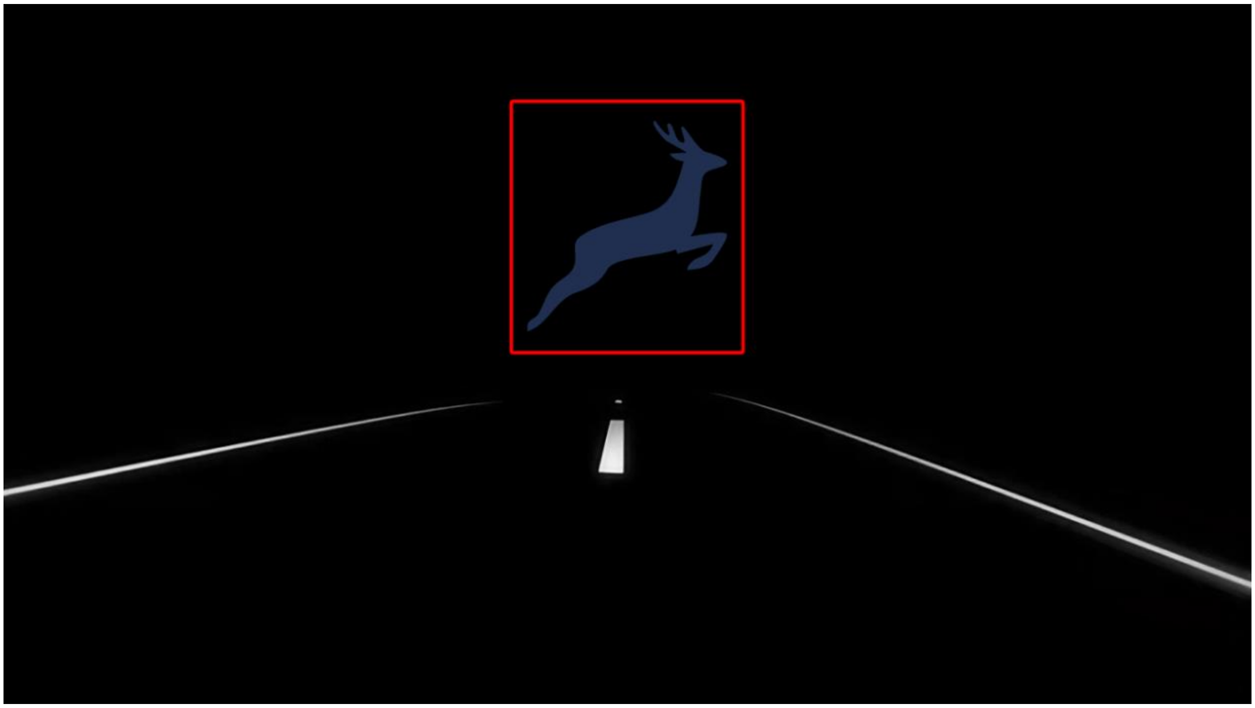
LiDAR Deer Detection (LiDD) System



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1. **Introduction**

State Farm Insurance estimates there were approximately 1.5 million vehicle crashes involving deer in the United States during the 1-year period between July 1, 2019 and June 30, 2020 [1]. Most of those collisions occurred during the low visibility hours of dawn and dusk and in the spring and fall mating, migration, and hunting seasons. The total cost associated with wildlife-vehicle collisions is high, estimated at $8.4 billion [2] annually, including the cost of human injury and fatality, wildlife survival and conservation, property damage, and law enforcement, emergency service, and road maintenance assistance.

Attempts have been made to minimize deer-vehicle collisions by influencing wildlife behavior, reducing wildlife populations, encouraging different driver behavior, and planning and designing roadways to avoid key habitats and ease deer detection. These methods have tended to be expensive, ineffective, and inaccurate resulting in costs continuing to rise [3].

