

American International University-Bangladesh (AIUB)

**Department of Computer Science**

**Faculty of Science & Technology (FST)**

**Research Methodology**

**Assignment**   
Submitted By

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| --- | --- | --- | --- | --- | --- |
| **Semester: Summer\_2023-2024 FINAL TERM** | | | | **Section: F** | **Group No: 10** |
| SL | SN | Student Name | Student ID | Individual  Contribution (100%) | Total Marks: 40 |
| Earned Marks: |
| **A** | 30 | MD TAFHIMUL HAQUE SADI | 22-47071-1 | Abstract, Introduction, Methodology, Result Validation, |  |
| **B** | 33 | MD RAKIBUL ISLAM | 22-47102-1 | Result validation, Reference, Introduction, Literature review |  |
| **C** | 5 | MAHBUB, MD. MOHIBBULLAH | 21-45134-2 | RQS result, Conclusion |  |
| **D** | 6 | MD. JISAN | |  |  | | --- | --- | |  | 21-45134-2 | | Quality testing, Reference |  |

Submission Date:

**The assignment will be Evaluated for the following Course Outcomes**

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| CO1: *Evaluate* all relevant resources for designing a computer science and engineering solution and determine the level of novelty of the research. | Total Marks (9) |
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| **Problem Analysis and use of State-of-the-Art** **Resources:** Discuss the research problem background with best use of state‐of‐art literature, resources, and technologies to produce a significant result that is likely to have a major impact. | [3 Marks] **A: B: C: D:** |
| **Critical Reflection and Creativity in Research Objective:** Deep insight demonstrated and presented a creative solution to the real‐life problem. And Results are critically confronted with various existing literature | [3 Marks] **A: B: C: D:** |
| **Novelty and Contribution of the Research:** Elaborately discuss and identify the contribution of the research to the development of scientific concepts by recognizing the research gaps of existing research and developments. | [3 Marks] **A: B: C: D:** |

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| CO2: *Analyze* the collected data to provide valid solution of the research problem acknowledging the limitations. | Total Marks (9) |
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| **Data Analysis:** Elaborately discuss the research method, its appropriateness and details on data collection, analysis, and synthesis for proposing valid solution to the research problem. | [3 Marks]  **A: B: C: D:** |
| **Solution and Validation:** Elaborately discuss the solution of the research problem by establish a direct connection between proposed solutions with the research objective based on the collected research data. | [3 Marks]  **A: B: C: D:** |
| **Limitation and Scope of Future Studies:** Elaborately discuss abstract and concluding remarks of the research with its limitations and scope of future studies. | [3 Marks]  **A: B:  C: D:** |

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| CO3: Determine and Demonstrate professional codes of ethics and standard in conducting research considering public safety; the impacts of engineering activity; economic, social, cultural, environmental and sustainability. | Total Marks (9) |
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| **Free of Plagiarism, Data Falsification Citations and References:** Submit plagiarism free research paper (similarity index is <10%). In-text citations and reference list citations were complete and properly formatted in APA or any other standard style. The Research data is not fabricated or altered intentionally to fit into the predetermined research findings. Materials are properly cited and referenced if they are taken from other sources. And not attributed to a source from which it has not been obtained *(i.e., false citation)* | [3 Marks]  **A: B: C: D:** |
| **Professional codes of ethics and standard:** The research elaborately demonstrates professional codes of ethics and standard in conducting research considering public safety; the impacts of engineering activity; economic, social, cultural, environmental and sustainability. | [3 Marks]  **A: B: C: D:** |
| **Formatting and Submission:** Submitted in due time, the report is complete and there are no errors in spelling, format, and grammar. Consistently  presents a logical and effective organization. | [3 Marks]  **A: B: C: D:** |

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| CO4: *Defend* the research solutions based on complex engineering activities by delivering an effective presentation to the audience. | Total Marks (9) |
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| **Presentation delivery (eye contact and body language):** Keeps eye contact with audience all the time, use natural gestures and movements, looks confident. | [3 Marks]  **A: B: C: D:** |
| **Enthusiasm/Audience Awareness:** Demonstrate strong enthusiasm about the topic, significantly increases audience understanding and knowledge of the topic, convinces an audience to recognize the validity and importance of the subject. | [3 Marks]  **A: B: C: D:** |
| **Creativity and Use of Media:** The presentation was creative in design and effectively use multimedia. | [3 Marks]  **A: B: C: D:** |

