Optical Camera Based Vehicular Visible Light Communications

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INTRODUCTION

The number of vehicles on roads is on the increase yearly with traffic congestion becoming a widespread problem and road accidents have been identified as the leading cause of death among young people as issued by the World Health Organisation [1]. Therefore, the ability of vehicles to wirelessly exchange information with the neighbouring vehicles and the road side infrastructure, known as **Intelligent Transport Systems and Services (ITS)**, can greatly improve road safety and transportation. Consequently, the increasing use of light emitting diodes in vehicle taillights, headlights and traffic lights offer excellent opportunities for implementation of **visible light communications (VLC)** based the wireless technology as part of ITS in smart environments.

The established wireless technology for vehicular communications is based on the dedicated short-range communications (DSRC), which is a 5.9 GHz radio frequency (RF) technology [2].

Drawbacks of RF technology for ITS purposes

- Low packet reception rate on dense roads
- Difficulty in visually recognizing the transmitters' position due to the omnidirectional feature of RF.

Consequently, VLC can serve as a complementary technology for vehicular communications

VEHICULAR VLC - CHALLENGES

The current challenges in vehicular VLC systems are [3]:

Increasing Robustness to Noise

- The IEEE 802.15.7 standard - Moves the communication to an upper band
- Capacitive filters - To remove the DC component introduced by the unmodulated parasitic light.

Increasing the Communication Range

- Increasing the transmit power - Limited by the eye safety standards
- Use of optical lenses – Narrower angle emission pattern -*Multi-hop transmission.*

Enhancing Mobility

- Use more photodiodes (PDs) - Oriented for different reception angles, tracking mechanism that adjusts the PD's position and relay VLC

Higher Data Rates

- Desirable provided it does not affect any of the other challenges.

