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Development of Adaptive Cruise Control (ACC) and Lane Keeping Assist (LKA) Systems for Electric Vehicles

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Abstract

This project investigates an IoT-power Adaptive Driver Assistance System (ADAS) crafted to enhance the comfort, efficiency, and reliability of Electric Vehicles (EVs). By seamlessly integrating Adaptive Cruise Control (ACC) and Lane Keeping Assist (LKA), the system aims to metamorphose driving into a secure, more comfortable, and energy-conscious experience using low-priced sensors and microcontrollers. The ACC module relies on ultrasonic sensing element linked to a NodeMCU, which intelligently corrects vehicle speed to maintain a secure following distance. In parallel, the LKA system uses a camera coupled with OpenCV and Python to detect lane boundaries and dominance steering through a servomechanism motor. IoT technology plays a pivotal role in real-time data monitoring, remote diagnostics, and over-the-air updates. Both simulation and on-route tests demonstrate the system's efficiency in optimizing energy usage, enhancing vehicle control, improving long-distance safety, and reducing driver fatigue. This advanced approach offers a scalable and cost-effective solution tailored for modern electric vehicles (EVs), laying the groundwork for smarter and safer roads. Its integration ensures improved performance and reliability, making it a valuable contribution to future transportation technologies and sustainable mobility solutions aimed at creating a safer and more efficient driving experience for all users.

Keywords: Adaptive Cruise Control, Lane Keeping Assist, IoT, NodeMCU, ultrasonic sensors, OpenCV, MATLAB Simulink I

INTRODUCTION

With the rapid growth of Electric Vehicles (EVs), the demand for sophisticated safety features is rising rapidly. Advanced Driver Assistance Systems (ADAS) have become integral, addressing common drive risks such as human errors, fatigue, and discrepant decision-making. This project concentrates on commingling Adaptive Cruise Control (ACC) and Lane Keeping Assist (LKA) within an IoT-enabled model specifically projected for EVs. The ACC module uses ultrasonic detector to invariably monitor the distance from fomite forrader. Datum from these sensors is processed by a NodeMCU microcontroller, which dynamically adjusts the vehicle's speed to assert safe following distances [1–4]. Complementing this, the LKA organization leverages a television camera and sophisticated simulacrum-processing algorithms with OpenCV and Python to notice lane marking. This data enables precise steering control through a servosystem motor, ensuring the vehicle remains centred within its lane. The integration of IoT engineering significantly enhances the system's

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performance by providing real-time monitoring, remote diagnostics, and predictive maintenance capabilities. These features allow for early detection of faults and efficient system management. Additionally, IoT facilitates continuous data analysis, leading to operational optimization and improved safety. The combination of advanced servosystem control and IoT connectivity results in a scalable, adaptable, and robust solution for modern intelligent transportation systems. This integrated approach not only increases reliability and efficiency but also supports future expansion and customization to meet evolving transportation demands [5].

Advanced Driver Assistance Systems (ADAS) play a vital role in reducing accidents caused by human error, which account for the majority of road mishaps globally. As electric vehicles (EVs) become increasingly mainstream, integrating ADAS technologies such as Adaptive Cruise Control (ACC) and Lane Keeping Assist (LKA) becomes essential. These systems not only enhance road safety by assisting drivers in maintaining safe speeds and lane positions but also contribute to a more comfortable and efficient driving experience. The adoption of ADAS in EVs marks a significant step toward smarter, safer, and more autonomous transportation systems for the future. The usance of IoT introduces a dynamic layer, enabling continuous system update, outback diagnostics, and adaptive feedback, which are vital for direct real-time changes in driving conditions.

LITERATURE REVIEW

Adaptive Cruise Control (ACC)

Adaptive Cruise Control (ACC) has evolved as a cornerstone of primary driver assistance technologies. Researches evince that ultrasonic sensor and microcontrollers like NodeMCU are pivotal for implementing efficacious ACC scheme. These systems apply control algorithms, such as Proportional-Integral-Derivative (PID) accountant, to regulate vehicle speed found on real-fourth dimension data point. ACC importantly reduces driver workload, heightens fuel efficiency, and improves road safety by autonomously adjusting speed in response to changing traffic conditions. Studies have demonstrated that ACC can lower the hazard of rear-end collision and optimize traffic flow by maintaining consistent vehicle spacing [6].

