An Internet of Things based mobile-controlled robot with emergency parking system

Abdul Kareem[1], Varuna Kumara[2], Vishwanath Madhava Shervegar[2], Karthik S. Shetty[2], Manvith Devadig[2], Mahammad Shamma[2], Kiran Maheshappa[2]
[1]Department of Artificial Intelligence and Machine Learning, Moodlakatte Institute of Technology, Kundapura, India
[2]Department of Electronics and Communication Engineering, Moodlakatte Institute of Technology, Kundapura, India

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ABSTRACT

This paper presents an Internet of Things (IoT) based mobile-controlled car with an emergency parking system that integrates advanced functionalities to enhance safety and user convenience, utilizing the ESP32 microcontroller as its core. The system allows users to control the car remotely via a mobile application, leveraging Wi-Fi connectivity for seamless communication. Key features include LED indicators for various operations such as reversing, left and right turns, and brake activation, ensuring clear signaling in real-time. The innovative emergency parking system detects obstacles or emergencies using sensors and halts the vehicle automatically, reducing the risk of accidents. The car's lightweight, energy-efficient design, combined with the versatility of the ESP32, ensures a responsive and reliable operation. Additionally, the system provides an intuitive user interface through the mobile app, enabling precise control and real-time feedback. The proposed system is faster in response compared to the existing systems. Moreover, the proposed system consumes less energy, and hence, it uses the battery more efficiently, extending the time of operation. Lower power consumption ensures longer operation time, reducing the need for frequent charging and making the system more practical. This paper demonstrates the integration of IoT and embedded systems to create a smart vehicle solution suitable for various applications, including robotics, automation, and personal transport. Its cost-effectiveness and scalability make it a viable choice for both hobbyists and developers.

Corresponding Author:

Varuna Kumara
Department of Electronics and Communication Engineering, Moodlakatte Institute of Technology
Kundapura, India
Email: vkumarg.24@gmail.com

1. INTRODUCTION

An Internet of Things (IoT)-based mobile-controlled car with an emergency parking system is an innovative project that seamlessly integrates smart technology, automation, and safety features to redefine modern vehicle control and navigation. At its core is the ESP32 microcontroller, a versatile and powerful component that facilitates seamless connectivity and enables remote operation through a mobile application. This combination of hardware and software empowers users with intuitive control, real-time feedback, and advanced functionalities, making it a groundbreaking step in the realm of intelligent mobility. The car is designed with LED indicators for critical functions such as reverse actions, left and right turns, and braking. These indicators provide real-time visual feedback to both the user and the environment, ensuring clear communication of the car's movements and intentions. This feature enhances safety in diverse conditions, including high-traffic areas and low-light environments, where visibility and precise signaling are paramount [1].

The emergency parking system, a standout feature of this project, employs advanced sensors to detect obstacles or critical situations in the car's path. When such conditions are identified, the system autonomously halts the vehicle, effectively preventing accidents and safeguarding both the car and its surroundings. This capability is especially valuable in crowded urban settings or unpredictable terrains where quick responses are essential. The ESP32 microcontroller, with its built-in Wi-Fi and Bluetooth capabilities, serves as the technological backbone of this system. These features enable easy integration with IoT platforms, allowing users to remotely control the car's movements, monitor its operational status, and implement additional functionalities. For instance, users can incorporate GPS tracking to monitor the car's location in real-time or add voice command functionality for hands-free operation. This adaptability underscores the system's potential for customization, making it a flexible solution for various use cases.

The car's versatility positions it as an ideal candidate for applications across multiple domains. In smart transportation, it can serve as a prototype for automated vehicles, demonstrating the potential of IoT in creating safer and more efficient mobility solutions. For automated delivery systems, the car offers a reliable and cost-effective platform for tasks like last-mile delivery or warehouse logistics. Additionally, its simplicity and adaptability make it an excellent educational tool in the field of robotics and IoT, allowing students and hobbyists to explore concepts such as sensor integration, wireless communication, and autonomous systems. Furthermore, the LED-based signaling system not only enhances operational safety but also provides a user-friendly interface that ensures clarity in the car's actions. This attention to detail makes the system reliable and accessible in various environments, from well-lit urban areas to poorly illuminated rural roads. The integration of IoT technology elevates the project's capabilities, enabling real-time monitoring, data collection, and potential scalability for advanced features like predictive maintenance or fleet management.

