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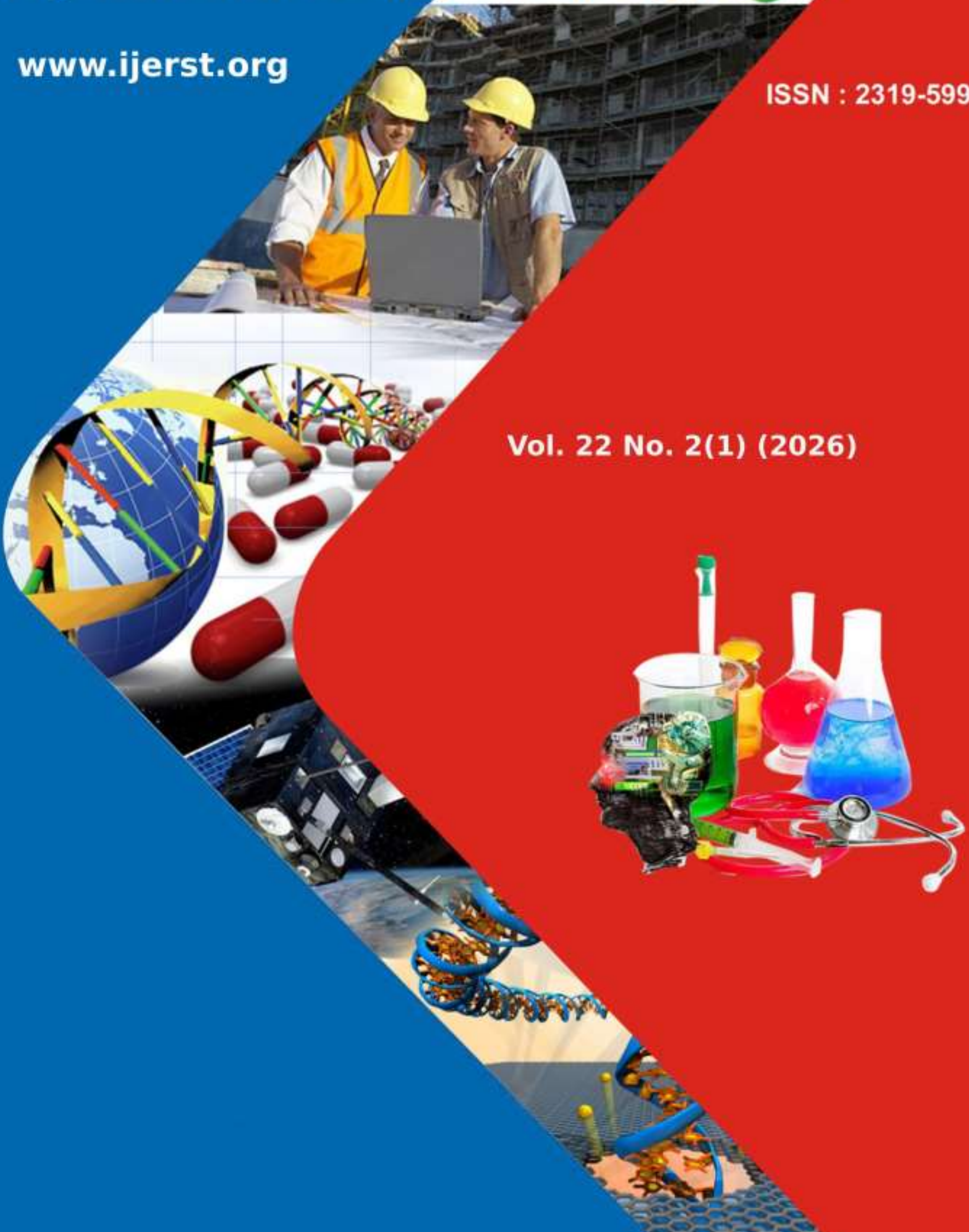

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Zigbee Based Smart Zone System for Accident Prevention and Automated Vehicle Speed Control Using IoT