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| Viva/Defense | Total Marks (4) |
| Defend the research in performance in the question/answer session. | **A: B: C: D:** |

A Computer Vision and Microcontroller-Based System for Adaptive Traffic Signal Control, Number-Plate Detection, and Energy-Efficient Street Lighting

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**Abstract**

This paper investigates the adaptive traffic control system which came up with a dynamic solution and vehicle number plate detection using computer vision. Another feature is a dynamic street lighting system to improve energy efficiency. The paper uses the Systematic Literature Review method. The suggested method dynamically modifies traffic signal timings depending on real-time vehicle counts by analyzing live traffic data from street cameras using OpenCV, a computer vision tool. Additionally, by tracking and detecting illegal vehicles, a vehicle number plate identification feature improves road safety. The technology uses sensor-controlled lamps that only turn on when there is traffic to save electricity. OpenCV is an open-source computer vision module that is used for taking live traffic data from the street using cameras. The main purpose of this research is to reduce traffic jams and save people valuable time. This research would be very helpful for traffic management authorities, urban planners, and policymakers aiming to develop smart city infrastructures. It also benefits those Communities that care about improved road safety and sustainable energy.

**Keywords:** Computer Vision, YOLOV5, Microcontroller, Adaptive Traffic Control, Number Plate Detection, Energy-Efficient Street Light.

INTRODUCTION

Two major issues that cities around the world confront are urban traffic congestion and inefficient street lighting energy use, particularly in nations like Bangladesh which are fast becoming more urbanized. In cities like Dhaka, traffic congestion is a major problem due to growing vehicle ownership, an aging population, and antiquated traffic control systems. Similar to this, traditional street lighting systems waste a significant amount of energy because they don't consider the current traffic situation. It is essential to use smart technologies to address these problems to increase traffic safety, decrease delays, and support sustainable energy use.

The efficient management of urban traffic and street lighting stands as one of the pivotal challenges in the realm of urban planning and development (Bhuyan et al., 2010a). Traditional systems often fall short in addressing the dynamic demands of modern cities, leading to increased congestion, energy wastage, and compromised road safety. Urban traffic management in Dhaka, as well as across Bangladesh, faces critical challenges exacerbated by rapid urbanization, increasing vehicle populations, and infrastructural constraints. Traditional traffic control systems, which often lack integration with advanced technologies, are increasingly inadequate, resulting in severe congestion, high energy consumption, and compromised road safety (Bhuyan et al., 2010b). These issues underscore the urgent need for an innovative approach to traffic management and street lighting systems in the region. Moreover, the traditional street lighting systems across Bangladesh do not utilize smart technologies, which results in excessive and wasteful energy consumption (Bhuyan,2023). Besides, microcontroller-based systems can provide compact, automated, real-time controlling, and low-cost solutions in numerous applications (Ali and Bhuyan,2018; Bhuyan et al., 2011; Bhuyan and Sheikh, 2021; Paul et al., 2023; Bhuyan et al., 2023; Bhuyan et al., 2020; Bhuyan and Hasan, 2020). The advent of Intelligent Transportation Systems (ITS) offers transformative solutions by integrating advanced technologies, such as computer vision, microcontroller-based control systems, and wireless sensor networks (Riaz et al., 2021).

The motivation for this research is to find a practical solution for aiming to develop a smart city by reducing traffic congestion, energy waste in streetlights, and illegal vehicle movement. The study aims to answer the following research questions:

* How can computer vision technologies (using OpenCV) be employed to dynamically adjust traffic signal timings based on real-time traffic conditions?
* How can sensor-based street lighting systems reduce energy consumption in urban areas without compromising road safety?
* How can computer vision techniques, such as number plate detection, be effectively implemented to identify and reduce the movement of unregistered or illegal vehicles in urban traffic systems?

In response to these challenges, our research work proposes a computer vision and microcontroller-based solution that aims to revolutionize traffic signal control and street lighting. This research seeks to harness these technologies to significantly enhance traffic management, signal control, and street lighting systems, ultimately fostering safer, more sustainable urban environments. By introducing this system, we anticipate setting a precedent for the use of advanced technological solutions in urban management, contributing to the global discourse on sustainable city development and smart infrastructure. This initiative not only addresses the immediate challenges faced by Dhaka but also offers a model that may be scaled up to implement broader national and international applications, representing a significant advancement towards intelligent and sustainable urban ecosystems.