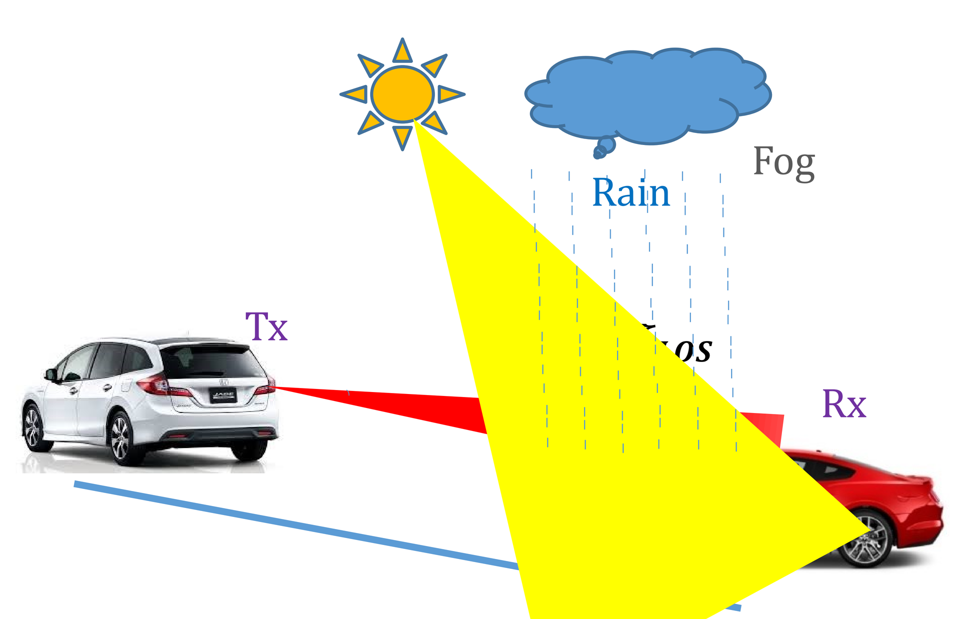

Fig. 1: A typical vehicular VLC link

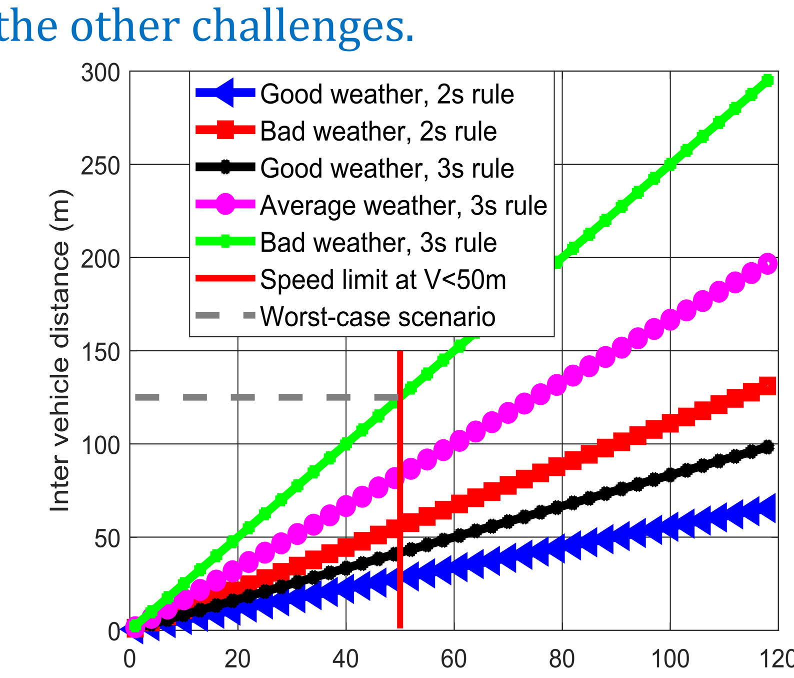

Fig. 2: Driving distances between vehicles vs speed using the 2 & 3 s rule.

VEHICULAR VLC - EFFECTS OF FOG

Few works have been reported on the investigation of fog on VLC systems. Moreover, previous works reported have only considered the use of a PD as the receiver (Rx) and non has considered the use of a camera as the Rx. Therefore, the use of camera-based Rx in vehicular communications given the availability of a dashboard camera is considered [4].

SYSTEM MODEL AND EXPERIMENTAL SETUP

The channel DC gain for the line of sight link can be expressed as [5]:

$$H(0)_{LOS} = \begin{cases} \frac{A_{IMAGE}(m+1)}{2\pi D_{T-CAM}^2} cos^m(\phi) g(\varphi) T_S(\varphi) cos\varphi, & 0 \le \varphi \le \Psi_{CAM} \\ 0, & \varphi > \Psi_{CAM} \end{cases}$$

where A_{IMAGE}, D_{T-CAM}, $g(\varphi)$ and $T_S(\varphi)$ are the projected image of the transmitter (Tx) on the IS of the camera, distance between Tx and receiver (Rx), gains of the optical concentrator and optical filter respectively. ϕ, φ, Ψ_{CAM} & m are the irradiance, incidence angle, the field of view (FOV) semi-angle of the camera and Lambertian order of emission of Tx respectively.

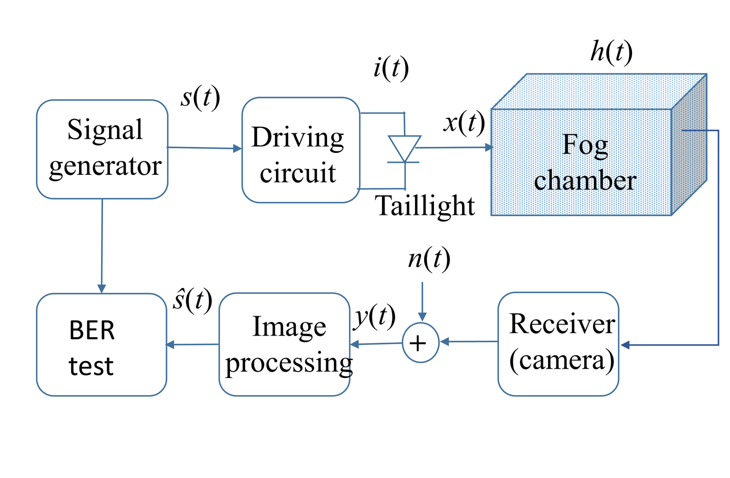

Fig. 3: The schematic block diagram of a OCC-based V2V system.

Fig. 4: Experimental setup for investigating the effect of fog on OCC-based V2V system.