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Abstract

The increasing rate of road accidents has become a major global concern, with over 1.3 million fatalities reported annually and nearly 50% of accidents occurring in high-risk zones such as school areas, hospitals, and sharp road curves, while intelligent transportation systems are expected to grow at over 17% annually. Additionally, human error, including over speed and delayed reaction to warning signs, contributes to more than 70% of road accidents, highlighting the need for automated safety mechanisms. These environments demand intelligent solutions that enhance driver awareness, enforce speed limits, and provide immediate alerts to prevent collisions. Traditional traffic control systems rely on static signboards, manual enforcement, and driver awareness, which are often ineffective due to negligence, poor visibility, or delayed human response. Moreover, conventional systems lack real-time communication, automated speed regulation, and integrated obstacle detection, reducing their effectiveness in preventing accidents. To address these challenges, the proposed smart zone for accident prevention and vehicle speed control system utilizes Zigbee wireless communication and the ESP32 microcontroller to create an intelligent safety framework. When a vehicle enters a predefined safety zone, Zigbee transmitters send signals that are processed by the ESP32 receiver to automatically reduce vehicle speed by controlling the motor. An ultrasonic sensor continuously detects obstacles, while a vibration sensor identifies abnormal movements or collisions. The system provides real-time alerts through an LCD display and buzzer, ensuring driver awareness. Additionally, IoT integration enables remote monitoring of vehicle status and safety zones through cloud platforms. This smart system enhances road safety, minimizes human error, reduces accident risks, and contributes to the development of intelligent and adaptive transportation systems.

Keywords: Accident Prevention, ESP32, Intelligent Transportation System, Internet of Things, Obstacle Detection, Smart Traffic Control, Speed Regulation, ZigBee Communication

1. Introduction

The increasing rate of road accidents has become a critical global issue, with more than 1.3 million fatalities reported annually and millions more injured worldwide. Studies indicate that nearly 50% of accidents occur in high-risk zones such as school areas, hospital surroundings, sharp curves, and construction sites [1]. Furthermore, human error—including overspeeding, distraction, and delayed response to warning signs—accounts for over 70% of road accidents, emphasizing the urgent need for automated safety mechanisms. With the rapid advancement of intelligent transportation systems, which are expected to grow at over 17% annually, there is a strong push toward integrating smart technologies that enhance road safety [2]. In real-world environments such as highways, urban roads, and restricted safety zones, there is a critical demand for systems [3] capable of real-time monitoring, automatic speed regulation, and obstacle detection to prevent accidents effectively [4].

Problem Statement: Traditional traffic management and vehicle safety systems rely heavily on static signboards, manual enforcement, and driver awareness [5]. Speed limits are typically indicated through roadside signs, which depend entirely on the driver's attention and compliance. However, these systems are often ineffective due to poor visibility, negligence, or lack of strict enforcement [6]. Additionally, conventional systems do not provide real-time communication between infrastructure and vehicles, limiting their ability to respond dynamically to changing road conditions. The absence of automated speed control and integrated sensing technologies further reduces their capability to prevent accidents in critical zones.

Motivation: In real-time scenarios, these limitations lead to several serious safety challenges. Drivers may fail to notice or respond to warning signs in time, resulting in overspeeding in sensitive areas such as schools and hospitals, increasing the risk of accidents [7]. The lack of obstacle detection systems prevents timely alerts about pedestrians, vehicles, or unexpected barriers on the road. Furthermore, delayed reaction times and human errors significantly contribute to collision risks, especially in accident-prone zones. The absence of real-time monitoring and automated intervention systems makes it difficult to enforce safety measures effectively. These challenges highlight the need for an intelligent, IoT-based solution that can automatically regulate vehicle speed, detect obstacles, and provide instant alerts, thereby enhancing road safety, reducing accidents, and supporting the development of smart and adaptive transportation systems.

2. Literature Survey

Sharma et al. [8] proposed an embedded system for vehicle accident prevention that utilized sensors and microcontroller-based control to monitor driving conditions and detect potential hazards. Gupta et al. [9] proposed an automatic vehicle speed control system for restricted zones that adjusted vehicle speed based on predefined limits using wireless communication and control mechanisms.

Ahmed et al. [10] proposed an ultrasonic sensor-based obstacle detection system for vehicles that detected nearby objects and generated warnings to avoid collisions. Patel et al. [11] proposed an Internet of Things (IoT)-based smart transportation system for traffic safety that integrated sensors and communication modules for real-time monitoring.

Mehta et al. [12] proposed a wireless vehicle monitoring system using sensor networks that enabled real-time tracking and condition monitoring of vehicles. Rahman et al. [13] proposed an IoT-based road safety monitoring system that collected and transmitted traffic data for real-time analysis and alert generation. Singh et al. [14] proposed a smart traffic control system using embedded controllers that automated traffic signal operations based on real-time traffic conditions.

