Intelligent Traffic Signaling Using IoT: A Real-Time Solution for Congestion in Urban Areas

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Abstract. Rapid urbanization has made significant changes and challenges to traffic systems. Increased vehicle usage in the metropolitan regions has resulted in the surge in roadway crowding and pollution near junctions, as the traffic signals are predetermined without considering the levels of congestion. This proposed work presents an IoT-assisted signal management system. The Infrared (IR) sensors placed along these intersecting roadways are utilized to identify the existence of vehicles and dynamically adjust the traffic release time accordingly. Additionally, the gas sensor detects the pollutant levels in the surroundings which helps in environmental monitoring. This dual focus approach ensures smoother flow of traffic along with promoting environmental health monitoring. This system also proposes a low-cost solution for dynamic traffic signaling using IR sensors. Unlike existing systems that only concentrate on traffic signaling or environment monitoring, this system focuses on both congestion control and air quality monitoring in a cost-effective manner.
Keywords: Internet of Things, IR sensor, gas sensor, Dynamic traffic signaling, air pollution detection.

1 INTRODUCTION

Continuous urban growth has resulted in an increase in population and problems associated with traffic congestion. Traditional traffic signal systems operate on fixed schedules, leading to increasing waiting time and fuel consumption. This not only affects transportation but also increases vehicle emissions.

Recent studies [1],[3] have proposed IoT-based traffic signaling systems for dynamic traffic management which improves traffic efficiency through real-time detection and proposes an AI-based traffic management framework to increase efficiency in solving traffic congestion. To observe environmental pollution, one of the recent research projects [2] proposed integrated traffic monitoring with air quality analysis using sensor-collected data. These studies demonstrate the necessity of employing intelligence to enhance traffic and environmental issues.

R. Vasanth Kumar Mehta et al. (eds.), *Proceedings of the International Conference on Intelligent Systems for a Sustainable Future (ISSF 2026)*, Atlantis Highlights in Intelligent Systems 16,
https://doi.org/10.2991/978-94-6239-693-7_33

However, although these methods have advantages, many existing solutions contain complex computations, advanced models, or require costly structures in which many developing countries have a hard time implementing them with limited resources. Current solutions focus on solving congestion problems or monitoring the air quality instead of providing cost-effective methods.

This system introduces a low-cost signaling system using IR sensors along with air quality monitoring using gas sensors. It adjusts signal timings in real-time based on vehicle presence while also tracking air quality. By combining traffic signaling systems along with air quality monitoring, this system aims to achieve a cost-effective solution for traffic congestion.

2 RELATED WORK

Satyananda Champati Rai et al. [1] proposed a system using IoT, inductive loops and programmable microcontrollers. This approach focuses on real-time management of traffic signals using live vehicle data processed through centralized units. IR sensors are used to ensure timely access for emergency vehicles. The main limitation of this work is high system complexity and dependency on external connectivity, making it limited for regions with limited network infrastructure and technical resources.

J. A. Martín-Baos et al. [2] developed an affordable prototype that records real-time traffic volume and Air Quality Index (AQI). Sensors collect data, which is subsequently processed using regression models to determine how vehicle flow influences pollution levels. However, a key limitation of this work is that, despite its effectiveness in analyzing and collecting data, this system does not interact with signal operations dynamically as conditions change to reduce the dense traffic flow dynamically.

Lyazat Naizabayeva et al. [3] proposed AI-based dynamic traffic control systems that integrate live air quality monitoring as an innovative approach to help decrease air pollution in Almaty, Kazakhstan. The ambition is to curtail motor vehicle emissions through controlled traffic flow based on pollution levels using ANN and LSTM models. A significant obstacle stems from the system's dependence on advanced AI models and specialized equipment, rendering implementation expensive and less practical in areas with scarce resources.

Shanmugasundar, M, et al. [4] presented an intelligent traffic management system using infrared sensors, a centralized mobile app for connecting to central system and alert emergency services. They also used data visualization tools to monitor traffic and also provided graphical data to city authorities for better future road planning. Their aim is to improve traffic flow, provide safety, and urban planning in cities.

