Software Requirements Specification (SRS)

HFDS1

Authors: J. Landers, E. Barrett, N. Holley, J. Pauls, & A. DuBois

Customer: Mr. Andrew Davenport, Insurance Quantified, formerly with GM

Instructor: Dr. Betty H.C. Cheng

Introduction

Data from the Michigan Department of Transportation 2022 Year End Report shows that there were 64,220 rear-end motor vehicle accidents during the year [1]. There were also 36,945 same-direction sideswipe accidents [1]. While the Michigan Department of Transportation does not reveal how many of these accidents were in highway conditions, it is given that there were 26,977 crashes on Interstate Routes [1] – roads that would allow the use of a Hands-Free Driving System (HFDS). Using this data, it is evident that there is a need for the development of safe and reliable embedded systems that allow for less stressful driving, while prioritizing the safety of the driver and other vehicles or obstacles.

This section describes the purpose of this requirements document, the scope of the project, defines any terms or abbreviations necessary to understand this document, and finally briefly details the organization for the remainder of the document.

1.2 Purpose

The purpose of this document is to provide clear and adequate information for the HFDS in a way that displays satisfaction of the customer's requirements and gives enough detail to design and implement this system. This document is intended to be understood by both developers, for the design and implementation of the system, and by the stakeholders, to ensure a clear understanding of all aspects of this system.

1.3 Scope

The HFDS is an embedded system in an automotive vehicle with the main objective of preventing injuries, collisions, and damage while the vehicle is automatically driving in highway conditions and without input for the wheel and speed. The HFDS to be developed uses mapping and radar data, as well as values from onboard sensors, to process and to be sent to the Driver Assist System and the Vehicle Control System. This processed data allows the HFDS to automatically and safely drive, following the road, without the need for input and intervention by the driver.

According to the National Highway Traffic Safety Administration's (NHTSA) "Road to Full Automation," HFDS can be classified as "additional assistance" [2]. The HFDS system detects lanes, driver attention, and any obstacles in the path of the vehicle in order to maintain proper safety and to avoid any accidents. If any of these cannot be detected, the system will utilize the Driver Attention System to issue warnings to the driver, to indicate a call to action, before determining that a complete disabling of the system and a full stop of the vehicle are necessary.

1.4 Definitions, acronyms, and abbreviations

Hands-Free Driving System (HFDS): The entire system that is described in this document.

LiDAR: The mapping technology used to determine whether a road allows for the use of the HFDS.

Obstacle: Any person, vehicle, or other object that the vehicle could possibly collide with while driving and must avoid.

Haptic Feedback System: The system used within the vehicle that can give the driver vibrations as warnings while the HFDS is in use.

Human Machine Interface (HMI): A screen display that is located to the right of the steering wheel. It can display both entertainment and general information about the vehicle.

1.5 Organization

After this section, the remainder of the requirements document is organized as follows. To begin, Section 2 describes the HFDS system. Section 3 contains an enumerated list of requirements for the HFDS. Next, Section 4 models the HFDS with a variety of diagrams and descriptions. Section 5 contains information about the prototyping of the HFDS. Section 6 includes any references used within this document. Finally, Section 7 details a point of contact for any additional inquiries.

3 Overall Description

The product is a system that allows the vehicle to drive without the user's interaction. The Hands-Free Driving System (HFDS) will automatically accelerate and decelerate the car within its lane and will keep the vehicle within its respective lane. The system is intended to make the life of its

user, the driver, easier by allowing the user to not have to steer or use the pedals.

3.2 Product Perspective

The HFDS is intended for use on the highway under certain conditions. The system automatically steers and accelerates/decelerates as needed. The Hands-Free Driving System (HFDS) is made up of six sub-systems.

The Driver Assist System "polls the necessary data needed to determine safe conditions, vehicle position, and current trajectory" [3]. This system will ensure a safe following distance from the vehicle in front of it and initiates braking, if necessary, by sending commands to the Vehicle Control Subsystem.

The Driver Attention System "uses camera(s) to monitor the driver's head movements and eyes to ensure active engagement with the road" [3]. If this system determines if the driver is distracted, and if their engagement is unsafe, warnings are issued to alert the driver to re-engage.

The Vehicle Control System takes input sent from the Driver Assist System and performs the actions necessary for hands-free driving.

The Human Machine Interface Subsystem is a system that accepts user inputs and displays information as needed. This system also displays any issues or warnings if necessary.

The Path Prediction Subsystem calculates the projected "blue" path based on information received from the Vehicle Position Subsystem and from precision LiDAR mapping data.

The Vehicle Position Subsystem "processes sensor data from the vehicle's cameras, radar, and GPS receiver to validate the vehicle's position in the real-world" [3]. This is necessary for determining when to issue any warnings for roadways that do not meet the criteria required for HFDS to be activated.

The user is also required to maintain attention to the road while the system is active. If the user is determined to be inattentive by the Driver Attention System, then the system will begin its warning phases to the user. The HFDS can also be suspended if the system determines that the driving conditions are unsafe. Conditions that are unsafe include construction zones and hazardous road conditions**.**

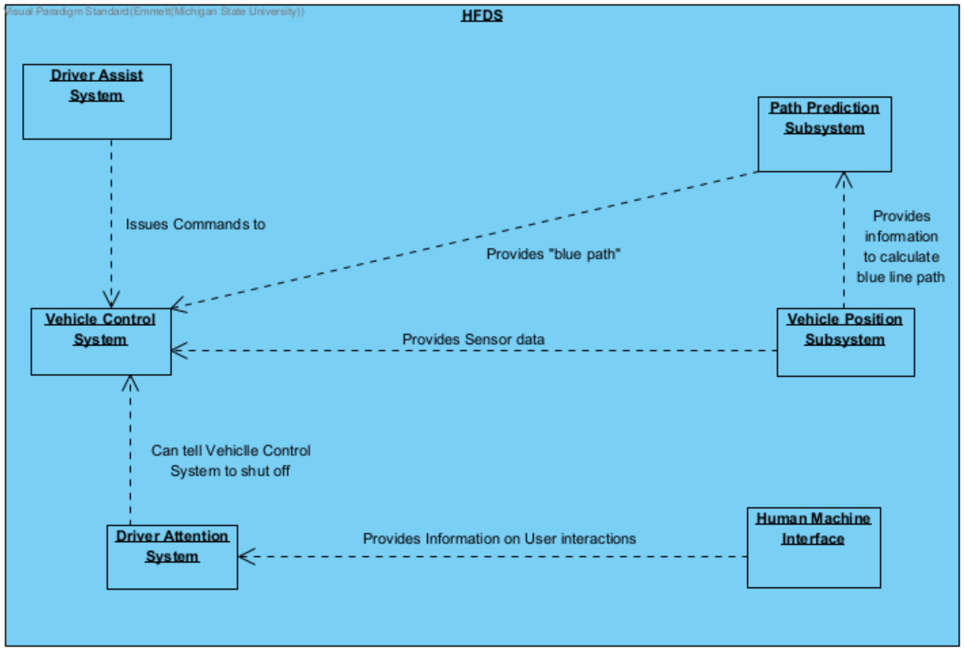


Figure 2.1.1 Diagram illustrating sub-systems of the Hands-Free Driving System

Constraints on the system:

All software for the HFDS system must be stored within the vehicle.

Except for information regarding GPS which is gained through satellite.

The user is only permitted to activate the HFDS system through a button on the steering wheel and if all conditions are met.

All communication to and from the HFDS system must be end-to-end encrypted using AES (Advanced Encryption Standard).

- The HFDS system must be permitted to be suspended by the user at any time.

3.3 Product Functions

The major functions the software will perform include automatic acceleration, lane keeping, and the switch back to manual and out of hands-free mode.

The automatic acceleration function allows the vehicle to automatically accelerate and decelerate based on road

conditions, ensuring that the vehicle maintains a safe distance from vehicles around it.

The lane keeping functions has the vehicle using lane detection technology to ensure that the vehicle remains within the lines of its respective lane.

The switch function allows the HFDS to suspend operation when the driver is determined to be inattentive or the conditions on the road are not suitable for the HFDS. When the vehicle comes to a stop, or driver input is detected, a switch will be made back into a manual driving mode.

Provided below is a high-level goal diagram illustrating the goals for the Hands-Free Driving system in relation to its major functions.

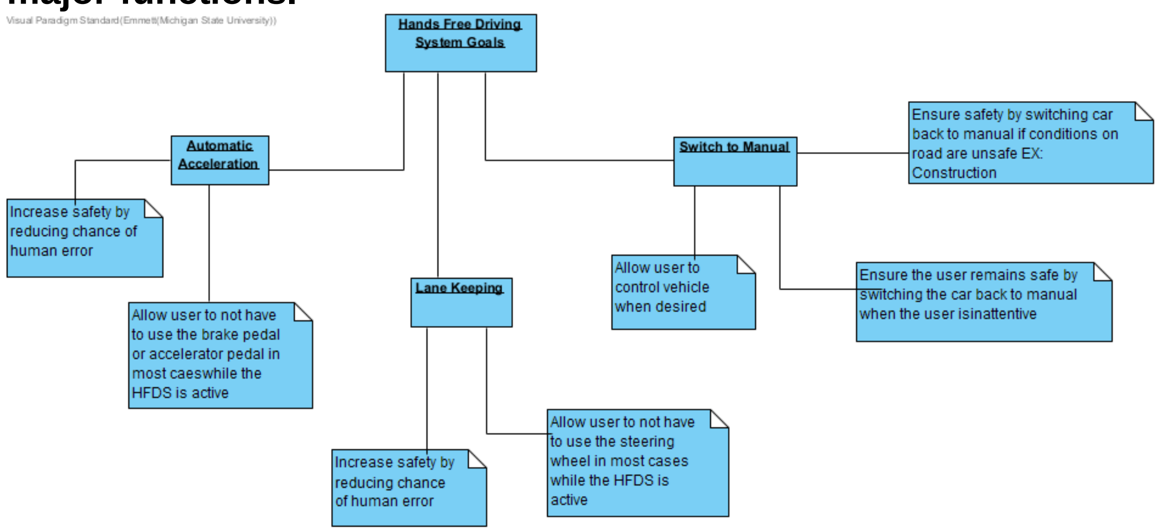


Figure 2.2.1 Goal diagram for the system

3.4 User Characteristics

It is expected that the user of the system, the driver, will have a valid license to drive a motor vehicle. Additionally, it is expected that the user will have read the manual for the vehicle and the system, so that they understand what the HFDS does and how to utilize the system safely.

3.5 Constraints

When the HFDS is active there a many safety-critical properties required. The first is that all the sensors involved in the system (Lidar, Radar, Cameras, and GPS sensors) must be ensured to be operational in order for the system to remain on. Operational in this sense means that the sensors are sending and receiving data and that data is confirmed to be accurate. If the sensors are not operational the control of the vehicle is returned to the user.

Another safety critical property is that for the HFDS to be online, then the user needs to be confirmed to be attentive, using the Driver Attention System. If the user is determined to not be attentive, then the system will begin its warning progression.

An additional property is that the system can only be active when the road conditions are determined to be safe. Some conditions when the system can not be active are a construction zone, a road not properly mapped with LIDAR mapping, and inclement weather (the presence of ice, rain, or snow).

A final constraint is that the system must ensure that an outside party cannot gain control of it. This means that all communication that the system does with external parties must be encrypted. Additionally, the system will not accept input that does not come directly from the user or the internal system for navigation. The exception to this rule is GPS data which comes from an external satellite. This data must be verified using the external sensors of the vehicle to ensure the safety of the driver.

3.6 Assumptions and Dependencies

It is assumed that the hardware for the system will have enough storage to hold all the required data for the system. It is assumed that the hardware will be able to run the software of the system at a sufficient speed to ensure responsiveness to new stimuli. It is assumed that the software of the system will be bug-free and will not have unintended behavior. It is assumed that the user will utilize the system in a way that is described in the manual for the vehicle. It is assumed that the user will adhere to the warnings given by the system for driver inattentiveness.