Fernandes et al. [15] proposed a Zigbee-based vehicle communication system for traffic applications that enabled wireless data exchange between vehicles and infrastructure. Kumar et al. [16] proposed an ESP32-based smart vehicle safety monitoring system that integrated sensors and wireless communication for real-time safety alerts. Gupta et al. [17] proposed an intelligent traffic monitoring system using embedded technology that collected and analyzed traffic data for improved management.

Zhang et al. [18] proposed a smart transportation monitoring system using sensor networks that enabled large-scale data collection and analysis for traffic management. Khan et al. [19] proposed an intelligent accident prevention system that utilized sensors and control algorithms to detect and avoid potential collisions. Roy et al. [20] proposed an IoT-enabled traffic safety monitoring system that integrated connected devices for real-time traffic data acquisition and analysis.

Verma et al. [21] proposed a smart vehicle monitoring system for accident prevention that combined sensor data with control mechanisms to enhance safety. Park et al. [22] proposed a sensor fusion-based vehicle safety system that integrated multiple sensor inputs for improved decision-making in intelligent transportation systems.

Hasan et al. [23] proposed an IoT-based smart transportation monitoring system that enabled real-time tracking and management of traffic conditions. Lee et al. [24] proposed a wireless vehicle communication system using Zigbee networks for efficient data exchange in transportation systems. Sharma et al. [25] proposed an IoT-based intelligent smart zone system for traffic safety that monitored restricted areas and enforced safety measures through automated alerts.

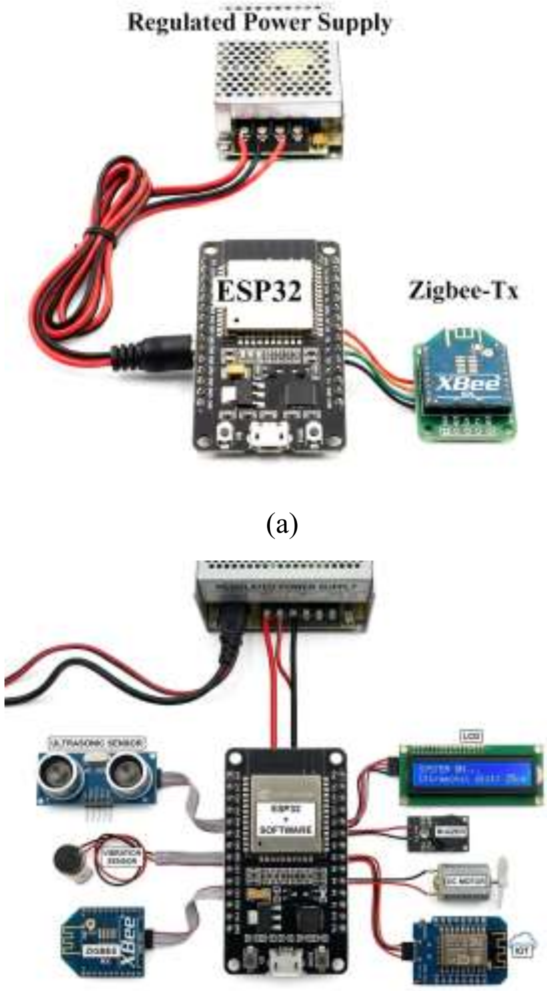
3. Proposed System

Figure 1 shows the e proposed system, Zigbee Smart Zone for Accident Prevention and Vehicle Speed Control, is designed to improve road safety by automatically controlling vehicle speed in restricted zones and detecting obstacles to prevent accidents. The system uses Zigbee wireless communication, embedded processing, sensor technology, and IoT monitoring to create an intelligent traffic safety mechanism. The system consists of two main modules:

- Transmitter Module (Roadside Unit)
- Receiver Module (Vehicle Unit)

The transmitter module is installed in predefined safety zones such as school zones, hospital zones, construction areas, and accident-prone locations. When a vehicle enters this smart zone, the transmitter sends a signal using Zigbee communication to the vehicle receiver module. The receiver module installed inside the vehicle receives this signal and automatically reduces the vehicle speed by controlling the DC motor. The system also includes an ultrasonic sensor to detect obstacles in front of the vehicle and a vibration sensor to detect abnormal vibrations or collisions.