Zahraa Talib et al. [5] proposed an IoT and cloud-based intelligent traffic control system, aimed at the busy junction of Holy Karbala, Iraq. It uses infrared (IR) sensors and microcontrollers to dynamically manage traffic lights with a self-developed control algorithm. The proposed system was simulated under different traffic light scenarios (TLS1–TLS4 and ring state) and found to be more efficient at low cost.

Paolo Fazzini et al. [6] proposed study on adaptive traffic signal control which demonstrates that coordinating signalized intersections using multi-agent deep reinforcement learning can significantly reduce the vehicular pollution and energy consumption, thereby improving environmental conditions.

Shima Damadam et al. [7] developed an automated signal management solution aimed at enhancing traffic movement in Shiraz city by using IoT, Multi-Agent Reinforcement Learning, to learn and optimize signals based on actual traffic patterns by collecting traffic data through monitoring cameras.

3 METHODOLOGY

Utilizing IoT, the system implements a smart signaling framework aimed at easing live traffic crowding. This methodology using IoT technologies is used for sensing the live traffic density and air pollution at intersections which is used for controlling the traffic signals accordingly. This system architecture includes IR sensors, gas sensor, Arduino Uno Hat, Neo Pixel LEDs, LCD display. The IR sensors, LED strip, LCD display, gas sensor are connected to Arduino Uno Hat in Fig 1. Ground and VCC of the respective sensors, LCD display and LED strip are connected to 5V and ground pins of the Arduino board as in Fig.1. The IR sensors positioned in the south, west, east, and north directions have their digital output pins connected to the Arduino board's A0, 3, A1, and 2 pins, respectively. The gas sensor transmits its analog readings through pin A3. The LED strip's Data IN (DIN) is connected to A5. The RS, EN pins of display connected to 8,9 pins of the Arduino Board respectively.

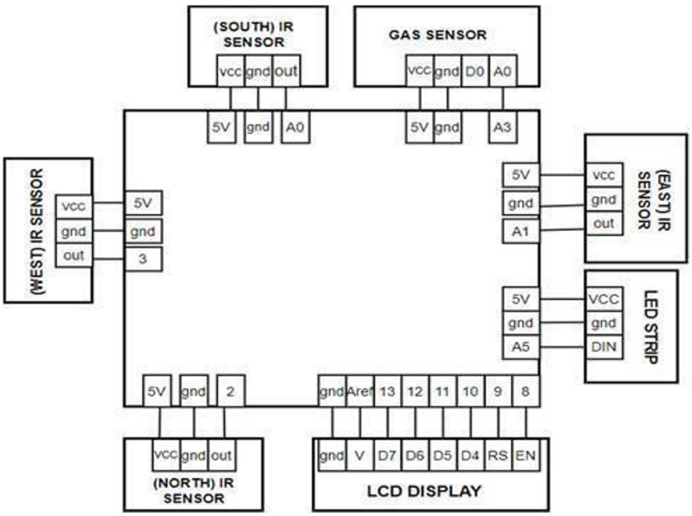

Fig. 1. Proposed Traffic Signaling system architecture connected to Arduino Uno

The IR sensor identifies vehicle presence within its assigned lane. If the vehicle is detected in any lane, the sensors output digital signal as LOW (0) which sets the green light signal duration to 20 seconds. If no vehicle presence is detected, the sensors output the digital signal as HIGH (1) which sets green light duration to 10 seconds. The Neo Pixel LED strip stimulates the traffic lights in four directions. The gas sensor is used for pollution monitoring. This converts analog signal reading (0-1023) to scaled values. If this value exceeds 400, this indicates that the air contains a higher concentration of harmful pollutants (like CO, NH3, NOx) which is considered pollution. LCD Display is used to display the vehicle presence of the four directions, current active direction, remaining traffic release time and current gas level.