Automotive manufacturers have risen to the challenge by developing in-vehicle methods to detect deer and warn drivers of the potential for danger. Methods currently used by manufacturers like Porsche, BMW, Mercedes, and Audi include using infrared thermal imaging which displays live wildlife information on the vehicle's instrument cluster or infotainment screen. While these systems are effective at providing real-time wildlife tracking information, they cause drivers to take their eyes off the road during a critical moment when drivers most need their eyes on the road.

This is a proposal for a Light Detection and Ranging (LiDAR) deer detection system intended for drivers of autonomous vehicles in North American regions with large deer populations and collision rates. The LiDAR Deer Detection (LiDD) system enables forward-facing scanning of vehicle surroundings with a high degree of accuracy. It notifies drivers when a deer is within collision range using a color-coded windshield deer indicator and seat vibration warning - both intended to give the driver enough time to become aware of the situation, gauge its urgency, and react - *before a collision occurs*. As opposed to previous solutions, drivers don't have to take their eyes off the road to receive deer tracking information.

2. Design

The LiDD system combines a forward-facing LiDAR system with augmented reality windshield display and seat vibration warnings to let drivers know when and where deer are located in their field of view so they have enough time to make an appropriate decision and react when there is potential for collision.

The LiDD system automatically turns on at dusk when deer are most active and turns off again after dawn breaks as deer are less likely to become a road hazard once the sun has arisen.

Storyboard

This is an example of how the LiDD system would work in the real world. It demonstrates a typical scenario when two people are driving down a road at night and a deer appears at the side of the road.

Dylan is driving down a dark road at night with his friend Maddy.

There is a deer off to the side of the road, but Dylan doesn't see it.

Not to worry, Dylan has a LiDAR deer detection system installed on the roof of his car.

The system spots the deer on the side of the road and displays a box around the deer projected onto his windshield using augmented reality.

The warning changes from green to yellow and then red as Dylan's vehicle gets closer and vibrates the seat.

Dylan manages to stop in plenty of time. He and Maddy are safe!

In this example, the LiDD system helped the driver safely avoid a collision with a deer.

Illustrations

The figures below illustrate a driver's perspective of the visual and vibration warning systems.

Figure 1

Figure 1 shows the different sized and colored boxes which will be displayed on the driver's windshield to identify and outline the deer's rough size and location. The size and color of the box varies depending on the size of the deer, how close it is to the vehicle, and how much time the driver has to react.

Red, yellow, and green box colors were chosen because they are standard around the world as colors that convey levels of urgency. The colors have been modified slightly so they'll be eye-catching and easy to see on the dark (nighttime) windshield.

The boxes outline the deer to get across the deer's approximate size and distance away from the vehicle without compromising the driver's field of view for safety reasons. If there are multiple deer, the system will draw a box around every deer.

Figure 2

Figure 2 shows a red box around a deer detected at the side of the road. The box is red and large when the driver has 2.5 seconds or less to react before there is a possible collision. The box follows the deer in real-time ensuring the driver always knows the position of the deer. The box appears on the windshield, so the driver does not have to take his or her eyes off the road to see the warning.

Figure 3

Figure 3 is the same as Figure 2 except this time, we're demonstrating the vehicle's driver seat vibrates when the deer is close. The vibration will increase in intensity as the box colors progress from green to yellow to red and indicate a low, medium, or high urgency to react. Vibrations are brief and act as a secondary warning system, decreasing the chance that the warning will be overlooked or ignored. It is also an accessibility feature for people who are color blind, serving as an indication of how urgent it is for them to react.

If there are multiple deer, the system will only invoke the vibration alert for the deer closest to the vehicle.

Visual and Vibration Decision Matrix

The matrix below indicates how the visual and vibration components work together with reaction times.