The system provides alerts through a buzzer and displays system information on an LCD display. Additionally, the system integrates IoT technology, enabling remote monitoring of vehicle status and safety zone activity. This intelligent system helps prevent accidents by ensuring that vehicles move at safe speeds in restricted areas and by detecting obstacles in real time.



(a)

(b)

Figure 1. Proposed System. (a) Transmitter. (b) Receiver.

3.1 Working Procedure

Figure 2 shows the detailed proposed workflow. The detailed analysis is given as follows:

RPS: The Regulated Power Supply provides a stable and continuous DC voltage to all modules in the system. It converts an unregulated battery or adapter input into a fixed output voltage suitable for the ESP32 microcontroller, Zigbee modules, sensors, LCD display, buzzer, and DC motor. This ensures reliable operation without voltage fluctuations. A stable power supply protects electronic components from damage and maintains proper functioning of the system during operation.

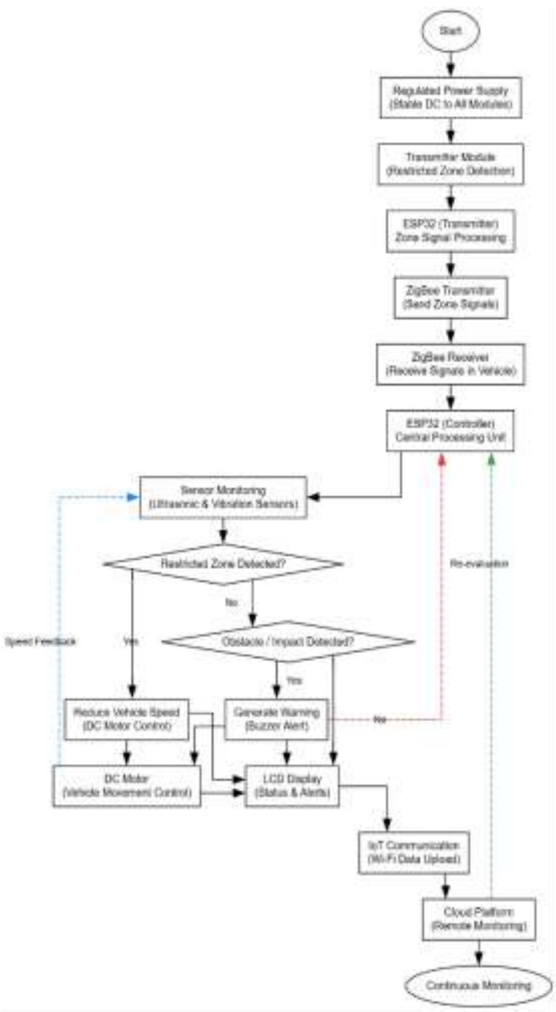


Figure 2. Proposed Workflow.

Transmitter Module: The transmitter module as shown in Figure 3 is installed near restricted zones such as school areas, hospital zones, construction sites, or accident-prone locations. This module is responsible for sending zone activation signals to vehicles approaching the safety zone. The ESP32 microcontroller controls the Zigbee transmitter and continuously sends signals indicating that the vehicle is entering a restricted zone. The Zigbee transmitter sends these wireless signals to the receiver module installed inside the vehicle. Zigbee communication is used because it provides reliable short-range wireless communication with low power consumption.

ESP32 Microcontroller (Controller Section): The ESP32 microcontroller acts as the main controller of the entire system. It receives signals from the Zigbee receiver and processes data from the connected sensors. Based on the received information, the ESP32 controls different components such as the LCD display, buzzer, and DC motor. The controller reduces vehicle speed when the vehicle enters a restricted zone and also processes obstacle detection signals. In addition, it manages communication with the IoT platform for remote monitoring. Because of its built-in Wi-Fi capability and high processing performance, the ESP32 is suitable for intelligent traffic safety applications.

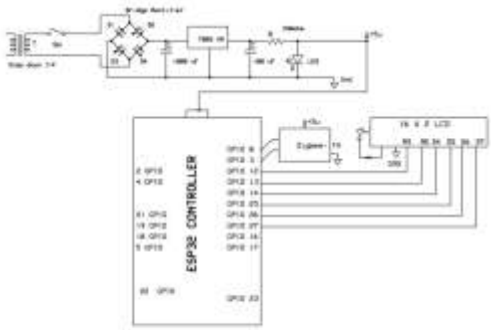


Figure 3. ZIGBEE Transmitter Schematic Diagram.

