Vehicular Management using a Li-Fi Communication System Powered by BIPV (Building Integrated Photovoltaics)

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Abstract

Objectives: Many vehicular accidents take place in India which are primarily due to lack of traffic discipline. Our aim is to minimize the accidents by creating an efficient communication system. Methods/Statistical Analysis: In our proposed system, we have used light as the carrier to create a fast and reliable communication system where OOK modulation technique is used, unlike other systems where RF is used. The LED’s are positioned in the headlights and taillights of the car which also contain the photodetector to receive light signal. The circuitry have designed and simulated in PROTEUS. Findings: It was found that by replacing all the windows of the car with BIPV, the system can run independently. Theoretically it can work up to 20m with a low bit error rate and this can be achieved by using an array of LED's or increasing the intensity of the LED. It was observed that by hindering the intensity of the LED, the range decreased and hence the validity of the relation between Intensity of LED and range was established. It was found that the data from individual cars were being transmitted immediately with no delay. It will help conserve energy and also act as a built-in glass for the vehicle thus allowing sufficient sunlight to enter. Application/Improvements: This system can be used for vehicular communication to detail about speed, position and traffic. In the future, automatic braking and intelligent synchronization can be implemented.

Keywords: Building Integrated Photovoltaics, Li-Fi, V2V Communication, Visible Light Communication

1. Introduction

Approximately 1.3 million fatalities occur due to road crashes every year and an additional 20-50 million people are injured. If this number is not reduced, then road traffic injuries are predicted to be the 5th leading cause of death by 2030 according to the Association for Safe International Road Travel. Incorporating efficient traffic management and proper security measures using vehicle-to-vehicle communication techniques can lead to an increase in road safety and prevent vehicle theft. In recent years, there has been a development in the Visible Light Communication (VLC) method for carrying data. It uses LED lights for data communication at a higher data rate than RF and has a larger bandwidth than RF. Because of the greater bandwidth, there will be less interference from signals emitted by neighboring cars in vehicular communication. Also, since the light frequency spectrum is large, this method works effectively for short range communication. In addition to this, Li-Fi is a more secure method of data transmission as it is a line-of-sight (LOS) communication hence making hacking more difficult. The color of the LED is what decides the frequency of operation of the system. A combination of many LED’s can also be used to improve the range or different colored LED’s can be used to encode different data’s in different frequencies respectively. The range of transmission depends upon the intensity of the LED and

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the wavelength of light used as shown in Figure 1. This is why white LED is preferred in the Li-Fi module as intensity of white LED is higher than that of other colored LEDs. The luminous intensity of white LED’s can go up to 90 mcd whereas other colors like Red, Blue, Green and Yellow can only deliver up to 50 mcd of luminous intensity. Results is shown for efficient vehicle to vehicle communication at 10Mbps at 20m outdoors at a low bit error rate. The various types of modulation techniques for Li-Fi are: OOK (On-Off Keying), OFDM (Orthogonal Frequency-Division Multiplexing), PWM (Pulse-Width Modulation), PPM (Pulse-Position Modulation) and SIM-OFDM (Sub-Carrier Index Modulation OFDM).

Section 2 focuses on the communication system we propose to manage traffic efficiently and section 3 shows the implementation methods used for this system along with the software simulations. In section 4, we shed light on the basic transmission and reception equations for Li-Fi and the signal to noise ratio in order is achieved efficient communication. Section 5 brings into focus the specifications of the BIPV used to power the system and section 6 suggests future improvisations for the proposed system.

2. Proposed System

In our system, we have proposed to use streetlights as the main medium to transmit and receive information to and from on-road vehicles. Power Line Communication (PLC) is used to distribute the data and then modulation is done using LEDs and information sent out as modulated light pulses from streetlights. The receiver in the vehicle contains a photodiode, which then converts light into current and can be used by the appropriate output device such as a LED or speaker. But because of the LOS feature of Li-Fi, data cannot be transmitted directly to every car using streetlights, as there will be obstruction from intermediate cars. To overcome this, we have enabled vehicle-to-vehicle communication using Li-Fi transceivers in each vehicle. In such an instance, one car receives data first hand from the streetlight and then transmits the data to other nearby vehicles in its LOS, which receive the data. They then transmit to vehicles in their LOS. Each streetlight will transmit data to a vehicle in its line of sight and within the Li-Fi range, which depends on the intensity of the LED. Thus, information is sent in a hierarchical form to all the vehicles and a dense communication network formed for managing traffic. This network can also be used to intimate stolen cars and default challan payments to a central unit and to indicate braking. The whole communication system is made eco-friendly and energy efficient by using BIPV as a power source.

