

Design and implementation of a visible light communications system for vehicle applications

Alin Cailean, Barthélemy Cagneau, Luc Chassagne, Suat Topsu, Yasser Alayli, Mihai Dimian

► To cite this version:

Alin Cailean, Barthélemy Cagneau, Luc Chassagne, Suat Topsu, Yasser Alayli, et al.. Design and implementation of a visible light communications system for vehicle applications. IEEE. 21st Telecommunications Forum (TELFOR), Nov 2013, Belgrade, Serbia. Telecommunications Forum (TELFOR), 2013 21st, pp.349-352. <hal-01214799>

HAL Id: hal-01214799

<https://hal.archives-ouvertes.fr/hal-01214799>

Submitted on 13 Oct 2015

HAL is a multi-disciplinary open access archive for the deposit and dissemination of scientific research documents, whether they are published or not. The documents may come from teaching and research institutions in France or abroad, or from public or private research centers.

L'archive ouverte pluridisciplinaire **HAL**, est destinée au dépôt et à la diffusion de documents scientifiques de niveau recherche, publiés ou non, émanant des établissements d'enseignement et de recherche français ou étrangers, des laboratoires publics ou privés.

Design and implementation of a visible light communications system for vehicle applications

Alin-M. Cailean, Barthélemy Cagneau, Luc Chassagne, Suat Topsisu, Yasser Alayli and Mihai Dimian

Abstract — This paper presents a visible light communication system, focusing mostly on the aspects related with the hardware design and implementation. The designed system is aimed to ensure a highly-reliable communication between a commercial LED-based traffic light and a receiver mounted on a vehicle. Enabling wireless data transfer between the road infrastructure and vehicles has the potential to significantly increase the safety and efficiency of the transportation system. The paper presents the advantages of the proposed system and explains some of the choices made in the implementation process.

Keywords — intelligent transportation system, light emitting diode, traffic light, vehicle safety, visible light communications.

I. INTRODUCTION

Light Emitting Diodes (LEDs) are highly reliable, energy efficient and have a life-time that exceeds by far the classical light sources. These unique features made the car manufacturers thinking of replacing the halogen lamps by LED lighting systems. At this moment, car lights based on LEDs are common. The efficiency of the LEDs made them being used also for LED-based traffic lights. This new generation of traffic lights is becoming more and more popular and begins to be used on extended scale. The main advantages of these traffic lights are: low maintenance cost, long life, low energy consumption and better visibility. These advantages had already convinced some of the cities authorities to replace the classical traffic lights with new generation LED-based traffic lights [1, 2] whereas, other cities are progressively do this replacement.

Besides the advantages mentioned above, LEDs are capable of rapid switching, which enables them to be used for Visible Light Communications (VLC). VLC uses the visible light spectrum as a communication medium and since there are no regulations that limit the use of the light spectrum, VLC has the potential to reach extremely high data rates [3].

This work was supported in part by the University of Versailles Saint-Quentin and Valeo Industry.

A part of the financial support is granted by the Fond Unique Interministeriel (FUI) project named *Co-Drive*, supported by the Pôle de Compétitivité *Mov'eo*.

Alin M. Cailean is with the LISV laboratory of the University of Versailles Saint-Quentin, 10-12 avenue de l'Europe - France and with the Department of Computers, Electronics and Automation, Stefan cel Mare University, Suceava, – Romania.

Barthélemy Cagneau, Luc Chassagne, Suat Topsisu and Yasser Alayli work at the LISV laboratory of the University of Versailles Saint-Quentin, 45 avenue des Etats-Unis 78035 Versailles France (corresponding authors phone: +33 1 39 25 49 44; e-mail: {barthelemy.cagneau, luc.chassagne}@uvsq.fr).

Mihai Dimian works at the Department of Computers, Electronics and Automation, Stefan cel Mare University, Suceava, – Romania.

The Intelligent Transportation System (ITS) is a particular area where VLC seems very useful. Either in vehicle-to-vehicle (V2V) or in infrastructure-to-vehicle (I2V) communication, VLC convinced an important segment of both the academia and industry that it is the appropriate wireless communication technique.

Several wireless communications technologies have been proposed and investigated for ITS data exchange: 802.11 (Wi-Fi), Bluetooth, VLC. Even though in terms of communication range, RF based solutions clearly outperform VLC systems, in high traffic density, the increased number of nodes will cause mutual interferences [4, 5]. This will lead to increased latencies, unacceptable for a reliable safety system.

