Flicker Free Visible Light Communication Using Low Frame Rate Camera

Alina E. Marcu, Robert A. Dobre, and Marian Vlădescu

Abstract—**Over the years, more and more conventional lighting systems tend to be replaced by LED lighting systems because of their advantages such as high energy efficiency, longer lifespan and lower heat generation. Because of the LEDs' capability of switching to different light intensities at fast rate, these lighting solutions could be used for both illumination and transferring data. This characteristic of the LEDs has led to the development of a new technology, known as Visible Light Communication (VLC). In this type of communication, the receiver is usually a photodetector. Lately, the tendency is to also use video cameras to receive the transmitted data. Solutions exist, but they use expensive cameras that can capture over 800 frames per second (fps). The communication proposed in the paper uses a LED as a transmitter and a camera with a common frame rate (120 fps) as the receiver. At those frame rates the challenge is to use a code that avoids flickering and does not need a synchronization between the transmitter and the receiver. A version for such code is also presented in the paper. The system was implemented and tested. The results confirm the functioning of the proposed low frame rate VLC communication system.**

Index Terms— **Visible Light Communication, Camera Receiver, CMOS Image Sensor, Low Frame Rate Camera.**

I. Introduction

THE VLC is an optical wireless communication that uses the visible light source (in our case, LEDs) as a transmitter and typically a photodetector (i.e., photodiode, phototransistor etc.) or an image sensor as the receiver [1]. By changing the light intensity of the LEDs, we can transfer data, but this changing must be very fast to prevent the effect of flickering. There are several advantages of the VLC system compared to the classic radio communication system: more energy efficient, by using light instead of radio waves, more secure compared to the radio waves who creates electromagnetic interferences and can be dangerous in hazardous operations [2]. As a disadvantage, the communication requires a permanent line-of-sight clearance between the transmitter and the receiver.

There are a variety of applications in which VLC can be used, for example in aviation, where it can be used to provide media services for passengers, in hospitals, where can be used where the medical equipment can interference with the radio waves, and in underwater wireless communications. An application in which VLC has a key role is the automotive communication. With the continuous development of the autonomous cars, the current road infrastructure system can be improved using VLC to provide a safe road traffic. The vehicle communication systems [3] can be divided in two subsystems: vehicle-to-vehicle (V2V) and vehicle-to-infrastructure (V2I). An important application of the V2I system could be the possibility that the car could communicate with the traffic signaling system. An example could be the automatic braking of the vehicle in case of the red lights and an audio warning in the case of yellow lights [4], thereby reducing the red lights crossing rate and increasing the traffic safety. In V2V systems, the vehicle headlights and taillights could be used to transmit messages about the current state of the car, hard brake warnings to the surrounding cars. An application that uses the V2V and V2I systems simultaneously is the Intelligent Transportation System (ITS) [5], who collects the traffic data from the systems, analyses it, and based on the given results it automatically adjusts the road system to the situation. The advantage of the ITS is that the traffic is monitored continuously, and in case of a traffic congestion, the traffic lights can adjust automatically to ease the traffic, increasing the efficiency and in case of an accident, the traffic lights can turn green to ease the access of the emergency vehicles. In the automotive applications, a modern approach in developing a VLC system is by using a CMOS image sensor [6] as a receiver. An advantage of the CMOS image sensor receiver is the possibility to receive multiple transmitted data by LEDs modulated individually [7]. Another advantage of using an image sensor as a receiver is the possibility to communicate with different transmitters. For example, the VLC system can receive simultaneously the information from the traffic signaling lights and from the taillights of the vehicle ahead. Because the possibility to separate the data that comes from multiple sources (e.g., the data from the LED itself, the data from the ambient light), the image sensor receiver can be

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used in outdoor applications without needing an optical filter placed in front of it. One existing solution uses cameras working at 1000 frames per second [8] and in other solutions, which use low frame rate cameras, a synchronization algorithm was developed in order to synchronize the image frame with the timing of the transmitted symbol and to increase the rate of the transmitted symbol to the limit of the symbol rate that corresponds with the image sensor frame image [9].

