Low Cost Advanced Driver Assistance System (ADAS) Architecture for Enhancing Road Safety in India

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***Abstract*—Road accidents are one of the leading causes of deaths worldwide. Advanced Driver Assistance Systems (ADAS) are the new age technologies that should be mandatorily included in every modern automobile, not just for convenience but primarily for the enhanced safety of motorists. ADAS forms an integrated architecture of cutting edge sensing, control, automation, communication, computation and prediction that proactively enhances safety and convenience of drivers and co-travelers. This paper presents a low cost ADAS architecture and prototype concept for wider implementation of ADAS across the entire spectrum of on-road vehicles in India. The proposed architecture leverages affordable software and hardware such as OpenCV, Raspberry Pi, ultrasonic sensors to create a modular and scalable ADAS alternative suitable for Indian conditions. The proposed low cost architecture offers basic ADAS features such as lane tracking, obstacle/blind spot detection and adaptive cruise control that can be mounted on any kind of two, three and/or four wheelers. In fact, the proposed low cost ADAS can be adapted and integrated with all existing passenger as well as commercial vehicles currently plying on Indian roads. Wide scale implementation of low cost ADAS will ensure much safer driving conditions in India and will also help minimize the tragic losses and exorbitant costs associated with road accidents in India.**

***Index Terms*—ADAS, Raspberry Pi, Lane Detection, Adaptive Cruise Control, Ultrasonic Sensors, OpenCV, Indian Road Safety**

I. INTRODUCTION

India is a densely populated country with an ever increasing number of vehicles on the road. The Ministry of Road Transport and Highways (MoRTH), Government of India, registers lakhs of road accidents each year [1]. The wide ranging reasons behind these accidents include bad road conditions, traffic congestion, poor lane discipline, lack of situational awareness while driving, automotive defects/failures, driver inattention/fatigue and many more [2]. Moreover, majority of the vehicles on Indian roads are not sufficiently equipped with advanced driver assistance systems (ADAS), which severely limits the responsiveness, accuracy and judgment of drivers negotiating unpredictable driving conditions in India. Availability of at least a basic level of ADAS technologies in all on-road vehicles would definitely lead to much safer driving conditions in India [3]. The high cost of implementing ADAS technologies in all vehicles would be easily offset by tremendous savings due to minimization of the various costs associated with road accidents that include vehicular repair, warranty claims, personal injury, insurance claims, police reporting, legal proceedings and many more. Still, the price sensitive India auto markets can benefit from low cost ADAS solutions that can be easily implemented on all existing and upcoming vehicles [4]–[6].

This paper aims to develop a low-cost ADAS prototype that can include detection of obstacles in front, rear, and blind spots. The prototype includes maintaining safe distances between vehicles using adaptive cruise control, identifying lane markings, and preventing unintended lane departures [7], [8]. In addition to this, it provides a platform for developing affordable safety technology for the Indian market