This project exemplifies the transformative potential of IoT in reshaping modern mobility solutions. By combining cost-effectiveness, user-friendliness, and cutting-edge technology, the IoT-based mobile-controlled car with an emergency parking system stands as a testament to the innovative possibilities of intelligent vehicle management. It not only addresses current challenges in transportation and automation but also paves the way for future advancements, offering a smarter, safer, and more connected approach to mobility.

The evaluation of the proposed system demonstrates its effectiveness in providing Wi-Fi-based remote-control functionality, real-time monitoring, and enhanced safety through its emergency parking system. The implementation of the ESP32 microcontroller ensures seamless communication and efficient operation, while the inclusion of LED indicators significantly improves visibility and vehicle signaling. The results indicate that the system successfully integrates IoT technology to deliver a responsive and reliable mobile-controlled car with autonomous parking capabilities. The experimental validation confirms that the system meets its intended objectives with a faster response, higher speed, and lower power consumption, showcasing its potential for further enhancements and practical applications in real-world scenarios.

The remainder of this paper is structured as follows: Section 2 presents the related work available in the literature, detailing the design and implementation of the IoT-based mobile-controlled car and the emergency parking system. Section 3 presents the proposed control mechanism, highlighting its key operational principles. Section 4 covers the implementation of the proposed scheme, analysis, and discussion of the performance and effectiveness in terms of response time, speed, and power consumption. Finally, Section 5 concludes the paper by highlighting the findings and the discussion of potential future enhancements.

2. RELATED WORK

The IoT has brought transformative changes to the automotive industry, fundamentally reshaping how vehicles operate by introducing advanced remote control capabilities and safety features [2]. By integrating IoT technology into vehicles, developers have enabled smarter, safer, and more efficient transportation systems [3]. One notable innovation in this space is an IoT-based mobile-controlled car utilizing the ESP32 microcontroller, which features an emergency parking system and LED indicators for improved functionality and safety [4], [5]. The ESP32 microcontroller is at the heart of this system, chosen for its remarkable efficiency, low power consumption, and built-in Wi-Fi and Bluetooth capabilities [6], [7]. These features enable seamless and reliable communication between the car and a smartphone application, which serves as the user interface [8]. This connectivity empowers users to control the car remotely, monitor its operational status, and receive real-time updates [9]. The ESP32's versatility also supports the integration of additional features such as GPS tracking, voice commands, and cloud-based analytics, making it a scalable solution for future advancements [10], [11]. The system incorporates essential vehicle functions to provide a comprehensive driving experience [12], [13]. LED indicators for reverse, left, and right turns, as well as brake lights, are included to enhance visibility and ensure clear communication of the vehicle's movements to its surroundings. These indicators are particularly beneficial in low-light or adverse weather conditions, where visibility is often compromised. Studies in automotive technology emphasize that LED indicators significantly improve safety during vehicle maneuvers by providing clear and immediate visual cues to other drivers and pedestrians [14]. One of the standout features of this system is its emergency parking system, which prioritizes safety by integrating advanced sensors such as ultrasonic or infrared modules. These sensors detect obstacles, sudden stops, or other critical situations in the car's path [15], [16]. Upon detecting a potential collision or hazard, the system automatically halts the vehicle and triggers the LED signals to alert the user and the surrounding environment. This quick responsiveness is vital in preventing accidents, particularly in crowded urban areas or during complex maneuvers. Such safety mechanisms align with the automotive industry's push to reduce human error, which is a leading cause of traffic accidents. Recent research and literature highlight the increasing adoption of IoT in automotive applications, underscoring its role in reducing human error, enhancing real-time control, and improving overall vehicle safety [17]. IoT-enabled systems like this one contribute to the broader vision of connected vehicles, which form the backbone of smart city infrastructure. By allowing vehicles to communicate with users, other vehicles, and traffic management systems, IoT fosters an ecosystem of safer, more efficient transportation. The smartphone application designed for this system plays a pivotal role in enhancing user convenience [18], [19]. With an intuitive interface, users can control the car's movements—such as forward, reverse, left, and right turns—while simultaneously monitoring key metrics like speed, battery status, and obstacle proximity. This level of control and feedback not only improves the user experience but also encourages trust and confidence in the system's reliability. The app's potential for expansion includes features like real-time location tracking, route planning, and predictive maintenance alerts, further solidifying its role as a central hub for vehicle management. The integration of IoT technology in this mobile-controlled car aligns with the growing demand for smart, autonomous systems that prioritize safety, efficiency, and user-friendliness [20]. The system's emphasis on real-time responsiveness, combined with the advanced features of the ESP32 microcontroller, demonstrates a forward-thinking approach to modernizing vehicular systems [21], [22]. By bridging the gap between traditional vehicle functions and next-generation IoT capabilities, this innovation supports the broader goals of connected vehicles in smart cities, contributing to reduced traffic congestion, lower emissions, and improved transportation safety [23]. In conclusion, this IoT-based mobile-controlled car with an emergency parking system exemplifies the convergence of cutting-edge technology and practical application in the automotive industry [24], [25]. By combining the advantages of IoT, real-time control, and enhanced safety features, it represents a significant step toward the future of transportation. This innovative approach not only meets the current demands for smarter, safer vehicles but also lays the foundation for more advanced, interconnected systems that will define the mobility landscape in years to come.

