Realization of Advanced Driver Assistance System Using FPGA for Transportation Applications

Ganesh Racha, Yedukondalu Kamatham, Srinivasa Rao Perumalla, Battuwar Akhila, Adarsh Gangula and Amrith Patalay
Department of Electronics & Communication Engineering, CVR College of Engineering, Hyderabad, India

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Abstract: Transportation is the basic mode of commuting and transporting goods from one place to another place. There are distinct modes of transportation that are available through air, water, road, etc. Road-based transportation is the most used mode for many human beings. The increased usage of road transportation is causing accidents which is a major significant global concern. Hence, there is a requirement for Advanced Driver Assistance Systems (ADAS) to reduce the number of road accidents. ADAS has been introduced to reduce human errors, which are one of the leading causes of accidents, such as distracted driving, fatigue, or poor judgment. This work deals with the design of an ADAS controller using Verilog HDL and AMD Xilinx FPGA EDA tools. The proposed design uses an algorithm for determining lane departure, adaptive cruise control, blind spot detection, parking assistance, driver monitoring, collision detection, etc. This algorithm is tested and simulated for different test cases for measuring safety and security of passengers.

1 INTRODUCTION

Land transportation is the most used mode of transportation and used to commute from one place to another. Land transportation is very vast, it is divided into two types, i.e. Heavy vehicles and Light Vehicles as shown in Figure 1. Heavy vehicles are used to commute or transport over longer distances, they are heavier, with an all-terrain build quality.

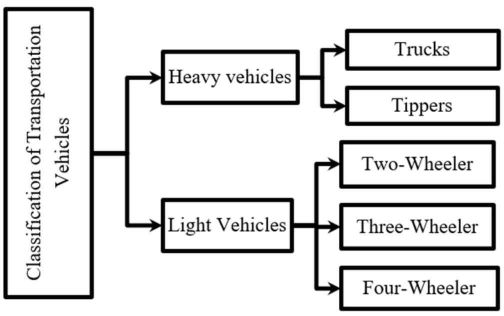

Figure 1: Classification of Transportation Vehicles

The heavy vehicles comprise Trucks, Tippers, etc, that can transport many people or commodities and are usually used for long-distance routes. Light vehicles are generally used for urban commuting and transportation. They are used to carry and transport light commodities. Light vehicles comprise two, three, and four-wheelers. Vehicles have two transmission modes, one as manual mode, and the other is automatic mode of transmission as shown in Figure 2.

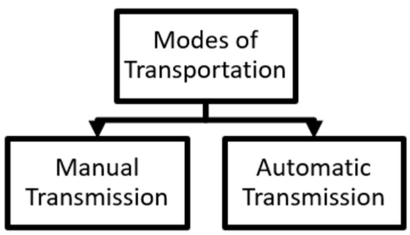

Figure 2: Modes of Transportation

In the manual mode of transmission, the gearbox and clutch must be engaged manually for vehicle movement, whereas in the automatic transmission mode, the clutch is engaged automatically, and the

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vehicle adjusts the gear according to the requirement of the user. This type of automatic advanced driving mechanism is used to make driving comfortable and smoother. Advanced Driver Assistance Systems (ADAS) are a group of technologies that are installed in cars to make driving safer and more convenient. Using a variety of sensors, cameras, radar, and other technologies, these systems keep an eye on the surroundings of the car, warn the driver of any dangers, and in some cases, step in to stop collisions. The following are the main objectives of ADAS: Improving safety by lowering the likelihood of crashes, particularly those initiated by human mistakes. With difficult activities like parking, changing lanes, and keeping a safe following distance, drivers can get help from ADAS. By automating processes like lane centering and speed adjustments, driving becomes more comfortable overall. Semi-autonomous and fully autonomous vehicles are built on the foundation of ADAS. The degree of intervention is typically used to categorize each ADAS element, ranging from Level 0 (no automation) to Level 5 (complete automation) as shown in Table I.