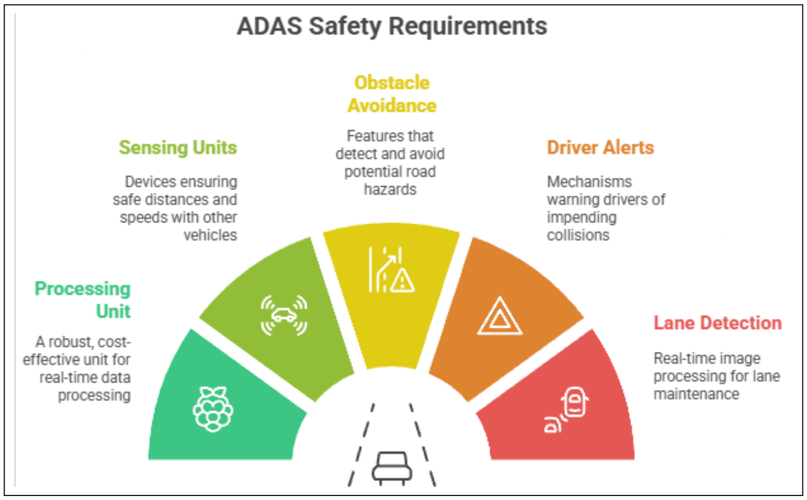

Fig. 1. Functional aspects of a typical ADAS system

and functions effectively in typical Indian road conditions [9]. The global ADAS market was valued at approximately $27.2 billion in 2023 and is projected to reach $74.9 billion by 2030, growing at a CAGR of 11.3% [10]. However, in emerging markets like India, adoption remains low due to various challenges such as high costs of commercial ADAS systems, limited adaptation to local driving conditions, lack of regulatory mandates comparable to European or North American markets and concerns about system reliability on poorly marked or maintained roads [11], [12]. The present study addresses these barriers by designing a system that is:

- Cost-effective and accessible for the Indian market
- Specifically calibrated for local road conditions and driving behaviours
- Reliable even with inadequate road infrastructure
- Scalable for integration into both new and existing vehicles

II. Literature Review

Autonomous vehicles primarily rely on lane-keeping and lane-changing models to ensure safe navigation. Traditional lane detection techniques primarily use edge detection, Hough transform, and adaptive thresholding methods. While these methods are computationally efficient, they often fail under poor lighting or weak lane marking conditions [13]–[15]. The functional aspects of a typical ADAS system are shown in Figure 1. Recently, deep learning models have been employed for effective lane recognition tasks. These models ensure better generalizability and performance robustness, albeit often at the cost of resource-intensive high end computation requirements. The high costs of computational resources demanded by advanced deep learning models prove inhibitive for large-scale low-cost embedded platform based deployments [16]–[20]. In terms of hardware, proximity based obstacle detection and avoidance have been built around ultrasonic sensor technologies. However, researchers have pointed out noise sensitivity and latency related issues in ultrasonic sensors that reduce effectiveness of tackling dynamic scenarios in real time [21]–[24].

Following are some of the recent ADAS solutions proposed by various researchers investigating this field:

- **OpenADAS Project**: The OpenADAS team built multiple ADAS functionalities such as overspeed alerts, traffic sign recognition, lane departure warning and forward collision warning on an open-source architecture using the Jestson Nano platform. This project successfully demonstrated how ADAS systems can be built on embedded systems. However, it could not directly translate into wider adoption of embedded system based ADAS due to the accessibility and affordability issues with its NVIDIA Jetson ecosystem. *The OpenADAS project is a classic example that depicts the trade offs ADAS developers face, while designing cost effective scalable solutions using powerful GPU-based platforms.*
- **Advanced Driver Assistance Systems (ADAS) by nirmal-25**: This project used deep learning to estimate anterior vehicular distances as well as to detect traffic lights/signs effectively in real time. However, since this system did not account for environmental noises, occlusions and other similar edge scenarios, its implementation remained dependent on idealistic input conditions [25], [26]. *This project depicts the limited applicability of idealized ADAS architectures in dynamic real-time Indian road scenarios.*
- **MATLAB-Simulink Based ADAS Projects**: These projects offer flexible and versatile options to design and simulate novel ADAS architectures for various use case scenarios. However, hardware integration limitations and discrepancies of simulation results against the real world dynamics of road conditions limit their effective deployment. *The Matlab-Simulink projects provide perfect simulation environments for testing novel architectures for diverse applications, but offer limited embedded deployment capabilities for real world implementation.*

