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Beaming Connections: Vehicle Communication via LiFi

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ABSTRACT
This paper introduces Li-Fi technology to improve communication between vehicles, giving drivers real-time updates about nearby vehicles. By providing clear and timely information about the surroundings, it enhances driver awareness and helps reduce accidents. The system is designed to be cost-effective and adaptable, making it suitable for all types of vehicles. Using LED lights installed in vehicles, the system transmits data through quick, invisible light pulses that nearby cars can pick up with Li-Fi transceivers. This light-based communication is fast, secure, and unaffected by electromagnetic interference, paving the way for safer and smarter driving experiences on our roads.

***Keywords:-** Li-Fi technology, Vehicle-to-Vehicle communication, Visible Light Communication, accident prevention, smart driving.*

INTRODUCTION

Li-Fi, short for Light Fidelity, is an exciting leap forward in communication technology, using light from LEDs to transmit data. Building on optical wireless communication (OWC) principles[1,2], Li-Fi works by rapidly switching LEDs on and off at speeds too fast for the human eye to notice. This means the light continues to serve its primary purpose illumination while also functioning as a data carrier. One of the standout features of Li-Fi is its ability to transmit data even when the LEDs are dimmed below human visibility[3,4]. This makes it energy-efficient and practical in various scenarios, like hospitals or airplanes, where electromagnetic interference from traditional RF systems, like Wi-Fi, can be problematic. However, since LEDs are primarily designed for lighting, balancing brightness and data transmission remains a challenge[5,6].

Li-Fi uses parts of the spectrum like infrared and near-ultraviolet light, sidestepping the crowded radio frequency (RF) bands[7]. This not only allows it to handle more data but also positions it as a strong complement to existing technologies like Wi-Fi. For example, Li-Fi could handle high-speed tasks while Wi-Fi manages broader, long-range communication[8]. One of the exciting prospects for Li-Fi is its role in IoT devices and mobile applications. Imagine a system where your smartphone’s screen communicates with a sensor-equipped device just using light. PureLiFi showcased such innovations at the 2014 Mobile World Congress, demonstrating a consumer-ready system that made Li-Fi practical for everyday use[9,10].

Of course, like any new technology, Li-Fi has its challenges. It requires a clear line of sight to work and may struggle in outdoor environments where sunlight interferes. But with ongoing advancements in modulation techniques and smarter system designs, these limitations are being tackled head-on[11]. Li-Fi’s future is promising, not just as a standalone technology but as part of a larger ecosystem. By combining lighting and communication, it could make our homes, offices, and even our vehicles smarter and more connected. As researchers and industries continue to refine the technology and address its challenges, Li-Fi could soon become a staple in how we connect and communicate in the digital age[12,13].

RELATED WORK

Li-Fi is a promising new technology that uses light to provide high-speed internet connections, making it a potential game-changer for indoor networking. In one study, eight Li-Fi attocell Access Points (APs) were set up in a single study hall, alongside two Wi-Fi APs supporting seven other study halls[14]. This hybrid network setup was designed to test whether Li-Fi could offer an affordable, efficient solution for indoor environments. Wi-Fi APs typically deliver data speeds ranging from 300 to 867 Mbps, depending on their mode of operation. On the other hand, each Li-Fi AP in the study covered a circular area with a radius of 2.8 to 3.5 meters and could support up to eight users at a time. The total data rate per study hall reached about 344 Mbps. What makes this study particularly interesting is that it used regular LED lighting fixtures with an electrical transfer speed of just 2 MHz, demonstrating that Li-Fi could work with existing infrastructure without needing significant upgrades.

However, despite its advantages, Li-Fi still faces a few hurdles. These include handling interference between overlapping coverage areas (attocells), ensuring smooth transitions as users move between different zones, and maintaining consistent speeds in changing environments. Nevertheless, the study shows that when carefully implemented, Li-Fi can complement traditional Wi-Fi and provide faster, more reliable connections in crowded indoor spaces[15].

