An efficient solution to smart fee collection system using Light Fidelity

ANUSHKA[1], SHARAD SAXENA[1], RAJESH KUMAR[1], ARPIT SAGAR[1] and MANPREET SINGH[1]

[1]Department of Computer Science and Engineering,
Thapar Institute of Engineering and Technology, Patiala-147004, Punjab, India.
e-mail: aanushka_phd20@thapar.edu

Abstract: Light Fidelity (LiFi) based Smart Fee Collection System is an innovative approach to modernize traditional Fee collection processes at various locations like smart parking, mall parking, subway, fee plaza, etc. The system simply enhances the speed, accuracy, and overall efficiency of fee collection system by reducing waiting time, minimizes errors, reduce infrastructure cost and bolsters data security. The methodology includes the design and development of LiFi Transmitter in the vehicle LED DRLs, fog light or head light and LiFi Receiver at the fee collection gate, coupled with software for seamless communication and payment processing. This paper outlines the development and implementation of a prototype utilizing LiFi technology for data transmission to optimize fee collection processes. The research unequivocally illustrates the transformative effects of this LiFi based system, notably streamlining and improving user experience. Rigorous testing and optimization have been undertaken to assess system performance across diverse conditions, ensuring reliability and robustness.

Keywords. LiFi, VLC, Data Transmission, Fee Collection, Vehicle Communication.

1. Introduction

In the realm of modern communication technologies, LiFi emerges as a pioneering solution, capitalizing on light waves to transmit data wirelessly within the visible light spectrum. LiFi is a 5G technology with peak transmission speeds of 8 Gbps, and can significantly impact various industries and open new applications in the future. Its introduction signifies a paradigm shift compared to conventional RF technologies and can achieve up to 14 Gbps in data rate, surpassing WiFi's current rate of up to 5 Mbps [1]. LiFi's emergence holds paramount importance as an alternative to traditional RF communication methods, offering a compelling solution to spectrum congestion and associated with cable communication, evolving over the years to offer proven security and efficiency with high data rates. This method effectively maintains safe distances between vehicles, reducing accidents, by utilizing light fidelity (Li-Fi) technology [3]. Although further investigation into its sustainability for inter-vehicle communication is required, the small-scale mock-up demonstrates productive results in maintaining safe distances and preventing accidents. Li-Fi communication between vehicles involves data transmission through bulbs and reception via photo detectors, simplifying the process without the need for protocols, thereby reducing complexity. Additionally, LiFi technology has the potential to significantly enhance Wi-Fi network performance by efficiently offloading traffic.

LiFi integration transcends conventional boundaries, driving innovation in smart technologies across diverse sectors. Within automotive applications, LiFi showcases immense promise in empowering vehicle-to-vehicle (V2V) communication systems, ushering in a new era of intelligent transportation infrastructure shows promising results in reducing accidents and eliminating the need for complex wireless networks and protocols, by enabling instantaneous data exchange between vehicles, LiFi facilitates enhanced road safety and operational efficiency electromagnetic interference concerns by tapping into the vast and unutilized bandwidth of visible light. LiFi not only addresses these challenges but also enhances security, and reliable communication channels, marking a significant advancement in wireless communication technology and offers high data rates that can significantly improve Wi-Fi network performance by offloading traffic to LiFi [2].

LiFi technology, also known as Visible Light Communication (VLC), provides a secure, efficient, and high-rate data transmission solution for vehicle-to-vehicle communication, showing promise in regulating motor speeds. It eliminates the complexity

[4]. Its high bandwidth and minimal latency capabilities are pivotal in supporting swift and dependable data transmission, thereby fostering the deployment of advanced functionalities like collision avoidance and cooperative driving. LiFi communication systems in traffic lights can provide low-cost, high-data-rate, and efficient-bandwidth vehicular communications for safe driving conditions and entertainment applications [5]. This transformative potential approach underscores the ongoing research and development endeavors focused on harnessing LiFi technology to optimize vehicular communication systems.

One notable area where LiFi stands to revolutionize the automotive landscape is in smart fee collection systems. By leveraging LiFi technology, vehicles can seamlessly communicate with toll booths or infrastructure, streamlining fee collection processes with unprecedented speed and efficiency. Moreover, LiFi-enabled fee collection systems offer inherent advantages, including faster transaction speeds, enhanced reliability, and heightened security, thereby enhancing the overall fee collection experience for both commuters and transportation authorities.

Existing fee collection systems, reliant on technologies such as RFID and barcode scanning, grapple with inherent limitations pertaining to accuracy, speed, and security. These constraints have been impeding the efficiency and effectiveness of fee collection processes, necessitating innovative solutions that align with the dynamics of our digital age. The GPS-based fee systems rely on satellite navigation to track vehicle locations and calculate fee charges. Nevertheless, this system presents its drawbacks like GPS accuracy can be affected by signal blockages, leading to inaccuracies in fee calculation, especially in urban environments and tunnels. GPS signals can be susceptible to jamming and spoofing attacks, compromising system reliability. GPS signals can experience multipath reflections and signal blockages in urban settings, leading to reduced accuracy.

In contrast, the proposed system leverages Li-Fi technology. All vehicles are registered by manufacturers with government authorities, possessing vehicle registration plates and certificates. Microcontrollers within vehicles store these details, which are transferred via Li-Fi to fee plazas. As vehicles approach a fee gate, IR sensors detect them, and Li-Fi transceivers communicate as the gates close. This system utilizes Daytime Running Lights (DRL), with the receiver section accepting signals from the DRL. The adoption of Li-Fi technology in the proposed system aims to overcome the limitations of the existing RFID-based fee payment method, facilitating seamless data transfer of vehicle details for faster and more efficient fee payment processing. Additionally, it eliminates the need for separate lanes for RFID-tagged vehicles, enhancing traffic flow and user convenience. The GPS based fee collection system can be linked with Li-Fi technologies. This integration aims to mitigate inaccuracies caused by GPS signal blockages, especially in urban environments and tunnels. Furthermore, the use of Li-Fi for data transfer at fee plazas enhances reliability by reducing susceptibility to GPS signal jamming and spoofing attacks. This integrated approach holds the potential to provide more accurate and robust fee calculation, ensuring consistent communication between vehicles and fee infrastructure, and, consequently, improving the overall efficiency and effectiveness of the fee collection process.