Table 1: Levels of Transportation Vehicles

S. No	Level	Automation
1	0	Manual Mode (No Automation)
2	1	Human Assistance
3	2	Partial Automation
4	3	Tentative Automation
5	4	Constrained Automation
6	5	Complete Automation

Level 0 completely works in manual mode. Level 1 provides a feature for the driver to monitor the vehicle. Level 2 automates vehicle monitoring, steering, and acceleration with the help of ADAS. Level 3 uses ADAS with environmental capabilities using human intervention. Level 4 uses Level 3 features with certain specific conditions. Level 5 works with full automation. This work deals with the design of Level 2-based ADAS design using AMD Xilinx FPGA with Verilog HDL. The rest of the paper is organized as follows: The literature review of vehicles is given in section II. Section III gives the design specifications and analysis of the ADAS Level 2 system. Section IV gives the design synthesis and simulation test case analysis for the ADAS system. The conclusions drawn are presented in Section V.

2 LITERATURE REVIEW OF VEHICLES

Adaptive Cruise Control (ACC) is an advanced feature that controls speed and distance adjustments between vehicles. Using sensors, it detects the vehicles ahead and maintains a safe following distance without driver intervention. This reduces stress during long drives and helps for smoother traffic flow, particularly on highways. Some systems include stop-and-go functionality for city traffic. Even with its benefits, ACC faces challenges like sensor accuracy, ensuring that drivers remain attentive while driving, and addressing any legal concerns. These issues must be resolved for ACC to achieve widespread adoption and improve road safety (Vahidi, Eskandarian, et al. , 2003). Lane Centering Assistance (LCA) is a driver assistance system designed to keep vehicles aligned in the center of their lane. It uses sensors like cameras and radar to monitor the road markings and the vehicle's position. It adjusts the steering to the correct position even on curved roads and at different speeds (Bifulco, Simonelli, et al. , 2013). LCA enhances safety and reduces driver workload by maintaining a steady path, mainly while they are driving on highways. LCA does have issues which mainly include handling complex road conditions and ensuring smooth integration with other driving systems (Tolosana, Ayerbe, et al. , 2017).

The Advanced Parking Assistance System helps drivers park safely and easily by using sensors and automatic controls. It integrates vehicle position data, planning of path for parking, and Human Machine Interface (HMI) to guide drivers from the parking lot entrance to a parking area. The system gives suggestions on steering and movement commands, displayed on a screen or by audio. It adjusts for driver errors and uses a path-planning method that generates simple, easy-to-follow routes. The main aim of the system is to reduce stress and improve parking efficiency, especially for elderly drivers (Wada, Yoon, et al. , 2003). Blind spot detection helps drivers identify areas around their vehicles that are hard to see which can cause accidents. Modern systems use cameras or sensors to alert drivers visually. Some advanced systems include physical warnings, like force-feedback pedals and steering wheel resistance to actively warn drivers of potential collisions. These systems can detect vehicles in blind spots and give warnings to guide drivers away from danger. For example, when a driver tries to change lanes into an occupied spot, the steering wheel resists turning (Racine, Cramer, et al. , 2010). Collision avoidance systems help drivers prevent accidents by warning about potential dangers or even taking control of the vehicle if necessary. These systems rely on sensors to detect accidents and provide alerts, or even apply brakes or steering by themselves to avoid a crash. Automated collision avoidance systems can act when drivers fail to respond to emergencies, ensuring safety. However, this system is not so advanced yet, so it sometimes gives false alarms about the hazards and has problems facing liability issues. There are more Advanced systems being developed to enhance accuracy and reliability (Vahidi and Eskandarian, 2003).