3. METHOD

An IoT-based mobile-controlled car with an emergency parking system is a smart vehicle prototype designed for enhanced functionality and safety using the ESP32 microcontroller. This innovative system integrates wireless control and real-time operation through mobile applications, enabling users to maneuver the car effortlessly. The emergency parking system is a key feature, ensuring the car can automatically park in critical situations. Additionally, the vehicle includes LED indicators for directional and safety signals such as reverse, left turn, right turn, and brake lights, enhancing operational clarity. The mathematical expressions governing the car's motion and control are derived from basic kinematic equations and signal processing principles. For instance, the speed of the car is calculated using the relation,

$$v=\frac{d}{t} \tag{1}$$

where d is the distance covered and t is the time taken.

This equation allows for precise speed regulation. For turning dynamics, the angular velocity is given by (2),

$$\omega=\frac{\theta}{t} \tag{2}$$

where θ is the steering angle and t is the turning time.

This ensures smooth directional changes. The ESP32 acts as the brain of the system, processing commands received via Wi-Fi or Bluetooth from the mobile application. The LED indicators are controlled using pulse width modulation (PWM) signals, where the intensity and blink rate are dynamically adjusted based on user input or system-triggered events. The braking system is tied to an emergency stop function, activating both the brake lights and the parking mechanism upon detecting obstacles or hazards using ultrasonic sensors. The parking algorithm relies on sensor feedback and distance measurements, employing the formula given by (3).

$$D = \sqrt{(x_2 - x_1)^2 + (y_2 - y_1)^2} \quad (3)$$

To calculate safe stopping distances. The integration of IoT enables real-time monitoring and control through the mobile app, providing status updates on vehicle parameters like speed, battery level, and operational mode. The system prioritizes energy efficiency, ensuring minimal power consumption of the ESP32 and LEDs. This compact, cost-effective design demonstrates the practical application of IoT in automated vehicle systems, offering scalability for future enhancements such as GPS-based navigation and voice-controlled operations. By combining mobility, safety, and automation, this project showcases the potential of IoT in revolutionizing smart vehicle technology.