The scope of the research revolves around harnessing the transformative capabilities of Li-Fi technology to address these longstanding challenges. The novelty of the work is to develop a Li-Fi-based fee collection system capable of revolutionizing the traditional fee collection process, offering tangible advantages to both transportation infrastructure and the travelling public. In the proposed fee collection system, vehicles equipped with Li-Fi-enabled devices traverse under Li-Fi-enabled fee booths, initiating a seamless exchange of fee information through light beams. In pursuit of the objective the work is presented in different sections as follows. Section 2 presents an in-depth literature review to provide the context and background for our study. Following that, Section 3, gives the proposed methodology. Section 4 delves into the experimental results and discussions. Finally, Section 5, conclude the paper, summarizes contributions and offering insights into potential directions for future research.

2. Literature Survey

LiFi is a 5G technology with peak transmission speeds of 8 Gbps, and can significantly impact various industries and open new applications in the future [6]. LiFi functions akin to WiFi, yet employs light as the medium for signal transmission. By integrating the swift data transfer capabilities of LiFi with the widespread coverage of WiFi, Hybrid LiFi and WiFi Networks (HLWNets) enhance the indoor wireless communication system capacity. LiFi can seamlessly complement WiFi or be integrated into hybrid connections to enhance network performance and coverage, offering a versatile solution for diverse communication needs. WiFi and LiFi integration in wireless HetNets can provide superior service quality in indoor settings; however, ongoing and prospective research hurdles necessitate further investigation [7]. One prospective strategy for indoor wireless communication involves harmonizing LiFi and WiFi, forming hybrid LiFi and WiFi networks (HLWNets). This fusion exploits LiFi's rapid data transfer capabilities alongside WiFi's widespread coverage. By combining the strengths of both technologies, HLWNets deliver high-speed data transmission and pervasive connectivity, promising a robust solution for indoor wireless communication challenges [8]. In indoor settings, a hybrid LiFi/WiFi network (HLWN) combines LiFi's high-speed, low-latency connectivity with WiFi to address future wireless communication needs. This paper investigates dynamic Load Balancing (LB) with handover in HLWNs using the orientation-based random waypoint (ORWP) mobility model. To optimize LiFi systems, an orthogonal frequency division multiplexing access (OFDMA)-based Resource Allocation (RA) method is proposed. Additionally, an enhanced evolutionary game theory (EGT)-based LB scheme with handover in HLWNs is introduced, enhancing user data rates and fairness in indoor wireless networks [9]. Hybrid networks combine fast data transfer with wide coverage from WiFi, improving network performance and addressing traffic restriction challenges [10].

Intelligent Transport Systems (ITS) encompass advanced applications aimed at enhancing road safety and traffic management. Vehicular communication, a cutting-edge technology within ITS, holds promise for improving these systems. Li-Fi technology using LED bulbs can provide connectivity within a larger area with more security, higher data rates, and high-speed, aiming to reduce traffic congestion and road accidents [11]. Specifically, the Vehicle-to-Vehicle (V2V) communication system, utilizing emerging wireless technologies, serves as an early warning system to mitigate road accidents and traffic congestion. Li-Fi technology emerges as a pivotal component in smart transportation systems, augmenting safety measures by enabling early warning signals and facilitating seamless communication between vehicles. Utilizing LED bulbs, Li-Fi showcases successful V2V communication, bolstering road safety and traffic management efforts. Additionally, Li-Fi empowers autonomous vehicles to communicate with each other and the broader traffic network, minimizing human error and enhancing traffic flow [12]. Through shared data among connected vehicles, Li-Fi contributes significantly to reducing highway accidents, underscoring its pivotal role in fostering safety and mobility within ITS. IoT-based smart city transportation management can optimize system optimization and reduce energy consumption by 25%, offering a hierarchical approach to total transportation management [13].

Integrating LiFi communication systems into traffic lights can offer a cost-effective solution, providing high-data-rate and efficient-bandwidth vehicular communications [14]. This technology not only enhances safe driving conditions but also facilitates entertainment applications. Additionally, LiFi-based V2V communication systems utilizing vehicles' headlight and tail light can significantly reduce emergency vehicles' waiting time in traffic-dense roads by triggering traffic signals to turn green when alerted, thus improving emergency response efficiency. Furthermore, the adoption of LiFi technology in vehicle-to-vehicle communication systems, leveraging LED bulbs, shows promising results in reducing accidents and simplifying wireless network configurations. LiFi offers secure, efficient, and high-rate data transmission for vehicle-to-vehicle communication, making it a promising option for controlling motor speeds [15].
LiFi technology's high speed and eco-friendly data communication capabilities between vehicles contribute to making transportation systems smarter, leading to a reduction in accidents and alleviation of traffic congestion, especially in smart cities. Moreover, LiFi technology effectively maintains safe distances between vehicles, further reducing the likelihood of accidents, enhancing road safety and traffic management while eliminating queues at toll gates, thereby reducing time and fuel consumption. Additionally, a smart parking system combining WiFi and wireless sensor networks detects parking space occupation and provides navigation, thereby improving the efficiency of indoor parking systems [16]. Furthermore, another paper [17] presents a distributed multiuser multiple-input multiple-output architecture for LiFi, catering to industrial wireless applications' requirements, offering moderate data rates, reliable real-time communication, and integrated positioning. This architecture holds potential for future IEEE Std 802.15.13 support. Researchers have diligently ensured that the proposed Li-Fi systems for fee collection are user-friendly and deliver tangible benefits, such as enhanced fee processing and communication.