The driver's fatigue detection system monitors the driver's alertness level using sensors. These sensors track facial movements, and eye and head position to determine if the driver shows signs of fatigue. When the system detects drowsiness or a lack of attention it generates an alert to warn the driver and apply the brakes. This system is very useful in preventing accidents caused by fatigue which ensures safe driving conditions for long-distance travel (Hossan, Alamgir, et al. , 2016). Adaptive Cruise Control helps drivers maintain a safe distance and desired speed on roads by automatically controlling acceleration and brakes. However, its performance can vary in heavy traffic or when vehicles suddenly cut in, often requiring manual driving by the driver. Even though ACC helps reduce drivers' efforts by maintaining speed and a good distance between vehicles, it needs more improvements in the system for a better experience for the driver (Marsden, McDonald, et al. , 2001). An Adaptive Driver Voice Alert System adjusts voice alerts based on the driver's emotions to enhance safety. It uses facial emotion recognition to detect moods like happiness, anger or fear. Depending on the detected mood, the system modifies alerts to ensure they are clear. For example, during anger, alerts become more detailed to reduce aggressive driving. This emotionally adaptive approach helps drivers respond better to alerts, improving road safety (Sarala, Yadav, et al. , 2018). This system explores decision-making processes for Level 0 ADAS in Russian public transport, focusing on enhancing road safety. Two new systems, Turn Assist System (TAS) and Lateral Clearance Warning (LCW), are proposed along with Forward Collision Warning (FCW), Pedestrian Collision Warning (PCW), and Blind Spot Monitoring (BSM). Testing in MATLAB/Simulink confirmed that the systems meet the requirements and improve safety (Wassouf, Korekov, et al. , 2023). The buses lag in adopting autonomous safety systems, but cities like London are introducing ADAS for buses. On-road trials show that Forward Collision Warning (FCW) reduces pedestrian collision risks. Some tests show that vehicle retarders maintain safe deceleration rates for emergency stopping, for both sitting and standing passengers (Blades, Douglas, et al. , 2020).

A driver behavioral analysis system studies driving patterns to improve advanced driver assistance systems. It uses data like vehicle speed, distance, and acceleration to understand driver habits and reaction delays. By analyzing these behaviors, it helps create systems that adapt to individual drivers, improving comfort and safety. The system also identifies factors like vehicle spacing and reaction time, which influence driver actions (Chen, Zhao, et al. , 2018). Future advancements in Advanced Driver Assistance Systems (ADAS) focus on greater automation and enhanced safety features. ADAS is expected to integrate more software-driven functionalities, contributing to the rise of more autonomous vehicles. These systems will increasingly rely on advanced sensors like Light Detection and Ranging (LiDAR) and cameras along with AI algorithms, to provide intelligent driving support. Key trends include improvement in lane departure warnings, adaptive cruise control, and driver monitoring. However, challenges like cost reduction, testing reliability, and user safety concerns need to be addressed. ADAS will continue to evolve, becoming integral to safer and smarter transportation (Kaur and Sobti, 2017). Drowsiness detection using facial landmarks helps identify if a driver is sleepy by analyzing their face. This system monitors eye movements, blinks, and yawns using a feature known as Eye Aspect Ratio (EAR), which tracks eye closure duration to determine drowsiness. If the EAR stays below a threshold for a few seconds, an alarm is triggered to alert the driver. Preliminary tests showed 87% accuracy, making it a promising tool for reducing accidents caused by driver fatigue (Cueva and Cordero, 2020).

AI-based ADAS has been proposed to predict the dangers that can happen due to road conditions and is designed to operate on an embedded platform (Huang, Chen, et al. , 2022). Autonomous vehicles rely on Advanced Driver Assistance Systems (ADAS) for driving and parking tasks. The use of Frequency Modulated Continuous Wave (FMCW) radar in collision avoidance, particularly for detecting proximity collisions is a problem for short-range radars (Ekolle, et al. , 2023). The adoption of Autonomous Vehicles (AVs) remains limited due to public mistrust, even though there are many advancements in the system. This precise customization of the Support Vector Machine (SVM) enhances safety and driver support (Hwang, Jung, et al. , 2022). Facial gestures and emotion recognition are critical components of Driver Assistance to enhance road safety. By analyzing eye and lip movements, the sensors classify emotions into happy, angry, sad, or surprised (Dragaš, Grbić, et al. , 2021). The system aims to detect driver inattentiveness or fatigue and switch the car to automatic mode if necessary (Agrawal, Giripunje, et al. , 2013). The system focuses on eye monitoring to detect driver fatigue and prevent accidents. A front-facing camera records a video, from which frames are extracted to detect faces using Histogram of Oriented Gradients (HOG) and Support Vector Machine (SVM). Facial landmarks identify eye and mouth positions, allowing the calculation of Eye Aspect Ratio (EAR) and Mouth Aspect Ratio (MAR) to estimate fatigue. When drowsiness is detected, the system alerts the driver (Kaur, Ponnala, et al. , 2023).