3.7 Approportioning of Requirements

Based on discussions with the project sponsor the following are requirements that may be added in future releases of the HFDS. In its current state the HFDS does not allow for the system to switch lanes and instead if a lane change is required the user is alerted that a change to manual is required. In future versions the system should be able to change lanes for the user in a way that ensures user safety. It its current state the HFDS system is unable to stay on while in a construction zone. In future versions the system should be

able to remain on while in a construction zone and reduce its speed and follow posted signage.

4 Specific Requirements

Section 3 details an enumerated list of requirements, beginning with primary requirements that describe the core functions of the HFD system, secondary requirements that contain qualitative details, and the invariant requirements which must always be true.

Primary Requirements:

1. The state of the system will be represented to the driver as a light bar on the steering wheel
   - 1.1. White showing the system is validating whether HFD can be activated
   - 1.2. Blue showing the system is validated and ready to be turn on HFD
   - 1.3. Green showing the HFD is currently activated
   - 1.4. Red for giving warnings to the driver
2. Dashboard indicator will also show system status with same color pattern as steering wheel light indicator
3. The system shall determine if all conditions are met to enter hands free driving mode, not allowing the system to activate if even a single of the conditions are not validated
   - 3.1. The driver must be driving on a highway that has been enabled by the Path Prediction Subsystem
   - 3.2. The Driver Assist System must validate
     - 3.2.1. Road condition
       - 3.2.1.1. Lane markings must be clearly visible
       - 3.2.1.2. Lane must be wide enough (at least 3 feet wider than car on each side)
       - 3.2.1.3. Lane marking are regular and not crossing (there cannot be multiple markings on top of each other)
       - 3.2.1.4. Not a construction zone
     - 3.2.2. Current trajectory and Predicted path
       - 3.2.2.1. The vehicles “blue path” (projected path) will be calculated based on information from the Vehicle Position Subsystem and precision LiDAR mappings
         - 3.2.2.1.1. Valid if able to be calculated
       - 3.2.2.2. Sensor input
       - 3.2.2.3. Ensure data being received is inside a 13% threshold of normal
   - 3.3. The system will also perform a system check on vehicle condition

3.3.1. Checking that the vehicle is in good operating condition
3.3.1.1. Check-engine light is not lit
3.3.1.2. Not using a spare tire
3.3.1.3. No aftermarket modifications have been added
3.3.2. Ensure vehicle speed is between 24.1 and 136.8 KMH

4. If ALL conditions are validated the system can be activated by the user through a button on the steering wheel

4.1. The vehicle will enter an adaptive cruise control state and stay within its existing lane for the duration of the session
4.1.1. The vehicle will leverage the ACC system to accomplish this
4.1.1.1. Monitoring and ensuring a safe following distance of 5 seconds, allowing time for the driver to react in an emergency
4.1.1.2. The system will initiate breaks if distance is too small, but also throttle to set speed if necessary
4.1.2. The system will leverage lane assist to actively stay in current lane

5. While the system is active it constantly monitors driver engagement through the Driver Attention System

5.1. The goal for proper engagement is to ensure the driver has enough time to resume control given unexpected circumstances
5.1.1. Camera monitoring system monitors
5.1.1.1. Driver's eyes for attentiveness ensuring drivers eyes are within 45 degrees right of straight and 70 degrees left of straight
5.1.1.2. Driver's head movement ensuring drivers head is within 45 degrees right of straight and 70 degrees left of straight
5.1.1.3. The camera monitoring system must work in all lighting conditions

5.2. If driver is not engaged warnings are issued to the driver at the following levels
5.2.1. Level 1: if driver is not engaged for 3 seconds, the wheel light indicator begins flashing green
5.2.2. Level 2: After level 1, if driver is not engaged for 3 more seconds, the wheel light indicator begins flashing red with beeping audio queues (1 every second) and continuous seat vibration
5.2.3. Level 3 (Final): After level 2, if driver is not engaged for 3 more seconds, the system will begin flashing red faster on the wheel light indicator, seat will still continuously vibrate, and an audio queue will tell driver to reengage, or system will abort
5.2.4. After level warning level 3, the driver will have 3 seconds to reengage, or system will abort
5.2.5. Aborting the system involves
5.2.5.1. If driver does not take control

5.2.5.1.1. The car will stop accelerating and roll to a coast

5.2.5.1.2. The car will gently brake coming to a gradual stop within the lane

5.2.5.1.3. The car will put its hazard lights on

5.2.5.2. If driver does take control

5.2.5.2.1. Driver will be able to drive as normal

5.2.5.3. If system is aborted HFD cannot be reactivated for the remainder of the drive

6. While HFD is activated the system will continue to check all of the conditions it required to be activated and will issue warning level 3 to driver if any of these conditions are invalidated, aborting the system 3 seconds after the warning is issued
7. Disabling HFD

7.1. The driver can once again press the button on the steering wheel to disengage HFD, relinquishing control to the driver

7.2. Any driver intervention will pause HFD and give control to the driver

1.1.1. Manual control (control indicates torque on the wheel, not just having hands on it) of the steering wheel for less than 5 seconds

1.1.2. Manual breaking for less than 5 seconds

1.1.3. Manual throttling for less than 5 seconds

1.1.4. HFD will return to same speed before the intervention

7.3. Any driver intervention of 5 seconds or greater will disable HFD

1.1.5. Manual control (control indicates torque on the wheel, not just having hands on it) of the steering wheel for 5 seconds or greater

1.1.6. Manual breaking for 5 seconds or greater

1.1.7. Manual throttling for 5 seconds or greater

8. The system will have hardware redundancies in place to ensure there is no situation where HFD is stuck on
9. The system will have sensor redundancies to ensure data collected is accurate and sensor is working correctly
10. The system will display sensor information to the user through the dashboard
11. The system will issue warning through the display and audio system
12. The system will respond to user input through navigation controls
13. The system will accept user input information through dashboard

Secondary Requirements:

1. The driver should not be distracted from road engagement by excessive notifications and alerts

1.1. Alerts should be small in number, as there is not unlimited time and distance before the driver needs to take control.

1.2. There should be an indication of the time until the system aborts hands-free mode, until the driver takes control.

1.3. There should be an indication of the time until the system aborts hands-free mode, until the driver takes control.

    1.4. Driver should be alerted just enough to get them to pay attention to the road
2. Do not wrongly accuse driver of not paying attention to road
3. Clearly indicate car is in HFD mode
4. Ensure that warnings and other information is clear to the user
5. Transition from manual to hands free (and backwards) should be easy for driver

Invariant Requirements:

1. The vehicle will not attempt to drive on roadways that do not meet certain highway conditions, such as construction, or that are not properly mapped with LiDAR mapping
2. The Vehicle Control System will only receive authorized commands, avoiding any malicious commands
3. The system will never tolerate and continue to drive with a prolonged disengaged driver
4. The system can only be activated by the user
5. The system shall detect any single point of failure
    5.1. In the process, safely relinquishing control to the user, allowing the driver time to reengage
6. The system will always monitor driver engagement while active
7. Any driver intervention relinquishes control to the driver
8. An inactive driver will lead to the vehicle coming to a stop
9. All hardware and sensor redundancies must be in place to ensure safe operation
10. If the system determines the conditions are unsafe while active, it will safely transition to driver or abort
11. The driver must be able to take over control at any point during operation
12. The system will only avoid collisions by braking and will not swerve for the driver

5 Modeling Requirements

The purpose of this section is to showcase multiple diagrams and models that serve to outline the HFDS system. The various figures include Use Case Diagrams, Domain Models, Sequence Diagrams, and more. Each diagram is explained thoroughly and utilizes Unified Modeling Language (UML).

5.2 Use Case Diagram

The use case diagram below depicts all of the primary use cases in our system. The actors for our use case diagram are the driver, the haptic feedback system, the sound system, the Human Machine Interface subsystem (HMI), the Driver Assist System, and the Vehicle Control System, and they are portrayed as stick figures. The various use cases are displayed as bubbles in the diagram, with lines demonstrating the connection from use case to use case to actor. For example, the driver can activate HFDS, then the control changes to the vehicle control system. Following the diagram is a collection of tables detailing the use cases and their relationships.

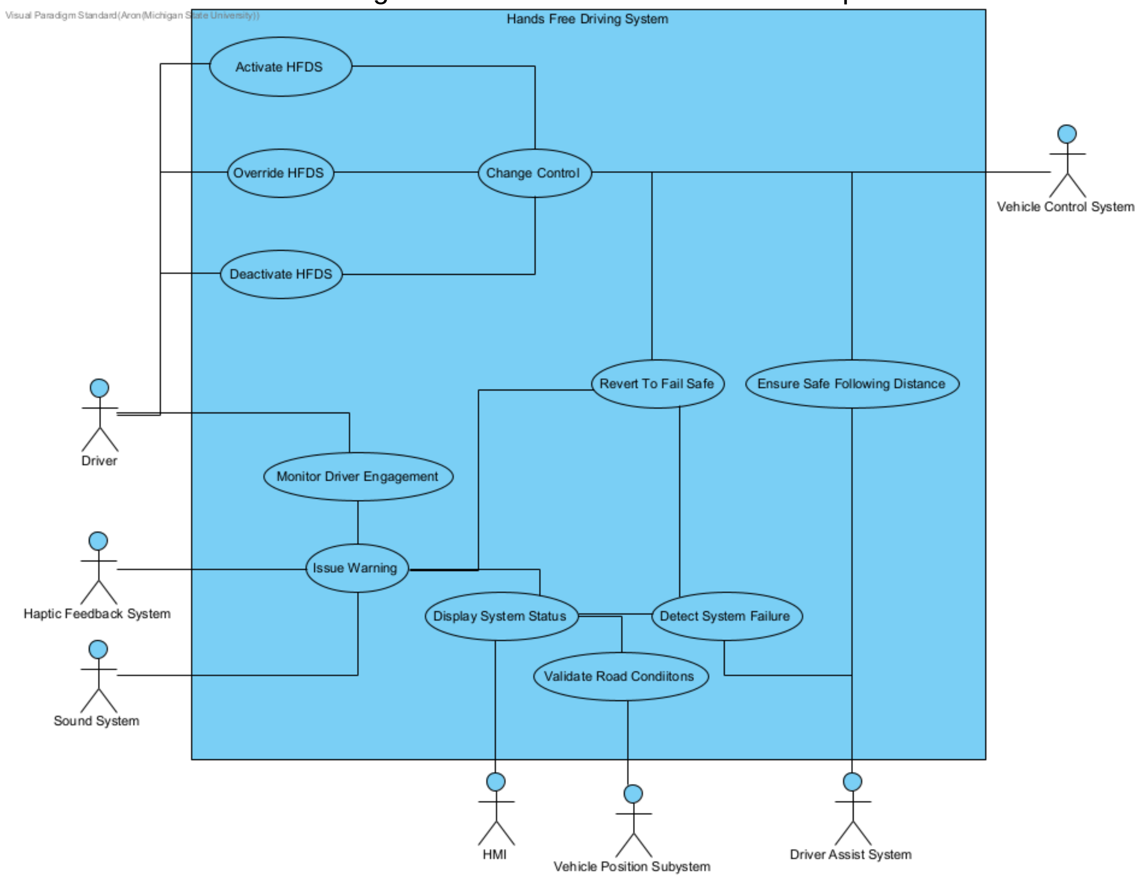


Figure 1: Use case diagram

Use Case:	***Activate HFDS***
Actors:	***Driver***
Descriptio n:	***The driver of the vehicle is able to activate HFDS once the system has validated safe conditions, once activated the system will control the car.***
Type:	***Primary***
Includes:	***N/A***
Extends:	***N/A***
Cross-refs:	***Requirements: Invariant 4,***
Use cases:	***N/A***