A recent work done in 2020, Li-Fi based automatic toll collection system that utilized a deep learning algorithm to recognize license plates, transmitting data from a camera located at the toll gate to a deep learning algorithm, which was trained to recognize license plates and process toll payments [18]. Later in 2021, a parking system utilizing Li-Fi technology was proposed, providing real-time availability and location information to drivers via their mobile devices, thereby optimizing time and fuel efficiency while minimizing wireless interference [19]. Another study done in 2022, proposes a framework leveraging Li-Fi technology, utilizing LED bulbs for vehicle-to-vehicle communication to mitigate road accidents. Through optical wireless transmission, data exchange between vehicles is facilitated, aided by ultrasonic sensors for proximity detection. With Li-Fi, various data types can be transferred efficiently and cost-effectively, harnessing the widespread use of LED lighting for communication while offering environmental benefits. This project highlights the potential of visible light communication (VLC) to enhance efficiency alongside existing RF communication methods [20]. Later in 2023, an innovative application framework utilizing Li-Fi to alleviate time delays and congestion at toll booths was proposed by harnessing the visible light spectrum, enabling seamless vehicle passage through toll booths using only Daytime Running Lights (DRL). This approach not only addresses traffic congestion but also presents interdisciplinary benefits across various domains [21]. An advanced solutions is proposed for autonomous buses using LiFi technology, significantly enhancing the passenger experience and reliability of autonomous buses by providing reliable wireless connections, real-time tracking, and seat location assistance [22]. Exploring further, Table 1 below presents insights into LiFi's applications across domains and outcomes from literature studies, offering valuable insights into its real-world effectiveness and feasibility.

Table 1: LiFi applications and relative work

Application	Reference	Outcome
Vehicle to Vehicle Communication	[23]	Li-Fi technology, using LED bulbs for vehicle-to-vehicle communication, can significantly reduce road accidents by providing highly-reliable communication between vehicles.
	[24]	Vehicle-to-vehicle communication using Li-Fi and Wi-Fi technologies can help prevent accidents by transmitting data continuously to the opposite vehicle using headlights, storing data in secure digital cards, and locating accident-prone zones.
Smart Cities	[25]	Li-Fi technology, using LEDs for both illumination and communication, is a feasible, efficient, and reliable solution for smart cities, enabling the internet of things (IoT).
	[26]	Li-Fi technology can efficiently integrate wireless links for data transfer in urban areas, improving data collection and reducing urban 3D space waste.
	[27]	The proposed LiFi-based COVID-19 surveillance system in hospitals offers

Healthcare		high-capacity and security, with a metamaterial antenna embedded by Mach Zehnder interferometer for secure data transmission and patient monitoring.
	[28]	LiFi in an operating room can provide sufficient signal strength for mobile communication, with SDMA with zero forcing increasing data rate by 2.7 times compared to baseline TDMA.
	[29]	Li-Fi technology effectively monitors hospital patients by transmitting data through LED light bulbs, avoiding frequency interference with the human body.
Coal Mines	[30]	Visible light communication (VLC) system offers superior performance in underground mining operations, reducing energy consumption, data rates, and maintenance requirements compared to traditional radio frequency (RF) systems.
	[31]	Li-Fi technology with sensors in coal mines enhances safety and improves working conditions by providing real-time situational awareness for dangerous gases like carbon monoxide.
Under Water	[32]	Li-fi underwater communication system offers high speed data transfer and security while reducing power consumption and transmission losses.
Air planes	[33]	This paper proposes a novel Monte Carlo ray-tracing technique for in-flight LiFi channel modeling, enabling seamless on-board connectivity in dense cabin environments without RF interference.
	[34]	Li-Fi offers faster, safer, and more competent wireless communication in aircraft, mitigating hacking and loss of communication while enabling high-speed data connectivity for passengers without electromagnetic interference.
Industrial	[35]	LiFi in industrial wireless applications offers seamless mobility, reliable low-latency communications, and integration with positioning and 5G systems.
	[36]	Distributed multiuser MIMO architecture for LiFi in industrial wireless applications offers moderate data rates, reliable real-time communication, and integrated positioning, with potential for future IEEE Std 802.15.13 support.
Indoor Environment	[37]	Deep learning-based LiFi communication techniques can effectively learn the indoor environment and user behavior, providing superior performance compared to conventional channel estimation techniques in realistic indoor environments.

3. Proposed Methodology

The proposed methodology for a smart fee collection system leveraging LiFi technology entails the integration of LiFi transmitters within vehicle headlights and LiFi receivers stationed at toll booths. Upon a vehicle's approach to the toll booth, the LiFi receiver captures and decodes the vehicle number embedded within the LiFi signal emitted from the vehicle's headlights. Subsequently, the received vehicle number is processed by the payment system for fee calculation and verification. Upon successful payment authentication, a signal is sent to activate both toll gates, facilitating the seamless passage of the vehicle.

This methodology operates on the principle of LiFi communication, utilizing light waves for data transmission between the vehicle and the toll booth infrastructure. By harnessing LiFi technology, the system ensures secure and high-speed data transfer, mitigating concerns regarding data interception or interference. Additionally, the integration of LiFi transmitters within vehicle headlights ensures a reliable and consistent signal transmission, even in adverse weather conditions or congested traffic scenarios.

From a technical standpoint, the implementation of LiFi-based fee collection involves meticulous hardware integration and software development. The LiFi transmitters within vehicle headlights must be designed to emit encoded light signals containing the vehicle identification information effectively. Similarly, the LiFi receivers installed at toll booths need to be equipped with robust decoding algorithms to accurately interpret the received signals and extract the relevant vehicle data.

Furthermore, the payment processing system integrated into the fee collection infrastructure requires sophisticated algorithms for real-time transaction verification and authentication. Security measures, such as encryption techniques, are implemented to safeguard sensitive payment information during transmission. Through seamless integration and meticulous implementation, the smart fee collection system promises enhanced efficiency, security, and user experience in vehicular toll transactions.

The block diagram of the proposed method depicted in Figure 1 provides a visual representation of the system's architecture and workflow. It outlines the key components and their interactions, illustrating how data flows through the system and how various modules are interconnected also giving insights into the system's structure and operation, facilitating effective communication and collaboration during the development and implementation phases.

