Northumbria Research Link

A Real-time Vehicular Visible Light Communications for Smart Transportation

Karunankitha Lega
Optical Communications Research Group Northumbria University
Newcastle UponTyne,UK
karunankitha.lega@northumbria.ac.uk

Sai Naga Haneesh Sammeta
Optical Communications Research Group Northumbria University
Newcastle Upon Tyne,UK
sai.sammeta@northumbria.ac.uk

Divya Bollepally
Optical Communications Research Group Northumbria University
Newcastle Upon Tyne,UK
divya.bollepally@northumbria.ac.uk

Guru Kalyan Mallavarapu
Optical Communications Research Group Northumbria University
Newcastle Upon Tyne,UK
guru.mallavarapu@northumbria.ac.uk

Elizabeth Eso
Optical Communiations Research Group Northumbria University
Newcastle upon Tyne, UK
elizabeth.eso@northumbria.ac.uk

Zabih Ghassemlooy
Optical Communiations Research Group Northumbria University
Newcastle upon Tyne, UK
z.ghassemlooy@northumbria.ac.uk

Stanislav Zvanovec
Department of Electromagnetic FieldCzech Technical University in Prague Prague, CR
xzvanove@fel.cvut.cz

***Abstract*—In this paper, we demonstrate a real time vehicular visible light communications prototype using Raspberry Pi's for switching of light emitting diodes, signal processing and detection at the receiver side. The low cost system is attractive offering a communication link span of up to 12 m with error free transmission at a data rate of 9.6 kbps , as it shows good performance in the communication distance achieved.**

Keywords—visible light communications, Raspberry Pi and real time

I. INTRODUCTION

Visible light communications (VLC) is a wireless technology that has been proposed for data communications between vehicles as part of the emerging intelligent transport system in smart cities [1]. The currently established technology for vehicular environments known as the dedicated short range communications (DSRC) is a radio frequency-based technology, which offers several features such as intersection collision warning and emergency braking warning [2]. However, there are still some doubts regarding the capability of the DSRC technology to satisfy the latency and reliability demands in ITS as well as security issues and the network outages [3-4]. To address these challenges, the VLC technology has emerged as an attractive and complementary option. Furthermore, the widespread use of light emitting diodes (LEDs) in vehicles and road side infrastructures makes VLC even more attractive and a cost effective option as it makes use of the already available infrastructures i.e., headlights (HL), taillights (TLs), traffic lights and street lights [5]. In addition, the light directionally feature ensures higher security than the DSRC technology as the possibility of eavesdropping is drastically reduced. Moreover, the shorter coverage range of VLC technology gives rise to a smaller collision domain as vehicles receive signals mainly from neighbouring vehicles, thus leading to lower packet error rates due to reduced inter-vehicle-interference (VI) [3].

Table I provides a comparison of VLC and RF technologies for vehicular applications [6-8].

Table I.COMPARISON OF VLC AND RF TECHNOLOGIES

S. No	**FEATURE**	**VLC**	**RF (DSRC)**
1	Communication scenario	Line of sight (LOS) (point to point)	Both LOS and non-LOS(point-to-multipoint)
2	Carrier frequency	400-790 THz	5.85-5.92 GHz
3	Power efficiency	High	Medium
4	License	Free	Required
5	Security	High	Poor
6	Coverage area	Shorter range than DSRC	Longer range than VLC
7	Cost	Less	More

In [9-10], vehicular VLC (VVLC) links were experimentally demonstrated. However, the received signals were processed off-line(i.e., not in real-time communications environments). In [11], vehicle-to-vehicle (V2V) communications based on the VLC technology was also demonstrated using an arduino-uno board to drive the transmitter (Tx) and for signal processing at the receiver (Rx). A link span of 1 m was demonstrated for a Tx at a switching speed of 1 kHz. Moreover, in [12], a V2V-based VLC prototype system was demonstrated using a MSP430 microcontroller (Texas instruments) for LED switching and decoding of the received signal. A single 5mm white LED and a photodiode (PD) were used as the Tx and the Rx, respectively over a very short link span of 12 cm with a data rate and bit error rate (BER) of 3.5 kbps and 10^{-3}, respectively. In this work, we demonstrate a real time VVLC prototype system using Raspberry Pi for controlling the switching of the Tx as well as for signal processing and detection at the Rx. We achieve a communication link span of up to 12 m with 100% success rate at a data rate of 9.6 kbps.

