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Long-range radio and Internet of things-inspired smart road reflectors for smart highways

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ABSTRACT

The Internet of things (IoT) has been proven as an efficient technology for real-time monitoring of physical things through the Internet from any location. With the advancement in sensors and communication technologies, the implementation of IoT is adopted in wide extensions. Road reflectors on highway roads need to be automated and also powered with intelligence. With this motivation, we have proposed and implemented IoT and long range (LoRa) based architecture for the realization of smart road reflectors on the highway. To realize the proposed architecture, the hardware of the smart reflector and gateway is implemented on the university campus. During our implementation of the hardware, we observed the light intensity values that are sensed by smart reflectors on the server through LoRa and internet connectivity. In the future, we will be integrating additional sensors and also power the smart reflector with artificial intelligence to predict the fog status of a particular road.

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1. INTRODUCTION

Highways and roads are critical components of national infrastructure that promote seamless access for humans and goods. However, safety remains a significant concern, with several accidents occurring as a result of poor visibility, particularly at night or during inclement weather [1], [2]. Traditional road reflectors, while useful, have limitations in their effectiveness under such conditions. The United Nations 2030 agenda for the transport system will be completed with digital technologies like the Internet of things and artificial intelligence [3].

The implementation of digital technologies on highways empowers to provide smarter, intelligent, reliable, and renewable energy sources experience to the users traveling along the highways [4]. On the highways road reflectors (road studs) are deployed on the road to ensure traffic and safe driving by providing pavement markers. Road studs have been regularly utilized in various nations for more than 75 years to delineate road lanes at night and in low visibility [5]. The advancement in lighting technology like light emitting diode (LED) technology has empowered road studs with the capability of emitting light during night-time. Self-illuminating active road studs were recently introduced and produced for commercial usage, thanks to the advancement of light-emitting diode (LED) technology [6].

Current methods to boost roadway safety and management usually involve complicated structures of cameras, sensors, and communication technology [7]. These technologies can monitor traffic circumstances, weather-related visibility concerns, and other essential factors driving highway safety. The existing systems primarily rely on short-range communication technologies, which confine their operational range and may be impeded by the highway's topography.

The advancement in sensors and wireless communication technology encouraged the adoption of IoT for different applications in automation and real-time monitoring [8]. IoT-based vehicle accident detection and rescue information system detects car accidents and sends location information to the vehicle owner, nearest hospital, and police station via a web service [9]. Intelligent reflecting surface (IRS) is implemented on the road, in which the two big-size road reflectors can be utilized as a communication medium with Low Earth Orbit (LEO) satellite [10]. A Smart Road Stud (SRS) is implemented for vehicle speed detection technique with two identical three-axis geomagnetic sensors, wireless communication, self-powering module, and controlled light-based traffic direction [11], [12]. The research question of this study is: How can the amalgamation of IoT technologies and smart reflectors improve highway monitoring and management?

Based on this research question, the authors have reviewed the following literature. IoT has empowered us to implement a safe and smooth road experience on the highway with unique features such as vehicle position, speed, and lane tracking. Raspberry Pi 3 B+ based prototype is integrated with a camera module and mounted on smart road reflectors, to evaluate road conditions with appropriate location data [13]. IoT-based Digital Notice Board with a smart reflector is implemented in this study to visualize the road information and the notice board is embedded with an ATmega328 Microcontroller, global system for mobile communication (GSM) module, liquid crystal display (LCD), and buzzer to communicate any information to people in public places [14]. Radio frequency identification (RFID) tags embedded in smart road reflectors with sensors are used to collect data on crucial aspects of their life and the obtained data can be employed in road performance measurement systems [15]. Vehicular Ad Hoc Network (VANET) is embedded in the smart road reflectors to establish VANET infrastructure on roads to obtain real-time highway data with IoT [16]. Light detection and ranging (LiDAR) sensors are a critical component of autonomous smart road reflectors for the next generation as an aid function and also to compare and analysis on sensor quality, factory metrics are used [17], [18].