Wi-Fi Access Points (APs) can provide data speeds ranging from 300 Mbps to 867 Mbps, depending on how they are set up and the conditions of the network. These speeds are achievable using radio frequencies, but performance can vary based on factors like interference and traffic on the network. On the other hand, Li-Fi APs use light to transmit data and offer a different set of benefits. Each Li-Fi AP covers a circular area with a radius of 2.8 to 3.5 meters, making it perfect for smaller, defined spaces like a study hall or office. A single Li-Fi AP can support up to eight users at once, with a maximum total data rate of 344 Mbps per study hall. This makes Li-Fi a great option for environments where several users need a fast, reliable internet connection at the same time. What's really exciting is that the Li-Fi system in this study uses regular, unmodified LED lights, with an electrical transfer speed of about 2 MHz. This means Li-Fi can be implemented using existing lighting systems, making it a cost-effective and practical solution for boosting indoor connectivity without needing significant upgrades or extra equipment. It's a clear example of how Li-Fi can transform everyday infrastructure into a powerful tool for high-speed communication[16].

The goal of this project is to demonstrate how remote system administration can seamlessly integrate with lighting through Li-Fi technology. What makes this framework especially exciting is its quick response time, which is a key focus of the proposed paper. With the growing demand for remote communication, the radio spectrum below 10 GHz (used for cm-wave communication) is becoming overcrowded and insufficient. In response, the communication industry is looking into utilizing higher frequencies above 10 GHz. However, as we move to these higher frequencies, challenges arise[17]. Higher frequencies suffer from greater path loss, meaning signals don't travel as far or as easily. Additionally, obstacles and interference like shadowing become more problematic, making it even harder to maintain strong and reliable communication. Li-Fi, or Light Fidelity, continues this trend by using light instead of radio waves for high-speed data transmission. By tapping into existing lighting systems, Li-Fi can provide a fully integrated solution, offering multi-user access and smooth handovers between devices. This study examines how a Li-Fi attocell system, which uses DCO-OFDM technology (a method for organizing and sending data), functions in a real-world setting. It compares the performance of Li-Fi with the leading radio frequency femtocell systems, shedding light on how Li-Fi might overcome the challenges faced by traditional wireless communication. This project helps us see how Li-Fi can offer a future-proof, high-speed communication solution that could alleviate the pressure on crowded radio frequencies[18].

In this project, we explore an innovative way to use visible light for wireless data transmission. The system consists of an Arduino, a photodiode, a driver, and a 16x2 LCD display, which together create a simple yet effective setup for sending data. The exciting part of this approach is that it takes advantage of the light sources we already use in everyday life. Instead of relying on traditional wireless signals, this system uses light as a pathway for communication, which is both creative and efficient. If fully functional, this system could turn any light source into a data transmission hub. To test its effectiveness, the system was evaluated in various scenarios, demonstrating that light can indeed provide reliable and long-range communication. The beauty of this setup is that it uses something as simple and widespread as light to enable wireless data transfer, which could be a game changer in improving communication infrastructure[19].

This study introduces a creative way to use Li-Fi technology for transmitting picture and video data in indoor environments. The concept centers around using Li-Fi to wirelessly send visual data from camera hubs to end-users, creating a seamless communication network. Each camera is equipped with a Li-Fi handset, allowing it to communicate with other hubs within the system. One of the innovative aspects of this system is the use of a double roof design, which allows light to pass through unobstructed, creating the ideal conditions for data transmission. Additionally, optical fibers are used to carry information across walls, ensuring smooth communication even in spaces with physical barriers. This system is designed with environments in mind that have clear sightlines for light to travel, enabling the uninterrupted flow of data[20].

The camera hubs do more than just capture visual data; they're also equipped with charging capabilities to keep their batteries powered, ensuring the system operates without any interruptions. Given that large amounts of visual data are captured in these setups, efficiency is key. The system employs H.264 video coding to compress the visual data, reducing the file sizes while maintaining quality. This ensures that the data can be transmitted efficiently without overloading the network. The beauty of this system lies in its simplicity and impact. By integrating Li-Fi into existing lighting setups, it makes wireless communication more accessible, energy-efficient, and secure. The result is a reliable, cost-effective solution for visual data transmission that benefits both the environment and users, all while tapping into the potential of indoor lighting as a medium for communication[21].