The work concerning I2V communication using VLC is mostly focused on the communication between traffic lights and vehicles [6-9]. This is due to the fact that the high power of the traffic light enables longer communication distances.

Concerning the VLC receivers, they use a light sensing part, as camera systems or photodetector elements. The detection of a LED traffic light with embedded high-speed camera has been demonstrated [10] with good BER performances for distances of few tens of meters. This approach has the advantage of a significant increase of the field of view (FOV). A camera system can be also used for parallel communication as in [11], where the surface of the traffic light is divided into several partitions, each of them representing a channel. Nevertheless, using camera systems implies complex and time consuming image processing techniques. Another disadvantage of this type of sensing systems is represented by the camera's limited number of frames per second (fps) which is limiting the communication speed. For improved performances, the camera has to be a high speed model and is actually reserved for laboratories prototypes.

Using photodetectors for light detection helps reducing the implementation cost and also offers the premises for efficient large scale implementation. In terms of performances, this solution is efficient at both short and long ranges. However, increasing the distance results in a narrow angle of communication. A solution for this problem is presented in [12], where the sensing element has been enhanced for an active control of the position. At shorter distances, active control of the photosensing element is not required since the angle of emission of the light is wide enough. For improved performances, optical parts are used to focus the light on the photosensing element.

Hereafter, we present some of the aspects regarding the design and the implementation of an I2V VLC system between a traffic light and a receiver. The paper

approaches the issues concerning both the transmitter and the receiver modules.

II. SYSTEM IMPLEMENTATION AND CHARACTERISTICS

This section presents a detailed description of the VLC prototype explaining the choices we made in different implementation phases.

As showed in Figure 1, the system consists of a broadcast station unit represented by a LED-based traffic light and a photodiode based receiver that is supposed to be embedded on a vehicle. Both emitter and receiver are interfaced with PCs.

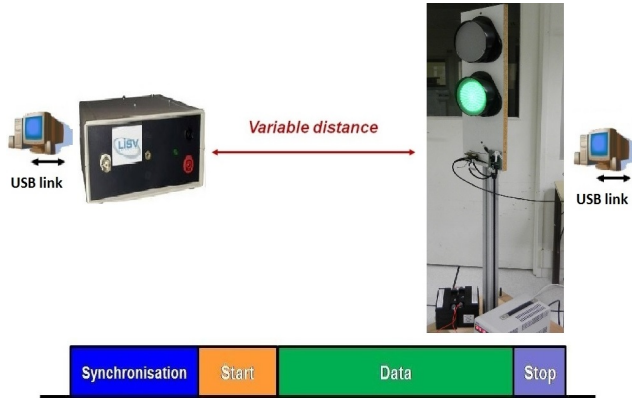


Fig. 1. Visible light communication system consisting of a LED traffic light and a vehicle mounted receiver.

A. Considerations regarding the data broadcasting module

The emitter module was developed based on a commercial LED-based traffic light. Even though from a VLC point of view a LED traffic light can be enhanced, so that it exhibits improved performances, and still comply with the standards, we chose a commercial traffic light in order to prove that any traffic light can become a data broadcast unit with little modifications and at an extremely low implementation cost. We mention here that the number of LEDs can be increased, or that the illumination pattern can be optimized leading to an extended communication range. In the case of VLC, any source of light can become a broadcast station unit without affecting the original purpose of signaling.

The heart of the emitter module, responsible for data processing and decisions is represented by a low-cost 8-bit microcontroller, namely Microchip PIC18F2550. It converts the message into a binary array and deals with the data encoding and packaging. After creating the data frames, the microcontroller commands a digital power switch that handles the switching of the LEDs according with the digital data and the modulation frequency. Due to the limited computation power of the microcontroller, the modulation frequency cannot exceed 40 kHz with this configuration. However, the purpose of the setup is to demonstrate the reliability of the VLC system for outdoor communication. This aspect must not be considered an impediment, since for outdoor VLC, the data rates start as low as 11.67 kHz [13]. Also, in vehicle safety application connectivity is more important than the data rate.

To maintain the complexity level and the implementation cost as low as possible, the system uses asynchronous transmission. A digital frame has been defined (Fig. 1). It consists of several synchronization bits

used to alert the receiver that a message is being sent and to provide information regarding the coding, start and stop bits, an additional flag that notifies the data frame length and the data to send.

As a modulation technique, the standard for short-range wireless optical communication using visible light [13] specifies for outdoor application the usage of On-Off Keying (OOK) amplitude modulation and also of Variable Pulse Position Modulation (VPPM). Since, the VPPM is intended for applications that require dimming, which is not the case of a traffic light, we have thus selected OOK.