Receiver Module: The receiver module as shown in Figure 4 is installed inside the vehicle and receives signals transmitted from the smart zone transmitter. The Zigbee receiver captures the wireless signal and sends it to the ESP32 microcontroller. The ultrasonic sensor continuously monitors the distance between the vehicle and obstacles in front of it. If an object is detected within a certain range, the system generates a warning and reduces vehicle speed. The vibration sensor detects abnormal vibrations that may indicate sudden impacts or collisions. The ESP32 processes these sensor readings and takes appropriate safety actions.

Output Modules: The output section consists of the LCD display, buzzer, DC motor, and IoT module. The LCD display shows system information such as zone activation status, obstacle detection alerts, and system operation messages. The buzzer provides audible alerts whenever a safety warning occurs, such as entering a restricted zone or detecting an obstacle. The DC motor represents the vehicle motor in the prototype system, and its speed is controlled by the ESP32 to ensure safe vehicle movement in restricted areas. The IoT module sends system data such as sensor readings, alerts, and zone status to cloud platforms, enabling remote monitoring of traffic safety conditions.

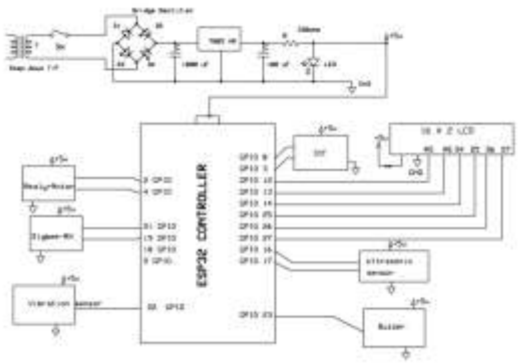


Figure 4. ZIGBEE Receiver Schematic Diagram.

4. Results and Discussion

Figure 5 shows the complete hardware setup of the ZigBee smart zone accident prevention system developed using the ESP32 microcontroller. The system integrates ZigBee communication modules, ultrasonic sensors, vibration sensors, DC motor control, LCD display, and buzzer for monitoring vehicle conditions and automatically controlling vehicle speed in restricted zones.

Figure 6 shows the LCD display indicating “ZigBee Accident Prevention”, which confirms that the smart safety zone has been activated. When a vehicle enters the defined zone, the ZigBee transmitter sends a signal to the receiver module to initiate safety control operations.

Figure 7 illustrates the system status displayed on the LCD when the vehicle enters the restricted safety zone. The display shows “Zone: ON, V: LOW”, indicating that the smart zone is active and the vehicle speed has been automatically reduced to prevent accidents.

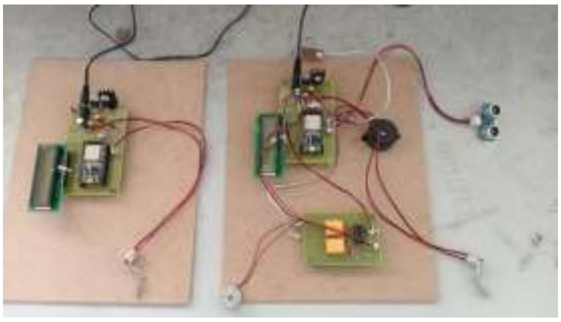


Figure 5. Hardware Prototype of ZigBee Smart Zone Accident Prevention System.

Figure 6. LCD Display Indicating ZigBee Zone Activation.

Figure 7. LCD Display Showing Vehicle Speed Control Status

5. Conclusion

The proposed ZigBee Smart Zone for Accident Prevention and Vehicle Speed Control System offer an effective and intelligent solution to reduce road accidents by integrating wireless communication, automation, and real-time monitoring. By utilizing ZigBee technology and the ESP32 microcontroller, the system automatically enforces speed control when vehicles enter high-risk zones, significantly minimizing human error such as overspeeding and delayed reaction. The inclusion of ultrasonic and vibration sensors enables continuous obstacle detection and accident identification, ensuring immediate response to potential hazards. Real-time alerts through the LCD display and buzzer enhance driver awareness, while IoT integration allows remote monitoring and data analysis for improved traffic management. This system overcomes the limitations of traditional traffic control methods by providing adaptive, automated, and data-driven safety mechanisms. Finally, it contributes to safer road environments, reduces accident risks, and supports the advancement of smart and intelligent transportation systems.

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