Lane Keeping Assist (LKA)

Lane Keeping Assist (LKA) systems have seen rapid advancements, largely driven by improvements in computer vision technologies. OpenCV is widely utilised for real-time lane detection, using techniques like Canny Edge Detection and Hough Line Transform to identify lane boundary even under challenging conditions, such as poor visibility or worn road markings. Emerging LKA systems comprise car learning algorithms to enhance accuracy in complex environs, such as urban traffic or multi-lane highways. Research points out that LKA can reduce the incidence of lane-departure-related accidents, particularly on long highway journeys where driver fatigue is prevalent [7].

IoT in Automotive Systems

The Internet of Things (IoT) has revolutionised automotive organisation by enabling real-time data acquisition, remote diagnostics, and prognostic analytics. IoT enhances vehicle performance and safety through features like over-the-aviation software updates, prognostic alimony, and real-time monitoring. In ADAS, IoT facilitates data-driven decision-making and supports advanced communication protocols, such as vehicle-to-vehicle (V2V) and vehicle-to-substructure (V2I) fundamental Interaction [8]. This connectivity allows vehicles to respond dynamically to shift road precondition, traffic signals, and environmental factors, promoting secure and to a greater extent efficient motor experiences.

Challenges in ADAS Development

Despite notable advances, ADAS development faces several challenges. These include sensor calibration inaccuracies, environmental factors such as adverse weather conditions, and the computational demands of real-time data processing. Control system dependability under diverse conditions requires robust hardware, optimised algorithms, and resilient communication networks.

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Additionally, cybersecurity concerns are increasingly relevant as connected vehicles get more susceptible to potential cyber threats, necessitating robust security protocols to safeguard critical systems [9].

METHODOLOGY

System Overview

The ADAS theoretical model comprise of two main subsystems:

- *Adaptive cruise control (ACC):* Utilizes ultrasonic sensors to assess the distance from vehicles in advance. This data point is processed by a NodeMCU microcontroller, which adjusts the vehicle's speed via a motor driver connected to a DC motor. The system continuously monitors traffic conditions, dynamically adapting to keep safe distance and prevent collisions [10].
- *Lane keeping assist (LKA):* Employs a camera for lane detection. OpenCV and Python process the captured images to identify lane boundaries, while a servomechanism motor adjusts steering to keep the vehicle aligned within its lane. The LKA system provides subtle steering correction, ensuring smooth lane-centring without abrupt movements.

Hardware Components

- *The ultrasonic sensor (HC-SR04):* Enables accurate distance measurement, making it essential for the Adaptive Cruise Control (ACC) system, as shown in Figure 1. Its precise sensing capabilities help maintain safe vehicle distancing by detecting obstacles and adjusting speed, accordingly, enhancing both safety and system performance in real-time driving conditions.
- *NodeMCU microcontroller:* handles data point processing, executes advanced control algorithms, and manages communication between system components. It serves as the central unit coordinating data flow, decision-making, and real-time responses within the arrangement, ensuring efficient performance and seamless integration across the entire setup [11–13].
- *The DC geared motor and L298N motor:* drivers help regulate vehicle speed by controlling acceleration and deceleration. They enable precise velocity adjustments, ensuring smooth motion transitions. As shown in Figure 2, this setup allows for efficient motor control in response to varying speed requirements during operation.
- *Servo motor:* The servo motor provides precise steering control for the Lane Keeping Assist (LKA) system, ensuring accurate lane alignment and vehicle stability. As illustrated in Figure 3, it plays a crucial role in maintaining the vehicle's position within the lane, enhancing safety and driver assistance functionality [14].

Figure 1. Ultrasonic sensor (HC-SR04).

Figure 2. Ultrasonic sensor (HC-SR04).

Figure 3. Servo motor.

Figure 4. Lead-acid battery.

Figure 5. IoT module (ESP8266).

- *12 V lead-acid battery:* The 12 V lead-acid battery, through a buck converter, efficiently delivers regulated power to all system components, ensuring stable and reliable operation, as illustrated in Figure 4.
- *Camera module:* Equipped with high-resolution capability for real-time lane detection.
- *IoT module (ESP8266):* Facilitates wireless data transmission for remote monitoring and diagnostics (Figure 5).

Software Implementation

- *MATLAB Simulink:* Simulates ACC performance, optimize control algorithms, and analyses system behaviour under various driving conditions.
- *Python with OpenCV:* Processes live camera feed for LKA, utilizing image recognition techniques to detect and track lane markers accurately [15].
- *IoT Platform (ThingSpeak):* Collects and visualises real-time data, offering insights into vehicle performance and system health.

