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Automotive Radar for Collision Avoidance

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Abstract: *This project introduces a low-cost prototype of an Advanced Driver Assistance System (ADAS) that integrates Doppler radar with computer vision to enhance vehicle safety. The system is designed to detect obstacles in real time, estimate the speed of nearby vehicles, and recognize road lanes, thereby assisting drivers in navigating complex traffic situations. The Doppler radar sensor provides reliable velocity measurements even in poor visibility conditions such as fog or rain, while the vision module, based on lane detection algorithms, helps in maintaining proper road alignment. Together, these components form a sensor fusion framework that reduces accident risks by delivering accurate and timely driving assistance.*

The hardware implementation is based on affordable and widely available components, including the HB100 Doppler radar module, a standard camera, and a Raspberry Pi 4. The Raspberry Pi acts as the central processing unit, executing both radar signal processing and computer vision tasks. By eliminating the need for expensive automotive-grade systems, this design makes ADAS functionalities more accessible for low-cost applications, particularly in regions where advanced safety systems are not yet common.

Testing in a simulated environment has shown promising results, demonstrating that the system performs effectively across varied weather and lighting conditions. Radar ensures robust speed detection regardless of external factors, while the camera enables contextual awareness of road structures. This synergy enhances reliability and sets the stage for future improvements. Further advancements may include machine learning-based object classification, integration of additional sensors like LiDAR, and optimization for real-world deployment. The outcomes suggest that combining Doppler radar and embedded vision can provide a practical pathway toward safer and smarter driving technologies..

Keywords: Advanced Driver Assistance System (ADAS), Doppler Radar Sensor, Lane Detection, Sensor Fusion, Embedded Vision, Real-Time Processing, Raspberry Pi 4, Vehicle Safety

I. INTRODUCTION

The necessity to decrease traffic accidents and the growing concern for traffic safety have prompted engineers and researchers to create reasonably priced Advanced Driver Assistance Systems (ADAS). In order to reduce the likelihood of accidents, these systems are designed to help drivers by continuously monitoring their environment, sending out timely warnings, and, in certain situations, offering active support. The three crucial functions of this work's cost-effective embedded ADAS prototype are obstacle detection, lane marker recognition, and vehicle speed estimation. Through the integration of computer vision algorithms and radar-based velocity monitoring, the system guarantees dependable real-time assistance that adjusts to changing traffic and road conditions.

The central processing platform used in the prototype is the Raspberry Pi 4, which manages multiple operations such as data collection, signal processing, image analysis, and result visualization. Its compact size, portability, and low power requirement make it highly suitable for experimental research setups and small-scale vehicular integration.

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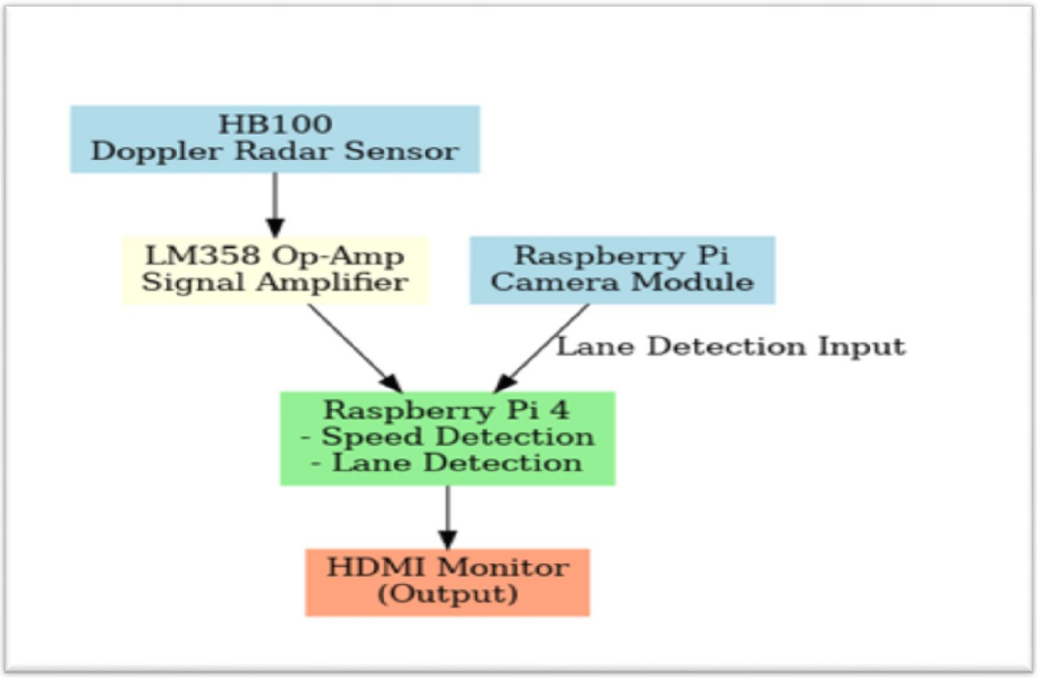