Table 1: Use case description for *Activate HFDS*

Use Case:	***Detect System Failure***
Actors:	***Driver Assist System***
Descriptio n:	***The system will go through a number of conditions and validate them in order to enable the HFDS. There will be hardware and software redundancies in place.***
Type:	***Primary***
Includes:	***N/A***
Extends:	***N/A***
Cross-refs:	***Requirements: 3.3.1.1, 3.3.1.2, 3.3.1.3, 8, 9, Invariant 5, Invariant 9***
Use cases:	***N/A***

Table 2: Use case description for *Detect System Failure*

Use Case:	***Validate Road Conditions***
Actors:	***Vehicle Position Subsystem***
Description:	***The system shall determine if road conditions are safe by monitoring vehicle position through GPS, cameras, radars, and comparisons to LiDAR mappings. The system will monitor the current trajectory. The system shall monitor the road and identify lane markings within 700m using edge detection on the camera sensor input. The system will make sure it is not in a construction zone.***
Type:	***Secondary***
Includes:	***N/A***
Extends:	***N/A***
Cross-refs:	***Requirements: 3.2.1.1, 3.2.1.2, 3.2.1.3, 3.2.1.4, 3.2.2.1, 3.2.3.1, 3.3.2, 3.1, 8, 9, Invariant 1, Invariant 5, Invariant 9, Invariant 10***
Use cases:	***N/A***

Table 3: Use case description for *Validate Road Conditions*

Use Case:	***Monitor Driver engagement***
Actors:	***Driver***
Descriptio n:	***The system shall monitor driver engagement (Proper engagement is enough attention to reach appropriately to resume control or to unexpected circumstances). An infrared camera will monitor the angle of the drivers eyes and the drivers head within a threshold.***
Type:	***Primary***
Includes:	***N/A***
Extends:	***N/A***
Cross-refs:	***Requirements: 5, 5.1 (all subpoints), Invariant 3, Invariant 6***
Use cases:	***N/A***

Table 4: Use case description for *Monitor Driver Engagement*

Use Case:	***Issue Warning***
Actors:	***N/A***
Description:	***If the driver is not engaged for 3 seconds, issue warning level 1, if still not engaged for another 3 seconds, issue warning level 2, after 3 more seconds, issue warning level 3, after 3 more seconds the system will abort HFD where the car will coast, gently brake, stop within lane, and put on its hazard lights. HFD cannot be enabled for the rest of the drive if this happens. Warnings will not be excessive in order to not unnecessarily distract the driver.***
Type:	***Secondary***
Includes:	***N/A***
Extends:	***N/A***
Cross-refs:	***Requirements: 5.2, 5.2.1, 5.2.2, 5.2.3, 5.2.4, Secondary 1, Secondary 1.1, Secondary 1.4, Secondary 2,***
Use cases:	***Validate Condition***

Table 5: Use case description for *Issue Warning*

Use Case:	***Display System Status***
Actors:	***HMI***
Description:	***The system will display sensor information to the user through the steering wheel light bar (status represented by white, blue, green, and red lights). The system will be able to issue warnings through the sound system, haptic feedback system, HMI, and dashboard (will have the same light status system on dashboard). There will be an indication of time if HFDS needs to be aborted due to invalid conditions.***
Type:	***Primary***
Includes:	***N/A***
Extends:	***N/A***
Cross-refs:	***Requirements: 1 (all subpoints), 2, 10, 11, Secondary 3,***
Use cases:	***N/A***

Table 6: Use case description for *Display System Status*

Use Case:	***Override HFDS***
Actors:	***Driver***
Description:	***Any intentional driver intervention will deactivate HFDS and relinquish control to the driver. The system is not built to avoid collisions, the driver should be engaged and ready to take over at any time.***
Type:	***Primary***
Includes:	***N/A***
Extends:	***N/A***
Cross-refs:	***Requirements: 7.2 (all subpoints), Secondary 5, Invariant 7***
Use cases:	***N/A***

Table 7: Use case description for *Override HFDS*

Use Case:	***Revert to Failsafe***
Actors:	***Vehicle Control System***
Descriptio n:	***If the driver does not reengage after warnings the system will abort or. In aborting the system will end hands free mode. After aborting, HFD system cannot be re-engaged for the remainder of this drive. If the driver is inactive the vehicle comes to a stop; will start rolling to a coast (stop accelerating), gently brake coming to stop gradually, come to a stop within the lane, and put on its hazard lights.***
Type:	***Secondary***
Includes:	***N/A***
Extends:	***N/A***
Cross-refs:	***Requirements: 5.2.4.1.1 (all subpoints), 5.2.4.1.3***
Use cases:	***N/A***

Table 8: Use case description for *Revert to Failsafe*

Use Case:	***Deactivate HFDS***
Actors:	***Driver***
Description:	***The system will be able to be deactivated by the user.***
Type:	***Primary***
Includes:	***N/A***
Extends:	***N/A***
Cross-refs:	***Requirements: 7.1***
Use cases:	***N/A***

Table 9: Use case description for *Deactivate HFDS*

Use Case:	***Change Control***
Actors:	***N/A***
Description:	***Switch control from the driver to the HFDS (more specifically the Vehicle Control System) smoothly.***
Type:	***Secondary***
Includes:	***N/A***
Extends:	***N/A***
Cross-refs:	***Requirements: Secondary 5,***
Use cases:	***N/A***

Table 10: Use case description for *Change Control*

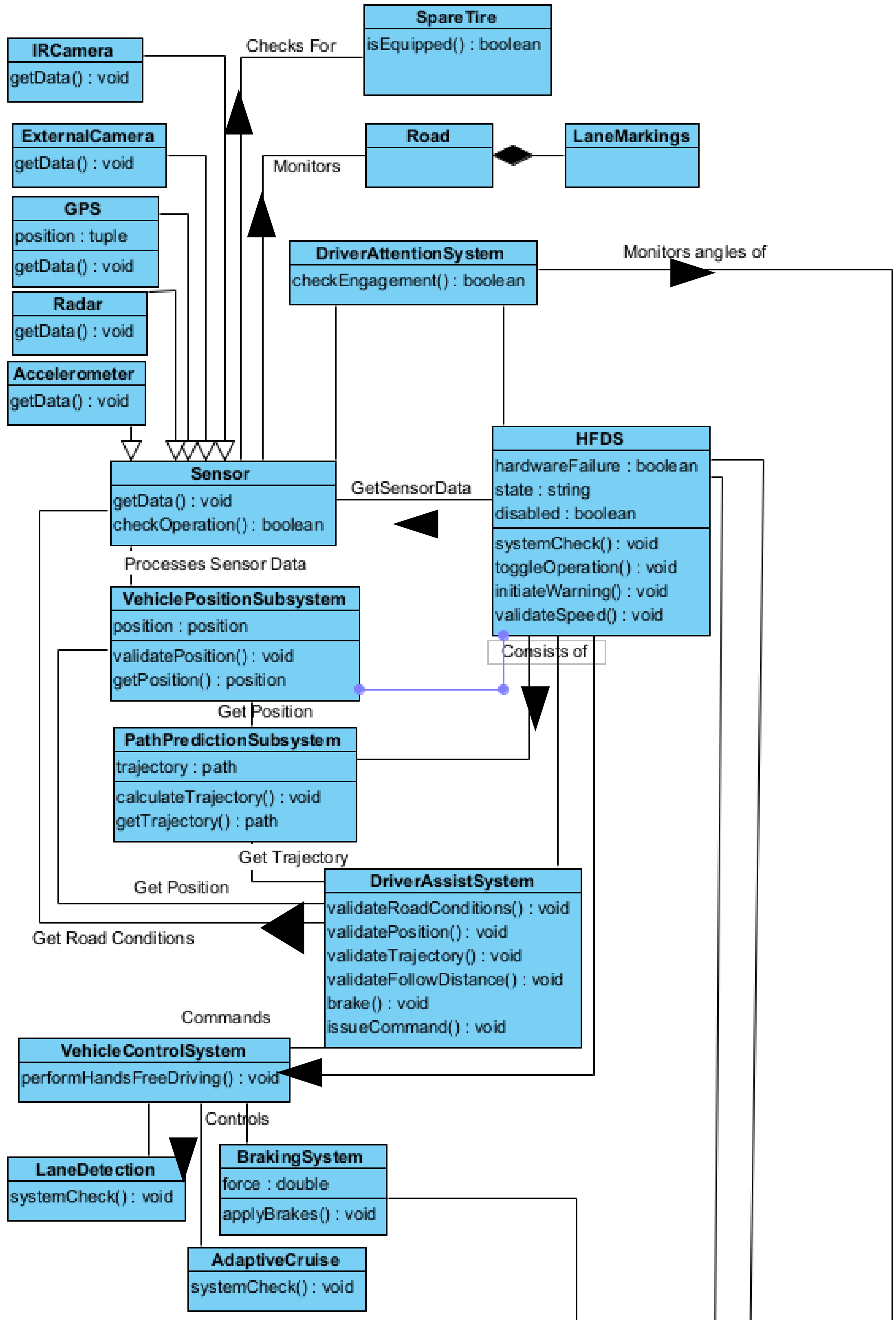
Use Case:	***Ensure Safe Following Distance***
Actors:	***Driver Assist System, Vehicle Control System***
Description:	***System will monitor and ensure a safe following distance in an adaptive cruise control and lane assist state. Safe distance is enough distance for the driver to resume control and react and initiate breaks if necessary. The driver should always be ready to take control.***
Type:	***Secondary***
Includes:	***N/A***
Extends:	***N/A***
Cross-refs:	***Requirements: 4.11 (all subpoints)***
Use cases:	***N/A***

Table 11: Use case description for *Ensure Safe Following Distance*

5.3 Domain Model

5.3.1 Domain Model

Figure 2 shows the domain model for the HFDS system. The model shows how the classes of the system interact and communicate with each other. A line between two classes indicates a direct relationship between them. A line with an arrow indicates generalization of a class. For example in Figure 2, the IRCamera is a type of sensor, so the line between the two classes ends with an arrow pointing at the sensor indicating that the IRCamera is a sensor. Each class in the diagram is supplemented with a data dictionary entry further detailing it.


SpareTire
isEquipped() : boolean
IRCamera
getData() : void
Checks For
ExternalCamera
getData() : void
Road
LaneMarkings
Monitors
GPS
position : tuple
getData() : void
DriverAttentionSystem
checkEngagement() : boolean
Monitors angles of
Radar
getData() : void
Accelerometer
getData() : void
HFDS
hardwareFailure : boolean
state : string
disabled : boolean
systemCheck() : void
toggleOperation() : void
initiateWarning() : void
validateSpeed() : void
Sensor
getData() : void
checkOperation() : boolean
GetSensorData
Processes Sensor Data
VehiclePositionSubsystem
position : position
validatePosition() : void
getPosition() : position
Consists of
Get Position
PathPredictionSubsystem
trajectory : path
calculateTrajectory() : void
getTrajectory() : path
Get Trajectory
DriverAssistSystem
validateRoadConditions() : void
validatePosition() : void
validateTrajectory() : void
validateFollowDistance() : void
brake() : void
issueCommand() : void
Get Position
Get Road Conditions
Commands
VehicleControlSystem
performHandsFreeDriving() : void
Controls
LaneDetection
systemCheck() : void
BrakingSystem
force : double
applyBrakes() : void
AdaptiveCruise
systemCheck() : void

