IJARSCT
International Journal of Advanced Research in Science, Communication and Technology
International Open-Access, Double-Blind, Peer-Reviewed, Refereed, Multidisciplinary Online Journal
ISSN: 2581-9429
Volume 5, Issue 4, October 2025
Impact Factor: 7.67

Implementing Doppler Radar in ADAS

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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 vehicle, 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, Real-Time Processing, Raspberry Pi 4,Vehicle Safety

I. INTRODUCTION

The rising concern for traffic safety and the need to reduce road accidents have encouraged researchers and engineers to design affordable Advanced Driver Assistance Systems (ADAS). These systems are developed to aid drivers by continuously monitoring the surroundings, issuing timely warnings, and in some cases providing active assistance to lower accident risks. This work proposes a cost-efficient embedded ADAS prototype that performs three essential tasks: detecting obstacles, identifying lane markings, and estimating the speed of moving vehicles. By combining radar-based velocity measurement with computer vision techniques, the system ensures reliable real-time support that adapts to varying road and traffic 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.

To measure speed and detect motion, the system makes use of the HB100 Doppler radar module. With an effective detection range of approximately 20 meters, the sensor utilizes the Doppler effect to measure relative speed and operates over a specified frequency bandwidth to ensure accurate detection and signal processing, where shifts in frequency of the reflected signal indicate the velocity of objects. This allows the module to provide speed measurements that are independent of environmental factors like poor lighting or bad weather, which are common

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limitations in vision-only systems. Because the raw signal from the radar is weak, it is strengthened using an LM358 operational amplifier before being processed by the Raspberry Pi for accurate interpretation.

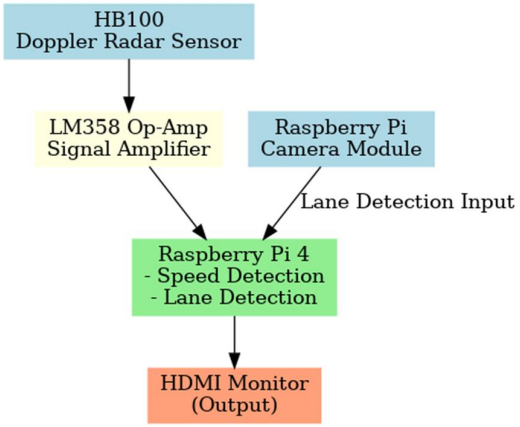

Fig. 1:Block diagram of implementation of Doppler radar with Raspberry Pi

Simultaneously, a Raspberry Pi Camera is used to capture live video of the driving environment. The recorded frames are analyzed with Python-based computer vision algorithms, mainly edge and line detection, to recognize lane boundaries and support path tracking. For user-friendly assistance, lane markings and safe-distance indicators are displayed directly on the live video feed, enabling better navigation awareness for the driver.

A regulated 5V DC-DC power supply ensures that all components operate reliably, making the setup portable and adaptable for direct in-vehicle applications. A major strength of this system is real-time sensor fusion, where radar data is combined with camera-based lane detection to assess safety conditions. This enables the prototype to identify risks such as lane drifting or rapidly approaching objects and immediately generate alerts to the driver.

The developed prototype shows that a combination of inexpensive sensors, embedded computing, and efficient software can successfully deliver core ADAS features without the need for high-cost automotive-grade systems. While it may not match the precision of commercial solutions, it provides a practical and economical platform that bridges the gap between research-level design and real-world automotive safety requirements.

II. LITERATURE SURVEY

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 can successfully deliver core ADAS features without the need for high cost automotive-grade systems. While it may not match the precision of commercial solutions, it provides a practical and economical platform that bridges the gap between research-level design and real-world automotive safety requirements. such as the U.S. mandate on Automatic Emergency Braking (AEB) accelerating its deployment. They also noted that advanced Level 2+ driver-assistance platforms increasingly rely on multi-sensor fusion, combining several radars with multiple cameras to achieve robust safety functions. In a similar direction, Prasad and Kumar (2024) investigated radar use for blind spot monitoring and demonstrated how inexpensive Doppler sensors can enhance lane-change safety. Their findings confirm that even low-cost modules like the HB100, when coupled with processors such as Raspberry Pi, can make practical contributions to ADAS development. Yeo (2024) examined the development of 4D radar technology operating within the 76–81 GHz frequency band, emphasizing its ability to go beyond conventional radar functions by providing angular and elevation information alongside standard range and velocity measurements. This advancement allows for highly detailed environmental mapping, which is essential for autonomous navigation and intelligent transportation systems. By capturing richer spatial data, 4D radars enable vehicles to better understand their surroundings, making it possible to detect multiple objects more accurately and differentiate between static and dynamic obstacles in real time. While the study acknowledges that such advanced radar systems are currently expensive and limited to high-end automotive and research applications, it underscores the transformative potential of this technology. The insights gained from 4D radar