An intelligent system is implemented to overcome animal-vehicle crashes during the nighttime by integrating the Histogram of Oriented Gradients (HOG) method and a Convolutional Neural Network (CNN) [19]. An intelligent road marking system with a wireless network positioned in smart road reflectors is being developed, so that the light can be emitted when the oncoming vehicle is detected and also broadcast the information on the wireless network [20]. A dynamic traffic control system is implemented to automate the current traffic control system and also employs infrared sensors to detect traffic intensity, after which a microprocessor controls traffic light switching, and the message is displayed on smart road reflectors through GSM/global packet for radio service (GPRS) modules [21], [22].

An intelligent traffic control system based on big data and internet of things will be part of smart traffic solutions for smart cities, where sensor systems, monitoring systems, and display systems are all eco-systems in and of themselves [23]–[25]. The usage of a variety of techniques and algorithms is required for the deployment of an IoT intelligent transportation system (ITS) for smart road reflectors [26], [27]. A novel modular traffic modeling environment is created to investigate road networks while incorporating advancements in IoT technologies like low-power, embedded devices integrating as part of a next-generation traffic management system (TMS) to mimic real-world traffic conditions [28]. From the above literature review, it is identified that IoT is implemented in different application areas for intelligent and real-time monitoring, however, in the smart reflector system, there is a drawback in the connectivity for long-range data transmission.

Motivated by the facts above, this study focuses on implementing a smart road reflector with sensory technology and a LoRa network to establish real-time and IoT-based automation on the road. The main contributions of this study are as follows.

- IoT and LoRa-based architecture for the realization of smart road reflectors on highways is proposed.
- To realize the proposed architecture, the hardware of the smart reflector and gateway is implemented on the university campus.
- In this study, light intensity values of smart reflectors are visualized on the server through the Internet.

The organization of this study is as follows: Section 2 covers the proposed system; section 3 covers the results and discussion, and the article concludes in the final section.

2. METHOD AND PROPOSED ARCHITECTURE

In this study, a smart reflectors-based system with long-range communication and IoT is proposed to enhance the currently available reflectors. The proposed system requires hardware and software for real-time implementation. First, the proposed architecture is discussed in detail to understand the function of the system and later on, the hardware prototype which is based on LoRa is firmware for implementation.

Generally, reflectors are used on highways to clarify the curves and turnings to the drivers and provide road safety through their reflected colors. They provide directional cues to the drivers at night about which side of the road is left or right. In this paper, the Internet of things and LoRa radio-based smart road reflectors for smart cities are proposed to reduce energy consumption due to traffic signal lights. The proposed architecture for a smart reflector on a road or highway is shown in Figure 1. When the traffic signal lights are incident on reflectors, the reflectors will glow, and the turnings and curves will be clear to the drivers during the night. This will also save consumption of energy because reflectors will shine only when the light is incident. In the proposed system, smart reflector arrays (1, 2, …, M) on a road or highway have been used by us. The reflectors are connected to the cloud server through the Wi-Fi-enabled LoRa gateway. The entire information that is sent by smart reflectors to the cloud server through a gateway can be sent to the authorities via a Web App for the data forecast and interpretation.

