases where there is anything non-functional that could hinder the HFDS’s ability to operate, the HFDS should not be available for the user to use. This includes the systems essential to the functionality of the HFDS, such as the Adaptive Cruise Control system. The system should only operate on approved roads and when all conditions are met for the system to be turned on. While the system is active, any amount of intervention with the brake, steering wheel, or throttle will stop the HFDS.

2.6 Approportioning of Requirements

When the highest warning level has been achieved and the driver does not relinquish control, the HFDS will force the vehicle to come to a stop. The HFDS does not currently have anything in place to assure the safety of the inattentive person after the car comes to a stop.

3 Specific Requirements

Section 3 hierarchically outlines the specific requirements for the HFDS. System requirements identify the functionality that is needed by the HFDS to satisfy the customer's requirements. First, enumerated are the system requirements. Next, invariants are covered – these are "rules" that must always be true. Lastly, the cyber security requirements are listed. As the HFDS contains software, it is necessary to be protected from malicious actors.

Requirements

The HFDS allows a vehicle to be able to drive in its existing lane without needing to control the steering wheel. Outlined below are requirements comprising the HFDS.

1. To enable the HFDS via a button on the steering wheel, the following conditions are checked:
   - 1.1. Adequate LiDAR mapping of highways.
   - 1.2. The Driver Assist System must validate road conditions, current trajectory, sensory input, and projected path.
     - 1.2.1. Data from external cameras, LiDAR, and GPS.
   - 1.3. The driver must be on a highway that has been enabled by the Path Prediction Subsystem.
   - 1.4. The driver is considered attentive, meaning their eyes are focused on the road.
   - 1.5. Peripherals (icon on dash and steering wheel lights) and external cameras must be functional.
2. The system will not exceed the speed limit set by the driver and will remain in the same lane - slowing as necessary to avoid collisions with vehicles that are ahead.

2.1. The Driver Assist System must be able to send commands to the Vehicle Control Subsystem when steering and accelerating is necessary to stay in the current lane and a safe distance from vehicles and pedestrians.

3. Warnings are issued if:
    3.1. The system needs the driver to reclaim control.
        3.1.1. A subsystem is determined to be non-functional by the Conditions Validator.
        3.1.2. Unable to validate vehicle position, determined by the Conditions Validator.
        3.1.3. Insufficient road data determined by the Driver Assist System.
    3.2. The driver is deemed distracted via the Driver Attention System.
        3.2.1. Infrared cameras inside the vehicle monitor driver's eyes and head placement.
        3.2.2. The driver's head is not within 10 degrees of a forward-facing position and eyes are not focused on the road.
4. Do not irritate the driver with false warnings by only sending them when necessary.
5. Warnings include three levels (3 seconds between each warning):
    5.1. The steering wheel light flashes green (Level 1).
    5.2. The steering wheel light flashes red and the seat vibrates (Level 2).
    5.3. The steering wheel light flashes red, the seat vibrates, and an audio cue is activated (Level 3).
6. Camera monitoring must work in all lighting conditions.
7. Lane detection and adaptive cruise control are pre-existing features.
8. Once HFDS is engaged:
    8.1. The hands-free mode must enter an adaptive cruise control state and stay within its existing lane for the duration of the session.
    8.2. The system shall maintain a safe following distance to cars ahead.
    8.3. Vehicle Position Subsystem must be able to validate the vehicle's position in real time with data from:

8.3.1. External cameras by checking the vehicle's position relative to its surroundings (road, other vehicles).

8.3.2. LiDAR to determine the road's shape.

9. If the system identifies the driver as inactive, the system aborts hands-free mode:
    9.1. Hazards are turned on.
    9.2. Vehicle pulls over to the nearest shoulder.
    9.3. Vehicle slows down to a stop.
    9.4. HFDS cannot be reactivated for the remainder of the trip.
10. The driver can intervene and regain control of the vehicle by either controlling the steering wheel, brakes, or throttle.
    10.1. Any driver engagement will regain control of the vehicle.
11. The driver can disable HFDS at any time by pressing the same button used to activate.
12. The dashboard must have a visible icon lit up when HFDS is enabled.
13. Lane changing will be done through Lane Change on Demand and the system will look for an acceptable opening.
    13.1. The turn signal will be on.
    13.2. Lane change will be complete only after the system has determined it to be safe.
    13.3. If the lane change is unable to be completed, go to warning level three, and relinquish control to the driver.

Invariants

1. The HFDS shall detect any single point of failure, then relinquish control to the driver.
    1.1. A subsystem is not functional.
    1.2. Activate warning level three and give the driver control.
    1.3. HFDS cannot be activated for the remainder of the trip.
2. The driver shall be able to reclaim control of the vehicle through the steering wheel, brakes, or throttle at any time when HFDS is active.

2.1. If there are no other issues and the driver only needed to reclaim control for a brief period, HFDS can be reactivated.

2.2. If the driver steers the wheel, the light bar will turn blue for the duration, and then turn back to green when the driver is done steering.

3. The vehicle must be kept at a safe following distance of 400 meters (about 1312.34 ft), avoiding other vehicles and pedestrians.

Cybersecurity Requirements

1. HFDS components must be repaired at a verified dealership.
2. Defend against unauthorized access to the HFDS to ensure vehicle and driver safety.

4 Modeling Requirements

Section 4 uses a variety of diagrams to model the requirements in Section 3. First, the section contains a use case diagram, giving a high-level overview of the HFDS and descriptions for each use case. Next, there is a domain model (class diagram), which describes how the HFDS interacts with the real world and how the subsystems inside the HFDS interact with one another. The section then covers the sequence diagrams for the HFDS. The sequence diagrams model numerous situations for the HFDS, further describing interactions. Lastly, the section includes the state diagrams, which model different scenarios for the HFDS.

4.1 Use Case Diagram

The first diagram, Figure 1, is the use case diagram. The high-level goal of the use case diagram is to model the requirements in Section 3. The use case diagram contains eight actors (driver, external cameras, LiDAR, adaptive cruise control, brakes, steering wheel, peripherals, and internal cameras), which are seen as stick figures. The actors interact with six subsystems (Vehicle Position, Human-Machine Interface, Driver Assist, Path Prediction, Vehicle Control, and Driver Attention), which are the darker gray, smaller boxes within the HFDS boundary. The HFDS comprises of these six subsystems.

Figure 1 illustrates the functionality of the HFDS, including connections between the actors and the use cases. The connections are seen as solid black lines and dotted lines for use cases that require or extend another use case. There are a variety of different use cases, including turning on/off the HFDS, activating HFDS, issuing/displaying warnings, ensuring driver engagement, and validating safe road conditions.

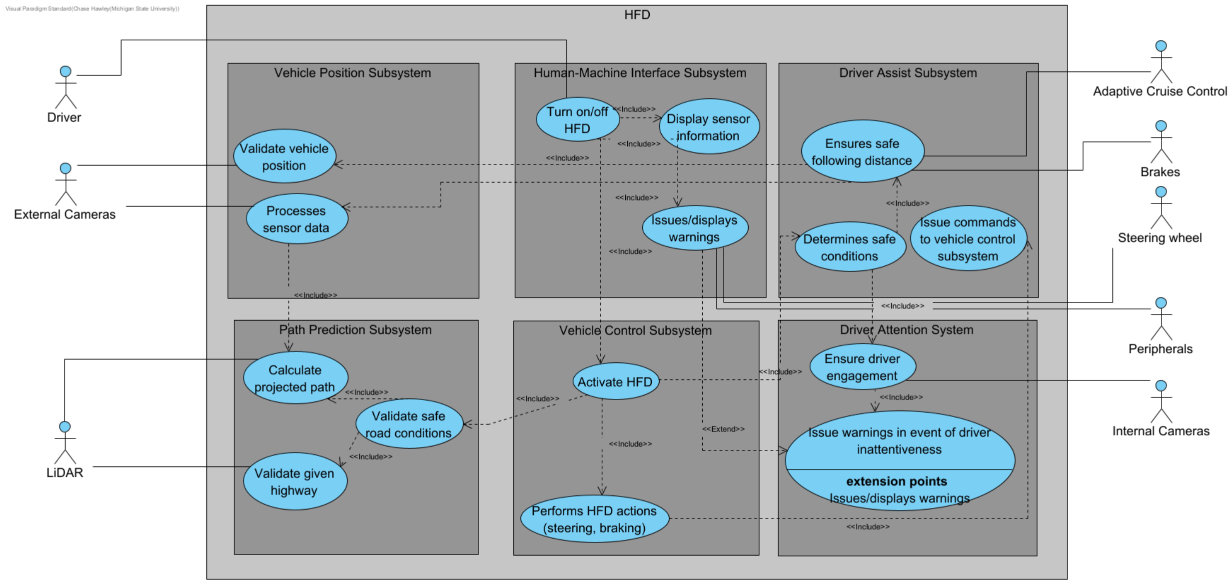

Figure 1: Use case diagram for the HFDS.

