International Journal of Scientific Engineering and Research (IJSER)
ISSN (Online): 2347-3878
SJIF (2024): 6.623

Next-Gen Smart Instrument Cluster with ESP32

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Abstract: ***This paper presents the design and implementation of a Next-Generation Smart Instrument Cluster utilizing the ESP32 microcontroller. Traditional analog vehicle dashboards are being rapidly replaced with digital interfaces that offer real-time monitoring, interactivity, and enhanced user experience. This paper proposes a cost-effective, feature-rich digital instrument cluster built using the ESP32, TFT display, DS1307 RTC module, potentiometers, and push buttons. The system emulates an automotive dashboard that includes arc-based RPM gauge, fuel level and battery indicators, gear and drive status displays, and real-time date and time features. Using TFT_eSPI graphics library, the interface supports dynamic visualizations with smooth animations and responsive controls. Direction indicators, gear shift logic, and brightness modes add further utility to the cluster. The ESP32's integrated Wi-Fi and Bluetooth expand its potential for future connectivity and IoT integration. Results demonstrate the system's real-time performance and flexibility, while future work could involve CAN bus interfacing, voice control, and data logging to cloud platforms. The paper provides an educational and practical model for modern vehicle instrumentation, demonstrating how open-source hardware can transform conventional automotive displays into intelligent, connected dashboards.***

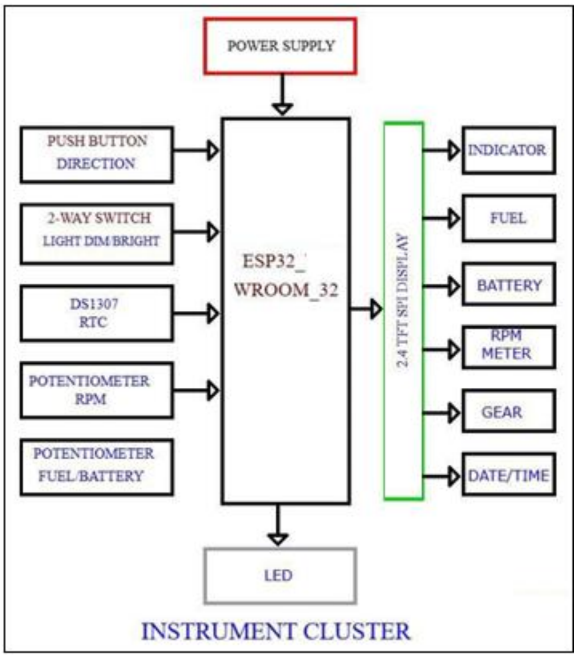
Keywords: ESP32, Instrument Cluster, Automotive Dashboard, Smart Display, Embedded Systems, RPM Gauge, Real-Time Clock, TFT Display, IoT

1. Introduction

The Next-Gen Smart Instrument Cluster with ESP32 is designed to modernize vehicle dashboards using digital displays, real-time data monitoring, and wireless connectivity. Built on the powerful ESP32 microcontroller, it offers a high-resolution GUI, customizable features, and seamless integration with external systems. The paper aims to replace static analog meters with an adaptive, efficient, and user-friendly digital interface. The next-generation smart instrument cluster with ESP32 is a highly advanced and cost efficient solution designed to modernize vehicle dashboards with digital intelligence and connectivity. Powered by the ESP32 microcontroller, known for its dual-core processing, low power consumption, and built-in Wi-Fi and Bluetooth capabilities, this smart cluster redefines how vehicle data is displayed and interacted with. It replaces traditional analog dials with high resolution digital displays, allowing real-time visualization of critical information such as speed, fuel levels, battery status, navigation, and engine diagnostics. The ESP32's wireless features enable seamless integration with smartphones, providing access to notifications, calls, and media controls, while IoT functionality allows cloud-based data logging, over-the-air firmware updates, and remote diagnostics. Additionally, the system supports multiple sensors and communication protocols like CAN, I2C, and SPI, making it suitable for both conventional and electric vehicles. With customizable UI designs, touchscreen interfaces, and voice control options, the next-gen smart instrument cluster enhances user experience, safety, and vehicle intelligence, paving the way for smarter and more connected transportation solutions.