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highlight a pathway where current low-cost Doppler radar modules, like the HB100, could gradually evolve into more sophisticated systems through incremental technological improvements. Yeo suggests that as production scales and costs decrease, the integration of 4D radar into mainstream vehicles could become feasible, bridging the gap between today's budget-friendly Doppler sensors and the next generation of high-performance automotive radar solutions. Armanious et al. (2024) introduced the Bosch Street Dataset, a comprehensive multi-modal dataset that integrates imaging radar and camera data. This dataset underscores the importance of sensor fusion for reliable perception in complex urban environments, where using a single sensing modality may not be sufficient. Their work directly supports the concept adopted in the present project, which combines radar and vision inputs for enhanced decision-making. Industry perspectives also reinforce radar's advantages. Keysight Technologies (2023) emphasized radar's capacity for Doppler based velocity estimation, non-line-of sight detection, and resilience under all weather conditions. Such features make radar an essential supplement to vision based approaches. Keysight Technologies (2023) discussed the advancements of automotive radars operating in the 76–81 GHz range, focusing on Doppler-based velocity measurement, non-line-of-sight detection, and reliable performance under various weather conditions. Their report highlighted how these features enhance vehicle safety, which supports the idea of using radar as a dependable sensing element for speed monitoring in the present work. Viswanath et al. (2023) proposed a system for automatic motion detection and distance estimation using Doppler radar. Their study showed that radar can accurately track moving objects and calculate distances, establishing it as a cost-effective solution for traffic monitoring. These findings are directly relevant to the current project, which applies Doppler radar to vehicle speed detection. Srivastav and Mandal (2023) reviewed the role of deep learning in radar-based autonomous driving systems, identifying challenges such as limited datasets, computational requirements, and the need for sensor fusion. They emphasized that machine learning enhances radar's perception capabilities by improving object classification interference. Their and insights reducing provide direction for extending this project toward AI-driven radar analysis in the future. Keifer et al. (2022) demonstrated the design of a radar gun using the HB100 module, capable of measuring both velocity and spin. Their work illustrated the flexibility of low-cost radar modules in applications beyond speed sensing. This serves as a useful reference for the current project, which also employs the HB100 module for velocity measurement. Mangla et al. (2021) investigated the use of the HB100 radar sensor in an ADAS dimmer design, where radar signals controlled lighting adjustments based on vehicle detection. Their research demonstrated radar's adaptability for safety-related reinforcing automotive functions, the suitability of radar technology for applications like those addressed in this project. Tun and Zin (2019) developed a radar based system for vehicle speed detection and tested it under practical conditions. Their results confirmed the effectiveness of low-cost Doppler radar modules for real-world speed monitoring applications. Their work provides a foundation for the present project's approach to speed detection. Lee (2016) presented a teardown and analysis of the HB100 Doppler radar, explaining its internal operational principles, circuitry, constraints. and performance This early investigation remains valuable for understanding the technical aspects of HB100-based designs and has informed hardware integration decisions in the current project.

III. PROPOSED METHODOLOGY

Circuit Diagram

This circuit diagram shows the interfacing of an HB100 Doppler radar sensor with a Raspberry Pi 4 for speed or motion detection. The HB100 radar operates by transmitting microwave signals and detecting frequency shifts caused by moving objects. Its output is a small analog signal, which is very weak and requires amplification. That's why the LM358 operational amplifier module (MOD2 in the diagram) is used to amplify the Doppler signal before it is processed by the Raspberry Pi.

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.

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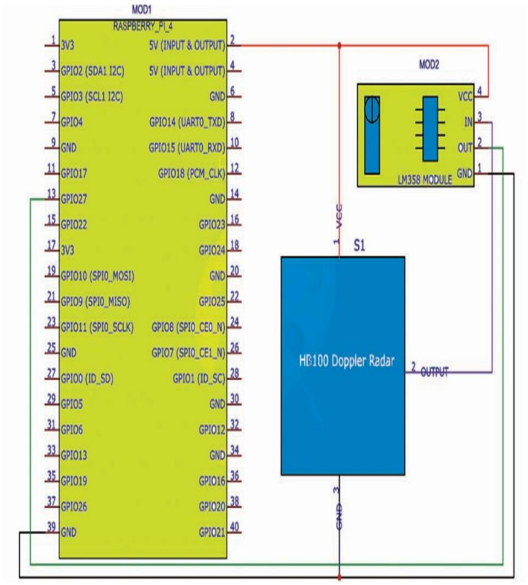

Fig. 2: Interfacing Raspberry Pi with Doppler Radar

1] HB100 Doppler Radar Sensor

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.

2] 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 gain bandwidth product of 1 MHz and a low input offset voltage (typically 2 mV). 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. This amplification ensures that even small variations in the Doppler frequency can be accurately detected and converted into speed readings.

3] Raspberry Pi 4 Model B

The Raspberry Pi 4 Model B serves as the main processing and control unit of the system. It is powered by 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 to combine both sets of data for real-time analysis.