Another important focus of the project is understanding how Li-Fi affects the quality of LED lighting. By applying different Li-Fi modulation techniques and tracking how these changes impact light quality, we aim to better understand this interaction. While this process can be costly and time-consuming, the goal is to develop a simpler model that can quickly assess how Li-Fi influences LED performance. Such a model would allow us to directly link the LED driving current to the quality of the light being emitted,

Recent Trends in Androids and IOS Applications
Volume 7 Issue 1
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helping us answer important questions like: How do changes in driving current affect light quality? And what is the maximum variation in light quality that can occur over the LED's range? Since Li-Fi controls the driving current of LEDs to transmit data, understanding these shifts is crucial for maintaining optimal lighting while ensuring reliable data transfer[22].

To build this model, we use an optical spectrometer to measure key parameters such as Color Rendering Index (CRI), Correlated Color Temperature (CCT), and chromaticity at different driving currents. By taking thousands of samples, we can create an accurate transfer function that shows how Li-Fi impacts light quality. This will allow us to determine whether the changes are within acceptable limits according to industry standards. Ultimately, the goal is to find the right balance between efficient data transmission and high-quality lighting, ensuring that Li-Fi technology enhances both communication and lighting for users.

TECHNICAL ARCHITECTURE

Detailed System Overview: Li-Fi Transmitter and Receiver in Vehicles

Our system involves the integration of two main components a **Li-Fi transmitter** and a **Li-Fi receiver** that are installed in each vehicle to enable communication through light. These components are connected to an **Esp-32 microcontroller**, which serves as the brain of the system. The Esp-32 not only handles the management of the transmitter and receiver but also links to a range of sensors within the vehicle. The reason we chose the Esp-32 is because it's highly versatile, offering built-in Wi-Fi and Bluetooth capabilities, which make it perfect for handling both data transmission and communication between various sensors in the vehicle.

This setup connects to multiple sensors that provide crucial data for the vehicle's operation. The system includes:

1. **Vibration Sensor**: This sensor tracks vibrations within the vehicle, helping monitor movements and detect any mechanical issues.
2. **Gas Sensor (MQ3)**: The MQ3 sensor monitors the air quality inside the vehicle by detecting gases like alcohol and carbon monoxide, ensuring the passengers are breathing clean and safe air.
3. **Ultrasonic Sensor**: The ultrasonic sensor helps measure the distance to nearby objects, making it ideal for tasks like parking assistance and collision detection.
4. **PC Camera**: A camera captures visual data from the vehicle's surroundings, supporting functions like driver assistance and contributing to autonomous vehicle technologies.

Now, here's where the magic happens: all the data collected by these sensors is converted into binary values, which are then transmitted through Light Fidelity (Li-Fi) a technology that uses visible light to transfer data wirelessly. An LED bulb inside the system emits light based on the binary data, acting as the transmitter.

To ensure the light remains focused and doesn't scatter, the LED is placed inside a funnel. This helps direct the light precisely, which increases the efficiency and accuracy of data transmission. The funnel helps the system maintain a strong, stable connection by reducing signal loss, making the communication much more reliable.

On the receiving end, a solar panel is strategically placed to capture the light emitted by the LED. Although it's called a solar panel, in this case, it's not generating power but is instead being used to detect the modulated light. The solar panel converts the light back into electrical signals, which are then sent to the receiver, where they're decoded into binary data.

Finally, the received data is processed and converted into a human-readable format. Whether it's displayed on a dashboard or sent to an onboard computer, the data can be easily interpreted and used by the vehicle's systems. This entire process

Recent Trends in Androids and IOS Applications
Volume 7 Issue 1
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leverages the power of light for both transmitting and receiving data, making it an innovative alternative to traditional radio-frequency communication. Not only is Li-Fi more secure, but it also offers faster speeds and is less likely to face interference making it perfect for vehicles that need reliable and efficient communication.

