International Journal of Advanced Engineering, Management and Science (IJAEMS)
Peer-Reviewed Journal
ISSN: 2454-1311 | Vol-11, Issue-2; Mar-Apr, 2025
Journal Home Page: https://ijaems.com/
DOI: https://dx.doi.org/10.22161/ijaems.112.12

Density Based Traffic Control System and Emergency Vehicle Detection Using Arduino

Ankita Jangir, Divya Jain, Khushi Nayak, Vikas Ranveer Singh Mahala

Department of Electrical Engineering, Swami Keshvanand Institute of Technology, Management & Gramothan, Jaipur, India.

Received: 03 Mar 2025; Received in revised form: 25 Mar 2025; Accepted: 31 Mar 2025; Available online: 07 Apr 2025

Abstract *— Urban traffic congestions cause delays and ineffi- cient fuel expenditure in cities. Regular fixed-time-based traffic systems are not able to respond quickly to real-time conditions and thus cannot manage traffic efficiently. This paper proposes an adaptive traffic control system using an Arduino microcontroller to automatically adjust signal timings based on vehicle density detected by IR sensors. Moving traffic is monitored by the system in real-time to optimize signal changes for better flow and reduce congestions. The other technology associated is RFID, which creates a foolproof emergency vehicle pass using minimal time delay at intersections. The system provides priority to emergency vehicles while optimizing other traffic. This system improves the efficiency of traffic and decreases the waiting time, which enables better road clearance for emergency service vehicles. The model is cost-effective, very adaptable, and promises a great step forward in urban traffic management.*

Keywords*—*Adaptive Traffic Control, Arduino, IR Sensors, RFID, Emergency Vehicle Priority, Urban Traffic Management.

I. INTRODUCTION

Traffic congestion has been and is one of the significant challenges facing urban planners in every corner of the world. As cities expand and the number of vehicles increases, tra- ditional traffic controlling systems either remain unable to manage the increased traffic flow or do so ineffectively. Con- ventional traffic signals are based on a fixed time interval-and hence do not change, to best suit real-time traffic conditions

[1]–[3]. This leads to prolonged delays, increased consumption of fuel, and created air pollution due to long idling vehicles at traffic lights. Instead, the density-based adaptive traffic control system seems a more efficient solution that changes signal timing according to the real-time density of vehicles. Such a system enables smooth traffic flow with less problem caused by traffic congestion. Besides general congestion, emergency vehicles, such as ambulances, fire trucks, and police cars, often get stuck at intersections behind traffic lights, causing further delays in life-saving operations. In critical cases, a matter of a second could spell the difference between life and death; every second counts, and one can just imagine the lifeline lost just by one second of intersection delay [4]–[7]. At present, traffic management authorities are depending upon manual systems or dedicated lanes for emergency vehicles, which does not guarantee efficacy, especially during peak hours. It is imperative that, in order to cut down emergency response times considerably, an automated smart system is called for, whereby an emergency vehicle being able to automatically detect and grant itself priority clearance [8]–[10]. To mitigate this problem, an adaptive traffic light controlling system based on traffic density on the road, using IR sensor to detect number of vehicles at an intersection, is proposed where the proposed system also detects the emergency vehicle separately to give priority to emergency vehicles [11]–[13].

II. METHODOLOGY

The entire design approach entails the design and the implementation of the input subsystem, control unit (control program), and output subsystem. The input subsystem is composed of sensors programmed and implemented according to some already existing principles to guarantee the maximum operational performance. The control unit is brought into operation through a microcontroller-based control program that interprets the input and interprets it to generate a desired output.

A. Block Diagram

Fig.1 shows the block diagram of the entire system that gives an idea of the basic elements of the system- Mains Supply, DC Power Supply, IR Sensors, Controller, Traffic Lights, and RFID module. The block diagram was drawn in such a way as to give an exact idea of the overall working of the system in a single glance; so the main supply supplies 230VAC power, which gets converted into 5VDC [VDD] through the DC power supply to run the IR sensor, the controller, the RFID module, and the traffic lights. The sensors provide information to the controller, and based on that, logical operations are executed to set the traffic lights' state to control traffic at the road intersection.