Tables 1-15 show the use case descriptions for each use case (blue bubbles in Figure 1) of the HFDS. Each table contains a use case name, the actors acting upon that use case, a description, use case type (primary or secondary), use cases the use case includes to be functional, use cases the use case extends, which requirements the use case models, and which use cases are dependent upon the use case.

Use Case:	***Validate vehicle position***
Actors:	***External Cameras***
Description:	***Validate the vehicle's position in the real world, in real time. Position relative to the road and surroundings (other cars, obstacles, etc.).***
Type:	***Primary***
Includes:	***None***
Extends:	***None***
Cross-refs:	***7.4***
Use cases:	***None***

Table 1: Validate vehicle position use case.

Use Case:	***Processes sensor data***
Actors:	***External Cameras***
Description:	***Process sensor data and ensure sensors are working. Sensor data is used to calculate the projected path.***
Type:	***Primary***
Includes:	***Calculate projected path***
Extends:	***None***
Cross-refs:	***1.2, 1.5***
Use cases:	***Calculate projected path***

Table 2: Processes sensor data use case description.

Use Case:	***Calculate projected path***
Actors:	***LiDAR***
Description:	***Use LiDAR and sensor data to calculate projected path for the trip. If the path meets requirements, then HFDS may be able to be activated. This projected path is used to validate safe road conditions.***
Type:	***Primary***
Includes:	***None***
Extends:	***None***
Cross-refs:	***1.1, 1.2.1***
Use cases:	***None***

Table 3: Calculate projected path use case description.

Use Case:	***Validate given highway***
Actors:	***LiDAR***
Description:	***Check the current highway against the list of pre-approved highways; if the highway is contained within the list of pre-approved highways, HFDS may be activated.***
Type:	***Primary***
Includes:	***None***
Extends:	***None***
Cross-refs:	***1.1, 1.2***
Use cases:	***None***

Table 4: Validate given highway use case description.

Use Case:	***Validate safe road conditions***
Actors:	***None***
Description:	***Uses Validate given highway and calculate projected path use cases to determine if road conditions are suitable to activate HFDS.***
Type:	***Primary***
Includes:	***Calculate projected path*** ***Validate given highway***
Extends:	***None***
Cross-refs:	***1.1, 1.2, 2.1***
Use cases:	***Calculate projected path*** ***Validate given highway***

Table 5: Validate safe road conditions use case description.

Use Case:	***Turn on/off HFDS***
Actors:	***Driver***
Description:	***Once road and Driver Conditions are validated, begin to perform HFDS actions. Drivers can turn on and off HFDS through a button on the steering wheel.***
Type:	***Primary***
Includes:	***Display sensor information*** ***Activate HFDS*** ***Issues/displays warnings***
Extends:	***None***
Cross-refs:	***1, 10, 11***
Use cases:	***Display sensor information*** ***Issues/displays warnings*** ***Activate HFDS***

Table 6: Turn on/off use case description.

Use Case:	***Display sensor information***
Actors:	***None***
Description:	***Display sensor information to the driver. Sensor information includes the dashboard icon if HFDS is active and steering wheel lights (green - HFDS active, yellow - warning, red - warning).***
Type:	***Primary***
Includes:	***None***
Extends:	***None***
Cross-refs:	***5.1, 5.2, 5.3, 11***
Use cases:	***None***

Table 7: Display sensor information use case description.

Use Case:	***Issues/displays warnings***
Actors:	***Steering wheel*** ***Peripherals***
Description:	***Issue warnings to the driver if caused by road conditions or driver inattentiveness. These warnings include steering wheel light changes (yellow or red), seat vibrations, and an audio warning.***
Type:	***Primary***
Includes:	***None***
Extends:	***None***
Cross-refs:	***5.1, 5.2, 5.3***
Use cases:	***None***

Table 8: Issues/displays warnings use case description.

Use Case:	***Ensures safe following distance***
Actors:	***Brakes*** ***Adaptive Cruise Control***
Description:	***Validates that the car is within safe parameters for following distance***
Type:	***Primary***
Includes:	***Validate vehicle position*** ***Processes sensor data***
Extends:	***None***
Cross-refs:	***2, 7***
Use cases:	***Validate vehicle position*** ***Processes sensor data***

Table 9: Ensures safe following distance use case description.

Use Case:	***Determines safe conditions***
Actors:	***None***
Description:	***Takes data from sensors to determine both if the path is safe and the driver is attentive. If both these conditions are met, allow activation of HFDS.***
Type:	***Primary***
Includes:	***Ensures safe following distance***
Extends:	***None***
Cross-refs:	***1.1, 1.2, 1.3, 1.4, 1.5, 8.2, 8.3, 9***
Use cases:	***Ensures safe following distance***

Table 10: Determines safe conditions use case description.

Use Case:	***Issue commands to vehicle control subsystem***
Actors:	***None***
Description:	***Alter inputs to vehicle steering to keep it within its lane.***
Type:	***Primary***
Includes:	***None***
Extends:	***None***
Cross-refs:	***2, 2.1***
Use cases:	***None***

Table 11: Issue commands to vehicle control subsystem use case description.

Use Case:	***Ensure driver engagement***
Actors:	***Internal Cameras***
Description:	***Utilize internal cameras to validate the attentiveness of the driver. Monitor eyes and head placement.***
Type:	***Primary***
Includes:	***Issue warnings in event of driver inattentiveness***
Extends:	***None***
Cross-refs:	***3.2.1, 3.2.2, 6, 8.3, 9***
Use cases:	***Issue warnings in event of driver inattentiveness***

Table 12: Ensure driver engagement use case description.

Use Case:	***Issue warnings in event of driver inattentiveness***
Actors:	***None***
Description:	***If Ensure driver engagement detects an inattentive driver, send warning to Issues/displays warning.***
Type:	***Primary***
Includes:	***None***
Extends:	***Issues/displays warnings***
Cross-refs:	***3.2***
Use cases:	***None***

Table 13: Issue warnings in event of driver inattentiveness use case description.

Use Case:	***Activate HFDS***
Actors:	***None***
Description:	***Validate that all conditions are acceptable for the HFDS to activate; if so, activate HFDS.***
Type:	***Primary***
Includes:	***Validate safe road conditions*** ***Determines safe road conditions***
Extends:	***None***
Cross-refs:	***1***
Use cases:	***Validate safe road conditions*** ***Determines safe road conditions***

Table 14: Active HFDS use case description.

Use Case:	***Performs HFDS actions (steering, braking)***
Actors:	***None***
Description:	***When HFDS is active, keep the vehicle and driver safe by steering and braking/accelerating when necessary.***
Type:	***Primary***
Includes:	***Issue commands to vehicle control subsystem*** ***Activate HFDS***
Extends:	***None***
Cross-refs:	***8.1, 8.2, 8.3***
Use cases:	***Issue commands to vehicle control subsystem*** ***Activate HFDS***

Table 15: Performs HFDS actions (steering, braking) use case description.