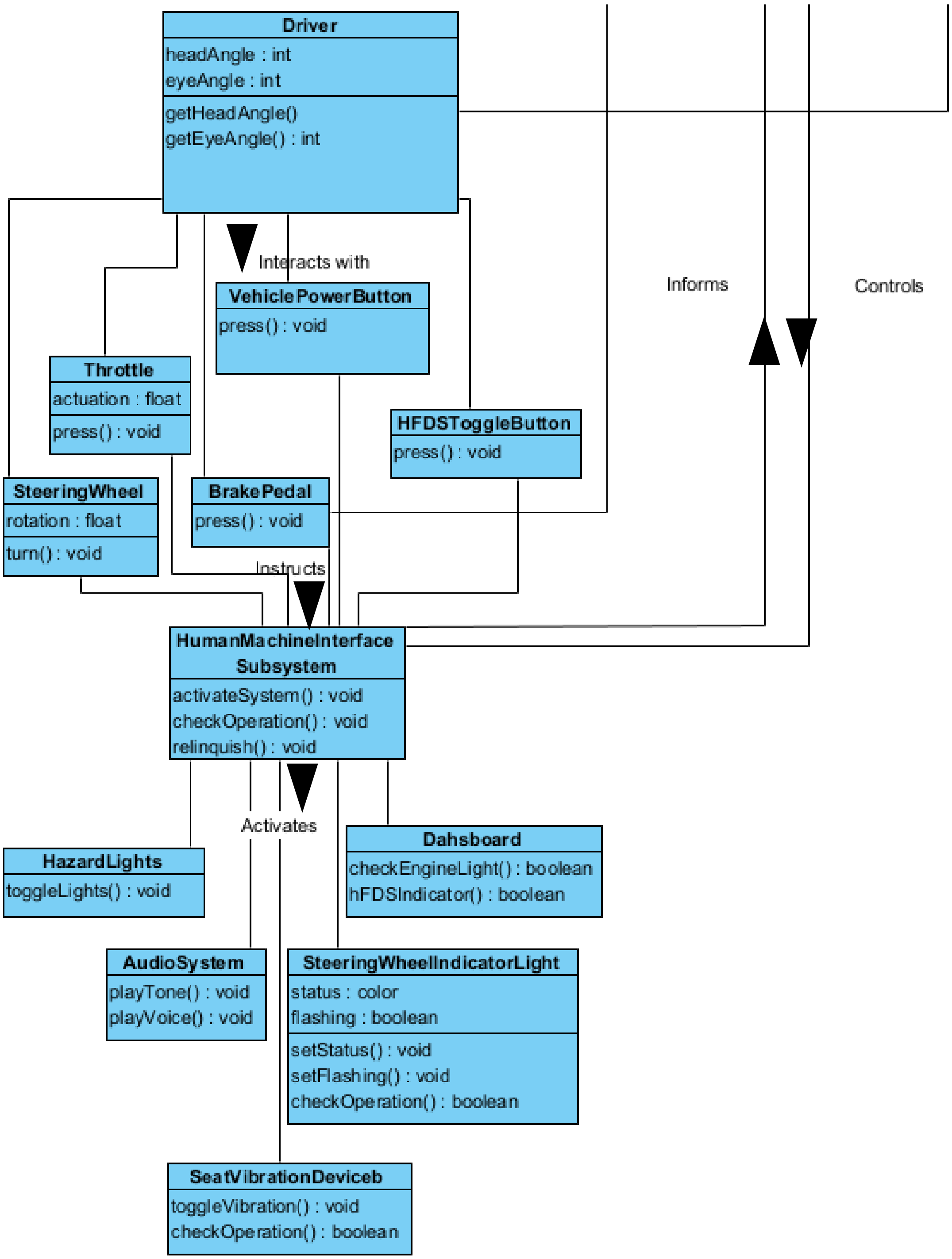


Figure 2: HFDS Domain Model

<table>
<tr><th>Class</th><th colspan="2"></th></tr>
<tr><td rowspan="7">Accelerometer</td><td colspan="2">Description: Displays the current speed of the vehicle. Used to ensure we are within the allowed speed threshold for HFDS</td></tr>
<tr><td colspan="2">Export control: Private</td></tr>
<tr><td rowspan="3">Relationships</td><td>Associations:</td></tr>
<tr><td>Aggregations:</td></tr>
<tr><td>Generalization: Inherits from Sensor</td></tr>
<tr><td colspan="2">Attributes: None</td></tr>
<tr><td colspan="2">Operations: getData() : void</td></tr>
</table>

<table>
<tr><th>Class</th><th colspan="2"></th></tr>
<tr><td rowspan="7">Adaptive Cruise</td><td colspan="2">Description: The Adaptive Cruise System maintains vehicle speed and distance from other vehicles. It works with the Lane Detection to ensure the vehicle stays within the lane.</td></tr>
<tr><td colspan="2">Export control: Private</td></tr>
<tr><td rowspan="3">Relationships</td><td>Associations: VehicleControlSystem</td></tr>
<tr><td>Aggregations:</td></tr>
<tr><td>Generalization:</td></tr>
<tr><td colspan="2">Attributes: None</td></tr>
<tr><td colspan="2">Operations: systemCheck() : void</td></tr>
</table>

<table>
<tr><th>Class</th><th colspan="2"></th></tr>
<tr><td rowspan="7">Audio System</td><td colspan="2">Description: Used to alert the driver that they need to regain control of the steering.</td></tr>
<tr><td colspan="2">Export control: Private</td></tr>
<tr><td rowspan="3">Relationships</td><td>Associations: HumanMachineInterfaceSubsystem</td></tr>
<tr><td>Aggregations:</td></tr>
<tr><td>Generalization:</td></tr>
<tr><td colspan="2">Attributes: None</td></tr>
<tr><td colspan="2">Operations:
• playTone() : void
• playVoice() : void</td></tr>
</table>

<table>
<tr><th>Class</th><th colspan="2"></th></tr>
<tr><td rowspan="7">BrakePedal</td><td colspan="2">Description: The brake pedal has various effects on the HFDS, such as disabling it when pressed. The HFDS can also passively brake the vehicle.</td></tr>
<tr><td colspan="2">Export control: Private</td></tr>
<tr><td rowspan="3">Relationships</td><td>Associations: Driver, HMIS</td></tr>
<tr><td>Aggregations:</td></tr>
<tr><td>Generalization:</td></tr>
<tr><td colspan="2">Attributes: None</td></tr>
<tr><td colspan="2">Operations: press() : void</td></tr>
</table>

<table>
<tr><th>Class</th><th colspan="2"></th></tr>
<tr><td rowspan="7">Braking System</td><td colspan="2">Description: The braking system of the vehicle.</td></tr>
<tr><td colspan="2">Export control: Private</td></tr>
<tr><td rowspan="3">Relationships</td><td>Associations: VehicleControlSystem, BrakePedal</td></tr>
<tr><td>Aggregations:</td></tr>
<tr><td>Generalization:</td></tr>
<tr><td colspan="2">Attributes: force: double</td></tr>
<tr><td colspan="2">Operations: applyBrakes() : void</td></tr>
</table>

<table>
<tr><th>Class</th><th colspan="2"></th></tr>
<tr><td rowspan="7">Dashboard</td><td colspan="2">Description: The vehicle’s dashboard. This is where the driver can view all sorts of information such as vehicle speed and view indicators such as the check engine light and the HFD light.</td></tr>
<tr><td colspan="2">Export control: Private</td></tr>
<tr><td rowspan="3">Relationships</td><td>Associations: HMIS</td></tr>
<tr><td>Aggregations:</td></tr>
<tr><td>Generalization:</td></tr>
<tr><td colspan="2">Attributes: None</td></tr>
<tr><td colspan="2">Operations: checkEngineLight() : boolean
hFDSIndicator(): boolean</td></tr>
</table>

Driver	***Description:*** The operator of the vehicle. The HFDS tracks their attention to ensure their safety.		
	Export control: Private		
	Relationships	Associations: HFDSToggleButton, VehiclePowerButton, BrakePedal, Throttle, SteeringWheel	
		Aggregations: Has parts Driver'sEyes and Driver'sHead	
		Generalization:	
	Attributes: eyeAngle() : int headAngle() : int		
	Operations: getEyeAngle() : int getHeadAngle() : int		

Class		
DriverAssist System	***Description:*** The system that validates the various HFD systems. It ensures the system is performing in nominal conditions.	
	Export control: Private	
	Relationships	Associations: VehiclePositionSubsystem, Sensor, VehicleControlSystem, HFDS
		Aggregations:
		Generalization:
	Attributes: None	
	Operations: • validateRoadConditions() : void • validatePosition() : void • validateTrajectory() : void • validateFollowDistance() : void • brake() : void • issueCommand() : void	

<table>
<tr><th>Class</th><th colspan="2"></th></tr>
<tr><td rowspan="7">Driver Attention System</td><td colspan="2">Description: The DriverAttentionSystem is responsible for checking if the driver is paying attention, and if they aren’t, it is responsible for regaining their attention.</td></tr>
<tr><td colspan="2">Export control: Private</td></tr>
<tr><td rowspan="3">Relationships</td><td>Associations: HFDS, Driver’sEyes, Driver’sHead, Sensor</td></tr>
<tr><td>Aggregations:</td></tr>
<tr><td>Generalization:</td></tr>
<tr><td colspan="2">Attributes: None</td></tr>
<tr><td colspan="2">Operations: checkEngagement() : boolean</td></tr>
</table>

<table>
<tr><th>Class</th><th colspan="2"></th></tr>
<tr><td rowspan="7">External Camera</td><td colspan="2">Description: Checks to ensure road conditions are nominal</td></tr>
<tr><td colspan="2">Export control: Private</td></tr>
<tr><td rowspan="3">Relationships</td><td>Associations:</td></tr>
<tr><td>Aggregations:</td></tr>
<tr><td>Generalization: Inherits from Sensor</td></tr>
<tr><td colspan="2">Attributes:</td></tr>
<tr><td colspan="2">Operations: getData() : void</td></tr>
</table>

Class		
GPS	***Description:*** Global Positioning System.	
	Export control: Private	
	Relationships	Associations:
		Aggregations:
		Generalization: Inherits from Sensor
	Attributes: position : tuple	
	Operations: getData() : void	

Class		
HFDS	***Description:*** The central Hands-Free Driving System. All components of the system report to it directly or indirectly. Responsible for allowing the vehicle to operate without the need for the user to interact with the steering in any way.	
	Export control: Private	
	Relationships	Associations: Sensor, HMIS, DriverAssistSystem, PathPredicitionSubsystem, VehiclePositionSubsystem
		Aggregations:
		Generalization:
	Attribute: • hardwareFailure : boolean • state : string • disabled : boolean	
	Operations: • systemCheck() : void • toggleOperation() : void • initiateWarning() : void • validateSpeed() : void	

Class		
HFDSToggle Button	***Description:*** The button to enable the HFDS. Pressed by driver to start the system	
	Export control: Private	
	Relationships	Associations: Driver, HMIS
		Aggregations:
		Generalization:
	Attributes: None	
	Operations: press() : void	

Class		
HazardLights	***Description:*** Hazard lights for the vehicle. Enabled when vehicle pulls over if user drops attention and does not retake control of the vehicle.	
	Export control: Private	
	Relationships	Associations: HMIS
		Aggregations:
		Generalization:
	Attributes: None	
	Operations: toggleLights() : void	

<table>
<tr><th>Class</th><th colspan="2"></th></tr>
<tr><td rowspan="7">Human Machine Interface Subsystem</td><td colspan="2">Description: The Human Machine Interface Subsystem alerts the driver of the Hands-Free Driving status and attempts to regain driver attention when needed. It contacts other components to help regain this attention.</td></tr>
<tr><td colspan="2">Export control: Private</td></tr>
<tr><td rowspan="3">Relationships</td><td>Associations: SteeringWheelIndicatorLight, SeatVibrationDevice, AudioSystem, HFDS, HazardLights, Dashboard, HFDSToggleButton, BrakePedal, SteeringWheel, Throttle, VehiclePowerButton</td></tr>
<tr><td>Aggregations:</td></tr>
<tr><td>Generalization:</td></tr>
<tr><td colspan="2">Attributes:</td></tr>
<tr><td colspan="2">Operations:
• activateSystem() : void
• checkOperation() : void
• relinquish() : void</td></tr>
</table>