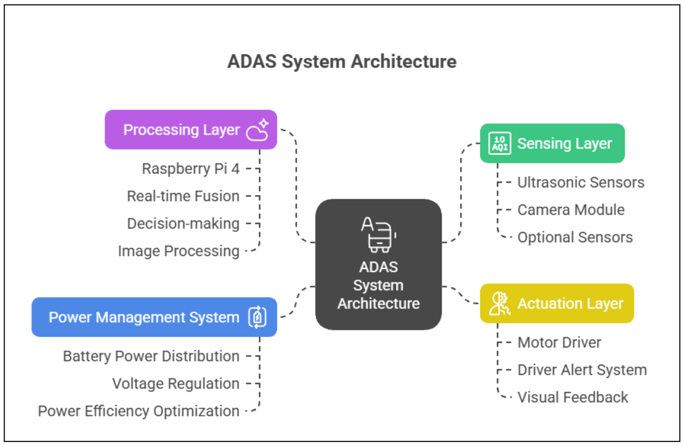

Fig. 2. Individual layers and component integration of the proposed low cost ADAS solution

- **Low-Cost Raspberry Pi Implementations**: Studies by Patil *et al.* [27], Deshmukh *et al.* [28], and Sharma *et al.* [29] explored affordable and scalable ADAS alternatives that featured traffic monitoring, lane detection and adaptive cruise control. These researchers utilized Raspberry Pi platforms for their ADAS architectures to ensure scalability. However, practical implementation in Indian road conditions demands system robustness and quick response times, which represent the actual test requirements of these frugal ADAS models [30], [31]. *These studies successfully demonstrated the feasibility of frugal ADAS designs, but require suitable optimization and field testing to prove reliable under Indian traffic conditions.*
- **Deep Learning for Complex Roads**: Maddiralla *et al.* [16] and Zhang *et al.* [17] applied convolutional learning models to develop multitasking based ADAS architectures for effectively negotiating weakly marked, broken and/or curved lane markings on roads. This approach significantly improved accuracy of broken lane identification and segmentation as compared to previous models. However, it is computational resource heavy, and as such has limited application in embedded platform based low cost ADAS solutions. *Convolutional learning based ADAS architectures underscore the gap between resource-heavy accuracte broken lane detection and low cost deployability.*
- **Blind Spot Monitoring with Ultrasonics**: Research by Devi and Kumar [21], Singh *et al.* [22], and Shete [23] showcased the utility of ultrasonic sensor arrays in two and four wheelers for low cost blind spot detection applications. However, the applications require further fine tuning with adequate sensor fusion to tackle dynamic noisy traffic scenarios encountered in India [?]. *These investigations underscore the relevance of multi-sensor input based ADAS architectures to ensure robust performance under dynamic and noisy conditions.*
- **Model Predictive Cruise Control**: Landolfi *et al.* [32] devised a ADAS cruise control system based on model predictive control (MPC), which was experimentally validated using a hardware-in-the-loop platform. Although efficient, it required high end professional calibration and significant computational resources, deeming it unsuitable for low cost scalability applications in the Indian context [?]. *This example illustrates the research gap in low cost ADAS solutions that can handle complex asymmetric driving conditions.*
- **Embedded ACC for Two-Wheelers and Cars**: Jain *et al.* [33] and Awasthi *et al.* [34] provided a proof of concept for ADAS in small four wheelers and two wheelers. The authors focused on Raspberry Pi-based low cost ADAS that would be affordable and scalable in the Indian context. *This research opened doors to investigations on low cost ADAS designs for even two wheelers plying on Indian roads.*

The present study sought to overcome the research gaps listed above through a low cost ADAS design built on embedded firmware that integrated ultrasonic sensor technology with computer vision. The purpose of this study was to achieve accurate and quick response decision making ADAS, while simultaneously maintaining affordability and scalability for wider applications in Indian conditions [35], [36].