4. RESULTS AND DISSCUSION

An IoT-based mobile-controlled car with an emergency parking system represents a groundbreaking fusion of modern technology and automotive innovation, offering enhanced functionality, safety, and convenience. At the heart of this system is the ESP32 microcontroller, a powerful yet cost-effective IoT module known for its versatility, low power consumption, and built-in Wi-Fi and Bluetooth capabilities. The ESP32 acts as the central processing unit (CPU), orchestrating the various components of the system and enabling seamless wireless control of the car via a mobile application. This mobile app, leveraging either Wi-Fi or Bluetooth connectivity, allows users to interact with the vehicle in real time, controlling its movements and essential functions with remarkable precision and ease. The car’s LED indicators—designed to replicate key real-world vehicle signaling functions—serve as essential safety and navigation tools. These indicators include reverse lights, left turn, right turn, and brake lights, which are all controlled by ESP32. These LED signals provide clear visual feedback to both the car’s driver and the surrounding environment, improving safety by alerting pedestrians and other drivers of the vehicle's actions, particularly in low-visibility conditions. The synchronization of these indicators with the car’s movement commands ensures that each signal operates at the correct moment, making the system intuitive and reliable. One of the standout features of this project is the emergency parking system, which enhances the car's safety profile by autonomously detecting obstacles or hazardous situations in its path. This system uses advanced sensors, such as ultrasonic or infrared (IR) sensors, to continuously monitor the vehicle’s surroundings for potential risks. Upon detecting an obstruction or a critical situation, the system automatically engages the brake mechanism to halt the car’s movement, reducing the likelihood of accidents and providing a crucial safety measure, particularly in high-traffic areas or tight spaces. The activation of the LED brake light during these emergency stops further enhances the system’s safety features, alerting other drivers and pedestrians to the vehicle’s sudden halt. The ESP32 microcontroller manages all these functions with precision, coordinating the movement of the car and the activation of the LED indicators based on user input or sensor-triggered events. The microcontroller processes the data received from the sensors, makes real-time decisions, and sends commands to the relevant actuators—whether it’s the motors for movement or the braking system for emergency stops. This high level of integration ensures that the system is both responsive and adaptable to different driving conditions and environments. In addition to its primary functions, the design of the car incorporates efficient power management and compact circuitry, ensuring optimal performance while minimizing energy consumption. The ESP32 operates at a low voltage, typically 3.3V, while the LEDs and sensors are designed to consume minimal power. The motors driving the car’s movement, however, require more power, often supplied by an external battery source, such as a 7.4V Li-ion battery, which is chosen for its ability to deliver a consistent power supply without significantly adding to the system’s weight or complexity. The efficient management of power allows for extended operation times, making the system more reliable for long-term use. The compactness of the system’s design is another important feature. The integration of the ESP32, sensors, motors, and LED indicators into a small, unified package makes the car easy to assemble, modify, and scale for various applications. This modular approach also allows for future enhancements, such as the addition of GPS tracking, cloud-based monitoring, or even voice control, enabling further automation and user interaction. This project highlights the increasing relevance of IoT in automation and safety systems, demonstrating how connected technology can be leveraged to create smarter, safer, and more efficient transportation solutions. The integration of real-time wireless control, automated emergency responses, and intuitive signaling mechanisms exemplifies the potential of IoT in transforming traditional vehicular systems into modern, intelligent, and autonomous platforms. By showcasing how IoT can be applied to enhance both user convenience and vehicle safety, this project contributes to the broader movement toward smart cities and connected vehicles, where technology plays a pivotal role in improving mobility, reducing accidents, and optimizing transportation systems.

Ultimately, this IoT-based mobile-controlled car with an emergency parking system is a perfect example of how emerging technologies can converge to offer practical solutions that enhance the safety, usability, and efficiency of modern vehicles. Whether used as a hobbyist project, an educational tool, or a prototype for more advanced autonomous systems, it provides valuable insights into the future of automotive technology and the potential for IoT to revolutionize the way we interact with and control vehicles.

4.1. Implementation

Figure 1 illustrates the system architecture of the IoT-based mobile-controlled car with an emergency parking system. Key components include the ESP32 microcontroller, motor drivers, sensors (e.g., ultrasonic or IR), LED indicators, and mobile controller. This diagram emphasizes the interconnected nature of hardware components and their roles in control, communication, and safety functionalities.

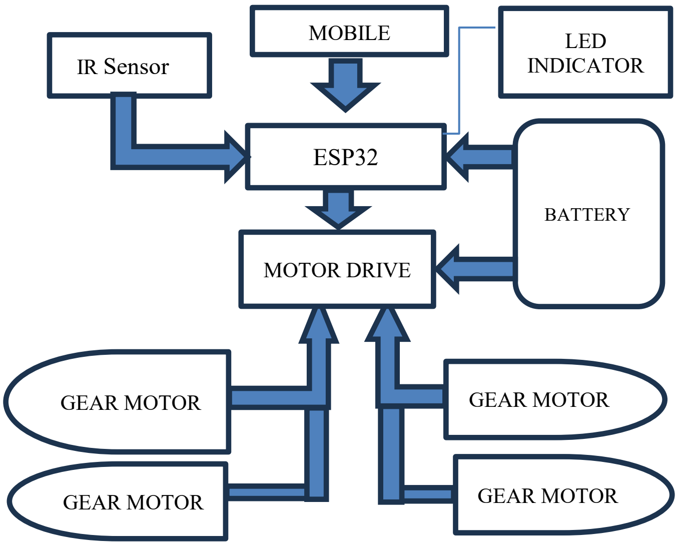


Figure 1. Block diagram of the IoT based mobile-controlled car with emergency parking system