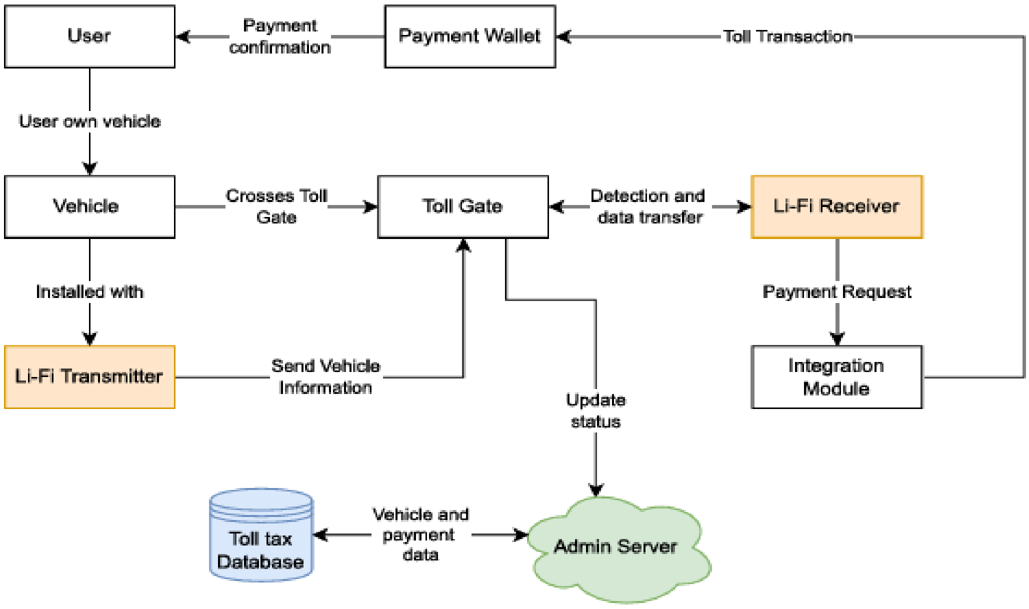


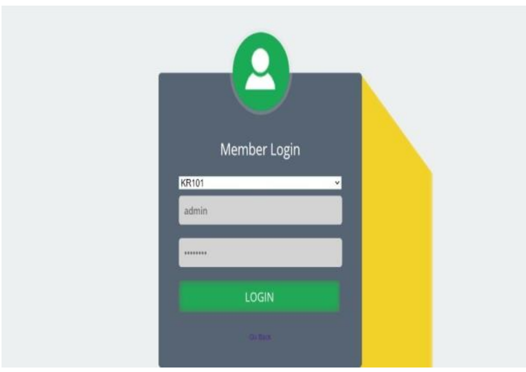
Figure 1. Block diagram of proposed method

3.1 Design Interfaces

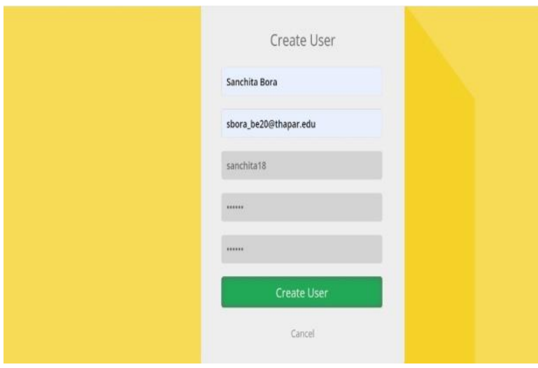
3.1.1 User Interface The Li-Fi-based Automatic Fee Collection System incorporates various user interfaces shown in Figure 2, catering to the diverse needs of its users:
3.1.2 Vehicle Interface User with a secure authenticated login and owns a vehicle with the transmitter installed.
3.1.3 Payment Portal Interface
Login/Registration: Users can log in to their accounts or register if they are new users. They can also use a guest checkout option.
Dashboard: After logging in, users are directed to a dashboard where they can view their recent transactions, account balance, and payment history.
Payment: Users can initiate a payment by selecting the fee booth location and vehicle details. The system calculates the fee amount and prompts the user to confirm the payment.
Transaction History: Users can access a comprehensive history of their fee transactions, including timestamps and fee booth locations.

3.1.4 Fee Booth Operator Interface
- Fee booth operators log in to their accounts with secure credentials.
- When a vehicle approaches, the system identifies the vehicle using its LiFi transmitter and fee gate receiver. The operator's screen displays vehicle details.
- The screen shows the fee amount owed by the driver based on their vehicle type and the distance traveled.
- After the payment is done, the portal confirms the transaction.

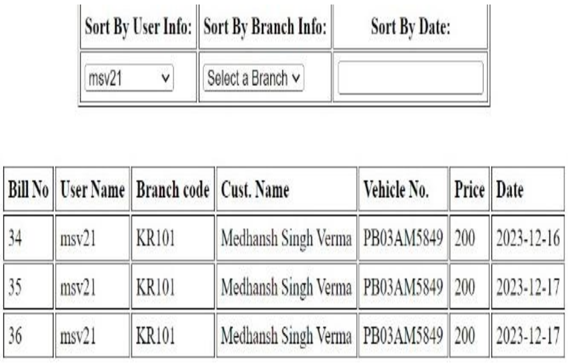
3.1.5 Administrator Control Panel
- The administrator's dashboard provides an overview of all fee booths, transaction statistics, and system status.
- Administrators can manage user accounts, review and approve new registrations, and handle account-related inquiries.
- Configurable settings for each fee booth, such as fee rates, payment methods, and operating hours.