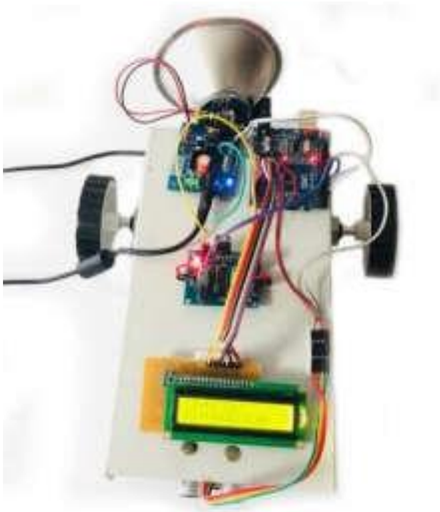

Fig.1:-*Object detection Setup*

A.
Detection of Disturbance:
This module uses a vibration sensor to detect sudden movements or disturbances in the vehicle. The sensor is designed to pick up vibrations that typically happen in the event of a collision, sudden braking, or even an accident. When the sensor detects unusual vibrations, it quickly triggers an alert and sends this information to nearby vehicles. This can help other drivers stay informed about potential hazards ahead, allowing them to adjust their speed or steering to avoid danger. The goal of this system is to increase safety on the road by enabling vehicles to communicate with each other, sharing crucial information in real time.

B. Distance Calculation:
The distance calculation module works using an ultrasonic sensor that measures the space between two objects or vehicles. It does this by emitting sound waves from the sensor's transmitter. These sound waves travel until they hit an object, then bounce back to the sensor. The time it takes for the sound waves to return is measured, and using a simple formula Distance = (1/2) * T * C the sensor calculates the distance. The speed of sound (C) is usually around 343 meters per second at 20°C (68°F), but it can change with the temperature or humidity. This module provides real-time data on how close objects or other vehicles are, which can be extremely useful for maintaining safe distances, especially in busy traffic or during parking maneuvers. It's a crucial part of the system for preventing accidents and enhancing vehicle safety features.

C. Monitoring of Atmospheric Gas or Alcohol:
This module uses a MQ3 sensor to detect the presence of alcohol in the air inside the vehicle, which helps monitor the driver's blood alcohol level. If the sensor detects alcohol vapors above a certain threshold, it sends an alert to the nearby vehicles. This system aims to prevent drunk driving accidents by giving other drivers a warning when someone is potentially impaired. The MQ3 sensor is sensitive enough to pick up even small amounts of alcohol, and by communicating this information to other vehicles, it creates a safer driving

Recent Trends in Androids and IOS Applications
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environment. This simple but effective approach could play a key role in reducing alcohol-related accidents on the road.

D. Monitoring the Face of the Driver:

A **PC camera** is positioned inside the vehicle, facing the driver, to keep track of the driver's face and ensure they stay alert. The camera is constantly scanning for any signs of drowsiness, particularly focusing on whether the driver's eyes are closed for longer than usual. If the driver's eyes are shut for a specified period of time, it's a sign that they might be falling asleep, which can be dangerous. When this happens, the system automatically takes a picture of the driver, and this photo is sent to the receiver. The vehicle's LCD display will show an alert, and a buzzer will sound to get the driver's attention. This immediate feedback encourages the driver to stay focused and alert, reducing the chances of an accident due to fatigue. This feature is especially useful on long trips, where drivers are more prone to drowsiness. The system acts as an extra layer of safety, helping to prevent sleep-related accidents by offering a simple but effective way to monitor and respond to driver fatigue.

WORKING OF LI-FI

Li-Fi (Light Fidelity) is an innovative wireless communication technology that uses visible light to transmit data, offering a unique alternative to traditional radio wave-based systems like Wi-Fi. By utilizing everyday light sources such as LED bulbs, Li-Fi enables fast, secure, and efficient data transfer through Visible Light Communication (VLC). This method encodes data into light signals, creating an entirely new way to send information wirelessly.

The Li-Fi system consists of two primary components: the Li-Fi Transmitter and the Li-Fi Receiver, each working together to facilitate the communication process.

Li-Fi Transmitter (Component A)

The process starts with the **ESP-32**, a versatile microcontroller that connects to the first transmitter. The ESP-32 handles the data, converting it into a binary format before sending it to the transmitter. This is where the magic of Li-Fi begins.

Once the data is ready, it is transmitted through an LED light bulb that acts as the communication medium. However, instead of keeping the light constantly on, the LED flickers at a high speed to encode the binary data:

- A **0** is represented by the LED being off.
- A **1** is represented by the LED turning on briefly.