<table>
<tr><th>Class</th><th colspan="2"></th></tr>
<tr><td rowspan="7">IRCamera</td><td colspan="2">Description: Infrared Camera</td></tr>
<tr><td colspan="2">Export control: Private</td></tr>
<tr><td rowspan="3">Relationships</td><td>Associations:</td></tr>
<tr><td>Aggregations:</td></tr>
<tr><td>Generalization: Inherits from Sensor</td></tr>
<tr><td colspan="2">Attributes:</td></tr>
<tr><td colspan="2">Operations: getData() : Void</td></tr>
</table>

<table>
<tr><th>Class</th><th colspan="2"></th></tr>
<tr><td rowspan="7">Lane Detection</td><td colspan="2">Description: Keeps track of the lane so that the vehicle may stay within it. An external system that reports to the HFDS.</td></tr>
<tr><td colspan="2">Export control: Private</td></tr>
<tr><td rowspan="3">Relationships</td><td>Associations: VehicleControlSystem</td></tr>
<tr><td>Aggregations:</td></tr>
<tr><td>Generalization:</td></tr>
<tr><td colspan="2">Attributes:</td></tr>
<tr><td colspan="2">Operations: system() : void</td></tr>
</table>

<table>
<tr><th>Class</th><th colspan="2"></th></tr>
<tr><td rowspan="7">Lane Markings</td><td colspan="2">Description: The markings on the road. These are tracked by the LaneDetection to keep the vehicle in the lane.</td></tr>
<tr><td colspan="2">Export control: Private</td></tr>
<tr><td rowspan="3">Relationships</td><td>Associations:</td></tr>
<tr><td>Aggregations:</td></tr>
<tr><td>Generalization: part of the Road</td></tr>
<tr><td colspan="2">Attributes:</td></tr>
<tr><td colspan="2">Operations:</td></tr>
</table>

<table>
<tr><th>Class</th><th colspan="2"></th></tr>
<tr><td rowspan="7">Path Prediction Subsystem</td><td colspan="2">Description: The “Blue Path” that predicts where the vehicle should go</td></tr>
<tr><td colspan="2">Export control: Private</td></tr>
<tr><td rowspan="3">Relationships</td><td>Associations: VehiclePositionSubsystem, DriverAssistSystem, HFDS</td></tr>
<tr><td>Aggregations:</td></tr>
<tr><td>Generalization:</td></tr>
<tr><td colspan="2">Attributes: trajectory : path</td></tr>
<tr><td colspan="2">Operations: calculateTrajectory : void
getTrajectory() : path</td></tr>
</table>

<table>
<tr><th>Class</th><th colspan="2"></th></tr>
<tr><td rowspan="7">Radar</td><td colspan="2">Description: The LiDAR Radar that tracks roads. Ensures that roads are safe to drive</td></tr>
<tr><td colspan="2">Export control: Private</td></tr>
<tr><td rowspan="3">Relationships</td><td>Associations:</td></tr>
<tr><td>Aggregations:</td></tr>
<tr><td>Generalization: Inherits from Sensor</td></tr>
<tr><td colspan="2">Attributes:</td></tr>
<tr><td colspan="2">Operations: getData() : void</td></tr>
</table>

<table>
<tr><th>Class</th><th colspan="2"></th></tr>
<tr><td rowspan="7">Road</td><td colspan="2">Description: The road the vehicle is driving on.</td></tr>
<tr><td colspan="2">Export control: Private</td></tr>
<tr><td rowspan="3">Relationships</td><td>Associations: Road, LaneMarkings</td></tr>
<tr><td>Aggregations:</td></tr>
<tr><td>Generalization:</td></tr>
<tr><td colspan="2">Attributes:</td></tr>
<tr><td colspan="2">Operations:</td></tr>
</table>

<table>
<tr><th>Class</th><th colspan="2"></th></tr>
<tr><td rowspan="7">Seat Vibration Device</td><td colspan="2">Description: Vibrates the seat to regain driver's attention during HFD.</td></tr>
<tr><td colspan="2">Export control: Private</td></tr>
<tr><td rowspan="3">Relationships</td><td>Associations: HMIS</td></tr>
<tr><td>Aggregations:</td></tr>
<tr><td>Generalization:</td></tr>
<tr><td colspan="2">Attributes:</td></tr>
<tr><td colspan="2">Operations: toggleVibration() : void
checkOperation() : boolean</td></tr>
</table>

<table>
<tr><th>Class</th><th colspan="2"></th></tr>
<tr><td rowspan="7">Sensor</td><td colspan="2">Description: The general class that all sensors inherit.</td></tr>
<tr><td colspan="2">Export control: Private</td></tr>
<tr><td rowspan="3">Relationships</td><td>Associations:</td></tr>
<tr><td>Aggregations: IRCamera, ExternalCamera, GPS, Radar, Accelerometer</td></tr>
<tr><td>Generalization:</td></tr>
<tr><td colspan="2">Attributes:</td></tr>
<tr><td colspan="2">Operations:
getData() : void
checkOperation() : boolean</td></tr>
</table>

<table>
<tr><th>Class</th><th colspan="2"></th></tr>
<tr><td rowspan="7">SpareTire</td><td colspan="2">Description: The vehicle's spare tire. Tracked because HFDS cannot be enabled when driving on a spare.</td></tr>
<tr><td colspan="2">Export control: Private</td></tr>
<tr><td rowspan="3">Relationships</td><td>Associations:</td></tr>
<tr><td>Aggregations:</td></tr>
<tr><td>Generalization: Checked by Sensor</td></tr>
<tr><td colspan="2">Attributes:</td></tr>
<tr><td colspan="2">Operations: isEquipped() : boolean</td></tr>
</table>

<table>
<tr><th>Class</th><th colspan="2"></th></tr>
<tr><td rowspan="7">Steering Wheel</td><td colspan="2">Description: The steering Wheel of the vehicle.</td></tr>
<tr><td colspan="2">Export control: Private</td></tr>
<tr><td rowspan="3">Relationships</td><td>Associations: Driver, HMIS</td></tr>
<tr><td>Aggregations:</td></tr>
<tr><td>Generalization:</td></tr>
<tr><td colspan="2">Attributes: rotation() : float</td></tr>
<tr><td colspan="2">Operations: turn() : void</td></tr>
</table>

<table>
<tr><th>Class</th><th colspan="2"></th></tr>
<tr><td rowspan="7">Steering Wheel Indicator Light</td><td colspan="2">Description: The light on the steering wheel indicating HFDS status</td></tr>
<tr><td colspan="2">Export control: Private</td></tr>
<tr><td rowspan="3">Relationships</td><td>Associations: HMIS</td></tr>
<tr><td>Aggregations:</td></tr>
<tr><td>Generalization:</td></tr>
<tr><td colspan="2">Attributes: status(): color
flashing() : boolean</td></tr>
<tr><td colspan="2">Operations:
• setStatus() : void
• setFlashing() : void
• checkOperation() : boolean</td></tr>
</table>

<table>
<tr><th>Class</th><th colspan="2"></th></tr>
<tr><td rowspan="7">Vehicle Control Subsystem</td><td colspan="2">Description: the subsystem controlling the vehicle. connects to various other autonomous systems to operate.</td></tr>
<tr><td colspan="2">Export control: Private</td></tr>
<tr><td rowspan="3">Relationships</td><td>Associations: DriverAssistSystem, BrakingSystem, AdaptiveCruise,LandDetection</td></tr>
<tr><td>Aggregations:</td></tr>
<tr><td>Generalization:</td></tr>
<tr><td colspan="2">Attributes:</td></tr>
<tr><td colspan="2">Operations: performHandsFreeDriving() : void</td></tr>
</table>

<table>
<tr><th>Class</th><th colspan="2"></th></tr>
<tr><td rowspan="7">Vehicle Position Subsystem</td><td colspan="2">Description: the subsystem that works to determine the vehicle’s position.</td></tr>
<tr><td colspan="2">Export control: Private</td></tr>
<tr><td rowspan="3">Relationships</td><td>Associations: Sensor, PathPredictionSubsystem, HFDS</td></tr>
<tr><td>Aggregations:</td></tr>
<tr><td>Generalization:</td></tr>
<tr><td colspan="2">Attributes: position() : position</td></tr>
<tr><td colspan="2">Operations: validatePosition() : void
getPostion() : position</td></tr>
</table>

<table>
<tr><th>Class</th><th colspan="2"></th></tr>
<tr><td rowspan="7">Vehicle PowerButton</td><td colspan="2">Description: Most new cars have push button ignitions, especially cars with self driving and driving assist capabilities.</td></tr>
<tr><td colspan="2">Export control: Private</td></tr>
<tr><td rowspan="3">Relationships</td><td>Associations: Driver, HMIS</td></tr>
<tr><td>Aggregations:</td></tr>
<tr><td>Generalization:</td></tr>
<tr><td colspan="2">Attributes:</td></tr>
<tr><td colspan="2">Operations: press() : void</td></tr>
</table>

5.4 Sequence Diagrams

This section includes the sequence diagrams to display various behavior paths for the HFDS system. The large blue boxes are the classes in the system. The dotted lines stemming from them are lifelines, and the arrows pointing from one lifeline to the other are messages being sent between classes. The text above the lines are the names of the functions (or the physical action being observed when it comes to the driver) being called to communicate to another class. The bracketed text seen near some of the lines is called a guarded statement and is the result of a non-void operation.

5.4.1 Fully Operational

In this first scenario, all of the systems are operational. This scenario serves to illustrate typical system behavior with no irregularities. The driver enables Hands Free Driving and the system activates, continuously performing the various actions needed to self-drive, such as checking the sensors continuously.

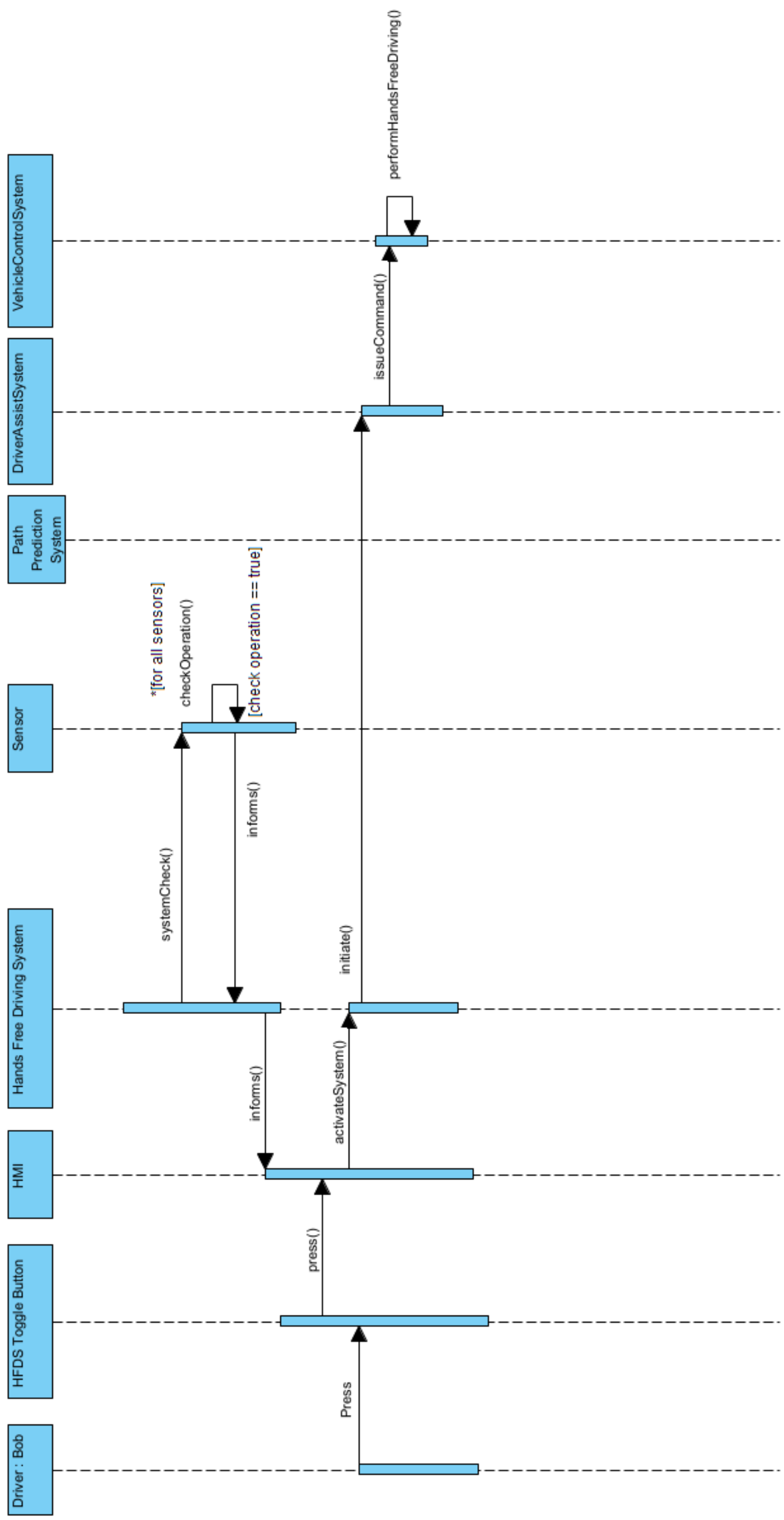


Figure 3: Sequence Diagram for Optimal Operation

5.4.2 One System Failure

In this scenario, the Path Prediction System fails to identify the proper path for the vehicle to take. The HFDS is informed of this, and calls the driver assist system to validate the trajectory. The trajectory is null, and thus the HFDS calls the HMIS to relinquish control back to the driver.