EXPERIMENTAL RESULTS

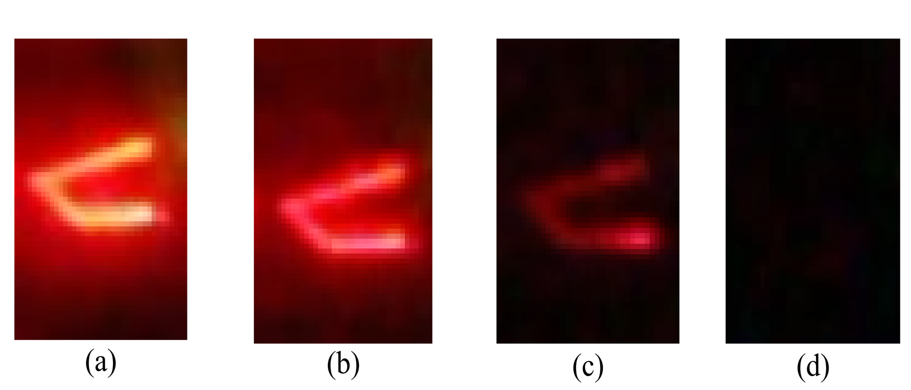

Fig 5: Captured images of the car taillight for a MI of 1: (a) clear weather, (b) 40 m, (c) 10 m and (d) 5 m meteorological visibilities.

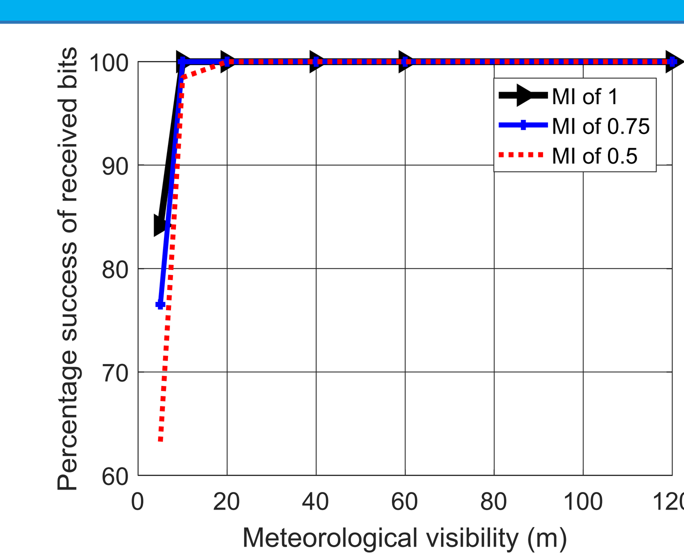

Fig. 6: Success rate of data transmission with fog for a range of MIs.

From the results obtained, the proposed OCC based V2V link shows high reliability even under the fog condition up to a meteorological visibility of 20 m (for all the 3 MIs employed).

A 400 M LONG DISTANCE ROLLING SHUTTER (RS) BASED OCC LINK

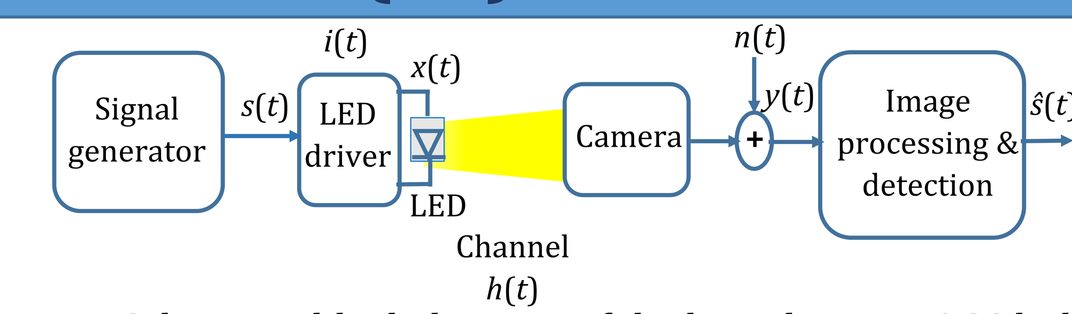

Fig. 7: Schematic block diagram of the long distance OCC link.