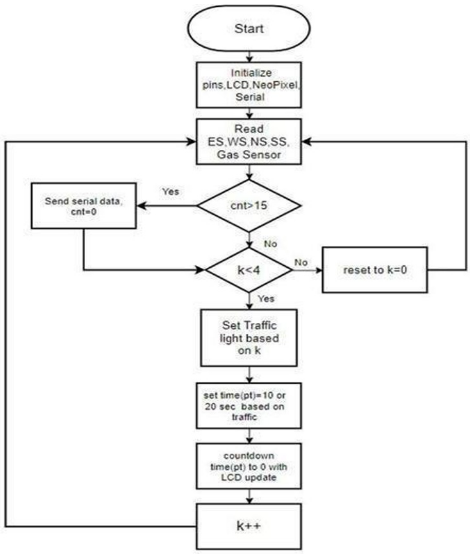

Fig. 2. Flow of proposed system activities

Fig.2. represents the sequence of operations done by traffic signaling systems. These operations include collecting data from the sensors, which is to check vehicle presence and gas levels, check the traffic signaling loop, and decide the traffic signaling time.

Algorithm 1 shows the working of Traffic Signaling System. The steps in the proposed methodology are summarized as the following :

Algorithm 1: Traffic Signaling System working process

Step 1: Reads input from all sensors
Step 2: if (cnt>15) for checking loop counter
        Send sensor data and gas level
    Reset cnt=0
    else
        Continue next step
Step 3: if (k<4)
    Set traffic light in green in direction based on k
    Set other directions to red
    Assign time=10 if there is no traffic; otherwise, set time=20
Step 4: Start at total time and count down to zero
Step 5: increment k
    If (k==4) then reset k=0
Step 6: Repeat step 2

4 RESULTS AND DISCUSSION

Our proposed traffic signal system is developed with Arduino UNO, infrared sensors, gas detectors, NeoPixel LED strips, an LCD screen, and an ESP8266 Wi-Fi module, all powered by a 3.3V power source. The system monitors real-time vehicle presence with IR sensors and adjusts signal durations accordingly. A gas sensor is also used to measure air pollution levels, and notifications are issued if safe limits are crossed. The ThingSpeak platform (accessible via the ThingView app) is utilized for visualizing data on traffic and pollution. The system seeks to ease traffic jams, decrease fuel consumption, and enhance urban air quality, providing an affordable, scalable answer for smart cities. Fig. 3. shows that there is a vehicle presence in the East direction and the signal timing for the East is set to 20 sec when the vehicles in the East gets their chance to go (only 10 sec for the remaining since there is no presence of vehicles).

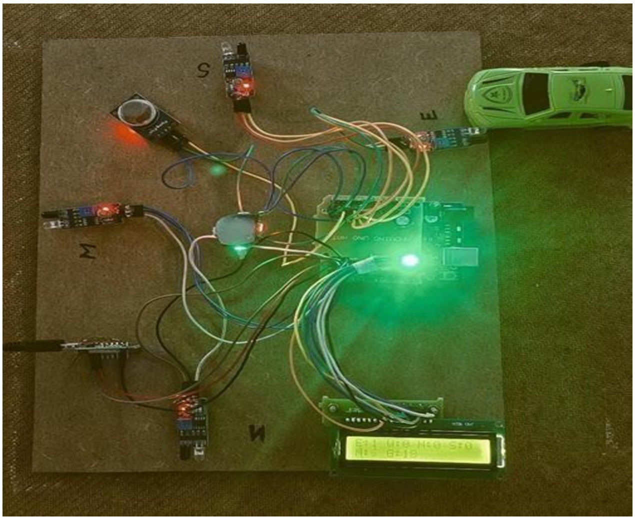

Fig. 3. Display showing vehicle presence in the East

Fig. 4. shows that there is a vehicle presence in the South direction and the signal timing for the South direction is set to 20 sec when the vehicles in the South gets their chance to go (only 10 sec for the remaining since there is no presence of vehicles).

