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A CONCEPTUAL FRAMEWORK FOR PRACTICAL IMPLEMENTATION OF LI-FI FOR V2V VANET COMMUNICATION

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ABSTRACT

The emergence of light fidelity (Li-Fi) has revolutionized the way information are sent from a source to destination. Despite the expensiveness of Li-Fi, it still found application in most time critical information transmission between a source and destination due to its fastness. Consequently, this paper presents a Li-Fi mimic approach for communicating sensed road anomalies among vehicles in a Vehicular Ad-hoc Network (VANET), towards minimizing the loss of lives and properties. These entailed the design of a laboratory road model and an algorithm for sensing road anomalies (potholes and speed bumps) based on light pulse emitted from an ultrasonic sensor. Furthermore, a Li-Fi mimic concept involving the use of a laser sensor for transmitting the sensed road anomaly to another vehicle within the transmission radius having a photodiode embed in it as the receiver and displaying the corresponding received information accordingly. Experimental results showed that the proposed Li-Fi mimic approach was able to successful communicate sensed road anomalies between the transmitted and received vehicle with about 99% accuracy and 1meter apart. Thus, indicating the potentials of using Li-Fi for communicating sensed road anomalies among vehicles towards notifying drivers of the presence of road anomalies, in order to make effective decisions.

1. INTRODUCTION

Light Fidelity (Li-Fi) is an evolving high-speed wireless communication system based on the concept of visible light [2, 3]. This technology uses light as a technology for sending packets between a sender and a receiver. It has found application in diverse fields among which include its usage for remotely monitoring patients conditions in hospitals [4], remotely controlling underwater vehicles [5], data communication on-board commercial aircraft [6] as well as in intelligent transportation system (ITS) [7]. The application of the Li-Fi technology in ITS has a wide scope among which include its used in transmitting information on traffic conditions among vehicles [7].

In developing countries like Nigeria, most of the road networks are characterized by the presence of anomalies among which include potholes, speed bumps, cracks, rutting etc as shown in plate 1 [1]. We note that of particular concern is the potholes and speed bumps anomaly usually caused by asphalt road

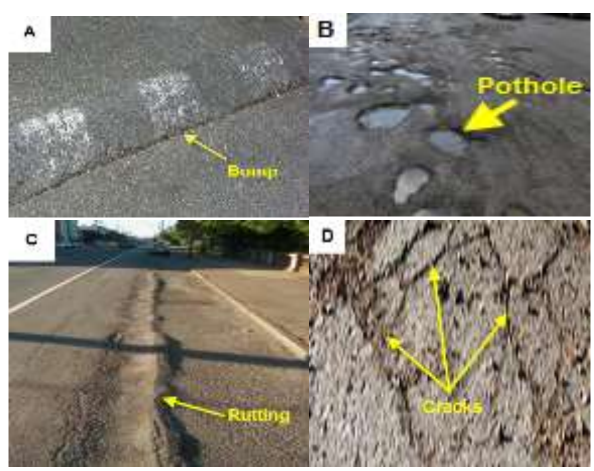


Plate 1: (A) Typical Bumps (B) Potholes (C) Rutting (D) Cracks [1]

exceeding their design lifespan, inadequate drainage system, use of inferior materials for road construction, poor maintenance culture and unsigned postage to notify drivers of speed bumps among others [8, 9]. The presence of this anomalies has induced the occurrence of most road traffic accidents within the country. Thus, leading to loss of lives and properties.

Towards addressing the persistency of these anomalous road traffic induced accidents, despite measures such as the repair of anomalous road, construction of new roads among others [9]. There is need for the utilization of technology driven solution among which include equipping vehicles with the capability of sensing and detecting the presence of this anomalies and notifying drivers as proposed in [10-13]. Also, the concept of vehicular ad-hoc network (VANET) that involves using vehicles within a communication radius in sending information from a source vehicle to a destination vehicle known as vehicle-2-vehicle communication (V2V) or between a vehicle to a road side infrastructure (V2I) has also been proposed for possible communications of this road anomalies [14, 15]. However, of essential is the quick and timely deliverance of such critical information with minimal end-to-end delay to the destination vehicle towards enabling drivers to make appropriate decisions.