2.1 Vehicle to Vehicle Communication

Both the headlight and taillight of each car has a Li-Fi transmitter and a receiver. Data transfer can occur between any transmitter-receiver pair is shown in Figure 2. Information regarding speed and shift of lane of the car in front is continuously sent to the car behind. The Li-Fi transmitter in the taillight of car 1 sends information to the Li-Fi receiver in the headlight of car 2. If speed of car 1 is suddenly reduced, then car 2 will know to slow down based on the information displayed on the LCD of car 2.

2.2 Street Light to Vehicle Communication

Traffic congestion and road condition details are sent via the transmitter in the streetlight to the Li-Fi receiver in the headlight or tail light of the car within the range of transmission (i.e. car 1) is shown in Figure 3. These details can then be displayed on the LCD display in the car and then transmitted to car 2 through vehicular communication similar to how speed is transmitted. Once car 2 comes within the range of transmission, the street light can directly transmit to car 2. However, even if it fails to do so, it would have already received the data from car 1. Thus, in one way or the other, all the cars in a particular
area receive the required information. Simultaneously, each car continuously sends its vehicle number to the streetlights it passes. It is compared to the vehicle number of a stolen car or cars with unpaid challans to find a match in order to indicate theft and defaulters to a LCD present in a central unit. Hence, the Li-Fi module in the streetlight and car acts as a transceiver unit.

3. System Implementation

The system implementation is shown using a traffic light and two cars as shown. Implementation is done using Proteus. The implementation shows a scenario in which car 1 is functioned as a transmitter and car 2 is functioned as a receiver. The streetlight contains a transceiver circuit. However, in reality, every car will contain a transmitting and receiving circuit.

3.1 Transmitting Circuit

The speed sensor sends the speed to the microcontroller which then compares the value of current speed with that of the previous speed of the transmitting car, in this case car 1. When the speed reduces suddenly, it senses that the car is braking and sends that information to the transmitting circuit. The in-built analog-to-digital converter in the PIC takes care of analog to digital conversion. Similarly, when the car is going to shift to a different lane, a trigger switch circuit is used to sense the change in position of the vehicle and inform the transmitting circuit whether the car is turning right or left. The transmitting circuit consists of a LED Driver, which makes the current constant and sends it to the LED, which transmits the information to car 2 is shown in Figure 4. The modulation technique used for transmitting a Li-Fi Signal is achieved using an LED driver before the LED which makes it flicker at high rates that are not perceptible to the human eye. In the proposed system, we use the simplest form of modulation technique for an LED i.e. OOK (On-Off Keying). OOK is a modulation technique in which the LED driver switched the LED on and off at very high rates where the presence of a signal is encoded as a binary 1 and the absence of a signal is encoded as a binary 0. In the case of streetlight to vehicle communication, the same module is used to transmit ID to the streetlight and the data received from the streetlight to car 2 (Figure 5). The simulation shows that as speed decreases, it is displayed on the LCD of car 1 which will then get transmitted to car 2 along with the vehicle number so that the driver in car 2 will be able to identify where the data comes from (Figure 6). Using the trigger switch, car 1 senses whether the driver is going right or left and informs car 2. With this information, the driver of car 2 will know if car 1 is going to shift lanes. In the streetlight, traffic and road conditions are inputted through a common relay, processed using the microcontroller, and then transmitted is shown in Figure 7. The street light transmits traffic information to the cars along with the road names while simultaneously monitoring the cars to detect theft and unpaid challans. This information is obtained by means of a relay is shown in Figure 8.
3.2 Receiving Circuit

The receiving circuit consists of a photodiode and trans-impedance amplifier. Photodiode converts the light energy into current and trans-impedance amplifier converts the current value to a voltage reading. This voltage is then processed by the microcontroller and displayed on the LCD as shown in Figure 9 and Figure 10. The speed of car 1 is displayed on the LCD of car 2. The street light scans each car that passes it. It matches the vehicle number to the vehicle number of stolen cars and cars with an unpaid challan found from a database. The case displayed in the about scenario is that of a normal car as shown in Figure 11. Similarly, the outputs for other conditions can be shown.