4.2 Domain Model (Class Diagram)

The domain model diagram describes how the system interacts with the real world, as well as how internal components of the system interact with each other. The Driver Interaction System is responsible for allowing the driver to control the vehicle manually, as well as communicating the system state to the driver. The Warning Subsystem is responsible for issuing warnings to the system and defining their criticality and significance. The Driver Assist System is responsible for validating the conditions needed for activating HFDS, and monitoring the functionality of and issuing commands to any system that autonomously controls the vehicle, such as Lane Change on Demand and Adaptive Cruise Control. The Driver Attention Subsystem ensures that the driver is paying adequate attention to the road. Lastly, the Vehicle Control Subsystem handles controlling the vehicle, as well as taking/relinquishing control to the driver.

Figure 2 illustrates the subsystems and actors as classes that have associations with one another. Classes are diagrammed as blue squares, and associations are black lines. The black lines with open diamonds at one end represent aggregation – one class has a relationship with another.

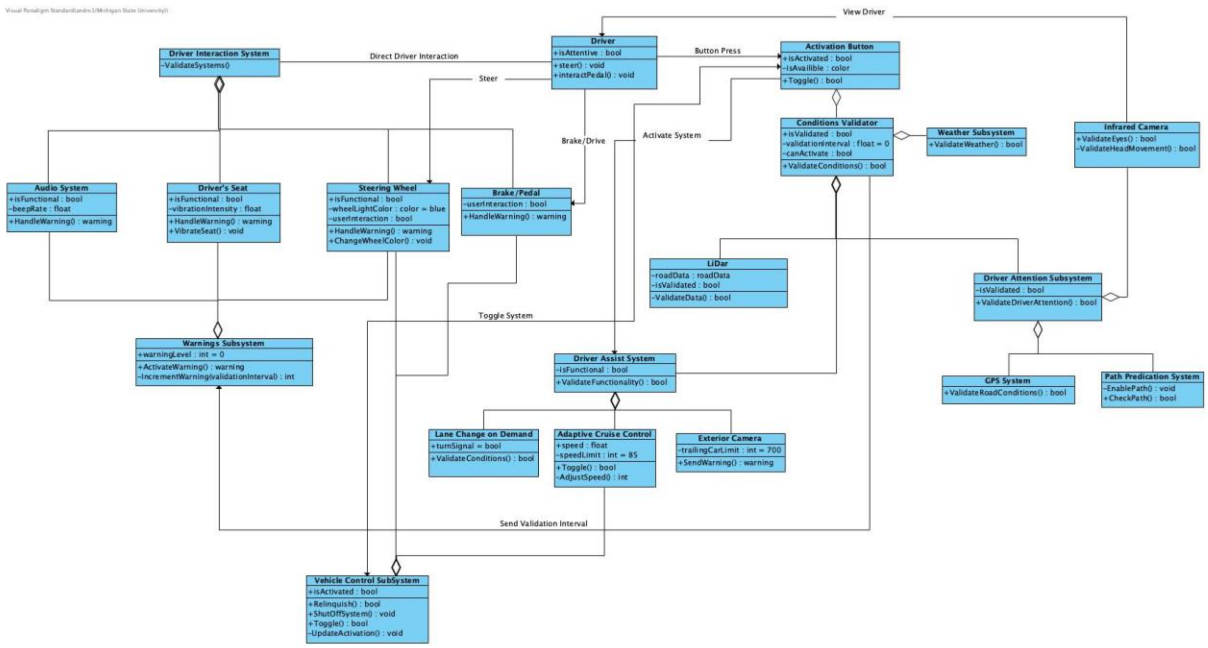

Figure 2: Domain model for HFDS.

Tables 16-35 are data dictionaries which provide specify details of each class in the domain model including: the class name, the class attributes, the class operations, the class relationships, and descriptions.

Element Name		**Description**
Activation Button		The button on the steering wheel that activates the Hands-Free Driving system.
Attributes		
	isActivated: bool	Whether the system is currently enabled or not.
	isAvailable: color	The color that is displayed in the button's back light, indicating whether the system is available.
Operations		
	Toggle(): bool	Enables/Disables the system and returns current activation state.
Relationships		Activation Button is used by the Driver to enable the system through a button press. Additionally, the Activation Button interacts with the Conditions Validator to determine whether the system is available.
UML Extensions		N/A

Table 16: Data dictionary for the Activation Button class.

Element Name		**Description**
Adaptive Cruise Control		The system responsible for maintaining a safe following distance and speed.
Attributes		
	speed: float	The current speed of the vehicle.
	speedLimit: int	The current speed limit according to road data.
Operations		
	Toggle(): bool	Enables/Disables the system and returns current activation state.
	SlowVehicle(): int	Detects whether there is a vehicle going below the set speed ahead and returns its speed.
Relationships		Adaptive Cruise Control is a sub-model of the Driver Assist System, which encapsulates all of the systems that directly control the car.
UML Extensions		N/A

Table 17: Data dictionary for the Adaptive Cruise Control class.

Element Name		**Description**
Audio System		The system that sends audio signals to the speakers and plays them to the driver.
Attributes		
	isFunctional: bool	Whether the audio system is currently functioning as expected.
	beepRate: float	How frequently (in seconds) the audio system should play the warning beeps.
Operations		
	SendWarning(): Warning	Sends a warning to the speakers, initiating the beeping alert for an inattentive driver.
Relationships		Audio System is a sub-model of the Driver Interaction System, which encapsulates all of the systems that interface with the driver.
UML Extensions		N/A

Table 18: Data dictionary for the Audio System class.

Element Name		**Description**
Conditions Validator		The system that is responsible for ensuring all initial conditions are good enough to activate the system.
Attributes		
	isValidated: bool	Whether the current conditions are good enough to enable the system.
	validationInterval: float	The frequency (in seconds) that the conditions will be reevaluated to determine whether the system is still available.
Operations		
	ValidateConditions(): bool	Checks the current conditions and returns whether they meet the requirements for system availability.
Relationships		Conditions Validator is used by the Activation Button to display the current validation status through its backlight. It also uses LiDAR and Driver Attention Subsystem to validate the current conditions.
UML Extensions		N/A

Table 19: Data Dictionary for the Conditions Validator class.

Element Name		**Description**
Control System		The system that determines whether the driver is trying to resume manual control without a press of the Activation Button and disables the system after failure to pay attention.
Operations		
	Relinquish(): bool	Returns control to the driver after detecting input from the driver to a control system.
	ShutOffSystem(): void	Permanently disables the HFDS when the driver has not responded to warnings adequately.
Relationships		The Control System receives information from the Warnings Subsystem when the Driver has failed to respond to warnings adequately, disabling the HFDS for the rest of the drive.
UML Extensions		N/A

Table 20: Data dictionary for the Control System class.

Element Name		**Description**
Driver		A model representing information about the driver.
Attributes		
	isAttentive: bool	Whether the driver has been determined to currently be attentive or not.
Relationships		Interacts with the Activation Button to enable/disable the system. Is observed by the Infrared Camera to determine whether the Driver is currently attentive. Interacts with the Driver Interaction System by observing given warnings/retaking control.
UML Extensions		N/A

Table 21: Data dictionary for the Driver class.

Element Name		**Description**
Driver Assist System		Determines whether the Driver Assist System is functional to allow the HFDS to function.
Attributes		
	isFunctional: bool	Whether the Driver Assist System is considered functional.
Operations		
	ValidateFunctionality(): bool	Updates whether the Driver Assist System is considered functional.
Relationships		Checks the functionality of the Lane Change on Demand, Adaptive Cruise Control, and Exterior Camera systems.
UML Extensions		N/A

Table 22: Data dictionary for the Driver Assist System.