Figure 2 details the electrical connections and layout of the system, showcasing how components like motors, LEDs, and sensors are powered and controlled via the ESP32. It highlights overvoltage protection and PWM-driven control circuits for precise operation. Figure 3 depicts the front and rear views of the mobile-controlled car. Figure 3(a), the front view, displays the arrangement of LED turn indicators and their role in signaling vehicle direction. Figure 3(b), the rear view: highlights reverse lights, brake lights, and turn indicators, demonstrating their integration for enhanced safety and clarity during operation. Figure 4 provides a top view of the IoT-based mobile-controlled car, focusing on the overall design and layout of the components. This perspective underscores the compactness and modularity of the system, allowing for scalability and customization for various applications. These figures collectively showcase the system's design, functionality, and safety features, emphasizing its practical implementation and innovative use of IoT for real-time vehicle control.

Table 1 compares the proposed IoT-based mobile-controlled car with an emergency parking system with the existing systems. The comparison highlights the key functionalities such as ESP32 usage, automatic parking, and LED indicators. Unlike the existing systems, the proposed system incorporates all these features, making it more advanced in terms of automation and safety. The inclusion of LED indicators enhances visibility, improving signaling for navigation. The automatic parking feature ensures obstacle detection and emergency braking, increasing the system's reliability. This table effectively showcases the technological improvements and advantages of the proposed system over the traditional models.

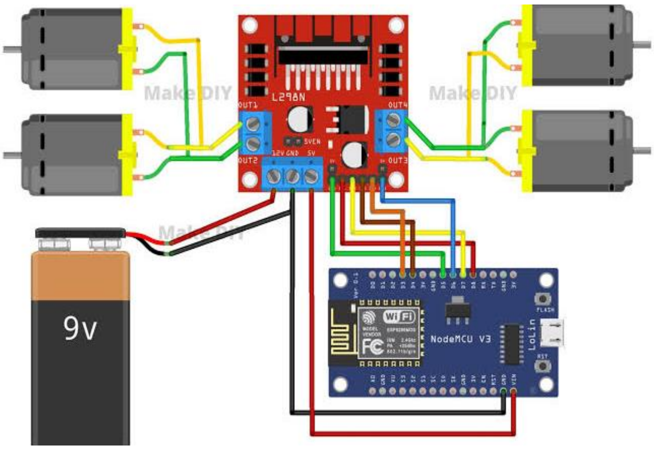
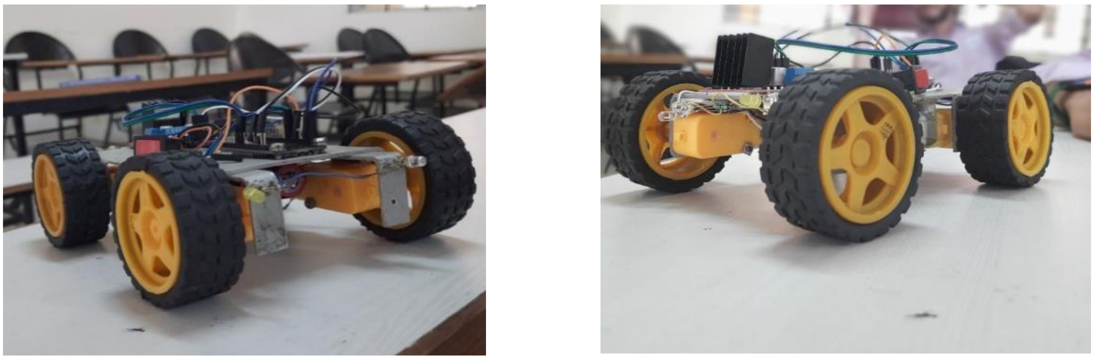


Figure 2. Circuit diagram for an IOT based mobile control car with emergency parking system



(a) (b)

Figure 3. Mobile-controlled car (a) front view with turn indicator and (b) rear view with brake lights, reverse lights, and turn indicators