III. Methodology

This section explains the methodology followed in the present study for designing a low cost and efficient ADAS architecture. This methodology focused on low cost system architecture design, suitable component selection and priority safety features as its key aspects. These features included effecient image processing based real time lane detection, proximity sensing for safe distance computations, obstacle detection, alerts and avoidance responses, collision avoidance and related driver alerts. A powerful yet cost effective central processing unit, the Raspberry Pi 4 Model B was selected to handle image processing and sensor fusion in real time. The selection of the above mentioned processing unit ensured sufficient computational capacity and efficient power management at a relatively lower cost. The selected ADAS features ensured passenger and driver safety, especially in the context of Indian road traffic conditions. The Raspberry Pi Camera Module 2 was integrated to provide vision-based sensing with high-quality video capture, while HC-SR04 ultrasonic sensors were deployed for accurate, light-independent distance measurement and collision avoidance. To control movement, the L298N motor driver was employed for speed and direction control of DC motors mounted on a modular robot chassis, thereby simulating realistic vehicle dynamics. Power requirements were fulfilled using rechargeable Li-ion 3.7 V batteries, selected for their high energy density, lightweight construction, and reliable performance. The ADAS components are shown in Figure 2.

The overall system was organized into four modular layers to enable scalability and ease of upgrades. The sensing layer

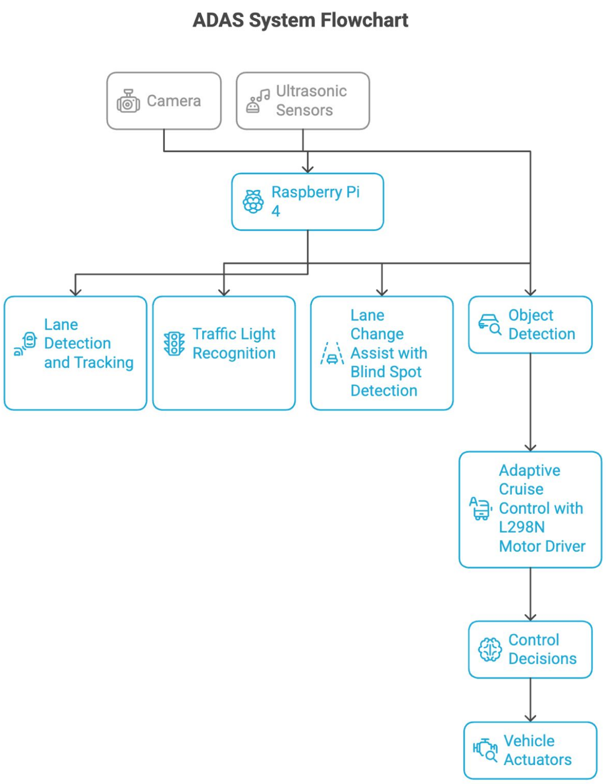

Fig. 3. The proposed low cost ADAS system flowchart

combined ultrasonic sensors and the camera module for environment perception, with provision for integrating additional sensors such as IR or LiDAR in future. The processing layer was powered by Raspberry Pi 4, responsible for real-time sensor fusion, safety-based decision-making, and image processing tasks that include lane and object detection. The role of the actuation layer was to initiate control actions based on the instructions received from the processing unit, such as issuing driver alerts, pop up visual feedback on dashboard interface, steering control, speed motor control and more. The power management system was tweaked to optimize performance while ensuring adequate voltage regulation for critical components. It also ensured balanced distribution and maintenance of adequate energy levels across the entire ADAS architecture with reliability. In the present work, a layered modular architectural framework was adopted for ADAS in order to keep the system operation reliable, safe, flexible and cost effective for scalability. The architectural layout of the proposed low cost ADAS system is depicted in Figure 3.