Fig. 1: Block diagram of implementation of Doppler radar with Raspberry Pi

The system incorporates the HB100 Doppler radar module, which functions at a frequency of 10.525 GHz and has an effective detection range of roughly 20 meters, to precisely estimate the speed of moving objects and detect motion. The Doppler effect, which states that the frequency shift of the reflected microwave signal is precisely proportionate to the velocity of the moving object, is the basis for this radar module's operation. The HB100 is ideal for outdoor applications where visual sensors could malfunction because, in contrast to vision-based systems, it operates consistently in all environmental circumstances, including low lighting, fog, and rain.

To solve this, a low-power, single-supply operational amplifier called the LM358 dual is used to enhance the intermediate frequency (IF) signal generated by the radar. Through this amplification stage, the signal is ensured to reach a voltage level appropriate for further digital processing. The signal is then amplified and sent to the Raspberry Pi 4, the system's main processing unit. To ascertain the speed of the seen object and extract the Doppler frequency shift, the Raspberry Pi analyzes signals in real time using a Fast Fourier Transform (FFT) or a similar technique. The radar sensor, analog amplification, and digital processing work together to provide accurate, real-time speed readings that are highly reliable and resilient to environmental disturbances.

All parts areguaranteed to function dependably by a regulated 5V DC-DC power source, which makes the setup portable and flexible for direct in-vehicle applications. This system's real-time sensor fusion, which evaluates safety circumstances by combining camera-based lane detection with radar data, is one of its main advantages.

This makes it possible for the prototype to recognize dangers like lane drifting or quickly approaching objects and notify the driver right away.

The created prototype demonstrates that fundamental ADAS functionalities may be effectively delivered without the need for expensive automotive-grade systems by combining low-cost sensors, embedded computing, and effective software. It offers a useful and affordable platform that connects research-level design with actual vehicle safety standards, even though it might not be as precise as commercial solutions.

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II. LITERATURE SURVEY

[1] According to Fu et al. (2025), radar is gaining greater importance in both driver assistance and autonomous driving applications, with regulatory measures, embedded computing, and efficient software enabling core ADAS features without the need for high-cost automotive-grade systems. The U.S. mandate on Automatic Emergency Braking (AEB) is accelerating radar deployment, and advanced Level 2+ platforms increasingly rely on multi-sensor fusion, combining several radars with multiple cameras to achieve robust safety functions.

[2] Fei (2025) explored the architectural and signal processing aspects of automotive radar systems, emphasizing modular design and scalability. His work highlights how radar can be tailored for various driving environments, from urban congestion to highway cruising, and how signal processing advancements are enabling more precise object detection and classification.

[3] Sharma and Patel (2025) investigated the integration of radar and vision systems, showing that sensor fusion significantly enhances ADAS performance. Their study demonstrated that combining radar's robustness in adverse weather with camera-based semantic understanding leads to more reliable obstacle detection and lane-keeping capabilities.

[5] Zhang et al. (2024) proposed a radar-centric multi-sensor fusion framework for autonomous driving. Their approach leverages radar's resilience to environmental noise and integrates it with other modalities to improve object tracking and decision-making, especially in cluttered urban scenarios. This helps the car track objects better and make smarter decisions, especially in crowded city areas where there's a lot going on.

[6] Yeo (2024) examined the emergence of 4D radar operating in the 76–81 GHz band, which adds elevation and angular resolution to traditional range and velocity data. This enables richer environmental mapping and more accurate differentiation between static and dynamic objects. While currently limited to high-end vehicles, Yeo suggests that cost reductions could make 4D radar mainstream. It can tell the difference between a parked car and a moving one, or between a curb and a pedestrian. Right now, this technology is mostly used in luxury cars, but Yeo believes it will become more affordable and common in the future.

[7] Armanious et al. (2024) introduced the Bosch Street Dataset, a multi-modal collection featuring imaging radar. This dataset supports training and benchmarking of autonomous driving algorithms, particularly in radar-based perception tasks, and underscores the growing role of radar in machine learning pipelines.