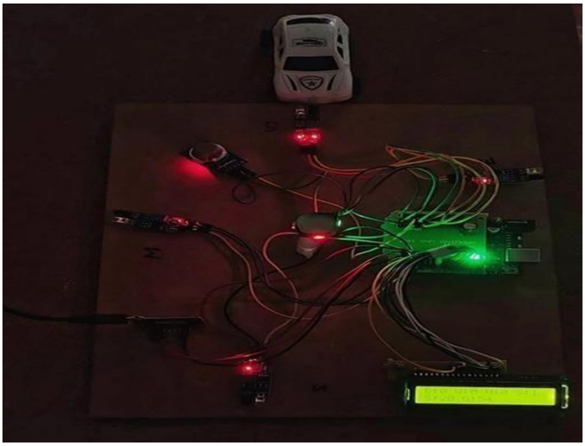

Fig. 4. Display showing presence of vehicles in the South

Fig. 5. shows that there is vehicle presence in the West and North directions and the signal timings for the West and North are set to 20sec when the vehicles in the West and North gets their chance to go (only 10 sec for the East and South since there is no presence of vehicles).

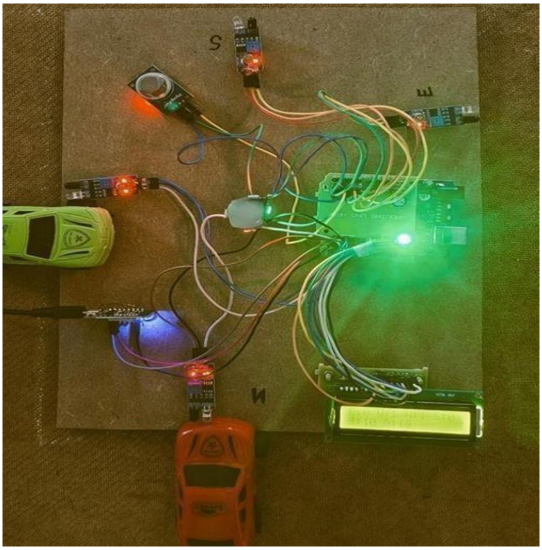

Fig.5. Display showing vehicle presence in North and West

Fig. 6. and Fig. 7. depict the visual representations of pollution and Vehicle flow intensity in E, W directions in the ThingView App.

Fig. 6. Pollution graph in the ThingView App

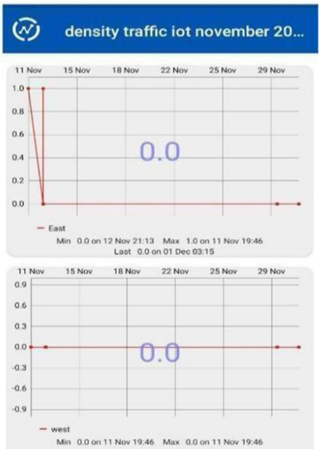

Fig. 7. traffic density graph in East and West directions

Unlike AI-driven adaptive traffic management systems that depend on camera monitoring and deep learning algorithms [3], the suggested system provides a more economical and hardware- efficient solution. Advanced proposed works have the possibility of providing optimized solutions but contain complex solutions. Few of these approaches [5] use self-developed algorithms. But our proposed method purely focuses on providing a low-cost solution for the cases where a solution is required but are lacking resources. Through the sensing of IR sensors that can be present at the lanes, the vehicle presence can be known and the traffic release time can be changed accordingly. This whole process does not require a complicated mechanism or require advanced resources and combined with air quality monitoring it provides a perfect solution for this traffic congestion we face today.

5 CONCLUSION AND FUTURE WORK

This paper presents a cost-effective dynamic traffic signaling and air quality monitoring system using IoT. The main contribution of this work is integration of traffic signaling control along with air quality monitoring in a single system using a simple Arduino board. This system adjusts the signal timings based on the presence of the vehicle which helps in effectively reducing traffic congestion along with monitoring the air quality. Compared to the traditional traffic signaling systems, which have fixed timings irrespective of the density of vehicles, this system provides more efficient solution suitable for the transportation problems caused by traffic congestion. In future, this system can also be improved by adding emergency vehicle detection to provide priority signal control.

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