All computer vision related tasks were managed using the OpenCV library, whereas the entire software of ADAS prototype was developed in Python. The software development phase included incorporation of various ADAS functionalities such as an L298N motor driver based adaptive cruise control logic, ultrasonic sensors based obstacle detection and avoidance logic, computer vision based lane detection and tracking, recognition of traffic light status and an active lane change assist that included blind spot monitoring and support as well. For the lane detection algorithm, the video frames received from the Raspberry Pi integrated camera were processed in real time. Gaussian blur based smoothing was employed for image denoising, after grayscale conversion was carried out for each video frame. The image processing performance was optimized by specifying a region of interest that was masked over all images. In this way, all unnecessary details were filtered out from the images. However, the Canny edge detection protocol was applied to extract and retain the edge features from the images. Lane boundaries were estimated from the captured images by identifying and averaging the existence of thick line segments using the Hough transform. Algorithms were developed to compute the dynamic position of the vehicle's centre relative to the identified position of the lanes, which helped ADAS determine the current and future alignment of the vehicle with respect to the road lanes. Distances from the identified obstacles were computed on the basis of the time of flight of the pulses periodically transmitted by the ultrasonic sensors. A moving average filter was employed to reduce the noise in the recorded measurements, which was followed by comparison of the processed values with the safety standards predefined by the developer. The proposed ADAS software was programmed to generate warning signals for the driver and simultaneously initiate automatic speed and steering regulation features of the adaptive cruise control module, as soon as an unsafe proximity event was detected for an obstacle on the road. Table I depicts a summary of the various challenges faced during the proposed ADAS implementation. The corresponding corrective/work around solutions for each of the challenges have also been enlisted therein.

TABLE I
A SUMMARY OF IMPLEMENTATION CHALLENGES AND SOLUTIONS

Challenge	**Solution Implemented**
Variable lighting conditions affecting camera performance	Adaptive thresholding and contrast enhancement algorithms
False positives in obstacle detection	Multi-sensor confirmation protocol and temporal filtering
Processing delays affecting real-time response	Code optimization and parallel processing techniques
Lane detection on poorly marked roads	Enhanced edge detection and prediction algorithms
Power consumption management	Sleep modes for non-critical functions and efficient code execution

In this study, robust measures were taken to ensure conformance of the proposed ADAS with the requirements of driving in typical Indian scenarios. Firstly, a multi directional obstacle detection and avoidance strategy was implemented through the deployment of multiple ultrasonic sensors at all blind zones of the vehicle, apart from its rear and front ends. Secondly, a drift alert mechanism was incorporated to notify the driver regarding unintended lane departures. Thirdly, even poorly marked roads were designated to be well detected by OpenCV based on a robust Raspberry Pi Camera V2 powered lane detection module. Fourthly, timely and effective decision making was ensured by the Raspberry Pi 4 control unit of the proposed ADAS system. This control unit was designed to execute decisions in real time based on a smart fusion of inputs gathered from multiple sensors. Moreover, the L298N driver based motor actuation provided smooth speed adjustments in accordance with the adaptive cruise control system requirements that mandated safe distance standards from other moving vehicles and obstacles. Due emphasis was laid on smooth and robust system integration among all components to maximize the overall functional performance of the proposed ADAS prototype. The proposed ADAS was tailor-made to match the challenging road conditions encountered by drivers in India. Its robust system integration enabled all hardware and software modules to function cohesively for a seamless drive assistance experience.

IV. Results and Discussions

This section presents the results and related discussions on the performance of the ADAS prototype proposed in the current study. Firstly, the proposed ADAS setup is shown in Figure 4. This prototype chassis was extensively field tested under simulated driving conditions that mirrored real world scenarios. The test strategy was broadly classified into the following three phases:

- **Scenario Testing:** The first phase included operating the prototype under different driving condition scenarios that involved testing of adaptive speed control against moving obstacles, lane maintenance under poorly marked/turning road conditions and multi-directional obstacle avoidance.
- **Environmental Testing:** The second phase focused on testing the prototype control behavior under varying lighting conditions that made lane detection difficult. The prototype was also subjected to different road surface conditions generally expected to be encountered in India. This test helped evaluate robustness of the proposed ADAS functionalities.
- **Reliability Testing:** The third and final phase of testing focused on reliability and endurance of the developed prototype under long driving durations. This test design helped identify the system fatigue related shortcomings in the ADAS architecture.

