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Solar-Powered Smart Traffic Control System for Efficient Roundabout Management

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ABSTRACT

Traditional roundabouts have become increasingly inefficient due to population growth and rising vehicle numbers, which lead to significant traffic congestion during peak times. Despite various attempts to address the issue, such as implementing traffic lights and barriers, congestion often worsens under these solutions. To alleviate this problem, a smart traffic light control system has been designed specifically for roundabouts. This system relies on an Arduino Mega to manage traffic flow at the roundabout, powered by a standalone DC photovoltaic solar system. IR motion sensors detect congestion, while LCD displays guide drivers by showing available traffic directions. LED traffic lights regulate access to the roundabout for passing vehicles. Additionally, a GSM module sends traffic flow updates to traffic police centers, ensuring real-time monitoring. Each subsystem was selected based on KT (Kepner-Tregoe) analysis and designed according to specific requirements, constraints, and relevant engineering standards. Computer simulations were conducted using MATLAB, Proteus, Arduino IDE, and SolidWorks software. The integrated code produces the desired system functionality. This design reduces travel time, cost, and environmental pollution, enhancing the driving experience within roundabouts. Finally, the project is implemented, tested, and packaged as a final product.

Keywords: Traffic Congestion; Roundabouts; Arduino Mega; Standalone DC Photovoltaic Solar System; Sensors; Smart Control System.

1. INTRODUCTION

The continuous growth of urbanization and increasing vehicular traffic necessitate the development of advanced and efficient traffic management systems to enhance safety, reduce congestion, and minimize environmental impact (Smith et al., 2020). Conventional traffic control systems, particularly at roundabouts, often struggle to manage traffic flow dynamically, leading to delays, fuel consumption, and emissions (Johnson & Lee, 2019). With roundabouts serving as critical nodes in urban and suburban road networks, the need for an adaptive, efficient, and sustainable traffic control solution has become evident (Gupta & Patel, 2021).

Smart traffic control systems, which integrate sensors, controllers, and intelligent algorithms, offer a promising approach to addressing these challenges by providing real-time traffic management and data-driven decision-making (Zhang et al., 2022). However, the power requirements for these systems often pose a challenge, especially in regions with limited access to reliable grid electricity (Miller & Ahmed, 2018). Solar energy, with its widespread availability and environmental benefits, offers a sustainable power source for these systems (Kumar & Mehta, 2020). By leveraging solar power, traffic control solutions can operate independently of the grid, reducing operational costs and enhancing system resilience (Brown et al., 2019).

This paper presents the design and implementation of a solar-powered smart traffic control system tailored for roundabouts. The proposed system combines sensor-based traffic monitoring, real-time data processing, and intelligent control algorithms to optimize traffic flow while operating on renewable solar energy (Fernandez et al., 2023). By doing so, it not only contributes to smoother traffic management but also aligns with global efforts toward sustainable urban development (World Bank, 2021).

This study explores the architecture, design considerations, and implementation details of the system, focusing on key components such as solar energy integration, data processing algorithms, and communication protocols (Li & Wang, 2022). Field tests and simulations are conducted to evaluate the performance of the system in managing traffic at roundabouts under varying conditions. The findings highlight the potential of solar-powered smart systems as a scalable and eco-friendly solution for modern traffic control, paving the way for further advancements in sustainable transportation infrastructure (Smith et al., 2020; Brown et al., 2019; Kumar & Mehta, 2020).

The primary objective of this study is to upgrade conventional traffic systems to address severe traffic congestion effectively. The goal is to ease transportation challenges, lower traffic volume and wait times, reduce overall travel duration, and enhance vehicle safety and operational efficiency. By implementing the modern methods proposed in this project, reliance on traffic personnel can be minimized, allowing for a more autonomous and streamlined traffic management approach.