(a) User APP



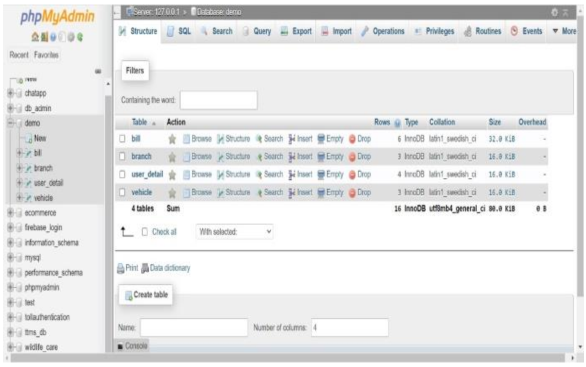
(b) User Registration Portal



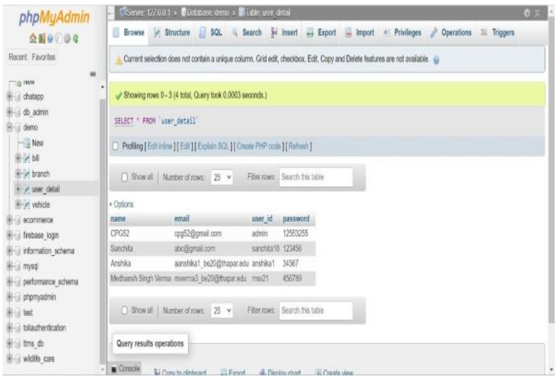
Sort By User Info:	Sort By Branch Info:	Sort By Date:
msv21	Select a Branch	

Bill No	User Name	Branch code	Cust. Name	Vehicle No.	Price	Date
34	msv21	KR101	Medhansh Singh Verma	PB03AM5849	200	2023-12-16
35	msv21	KR101	Medhansh Singh Verma	PB03AM5849	200	2023-12-17
36	msv21	KR101	Medhansh Singh Verma	PB03AM5849	200	2023-12-17

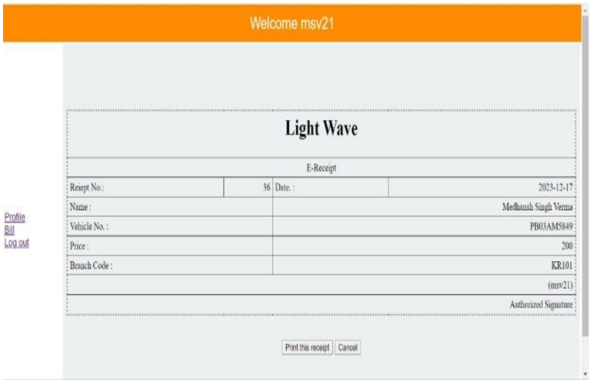
(c) Database Entry



(d) Database Visualization



(e) Reporting and Selection



(f) Report Generation

Figure 2. Software Interfaces Designed (a) to (f)

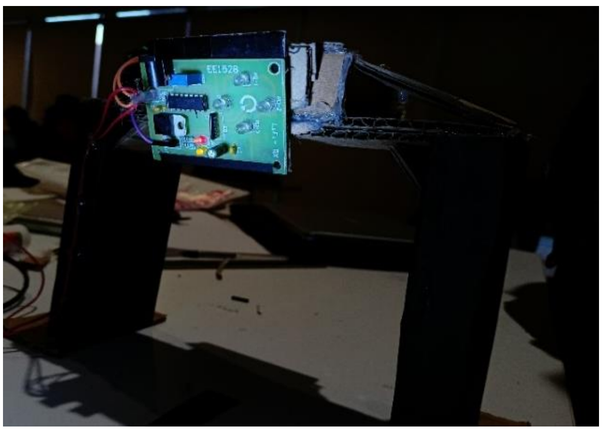
3.2 Hardware Interfaces

3.2.1 LiFi Transmitter Integrated onto vehicle, this device enables distinctive data transmission by utilizing an array of LED lights for visible light communication. Each light emits encoded signals with unique identifiers.

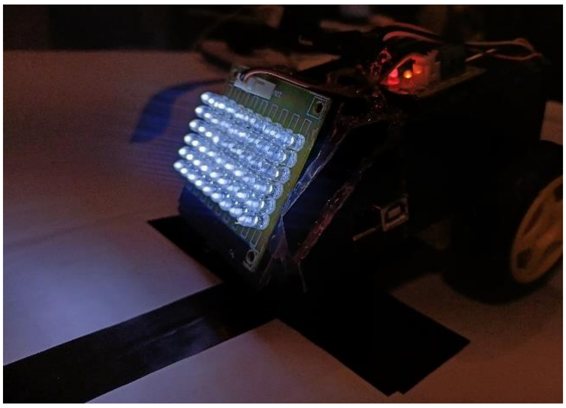
3.2.2 LiFi Receiver Deployed at fee gates, this receiver facilitates data reception and detection, enabling seamless communication within LiFi networks.

Figure 3 (a) to (f) showcases a series of hardware interfaces meticulously crafted for the implementation of the proposed system. Each interface, depicted from (a) to (f), represents a distinct component designed to full fill specific functionalities within the system architecture. These interfaces encompass a variety of hardware elements, ranging from LiFi transmitters and receivers to microcontroller units and sensor modules. The hardware and software integration model shown in Figure 4 illustrates the seamless fusion of physical components and digital systems within the proposed method. This model depicts how hardware components, such as LiFi transmitters and receivers, are interconnected and interact with software elements, including data processing algorithms and user interfaces. Through this integration, hardware functionalities are harnessed to facilitate data transmission, while software systems manage data processing, analysis, and user interactions.

(a) Transmitter on vehicle



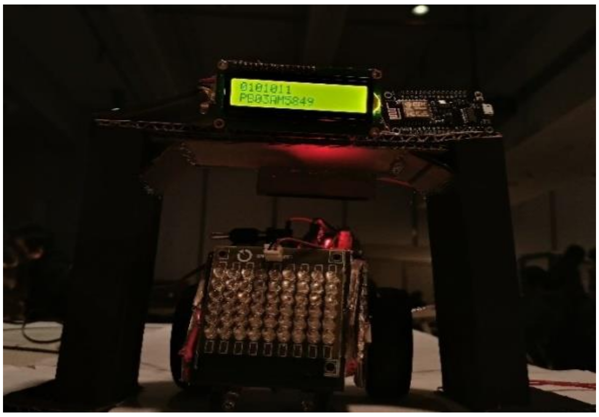
(b) Receiver on fee collection booth



(c) Vehicle following the line

(d) Data Transmission

(e) Data Received



(f) Vehicle passing through the booth

Figure 3. Hardware Interfaces Designed (a) to (f)