Control Algorithm

- *Data collection:* Ultrasonic sensors capture real-time distance measurements. Cameras acquire high-definition images for lane detection.
- *Data processing:* ACC algorithms adjust speed based on proximity data. LKA algorithms analyse lane markers and calculate necessary steering corrections.
- *Organization control:* The NodeMCU processes the data and sends control signals to actuators for speed and steering adjustments.
- *IoT integration:* System performance data is carried to cloud platform for remote monitoring, predictive analytics, and diagnostics.

SYSTEM WORKFLOW

Data Acquisition

- Ultrasonic sensors evaluate the distance to surrounding vehicles.
- Cameras capture real-time road images for lane detection and environment analysis.

Decision-Making

- ACC algorithms process distance data to determine optimal speed adjustments.
- LKA algorithms analyse visual data to maintain accurate lane positioning.

Control Execution

- The NodeMCU coordinates speed and steering adjustments based on real-time data inputs.

IoT Connectivity

- System data is uploaded to an IoT platform for continuous monitoring and predictive maintenance.

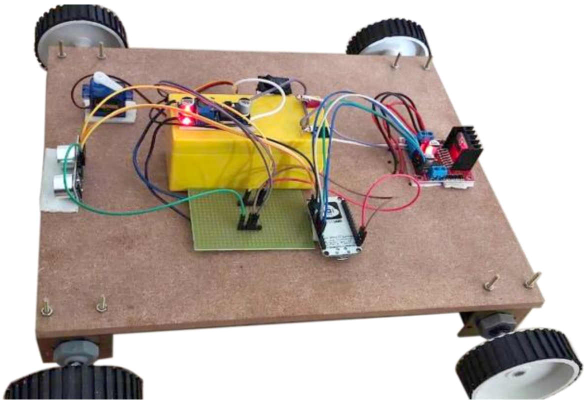

Figure 6. Prototype of proposed model.

Feedback Loop

- Continuous sensor feedback ensures the system adapts dynamically to changing road conditions, enhancing reliability and safety.

Moreover, Figure 6 shows the prototype of the proposed model.

SOLUTION AND DISCUSSION

The integrated ADAS system undergoes extensive validation through simulation and real-world testing to evaluate its performance, reliability, and safety.

ACC Performance

MATLAB/Simulink simulations demonstrate that the ACC system effectively maintains safe following distances in various traffic scenarios. The PID controller facilitates smooth speed transitions, rapid response to sudden braking, and ordered performance during stop-and-go traffic. Real-world trials support the system's ability to handle complex traffic situations with minimal device driver intervention [16].

LKA Performance

The LKA system showcased high accuracy in lane detection under various conditions, including low light and adverse weather. Real-time steering adjustments kept the vehicle centred within its lane, even on sharp curves and highways with faded markings. The image processing algorithms performed efficiently, ensuring timely corrective actions without noticeable latency.

IoT Monitoring

The IoT module enables real-time tracking of system performance, allowing remote diagnostics and data analysis. This feature proves invaluable for predictive maintenance, identifying potential issues before they escalate. IoT analytics also provides insights into driving patterns, contributing to continuous system optimization.

FUTURE WORK

- *Sensor upgrades:* Incorporating LiDAR and radar for enhanced environmental perception.
- *AI integration:* Leveraging machine learning algorithms to improve decision-making in complex driving scenarios.
- *V2X communication:* Enabling vehicle-to-vehicle (V2V) and vehicle-to-infrastructure (V2I) communication for coordinated traffic management.
- *Advanced IoT features:* Utilizing cloud-based analytics for predictive maintenance and real-time diagnostics.
- *Energy efficiency optimization:* Refining control algorithms to reduce energy consumption, thereby extending EV battery life [17].

CONCLUSION

This project successfully developed an IoT-based Adaptive Driver Assistance System, integrating ACC and LKA functionalities to enhance the safety, efficiency, and reliability of Electric Vehicles. The combination of ultrasonic sensors, real-time image processing, and IoT technology resulted in a cost-effective solution that significantly improves driving safety and comfort. Both simulations and real-world tests validated the system's effectiveness, demonstrating its potential for widespread adoption in smart transportation ecosystems. Its scalability and adaptability position it as a key component for future autonomous driving technologies.

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