4. Math

The OOK signal is defined by the following equations, given by \( \gamma \):

\[
X(t) = \begin{cases} 
\gamma(t) & \text{if } P(t) = 1 \\
0 & \text{if } P(t) = 0
\end{cases}
\]

\[
X(t) = X(t) - P_t \left[ 1 + m_o d(t) \right]
\]

\[
X(t) = P_t \left[ 1 + m_o \sum_k \alpha_k P(t - kT) \right] \quad (1)
\]

\[
X(t) = P_t \left[ 1 + m_o \sum_k \alpha_k P(t - kT) \right] \quad (2)
\]
Where \( Pt \) = Average transmitted optical power of LED
\( m_0 \) = OMI (optical modulation index) of LED
\( X(t) \) = OOK Signal

\[ P_r(t) = hX(t) + n(t) \]  
\( h \) = Channel DC gain
\( n(t) \) = AWGN (Additive white Gaussian noise)

The received optical signal is converted to electrical form.
\[ I(t) = R[hX(t) + n(t)] \]  

C. Signal to Noise Ratio (SNR)

SNR is defined as the ratio of the desired signal power to the noise power. The SNR of the receiver is expressed as:

\[ SNR = \frac{S}{N} \]  
\( S \) = desired signal power
\( N \) = total Additive White Gaussian Noise (AWGN)

\[ S = R^2 P_r^2 \]  
\( P_r \) = received power of the light signal
\( R \) = responsivity of the Photo detector

The total noise is given by:

\[ \sigma_{total}^2 = \sigma_{shot}^2 + \sigma_{thermal}^2 \]  
\( \sigma_{shot}^2 = 2qgP_rB + 2qI_2l_2B \)  
\( \sigma_{thermal}^2 = \frac{8\pi k T_k}{G} \eta A_r I_2 B^2 + \frac{16\pi^2 k T_k \Gamma}{g_m} \eta^2 A_r^2 I_2 B_3 \)  

Where, \( q \) = electronic charge (1.602 × 10⁻¹⁹ C)
\( B \) = system bandwidth
\( I_{bg} \) = received background noise current
\( k \) = Boltzmann’s constant
\( T_k \) = absolute temperature
\( G \) = open-loop voltage gain
\( \eta \) = fixed capacitance of PD per unit area
\( \Gamma \) = field-effect transistor (FET) channel noise factor
\( g_m \) = FET trans-conductance
\( A_r \) = detection area of the PD
\( I_2 \) = noise bandwidth factor for background noise

5. BIPV Specifications

There are two types of BIPV cells, namely crystalline and amorphous. In our model, we propose to use amorphous, as it does not require direct sunlight. We calculated the total wattage required by calculating the current required by each component which was totally approximately 2A. The size of the BIPV cell required is then calculated using (10).

The voltage used by the circuit is 12V.

\[ \text{Power required} = \text{Voltage} \times \text{Current} \]  
\[ \text{Power required} = 12V \times 2A \]  
\[ = 24W \]  

From Table 1 and equation (1), we arrived at the conclusion to use a BIPV glass of opacity 30% and size 1200 * 600mm is shown in Figure 12 which gives a nominal peak power of 25Ws shown in Table 1. Higher opacity allows more sunlight to pass through which is an advantage in car windows and sunroofs is shown in Figure 13.
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Figure 13. Placement of the Unit in a Car.

Table 1. Specification for BIPV of size 1200 x 600 mm

| Electrical data test conditions               | XL- clear 30% |
|----------------------------------------------|---------------|
| Nominal peak power (Wp)                      | 25            |
| Open-circuit voltage (V)                     | 45            |
| Short-circuit current (A)                    | 0.80          |
| Voltage at nominal power (V)                 | 34            |
| Current at nominal power (A)                 | 0.74          |
| Power tolerance not to exceed (%)            | +/- 5         |

6. Future Proposal

In the future the communication systems will be lot smarter than they are today. In the proposed system the information about road conditions and car details are received by the streetlights from a common wired relay system. This can be improved if cars are able to store traffic information received over a period of time. Cars traveling in one direction will be able to communicate the stored information to cars traveling in the opposite direction directly using Li-Fi. Thus, we'll be able to transmit and receive traffic conditions using vehicular communication as well and be less dependent on communication using streetlights. V2V communication will be much more effective as distance between streetlight to car is larger than the distance between two cars.

7. Conclusion

Hence, the proposed a Li-Fi communication system will help reduce traffic congestion and accidents effectively. This system is shown to be more advantage than RF. Using BIPV will help conserve energy and also act as a built-in glass for the vehicle thus allowing sufficient sunlight to enter. In the future, when the use of relays to transmit information is not required, the system will be self-sufficient to form a network for transmitting and receiving data required for proper maintenance of traffic. Therefore, Li-Fi acts as a very dependable and fast communication system that can be implemented in vehicles for vehicular interaction at very high rates.

8. References

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