As a coding technique, two types of coding were analyzed and implemented: the biphase (Manchester code) and the Miller code. Both the codes are simple OOK based, without having any error detecting or error correcting capabilities. Even though the Manchester code is a classical code recommended by the upper mentioned standard, we also chose to investigate Miller code due to its multi-channel capabilities [14]. To easily test different configuration without rebooting or uploading the commands, the used coding technique is specified by the frame, so that the receiver can decode messages encoded using both the codes.

The designed traffic light has two operating modes. It can work independently, broadcasting a predefined message, (e.g. the speed limit or road works in progress). In this operating mode it is able to control the changing of the traffic light and to broadcast data regarding the time before the next color change. In the second operating mode, it can be connected with a PC through a USB link, broadcasting in real time any message coming from a traffic center (e.g. traffic jams, alternative routes, etc).

The developed module can be easily integrated into any LEDs-based traffic light. It was designed with low cost electronics, so that large scale implementation of such a system would have a reasonable cost. Moreover, substantial savings will be made by the usage of LEDs instead of classical lighting sources to cover the cost of the device.

B. Considerations regarding the data receiving and decoding module

The VLC receiver is a crucial component of the VLC system. Its design determines the overall system performances. The receiver module (Figure 2) is responsible for data recovery from the amplitude modulated light beam. Despite, the electronic is not embedded, all the components have been chosen for their low cost and their compactness.

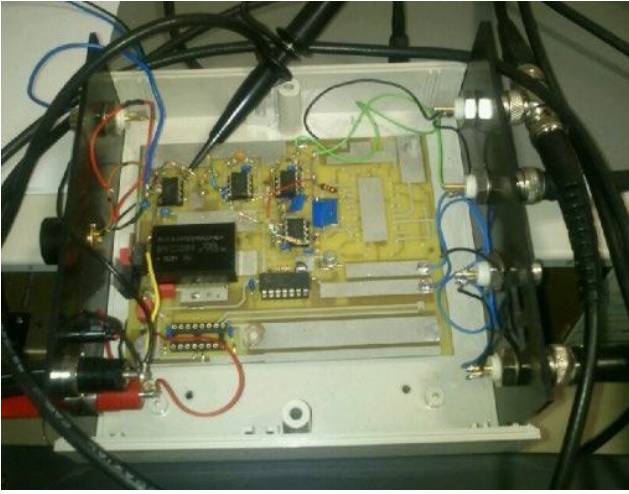


Fig. 2. Test bench of the visible light receiver.

In the next paragraphs, we discuss the implementation process of the aspects we introduced previously and the some of the problems we encountered.

Due to the high complexity of the VLC prototypes that integrate camera systems as light detection elements, and due to the reasons mentioned in the introduction, we focused our attention on photodiodes as light sensing elements. The photodiode's quick response enables the possibility of high-speed communications. However, the performances of such a system are affected by unwanted captured light, and may lead to a low Signal-to-Noise Ratio (SNR). To understate this effect, the light passes through an optical lens which focuses it on the silicon photodiode. The photodiode will generate a current proportional with the incident light. Reducing the receiver's FOV increases the robustness against noise from daylight or from other VLC transmitters [15], but has the disadvantage of narrowing the service area. In this case the optical reception system reduces the reception angle to $\pm 10^\circ$.

In the next step, the signal from the light sensitive element is processed through a classical transimpedance circuit, which limits the bandwidth to 100 kHz according to eq. 1, and prevents the photoelement's saturation in case of direct exposure to high intensity light (e.g. sunlight). As far as 100 kbps, this data rate is sufficient for most of the outdoor long range applications.

$$BW = \sqrt{\frac{GBP}{2\pi R(C + C_p)}} \quad (1)$$

where GBP is the gain-bandwidth product of the operational amplifier, R the gain resistance, C_p the capacitive part of the photodiode and C the capacitive part of the amplifier.

This approach experimentally proved its efficiency, regarding the saturation. However, when the distance is increasing and consequently the SNR decreases, what was actually meant to be a solution for the saturation, became a service area decreasing problem due to insufficient gain. To overcome this new problem the solution is represented by the usage of an Automatic Gain Control (AGC) mechanism, which will be further described. This way, for this stage, the system is able to work with two

amplification values: one for short distance and one for long distance. The two gain values are obtained by setting different values of R (see eq. 2), since the value of the output signal is proportional with R . C is thus selected so that the BW level is maintained.

$$V_{out} = R \cdot S_\lambda \cdot P \quad (2)$$

where V_{out} represents the amplitude of the output signal, S_λ the photodiode's spectral sensitivity and P the received optical power.