These quick flashes happen so rapidly that the human eye can't detect the flicker, making it appear as if the light is continuously on. This method allows data to be transmitted invisibly and securely, using the light's intensity variations as the carrier of information.

Li-Fi Receiver (Component B)

On the receiving side, a photovoltaic cell (or photodiode) captures the light emitted from the LED. It detects the changes in the light intensity, which correspond to the binary data that was transmitted. Once the photovoltaic cell absorbs the light, it converts the fluctuations into an electrical signal.

The electrical signal is then processed by the receiver, which decodes the binary data back into its original format. Finally, the data is sent to the Arduino board for further use or analysis.

In short, the combination of the ESP-32, the LED transmitter, and the photovoltaic receiver creates a seamless and secure Li-Fi communication system. By taking advantage of the rapid flickering of visible light, Li-Fi enables wireless data transmission that's both fast and secure, offering a promising alternative to conventional wireless communication methods. With Li-Fi, we can send and receive data without relying on radio

Recent Trends in Androids and IOS Applications
Volume 7 Issue 1
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waves, opening up new possibilities for the future of wireless technology.

RESULTS AND DISCUSSION

The primary aim of this system is to ensure the safety of both drivers and passengers by continuously monitoring the vehicle's environment using data collected from various sensors. By doing so, it can help prevent accidents and promote safer driving behaviors.

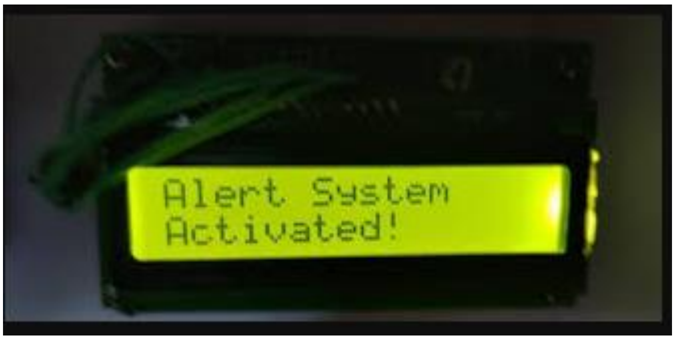

Fig.2:-*Object Detected and Alaram Activated*

Ensuring Driver and Passenger Safety

A key feature of the system is its ability to detect disturbances, such as sudden vibrations caused by an accident or unexpected vehicle movements. The **vibration sensor** plays an essential role in identifying these disturbances in real-time and sending alerts to nearby vehicles. This early warning system enables other drivers to adjust their speed or change lanes, potentially reducing the risk of a multi-vehicle collision.

In addition, the ultrasonic sensor helps monitor the distance between the vehicle and other objects in its surroundings. This is especially helpful in situations like parking or driving through heavy traffic, where visibility can be limited. By accurately calculating the proximity of nearby vehicles or obstacles, the system can issue warnings to the driver, reducing the likelihood of collisions caused by human error or misjudgment.

Preventing Drunk Driving

Another critical feature is the MQ3 alcohol sensor, which continuously monitors the driver's blood alcohol levels. If the sensor detects alcohol in the driver's breath, it immediately sends out a warning to the driver and other nearby vehicles. This helps prevent accidents caused by impaired driving, which remains one of the leading causes of road accidents.

Monitoring Driver Alertness

The PC camera adds another layer of safety by monitoring the driver's face. If the camera detects that the driver's eyes are closed for too long, it triggers an alert, capturing a picture and displaying a message on the receiver's LCD. This helps identify signs of driver fatigue or distraction, allowing the system to encourage the driver to take a break and reduce the risk of accidents due to drowsy driving.

CONCLUSION

By integrating multiple sensors such as vibration sensors, ultrasonic sensors, alcohol sensors, and cameras this system offers a comprehensive safety solution. The continuous monitoring of the vehicle and the driver's state ensures that potential risks are detected early, providing real-time warnings to prevent accidents. Ultimately, this system has the potential to significantly reduce road accidents and promote safer driving practices, benefiting everyone on the road. With its ability to detect disturbances, ensure driver alertness, and prevent drunk driving, it represents an important step forward in the effort to make driving safer.

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