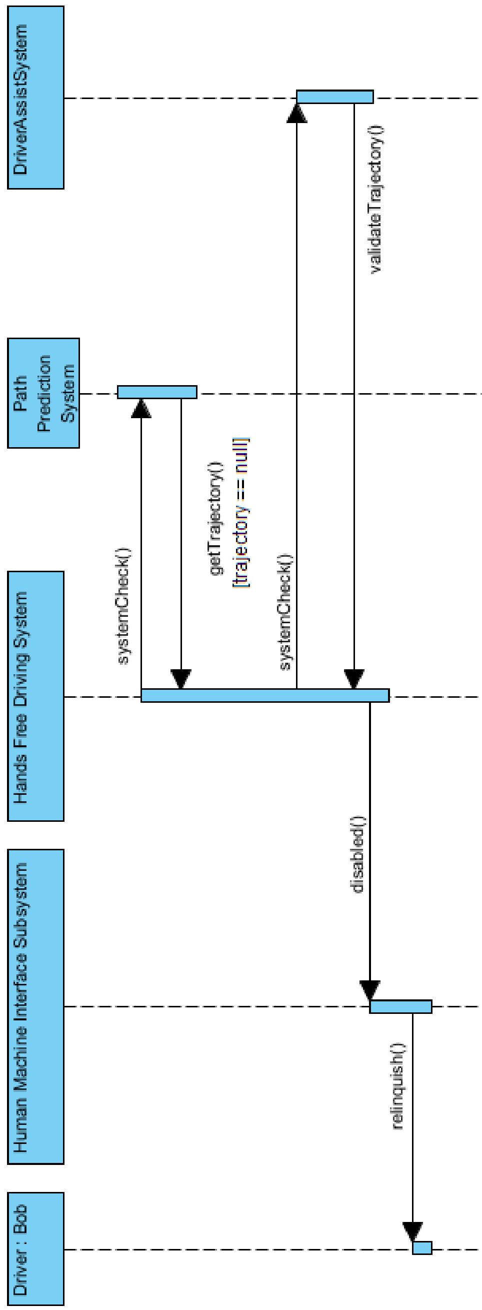


Figure 4: Sequence Diagram for One System Failure

5.4.3 Driver Not Engaged

This scenario demonstrates how the system reacts when Hands Free Driving is enabled, but the driver stops paying attention to the operation of the vehicle. The system attempts to regain the driver's attention using flashing signals, audio prompts, and seat vibration. When all this fails, Hands Free Driving disengages.

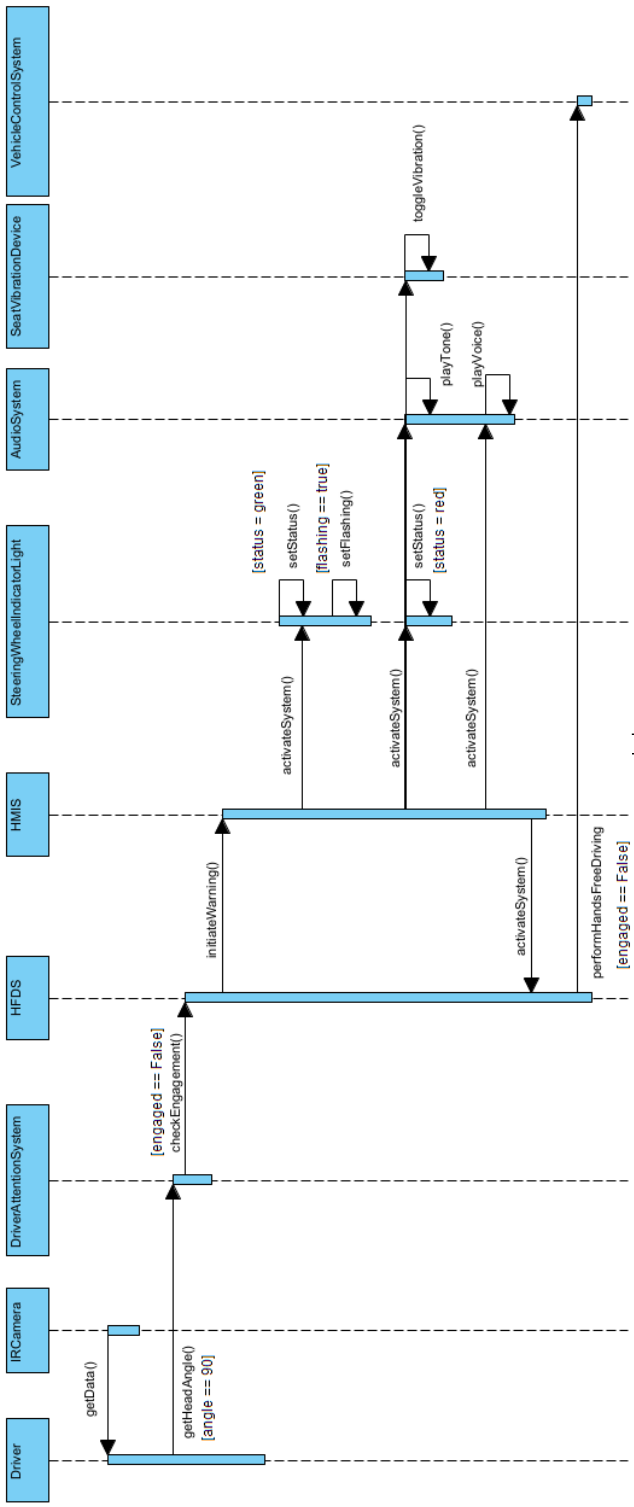


Figure 5: Sequence Diagram for Distracted Driver

5.4.4 Back and Forth Control Changes

This scenario shows control of the vehicle going from the driver to the HFDS, and back to the driver.

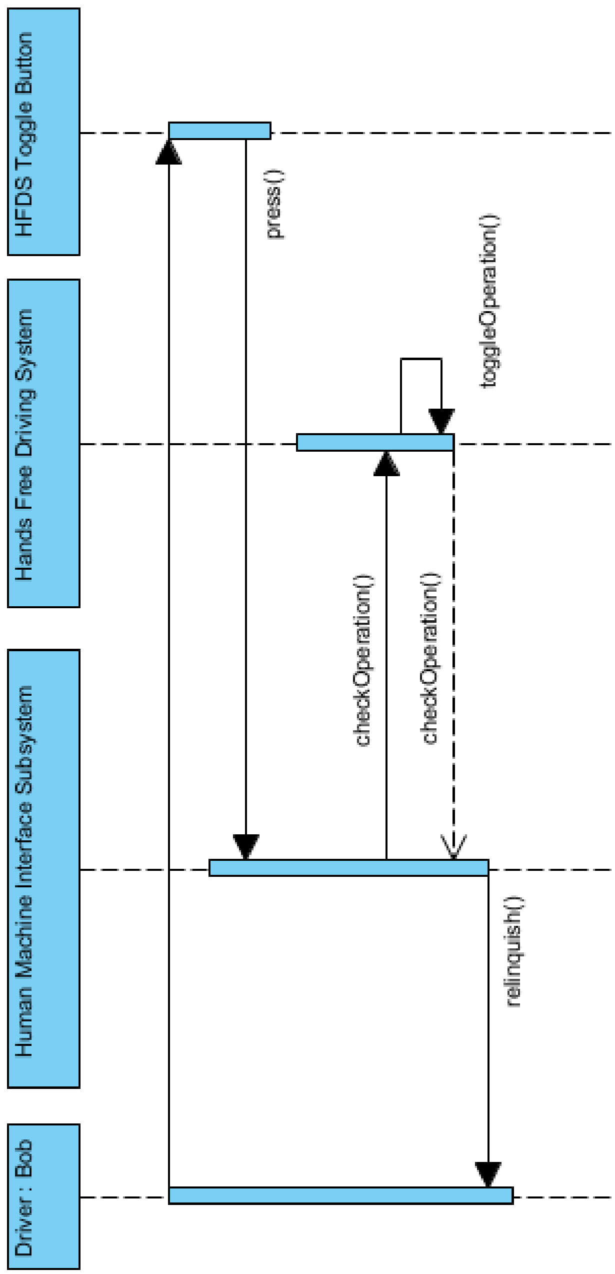


Figure 6: Sequence Diagram for Control Changes

5.4.5 System Security

In this scenario, the system is checking the integrity of the vehicle's Hands-Free Driving Systems. When it detects a faulty sensor, it calls for the HMIS to disable HFD and relinquishes control back to the driver.

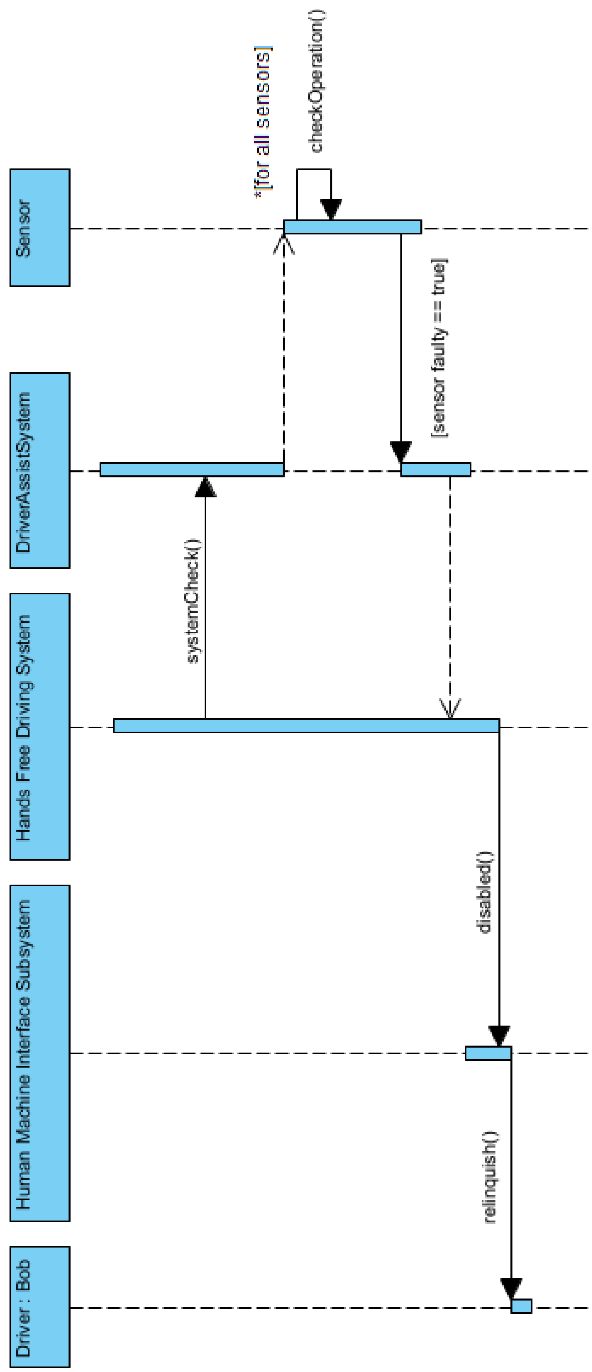


Figure 7: Sequence Diagram for System Security

5.5 State Diagrams

This section includes the figures that represent the states of our system. The initial state is represented by the black circle pointing to a state. The arrows between the states are transitions. In each transition a trigger causing that transition can be labeled, and well as an action generated by that transition (i.e. trigger/generated).