In the next stage, the signal passes through several filtering processes where low and high frequency noise, such the one from classical light sources is eliminated. After the filtering process, the signal is amplified until it reaches a value of few volts. For small to medium distances, the current gain is sufficient for proper data recovery, however, when the distance increases, the data recovery process is affected.

In dynamic conditions such as those met in traffic situations, where the vehicles are continuously changing their positions, there are significant variations of the signal's intensity and modifications of the SNR. Experimental tests have been performed and showed that when these conditions are fulfilled, a static value of the amplification is a significant impediment, leading to photodiode saturation or to insufficient signal amplification. Due to these circumstances, the prototype integrates an AGC stage responsible for the system's adaptation to the signal's intensity. After passing through the upper mentioned filtering and amplification stages, the signal is digitalized with the Analog-to-Digital Converter (ADC) included in the microcontroller. Based on the average of the ADC values, the signal level is continuously monitored by the microcontroller. When the signal drops under or raises above the optimum values thresholds, the microcontroller computes a new value for the gain and commands the switches according to the required gain. The AGC block is able to provide a complementary amplification of up to 10 times the previous amplifications blocks, and so, the signal's intensity is maintained while the emitter-receiver distance is changing.

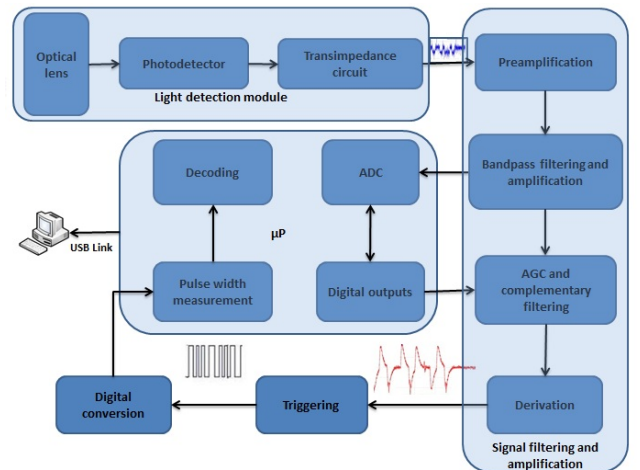


Fig. 3. Representation of the visible light receiver.

In the next step, the signal passes through a high-pass filter resulting in the derived signal consisting of alternated positive and negative pulses. The positive pulses are the equivalent of the rising edges whereas the negative ones are the equivalent of the falling edges. Based on these pulses, the signal is turned into a digital signal corresponding to light on and light off.

The core element of the receiver, responsible for signal processing, information treatment and decision taking is a low-cost 8-bit microcontroller Microchip 18F2550. The microcontroller is also responsible for the real time data decoding. The decoding is made based on the detection of the falling and of the rising edge and on pulse width measurement. For the pulse width measurement, the microcontroller uses the precise clock of an external quartz crystal operating at a frequency of 20 MHz. A BER is performed by comparing the original message with the received one. To facilitate the monitoring of the results, the receiver is connected with a PC through USB.

At the end of this section, we mention that for simplicity and for considerations about the price, the receiver's clock is not synchronized with phase locked-loop. This aspect does not affect the data decoding as long as the frequencies involved do not exceed a few tens of kilohertz.

C. System performances

Even through the aim of this paper is to present the hardware aspects of the proposed VLC system, we mention some of the aspects regarding its performances.

The proposed system was tested under various conditions, both indoor and outdoor. The results detailed in [16] clearly demonstrate that the system is well suited for data transmission even in the presence of perturbations represented by artificial lighting sources or by moderate sun. Neither the 100 Hz parasitic signal from the neon lights or the sunlight affect the BER which is maintained as low as 10^{-7} . The communication range achieved by the system can reach at this point up to 50 meters.

The data transmission is made with a 15 kHz modulation frequency but higher frequencies of up to 30 kHz could be easily achieved even in the same configuration. Table 1 summarizes the system's performances.

Table 1: Bit Error Ratio performances at 15 kHz

| Emitter-Receiver Distance | Data coding | BER | Testing conditions |
|---------------------------|-------------------|------------|------------------------------|
| 1 – 50 m | Manchester Miller | $<10^{-7}$ | Outdoor with daylight |
| 1-20 m | Manchester Miller | $<10^{-7}$ | Indoor with artificial light |

Due to the AGC the BER can be maintained for variable distances. Even when the emitter-receiver distance is lower than 1 meter (e.g. as vehicle is waiting in front of the traffic light), the AGC prevents the saturation of the photoelement.