Element Name		**Description**
Driver Attention Subsystem		Coordinates data to determine whether the driver is paying sufficient attention to continue operation.
Attributes		
	isValidated: bool	Whether the driver is paying sufficient attention to continue operation.
Operations		
	ValidateDriverAttention(): bool	Checks current data on driver’s attention and decides whether it meets the requirements for safe operation.
Relationships		Related to the Warning Subsystem by telling it to start/stop the alert protocol when the Driver stops/resumes paying attention to the road. Related to the Infrared Camera by ensuring that the Driver is paying sufficient attention to the road. Related to the GPS system, LiDAR system, and Path Prediction System by ensuring that the driver’s eye position is close enough to the current predicted path.
UML Extensions		N/A

Table 23: Data dictionary for the Driver Attention Subsystem.

Element Name		**Description**
Driver Interaction System		Determines whether all systems that interact directly with the driver are functional.
Attributes		
	isValidated: bool	Whether the systems are currently considered functional
Operations		
	ValidateSystems(): bool	Checks whether the systems are currently functional and updates isValidated.
Relationships		Checks whether the Audio System, Steering Wheel, and Driver's Seat systems are functioning to ensure warnings will be adequately delivered.
UML Extensions		N/A

Table 24: Data dictionary for the Driver Interaction System.

Element Name		**Description**
Driver’s Seat		Controls the vibration of the driver’s seat during warnings.
Attributes		
	isFunctional: bool	Whether the vibration system is functional.
	vibrationIntensity: float	How hard the vibrations sent through the driver’s seat should be
Operations		
	SendWarning(): warning	Receives a warning and propagates it, vibrating the seat if the warning stage is critical enough.
	VibrateSeat(): void	Vibrates the driver’s seat to warn them about lack of attention.
Relationships		The Driver’s Seat is checked for functionality by the Driver Interaction System and warnings are sent by the Warnings Subsystem.
UML Extensions		N/A

Table 25: Data dictionary for the Driver’s Seat class.

Element Name		**Description**
Exterior Camera		Observes the road for obstructions or unexpected conditions.
Attributes		
	trailingCarLimit: int	The minimum distance (in feet) to follow a detected car ahead.
Operations		
	SendWarning(): warning	Sends a warning through the system when unexpected conditions, such as construction, arise.
Relationships		The Exterior Camera is checked for functionality by the Driver Assist System.
UML Extensions		N/A

Table 26: Data dictionary for the External Camera class.

Element Name		**Description**
GPS System		Gets the current GPS position of the vehicle.
Operations		
	ValidateRoadConditions(): bool	Determines whether the roads are safe for HFDS operation based on the position of the car.
Relationships		The GPS System interacts with the Driver Attention Subsystem by providing current position data which is used with path prediction to determine where the driver should be looking.
UML Extensions		N/A

Table 27: Data dictionary for the GPS System class.

Element Name		**Description**
Infrared Camera		Observes the driver’s eye and head position to provide data on driver attention.
Operations		
	ValidateEyes(): bool	Determines the driver’s current eye position relative to the car and returns whether it is “forward.”
	ValidateHeadMovement(): bool	Determines the driver’s current head position and whether it indicates that the driver is looking at the road.
Relationships		The Infrared Camera sends data to the Driver Attention Subsystem so that it can determine whether or not to send a warning to the driver.
UML Extensions		N/A

Table 28: Data dictionary for the Infrared Camera class.

Element Name		**Description**
Lane Change on Demand		Allows for automated lane changes with the press of a button.
Attributes		
	turnSignal: bool	Whether the turn signal is currently active.
Operations		
	ValidateConditions(): bool	Whether the current conditions allow for a safe merge to be completed
Relationships		The Lane Change on Demand system is related to the Driver Assist System through being checked for functionality by it.
UML Extensions		N/A

Table 29: Data dictionary for the Lane Change on Demand class.

Element Name		**Description**
LiDAR		Verify whether adequate road data exists and provide it for path prediction.
Attributes		
	roadData: RoadData	LiDAR scan data on the road currently being traversed.
	isValidated: bool	Whether the LiDAR data is of sufficient quality for path prediction.
Operations		
	ValidateData(): bool	Determine whether the road data is sufficient for path prediction.
Relationships		The LiDAR system interfaces with the Driver Attention Subsystem to provide data for path prediction.
UML Extensions		N/A

Table 30: Data dictionary for the LiDAR class.

Element Name		**Description**
Path Prediction System		Determines the current projected path for the vehicle.
Operations		
	EnablePath(): void	Enables the path prediction system to start gathering data from LiDAR and GPS.
	CheckPath(): bool	Returns whether the projected path is safe to traverse during HFDS.
Relationships		The Path Prediction System provides path data to the Driver Attention Subsystem to validate the driver's attention in combination with eye positioning.
UML Extensions		N/A

Table 31: Data dictionary for the Path Prediction System.

Element Name		**Description**
Steering Wheel		A representation of the car's steering wheel.
Attributes		
	isFunctional: bool	Whether the steering of the car is functional.
	wheelLightColor: color	The current color of the warning light on the steering wheel.
Operations		
	SendWarning(): warning	Receives a warning and propagates it, changing the steering wheel's light color to match the warning's severity.
	ChangeWheelColor(): void	Changes the steering wheel's light color to match received warnings.
Relationships		The Steering Wheel is a subcomponent of the Driver Interaction System and receives warnings from the Warnings Subsystem.
UML Extensions		N/A

Table 32: Data dictionary for the Steering Wheel class.

Element Name		**Description**
Warnings Subsystem		Determines what level of warning to send out.
Attributes		
	warningLevel: int	The current severity of the warnings being sent out.
Operations		
	ActivateWarning(): warning	Sends a warning through the system, activating other system's warning responses.
Relationships		The Warnings Subsystem sends warnings to the Audio System, Steering Wheel, and Driver's Seat to alert the driver to any warnings. It receives information from the Driver Attention Subsystem to determine if the driver is paying sufficient attention.
UML Extensions		N/A

Table 33: Data dictionary for the Warnings Subsystem class.

Element Name		**Description**
Weather Subsystem		Controls the vibration of the driver’s seat during warnings.
Operations		
	ValidateWeather(): bool	Determine whether the current weather conditions allow for safe operation of the HFDS.
Relationships		The Weather Subsystem provides information on the weather conditions to the Conditions Validator.
UML Extensions		N/A

Table 34: Data dictionary for the Weather Subsystem class.

Element Name		Description
Brake/Pedal		The brake/pedal in the vehicle that the driver can interact with.
Attributes		
	userInteraction: bool	True if user is interacting with brake/pedal, false otherwise.
Operations		
	HandleWarning(): warning	Aids in relinquishing control from HFDS to the driver when there is driver interaction with the brake/pedal.
Relationships		The Driver can press the brake/pedal to regain control from HFDS. Part of the Driver Interaction System, as the driver can interact with the brake/pedal. Also, part of the Vehicle Control Subsystem. Used for controlling the vehicle through accelerating/braking.
UML Extensions		N/A

Table 35: Data dictionary for the Brake/Pedal class.

4.3 Sequence Diagrams

The following figures are sequence diagrams depicting how the system operates during various use cases. They illustrate the flow of communication between subsystems in the HFDS.

Figure 3 shows the HFDS's update process for validating the conditions for operation, which is continuously repeated, returning a Boolean value to the Vehicle Control Subsystem. A signal is sent to the Driver Interaction System to validate its relevant systems and ensure they are functional. A value is returned describing whether the Driver Interaction System is valid. This action also starts the Conditions Validator's loop as depicted in Figure 3, which ensures that all relevant systems are safe for operation. The Conditions Validator validates the weather, validates the LiDAR data, validates the functionality of the Driver Assist System, and validates the functionality of the Driver Attention Subsystem. If all of these validations are valid, the Conditions Validator then sends a Boolean back to the Vehicle Control Subsystem allowing the Driver to activate the HFDS via the Activation Button.