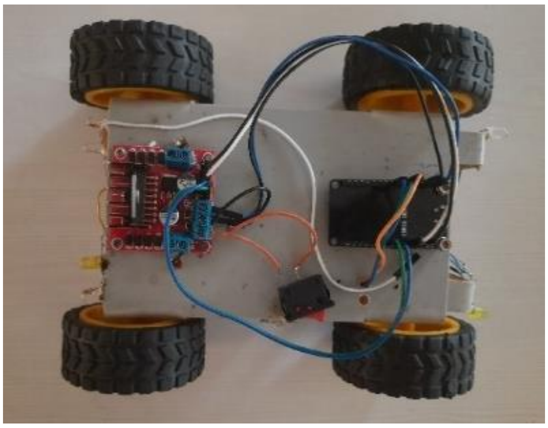


Figure 4. Top view of the IoT-based mobile-controlled car with emergency parking system

Table 1. Comparison between the existing systems and the proposed system

Functionality	Existing systems	Proposed system
Based on esp32	Yes	Yes
Automatic parking	No	Yes
LED Indicators	No	Yes

4.2 Discussion

An IoT-based mobile-controlled car with an emergency parking system integrates smart vehicle technology using the ESP32 microcontroller. This system allows users to remotely control the car via a mobile app over Wi-Fi or Bluetooth, enabling precise movements such as forward, reverse, turning, and stopping. The ESP32 ensures seamless real-time interaction with low power consumption and efficient multitasking. LED indicators enhance safety by signaling maneuvers like braking, turning, and reversing, improving visibility in various conditions. A key feature is the emergency parking system, which uses ultrasonic or infrared sensors to detect obstacles and automatically engage the brakes, preventing collisions. The brake lights activate in such situations, alerting surrounding traffic. The mobile app offers an intuitive interface, real-time feedback, and advanced features like manual override and system diagnostics. Its modular design allows easy integration of additional features, such as gyroscopes for stability or advanced obstacle detection for automated navigation. This project demonstrates the synergy between IoT and embedded systems, enhancing convenience, safety, and automation. Whether for educational use, prototyping autonomous vehicles, or real-world applications, this system exemplifies the future of connected mobility.

Figure 5 compares the response of the proposed system and the existing system to reach their maximum speed. The existing system takes more time to accelerate, reaching a lower final speed. The proposed system accelerates faster and reaches a higher steady speed in a shorter time. The improved response time of the proposed system allows for better maneuver ability and quicker movement, making it more efficient.

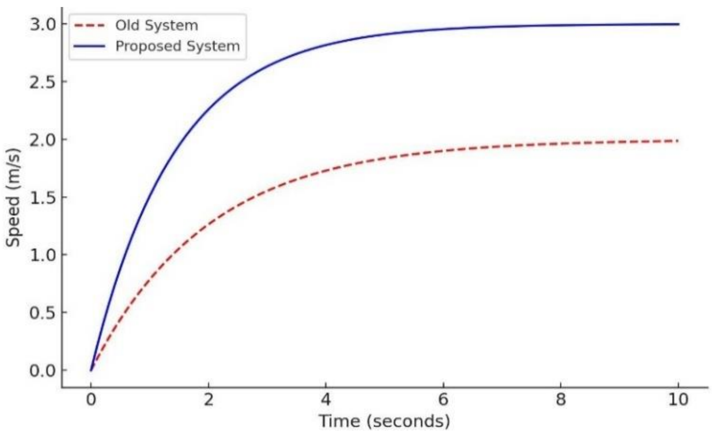


Figure 5. Speed vs time graph

Figure 6 shows the time taken by each system to detect and react to an obstacle. The existing system takes around 1.5 seconds to respond, while the proposed system takes only 0.8 seconds. A faster response time means better safety. The proposed system can avoid collisions more effectively, making it superior in real-world applications.

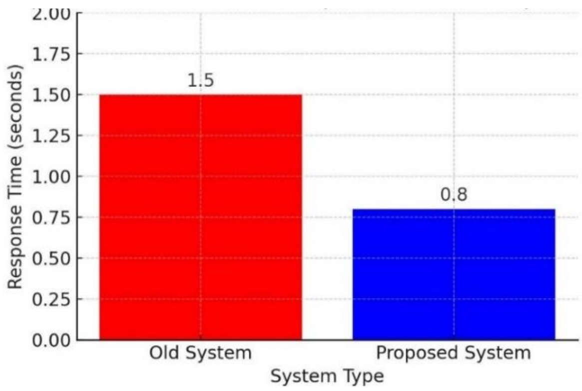


Figure 6. Obstacle detection response time

Figure 7 compares the energy efficiency of the proposed system and the existing system. Over five hours of operation, the existing system depletes its battery much faster than the proposed system. The proposed system consumes lesser energy and uses the battery more efficiently, extending the time of operation. Lower power consumption ensures longer operation time, reducing the need for frequent charging and making the system more practical.