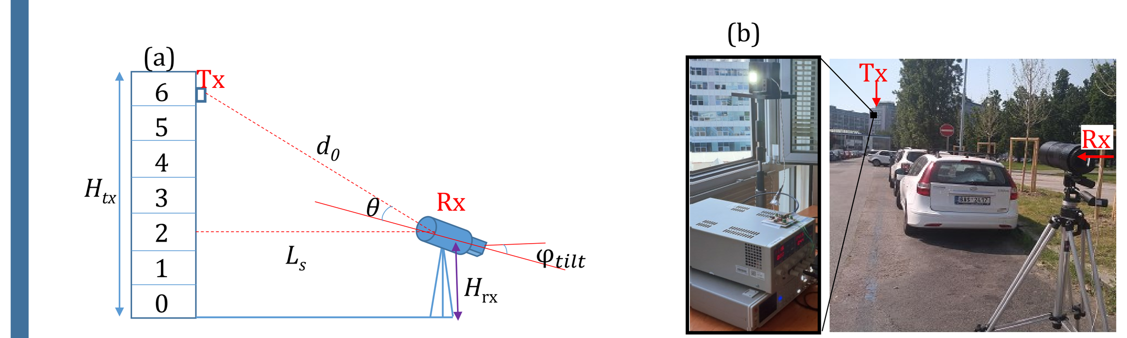

Fig. 8: Proposed OCC link (a) configuration (b) experimental setup.

Measurements were carried out for a link span of 150 to 400 m with 100% success rate of the received bits.

Table 1:Reviews of some works done on RS and long distance OCC links

Refs.	Tx (size)	Link span	Bit rate	BER	Shutter type
[6]	-	2 m	68bit/frame	Error free	RS
[7]	$18.7\times3.8cm^2$ (11×)	120 m	<200bps 200bps @4 m	$>10^{-2}$	RS
[8]	$48\times48cm^2$ (19 ×)	328 m	15bps	~0.04	Global shutter
Our work	$2.5\times2.5cm^2$	400 m	450bps	Error free	RS

CONCLUSIONS

We have developed a new technique to increase the link-span of a RS-based OCC using the defocusing feature of the camera. No works to the best of our knowledge have reported long distance based RS-OCC link beyond 120 m.

REFERENCES

[1] W. H. Organization, "World Health Organization Global Status Report on Road Safety 2018,"

[2] W. Shen and H. Tsai, "Testing vehicle-to-vehicle visible light communications in real-world driving scenarios," in 2017 IEEE Vehicular Networking Conference (VNC), 2017, pp. 187-194.

[3]A. Căilean and M. Dimian, "Current Challenges for Visible Light Communications Usage in Vehicle Applications: A Survey," in *IEEE Comms. Surveys & Tut.*, vol. 19, no. 4, pp. 2681-2703, 2017

[4] **E. Eso**, et al., 'Experimental Investigation of the Effects of Fog on Optical Camera-based VLC for a Vehicular Environment. 15th International Conference on Telecommunications, Graz, Austria, 2019

[5] J. M. Kahn and J. R. Barry, "Wireless infrared communications," Proc. of the IEEE, vol. 85, pp.265-298, 1997

[6] W.C. Wang, et al, "Long distance non-line-of-sight (NLOS) visible light signal detection based on rolling shutter patterning of mobile-phone camera," Opt. Express 25, 2017

[7] P. Chavez-Burbano et al., "Optical camera communication system for Internet of Things based on organic light emitting diodes,"Electron. Lett. 55, 334–336, 2019.

[8] P. Chavez-Burbano, et al., IEEE/CIC , (ICCC Workshops) pp. 22-2,. 2017.

PUBLICATIONS

[1] **E. Eso**, Z. Ghassemlooy, A. Burton and S. Zvanovec. Exploring Visible Light Technology for Vehicle to Vehicle Communications. Engineering and Environment PGR Conference, Northumbria University, UK, June 2018 (Poster).

[2] **E. Eso**, Z. Ghassemlooy, S. Zvanovec, A. Gholami, A. Burton, N. B. Hassan and O. I. Younus. Experimental Demonstration of Vehicle to Road Side Infrastructure Visible Light Communications. WACOWC , Iran, 2019.

[3] **E. Eso**, A. Burton, N. B. Hassan, M. Mansour Abadi, Z. Ghassemlooy and S. Zvanovec 'Experimental Investigation of the Effects of Fog on Optical Camera-based VLC for a Vehicular Environment. CONTEL, Graz, Austria, 2019

[4] **E. Eso**, S. Teli, N.B. Hassan, S. Vitek, Z. Ghassemlooy and S. Zvanovec. 'A 400 m Rolling Shutter based Optical Camera Communications Link'. (submitted to Optics letters).

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