Reaction Time	**Visual Alert**	**Vibration Alert**
> 6.5 seconds	None	None
4.6 - 6.5 seconds	Green Rectangle	Low Vibration
2.6 - 4.5 seconds	Yellow Rectangle	Medium Vibration
2.5 seconds or less	Red Rectangle	High Vibration

3. Implementation

Inputs

- Lidar point cloud data will be used to feed the deer model classifier.

Transformations

- Deer model classifier
    - I recommend using the deer classification algorithm in "Deer Crossing Road Detection with Roadside LiDAR Sensor" in *IEEE Access* [4].
        - The deer classification system is broken down into three main parts: background filtering, object clustering, and object classification.
    - The classifier is required to work with all species of deer in North America as this is where the system will be implemented. It should only be triggered by deer in that classification.

- Confidence Levels and False Positive Warnings

- Warnings should only be invoked between dusk and dawn.
- Warnings should only be invoked when there is a high confidence that a deer has been detected and is within a collision range of the vehicle while traveling at its current speed.
- The "Deer Crossing Road Detection with Roadside LiDAR Sensor" paper [4] defines a high confidence level in Table 2 as a deer detection accuracy rate of 99.8% or higher. That is the best rate researchers were able to achieve with the three models tested. To determine what makes the most sense for this detection system, we will need to consult with engineering and safety teams.
- It will be important to bear in mind that false positives will cause drivers to distrust the warning system and eventually ignore box and vibration warnings. For this reason, I chose to design this product around confidence levels rather than risk false positives. While every deer might not be recognized by the system, the driver will be more trusting and responsive to the warnings he or she does receive instead of potentially ignoring them, believing them to be another false positive.
- If confidence levels are too low, then the system shouldn't present information about deer.
- I want to avoid all unnecessary distractions and a false positive would constitute an unnecessary distraction.

- Box Warnings

  - Warning boxes should display on the windshield of the car in the location the deer appears on the road or at the side of the road.
  - They should move with the deer. So, for example, if the deer moves left, the box should move left and so on.
  - Boxes should instantly appear when a deer is detected and instantly disappear when they are not. The boxes should not fade in or out.
  - Similarly, if transitioning between a green to a yellow state, or a yellow to a red, the boxes should instantly change from one color to the next, not fade in or out.
  - If there are multiple deer, multiple boxes should be displayed, each framing a deer.
  - If the reaction time calculation is imprecise and requires the system to jump back and forward between color states, present the box color for the highest-level warning of the deer detected. For example, if it's jumping between green and yellow, present yellow. If it's jumping between all three, present the red box.
  - Do not display a box when the deer is out of view of the windshield.
  - Warning boxes should give the driver enough time to notice the deer and safely avoid collision based on the speed the vehicle is travelling and the distance the deer is from the vehicle.

- Assuming an average driver perception-reaction time of 1.5 seconds [5], the following box colors and reaction times are suggested:

Box Color	Reaction Time
None	> 6.5 seconds
Green	4.6 - 6.5 seconds
Yellow	2.6 - 4.5 seconds
Red	2.5 seconds or less

- If the time to react is greater than 6.5 seconds or the confidence level of the LiDAR classification system is low, no box should appear.
- I used reaction time to center our attention on the perspective of the driver over other measures such as distances.
- Reaction times are estimated and dependent on many variables such as the speed of the vehicle, the distance the deer is from the vehicle, road conditions, and individual driver reaction times.
    - I will need to coordinate with engineering and safety teams to determine the appropriate time to trigger the box warnings.
- If the vehicle is stopped and a deer is standing still or moving across the road and the reaction time is stagnant, make the box yellow, indicating it is not an immediate danger but that the driver should still be observant of the deer's movement.