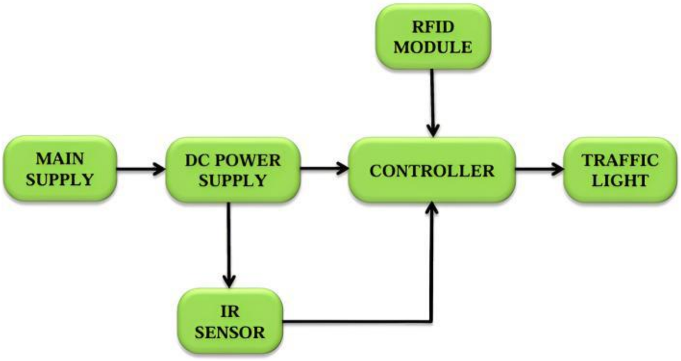

Fig. 1: Block diagram of density based traffic light control system

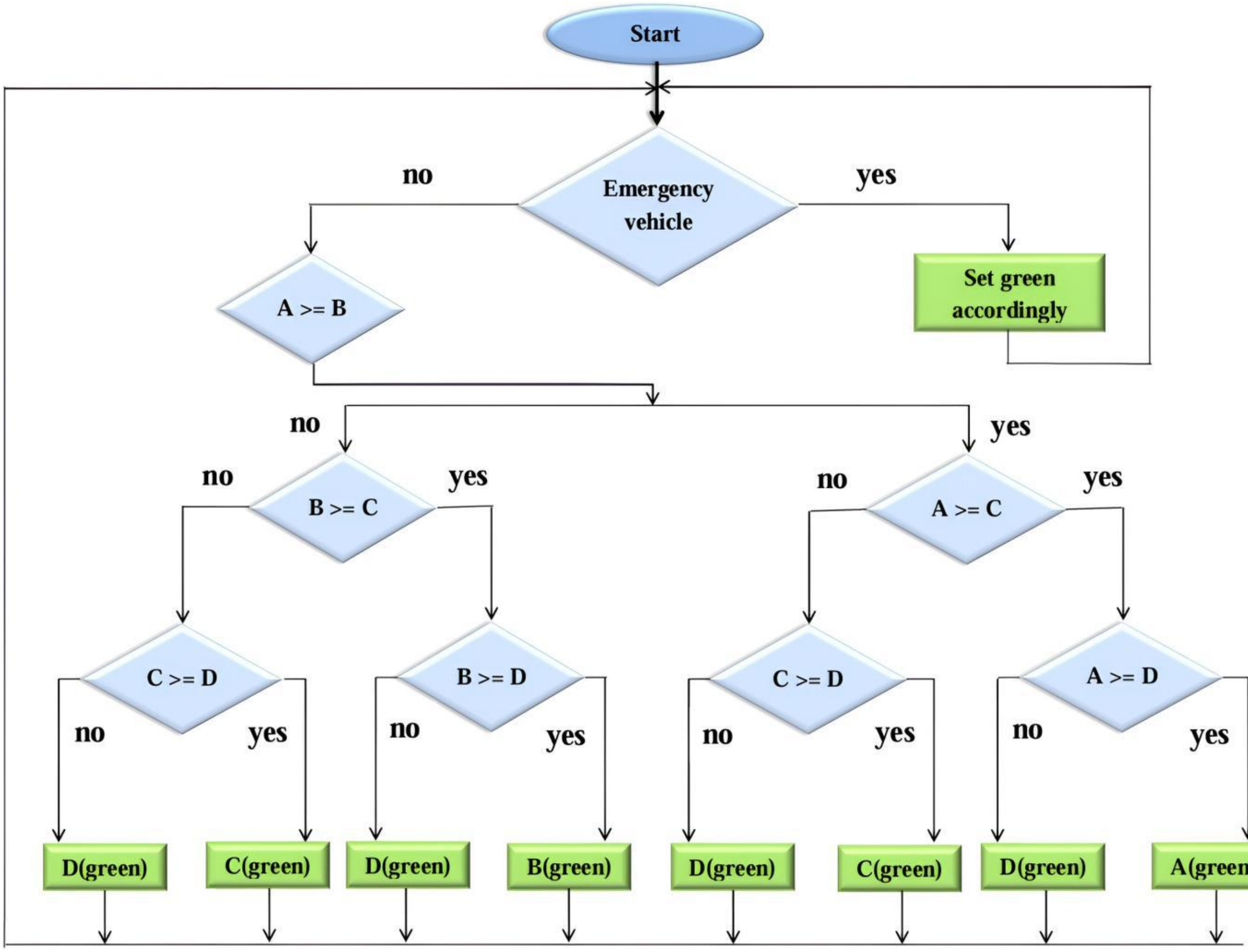

Fig. 2: Flow chart of the system

The main power supply builds a battery which increases the voltage steady thereon the safety controller, sensors, and many other components. The IR sensors fixed near the road check the density of the vehicles flowing at an intersection. This data is sent to the controller to dynamically vary the duration of the traffic signals on the basis of the actual vehicle counts: a longer green light for higher traffic density and a shorter green light under low traffic density.