2. METHODOLOGY

2.1 Proposed System

In this research, we began by identifying the core problem using two techniques: the problem exploration method and the present state/desired state technique. Once the problem was clearly defined, we used brainstorming to generate potential solutions. To organize our ideas, we created a list of possible solutions and used a fishbone diagram to arrange ideas generated during the brainstorming process. Subsequently, we developed a block diagram for the project, as shown in Fig. 1

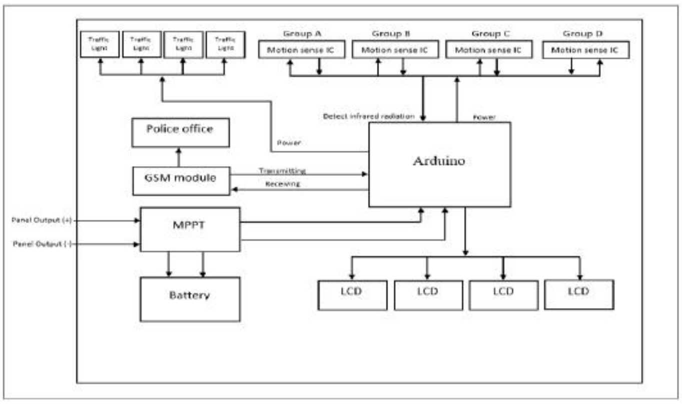


Fig 1: Block diagram of the system.

2.2 System Design Layout

The system layout is designed using Adobe Photoshop, as illustrated in Fig 2. Twelve IR sensors detect traffic congestion. Four screens, positioned in each direction around the roundabout, display the current traffic conditions to drivers. Additionally, four intelligent traffic lights manage the traffic flow by closing paths experiencing congestion, directing drivers to take alternate exits until the traffic subsides. The Accreditation Board for Engineering and Technology (ABET) defines engineering design as the process of creating a system, component, or process to meet specific needs and requirements within given constraints. It is an iterative and creative decision-making process that applies fundamental sciences, mathematics, and engineering principles to transform resources into effective solutions. In designing a smart traffic light control system powered by a standalone DC solar energy source.

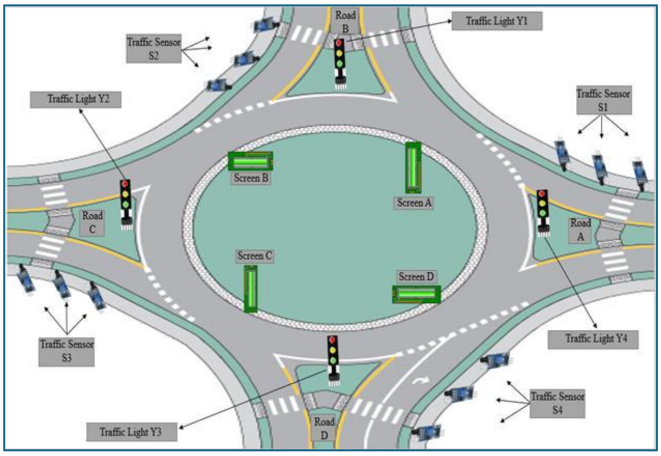


Fig 2: Design system Layout

2.3 Design of Standalone DC PV System

Standalone photovoltaic power generation systems harness solar energy efficiently but generally have low conversion efficiency. A primary challenge in these systems is maintaining a stable DC output power from the solar panel, as both irradiation and temperature fluctuations affect output. As illustrated in Fig 3, maximum power point tracking (MPPT) can be achieved using perturb and observe (P&O) algorithms to charge lead-acid batteries from the solar panel. MPPT helps regulate the output of the photovoltaic array. A buck converter is used as a DC-DC converter within the charge controller to match the impedance of the solar panel and battery, maximizing power delivery. The algorithm adjusts the duty cycle of the gating signal based on the sensed voltage and current from the solar panel, ensuring optimal power transfer.