A camera with a high frame rate over 800 frames per second costs around 350 $, while a camera with a frame rate of 120 frames per second costs around 70 $. Of great importance is the fact that video cameras are already commonly used in many applications. The integration of VLC in such systems is much easier if a specialized receiver would not be needed.

Besides this introduction, the paper contains four sections as follows: Section II describes the proposed system, Section III details the proposed code that could be used for low frame rate VLC, Section IV shows the results. Section V concludes the paper and presents possible future improvements.

II. Description of the Proposed VLC System

It was shown in the introduction that VLC systems tend to use video cameras as receivers. The current state of the research uses very high frame rate cameras which are expensive and not commonly used in video-enabled systems. So, using this kind of cameras for VLC would still mean adding a specialized receiver (the high frame rate camera itself) to the system. The high frame rate of these cameras reduces the difficulty of finding a communication code which would not be observed as flicker by the naked eye but assures higher data rates.

The VLC system proposed in this paper can be used with cameras which work at a frame rate of 120 fps. Although classic video cameras capture 50 or 60 frames per second, 120 fps camera tend to replace them because they offer greater image quality when panning or other maneuvers that involve camera movement are executed. Their cost is also notably reduced in comparison with the cost of 800 to 1000 fps cameras.

The prototype of the system was implemented using an Atmel based development board which is equipped with the necessary components to successfully play the role of the transmitter (i.e., a microcontroller and an LED), and a uEye UI-1485LE-M-GL camera as the receiver. The available camera was set to capture only grayscale images. By reducing the resolution of the acquired images, higher frame rates can be achieved. The resolution of 100 by 100 pixels was enough for the experiment and allowed the usage of a frame rate equal to 120 fps. Cameras with a resolution of 1280 by 720 pixels (also known as “HD ready”) which can capture 120 frames per second are commercially available. The data is sent from the transmitter to the receiver by switching the LED on and off fast enough so, by looking at it with the naked eye, a person would not observe flickering. The on and off switching sequence must be done in a way in which at least two symbols can be identified (i.e., an alphabet that can be represented using one bit). This would allow users to imagine their own higher-level codes and transmit them using the two symbols that are available. This type of modulation is called OOK (On-Off Keying). The luminance of each captured frame is then analyzed to determine if the LED was on or off. This computation was done using Matlab running on a laptop PC.

The great challenge is represented by finding a switching code that would assure a robust decoding, would not produce flicker, designed to be captured only using a sampling rate of only 120 samples per second (the frame rate of the camera) without having available a synchronization between the transmitter and the receiver. The prototype of the proposed system is presented in Fig. 1.

III. The Proposed Communication Code

Cameras which capture pictures with high frame rates allow faster on-off switching of the LED to be detected. Also, having available a high sampling frequency, finding a communication code which would assure robust decoding and would not provoke flicker when the transmitter and the receiver are not synchronized is not a difficult challenge. Having the possibility to sample the signal many times in a symbol period almost mimics the behavior of using the classical photodetectors as receivers, resulting in great robustness. Lowering the amount of samples values in a symbol period still could assure robustness if the transmitter and the receiver are synchronized. The difficulty of the problem is clear when the working conditions are characterized by low sample rate and no transmitter-receiver