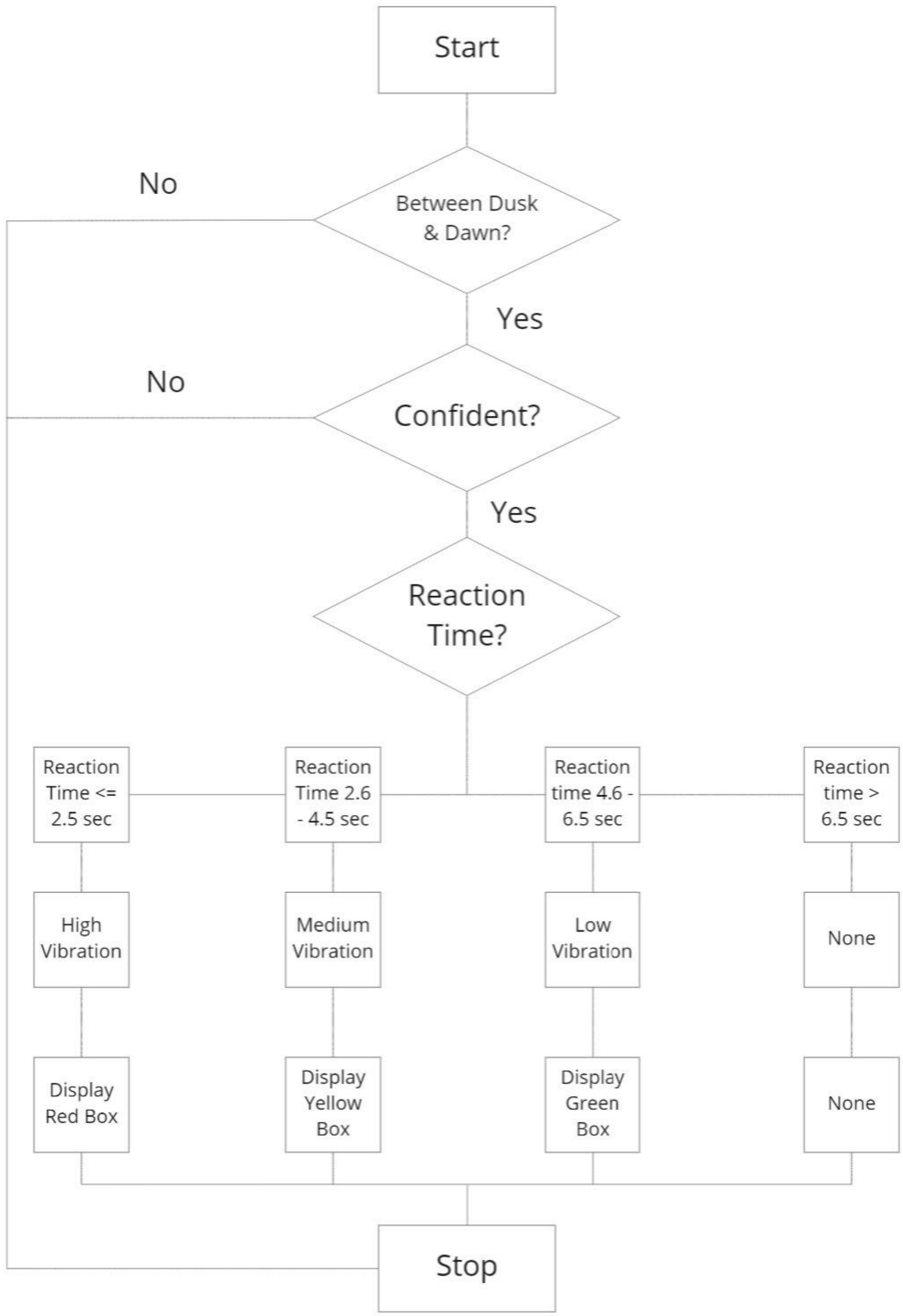
- Vibration Warning

    - Like the box warning, the seat vibration intensity will depend on several factors including the proximity of the deer to the car, the speed at which the vehicle is moving, and the time needed for the driver to react.
    - If the reaction time calculation is imprecise and requires the system to jump back and forward between vibration states, present the highest-level vibration warning of the deer detected. For example, if it's jumping between low and medium vibration levels, present the medium level once and stop. If it's jumping between all three, present the high-level vibration once then stop.
    - The vibration intensity should increase as the time needed to react decreases.