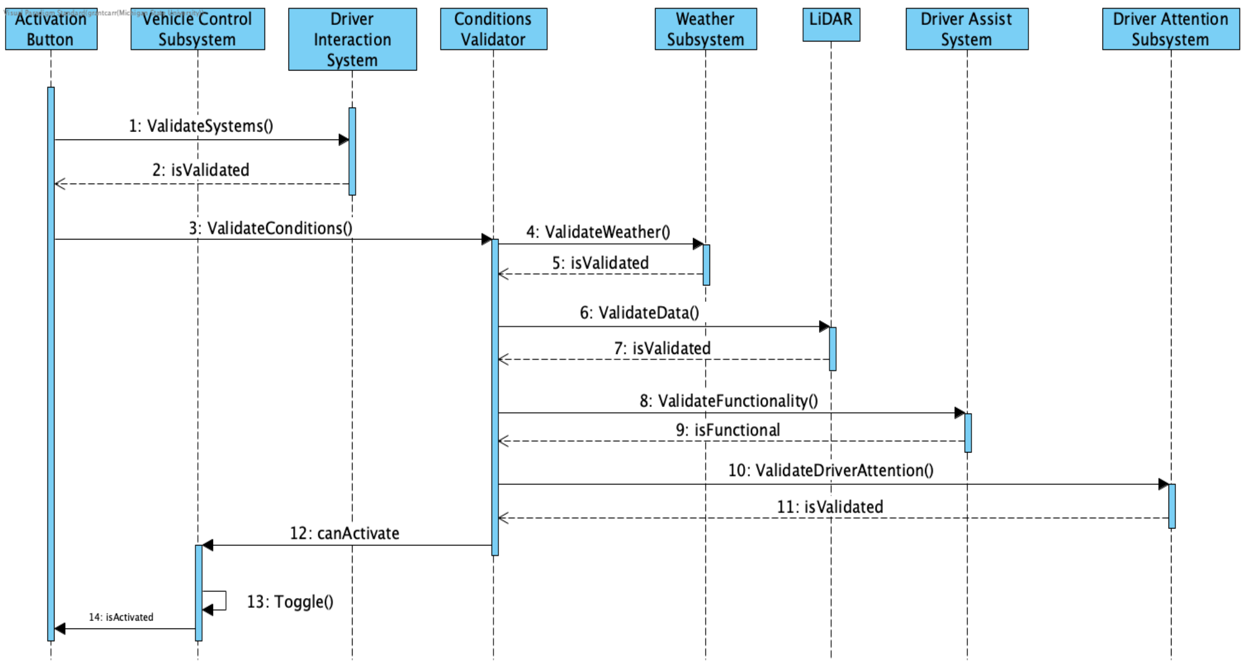

Figure 3: The HFDS reevaluates conditions continuously while active.

Figure 4 shows what happens when the user presses the activation button to enable the HFDS. If the HFDS is not active, a signal is sent to the Conditions Validator, beginning the validation loop seen in Figure 3. If the vehicle is safe for HFDS operation, a signal is sent to the Vehicle Control Subsystem, activating the HFDS.

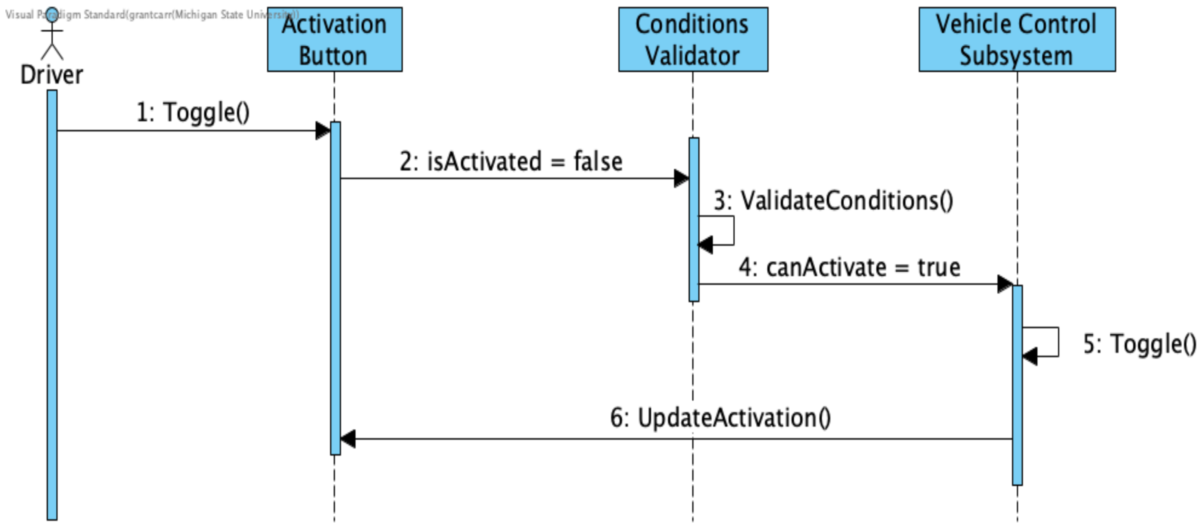

Figure 4: The HFDS is activated by pressing the Activation Button.

Figure 5 shows the HFDS being manually deactivated through the press of the Activation Button. This disables the system and sends a notification back to the button to allow its status light to change to the disabled color. It also sends a signal to the Vehicle Control Subsystem to deactivate the HFDS.

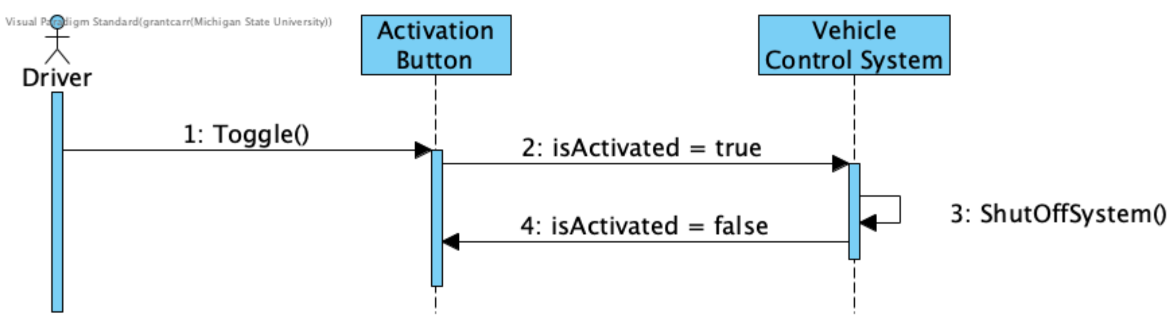

Figure 5: The HFDS is deactivated by pressing the Activation Button.

Figure 6 shows the driver reclaiming control from the HFDS by interacting with the steering wheel or pedals of the car. Interaction with the steering wheel or brakes sends a warning to the Vehicle Control System, notifying it to relinquish control of the vehicle from the HFDS. Upon sensing the interaction, the HFDS will safely relinquish control.

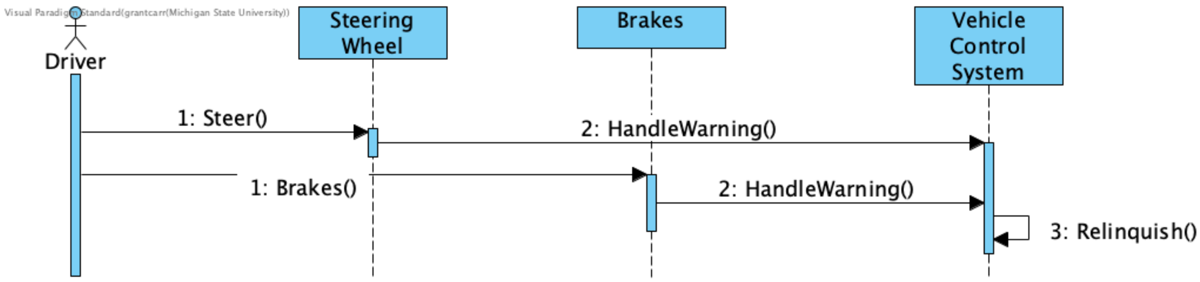

Figure 6: The driver reclaims control through manual interaction with the vehicle's controls.