The rest of the paper is organised as follows: In section II the VVLC system using Raspberry Pi is described. In section III Results and discussions are presented. Finally, conclusions are given in section IV.

II.SYSTEM MODEL

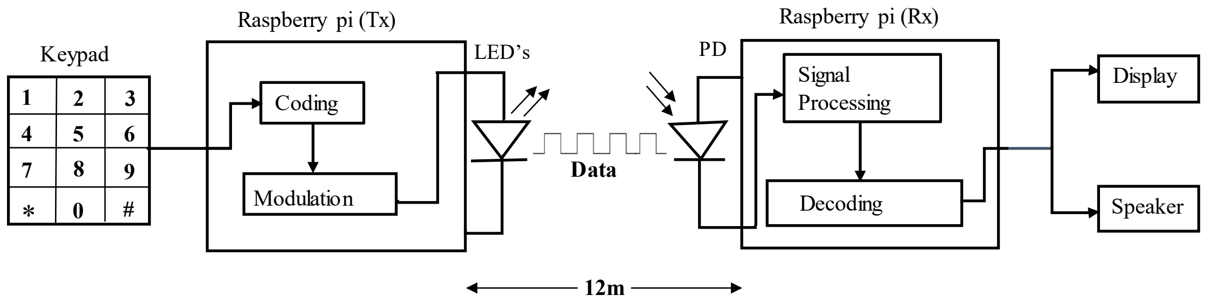


Fig. 1. Block diagram of the system

The schematic block diagram of the proposed V2V VLC link is shown in Fig. 1.The Tx side is composed of a LED array (4×5 matrix 5mm white LEDs), a raspberry pi 3b+ as the LED driver, a keypad for the user interface (i.e., to select the information to be transmitted) and an on off keying data stream for intensity modulation of the LED. The intensity modulated light is transmitted through the free space channel. The Rx is composed of a PD and a raspberry pi 3b+ for signal processing and detection. A Raspberry pi 6.7" touch screen display and a speaker are used for the decoded message to be represented in both text and audio formats, respectively.For the line of sight (LOS) link, the received signal is given as [13] :

$$y(t) = \mathcal{R}x(t) \otimes h(t) + n(t), \qquad (1)$$

where $y(t)$ represents the received signal current,$\mathcal{R}$ is the PD's responsivityand $x(t)$, $h(t)$ and $n(t)$ represents the transmitted optical pulse, the impulse response and the additive white Gaussian noise, respectively. Note, the main noise is the ambient light induced shot noise.

The channel DC gain for the LOS link can be expressed as [13]:

$$H(0) = \begin{cases} \frac{A_p(m+1)}{2\pi L_s^2} cos^m(\phi) g(\psi) T_s(\psi) \cos(\psi), & 0 \le \psi \le \psi_C, \\ 0, & \psi > \psi_C, \end{cases}$$

(2)

where $A_p$the active area of the PD is, L_s is the link span and m represents the Lambertian order of emission of the Tx. ψ, ϕ, $T_s(\psi)$, $g(\psi)$ and $\Psi_c$represents the angles of incidence, irradiance, the gains of an optical filter, concentrator and the width of the field of vision at the Rx respectively. The optical concentrator $g(\psi)$ can be given as follows [13]:

$$g(\psi) = \begin{cases} \frac{n^2}{sin^2\Psi_c}, & 0 \le \Psi \le \Psi_c \\ 0, & 0 \ge \Psi_c \end{cases}, \qquad (3)$$

For the line of sight (LOS) link, the received signal is given as [13] :

The received optical power in terms of the transmit optical power$P_t$is given as [13]:

$$P_r = H(0)P_t + n(t). \qquad (4)$$

A. *Raspberry pi serial communication*

To perform serial transmissionusing the raspberry pi,we have selected a baud rate of 9600, which is provided by the universal asynchronous Rx and Tx(UART) ports. The data packet comprises a start bit, 8-bit data, and a stop bit while the data format employed is the on off keying non return to zero (OOK-NRZ).The data packet structure is illustrated in Fig. 2.