# LITERATURE REVIEW

Traffic flow and congestion management will greatly improve with real-time adaptive traffic control systems, essential to the infrastructure development of smart cities (Shankaran and Rajendran, 2021). Computer vision technologies improve traffic monitoring and safety by recognizing unregistered vehicles, detecting vehicle number plates, and storing the extracted data in databases (Bookseller and Jagtap, 2013). Furthermore, by only turning on the lights when needed, automatic streetlights that react to vehicle movement also help to optimize energy use. It has been demonstrated that these responsive lighting solutions greatly lower energy consumption (Garg et al., 2019).

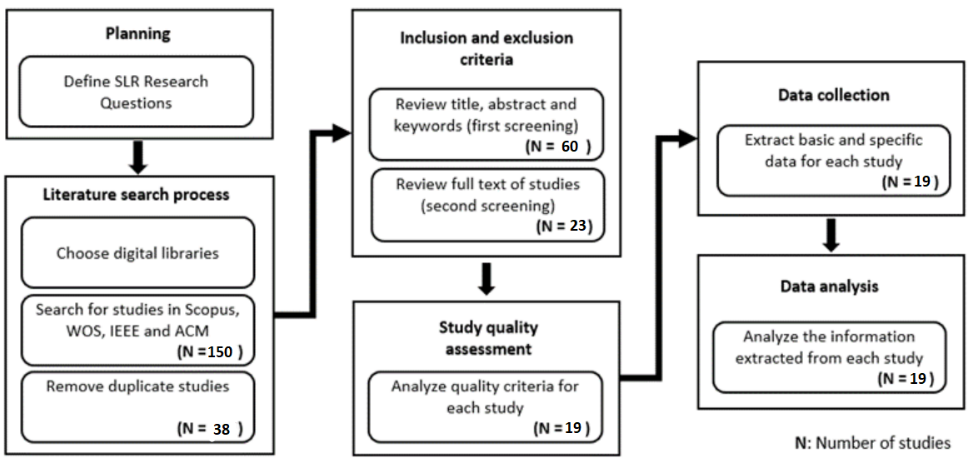
Conventional traffic control systems are ineffective at managing varying traffic volumes because they depend on predetermined timing at crossings, especially beyond peak hours (Bhuyan et al., 2010a; Bhuyan et al., 2010b). To reduce traffic in urban areas, more sophisticated technologies that can adjust to traffic density in real time are required (Shankaran and Rajendran, 2021). The creation of adaptive traffic signal systems, which may modify signal timings in response to current traffic conditions, is the result of advancements in control theory, artificial intelligence, and traffic technology (Zhuravleva et al., 2020). These systems are built on the foundation of Model-Based Control (MBC) theory, which enables precision control based on precise traffic models (Papageorgiou et al., 2003). According to Wang et al. (2018), self-adaptive traffic control systems are essential for controlling traffic flow, easing congestion, and possibly cutting emissions.

Smart street lighting is one example of how wireless sensor networks are being used more and more for energy reduction. Optimizing energy efficiency in lighting systems is crucial because of the growing need for dependable lighting throughout the day, particularly in metropolitan areas (Priya and Vijayan, 2017). If traditional streetlights are not adequately maintained, they can lead to significant energy waste because they are generally manually operated and connected to centralized power networks (Sunehra and Rajasri, 2017). Thus, minimizing electricity waste requires closely monitoring and managing streetlight energy consumption.

methodology

* **SLR Method**

To investigate the application of computer vision and microcontroller technologies for adaptive traffic control systems, vehicle number plate recognition, and energy-efficient street lighting, we utilized the Systematic Literature Review (SLR) technique in this study. The SLR approach was selected to offer a thorough, objective, and transparent assessment of previous research on these subjects, adhering to a clear process to guarantee repeatability. This method allows for the collection of data from a global perspective and helps to find the findings from various studies. Also helps to find limitations and gaps in the existing research.



Forward search: Using tools like Google Scholar's *"Cited by"* feature made it easier to find more recent publications that have cited the major articles in this research. This method enabled the identification of newer studies that support our research, ensuring we include the latest advancements in the field. A significant number of papers were collected for further analysis through a forward search.

Backward Search: A backward search involves reviewing the reference lists of the key articles initially selected. This helped in identifying earlier relevant studies on the topic. A substantial number of papers were gathered for further examination through a backward search.