Figure 7 shows how a warning is issued by the Conditions Validator and propagated to the necessary components by the Warning Subsystem. When a warning is issued, the Warning Subsystem will send the signal to the Driver Interaction System. Depending on the warning level, the dashboard, the driver's seat, and/or Audio System will inform the driver. If the warning is Level 3, seen in Section 3, and the driver does not interact with the vehicle, the Vehicle Control System will shut off the system and pull over to the nearest shoulder.

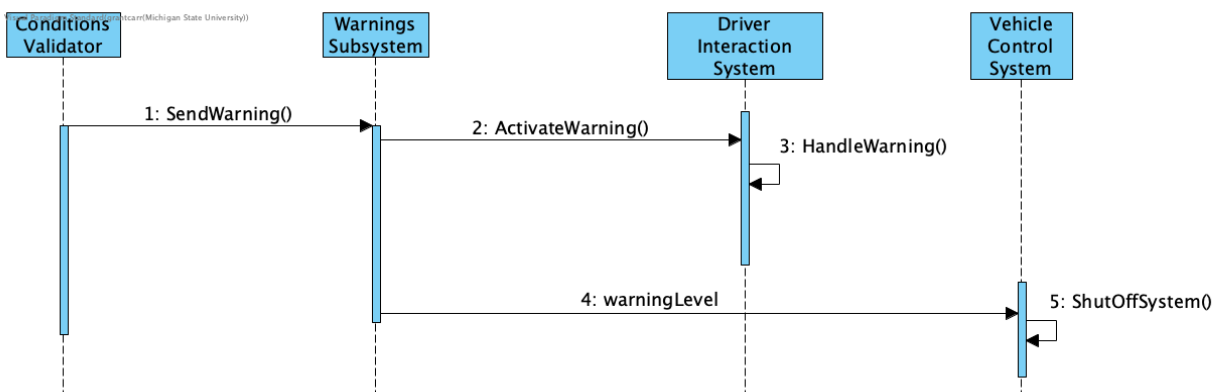

Figure 7: The Conditions Validator issues a warning that is communicated through the Driver Interaction System.

Figure 8 depicts how the HFDS ensures safe and controlled steering and acceleration. The Path Prediction System uses GPS and LiDAR data to plot the future path and check that it is safe in real time. Based on the path and safety, instructions are sent to the Vehicle Control Subsystem. The Vehicle Control Subsystem then issues controls to the Steering Wheel and Adaptive Cruise Control system to ensure that the vehicle safely remains on the path at a set speed.

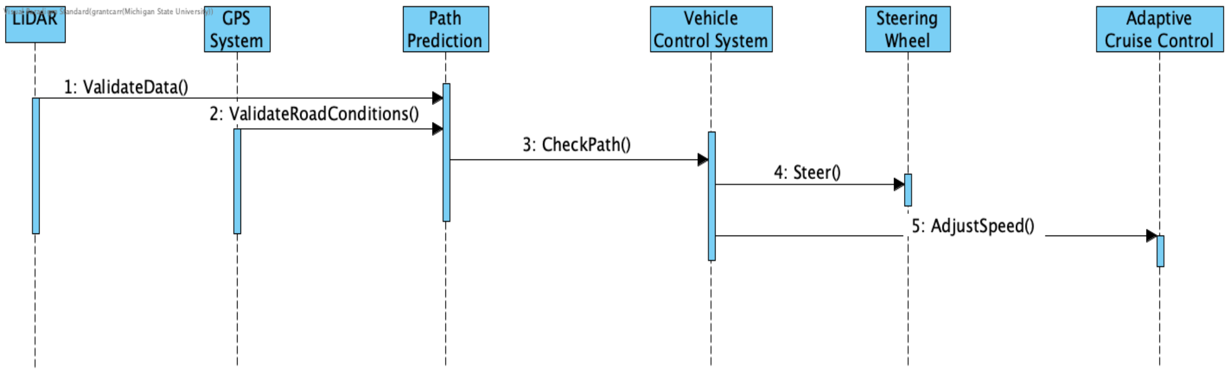

Figure 8: The Path Prediction System calculates the vehicle's future path and issues commands to the steering wheel and Adaptive Cruise Control.

4.4 State Diagram

The state diagram for the Hands-Free Driving System is provided in Figure 9. This shows the entry point for the system, as well as intermediate states and termination states, and how these states are reached.

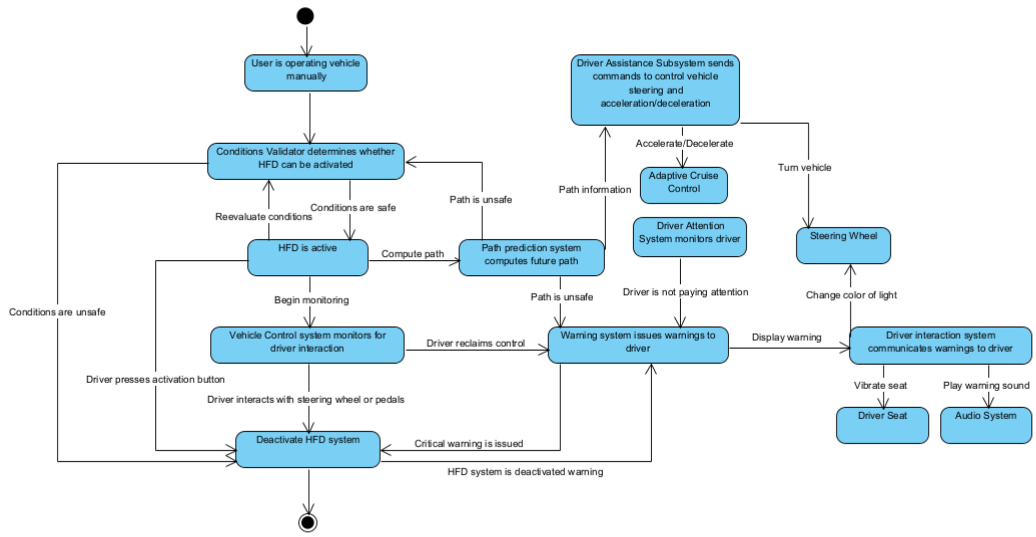

Figure 9: The state diagram for HFDS showing entry, intermediate, and termination states.

5. Prototype

The prototype highlights the various ways the driver can interact with the Hands-Free Driving system, and how the system will respond to those inputs. The final version will contain checks for exterior and interior sensors, LiDAR data, and more. In addition to these checks, the car will be able to be driven around a track and will include parameters for obstacle avoidance.

5.1 How to Run Prototype

Any chromium-based browser (Chrome, Edge, Opera, Brave, etc.) should be capable of running these modules. No plugins or downloads are required. This link will direct you to a page containing all five the scenarios: https://www.cse.msu.edu/~dagost37/prototype.html [5].

5.2 Sample Scenario

Outlined in Figures 10-17 are different scenarios provided within the prototype. Each interactive module highlights possible scenarios encountered when using the HFDS. These modules simulate the warning system; specifically, how the warning system responds to different kinds of driver behavior.

Interactive Module 1:

This interactive module allows the user to toggle HFDS on/off and choose whether they are "paying attention" to the road. If HFDS is not active, then the light bar on the wheel stays white (Figure 10). Not paying attention does nothing if HFDS is inactive. If HFDS *is* active, the light bar on the wheel turns green (Figure 11). Not paying attention while HFDS is active will cause the system to begin progressing its way through three stages of warnings (Figure 12).