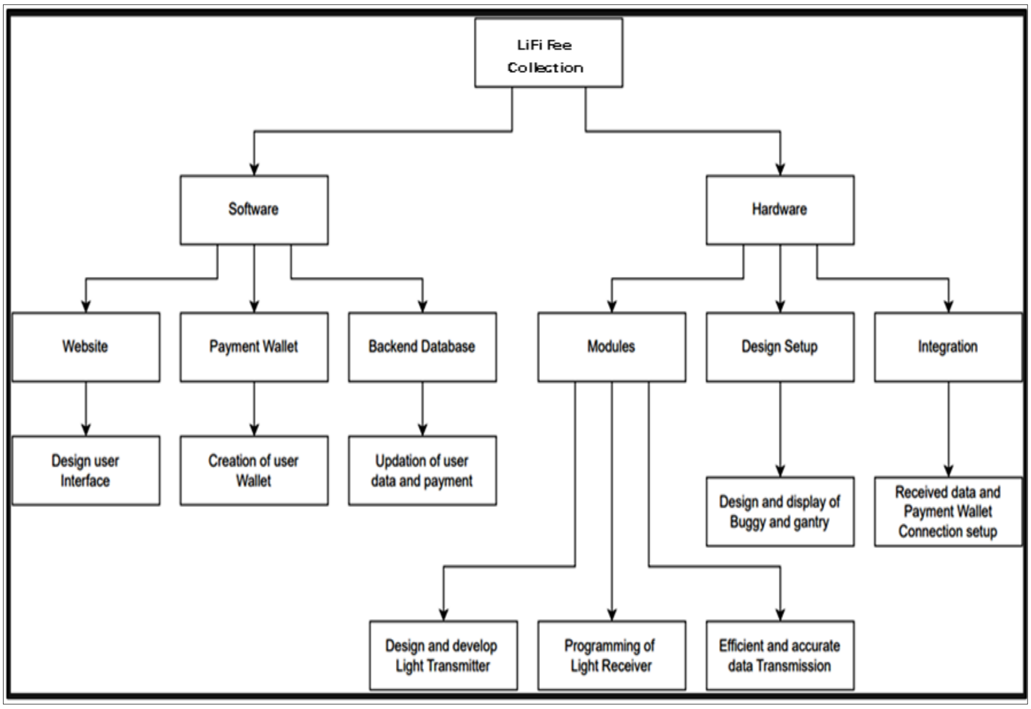


Figure 4. Hardware and software integration model

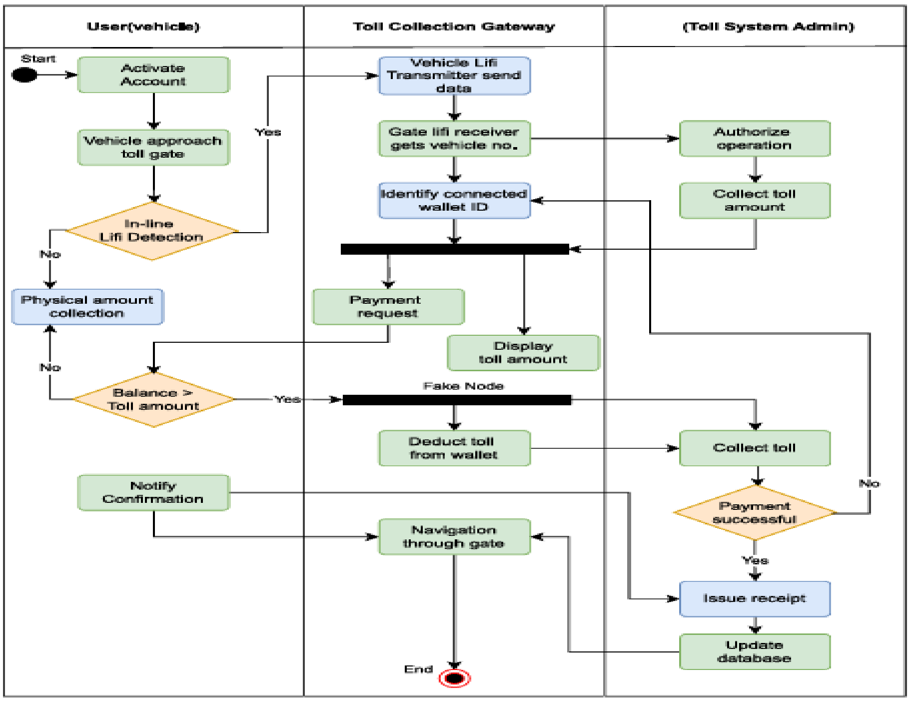


Figure 5. Working activity diagram

The working activity diagram shown in Figure 5 delineates the operational workflow of the proposed method, detailing the sequence of actions and interactions among system components during operation. This diagram illustrates how data is transmitted, processed, and managed within the system, depicting key activities such as vehicle recognition, fee calculation, payment processing, and gate activation. Visualizing the system's operational flow, helps in gaining a comprehensive understanding of the system's functionality and identify potential areas for optimization and improvement. The working activity diagram serves as a valuable tool for guiding the development, testing, and deployment of the proposed method, ensuring smooth operation and efficient performance in real-world scenarios.

Algorithm 1 outlines the procedure for data transmission using LiFi technology, where the input parameters include the transmitter pin (TX_PIN) and the blink delay (blinkDelay). It initiates by setting up the transmitter pin as an output and initializing the dataSent flag to TRUE. The algorithm iteratively transmits each bit of the data string and introduces a delay if the end of the string is reached, setting the dataSent flag to FALSE. Algorithm 2, on the other hand, delineates the process of data reception using LiFi, with input parameters including the receiver pin (RX_PIN), receive delay (receiveDelay), and the expected data sequence (expectedSequence). It initializes the LCD display for output and configures the receiver pin as an input. The algorithm continuously reads the digital signal from the receiver pin and appends either "1" or "0" to the received message based on the signal value until the entire expected sequence is received and processed.

Algorithm 1: Data transmission using LiFi.