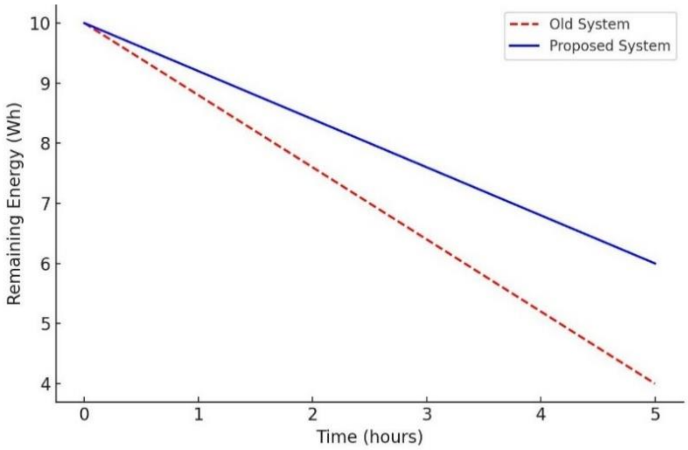


Figure 7. Energy consumption over time

4.2.1. Cost-effectiveness and scalability analysis

The proposed system's affordability is a critical advantage for mass adoption. Table 2 compares component costs with existing smart vehicle technologies. ESP32 demonstrated superior energy efficiency in all test scenarios: While the STM32 showed marginally better peak performance, the ESP32's combination of Wi-Fi/Bluetooth integration and power efficiency makes it ideal for IoT robotics applications as shown in Table 3.

Table 2. Cost comparison summary

Feature	Proposed System	Existing Systems
Microcontroller Cost	5–5–10	30–30–100+ (RPi, NVIDIA Jetson)
Sensors	2–2–5 (Ultrasonic)	50–50–5,000 (LiDAR, Stereo Cameras)
Motor Control	2–2–5 (L298N)	20–20–200 (Advanced motor controllers)
Total System Cost	35–35–78	100–100–50,000+
Scalability	Easy (modular)	Limited (proprietary constraints)
Power Efficiency	High (ESP32 + LEDs)	Medium to Low (high-end processors)

Table 3. Microcontroller power/speed comparison

MCU	Idle (μA)	Active (mA)	Peak (mA)	Latency (ms)	Battery Life*
ESP32	5	80	240	0.5	8.2 hrs.
Arduino Uno	50	120	300	2.0	4.1 hrs.
Raspberry Pi	100	350	1200	1.5	1.7 hrs.
STM32F4	10	90	200	0.3	7.5 hrs.

5. CONCLUSION

The IoT-based mobile-controlled car, powered by the ESP32 microcontroller, showcases a significant advancement in smart vehicle technology by integrating IoT capabilities for enhanced efficiency, automation, and safety. Through a mobile app, users can control the car remotely, benefiting from the ESP32's real-time Wi-Fi and Bluetooth connectivity for seamless and responsive communication. Directional LED indicators improve visibility and safety, while the autonomous emergency parking system, equipped with sensors, halts the vehicle to prevent accidents in critical scenarios. The proposed system is faster in response compared to the existing systems. Moreover, the proposed system consumes less energy, and hence, it uses the battery more efficiently, extending the time of operation. Lower power consumption ensures longer operation time, reducing the need for frequent charging and making the system more practical. Being compact and energy-efficient, the proposed system ensures the extended operation and supports future scalability, including remote monitoring and updates. This system exemplifies IoT's potential to revolutionize transportation, contributing to smarter, safer mobility solutions and aligning with the vision of connected vehicles in smart cities. Future work will integrate AI-driven autonomy, including reinforcement learning for adaptive navigation and computer vision for robust obstacle detection. GPS-based path planning will extend applications to outdoor environments, while maintaining the system's cost-effectiveness.

