Density Based Solar Powered Traffic Control System

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Abstract — The rapid increase in urban vehicle numbers has made traditional fixed-time traffic signal systems ineffective, leading to congestion and unnecessary fuel consumption. Conventional signals follow preset timing cycles and cannot react to real-time traffic conditions, which causes vehicles to wait even when some lanes are empty. To overcome this problem, this paper proposes a Density-Based Solar Powered Traffic Control System using an ESP32 microcontroller. The system uses two Infrared (IR) sensors in each lane to estimate traffic density and classify it into low, medium, and high levels based on vehicle position. According to the detected density, the signal timing is adjusted dynamically, giving longer green signals to congested lanes while skipping empty ones to improve traffic flow and reduce waiting time. An RFID-based priority feature is included to detect authorized emergency vehicles such as ambulances and fire brigades, and the controller immediately overrides the normal sequence to clear the intersection. For better user awareness, an OLED display provides a visible countdown timer for signal changes, and a buzzer gives an audible alert during emergency operation. The system is powered by a solar panel as the main energy source along with a rechargeable battery backup, and during low sunlight the battery can be charged from the electrical grid to maintain continuous operation. Overall, the proposed system offers a simple, reliable, and energy-efficient approach suitable for smart city traffic management.

***Keywords*:** Density-based Control, Solar Energy, RFID Priority, OLED Display, Hybrid Power System, Intelligent Transportation System

1.INTRODUCTION

Urban traffic congestion is a critical challenge faced by metropolitan areas due to rapid urbanization and the increasing number of private vehicles. Conventional traffic control systems operate on fixed time intervals and often fail to react to real-time traffic conditions, which leads to long waiting times and increased environmental pollution [1]. Earlier studies have also pointed out that fixed-time signaling causes vehicles to remain idle at intersections even when some roads are empty, resulting in unnecessary fuel consumption and driver inconvenience.

Recent developments in Intelligent Transportation Systems (ITS) have explored density-based traffic control using infrared (IR) sensors and microcontrollers [2]. Although such approaches help improve traffic flow, many do not include sustainable power arrangements or reliable emergency vehicle handling. In addition, dependence on the electrical grid reduces system reliability, especially in areas where power interruptions occur frequently.

To overcome these issues, this paper proposes a “Density-based Solar Power Traffic Control System.” The system uses an ESP32 microcontroller. The proposed design uses two IR sensors in each lane to identify low, medium, and high traffic density based on vehicle queue position. The system also integrates Radio Frequency Identification (RFID) technology to provide priority passage for emergency vehicles such as ambulances and fire brigades. An OLED display shows signal countdown timing, and a buzzer provides alerts during signal change and emergency operation. Solar energy is used as the primary power source, while a rechargeable battery acts as a backup during rainy conditions or temporary power cuts.

2. RELATED WORK

Significant research has been conducted in the field of adaptive traffic management, ranging from sensor-based density detection to solar-powered infrastructure. Bavkar et al. [1] proposed a density-based system using IR sensors and microcontrollers, demonstrating the effectiveness of dynamic signaling over fixed-time systems. Their work highlighted the limitations of the current infrastructure in India, noting that non-lane based traffic requires intelligent management rather than rigid timing. However, their reliance on standard power supplies raised concerns regarding energy consumption and reliability during outages. Addressing the issue of energy efficiency, Gujar et al.

[3] introduced a solar-powered traffic system. Their model utilized photovoltaic panels to power the microcontroller and sensors, aligning with global efforts to reduce energy costs in public infrastructure. While this addressed the power issue to some extent, the system lacked a comprehensive backup mechanism for periods of low solar irradiance, such as during monsoon seasons. Alyoubi et al. [6] expanded on this by designing a standalone DC photovoltaic system for roundabouts, incorporating LCD displays for user information. However, LCDs often suffer from poor visibility in direct sunlight, a limitation addressed in our proposed system through the use of OLED technology.

Further advancements by Manchuri et al. [2] utilized Arduino Nano technology for density detection. Their prototype effectively demonstrated how IR sensors could count vehicles and trigger signal changes. However, the system did not incorporate specific emergency vehicle priority protocols, which is a critical requirement for urban traffic networks. Jangir et al. [4] expanded on emergency handling by integrating RFID for vehicle detection, allowing ambulances to override signals. Yet, their system depended heavily on grid power, lacking the sustainability of renewable energy sources. Varshini et al. [5] also explored density-based systems using ultrasonic sensors and RFID, but the implementation did not address the need for a hybrid power backup to ensure 24/7 operation.

This paper builds upon these foundations, introducing a double-sensor density detection method for precision, an OLED interface for enhanced visibility, and a fail-safe power backup system that combines solar efficiency with grid reliability, thereby filling the gap left by previous studies.