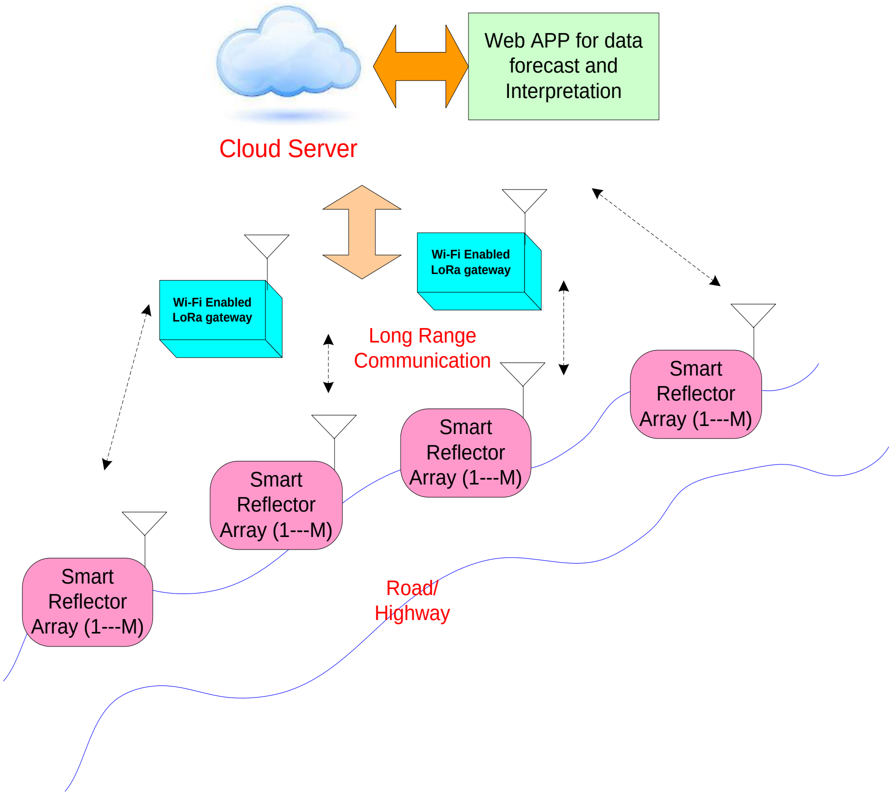

Figure 1. Proposed architecture for smart reflector

Figure 2 shows the block diagram of a smart reflector, which consists of several reflectors (1, 2, …, M), a sensing unit, a control unit, an energy source consisting of a group of piezo sensors, and a LoRa gateway. The energy is supplied through a group of piezo sensors, and a power supply is given to all reflectors, sensing units, control units, and LoRa gateway. There is a sensing unit in the smart reflectors that senses the light signal and sends a command to the control unit so that the reflector glows otherwise, the reflector remains off. The control unit is also connected to the LoRa gateway through which the data is sent to the cloud server. LoRa-based gateway is integrated with multiple reflectors, and the gateway is additionally equipped with a Wi-Fi modem for transferring the sensor values to log on to the main server through internet protocol (IP). The purpose of integrating the Wi-Fi modem is that the RF packets received from the smart reflector detection system cannot be directly logged onto the cloud server. Complete data from various sensing nodes are available on the main server for real-time monitoring. Apart from the main server, the users can get the status of each node using a web application or a Mobile application, which is based on the main server. Finally, the complete architecture makes wireless infrastructure implementation possible. In addition, the detection system description is demonstrated in Figure 2.

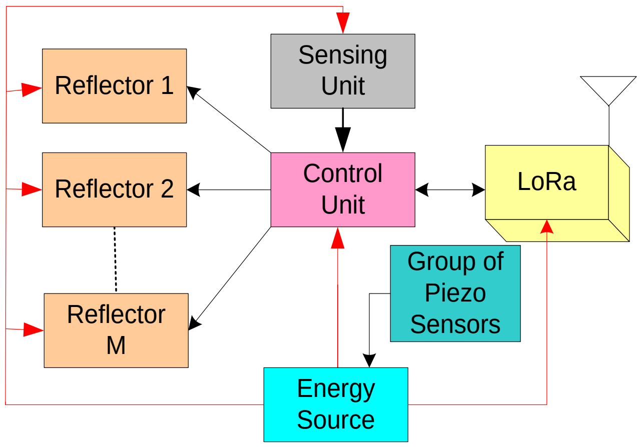

Figure 2. Block diagram of smart reflector

Figure 3 shows the Wi-Fi enabled LoRa gateway it has a controller, display, Wi-Fi Module, DC power supply unit and long range radio. The power adapter is provided for all the sections of the block diagram. The computing unit or controller is connected to the Wi-Fi module, display unit and LoRa transceiver. The LoRa receives the data from the smart reflector. The gateway is connected to the internet using the Wi-Fi module for pushing the data onto a cloud server and at the placement location of the gateway the internet signal has to be very stable for proper working of the system.