[8]Gupta and Nair (2024) reviewed deep learning methods for radar object classification, identifying key challenges such as data scarcity, sensor noise, and real-time inference constraints. Their work emphasizes the need for robust radar datasets and efficient neural architectures tailored to radar's unique signal characteristics.

[9]Keysight Technologies (2023) outlined how automotive radars are advancing safety features like adaptive cruise control, collision avoidance, and pedestrian detection. The report highlights innovations in radar chipsets and antenna design that are making these systems more compact and affordable.

[10]Viswanath et al. (2023) demonstrated automatic motion detection and distance measurement using Doppler radar. Their system, built on the HB100 module, showed reliable performance in detecting moving objects and estimating range, reinforcing the utility of Doppler radar in low-cost ADAS prototypes. Their system could detect moving objects and measure how far away they were. It worked well and showed that even inexpensive radar modules can be useful in basic driver assistance systems, especially for detecting motion and preventing collisions.

[13]Mehta and Jain (2023) implemented a real-time radar-based pedestrian detection system, showing that radar can reliably identify human movement patterns even in low-visibility conditions. Their system enhances ADAS responsiveness and contributes to pedestrian safety. What's impressive is that it works even in poor visibility—like at night or in fog. Their system helps cars respond faster to people crossing the road, which is a big step forward for pedestrian safety in ADAS.

[14] Chen et al. (2023) explored radar-based SLAM (Simultaneous Localization and Mapping) for autonomous driving in adverse weather. Radar's ability to penetrate fog and rain makes it ideal for mapping environments where cameras and lidar struggle, improving vehicle localization and path planning. Chen and his team explored how radar can be used for SLAM—short for Simultaneous Localization and Mapping. This is a method that helps a car figure out where it is

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and build a map of its surroundings at the same time. Radar is especially good for this in bad weather, where cameras and lidar might fail. Their work shows that radar can help cars navigate more safely in rain, fog, or snow.

III. PROPOSED METHODOLOGY

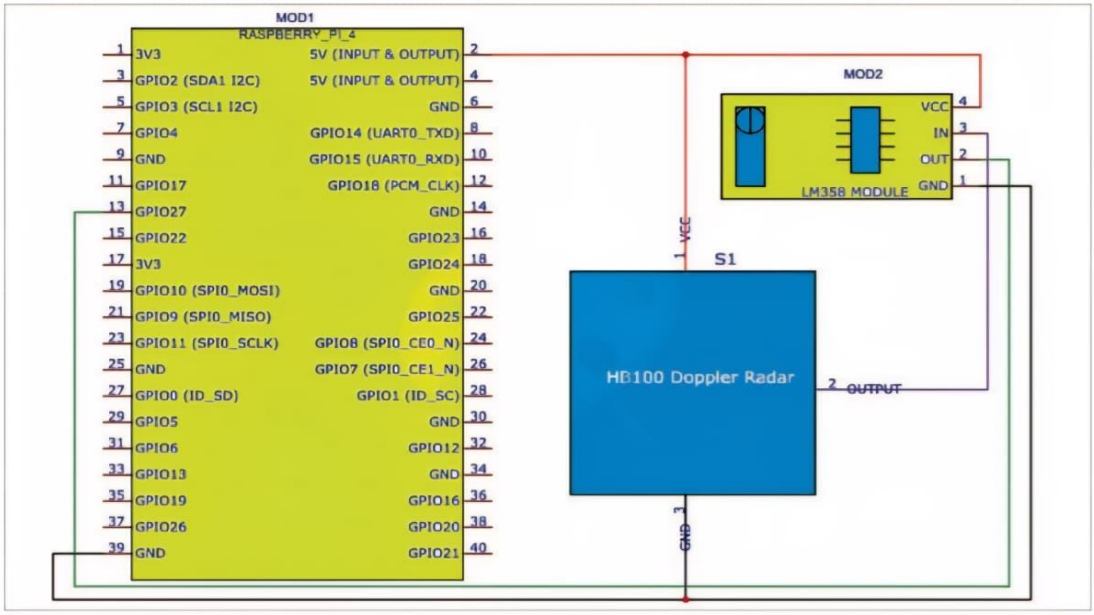

Fig. 2: Interfacing Raspberry Pi with Doppler Radar

The amplified output is then connected to the GPIO pins of the Raspberry Pi. Through this interface, the Raspberry Pi can read the frequency shifts generated by the HB100, which are directly proportional to the velocity of the moving object. By processing this signal, the system can measure speed, detect motion, or even contribute to ADAS (Advanced Driver Assistance System) applications. The Raspberry Pi also provides the required 5V supply to both the HB100 radar module and the amplifier circuit, ensuring proper operation of the entire setup.