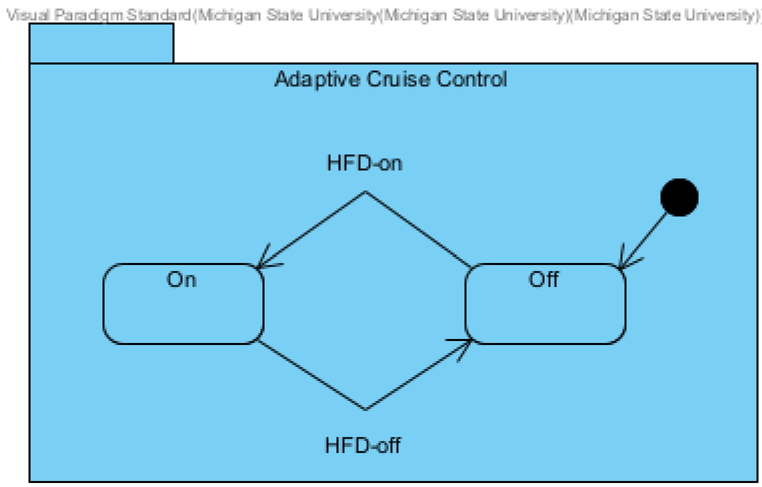


Figure 8: State Diagram for ACC

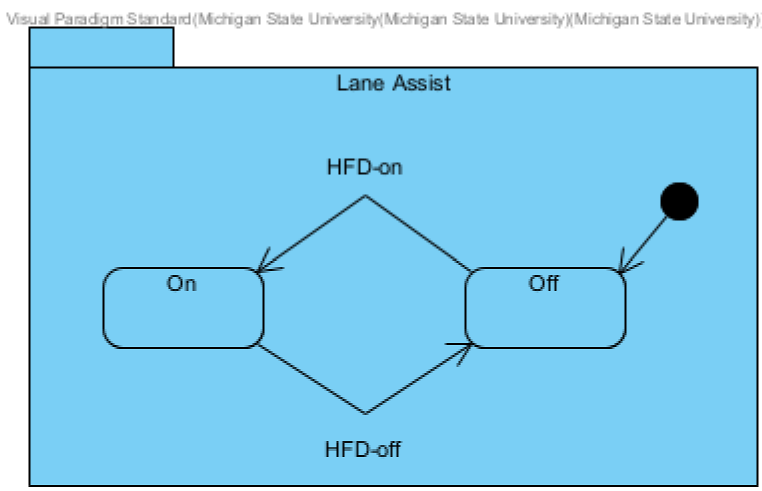


Figure 9: State Diagram for Lane Assist

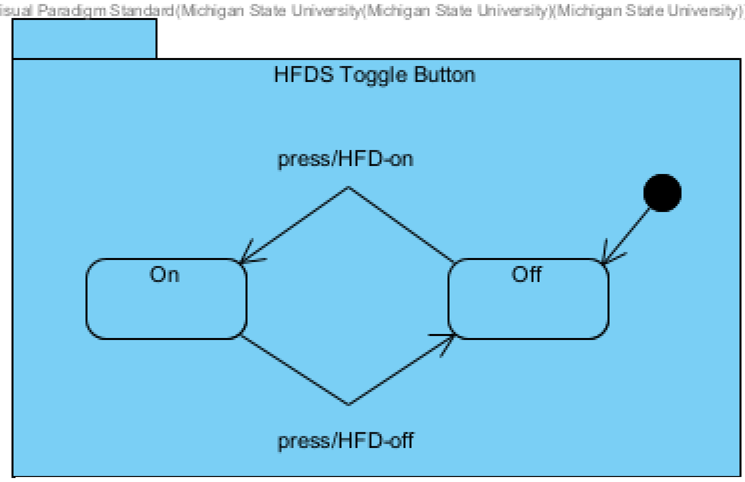


Figure 9: State Diagram for HFDS Toggle Button

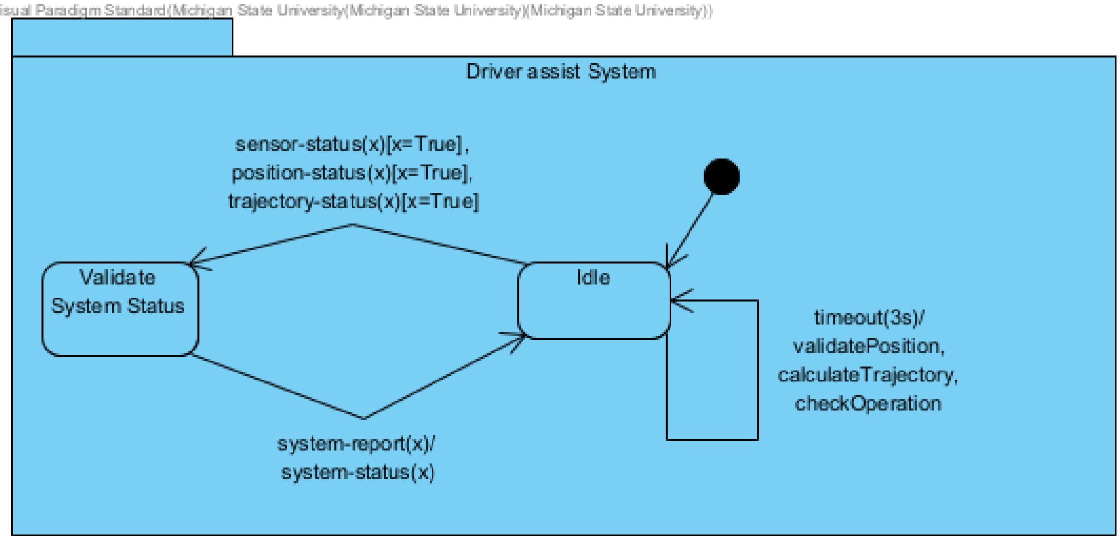


Figure 11: State Diagram for Driver Assist System

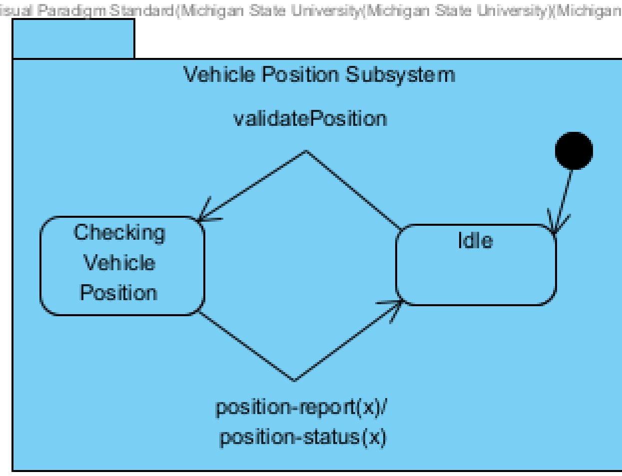


Figure 12: State Diagram for Vehicle Position Subsystem

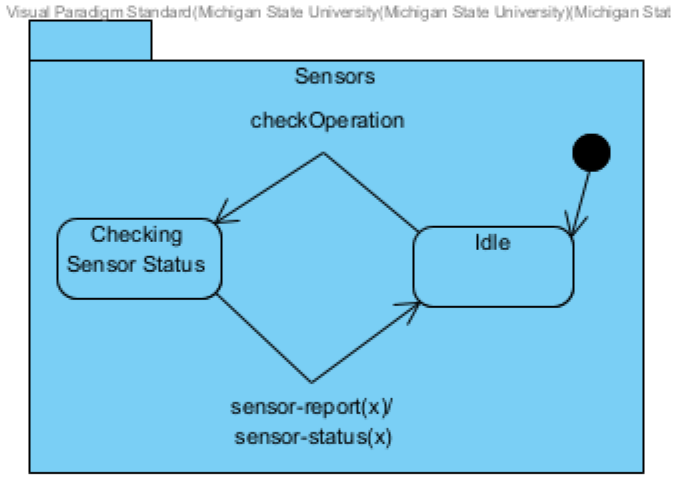


Figure 13: State Diagram for Sensors

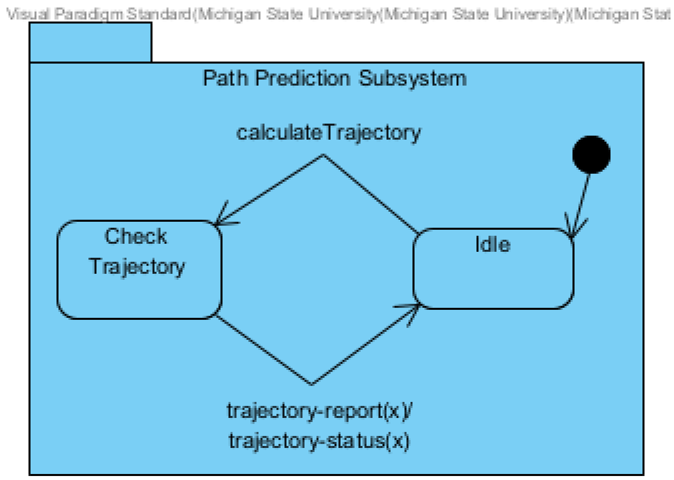


Figure 14: State Diagram for Path Prediction Subsystem

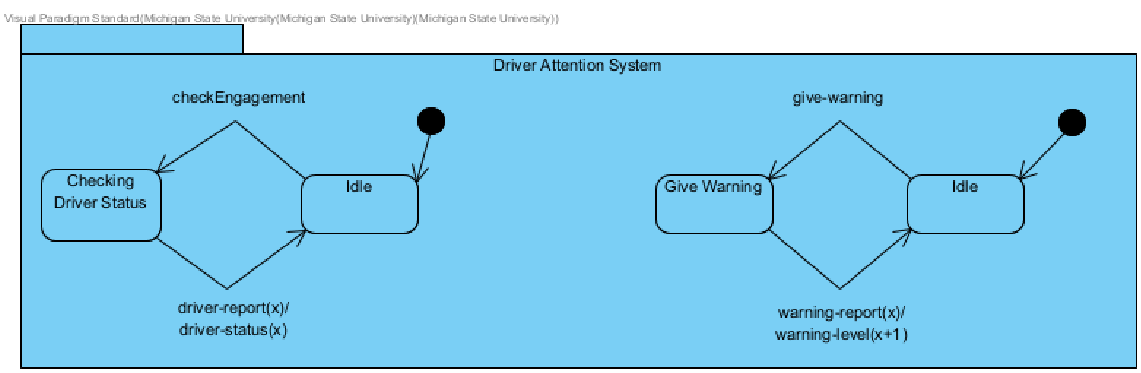


Figure 15: State Diagram for Driver Attention System

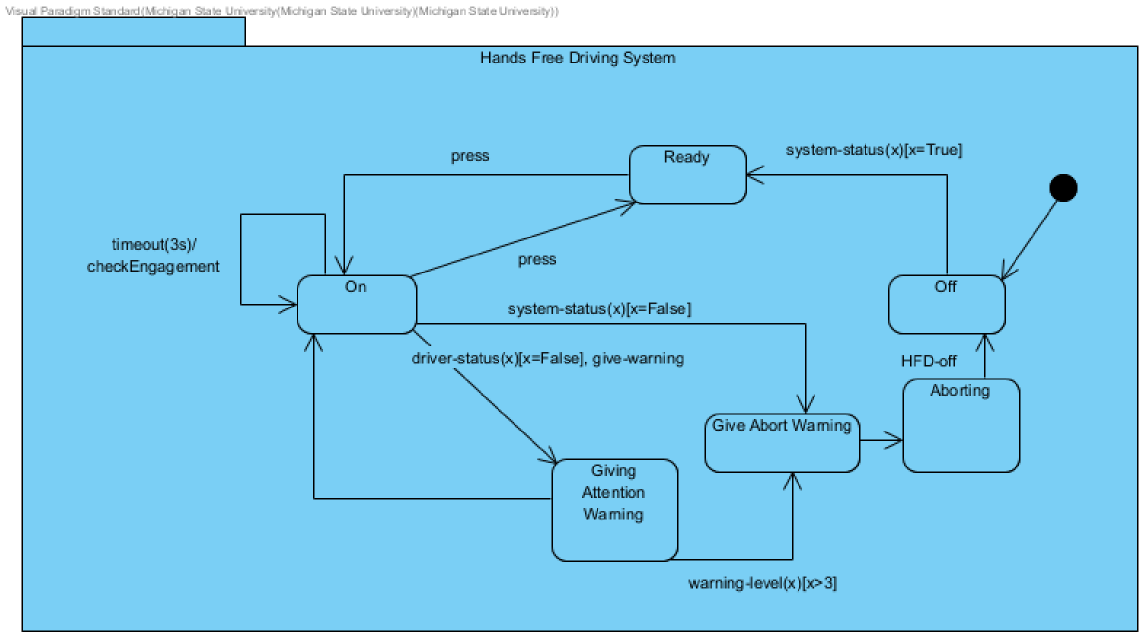


Figure 16: State Diagram for Hands Free Driving System

6 Prototype

To demonstrate the concept of HFDS we developed a prototype that displays the HFD system and user interface as it would behave in practice. This section is dedicated to access and explanation of the prototype.

5.1. How to run the prototype

The HFDS prototype is available at https://cse.msu.edu/~lander10/project.html and can be run within most common browsers.

The prototype consists of an attention system to simulate driver attention with an eye icon indicating whether the driver is currently paying attention. This attention can be toggled by clicking the "i" key.

The steering wheel is displayed on the screen as well indicating the status of HFDS with the appropriate colors.

5.2. Sample Scenarios

5.2.1. Scenario 1: No Proper Mapping

Figure 5.2.1.1 is the initial state of the first scenario in the prototype. Within this scenario the HFD system is deactivated as indicated by the red light on the steering wheel and the driver is paying attention as indicated by the eye icon.

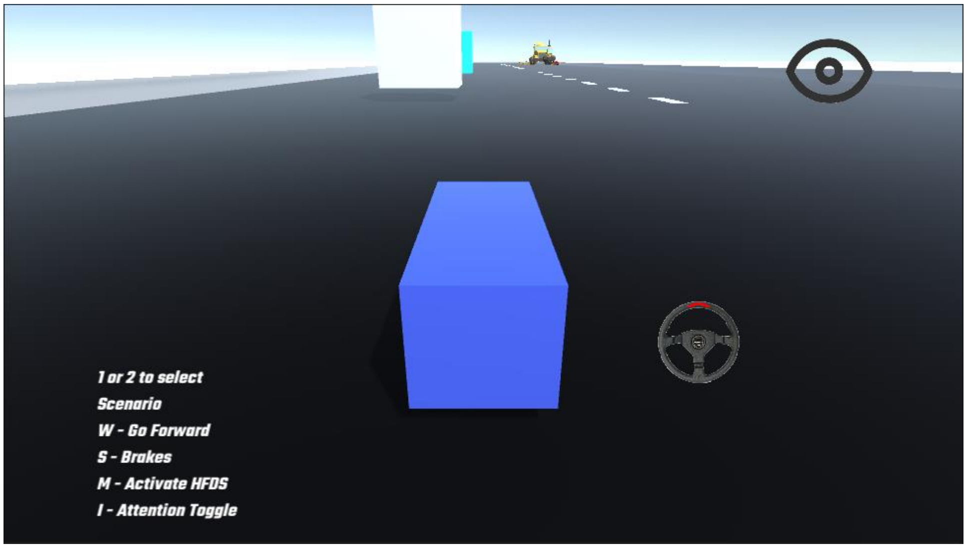