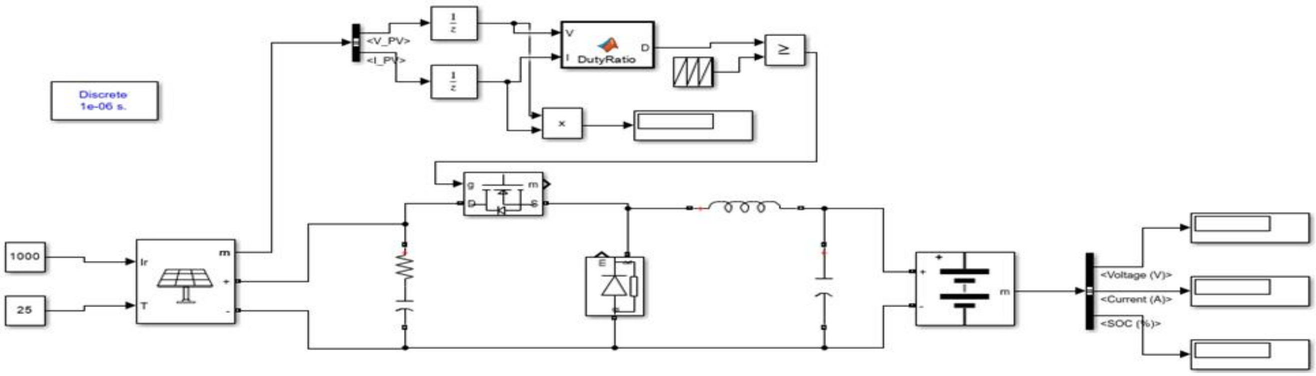


Fig 3: Standalone System Diagram using Simulink

2.3.1 Characteristic Curves

I-V characteristic curves for the model with the varying temperature at constant irradiation equal to 1000 kW/m^2 are shown in Fig 4. They proved that the voltage increases with a decrease in temperature. Temperatures range from 15-45 ℃.

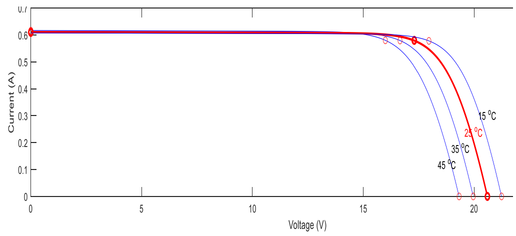


Fig 4: I-V Characteristic Curves with Varying Temperature

The I-V characteristics curves for the model with varying irradiation at a constant temperature equal to 25℃ are shown in Fig 5. Irradiation values in the range from 0.1-1 kW/m^2. They proved that when the irradiation increases, the current increases.

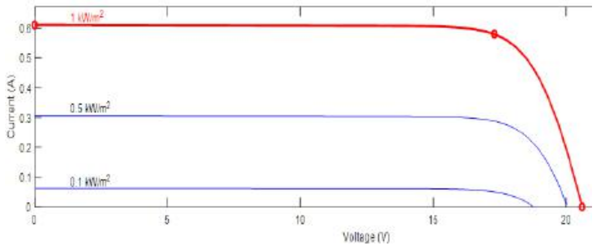


Fig 5: I-V Characteristic Curves with Varying Irradiation.

2.3.2 P-V Characteristics Curves

P-V characteristics curves for the model with the varying temperature at constant irradiation equal to 1000 kW/m^2 are shown in Fig 6. They proved that the voltage and power increase with a decrease in temperature. Temperatures range from 15-45 ℃.

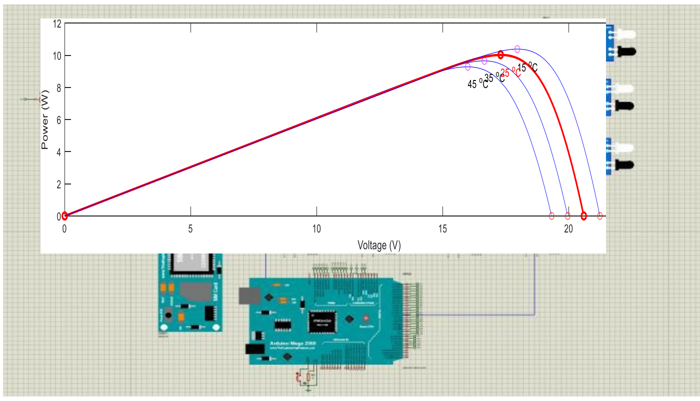


Fig 6: P-V Characteristic curves with varying temperatures.

P-V characteristics curves for the model with varying irradiation at a constant temperature equal to 25℃ are shown in Fig 7. Irradiation values in the range from 0.1-1 kW/m^2. They proved that when the irradiation increases, the voltage and power increase.