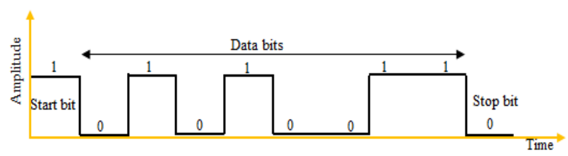


Fig.2. Data packet structure

For transmission of road safety related information (i.e., short traffic messages) between vehicles, a 3×4 matrix membrane keypad is used. A matrix keypad uses the combination of rows and columns when a button is pressed. A matrix membrane keypad requires sevengeneral purpose input/output (GPIO) pins for connections with the raspberry pi board. Table II shows the pins,which we have used for interfacing the keypad with the raspberry pi. Consequently,the Tx and the ground pins of the raspberry piare connected to the input and the ground pins of the LEDarray board.

Table II. THE USER INTERFACE CONNECTIONS TO THE RASPBERRY PI

Keypad pin	Raspberry pi GPIO pin
1	23
2	16
3	18
4	22
5	11
6	13
7	15

B. Data communication flow chart

The flow chart of the proposed V2V-based VLC system is shown in Fig.3. Note that, pre-defined messages have been configured for the different buttons of the keypad.In the source vehicle (i.e., the transmitting vehicle) when the user presses a key, the raspberry pi first detects the key pressed and then transmits the data in the binary format(i.e., the American standard code for information interchange (ASCII). For example, as shown in Fig.8, when keys 1 and 2 are pressed the binary equivalent in the ASCII format is transmitted via the LEDs by serial communications and the received signal is processed and decoded by the raspberry pi. To reduce the BER, we have introduced multiple transmissions by sending the data three times, at the cost of reduced throughput. However, throughput is not an issue in V2V communications, since the transmission data rates are very low (i.e., < 1 kbps in most cases). At the Rx, the regenerated electrical signal at the output of the optical Rx is applied to the Raspberry pi for signal processing and detection (based on the majority decision scheme). Note that, pre-defined text and audio messages have also been mapped to different keypad numbers; consequently, the user in the target (destination) vehicle can both see and hear the transmitted information.

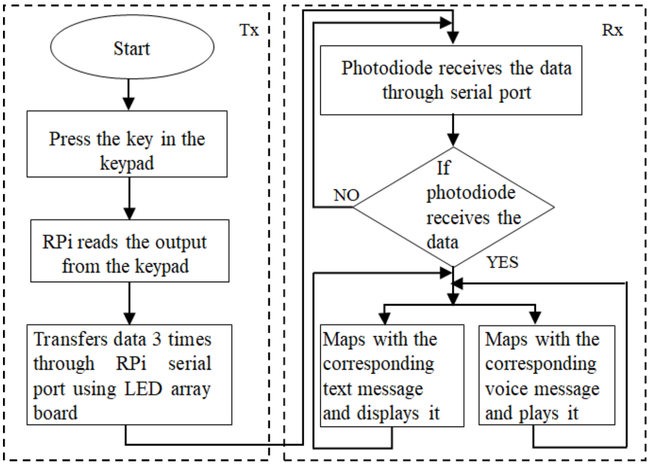


Fig. 3. Flow chart for the V2V based VLC system

III. RESULTS AND DISCUSSIONS

The prototype for theV2V based VLC system is shown in Fig.4, which consists of a Tx (i.e., white LED’s) and an optical Rx.Fig.5 shows the real-world driving scenario with two vehicles. In this work the data is transmitted and received over an experimental link span of up to 12 m in an indoor environment with very little ambient lights. The Tx and the Rx are in clear line of sight with no obstacles. The key parameters of the system are shown in Table III.