3 DESIGN SPECIFICATIONS AND ANALYSIS OF ADAS LEVEL 2 SYSTEM

Advanced Driver Assistance Systems (ADAS) are a group of technologies that are installed in cars to make driving safer and more convenient. Using a variety of sensors, cameras, radar, and other technologies, these systems keep an eye on the surroundings of the car, warn the driver of any dangers, and in some cases, step in to stop collisions. The main objective of ADAS is to improve safety by lowering the likelihood of crashes, particularly those initiated by human mistakes. With difficult activities like parking, changing lanes, and keeping a safe following distance, drivers can get help from us. By automating processes like lane centering and speed adjustments, driving becomes more comfortable.

The Level 2 ADAS refers to systems that provide "partial automation," which means that under some circumstances, the car can control both steering and acceleration/deceleration. However, the driver must always be actively involved and prepared to take over. Although level 2 systems are commonly referred to as "hands-off," this term only applies in a limited sense because the driver is still required to keep an eye on the vehicle and surroundings. The architecture of the FPGA-based ADAS system is shown in Figure 3.

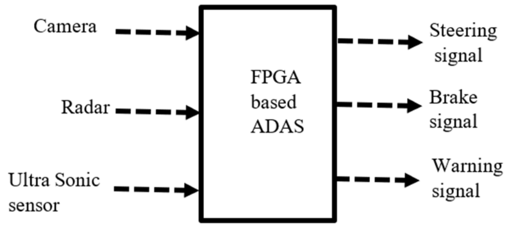

Figure 3: FPGA-based ADAS system architecture

The FPGA-based ADAS system architecture is designed by taking the inputs from the camera, radar, side camera, ultrasonic sensor, and the data of eye position. This architecture generates the steering signal, brake signal, and warning signal as outputs. The ADAS system is designed by using the following functionalities of Level 2:

1. Lane Departure Warning (LDW)
2. Blind Spot Detection (BSD)
3. Driver Monitoring (DM)
4. Adaptive Cruise Control (ACC)
5. Collision Detection (CD)
6. Parking Assistance (PA)

3.1 Lane Departure Warning (LDW)

The LDW system helps to detect when a vehicle starts to move out of its lane. The design of LDW is shown in Figure 4. It processes data from a camera(C_data), represented as an 8-bit signal (lane_position), to determine whether the vehicle is still within safe lane boundaries or not.

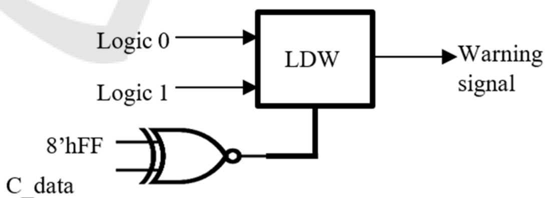

Figure 4: Design of Lane Departure Warning (LDW)

3.2 Blind Spot Detection (BSD)

The BSD system is designed to monitor areas around the vehicle that are difficult for the driver to see, particularly the blind spots. The design of BSD is shown in Figure 5. This system uses data from Side Cameras (SC). When a vehicle is detected in the blind spot, it activates a warning signal to alert the driver.

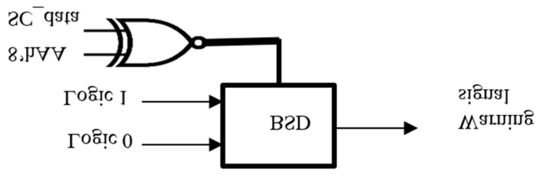

Figure 5: Design of Blind Spot Detection

3.3 Driver Monitoring (DM)

The DM is designed to track the driver's level of attentiveness and alertness. The design of BSD is shown in Figure 6. This system uses a camera to monitor the driver’s eye position(C_data), and if signs of drowsiness or distraction are detected, it activates a warning to alert the driver.