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4] 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

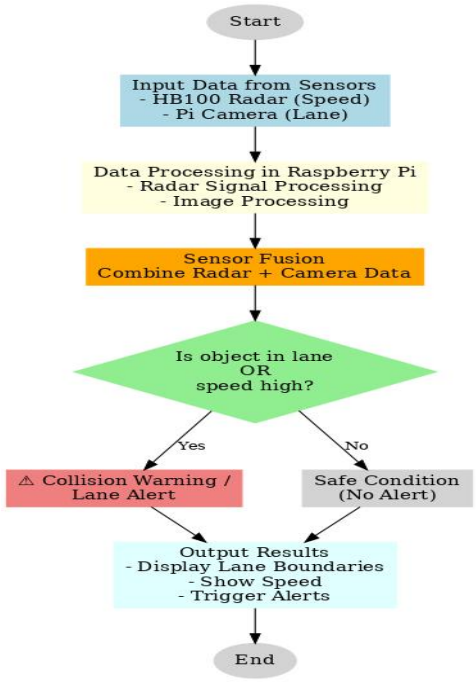

Fig.3: Flow Chart of Implementation of Doppler Radar with Raspberry Pi

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 on the live video, 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.

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Sample Output and Result

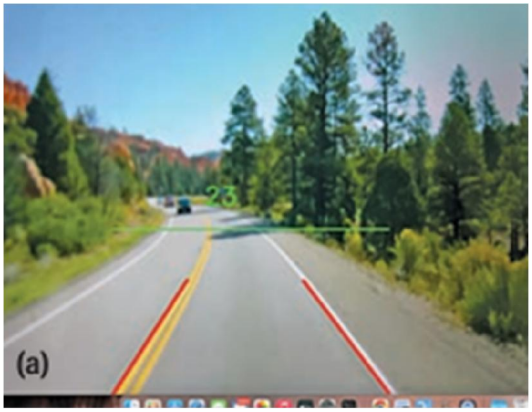

Fig. 4: (a) Radar and camera showing speed, direction, and lane

Figure (a) shows the output of the lane detection algorithm implemented using the Raspberry Pi Camera and OpenCV. The detected road lanes are highlighted with red lines over the live camera feed, while the detected vehicle speed is displayed numerically in green at the top of the image (for example, 23 km/h). This indicates that the algorithm successfully identifies lane boundaries using image processing techniques such as edge detection and Hough Line Transform, even under outdoor lighting conditions.

Fig. 4: (b) Car with the Doppler Radar

Figure (b) shows the practical hardware setup where the HB100 Doppler Radar module is mounted at the front of a vehicle. The radar transmits microwave signals, and the reflected signals from moving vehicles or obstacles are processed through the LM358 operational amplifier circuit to generate an analog output corresponding to the detected Doppler frequency shift. This signal is then read by the Raspberry Pi for calculating vehicle speed.

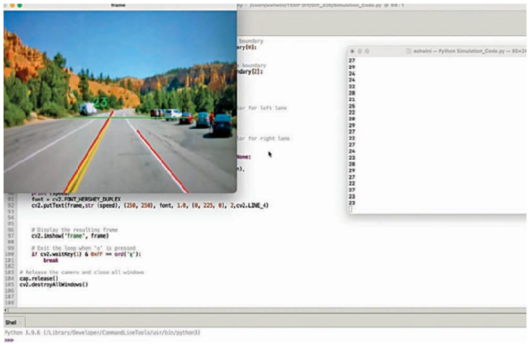

Fig. 4: (c) Code detecting path, lane displaying the speed of approaching vehicles

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Figure (c) (the Python terminal output) represents the real-time processing interface of the implemented system. The terminal window continuously displays the computed Doppler frequency and the corresponding speed values in meters per second and kilometers per hour. This verifies that the radar sensor and Raspberry Pi communication are functioning correctly and that the system can measure and display speed dynamically while simultaneously processing lane detection

IV. CONCLUSION

This paper demonstrates the effectiveness of using Doppler radar technology as a cost-friendly and reliable solution for vehicle speed measurement. By integrating the HB100 radar module with the Raspberry Pi, a functional prototype was developed that successfully detects moving objects and calculates their speed with reasonable accuracy. The use of the HB100 makes the system accessible for educational, research, and low-budget applications while still proving the core principle of radar-based velocity detection. This validates the idea that even basic radar modules can provide valuable data for traffic monitoring and safety applications.

Although the system is relatively simple compared to modern advanced driver assistance systems (ADAS), it lays a strong foundation for future development. Improvements such as integrating additional sensors like cameras, LiDAR, or ultrasonic modules can enhance detection reliability through sensor fusion. Moreover, applying image processing techniques alongside radar data could enable better object classification and context awareness. Upgrading to higher-frequency automotive radar modules in the 24 GHz range would further improve range, resolution, and performance under varying conditions. With these advancements, the project has the potential to evolve into a more sophisticated system that contributes to safer and smarter driving environments.

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