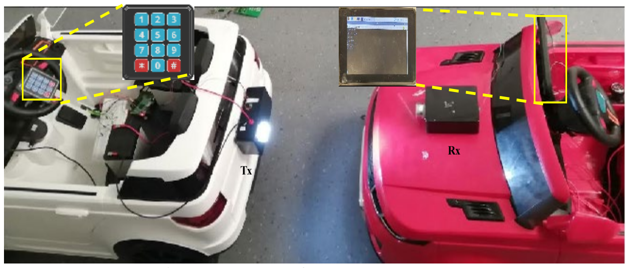


Fig.4. Prototype for V2V VLC system

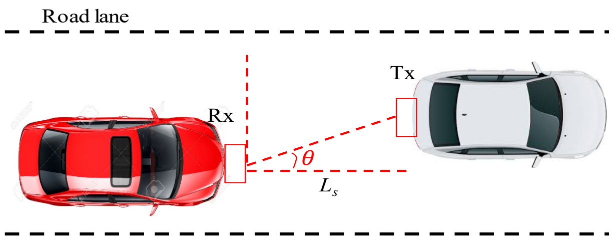


Fig.5. V2V system in driving scenario

Table III. KEY PARAMETERS OF THE SYSTE

Parameter	Value
Raspberry pi model	3b+ & 3b
Tx	20 LEDs
Data rate	9.6 kbps
Data bits	8 bits
Start bit	1 bit
Stop bit	1 bit
Distance between lens &photodiode	0.7 cm
Link-span Ls	12 m
Collection area of optical concentrator	9.62 cm^2
Irradiance angle θ	0-10º
Amplitude (Peak-Peak)	5 V

Fig. 6 shows the measured beam profile of the LED array with a half power angle of ~8º. The normalized light intensity is maximum when the Tx and the Rx are directly aligned (i.e., at 0º).As shown in Fig.6,it is apparent that, the light intensity is inversely proportional to the irradiance angle between the communicating vehicles. Furthermore, Fig. 7 shows the light intensity when the transmitting and receiving vehicles are in a straight path (i.e., line of sight) and at the irradiance angles of 5º and 10º for varying link spans. In this prototype, the Tx is fixed and the Rx is adjusted by 5º and 10ºfor each measurement lengths of 2, 4m,…..etc..At a link span of 2 m, the optical Rx can detect the maximum amount of light from the LEDs at all varying angles.

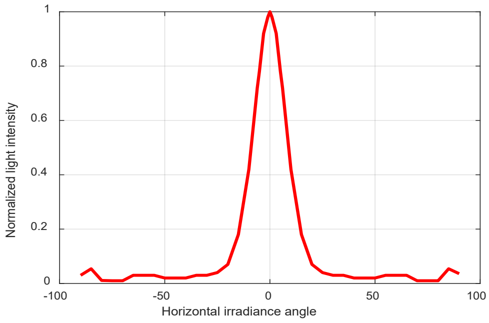


Fig.6. Beam pattern

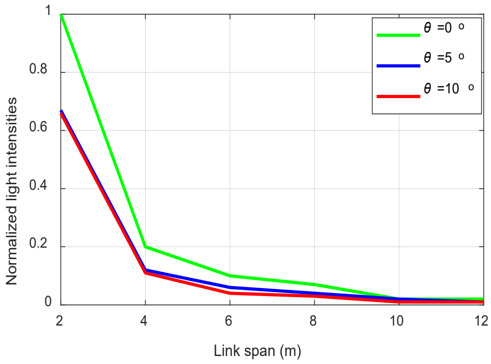
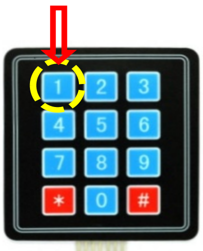


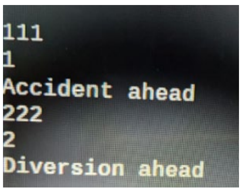
Fig.7. Light intensity of LEDs at receiver at different link-spans and offset angles

The algorithm at transmitter side works in such a way that, when the driver press key 1 once a 3-bit sequence (i.e., 111) is transmitted. At the Rx the algorithm makes decision based on the majority decision scheme. E.g., Fig.8(d) shows a received data bit sequence of (222?), where the maximum number of repeated bit is '2', thus displaying the 'Diversion ahead' message on the display screen and announcing it in sound .