1] HB100 Doppler Radar Sensor

Fig: HB100 Doppler Radar

The HB100 Doppler Radar sensor operates at a frequency of 10.525 GHz (X-band) and is primarily used for measuring the speed of moving vehicles or objects by applying the Doppler effect principle. When a moving object reflects the transmitted microwave signal, the frequency shift between the transmitted and received signals corresponds to its velocity. The HB100 provides an analog output voltage in the range of 100 mV to 1 V, depending on the reflected signal strength. It has an effective detection range of approximately 20 meters, making it suitable for short-range automotive applications. The module typically operates on a +5V DC supply and consumes around 30 mA of current. Its beamwidth is around 80° (E-plane) and 32° (H-plane), providing sufficient coverage for vehicle detection. In this project, the HB100 radar is used for vehicle speed detection as a part of the ADAS prototype.

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2] LM358 Operational Amplifier Module

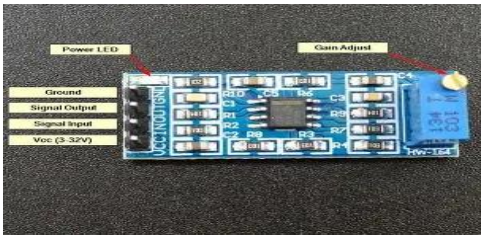

Fig: LM358 Operational Amplifier Module

The output signal from the HB100 radar is very weak and cannot be directly processed by the Raspberry Pi. Therefore, the signal is passed through an LM358 operational amplifier module to amplify and condition it. The LM358 is a dual operational amplifier capable of operating with a supply voltage range of 3V to 32V DC, making it ideal for low voltage.

embedded systems. It has a low input offset voltage (usually 2 mV) and a gain bandwidth product of 1 MHz. In this setup, the LM358 amplifies the Doppler radar's analog output, improving the signal strength and quality before sending it to the Raspberry Pi's GPIO pins or an ADC interface.

3] Raspberry Pi 4 Model B

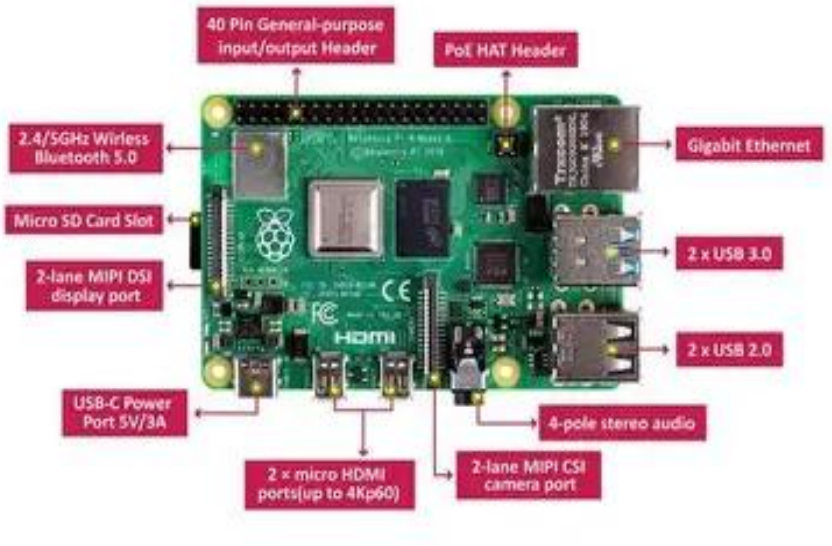

Fig: Raspberry Pi 4 Model B

The Raspberry Pi 4 Model B serves as the main processing and control unit of the system. A Broadcom BCM2711 quad-core Cortex-A72 processor operating at 1.5 GHz powers it, and it has three different RAM options: 2 G—2 GB, 4 GB, or 8 GB LPDDR4.It has a Broadcom BCM2711 quad-core Cortex-A72 processor running at 1.5 GHz, and it comes with multiple RAM options: 2 GB, 4 GB, or 8 GB LPDDR4. The board supports a 40-pin GPIO header, which is used to interface with the radar and amplifier circuit. It also includes dual micro-HDMI ports, USB 3.0 connectivity, and built-in Wi-Fi (802.11ac) and Bluetooth 5.0. The Raspberry Pi 4 operates at 5V DC via USB-C power supply and runs the Raspberry Pi OS, a Linux-based operating system. In this project, it is responsible for reading radar data, processing camera frames, running the Python-based speed detection and lane detection algorithms, and performing sensor fusion.