3. PROPOSED FRAMEWORK

The proposed system is a density-based solar powered traffic control system designed for a four-way road intersection. An ESP32 microcontroller is used as the main controller of the entire setup. It continuously receives information from the sensors placed on each road and accordingly controls the traffic lights, display units and alert system. The main objective of the system is to observe how many vehicles are actually waiting at a signal and then decide the signal timing instead of using a fixed timer. Each road direction (North, South, East and West) is provided with two IR sensors positioned at different distances from the signal pole. These sensors are used to check the length of the vehicle queue in that particular lane.

In this system three physical sensors are not required. Instead, density is identified through practical observation of vehicle position. When a vehicle stops near the stop line or close to the signal pole, the system assumes low traffic density. When the vehicle queue extends up to IR Sensor-1, it indicates medium density, and when vehicles reach IR Sensor-2, the lane is considered to have high density. The sensors are enabled only when the corresponding signal is red so that only standing vehicles are counted. During the green signal vehicles are moving continuously, therefore the readings are ignored to avoid false detection. The ESP32 processes this information and automatically decides the green signal duration. Roads with a longer queue are given more green time, whereas roads without vehicles are skipped. Because of this, unnecessary waiting time is reduced and the overall traffic flow becomes smoother.

To handle emergency situations, an RFID reader is installed on every lane. Emergency vehicles such as ambulances and fire brigades carry registered RFID tags. When such a vehicle approaches the intersection, the reader detects the tag and sends a signal to the ESP32 controller. The controller immediately interrupts the normal signal sequence and switches the corresponding lane to green, allowing the vehicle to pass without obstruction. After the vehicle crosses the junction, the system returns to its regular operation and continues monitoring the traffic density.

For user awareness, an OLED display is mounted at each side of the junction to show a countdown timer indicating how many seconds are left before the signal changes. A buzzer is also provided to give an audible alert during signal changeover and also when the emergency priority mode is activated so that nearby drivers and pedestrians can be cautious.

The system is powered mainly through a solar panel installed near the signal pole. The solar panel charges a rechargeable battery through a charging circuit, which supplies power to the controller and other components. During cloudy weather or low sunlight conditions, the same battery can be charged using the electrical supply to ensure the system continues working without interruption. In this way, the proposed system provides a practical, energy-efficient and reliable method for traffic management and can be effectively used in smart city application

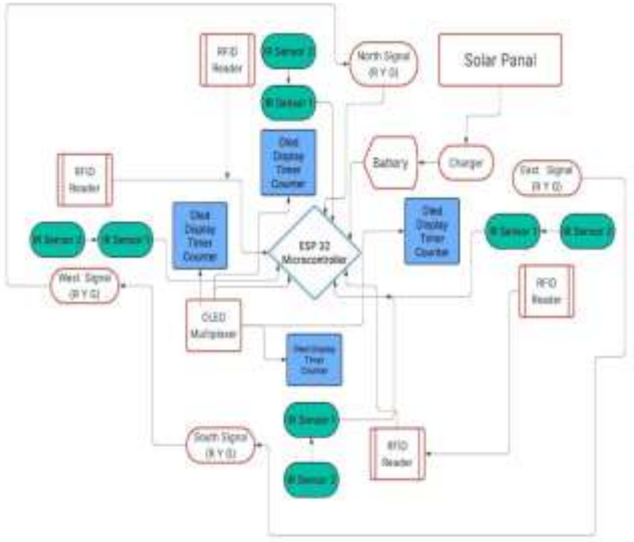

Figure 1: Block Diagram Of Density Based Solar Powered Traffic Control System

CONCLUSION

The Density-Based Solar Powered Traffic Control System proposed in this project provides a simple, practical, and efficient method for controlling traffic at road intersections. Unlike traditional fixed-time traffic signals, this system adjusts the signal duration based on the actual number of vehicles present in each lane, which is detected using infrared sensors placed at suitable positions. By analyzing the vehicle queue length, the system decides whether the traffic density is low, medium, or high and allocates green signal time accordingly, reducing unnecessary waiting time and minimizing congestion. The ESP32 microcontroller acts as the main control unit, continuously reading sensor inputs and managing signal changes in real time without manual intervention. To improve emergency response, RFID readers are installed to detect authorized emergency vehicles such as ambulances and fire brigades, allowing the system to immediately provide a green signal for faster and safer passage through the junction. An OLED display is used to show the countdown timer for each signal so that drivers and pedestrians can clearly understand the remaining time, while a buzzer gives warning alerts during signal transitions and emergency conditions to enhance safety. The system primarily operates on solar energy, making it energy-efficient and suitable for outdoor use, and a rechargeable battery backup ensures the traffic signals continue functioning during low sunlight or temporary power cuts. Overall, the proposed system offers a reliable, low-cost, and easy-to-implement solution that can improve traffic flow, reduce fuel wastage, and enhance road safety at busy intersections.

6. REFERENCES

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