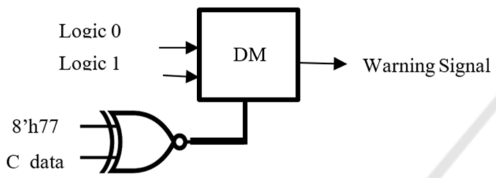

Figure 6: Design of Driver Monitoring

3.4 Adaptive Cruise Control (ACC)

The ACC system adjusts the vehicle's speed based on the distance to the vehicle ahead. The design of ACC is shown in Figure 7. The system uses input and distance from a radar sensor that is Radar_data(R_data).

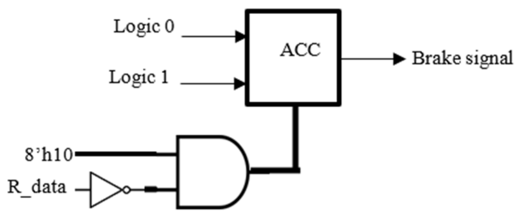

Figure 7: Design of Adaptive Cruise Control

3.5 Collision Detection (CD)

The CD system is designed to prevent accidents by monitoring the distance to nearby obstacles and activating the vehicle's brakes if a collision is going to happen. It uses input from radar that is obstacle data(O_data). The design of the CD is shown in Figure 8.

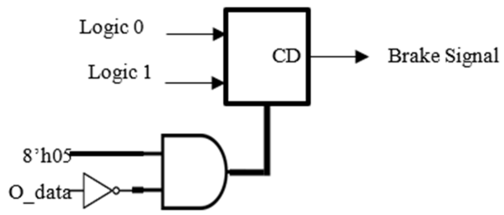

Figure 8: Design of CD

3.6 Parking Assistance (PA)

The Parking Assistance system is designed to help drivers park safely by detecting nearby obstacles during parking. The design of PA is shown in Figure 9. It uses ultrasonic sensors(U_data) to measure the distance between the vehicle and surrounding objects.

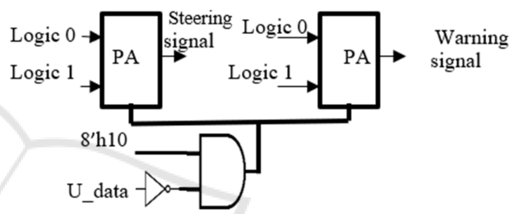

Figure 9: Design of Parking Assistance

The design of FPGA-based ADAS is shown in Figure 10. This system generates brake, warning, and steering signals as per the algorithm and the design inputs.

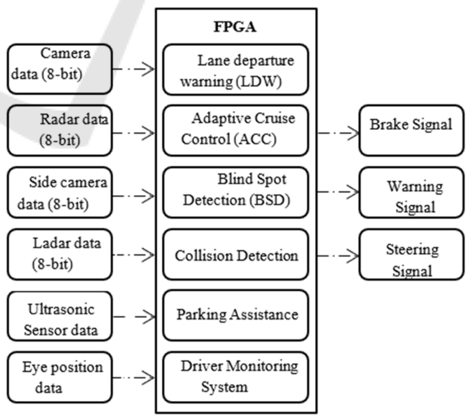

Figure 10: Design of FPGA-based ADAS

The algorithm used for brake, warning signal, and steering signals is shown in Figures 11 to 13. The algorithm which generates a warning signal is shown in Figure 11. The algorithm that generates the brake signal is shown in Figure 12. The algorithm that generates the steering signal is shown in Figure 13.