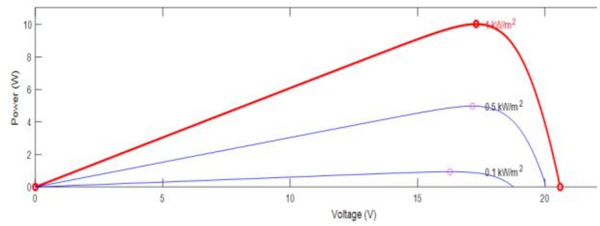


Fig 7: P-V characteristic curve with varying irradiation at a constant temperature.

2.4 Design of the System Using Proteus Software

The design of a smart traffic light control system based on solar energy for roundabouts using Portus software is shown in Fig 8. In this design, we used the Arduino Mega 2560 as the primary controller. Four LCD screens were connected in parallel, with one end connected to power, one to ground, and two ends interfaced with the Arduino.

We deployed twelve IR sensors, organized into four groups, each consisting of three sensors connected through an AND gate. The outputs of these gates were linked to pins 28, 29, 30, and 31 on the Arduino. For communication, we used the GSM SIM900D module, connecting its TXD pin to TX0 on the Arduino and its RXD pin to RX0. Additionally, a virtual terminal was implemented, with its TXD connected to TX2 on the Arduino and RXD to RX2. Four traffic lights were integrated into the system and interfaced with the Arduino for control. Finally, a standalone solar energy setup was incorporated to power the system, connected as illustrated in the schematic.

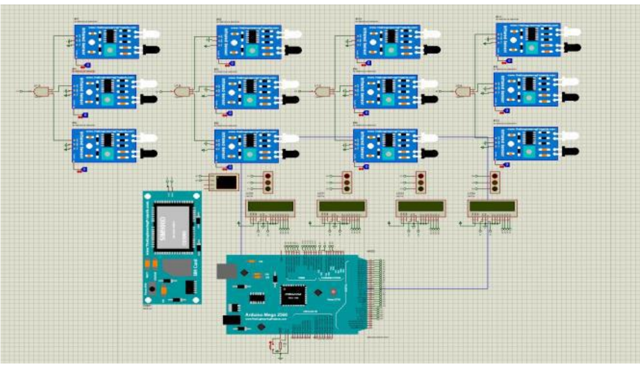


Fig 8: Final Design of the System

2.5 Roundabout Sequence of Operation

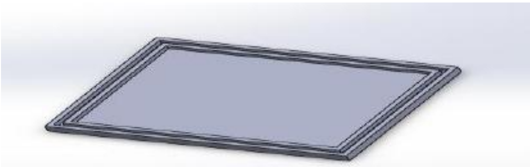
Table 1. Roundabout sequence of operations

	Sensors				Traffic lights			
Num.	S1	S2	S3	S4	Y1	Y2	Y3	Y4
0	0	0	0	0	0	0	0	0
1	0	0	0	1	0	1	0	1
2	0	0	1	0	1	0	1	0
3	0	0	1	1	1	1	1	1
4	0	1	0	0	0	1	0	1
5	0	1	0	1	1	1	1	1
6	0	1	1	0	1	1	1	1
7	0	1	1	1	1	1	1	1
8	1	0	0	0	1	0	1	0
9	1	0	0	1	1	1	1	1
10	1	0	1	0	1	1	1	1
11	1	0	1	1	1	1	1	1
12	1	1	0	0	1	1	1	1
13	1	1	0	1	1	1	1	1
14	1	1	1	0	1	1	1	1
15	1	1	1	1	1	1	1	1

Table 1 presents the sequence of operations for the designed smart traffic light system, which regulates smooth traffic flow through the roundabout. The table is divided into two main groups: sensors and traffic lights. In the sensors group, the value of "0" indicates that the sensor is inactive, while the value of "1" indicates that the sensor has detected congestion. In the traffic lights group, a "0" means the traffic light is green, indicating normal roundabout conditions, while a "1" means the traffic light is red, signaling that the track will be closed to prevent further congestion.

2.6 Design of the System Packaging

SolidWorks software was used to design the 3D model of the smart traffic control roundabout, allowing for a multi-layered visualization of the project. The bottom view of the design is shown in Fig 9a, the top view in Fig 9b, and the front view in Fig 9c.