Inclusion Criteria

* Research articles or case studies on adaptive traffic control systems
* Studies focusing on smart street lighting systems integrated with traffic management

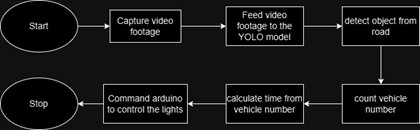
Exclusion Criteria

* Papers focusing only on traditional traffic systems
* Research related to number plate detection for purposes unrelated to traffic control

Many articles from various databases were initially identified. After applying the inclusion and exclusion criteria, performing forward and backward searches, and removing duplicates, the selection was narrowed down to *N* articles. These final articles concentrated on the impact of adaptive traffic control, smart street lighting, and number plate detection systems, as well as the technological strategies required for their successful implementation.

**Software Requirement**

An open-source computer vision library, OpenCV is used for programming functions mainly aimed at real-time computer vision. It is widely used for tasks, such as image and video processing, object detection, etc. A deep learning module called YOLOv5 is used for object detection. It is part of the You Only Look Once (YOLO) family of models, known for their real-time object detection capabilities. YOLOv5 is built on PyTorch and is commonly used for various computer vision tasks. The whole system works according to the flow chart in Fig. 1. When a vehicle crosses a specific area then the vehicle is counted and after that, the time is calculated. Then a command is sent to the Arduino to control the traffic signal.



**Figure 1.** Flow chart of traffic light control system.

results and analysis

## Research Result Analysis

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| RQ1: How can computer vision technologies (using OpenCV) be employed to dynamically adjust traffic signal timings based on real-time traffic conditions? | 1a,1b,11,12,15,16 | Those papers work on dynamic traffic signal timing based on real-time data. Using OpenCV collect the traffic condition of every road and set the traffic signal based on this traffic condition. |
| RQ2: How can sensor-based street lighting systems reduce energy consumption in urban areas without compromising road safety? | 10,13,17 | In this term, on highway roads, some sensors detect the vehicle if it is present in the sensor range. When any vehicle comes inside this range the light will turn on and after crossing the range the light will turn off. Thus, can save energy in urban areas. |
| RQ3: How can computer vision techniques, such as number plate detection, be effectively implemented to identify and reduce the movement of unregistered or illegal vehicles in urban traffic systems? | 19 | Using the haarcascade and easyOCR algorithm. The Haarcascade model is used here to detect the number plate with English digits by reading the captured video images recorded by the camera. After that, the texts are extracted from the image. |

## Solution Validation

As an example, we assume that a system named System1 uses the fixed time of 2 minutes for traffic lights for green on each road whereas another system named System2 has a dynamic time allocation method; each road1 has 30 vehicles and road2 has 6 vehicles; each vehicle takes 5 seconds to cross.

Now, we compute the number of vehicles that can pass through each of these systems.

For System 1, Road 1: Within two minutes duration, (2×60)/5 = 24 vehicles can pass when the green light is turned ON and the remaining 6 vehicles can’t pass out of 30 vehicles on that road.

So, each vehicle gets a time of 120/24=5 seconds.

For System1, Road2: Within two minutes duration, (2×60)/5 = 24 vehicles can pass when the green light is turned ON, but this road has 6 vehicles, as such all vehicles can pass through road2 within 5×6 =.30 seconds and the remaining 120 – 30 = 90 seconds are not utilized to pass through the signal on this road.

Here road1 and road2 both have 120 seconds to pass the vehicles when the green light is turned ON but road1 couldn’t allow 6 vehicles to pass and similarly, road2 has 90 minutes of idle time for the green signal. So, the total time is not being used efficiently in this method.

For System2, Road1: Road1 had 30 vehicles to vehicles to pass through, and as such road1 will take 30×5= 150 seconds. On the other hand, Road2 has only 6 vehicles to pass through, and as such road2 will take 6×5 = 30 seconds. So, in one cycle of signal rotation, this dynamic allocation method takes 150 + 30 = 180 seconds, i.e., a total of 180/60 = 3 minutes is used, whereas in the fixed preset-time method, it took 2 + 2 = 4 minutes.

Therefore, we can see that the dynamic time allocation system for the green light’s ON status is different when the number of vehicles on different roads varies. Thus, the system needs sensors to get information on the number of vehicles waiting to pass through the junction in a traffic signal. Times can be used efficiently in this method.