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4] Raspberry Pi Camera Module

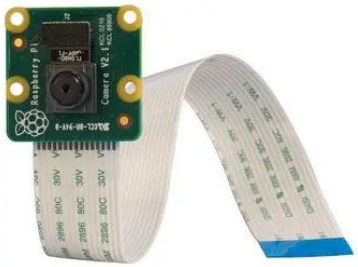

Fig: Raspberry Pi Camera Module

The Raspberry Pi Camera Module (v2) is used for real-time lane detection. It features a Sony IMX219 image sensor with an 8-megapixel resolution and supports video output up to 1080p at 30 frames per second. The camera connects to the Raspberry Pi using the Camera Serial Interface (CSI) ribbon cable, enabling high-speed data transfer. It has a 62.2° field of view, which provides a clear visual of road lanes for processing. The camera operates at 3.3V, which is directly supplied from the Pi board. Captured frames are processed using OpenCV and computer vision algorithms to identify lane markings and estimate vehicle position within the lane. This data is later combined with radar-based speed information to provide a comprehensive ADAS response.

Flow Chart:

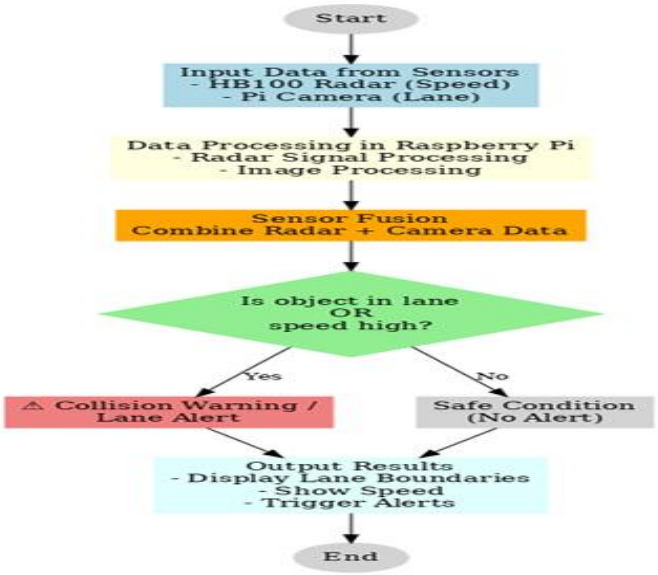

Fig. 3: Flow Chart of Implementation of Doppler Radar with Raspberry Pi

The flowchart starts with collecting data from two sensors: the HB100 Doppler radar, which measures the speed of moving objects, and the Pi Camera, which takes continuous video to detect lanes. These data signals are sent to the Raspberry Pi, where the radar data is checked to find the speed, and the video frames are analyzed with computer vision to spot lane lines.

Once each sensor has done its part, the system combines the data from both the Doppler radar and the Pi camera. This helps the system get a clearer picture of how fast an object is moving and where it is in relation to the lane. The combined information is then checked using control logic. If an object is found in the lane and is moving faster than a safe limit, the system gives a warning about a possible crash. If the car is drifting out of its lane, the driver is alerted. If there's no danger, the system marks the situation as safe. The last step shows real-time results, like drawing lane lines