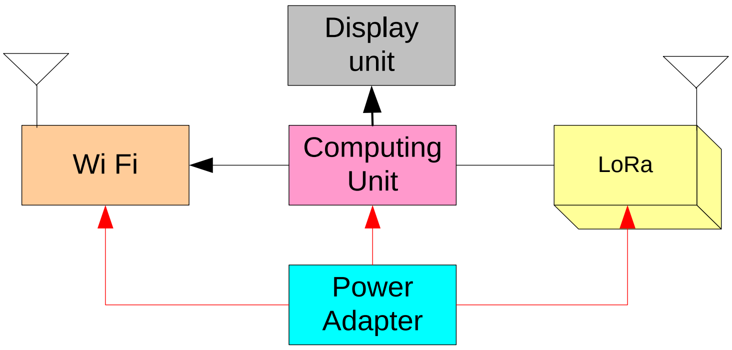

Figure 3. Wi-Fi enabled LoRa Gateway

3. RESULTS AND DISCUSSION

The hardware was designed for a smart reflector, which is based on an ATmega328P controller, a 433 MHz LoRa module, a light intensity sensor, and a group of piezo sensors. In the hardware of the smart reflector, we have embedded +5 V and +3.3 V voltage sources to support the operating voltage of the elements. In the hardware of the Wi-Fi-enabled LoRa gateway, ATmega328P microcontroller, ESP 8266 Wi-Fi module, and 433MHz LoRa module are also used. After the development of the hardware, the smart reflectors were deployed on the university campus to test and log the sensor values on a cloud server. Figure 4 shows the process of uploading the software in the smart reflector, and Wi-Fi-enabled LoRa gateway. The Wi-Fi-enabled LoRa gateway is connected to the local IP network through the 192.168.204.164 IP address. The Smart reflector is deployed on the gateway, and the road of the university campus is placed almost 1 km away from the smart reflector.

Figure 4. Firmware development

The light intensity sensor data (LUX) derived from the smart reflector's light intensity sensor is presented in Figure 5. In one instance, the recorded light intensity value is 6.0 LUX, and, in another instance, the recorded light intensity value is 1.0 LUX due to less intensity of light. The reflector status is ON/OFF as per the intensity of light. When the light intensity varies on the deployed reflectors, variation found in the LUX as per the intensity of light will be updated in the server. The LUX values visualized on the server can be monitored by the authorities.

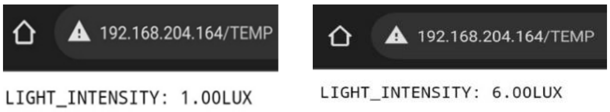

Figure 5. Light intensity values on local IP

Figure 6 illustrates the status of light intensity on the web server via internet connectivity. The dashboard of reflector status is visualized, where the on/off status is detailed and presented. Depending upon the status, the reflector status changes.

Figure 6. Light intensity and reflectors status on local IP

The study's objective is to create a smart reflector system that can adapt to fluctuations in the environment and transmit data to a central computer for monitoring. The notion that smart infrastructure can improve road safety and operational efficiency is supported by the adoption of LoRa technology for long-range communication and IoT integration for data logging and monitoring reasons. In contrast, other studies on IoT inclusion and smart infrastructure frequently emphasize the potential for enhanced security measures, energy efficiency, and real-time control and surveillance. Nonetheless, the particular emphasis of this study on light-responsive reflectors and their application for in-field testing gives a practical aspect to the theoretical benefits frequently addressed in literature. These data might be interpreted in several ways. To begin, effective execution proves the potential of amalgamating IoT technology with conventional safety equipment such as reflectors, thus enhancing their functionality. This could point to larger applications for smart infrastructure to enhance road safety, especially in low-light settings. Still, limitations include the dependency on certain hardware components that may affect scalability and cost-effectiveness, as well as the possibility of interference with signals in congested metropolitan environments, which might affect the accuracy of long-range communication.

4. CONCLUSION

Smart reflectors on the highway can provide the path and curves on the roads where the highway lightning system is absent. To overcome this challenge, we have proposed and implemented a LoRa-based smart reflector with a Wi-Fi-enabled LoRa gateway. To realize the system, we have implemented the hardware of a smart reflector and gateway on the university campus. During the implementation of hardware, we recorded the LUX values on the server through the internet and LoRa communication. The smart reflectors only turn on/off based on the light intensity in the outer environment rather than day and night.