In addition to handling normal traffic, this system is in- tended to facilitate the clearing of emergency vehicles when they approach illuminated Traffic Signal Junctions. Each such vehicle (in emergencies, typically ambulances, fire engines, and police cars) normally has an RFID tag attached to it. Upon approaching the traffic junction, the RFID reader reads the tag from the vehicle and sends a signal to the controller,

which shifts the green traffic light to the emergency vehicle immediately. There will not be any manual interference; response times in critical conditions will be minimized. The microcontroller acts as the brain of the system, takes inputs from both the IR sensors as well as the RFID module, efficiently provides intelligent control, and manages the flow of traffic lights accordingly.

The system design relied on Arduino because of its simplic- ity, cost-effectiveness, and flexibility. It can be easily paired with several other sensors such as infrared or ultrasonic to analyze traffic flow as well as detect emergency vehicles; quick responses made possible with real-time processing techniques adjust the signal based on traffic variations to contribute to the overall efficiency of the flow and the priority to emergency vehicles upon their detection; low power consumption keeps the overall operating cost low, allowing continuous activity without heavy energy expenses; in addition, because of Ar- duino's modular nature, it allows scalable aspects whereby new sensors or components can be easily introduced whenever

necessary; being an open-source platform, Arduino boasts extensive community support whereby many resources and libraries lengthen and quicken the development phase. Some connection options such as Wi-Fi or GSM appear to pro- vide convenience and efficiency for the remote monitoring and management of the system. All these features together contribute to making Arduino an ideal option for the construc- tion of an efficient and value-for-money smart traffic control system.

B. Flow chart

Fig.2 shows the flowchart of the entire system. The flowchart represents the systematic lanes priority based on traffic volume. First, it calls attention toward special cases for example, emergency vehicles like ambulance, fire brigade, etc. Then he follows simple hierarchy comparisons to decide which lane should get the green light, leading to restrictions based on traffic volume. This particular decision process is aimed at traffic management for streamlining vehicular movement in a safe and efficient manner.

This flowchart is the decision-making process for determin- ing which lane Broads A, B, C, or D gets the green signal at intersections. Following is a stepwise description:

1) **Start**
   - The process begins with the "Start" symbol.
2) **Checking for Emergency Vehicles**
   - The system first checks if an emergency vehicle is present in any lane.
   - **If Yes:** The signal is adjusted to allow the emer- gency vehicle to pass.
   - **If No:** The system proceeds to analyze traffic con- ditions.
3) **Comparing Lanes to Determine Priority**
   - The system prioritizes lanes based on traffic volume using a series of comparisons.

Case 1: $A \geq B$

- If lane A has traffic volume greater than or equal to

B, further checks are performed:

– **If** $A \geq C$, then check if $C \geq D$:

∗ **If Yes:** C gets the green signal.

∗ **If No:** Since $C < D$, lane D gets the green signal.

– **If** $A < C$, then check if $A \geq D$:

∗ **If Yes:** A gets the green signal.

∗ **If No:** Since $A < D$, lane D gets the green signal.

Case 2: $A < B$

- If lane A has less traffic than B, the comparison continues with D:

– **If** $B \geq C$, a simpler comparison is made with

D:

∗ **If Yes:** C gets the green signal.

∗ **If No:** Since $C < D$, lane D gets the green signal.

– **If** $B < C$, then check if $B \geq D$:

∗ **If Yes:** B gets the green signal.

∗ **If No:** Lane D gets the green signal.

4) **Final Decision**

- Based on direct comparisons, the lane with the highest traffic volume is granted the green signal.