III. CONCLUSION

This paper discusses the hardware aspects regarding the development of a VLC communication system consisting

of a commercial LED-based traffic light and a vehicle mounted receiver. We have presented the approach we followed, some of the difficulties we encountered and explained the choices we have made. Throughout the implementation process, we also focused on keeping the implementation cost as low as possible.

In a future work, from a hardware point of view we will analyze the usage of a multi-photo-detector receiver with the purpose of enlarging the reception angle. We also plan to improve the adaptive filtering stage but at this point, we still compare the analog filtering and the numerical filtering done by high performance DSPs.

REFERENCES

- [1] J. O'Connell, "The Philadelphia story," Traffic Technology International, New York 1997.
- [2] Intelligent Transportation Systems, "Stop-Go in Singapore," ITS International, New York, 2000.
- [3] Shuailong Zhang; Watson, S.; McKendry, J.J.D.; Massoubre, D.; Cogman, A.; Erdan Gu; Henderson, R.K.; Kelly, A.E.; Dawson, M.D., "1.5 Gbit/s Multi-Channel Visible Light Communications Using CMOS-Controlled GaN-Based LEDs," Lightwave Technology, Journal of , vol.31, no.8, pp.1211,1216, April15, 2013
- [4] S. Eichler, "Performance Evaluation of the IEEE 802.11p WAVE Communication Standard", In IEEE Vehicular Technology Conference, 2007.
- [5] A. Agarwal, T.D.C. Little, "Role of Directional Wireless Communication in Vehicular Networks", IEEE Intelligent Vehicles Symposium 2010, 688-693
- [6] N. Kumar, N. Lourenço, D. Terra, L.N. Alves, R.L. Aguiar, "Visible Light Communications in Intelligent Transportation Systems", IEEE Intelligent Vehicles Symposium 2012, 748-753.
- [7] M. Akanegawa, Y. Tanaka and M. Nakagawa, "Basic Study on Traffic Information System Using LED Traffic Lights", IEEE Transactions on Intelligent Transportation Systems, vol. 2, no. 4, 197-203, 2001.
- [8] T. Saito, S. Haruyama and M. Nakagawa, "A new tracking method using image sensor and photo diode for visible light road-to-vehicle communication", 10th International Conference on Advanced Communication Technology, Vol 1, pp 673-678 (2008).
- [9] S. Iwasaki, C. Premachandra, T. Endo, T. Fujii, M. Tanimoto, Y. Kimura, "Visible Light Road-to-Vehicle Communication Using High-Speed-Camera", IEEE Intelligent Vehicles Symposium, pp13-18 (2008).
- [10] T. Nagura, T. Yamazato, M. Katayam, T. Yendo, T. Fujii, H. Okada, "Improved decoding methods of visible lights communication system for ITS using led array and high speed camera", Vehicular technology conference, VTC 2010 IEEE 71st, ISSN: 1550-2252,2010.
- [11] M. Wada, T. Yendo, T. Fujii and M. Tanimoto, "Road-to-Vehicle Communication Using LED Traffic Light", Intelligent Vehicles Symposium, 2005. Proceedings. IEEE, 2005.
- [12] S. Okada, T. Yendo, T. Yamazato, T. Fujii, M. Tanimoto, Y. Kimura, "On-vehicle receiver for distant visible light road-to-vehicle communication", Intelligent Vehicle Symposium, IEEE ISSN: 1931-0587, 2009.
- [13] IEEE Standard for Local and Metropolitan Area Networks--Part 15.7: Short-Range Wireless Optical Communication Using Visible Light, IEEE Standard, 2011, 1-309
- [14] A. Cailean, B. Cagneau, L. Chassagne, S. Topsu, Y. Alayli, J-M. Blossville, "Visible light communication: application to cooperation between vehicles and road infrastructures", IEEE Intelligent Vehicles Symposium 2012, 1055-1059.
- [15] C. Liu, B. Sadeghi, E.W. knightly, "Enabling vehicular visible light communication (V2LC) networks", Vanet'11, Las vegas, USA, 2011.
- [16] A. Cailean, B. Cagneau, L. Chassagne, S. Topsu, Y. Alayli, M. Dimian, "A robust system for Visible Light Communication", IEEE Wireless Vehicle Symposium (WiVeC) 2013, in press.