The smart reflectors only turn on/off based on the light intensity in the outer environment rather than day and night. The study's major findings focus on the operational creation and setting up of a smart reflector system equipped with IoT capabilities. This system consists of an ATmega328P controller, a 433MHz LoRa module for long-range communication, a light intensity sensor for evaluating ambient lighting conditions, piezo sensors, and voltage converters to support component operation. In addition, an IoT-LoRa gateway with the same controller, LoRa module, and ESP 8266 Wi-Fi module for internet connectivity was built. The smart reflectors were tested on a university campus, demonstrating their ability to successfully log sensor information to a cloud server. In the future, we will integrate additional sensors in the smart reflector with artificial intelligence to predict fog weather on the roads.

REFERENCES

[1] "Reflective road markers improve visibility and driver safety," *Traffic Safety Direct*. https://trafficsafetydirect.com/reflective-road-markers-improve-visibility-and-driver-safety (accessed Mar. 15, 2024).
[2] P. J. Carlson, E. S. Park, and C. K. Andersen, "The benefits of pavement markings: a renewed perspective based on recent and

ongoing research," 2009. Accessed: Mar. 15, 2024. [Online]. Available: https://safety.fhwa.dot.gov/roadway_dept/night_visib/pavement_visib/no090488/

[3] R. Singh *et al.*, "Highway 4.0: Digitalization of highways for vulnerable road safety development with intelligent IoT sensors and machine learning," *Safety Science*, vol. 143, p. 105407, Nov. 2021, doi: 10.1016/j.ssci.2021.105407.

[4] A. Skar, A. Vestergaard, S. M. Pour, and M. Pettinari, "Internet-of-Things (IoT) platform for road energy efficiency monitoring," *Sensors*, vol. 23, no. 5, p. 2756, Mar. 2023, doi: 10.3390/s23052756.

[5] H. Wang, W. Quan, and W. Y. Ochieng, "Smart road stud based two-lane traffic surveillance," *Journal of Intelligent Transportation Systems*, vol. 24, no. 5, pp. 480–493, Sep. 2020, doi: 10.1080/15472450.2019.1610405.

[6] S. Bhadra, S. Khatua, and A. Kundu, "An automated reflector based traffic signal system," 2021, pp. 157–167. doi: 10.1007/978-981-15-7834-2_15.

[7] M. Gazzea *et al.*, "Traffic monitoring system design considering multi-hazard disaster risks," *Scientific Reports*, vol. 13, no. 1, p. 4883, Mar. 2023, doi: 10.1038/s41598-023-32086-6.

[8] Y. Cui and D. Lei, "Design of highway intelligent transportation system based on the Internet of Things and artificial intelligence," *IEEE Access*, vol. 11, pp. 46653–46664, 2023, doi: 10.1109/ACCESS.2023.3275559.

[9] S. Kandasamy, K. E., M. K., and M. M., "Antennas for narrow band IoT appliances and applications," 2022, pp. 222–236. doi: 10.4018/978-1-7998-9315-8.ch017.

[10] E. Hollnagel, *Barriers and accident prevention*. Routledge, 2016. doi: 10.4324/9781315261737.

[11] B. Matthiesen, E. Björnson, E. De Carvalho, and P. Popovski, "Intelligent reflecting surface operation under predictable receiver mobility: a continuous time propagation model," *IEEE Wireless Communications Letters*, vol. 10, no. 2, pp. 216–220, Feb. 2021, doi: 10.1109/LWC.2020.3024781.

[12] W. Quan, H. Wang, and Z. Gai, "Spot vehicle speed detection method based on short-pitch dual-node geomagnetic detector," *Measurement*, vol. 158, p. 107661, Jul. 2020, doi: 10.1016/j.measurement.2020.107661.

[13] J. Joshi *et al.*, "Data analytics based driver assistance system in vehicular ad-hoc networks," in *Proceedings of the 2017 International Conference on Machine Learning and Soft Computing*, Jan. 2017, pp. 203–208. doi: 10.1145/3036290.3036296.