III. EXPERIMENTAL SETUP

In order to demonstrate the function of the traffic man- agement system that has been developed, a prototype was designed for testing in an environment of real-world demon- stration. The testing scenario for the system was created to allow for traffic flows to be monitored for the management of emergency vehicles, and in regard to this page, there are no processes for emergency vehicles. Fig.6 represents the exper- imental setup of the density-based traffic light control system in operation, which was used for our research project, while Fig.7 shows the connections of the Arduino with IR sensors and the RFID module. The experimental setup includes:

Arduino Uno Microcontroller: It is the core of the system; will act as the central control unit for the whole system and is quite simple with regard to implementation, as an open-source microcontroller is used often as a more concerned notion of other types, such as minimal price, multi-usage, and simplicity. This would be the main processing unit for the system. The Arduino Uno [14]–[16] will receive signals from the sensors, processes the input, and produce outputs, such as a traffic light change, or an emergency vehicle detection. Fig.3 shows arduino uno board.

Fig. 3: Arduino uno

Infrared Sensors on the separate lanes: This consists of four Infrared (IR) sensors [17] placed in appropriate locations to observe traffic density from the different lanes of the intersection; and each sensor can figure out if a vehicle either passed over or interrupted the infrared beam. The number of vehicles detected by the IR sensors is fed to the Arduino Uno for evaluating the situation of traffic in each lane, as the sensors are placed in such a way that they can identify or monitor the flow of traffic of each lane independently, which would contribute in a comparative way as occur in monitoring a specific lane signal more adequately. By means of these sensors, the system determines an accumulation of traffic on some specific lane and thus will adjust the signal timings to eliminate the bottlenecks. Fig.4 shows infrared sensor used in experimental setup.

Fig. 4: Infrared Sensor

RFID Module for Emergency Vehicle Detection: This system has an RFID module [18] for the very important task of emergency vehicle detection, for which all emergency vehicles are fitted with electronically labeled or tagged from the entire length of the RFID module. When an emergency vehicle comes to the intersection, the RFID module sends a signal to Arduino Uno in order to get a real-time response and prioritizes the emergency vehicle's passage. The system then adjusts the traffic signals by turning red for all other lanes, allowing the emergency vehicle to pass through the intersection without any obstruction or delay. Fig.5 shows RFID module.

LED Based Traffic Signals: This project incorporates LED-based traffic signals, simulating real-life traffic signals which offer advantages over the classical forms of traffic sig- nals. The LEDs allow better visibility while providing massive power savings in the traffic signals simulation. Arduino Uno will control the traffic signals working with inputs coming from the IR sensors and the RFID module. The LED signals based upon the detected emergency vehicle will, as such, turn the non-emergency vehicle lanes to red enabling the emergency vehicle lane dynamic enumerate processes. All this general traffic logic is controlled by the Arduino Uno, which actuates command upon input from the IR sensors and RFID module.

Fig. 5: RFID module

Power Supply Unit: To power all the system components, there must be a stable and resilient supply. Such a supply will enable proper feeding of the voltage and current to the system including the Arduino Uno, IR sensors, RFID module, and LED traffic signals to keep it functional. This is of utmost importance in order to provide the necessary integrity to the system and ensure that constant testing should be operational throughout the total procedure experiment. A stable power supply unit ensures that the system remains operational and responsive in real-time.

A system inclusive of different traffic management scenarios was effectively tested to examine the performance. The types of tests simulated various real-life situations with varied traffic density along the lines of emergency vehicles involved:

Traffic Density Variations: The experiment evaluates the appropriateness of the system adjusting for different traffic density conditions at an intersection. The low-density traffic condition indicates a situation with minimal vehicles, and the system minimizes the green lights duration, which ulti- mately permits very rapid passage of vehicles with limited waiting times for the initial vehicle. The infrared sensors sense very few vehicles and the Arduino Uno decreases the amount of green light duration to eliminate non-existent traffic queue and allow traffic passage to resume without delay. The moderate-density traffic condition allows the Arduino Uno to dynamically extend the green light duration for traffic lanes with moderate densities of heavy traffic or multiple vehicles present. The traffic lights changes thus will be displayed in real time allowing the system to optimally relieve traffic lane congestion and still promote efficient passage with moderate- density traffic conditions. The high-density traffic condition allows queues of vehicles to form, and the system allows the traffic lights to maximize the green light for the lane with the highest congestion while adjusting for all other lanes to not remain at red lights for extended periods. Each of the above conditions results in the adaptive signal timing to allow for the ultimate finite limits of passage of existing intersection. During the continuation of traffic density conditions the signal timing are dynamically adjusted based on the data of the infrared sensors which limits wait time, enhance throughput. This direct signal timing adjustment largely aids in congestion relief, minutes and seconds will ensure the decisiveness of the delay, promotes traffic flow, and can optimize signal performance for intersections with high volume or minutes, so an overall goal of intersection optimization is achieved.