1. *Input;* TX_PIN, blinkDelay
2. *Setup:* pinMode(TX_PIN, OUTPUT), anddataSent=TRUE
3. ***Begin***

While ()
  { transmitBit(iter);
  If (iter !=string.end() exit ;
    Iter= iter +1;
  Elseif (iter == string.end())
    delay(blinkDelay);
  SET dataSent = FALSE; ***}***
While (transmitBit(iter))
{ If (iter == 1)
  DigitalWrite TX_PIN, HIGH, delay(blinkDelay)

Elseif (iter == 0)
  DigitalWrite TX_PIN, LOW, delay(blinkDelay) ***}***
4. ***End***

Algorithm 2: Data receiving using LiFi.

1. *Input;* RX_PIN, receiveDelay, expectedSequence
2. *Initilize:* lcd.blacklight(), lcd.print("R: ")
3. *Setup:* pinMode(RX_PIN, INPUT), lcd.init(), lcd.Cursor(0, 0)
4. ***Begin***
   While (length(receivedMessage) < length(expectedSequence))
     { bit=digitalRead(RX_PIN)
       If (bit == HIGH) *GOTO Step 5*;
       Elseif(bit == LOW) *GOTO Step 6;* ***}***
5. receivedMessage + = "1", delay(receiveDelay)
6. receivedMessage + = "0", delay(receiveDelay)
7. ***if*** (receivedMessage == expectedSequence)
8. ***set:*** lcd.Cursor(0,1)
9. ***print*** receivedMessage
10. ***Map:*** receivedMessage ->vehicle_number
11. lcd.print(vehicle_number)
12. ***End***

Test cases

The testing phase of our project played a crucial role in validating the functionality and performance of the smart fee collection system employing LiFi technology. Fig 6 illustrates various test case scenarios conducted to comprehensively evaluate the system's capabilities. Each test case was meticulously crafted to simulate real-world scenarios, encompassing aspects such as data transmission reliability, vehicle identification accuracy, payment processing efficiency, and gate activation responsiveness. By executing these test cases under controlled conditions, we were able to assess the system's effectiveness and reliability in diverse operational scenarios. The insights gained from these test cases provided invaluable feedback for refining and optimizing the LiFi-based fee collection system, ensuring its readiness for deployment in real-world transportation infrastructure.

Test Case: 1.0 | **Test Name:** Receiver Signal Capture
System: LiFi-based Toll Collection System | **Subsystem:** Receiver Signal Capture
Desgined By: CPG 52 | **Design Date:** 10-11-2023
Executed By: CPG 52 | **Execution Date:**10-11-2023
Short Description: Receiver is able to capture transmitted signal.

Pre-Condition: Line of sight transmission between Receiver and Transmitter

Steps	Action	Expected Response	Pass/Fail	Comment
1	Transmitter sending signal	Receiver is capturing the signal	Pass	
2	Vehicle number detection	Correct vehicle number detected	Pass	
3	Check post-condition		Pass	

Post-Condition: User balance details corresponding to the vehicle ID is visible in the database and wallet.

Test Case: 1.1 | **Test Name:** User and Admin Portal Access
System: LiFi-based Toll Collection System | **Subsystem:** User and Admin Portal Access
Degined By: CPG 52 | **Design Date:** 12-11-2023
Executed By: CPG 52 | **Execution Date:** 12-11-2023
Short Description: User and admin is able to sign in and log in through same portal

Pre-Condition: User with some email ID x and password y

Steps	Action	Expected Response	Pass/Fail	Comment
1	Login	System gives a form to input details and login	Pass	
2	Enter the details	Take input	Pass	
3	Click on "Login"	The corresponding account is made available without any conflict.	Pass	
4	Check post-condition		Pass	

Post-Condition: Show updated and correct details to the user or admin

Test Case: 1.2 | **Test Name:** Invalid Email
System: LiFi-based Toll Collection System | **Subsystem:** Invalid Email
Degined By: CPG 52 | **Design Date:** 14-11-2023
Executed By: CPG 52 | **Execution Date:** 14-11-2023
Short Description: User signing up with email that does not exist

Pre-Condition: User with some email ID x

Steps	Action	Expected Response	Pass/Fail	Comment
1	Sign Up	System gives a form to input details and login	Pass	
2	Enter the details	Take input	Pass	
3	Click on "Continue to Login"	System displays error that email-id does not exist and is not valid	Fail	
4	Check post-condition		Fail	

Post-Condition: No changes should be reflected in the database

Test Case: 1.3 | **Test Name:** Bill Generation
System: LiFi-based Toll Collection System | **Subsystem:** Bill Generation
Degined By: CPG 52 | **Design Date:** 16-11-2023
Executed By: CPG 52 | **Execution Date:** 16-11-2023
Short Description: Bill is generated against the vehicle number

Pre-Condition: Vehicle details exist in the database

Steps	Action	Expected Response	Pass/Fail	Comment
1	Details	The user details are being filled	Pass	
2	Toll Amount	Toll amount is being specified	Pass	
3	Click on "Submit"	The receipt for the toll amount is being created	Pass	
4	Check post-condition		Pass	

Post-Condition: The changes are being saved in the database

Figure 6: Test Cases designed

4. **Results and Discussion**

4.1 Experimental Setup

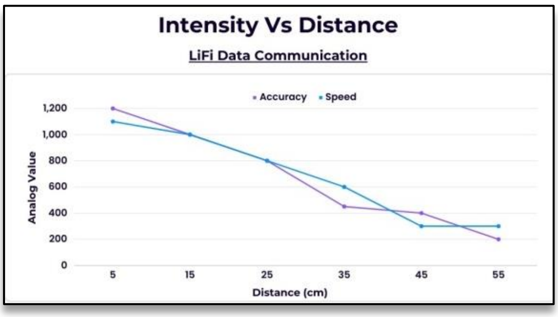
For LiFi implementation a transmitter and receiver module combo for data transmission is used. A cloud based user web interface is designed for fee management system. Specifically a Light Transmitter, Light Receiver, Buggy Motorcar, Integration Module (ESP8266-NodeMCU), Arduino Uno Microcontroller, Pair of IR Sensors, Driver Motor is used and software interface is enabled through PHP, SQL, HTML, CSS. Virtual vehicle numbers through a LiFi fitted buggy is collected at the designed gantry system. The vehicle number is mapped in SQL dataset for fee collection. Various performance parameters used for the designed system are:

Accuracy Data transmission accuracy of signal bits.