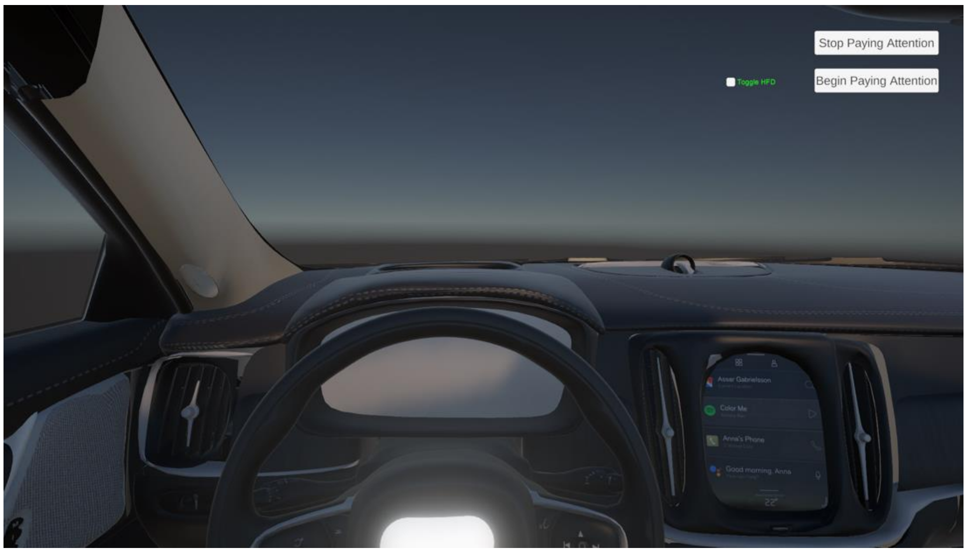

Figure 10: HFDS is not active.

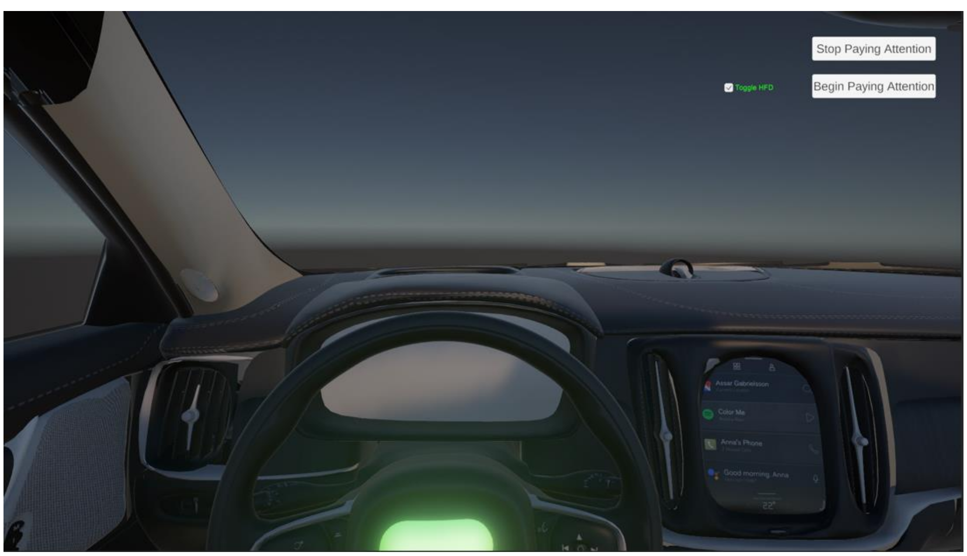

Figure 11: HFDS is active, driver is paying attention to the road.

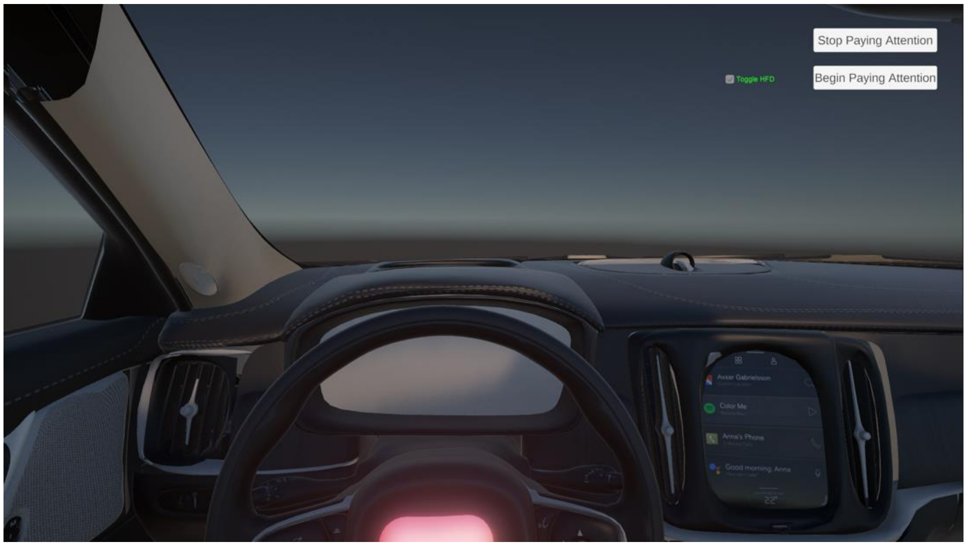

Figure 12: Driver has not been paying attention to the road for over 6 seconds and is now in warning level 2 – light bar flashes red, and the seat vibrates.

Interactive Module 2:

In this interactive module, HFDS is already active (Figure 13), but the user can turn the wheel left and right. While the wheel is being used by the driver, the light bar turns blue (Figure 14), signifying that HFDS is relinquishing control to the driver, but is ready to resume afterwards.

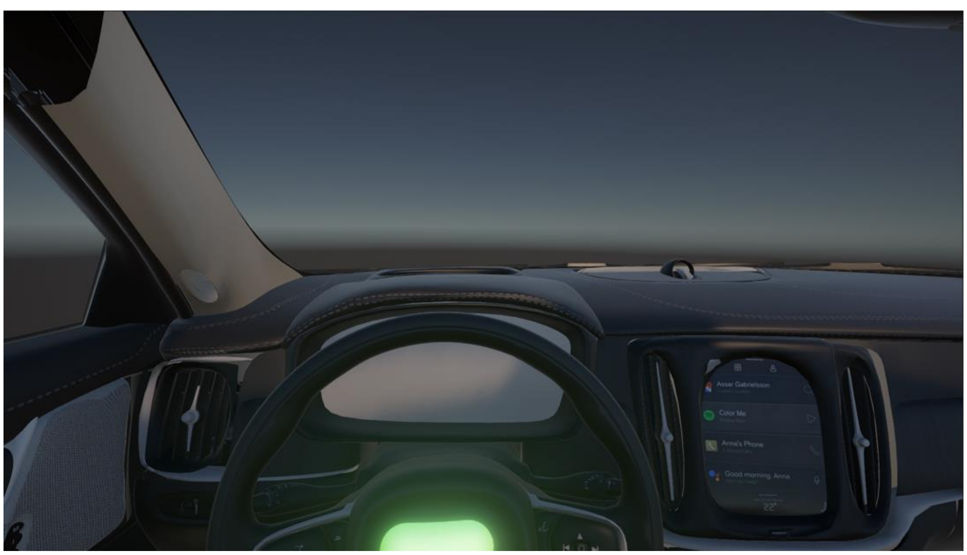

Figure 13: HFDS is actively in control of the car.

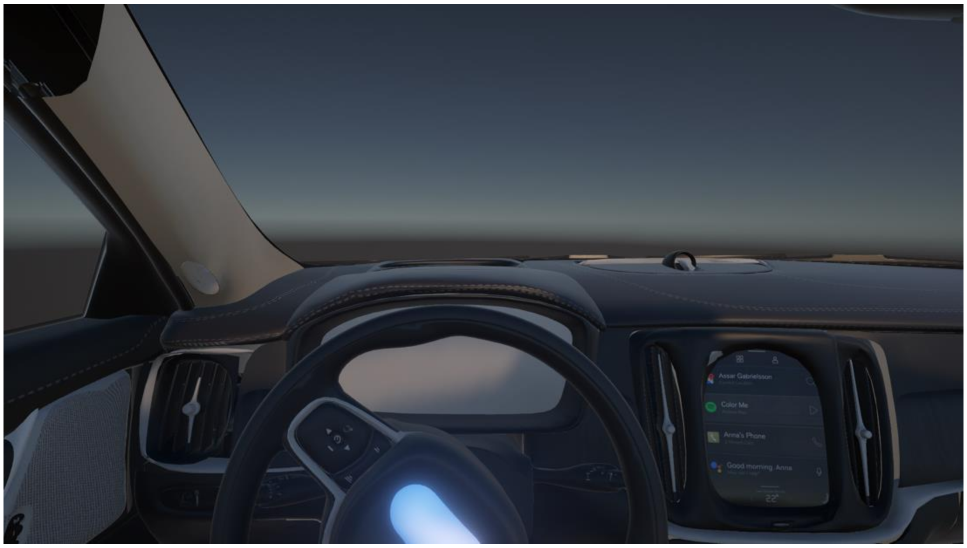

Figure 14: The driver turns the wheel right, HFDS remains on but is temporarily relinquishing control to the driver while they steer – signified by the blue light bar.