2. System Design and Components

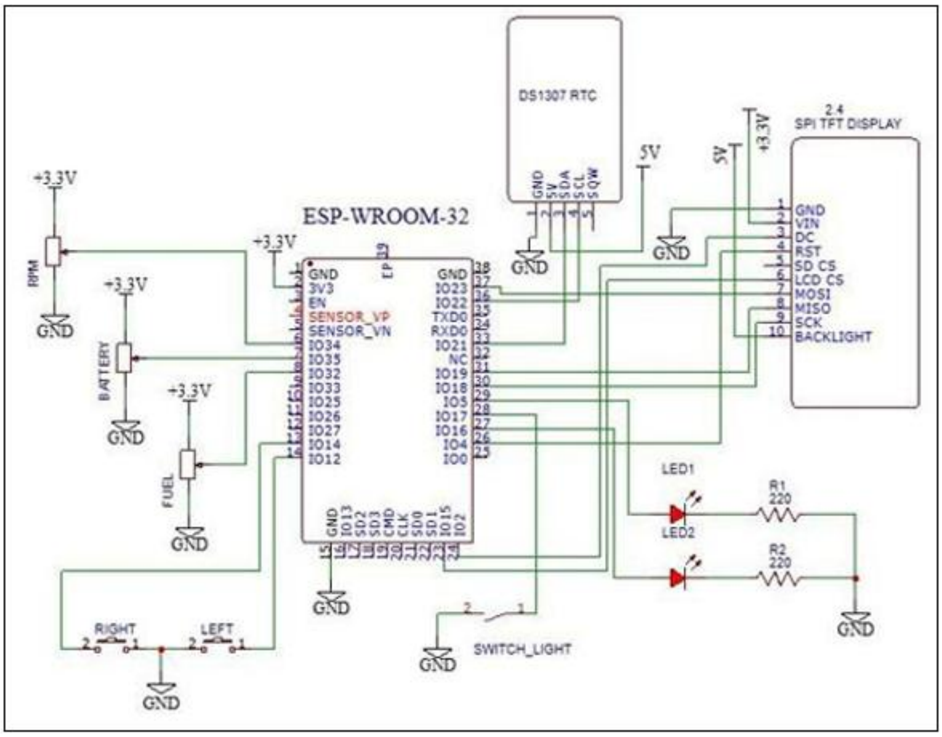
The digital instrument cluster utilizes an ESP32 to read analog inputs from two potentiometers, mapping one to control an arc-based RPM gauge and the other to display the fuel level. The system also reads battery voltage via a voltage divider circuit to ensure compatibility with the ESP32's ADC input range. A DS1307 RTC module continuously updates the date and time, which is displayed on the screen. The left and right push buttons enable directional indicators, visually represented as blinking arrows on the TFT display. A dedicated switch controls the LED's brightness, varying the PWM signal sent to the LED, while the display also updates to reflect the current brightness mode (dim or bright). The RPM and fuel levels dynamically change based on potentiometer inputs, with real-time graphical updates. Additionally, the instrument cluster displays the Drive (D), Parking (P), and Neutral (N) states on the screen. When both directional buttons are pressed simultaneously for three seconds, the Parking mode is activated and displayed. If the RPM remains at zero for five seconds, the system switches to Neutral mode. Conversely, if the RPM changes for five consecutive seconds, the display automatically switches to Drive mode. Furthermore, the gear position is indicated on the screen based on the RPM value, ensuring a more intuitive driving experience. The cluster GUI is designed using the TFT_eSPI graphics library, which provides seamless GUI widgets for smooth animations, crisp visuals, and optimized performance. This ensures a fluid and responsive user interface, making real-time data visualization more intuitive. The system serves as a foundation for developing more advanced automotive display systems, integrating additional sensors and communication interfaces for future enhancements.



3. Working Principle

Analog signals from potentiometers are converted to digital values by the ESP32's ADC and mapped to dynamic graphics for RPM and fuel levels. Push buttons control the left/right turn signals, while a switch toggles brightness levels. RPM thresholds trigger automatic gear and mode display updates, distinguishing between Drive, Neutral, and Parking states. The TFT_eSPI graphics library facilitates animated transitions and smooth rendering. The digital instrument cluster utilizes an ESP32 to read analog inputs from two potentiometers, mapping one to control an arc-based RPM gauge and the other to display the fuel level. The system also reads battery voltage via a voltage divider circuit to ensure compatibility with the ESP32's ADC input range. A DS1307 RTC module continuously updates the date and time, which is displayed on the screen. The left and right push buttons enable directional indicators, visually represented as blinking arrows on the TFT display. A dedicated switch controls the LED's brightness, varying the PWM signal sent to the LED, while the display also updates to reflect the current brightness mode (dim or bright). The RPM and fuel levels dynamically change based on potentiometer inputs, with real-time graphical updates. Additionally, the instrument cluster displays the Drive (D), Parking (P), and Neutral (N) states on the screen. When both directional buttons are pressed simultaneously for three seconds, the Parking mode is activated and displayed. If the RPM remains at zero for five seconds, the system switches to Neutral mode. Conversely, if the RPM changes for five consecutive seconds, the display automatically switches to Drive mode. Furthermore, the gear position is indicated on the screen based on the RPM value, ensuring a more intuitive driving experience. The cluster GUI is designed using the TFT_eSPI graphics library, which provides seamless GUI widgets for smooth animations, crisp visuals, and optimized performance. This ensures a fluid and responsive user interface, making real-time data visualization more intuitive. The system serves as a foundation for developing more advanced automotive display systems, integrating additional sensors and communication interfaces for future enhancements.