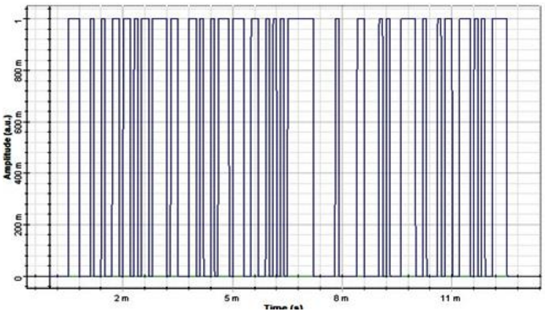
Range Data Transfer speed and detection in LiFi depends strongly on the range i.e the maximum distance at which the receiver can detect the transmitted light.

Payment Deduction Efficiency and robustness of the payment portal to successfully deduct the correct transaction and user account mapping a performance metrics for the entire system software.

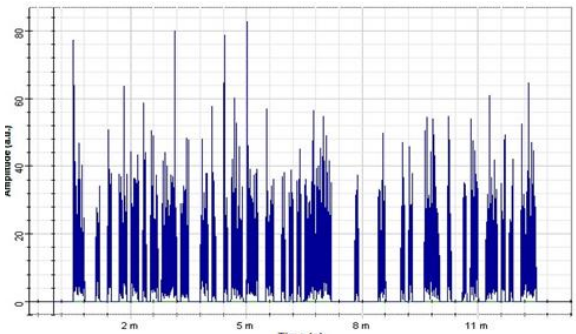
To validate the functionality of the proposed method various test cases are designed and are shown in Figure 6. Figure 7 (a)-(e) shows the accuracy of the proposed solution, signal transmitted by the vehicle, signal received at fee collection boot, and the filtered signal received at fee booth. The signal graph Figure 7(a) displays the intensity against distance showcasing how LIFI signal fluctuates with increasing distance. Understanding this relationship aids in optimizing network performance and coverage in different environment. The transmitter signal graph Figure 7(b) displays the waveform representing the data transmitted through the Li-Fi system. This signal is typically a modulated light signal, where changes in intensity encode digital information. The graph illustrates variations in light intensity over time, corresponding to the transmitted data bits. It may exhibit characteristics such as on-off keying (OOK) or other modulation schemes commonly used in Li-Fi communication



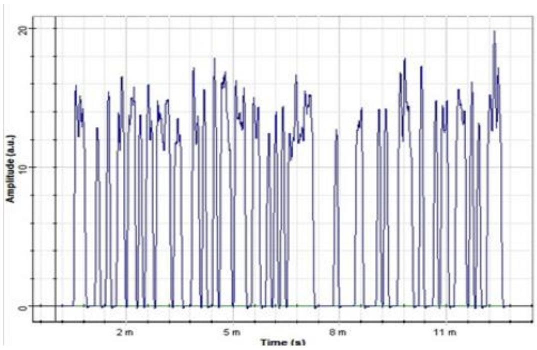
a) Accuracy and Speed Measurement



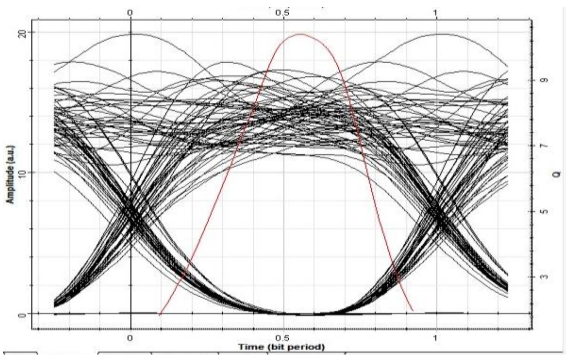
b) Transmitter Signal by Vehicle



c) Signal Received at Fee Collection Gantry



d) Signal After Filtering at Gantry



e) Eye Diagram with BER and Q factor

Figure 7: Graphical results (a) to (e) for fee collectio

The receiver signal graph Figure 7(c) displays the output of the LiFi receiver after receiving and demodulating the transmitted light signal. This signal undergoes several transformations and processing stages, including photo detection, amplification, and demodulation, to extract the transmitted data. The graph shows how the received signal differs from the transmitter signal due to factors like noise, attenuation, and interference. Figure 7(d) represents the received signal after passing through a filter designed to enhance signal quality and suppress noise or interference. It illustrates the effectiveness of the filtering process in improving the signal-to-noise ratio and enhancing the reliability of data transmission. This graph demonstrates the efficacy of the filtering process in refining the received signal, resulting in clearer distinctions between data bits and minimizing errors in data decoding. Optimizing the filter parameters based on the characteristics of the LiFi channel and the surrounding environment can significantly enhance the overall communication system's efficiency and robustness. Figure 7(e) displays the eye diagram for the received LiFi signal revealing its quality and integrity, depicting factors such as Bit Error Rate (BER) and Q factor. Through analysis of these metrics, the performance and reliability of the LiFi communication system can be assessed, ensuring optimal signal reception and data transmission.

4. Conclusions and Future Scope

In conclusion, the implementation of a smart fee collection system utilizing LiFi technology represents a significant advancement in transportation infrastructure. Through the integration of LiFi transmitters in vehicle headlights and receivers at toll booths, the system streamlines fee collection processes while enhancing security and efficiency. This study has highlighted the potential of LiFi in revolutionizing traditional fee collection processes, underscoring its role in modernizing transportation systems. Looking ahead, future research can focus on several areas to further enhance the smart fee collection system using LiFi. Firstly, optimizing LiFi hardware and software components to improve data transmission reliability and accuracy is essential. Additionally, exploring advanced encryption techniques to enhance the security of transmitted data will be crucial. Moreover, integrating LiFi technology with emerging concepts such as autonomous vehicles and smart city infrastructure can unlock new possibilities for intelligent transportation systems. Addressing scalability, interoperability, and regulatory challenges will be crucial for widespread adoption, ultimately leading to the realization of LiFi's full potential in modernizing transportation systems and improving the commuting experience.

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