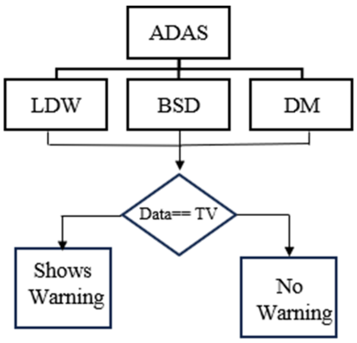

Figure 11: Algorithm for warning signal

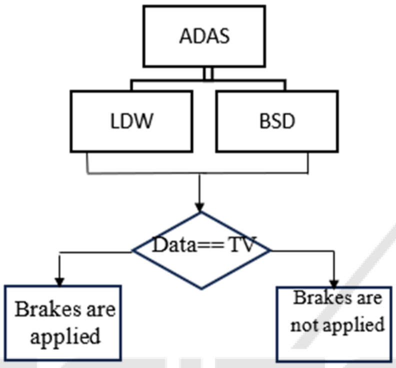

Figure 12: Algorithm for warning signal

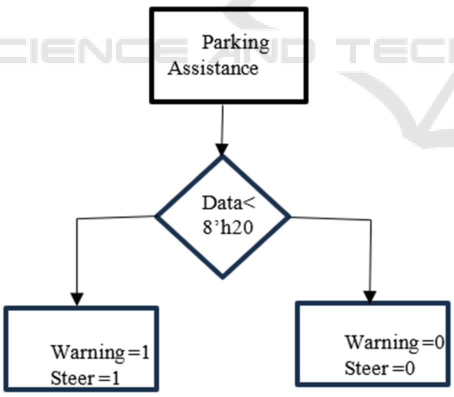

Figure 13: Algorithm for steer signal

In Figure 11 when the data is equal to the threshold then a warning signal is shown. In Figure 12 when the data is less than the TV, then the brakes are applied. In Figure 13 when the data is less than the threshold, then warning is shown, and steering is controlled. This data can be camera data, radar data, side camera data, ultrasonic sensor data, and the data of eye position based on the functionality of ADAS.

4 DESIGN SIMULATION AND SYNTHESIS RESULTS OF ADAS LEVEL 2 SYSTEM

The simulation and synthesis of ADAS done by using Verilog HDL and FPGA design tools. The simulations for different test cases and conditions are shown below.

4.1 Lane Departure Warning (LDW)

Let the TV be 8'hFF. If the camera_data value is less than or greater than the threshold then the warning signal is displayed. The simulation is shown in Figure 14.

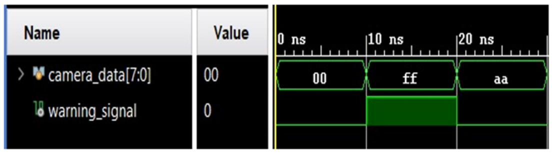

Figure 14: Simualtion of LDW test case

4.2 Blind Spot Detection (BSD)

Let the threshold be 8'hAA. If the side_camera_data value is less than or greater than the threshold then the warning signal is displayed. The simulation is shown in Figure 15.

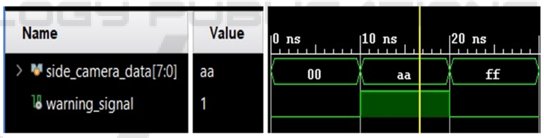

Figure 15: Simualtion of BSD test case

4.3 Driver Monitoring (DM)

Let the threshold be 8'h77. If the driver_camera_data value is less than or greater than the threshold then the warning signal is displayed. The simulation is shown in Figure 16.

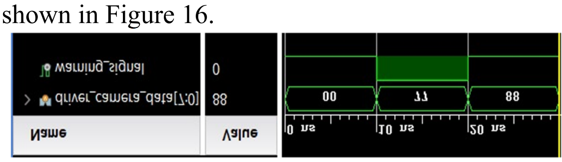

Figure 16: Simualtion of DM test case

4.4 Adaptive Cruise Control (ACC)

Let the threshold be 8'h10. If the side_camera_data value is lesser or reater than the threshold then, the brake signal is displayed. The simulation is shown in Figure 17.

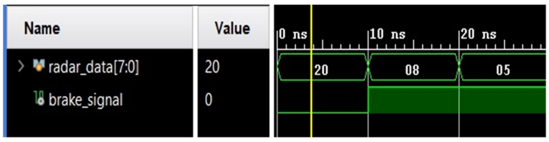

Figure 17: Simualtion of ACC test case

4.5 Collision Detection (CD)

Let the threshold be 8'h05. If the Obstacle_data value is less than the threshold then the brake signal is enabled. The simulation is shown in Figure 18.