In addressing the challenge of timely deliverance of sensed road anomalies, serves as the motivation and contribution of this research that explore the use of the Li-Fi concept for transmitting sensed road anomalies among vehicle. An implementation of the Li-Fi concept was done using a design model that has a laser sensor embed in it, which serve as the transmitter and another model vehicle with a photodiode embedded on, which serve as the receiver. The implementation was tested on an anomalous road anomaly laboratory model presented in [1].

The rest of the paper is structure as follows: Section 2 presents a review of similar work, the proposed conceptual framework and implementation is presented in section 3. Experimental results and analysis is presented in Section 4. While, section 5 concludes the paper.

2. Review of Related Work

In this section, a review of different technology-based approach towards establishing communication among vehicles or road side infrastructure is presented. We note that several approaches based on visual processing and signal processing has been proposed for road anomalies detection in literature [11, 16-18]. However, most reported approach focuses mainly on developing algorithm for the detection of potholes and speed bumps detection, with little or no focus on the possible communication of such detected road anomalies in either V2V or V2I VANET system. Efforts were made in [14, 15], for the possible communication of detected road anomalies among vehicles and road side infrastructure. Though, there was no practical implementation of the reported efforts.

Towards investigating the possibilities of the practical implementation of communicating detected road anomalies among vehicles, approaches that entailed the used of Li-Fi for transmitting information from a source to a destination were reviewed. Such approaches include the use of an optical wireless communication system proposed for communication in a V2V setup in [19]. A Light Emitting Diode (LED) was embed on a vehicle which serve as the transmitter and a camera receiver with an optical communication image sensor. The installed camera has a communication pixel, which responds sensitively to an output circuit of a flag image and changes in light intensity. The transmitted information and images were received by the trailing vehicle which decodes the encoded information by the transmitter. Results obtained show the successful transmission of the speed of the leading vehicle to the trailing vehicle. However, the proposed system was complex as a result of the need for complex image processing algorithm.

A V2V communication system based on Li-Fi technology was presented in [20]. LED bulbs were placed in the rear light of a leading vehicle and used for transmitting change in speed of the vehicle to other vehicles within the communication radius having a photodiode embed in them. Thus, serving as the receiver. The change in the vehicle speed was detected using a speed sensor, encoded by a microcontroller which was transmitted and received successfully. However, the system was implemented and tested on a small-scale prototype due to unavailability of all system components. Similarly, a Li-Fi data transmission was demonstrated and implemented through simulation using NI Multisim 12.0 software in [21], with a similar concept presented in [22]. The proposed system consists of a timer circuit, an optocoupler and an amplifier circuit. A function generator was used in generating an input signal that was converted to square waves by using 555 timer. These square waves correspond to bit 1's and 0's that regulates the state of a LED. The signal was transmitted using an optocoupler, amplified and displayed on an oscilloscope. The displayed results demonstrate the possibility of data transfer using Li-Fi. However, there was no hardware implementation to substantiate the results obtained.

In [23], data transfer between two PCs using single LASER and a photo diode was presented. The LASER was used in transmitting a colored image, and silicon photodiode was used as the receiver. The system consists of computer with MATLAB software that was used in processing the image, max232 IC for the serial communication and LASER switching circuit used to generate binary data streams. Experimental results showed that the develop system was able to successfully transmit data at a distance of 5 meters and baud rate of 9600 at a tradeoff of system complexity.