Emergency Vehicle Scenarios: The second series of pro- cedures introduced an emergency vehicle into the system at intervals of time. When emergency vehicles that have RFID tags get close to the intersection, the RFID module

Fig. 6: Density based traffic light control system in operation

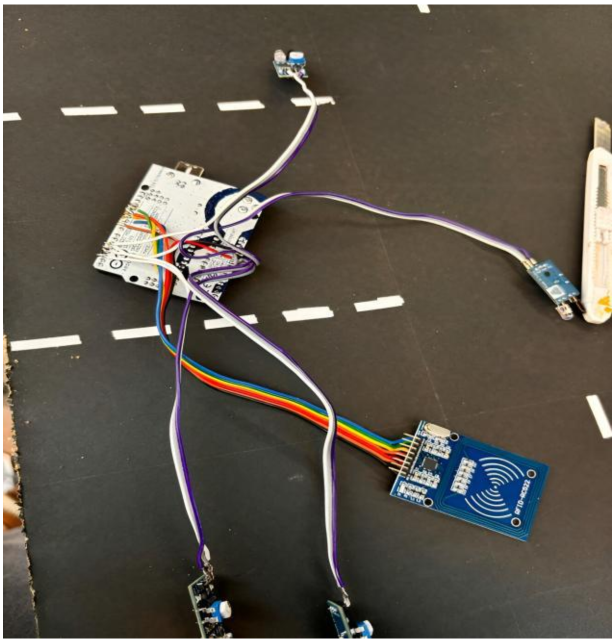

Fig. 7: Connections of arduino with IR sensors and RFID module

will detect the emergency vehicle. When the RFID module detects the emergency vehicle, it will send a signal to the Arduino Uno, which will receive the detection data and change the traffic light state to facilitate the emergency vehicle's movement through the intersection. When the system detects an emergency vehicle, it will change the traffic light to green for that lane of traffic and change other traffic lights to red. The objective is to provide the emergency vehicle as unobstructed

of a pathway through the intersection as possible. The system is designed to display traffic light patterns that respond to the arrival of emergency vehicles, and will do its best to provide priority to the emergency vehicle and allow the emergency vehicle to travel through the intersection without delay. Other vehicles will be stopped at the red traffic light to ensure the intersection is clear as soon as possible, while still minimizing the risk of delaying other traffic and enhancing emergent service response time.

Combination of Traffic and Emergency Vehicles: The last evaluation emulated a scenario of a heavily congested junction where traffic density converged with the presence of an emer- gency vehicle at the intersection. This evaluation was meant to ascertain how well the system was capable of handling not only an emergency vehicle's request for prioritization, as needed, while allowing normal traffic flow to maintain normal operations. Upon observing the emergency vehicle traveling through the intersection using the RFID module, the Arduino Uno modified or transitioned the traffic signal to prioritize the emergency vehicle's lane through a green signal. The system maintained the emergency vehicle's lane in a green signal while all other lanes were held in a red signal until the emergency vehicle exited the intersection. One major difference, however, in comparison to normal traffic signal systems that could delay vehicles "non-emergency" vehicles traveling through the intersection excessively, was the systems capacity to balance both requests for vehicles traveling through the intersection. It was designed to give a sufficient amount of green time, while at the same time, adjusting the other vehicles in the lanes cycles or signal timing, by putting them back into a green once the emergency vehicle was cleared. The system would minimize the delay for vehicles proceeding with the green signal while still allowing for normal optimal traffic flow. In other words, the emergency vehicle just simply moves through the intersection unimpeded while still allowing the remaining vehicles to continue progressing through the intersection (reducing congestion on the roads overall) as marked by their signals.

IV. CONCLUSION AND FUTURE SCOPE

The proposed density-based traffic control system using Arduino successfully adapts signal timings for real-time traffic conditions. The RFID-based emergency vehicle detection al- lows for a quick clearance for emergency services. This system is cost-effective, scalable, and efficient for urban traffic control, greatly enhancing congestion control and emergency response. Other Future Improvements:

- Machine Learning Algorithms - to predict the traffic and optimize the signal timings.
- Vehicle-to-Infrastructure (V2I) Communication - allow- ing real-time updates between vehicles and traffic signals.
- Solar-Powered Traffic Lights - increasing sustainability and lowering operational costs.
- Integration with Smart City Infrastructure-centralized traffic management through IoT networks. This research thus sets the foundation for intelligent traffic management systems that constitute contributions to smarter and effi- cient urban transportation networks.