The performance metrics of the proposed ADAS prototype against a few performance metrics are listed in Table II. These results showcase the satisfactory performance of the proposed low cost ADAS system against stringent targets pertaining to various performance metrics. The table also includes developer notes for further improvements that will be carried out as a future scope of the present study. A cost-wise and correspoinding feature based comparison of the proposed low cost ADAS against other contemporary ADAS systems available in the marked is tabulated in Table III. These results showcase the economic viability and scalability of the proposed ADAS for Indian vehicular applications.

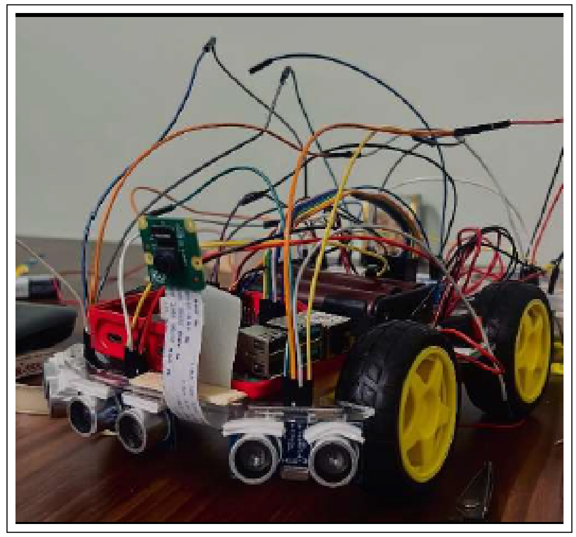

Fig. 4. The proposed low cost ADAS setup

TABLE II
PERFORMANCE METRICS

Metric	Target	Achieved	Notes
Lane Detection Accuracy	$> 90\%$	87%	Lower performance on poorly marked roads
Obstacle Detection Range	4 m	3.8 m	Sufficient for low-speed operation
System Response Time	< 100 ms	115 ms	Additional optimization needed
False Positive Rate	$< 5\%$	7%	Improved algorithms under development
Battery Life	> 3 hours	2.7 hours	Power optimization ongoing

TABLE III
COST COMPARISON WITH COMMERCIAL SYSTEMS

System Type	Approximate Cost (Rs)	Features
Present study prototype	8,550	Basic ADAS functionality, adaptable to Indian conditions
Entry-level commercial ADAS	30,000 – 45,000	Limited feature set, requires professional installation
Mid-range commercial ADAS	60,000 – 90,000	Comprehensive feature set, professional calibration required
Premium OEM ADAS	150,000+	Fully integrated system, vehicle-specific optimization

V. Conclusion and Future Work

This paper presented an efficient, robust and low cost ADAS architectural solution for the price sensitive Indian market and challenging Indian road conditions. This study promotes proliferation of low cost effective ADAS solutions in all existing and upcoming vehicles in India, whether they be two, three or four wheeler passenger/commercial vehicles. The proposed ADAS system included multiple safety and driver assistance features such as lane keeping assist, blind spot detection, adaptive cruise control, multi-sensor fusion based obstacle avoidance, collision warning, and more. The proposed architecture was based on budget friendly, power/computation resource efficient, yet optimized performance components, integrated modules and control algorithms. The developed prototype was rigourously tested under different testing scenarios that included difficult environmental conditions, endurance tests and simulated driving challenges commonly encountered by drivers in India. performed satisfactorily against stringent targets pertaining to multiple performance metrics such as lane detection accuracy, obstacle detection range, system response time, false positivity rate and battery life.

Future scope of this study includes additional optimization of the system components, development of improved algorithms, better power usage optimization, and improvements in ADAS cruise control effectiveness under poorly marked road conditions. Overall, this work demonstrates that affordable and scalable ADAS technology has the potential to minimize road accident-related losses and costs by significantly enhance road safety across India.

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