Figure 5.2.1.1 The initial construction zone scenario

Within figure 5.2.1.2 The vehicle has been brought to speed and HFDS activated as indicated by the green light on the steering wheel. We can see the approaching construction equipment on the highway.

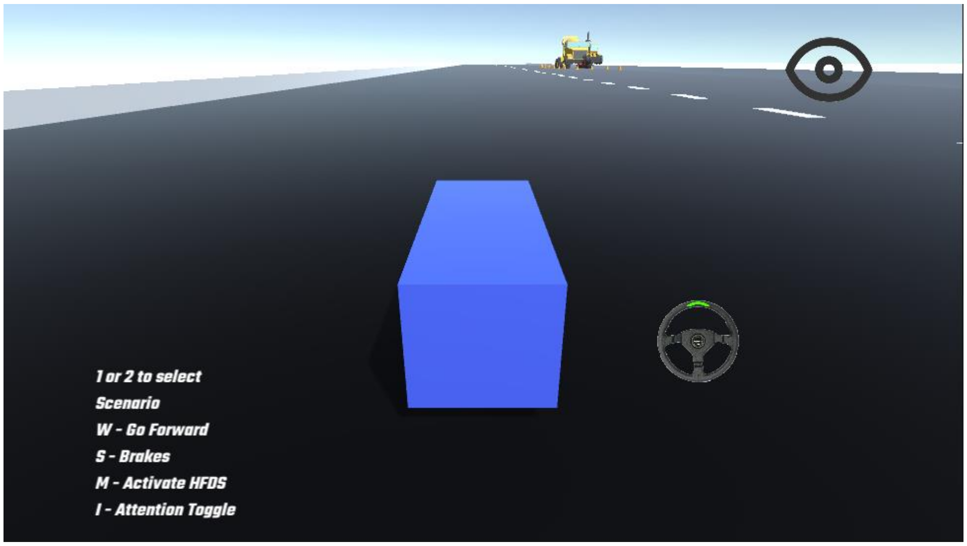


Figure 5.2.1.2 HFDS is active, construction zone in the distance.

Within figure 5.2.1.3 the vehicle has halted and HFDS deactivated as the system has detected the construction on the highway. The vehicle could be driven manually, but HFD will not be able to be activated until the construction zone has been left.

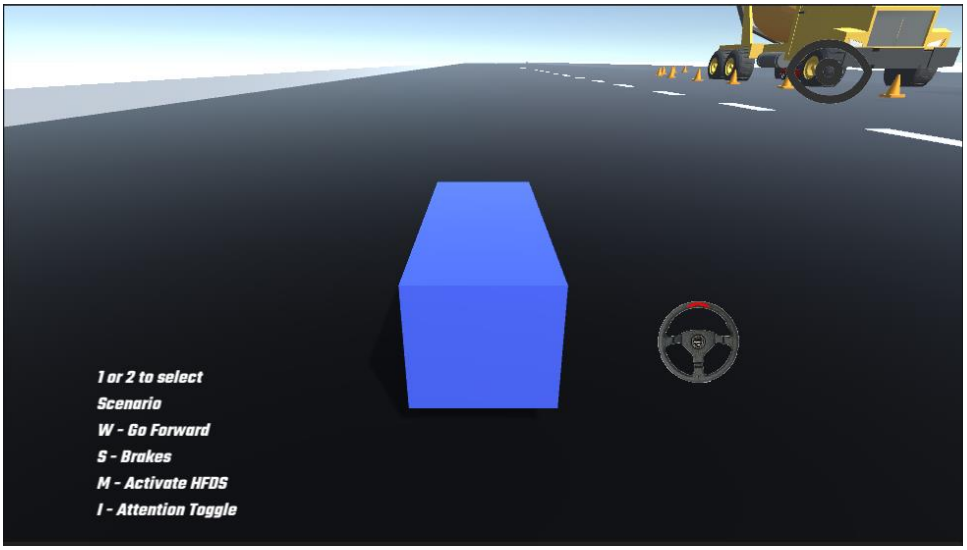


Figure 5.2.1.3 HFDS is deactivated within a construction zone.

5.2.2. Scenario 2: Fully Operational

In figure 5.2.1.4 the HFDS is able to be activated and interacted with on a valid highway without other obstruction. Here passing control between the HFDS and driver is able to be easily demonstrated as well as warnings if the driver becomes inattentive. As the driver becomes inattentive the steering wheel light and sounds will indicate HFDS status.

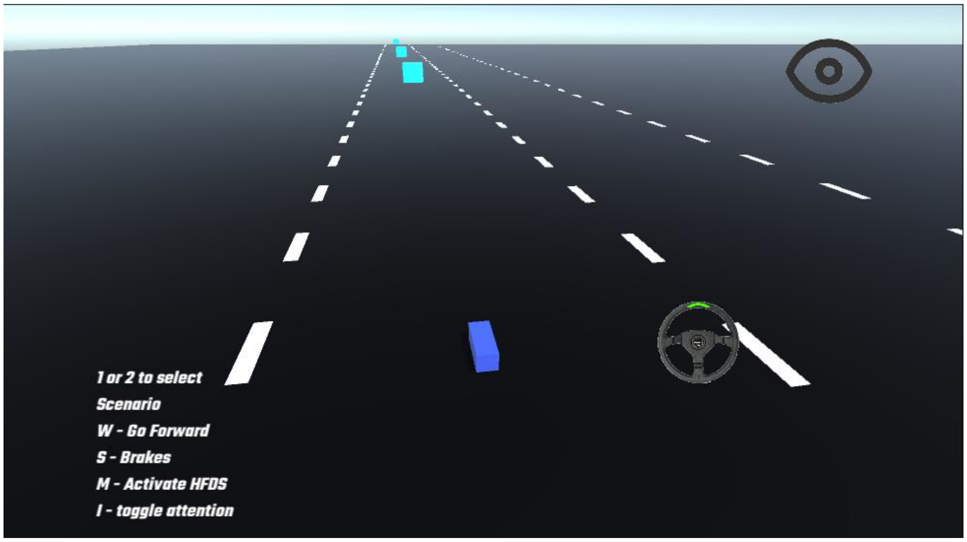


Figure 5.2.1.4 HFDS active on an unobstructed highway.

7 References

[1] "2022 Statewide Traffic Crash Data Year End Report.", Michigan State Police, www.michigan.gov/msp/-/media/Project/Websites/msp/cjic/Traffic-Crash-Reporting-Unit-Files/Year-End-2022-Traffic-Crash-Report.pdf. Accessed 12 Nov. 2023.

[2] "Automated Vehicles for Safety." *National Highway Traffic Safety Administration*, U.S. Department of Transportation, www.nhtsa.gov/technology-innovation/automated-vehicles-safety. Accessed 12 Nov. 2023.

[3] J. Landers, E. Barrett, N. Holley, J. Pauls, & A. DuBois. "Hands Free Driving – Team 1." cse.msu.edu/~lander10. https://cse.msu.edu/~lander10/index.html (Accessed Nov. 12, 2023).

8 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.