Table for the key performance indicators (KPIs) for both System 1 and System 2:

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| **TABLE 1.** The Key Performance Indicators (KPIs) for both System 1 and System 2 | | | | |
| **KPIs** | **System1** | | **System2** | |
| **Road1** | **Road2** | **Road1** | **Road2** |
| Total green signal time | 120 | 120 | 150 | 30 |
| Number of vehicles passed | 24 | 6 | 30 | 6 |
| Average waiting time per vehicles | 30 | 0 | 0 | 0 |
| Vehicles per unit time | 0.2 | 0.005 | 0.2 | 0.2 |

## Number-Plate Detection and Street Lightening

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| Number-Plate Detection | Street lighting system |
| The number plate of the vehicle is recognized using the haarcascade and easyOCR algorithm. The Haarcascade model is used here to detect the number plate with English digits by reading the captured video images recorded by the camera and then using the easyOCR, an open-source Optical Character Recognition (OCR) library, the texts are extracted from the image. However, if the number of features can be increased then the detection accuracy of this algorithm can be increased towards 100%. Fig2**-**flow chart of vehicle number plate detection  FIG 3. Number plate detection by the camera. | To simulate the system, the Proteus simulator is used (Bhuyan and Hasan,2020). One such simulation example is shown in Fig. 2 for the streetlight. It uses LDR and IR sensors as the sensors, LED bulbs as the streetlight, and Arduino Uno as the microcontroller. |

## Conclusion

In summary, a dynamic approach is provided by incorporating computer vision with microcontroller-based technologies into traffic management, street lighting, and number plate identification systems. Using technologies like *YOLOv5* for dynamic traffic control, *EasyOCR* and *Haarcascade* for precise number plate recognition, and the combination of IR and LDR sensors for energy-efficient street lighting, this research greatly increases traffic flow, boosts the effectiveness of law enforcement, eases traffic, and encourages energy conservation. The system has the potential to enhance urban living circumstances due to its real-time responsiveness and adaptive nature, even with certain restrictions. The integration of a computer vision and microcontroller-based system into Dhaka’s traffic management and street lighting infrastructure promises to revolutionize the urban landscape. By harnessing state-of-the-art technologies, this research initiative not only addresses the current inefficiencies but also sets a blueprint for future urban management solutions that can be replicated globally. This research initiative illustrates a commitment to environmental stewardship that goes beyond mere functionality. It emphasizes a sustainable development approach that benefits all city dwellers by reducing energy consumption, lowering costs, and contributing to a healthier urban environment. As such, it is a leap toward establishing smarter, greener, cheaper, and cleaner cities for city dwellers. By implementing and adopting this system, Dhaka city is poised to become a beacon of smart urban management, demonstrating that a city can transform its challenges into opportunities for growth and innovation.

**REFERENCES**

1)

* 1. Bhuyan, M. H., Kabir, M. A., Rahman, M. A., & Mamun, A. A. (2010, January 11-13). Development of an automatic traffic signal control system using PLC. In Proceedings of the Conference on Engineering Research, Innovation and Education (CERIE) (pp. 360-364). Shahjalal University of Science and Technology, Sylhet, Bangladesh.M. H. Bhuyan, M. A. Rabby, and M. M. G. Tarik, “Microcontroller based Automatic Traffic Light Control System Design,” Proceedings of the National Conference on Electronics and Telecommunications for Digital Bangladesh organized by the Bangladesh Electronics Society, Dhaka, 2-3 June 2010, pp. 139-142.
  2. Bhuyan, M. H., Rabby, M. A., & Tarik, M. M. G. (2010, June 2-3). Microcontroller based automatic traffic light control system design. In Proceedings of the National Conference on Electronics and Telecommunications for Digital Bangladesh (pp. 139-142). Bangladesh Electronics Society, Dhaka.