An implementation of a Li-Fi based communication approach between a streetlight and a mobile phone camera that served as receiver was presented in [24]. A Field Programmable Gate Array (FPGA) boards was used for the implementation of both the transmitter section embed on the streetlight and the receiver on the mobile phone camera. Thus, serving as the Li-Fi modulator and demodulator. Data streamed from the Power Line Cable (PLC) that integrate existing Bluetooth and Wifi network in powering the streetlight. This was encoded and fed to the LED driver that varies the intensity of the light. The transmitted data was received by a Light Dependent Resistor (LDR) incorporated in the phone's camera and decoded by the FPGA. Experimental results demonstrate the successful transmission between the streetlight and the mobile phone. However, the developed system was complex. Similarly, a concept for Li-Fi implementation using two computer system was presented in [25]. A light emitting diode was used as a transmitter and a silicon photodiode as receiver each embed on a separate computer system. The data to be transmitted were converted into byte format and later converted into light signal suitable for transmission by the LED. The signal was received by the photodiode and further converted into byte format, which was suitable for decoding by the receiving computer system. The proposed technique was able to establish communication between the two computer systems by transmitting a 'hi' message which was successfully received. Similarly, the possibility of using the concept of Li-Fi based on LEDs transmitter and photodiode receiver with LCD display for highway navigation was presented in [26, 27]. However, these approaches were illustrated via simulation and practical implementation of using it for communicating time critical information such as road anomalies were not explored

3. Proposed Conceptual Framework and Implementation

The proposed conceptual framework is in two folds with the first folds mainly on the adoption of the proposed laboratory test model and approach for potholes and speed bumps detection reported in [1]. The adopted road model was of design specification of 97x50x3 inches in length, breadth and height. The road model comprises of both potholes and bumps anomaly to enable an effective testing of the sensing capability of developed potholes and bumps detection algorithm. The adopted developed road anomaly sensing algorithm uses the principle of reflectivity of a light pulse emitted by an ultrasonic sensor embed on a model vehicle. The ultrasonic sensor was a low-cost distance measuring transceiver that has a separation distance of 2cm between the transmitter and the receiver. This was used to approximate the distance between the transmitted ultrasound signals at a frequency of 40Hz and the time taken to receive the reflected echo pulse by the receiver. The mathematical model in (1) [1], was design on the assumption that the height 'h' of the model vehicle formed a right angle with respect to the reported developed road model. This was used for the determination of the optimal tilt position for the placement of the low cost HCSR04 ultrasonic sensor on the model transmitter vehicle. The ultrasonic sensor was tilted at angle θ in front of the model transmitter car that does the sensing of the road anomaly. The time taken to receive the reflected pulse signal back by the ultrasonic sensor, when transmitted over an approximate distance 'c' of the road surface was computed.

The sensing unit comprises of a microcontroller, which help triggered the transmitted pulse as well as comparing the reflected distance with a preset threshold value, towards outputting either a pothole, speed bumps or a smooth road. If the distance measured by the sensor is smaller than the defined threshold, a bump is identified. However, if it is greater than, or equal to the defined threshold value, then a pothole or smooth road is declared respectively. Further details about the adopted approach can be found in [1]. The tilt position for the placement of the ultrasonic sensor is shown in Figure 1.