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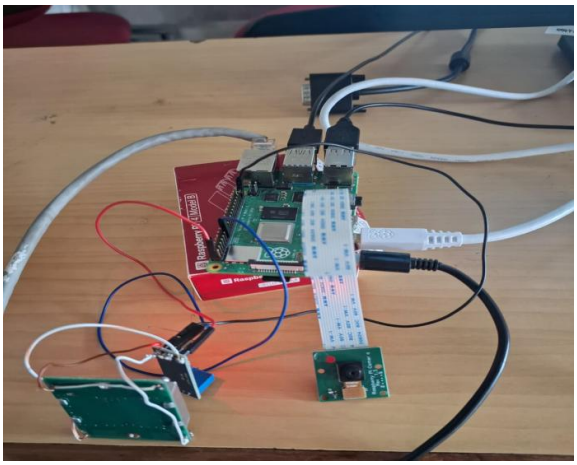
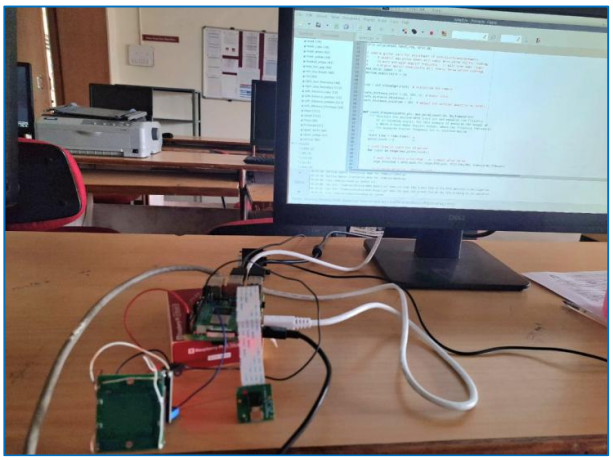
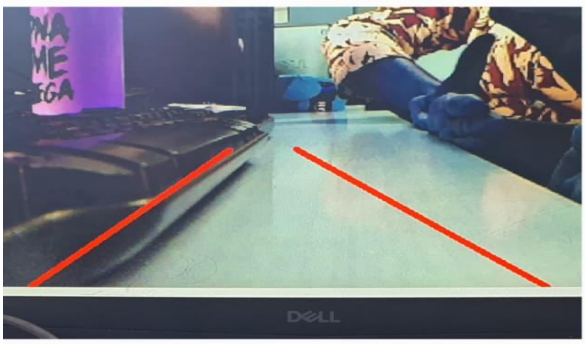
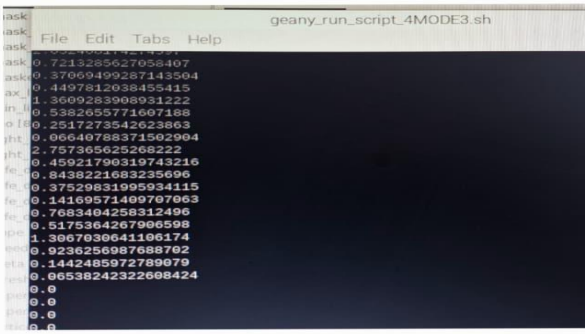
on the live video and showing the speed of the vehicle or object. The process ends after showing these results, making sure the driver gets help in time and road safety is improved.

IV. RESULTS AND DISCUSSION









What is displayed

Two red lines are visible in the image of a front-facing camera's live feed.

Lane boundaries are indicated by the red lines using computer vision techniques.

The ADAS lane detecting system includes this component.

The lines' capacity to identify where the car should remain on the road is advantageous to both the driver and the system.

Accurate lane detection is crucial to maintaining vehicle centering and preventing unintentional lane departure.

The numbers show how fast movement is happening in each frame.

Bigger numbers mean faster motion; smaller ones mean slower or no movement.

The speed starts high, changes as movement happens, then drops to zero when it stops.

Discussion:

This project is an Advanced Driver Assistance System (ADAS) prototype that uses computer vision and Doppler radar to increase vehicle safety. While the vision module detects road lanes to maintain the car's proper alignment, the radar precisely measures the speed of nearby vehicles, even in bad weather. They work together to create a sensor fusion system that helps drivers avoid collisions and drive safely in real time by detecting obstructions, tracking speed, and guiding lane position.

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Reliable performance under all driving circumstances is ensured by the integration of radar and vision. The system's capacity to identify both moving and stationary objects is improved by this fusion. It supports safer driving choices by sending out timely notifications and corrections. All things considered, the system exhibits great promise for application in intelligent and driverless cars of the future.

V. CONCLUSION

This study shows that Doppler radar technology is a practical, affordable, and trustworthy way to assess a vehicle's speed. A working prototype that can accurately determine an object's speed and detect moving items was created by combining the Raspberry Pi with the HB100 radar module. The HB100 demonstrates the fundamental idea of radar-based velocity detection while making the system affordable for low-budget, educational, and research applications.

This supports the notion that useful data for traffic applications can be obtained from even the most rudimentary radar devices. observation and security. The technology establishes a solid basis for future advancement even if it is rather simple in comparison to contemporary advanced driver assistance systems (ADAS).

Enhancements like adding more sensors, such as cameras, LiDAR, or ultrasonic modules, can improve detection reliability by fusing sensors. Using image processing methods in conjunction with radar data may also improve object classification and context awareness. Additional improvements in range, resolution, and performance could be achieved by switching to higher-frequency automotive radar modules in the 24 GHz range.

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