V. REFERENCES

[1] M. Eom and B.-I. Kim, "The traffic signal control problem for intersec- tions: a review," *European transport research review*, vol. 12, pp. 1–20, 2020.

[2] S. S. S. M. Qadri, M. A. Go¨kc¸e, and E. O¨ ner, "State-of-art review of traffic signal control methods: challenges and opportunities," *European transport research review*, vol. 12, pp. 1–23, 2020.

[3] E. P. Sharma, A. Mishra, and K. Singh, "Density based intelligent traic control system using ir sensors," *Image*, vol. 4, no. 5, 2015.

[4] K. Munasinghe, T. Waththegedara, I. Wickramasinghe, H. Herath, and

VI. Logeeshan, "Smart traffic light control system based on traffic density and emergency vehicle detection," in *2022 Moratuwa Engineering Research Conference (MERCon)*, pp. 1–6, IEEE, 2022.

[5] S. Moyer, "Mr. trafficlight," *Motor News. Automobile Club of Michigan*, no. 27, pp. 14–15, 1947.

[6] J. Guerrero-Iba´n˜ez, S. Zeadally, and J. Contreras-Castillo, "Sensor technologies for intelligent transportation systems," *Sensors*, vol. 18, no. 4, p. 1212, 2018.

[7] H. Dong, X. Wang, C. Zhang, R. He, L. Jia, and Y. Qin, "Improved robust vehicle detection and identification based on single magnetic sensor," *Ieee Access*, vol. 6, pp. 5247–5255, 2018.

[8] A. P. Davol, *Modeling of traffic signal control and transit signal priority strategies in a microscopic simulation laboratory*. PhD thesis, Massachusetts institute of technology, 2001.

[9] N. Hashim, A. Jaafar, N. Ali, L. Salahuddin, N. Mohamad, and

M. Ibrahim, "Traffic light control system for emergency vehicles using radio frequency," *Traffic*, vol. 3, no. 7, pp. 43–52, 2013.

[10] B. Zhou, J. Cao, X. Zeng, and H. Wu, "Adaptive traffic light control in wireless sensor network-based intelligent transportation system," in *2010 IEEE 72nd Vehicular technology conference-fall*, pp. 1–5, IEEE, 2010.

[11] B. Ghazal, K. ElKhatib, K. Chahine, and M. Kherfan, "Smart traffic light control system," in *2016 third international conference on electrical, electronics, computer engineering and their applications (EECEA)*, pp. 140–145, IEEE, 2016.

[12] F. L. Hall, "Traffic stream characteristics," *Traffic Flow Theory. US Federal Highway Administration*, vol. 36, no. 6, p. 29, 1996.

[13] K. Nellore and G. P. Hancke, "A survey on urban traffic management system using wireless sensor networks," *Sensors*, vol. 16, no. 2, p. 157, 2016.

[14] D. Patel and Y. Rohilla, "Infrared sensor based self–adaptive traffic sig- nal system using arduino board,"

in *2020 12th International Conference on Computational Intelligence and Communication Networks (CICN)*, pp. 175–181, IEEE, 2020.

[15] V. Mahala, R. Saini, S. Sharma, R. Verma, and R. Jangid, "High step-up modified four phase interleaved boost converter with coupled inductor topology," in *2021 Third International Conference on Inventive Research in Computing Applications (ICIRCA)*, pp. 129–134, 2021.

[16] M. Dudi, M. Bhati, N. Sharma, N. Choudhary, V. Mahala, and J. Vijay, "Optimizing solar powered charging stations for electric vehicles: Inte- gration fast and slow charging with renewable energy sources," 2024.

[17] D. Patel and Y. Rohilla, "Infrared sensor based self–adaptive traffic sig- nal system using arduino board," in *2020 12th International Conference on Computational Intelligence and Communication Networks (CICN)*, pp. 175–181, IEEE, 2020.

[18] S. Sharma, A. Pithora, G. Gupta, M. Goel, and M. Sinha, "Traffic light priority control for emergency vehicle using rfid," *Int. J. Innov. Eng. Technol*, vol. 2, no. 2, pp. 363–366, 2013.