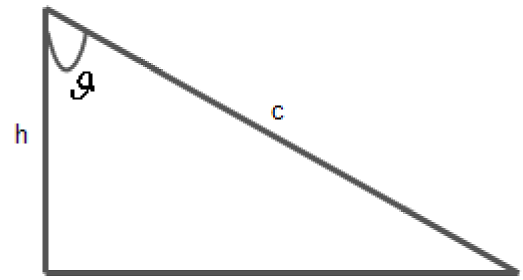


Figure 1: Ultrasonic Sensor Tilt Position

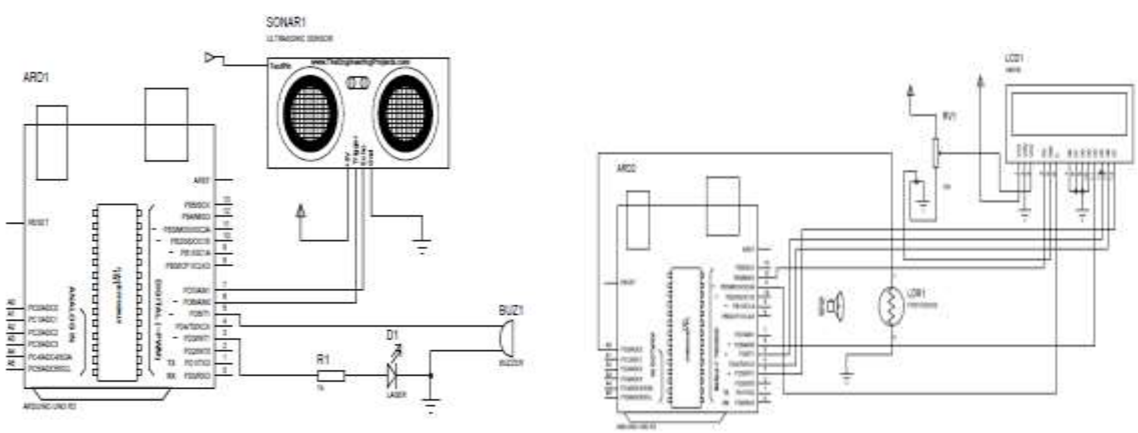
$$J = \cos^{-1}\left(\frac{h}{c}\right) \quad (1)$$

The second fold of the proposed conceptual framework involves the implementation of the Li-Fi concept in communicating the sensed road anomalies among vehicles, which is the major contribution of this

(a) Transmitter Model (b)Receiver Model

Plate 2: The Development Process of both the Transmitter and Receiver Model Vehicle

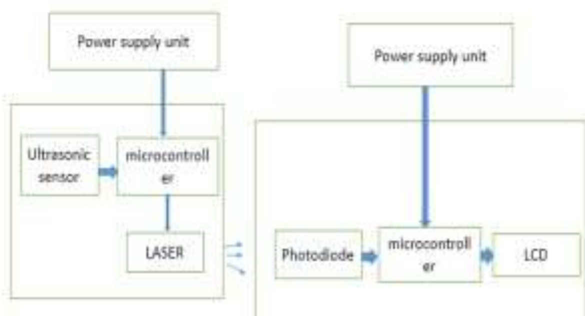
paper. This comprises of both the transmitter and the receiver unit which are embed on two different model



(a) Transmitter Circuit Diagram (b)Receiver Circuit Diagram

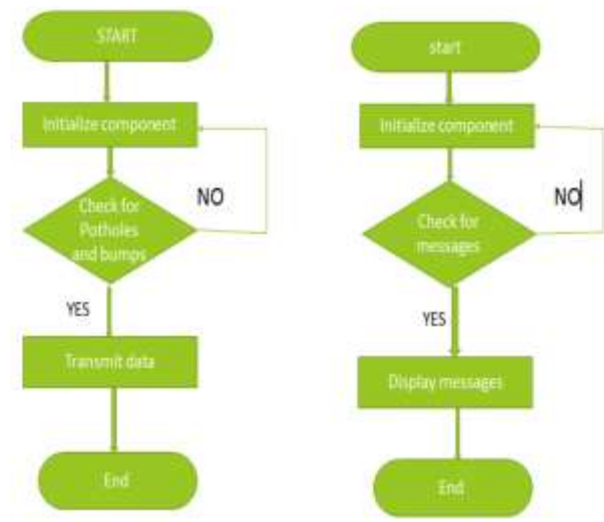
Figure 2: Design Transmitter and Receiver Circuit for the Li-Fi Concept for V2V Communication

vehicles respectively as shown in Plate 2. A laser sensor was embedded in the transmitting vehicle towards transmitting the detected road anomaly from the sensing unit to the receiving vehicle with a photodiode embed on it and display it accordingly on LCD. The transmitter and receiver unit for communicating the sensed road anomaly in the V2V was design using the circuitry in Figure 2(a) and (b) respectively. The simulation was carried out on proteus. Each of design circuitry contained basic components like the power supply, the laser sensor for the transmission of detected anomalies by the ultrasonic sensor embed on the transmitting vehicle, a photodiode embed on the receiving vehicle for receiving the transmitted message and display it accordingly on a LCD. The microcontroller co-ordinate and process all activities in the proposed