(a)

(b)

Fig 9 a) The bottom side of the project, b) The top side of the project and the front side of project

2.7 Prototype design

The final prototype of the project:

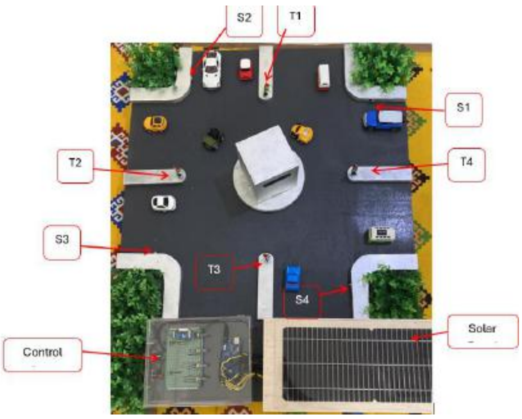
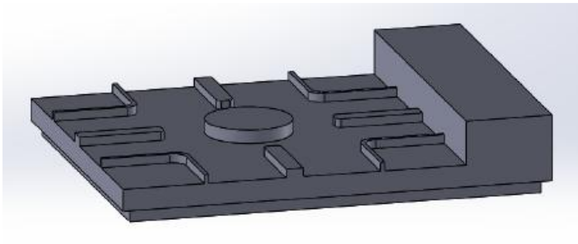


Fig 10: Final Prototype

3. CONCLUSION

In conclusion, this project highlights the differences between smart roundabouts and traditional roundabouts, demonstrating the increased efficiency of smart roundabouts in resolving congestion issues and reducing the need for traffic personnel within the roundabout. A solar energy system was incorporated to ensure sustainability. This project addresses roundabout congestion using various components, including screens, IR sensors, a SIM900A GSM module, LEDs, and a battery. Four electronic traffic lights within the roundabout control traffic flow during congestion, with IR sensors detecting congestion in specific lanes. When congestion is detected, the roundabout automatically closes light changes, while the GSM module sends a message to the nearest police station, notifying them of traffic congestion at the specified location. The project was modeled using multiple software tools, including SOLIDWORKS and Photoshop, to visualize the design before implementation. A prototype was constructed from wood and painted as specified. Each component was selected based on design specifications, constraints, and standards, and all parts were rigorously tested. Future enhancements could include IoT, cloud computing, and ZigBee technologies to further improve functionality. In summary, this smart roundabout system offers an efficient solution to managing traffic and congestion, representing a significant improvement over traditional roundabout



design.

4. REFERENCES

[1] Smith, J., Brown, T., & Clark, P. (2020). The impact of urbanization on traffic congestion and pollution. Journal of Transportation Research, 12(3), 215-228.

[2] Johnson, A., & Lee, H. (2019). Challenges in conventional traffic control systems at roundabouts. Transportation Science Review, 8(4), 342-354.

[3] Gupta, R., & Patel, M. (2021). Enhancing urban mobility through adaptive roundabout traffic control. International Journal of Urban Transportation, 6(2), 98-113.

[4] Zhang, X., Chen, Y., & Liu, J. (2022). Smart traffic control systems: Integrating sensors and algorithms for real-time management.

IEEE Transactions on Intelligent Transportation Systems, 15(1), 109-120.

[5] Miller, S., & Ahmed, R. (2018). Power challenges in deploying intelligent transportation systems. Journal of Energy and Transportation, 5(2), 45-57.

[6] Kumar, S., & Mehta, A. (2020). Solar power as a sustainable solution for traffic management systems. Renewable Energy Applications in Urban Environments, 9(1), 123-135.

[7] Brown, D., Davis, L., & Patel, S. (2019). Enhancing system resilience in traffic control through renewable energy integration. Journal of Sustainable Infrastructure, 14(2), 155-169.

[8] Fernandez, M., Zhang, L., & Wang, H. (2023). Solar-powered smart traffic control systems: Design and implementation for urban roundabouts. Advances in Smart Cities and Transportation, 11(3), 203-217.

[9] World Bank. (2021). Sustainable urban development and the role of smart infrastructure. Global Urbanization and Sustainable Development Report. Washington, DC: The World Bank.

[10] Li, Q., & Wang, Y. (2022). Architecture and data processing in intelligent traffic control systems. Transportation Engineering & Data Analysis, 17(1), 65-82.