4. Circuit Diagram



Paper ID: SE251127115931 DOI: https://dx.doi.org/10.70729/SE251127115931

5. Results and Analysis

The instrument cluster successfully emulated real-world automotive behavior. RPM and fuel readings were accurately reflected with responsive visual feedback. Indicators functioned seamlessly, and gear/mode logic performed reliably under test conditions. The system's modular design allows easy enhancement, such as IoT logging, sensor integration, and cloud connectivity. The Next-Gen Smart Instrument Cluster with ESP32 is an advanced, user-friendly system designed to enhance vehicle dashboards with real-time data display and connectivity. This system integrates various sensors and wireless communication capabilities, offering a digital interface that improves user experience and safety. Compared to traditional clusters, it provides better efficiency, remote monitoring, and customization options, making it a reliable and modern solution for next generation vehicles. Reliability and innovation are the key aspects that ensure user satisfaction and improved driving experience.

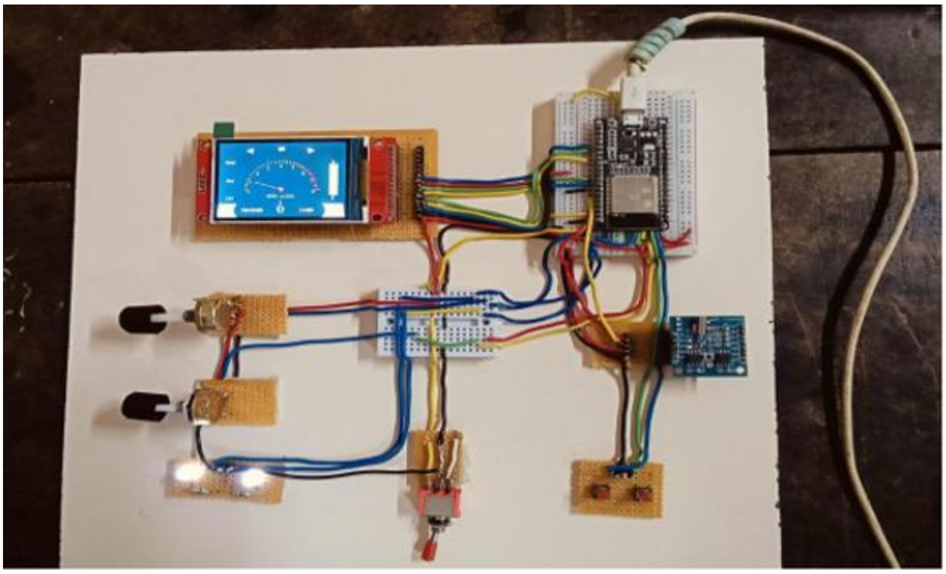


Figure: Next- Gen Smart Instrument Cluster with Esp32

6. Conclusion

The ESP32-based smart instrument cluster serves as a flexible and scalable alternative to traditional dashboards. Its real-time interactivity, visual appeal, and expansion capabilities make it suitable for automotive applications, electric bikes, and educational setups. The paper offers significant potential for future innovations, including CAN bus integration, OTA updates, and AI-based diagnostics for smart vehicles. In this paper, we propose a Next-Gen Smart Instrument Cluster using ESP32, offering a more advanced and efficient alternative to traditional dashboard systems. This modern solution enhances real-time data visualization, connectivity, and user experience by integrating IoT capabilities for remote monitoring and diagnostics. Unlike conventional analog or basic digital clusters, this system provides improved accessibility, customization, and real-time data accuracy, ensuring a smarter driving experience. The ESP32-based instrument cluster supports wireless communication (Wi-Fi, Bluetooth), enabling seamless integration with mobile applications and cloud services for enhanced vehicle diagnostics. Drivers can monitor key parameters such as speed, fuel level, battery health, and engine performance remotely, enhancing convenience and predictive maintenance. The system also reduces mechanical complexities, lowers production costs, and improves overall reliability, making it a cost-effective solution for modern vehicles. With features such as customizable digital displays, voice alerts, and smart notifications, this intelligent dashboard enhances safety and user engagement. Additionally, its energy-efficient design and compact architecture contribute to sustainability. By combining precision, connectivity, and adaptability, the Next-Gen Smart Instrument Cluster revolutionizes vehicle instrumentation, ensuring a smarter, safer, and more interactive driving experience while paving the way for future advancements in automotive technology.

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