(a) Transmitter Unit (b)Receiver Unit
Figure 3: Block Diagram of the Li-Fi Concept for V2V Communication

system. The whole unit used for setting up the Li-Fi system during simulation and the implementation is summarized by the block diagram in Figure 3. While the algorithm procedure for the design and implementation is summarized by the flow chart in Figure 4. This basically comprises the process initiation, the transmission and reception of the detected road anomaly which are send in form of pulse signal by the laser sensor on the transmitting vehicle and received by the embed photodiode on the receiving vehicle, which sent a corresponding voltage signal to the microcontroller to triggered the LCD to display the corresponding received message. The developed system was tested extensively on the design laboratory model and the results were analyzed and presented in section 4.



(a) Transmitter Process (b)Receiver Process
Figure 4: Flowchart for the Implementation of the Li-Fi V2V Communication System

4. Experimental Results and Analysis

Experimental results obtained during the testing of developed Li-Fi concept for communicating the sensed road anomalies is presented. The experimental setup is shown in Plate 3. A corresponding scenario of detected road anomaly transmitted in form light pulse by the laser sensor in the leading vehicle and received by the photodiode which in turn trigger the corresponding signal to the microcontroller and display the detected road anomaly as potholes as shown in Plate 4 (a) and similarly for bump as show in Plate 4(b). The developed system was able to successfully detect the sensed road anomalies which was in agreement with the results reported in [1]. In order to test the proposed Li-Fi conceptual framework in communicating the detected sensed anomaly, 20 different runs were carried out at varying distance and orientation angle between the transmitting and the receiving car model and the average values were computed as shown in Table 1. It was observed that when the model vehicles were placed at 45 and 90 degree orientation to each other, the proposed Li-Fi concept was unable to communicate the sensed road anomalies to the receiving vehicle (not presented in the paper due to page length constrained). However, at 180 degrees vehicle orientation, the detected road anomalies (either potholes or bumps) was successfully transmitted by the leading vehicle and received

Plate 3: Experimental Setup for Testing the Implemented Li-Fi Conceptual Framework for V2V Communication

accordingly by the receiving vehicle within a distance

(a) Received Pothole (b) Received Bump

Plate 4: Snapshot of Detect Road Anomaly Display by LCD on the Receiver Vehicle Model

of 0.5, 1, 1.5 and 2 meters apart respectively (see Table 1). This implies that for communication to be established in V2V by the proposed Li-Fi concept, the vehicle must be in a straight line, at line of sight to each other (180^0 orientation). Furthermore, as the distance between vehicles increases to 2.5 meters above, the transmitted signal got attenuated and was unable to reached the receiver. Thus, unable to

Table 1: Performance Analysis of the Li-Fi Conceptual Framework of the V2V VANET Communication

Detected Transmitted Anomaly	Vehicle Distance Apart(m)	Vehicle Orientation Angle (^{o})	Communication System Status
Bump/Potholes	0.5	180	Success
Bump/Potholes	1	180	Success
Bump/Potholes	1.5	180	Success
Bump/Potholes	2	180	Success
Bump/Potholes	2.5	180	Failed
Bump/Potholes	3	180	Failed

established communication between the vehicles. This may be attributed to the maximum communication range of the type of transmitting laser sensor used for the implementation. Summarily, deductions made from result analysis shows a promising potential of using the proposed conceptual framework for realtime communication of sensed road anomalies in VANET system.

5. Conclusion

This paper has presented a conceptual framework and a practical implementation of a Li-Fi mimick approach for communicating sensed road anomalies in a V2V VANET system. It involved the use of a laser sensor for transmitting the sensed road anomaly by the ultrasonic sensor embed on the transmitting vehicle to another model vehicle having a photodiode and LCD display embed on it serving as the receiver. The experimental results showed promising potentials of harnessing the framework for realtime road anomaly communication in VANET system as well as possibility of incorporating such technology in unmanned surveillance vehicles. Future research efforts will consider how to extend the communication range between the vehicles and ensure the security of the transmitted message from malicious attack.

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