Interactive Module 3:

This interactive module highlights what happens during a level 1 warning (light bar flashes green, Figure 15). A level one warning occurs after the driver fails to pay attention for 3 consecutive seconds.

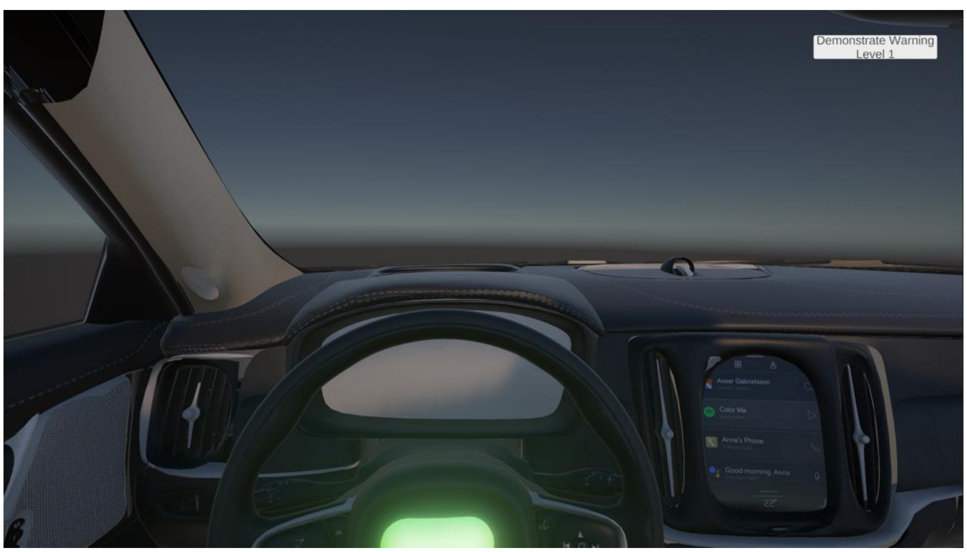

Figure 15: A level one warning, light bar flashes green

Interactive Module 4:

This interactive module highlights what happens during a level 2 warning (light bar flashes red and seat begins to vibrate, Figure 16). A level two warning occurs after the driver fails to pay attention for 6 consecutive seconds.

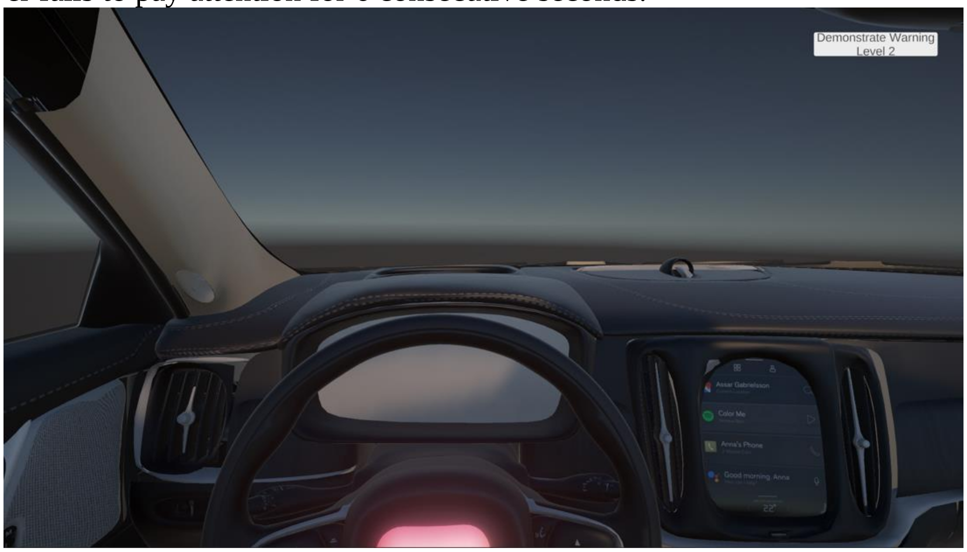

Figure 16: A level two warning, light bar flashes red and seat begins to vibrate, which is simulated by camera shaking.

Interactive Module 5:

This interactive module highlights what happens during a level 3 warning (light bar flashes red, seat begins to vibrate, and an audio cue asks the driver to pay attention to the road, Figure 17). A level three warning occurs after the driver fails to pay attention for 9 consecutive seconds. If the driver fails to regain attentiveness to the road during this warning stage, the vehicle will activate the hazards, and begin slowing to a stop. The driver is informed of this through an audio cue, and HFDS will no longer be usable for the duration of the current trip.

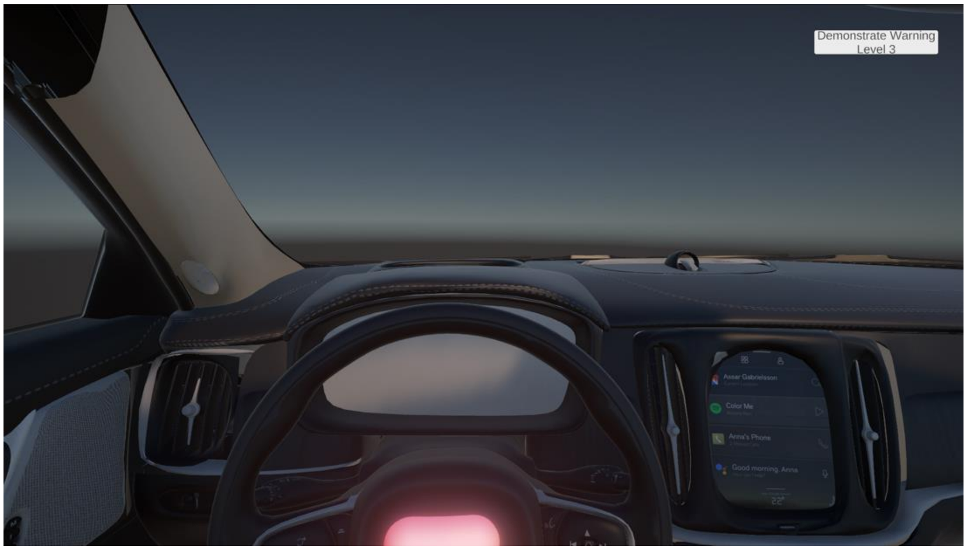

Figure 17: A level three warning, light bar flashes red, seat vibrates, and an audio cue asks the driver to pay attention to the road.

6. References

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[2] "Super Cruise - Hands Free Driving." Super Cruise - Hands Free Driving | Cadillac Ownership, Cadillac, www.cadillac.com/technology/super-cruise. [Accessed 3 Oct. 2023].

[3] "What Is Super CruiseTM?" GMC, GMC, www.gmc.com/connectivity-technology/super-cruise. [Accessed 3 Oct. 2023].

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[5] A. Dagostino et al, "CSE435: Hands Free Driving – Group 3." Michigan State University, https://cse.msu.edu/~dagost37/. [Accessed 13 Nov. 2023].

7. Point of Contact

For further information regarding this document and project, please contact **Prof. Betty H.C. Cheng** at Michigan State University (chengb at msu.edu). All materials in this document have been sanitized for proprietary data. The students and the instructor gratefully acknowledge the participation of our industrial collaborators.