1. Bhuyan, M. H. (2023, January 26-28). Design and implementation of smart cities for sustainable development [Invited talk]. In Proceedings of the International Conference on Electronics and Informatics (p. 33). Bangladesh Electronics and Informatics Society, Bangladesh Atomic Energy Center, Dhaka, Bangladesh.
2. Ali, M. S., & Bhuyan, M. H. (2018, December 20-22). Design and implementation of a low-cost blood pressure measuring device. In Proceedings of the International Conference on Electrical and Computer Engineering (pp. 309-312). Bangladesh University of Engineering and Technology, Dhaka.
3. Bhuyan, M. H., Haque, M. M., Rauf, M. A., & Khan, M. M. I. (2011, January 11-13). Design and implementation of a microcontroller based elevator control systems. Proceedings of the Conference on Engineering Research, Innovation and Education, Sylhet, Bangladesh, 504–507.
4. Bhuyan, M. H., & Sheikh, M. (2021). Designing, implementing, and testing of a microcontroller and IoT-based pulse oximeter device. IOSR Journal of Electrical and Electronics Engineering (IOSR-JEEE), 16(5, Series-2), 38–48, ISSN: e-2278-1676, p-2320-3331.
5. Paul, N. K., Saha, D., Biswas, K., Akter, S., Islam, R. T., & Bhuyan, M. H. (2023). Smart trash collection system – An IoT and microcontroller-based scheme. Journal of Engineering Research and Reports(JERR), 24(11), 1–13, ISSN: 2582-2926.
6. Bhuyan, M. H., Ali, M. A., Khan, S. A., Islam, M. R., Islam, T., & Akter, J. (2023). Design and implementation of solar power and an IoT-based pisciculture management system. Journal of Engineering Research and Reports, 24(2), 15–27, ISSN: 2582-2926.
7. Bhuyan, M. H., Hasan, M. T., & Iskander, H. (2020). Low-cost microcontroller-based ECG machine. International Journal of Biomedical and Biological Engineering, 14(7), 192–199, e-ISSN: 1307-6892.
8. Bhuyan, M. H., & Hasan, M. (2020). Design and simulation of heartbeat measurement system using Arduino microcontroller in Proteus. International Journal of Biomedical and Biological Engineering, 14(10), 350–357, e-ISSN: 1307-689.
9. Riaz, M. T., Riaz, S., Husnain, S., Ali, H., Amin, S., Ahmad, S., & Muhammad, A. S. (2021, October 26-27). The intelligent transportation systems with advanced technology of sensor and network. In 2021 IEEE International Conference on Computing, Electronic and Electrical Engineering (ICE Cube) (pp. 1-6). IEEE. <https://doi.org/10.1109/ICECube53880.2021.9628331>.
10. R, S. S., & Rajendran, L. (2021, January 1). Real-Time Adaptive Traffic Control System For Smart Cities. IEEE Xplore. <https://doi.org/10.1109/ICCCI50826.2021.9402597>
11. Bookseller, A., & Jagtap, R. (n.d.). Image processing based Adaptive Traffic Control System (pp. 33–37). SICETE. Retrieved September 18, 2024, from <https://www.iosrjournals.org/iosr-jece/papers/sicete-volume6/71.pdf>
12. Garg, S., Ahuja, S., & Randhawa, S. (2019). Real time adaptive street lighting system. In A. Saha, N. Kar, & S. Deb (Eds.), *Advances in computational intelligence, security, and Internet of Things* (Vol. 1192). Springer, Singapore. [https://doi.org/10.1007/978-981-15-3666-3\_19](https://doi.org/10.1007/978-981-15-3666-3_19%20%20%20%20%20%20%20%20%20%20%20%20)
13. Zhao, Z. (2021). Analysis on the “Douyin (Tiktok) Mania” Phenomenon Based on Recommendation Algorithms. E3S Web of Conferences, 235(03029), 1–10. <https://doi.org/10.1051/e3sconf/202123503029>
14. Papageorgiou, M., Kiakaki, C., Dinopoulou, V., Kotsialos, A., & Yibing Wang. (2003). Review of road traffic control strategies. Proceedings of the IEEE, 91(12), 2043–2067. <https://doi.org/10.1109/jproc.2003.819610>
15. Wang, Y., Yang, X., Liang, H., & Liu, Y. (2018). A Review of the Self-Adaptive Traffic Signal Control System Based on Future Traffic Environment. Journal of Advanced Transportation, 2018, 1–12. <https://doi.org/10.1155/2018/1096123>
16. Priya V, S., & Vijayan, M. (2017). Automatic street light control system using WSN based on vehicle movement and atmospheric condition. International Journal of Communication and Computer Technologies, 5(1), 6–11, ISSN: 2278-9723.
17. Sunehra, D., & Rajasri, S. (2017, September 21-22). Automatic street light control system using wireless sensor networks. In 2017 IEEE International Conference on Power, Control, Signals and Instrumentation Engineering (ICPCSI) (pp. 2915–2919). IEEE. <https://doi.org/10.1109/ICPCSI.2017.8392257>.