Vibration States	Reaction Time
None	> 6.5 seconds
Low Vibration	4.6 - 6.5 seconds
Medium Vibration	2.6 - 4.5 seconds
High Vibration	2.5 seconds or less

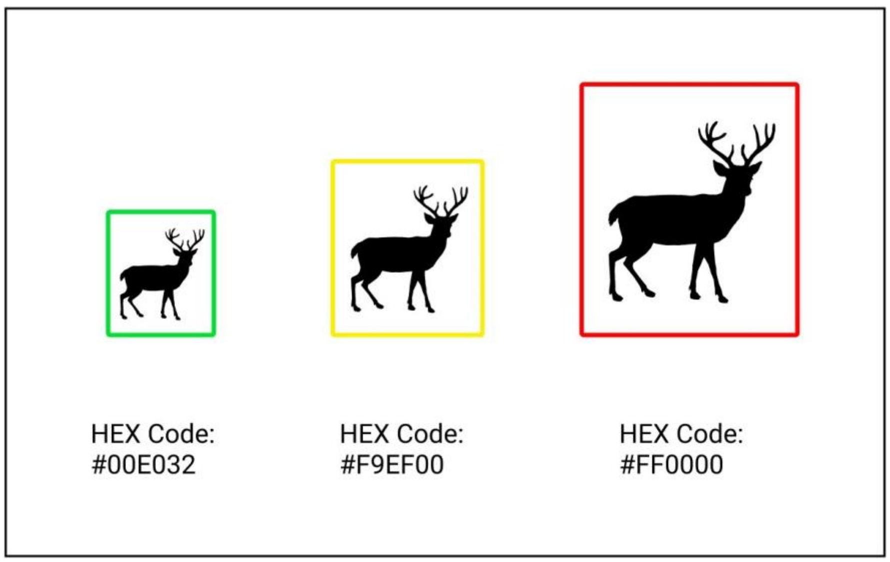
- Each vibration level should last for a half second.
- The vibration intensity should express higher urgency as reaction times lessen without startling drivers, making them break attention from the road.
- I will need to consult with design teams to determine the appropriate level of vibration for each of the three categories.
- If the time to react is greater than 6.5 seconds or the confidence level of the LiDAR system is low, there should be no vibration warning.
- If there are multiple deer, the system should invoke the vibration alert for the deer closest to the vehicle.
- If the vehicle is stopped and a deer is standing still or moving across the road and the reaction time is stagnant, vibrate the seat once on medium level. Don’t continuously vibrate.
- If there is no deer detected and no box displayed, then there should be no vibration.

- Decision Tree
  - The decision tree (below) is a visual representation of the warning transformations described above.


Start
No
Between Dusk & Dawn?
Yes
No
Confident?
Yes
Reaction Time?
Reaction Time <= 2.5 sec
Reaction Time 2.6 - 4.5 sec
Reaction time 4.6 - 6.5 sec
Reaction time > 6.5 sec
High Vibration
Medium Vibration
Low Vibration
None
Display Red Box
Display Yellow Box
Display Green Box
None
Stop

Outputs

- Box Warning
    - The boxes need to be perceivable from the driver's field of view.
    - The box should follow the deer in real-time, so the driver always knows the position of the deer.
    - The box should be rectangular-shaped, centered over the deer, and expand or shrink to fit the size of the deer.
    - The interior of the box should be transparent so the driver can still see the deer.
    - Box outer edge should be 2 pixels.
    - Box corners should be rounded, border radius 2 pixels.
    - Box colors should be as follows:



- Vibration Warning
    - The vibration should be intense enough to alert the driver that their attention is needed, but not be so intense as to startle to an uncomfortable level.

References

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