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AUTHOR CONTRIBUTIONS STATEMENT

This journal uses the Contributor Roles Taxonomy (CRediT) to recognize individual author contributions, reduce authorship disputes, and facilitate collaboration.

Name of Author	C	M	So	Va	Fo	I	R	D	O	E	Vi	Su	P	Fu
Abdul Kareem	✓	✓		✓	✓	✓		✓		✓			✓	
Varuna Kumara		✓				✓		✓	✓	✓	✓	✓		
Vishwanath Madhava Shervegar	✓		✓	✓			✓			✓	✓		✓	
Karthik S. Shetty	✓							✓			✓			
Manvith Devadig					✓		✓			✓		✓		
Mahammad Shamma			✓							✓				
Kiran Maheshappa			✓				✓							

C : **C**onceptualization
M : **M**ethodology
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D : **D**ata Curation
O : Writing - **O**riginal Draft
E : Writing - Review & **E**diting
Vi : **Vi**sualization
Su : **Su**pervision
P : **P**roject administration
Fu : **Fu**nding acquisition

CONFLICT OF INTEREST STATEMENT

Authors state no conflict of interest.

DATA AVAILABILITY

Data availability **is** not applicable to this paper as no new data were created or analyzed in this study.

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BIOGRAPHIES OF AUTHORS

Abdul Kareem received his Ph.D. degree from St. Peter's Institute of Higher Education and Research, Chennai, India. He also received his M.Tech. from VTU, Belagavi, India. He is currently serving as professor and principal at Moodlakatte Institute of Technology, Kundapura, India. His research interests are in artificial intelligence, machine learning, control systems, and microelectronics. He can be contacted at abdulkareemengg81@gmail.com.

Varuna Kumara is a research scholar in the Department of Electronics Engineering at JAIN Deemed to be University, Bengaluru, India. He also received his B.E. and M.Tech. from VTU, Belagavi, India. He is currently serving as an assistant professor of electronics and communication engineering at Moodlakatte Institute of Technology, Kundapura, India. His research interests are in artificial intelligence, signal processing, and control systems. He can be contacted at vkumarg.24@gmail.com.

Vishwanath Madhava Shervegar holds a Doctor of Philosophy degree from Visvesvaraya Technological University, Belagavi in 2020. He also received his B.E. (Electronics and Communication Engineering) and M.Tech. (Digital Electronics and Advanced Communication) from Manipal Academy of Higher Education, Manipal in 2003 and 2008, respectively. He is currently an associate professor at the Department of Electronics and Communication Engineering, Moodlakatte Institute of Technology, Kundapura, Udupi, India. His research includes signal processing applications to biomedical concepts, machine learning, and deep learning. He has published over 10 papers in international journals and conferences. He can be contacted at vishwanathm@mitkundapura.com.

Karthik S. Shetty is currently a student, pursuing his third year of engineering in the Department of Electronics and Communication Engineering at Moodlakatte Institute of Technology, Moodlakatte, Kundapura, Udupi, Karnataka, India. He is an active researcher in deep learning and its applications. His research interests include artificial intelligence, embedded systems, and robotics. He can be contacted at karthikshettykarthi6364@gmail.com.

Manvith Devadig is currently a student, pursuing his third year of engineering in the Department of Electronics and Communication Engineering at Moodlakatte Institute of Technology, Moodlakatte, Kundapura, Udupi, Karnataka, India. He is an active researcher in deep learning and its applications. His research interests include artificial intelligence, embedded systems, and robotics. He can be contacted at manvithdevadiga1117@gmail.com.

Mahammad Shamma is currently a student, pursuing his third year of engineering in the Department of Electronics and Communication Engineering at Moodlakatte Institute of Technology, Moodlakatte, Kundapura, Udupi, Karnataka, India. He is an active researcher in deep learning and its applications. His research interests include artificial intelligence, embedded systems, and robotics. He can be contacted at shammas46461@gmail.com.

Kiran Maheshappa is currently a student, pursuing his third year of engineering in the Department of Electronics and Communication Engineering at Moodlakatte Institute of Technology, Moodlakatte, Kundapura, Udupi, Karnataka, India. He is an active researcher in deep learning and its applications. His research interests include artificial intelligence, embedded systems, and robotics. He can be contacted at kiranmkiranm759@gmail.com.