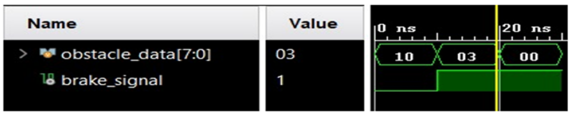

Figure 18: Simulation of CD test case

4.6 Parking Assistance (PA)

Let the threshold be 8'h20. If the Ultrasonic_data value is less than the threshold then the steering and warning signals are enabled. The simulation is shown in Figure 19.

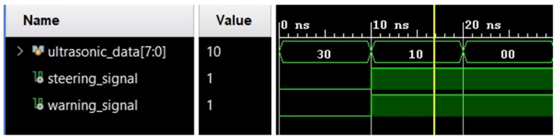

Figure 19: Simulation of CD test case

The detailed simulation result for all test cases and the synthesis design are shown in Figure 20 and Figure 21.

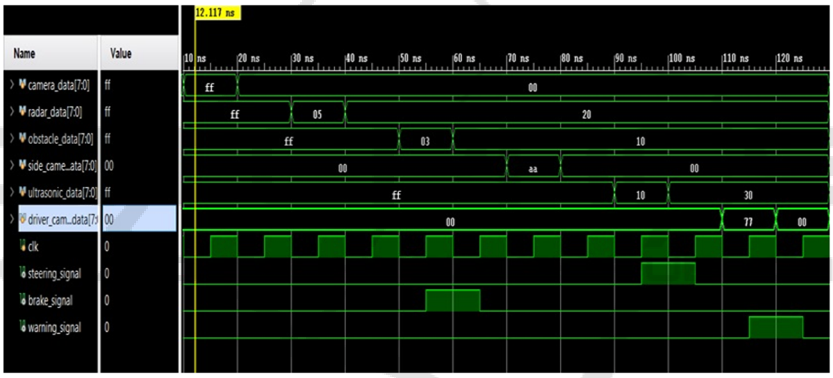

Figure 20: Simulation of ADAS for all test cases

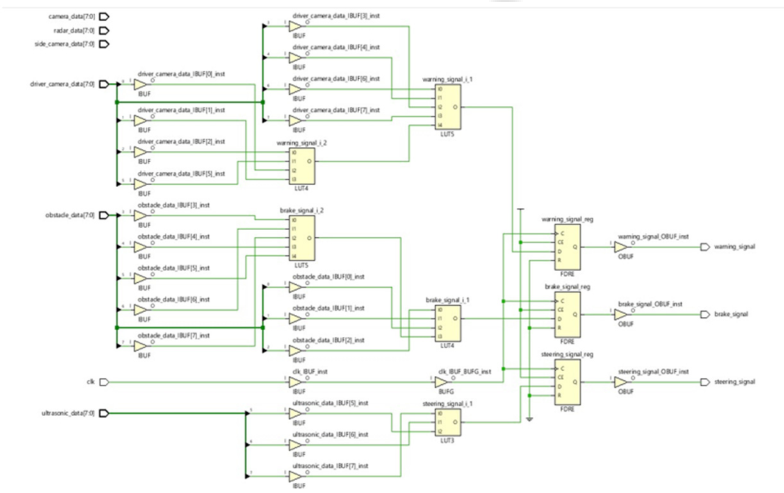

Figure 21: Synthesis of ADAS for all test cases

5 CONCLUSIONS

Using Artix FPGA technology and a 4-bit encoding technique, this study presents an energy-efficient FPGA-based Advanced Driver Assistance Systems (ADAS) system. For essential ADAS features, the architecture provides real-time performance. The system provides an optimal blend of computing capability and resource efficiency with an impressively low on-chip power consumption of 0.466 W and efficient utilization of merely 5 Look-Up Tables (LUTs). For safety-critical automotive applications, its parallel processing capabilities guarantee quick and precise decision-making. This small and expandable solution shows how FPGA technology can revolutionize vehicle safety, facilitate integration into energy-efficient automotive platforms, and open the door for more sustainable and advanced ADAS solutions.

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