[14] G. H. Palli, G. F. Mirza, A. A. Shah, B. S. Chowdhry, T. Hussain, and U. U. Rehman, "Defects detection & condition assessment of road infrastructure using deep learning algorithm," in *2021 International Conference on Robotics and Automation in Industry (ICRAI)*, Oct. 2021, pp. 1–8. doi: 10.1109/ICRAI54018.2021.9651336.

[15] S. Mariammal, A. S. Asmin, and K. Rajkumar, "Digital notice board," 2022, p. 020003. doi: 10.1063/5.0078342.

[16] K. Kõrbe, K. Kuhi, and O. Koppel, "Measuring temperature and water content in road structures with sensor equipped RFID tags," in *Proceedings of the 8th International Conference of DAAAM Baltic Industrial Engineering*, 2012, pp. 315–320.

[17] G. Khayat *et al.*, "Intelligent vehicular networking protocols," 2020, pp. 59–86. doi: 10.1007/978-3-030-44907-0_4.

[18] S. Islam *et al.*, "Autonomous driving vehicle system using LiDAR sensor," 2022, pp. 345–358. doi: 10.1007/978-981-16-7610-9_25.

[19] A. M. S. Maharjan and A. Elchouemi, "Smart parking utilizing IoT embedding fog computing based on smart parking architecture," in *2020 5th International Conference on Innovative Technologies in Intelligent Systems and Industrial Applications (CITISIA)*, Nov. 2020, pp. 1–9. doi: 10.1109/CITISIA50690.2020.9371848.

[20] Y. Munian, A. Martinez-Molina, D. Miserlis, H. Hernandez, and M. Alamaniotis, "Intelligent system utilizing HOG and CNN for thermal image-based detection of wild animals in nocturnal periods for vehicle safety," *Applied Artificial Intelligence*, vol. 36, no. 1, Dec. 2022, doi: 10.1080/08839514.2022.2031825.

[21] D. Samardzija, E. Kovac, D. Isailovic, B. Miladinovic, N. Teslic, and M. Katona, "Road Nail: Intelligent road marking system testbed," in *2010 IEEE Vehicular Networking Conference*, Dec. 2010, pp. 134–138. doi: 10.1109/VNC.2010.5698254.

[22] S. Parekh, N. Dhami, S. Patel, and J. Undavia, "Traffic signal automation through IoT by sensing and detecting traffic intensity through IR sensors," 2019, pp. 53–65. doi: 10.1007/978-981-13-1742-2_6.

[23] A. Soman and A. Antony, "Colored solar cells with spectrally selective photonic crystal reflectors for application in building integrated photovoltaics," *Solar Energy*, vol. 181, pp. 1–8, Mar. 2019, doi: 10.1016/j.solener.2019.01.058.

[24] M. Naderi Soorki, W. Saad, M. Bennis, and C. S. Hong, "Ultra-reliable indoor millimeter wave communications using multiple artificial intelligence-powered intelligent surfaces," *IEEE Transactions on Communications*, vol. 69, no. 11, pp. 7444–7457, Nov. 2021, doi: 10.1109/TCOMM.2021.3106686.

[25] A. Gehlot *et al.*, "Internet of Things and long-range-based smart lampposts for illuminating smart cities," *Sustainability*, vol. 13, no. 11, p. 6398, Jun. 2021, doi: 10.3390/su13116398.

[26] Q. Ren, K. L. Man, M. Li, B. Gao, and J. Ma, "Intelligent design and implementation of blockchain and Internet of things–based traffic system," *International Journal of Distributed Sensor Networks*, vol. 15, no. 8, p. 155014771987065, Aug. 2019, doi: 10.1177/1550147719870653.

[27] P. Masek *et al.*, "A harmonized perspective on transportation management in smart cities: the novel IoT-driven environment for road traffic modeling," *Sensors*, vol. 16, no. 11, p. 1872, Nov. 2016, doi: 10.3390/s16111872.

[28] S. Muthuramalingam, A. Bharathi, S. Rakesh kumar, N. Gayathri, R. Sathiyaraj, and B. Balamurugan, "IoT based intelligent transportation system (IoT-ITS) for global perspective: a case study," 2019, pp. 279–300. doi: 10.1007/978-3-030-04203-5_13.

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