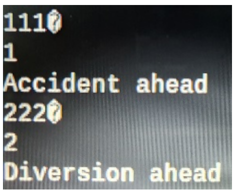


(a)

(b)

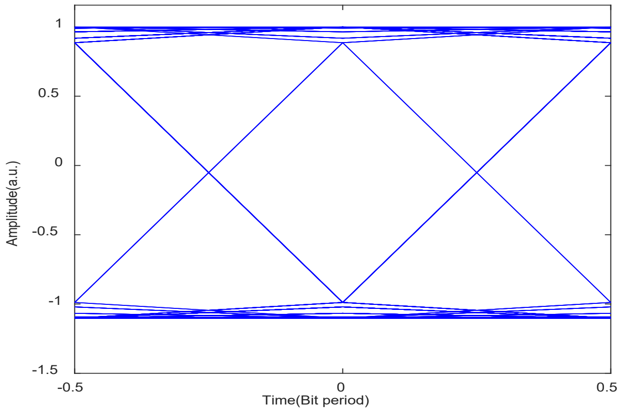


(c)

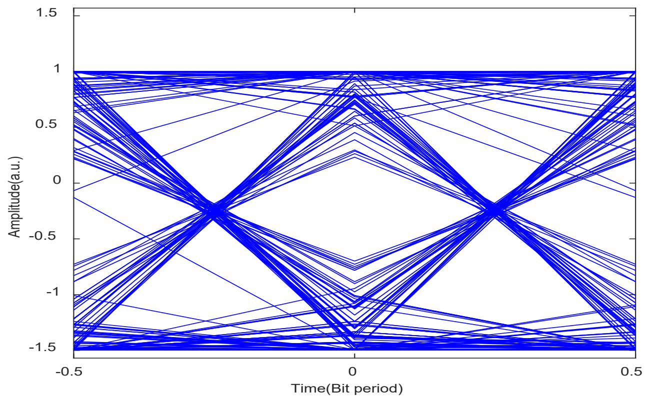


(d)

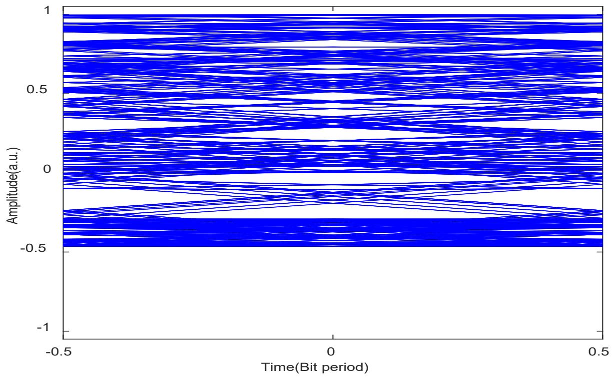
Fig.8. Results for transmitted signal on display screen: (a) when user press key '1', (b) when user press key '2', (c) clear transmission, (d) error in transmission.



(a)



(b)



(c)

Fig.9. Eye diagrams of the received optical signal at different link-spans: (a) 2m, (b) 6m and (c) 12m.

Fig. 9 Show the eye diagrams of the received signal for different link spans. At a 2 m distance between the Tx and the Rx, the eye is perfectly open with no errors. As the transmission distance increases the light from the LEDs diverges and spreads widely, thus resulting in much-reduced light intensity at the Rx, thus leading to the closing of the eye. At the transmission range of 12 m, the eye diagram is almost close i.e., increased BERs. Note that eye diagrams are captured at the PD's output not after the RPi's output. The Rpi's which does the does the signal processing, filtering and detection which gives error free transmission.

IV. CONCLUSIONS

We demonstrated a real time VVLC prototype system using Raspberry Pi for controlling the switching of the Tx, signal processing and detection at the Rx. We carried out experimental measurement in terms of the eye diagram, beam profile at different link spans and light intensity of LED array for a range of offset angles. We showed that, the link offer error free over a shorter transmission range (i.e., up to 2 m) and a higher BER at a link-span of 12 m.

ACKNOWLEDGMENT

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