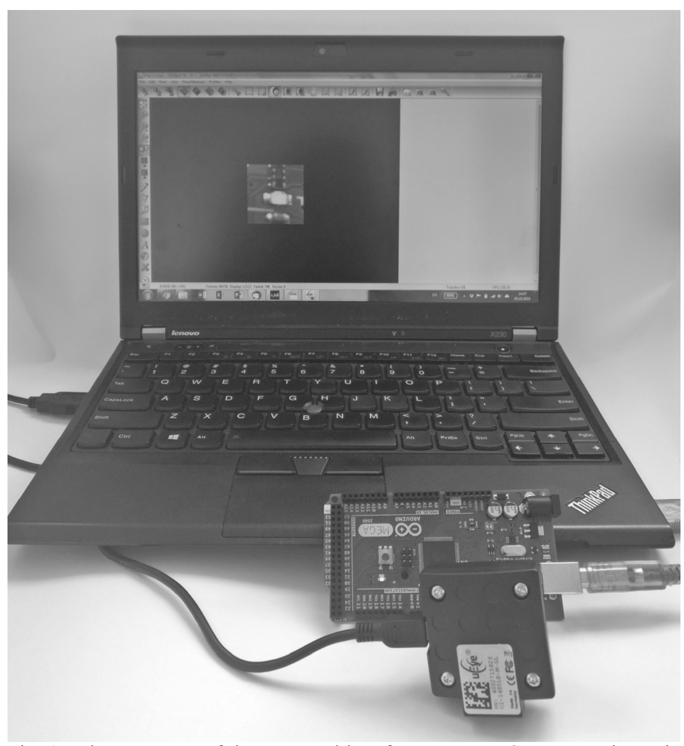

Fig. 1. The prototype of the proposed low frame rate VLC system. The main parts can be observed (the development board, the camera and the image processing station represented by a laptop computer). On the screen of the computer can be observed the LED which represents the transmitter in this system.

synchronization. This is the situation of a low frame rate video-based VLC system. The paper presents a code that was successfully used in a low frame rate VLC system.

The lack of synchronization between the transmitter and the receiver means that the sampling moments can be anywhere in the symbol period. A code must be invariant to the sampling moments to be able to be used in such conditions. Also, to consist the base of a higher-level communication, the alphabet of this code must contain at least two symbols, clearly distinguishable by the receiver. This way, one symbol could play the role of logic “1” and the other symbol would be logic “0”. It is obvious that a sequence of those symbols could form larger code words which could then be interpreted by the receiver, leading to a second level code which could have more symbols. This paper presents only the physical level of the communication that is the correct transmission of the two base symbols of the code. It was considered that large brightness in the sampled frame would correspond to a logic “1” and lower brightness frames would represent the logic “0”. The code symbols are made from specific sequences of frames.

The proposed symbols have two parts: one common preamble and the symbol identifier. The preamble has the role of a synchronization sequence, to signal the receiver that a new symbol starts. The two symbols that form the alphabet of the proposed code are illustrated in Fig. 2, along with some arbitrary chosen sample points. Let us consider that the first code corresponds to “1” and the second one to “0”. This convention is used further on. The sample points are spaced at 1/120 seconds because the frame rate of the video camera is 120 fps. It can be observed that the LED is switched on or off after some time intervals which can be identified as being long or short. Short time interval switching occurs every time the next character is different from the last one (i.e., changing from “1” to “0” or from “0” to “1”). The drawing in Fig. 2 is correctly scaled so times can be measured. For simplicity, the time intervals are also specified: the long one is 1/240 seconds long and the short one lasts 1/480 seconds. This time scaling was necessary to avoid flickering. There is no information that would guarantee that the sampling points would always fall in the time moments considered in Fig. 2. Because of this, the receiver must not recognize absolute brightness values, but their changing pattern in time. This approach works only if the possible received pattern are the ones considered in Fig. 2 or their logically negated values. The proposed code has this remarkable property: no matter where the sampling points fall on the signal, the only possible received sequences are the one shown in Fig. 2 or their negated values. The symbols can now be translated into two patterns: “AABBAB” and “AABBAA”,

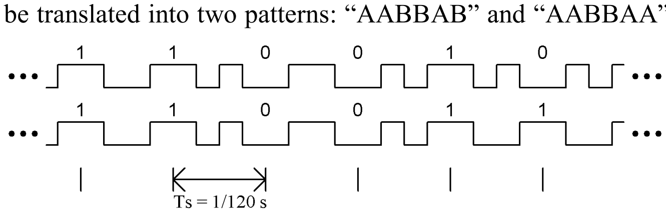

Fig. 2. The two symbols of the proposed code. The first four bits in each word represent the preamble and the last two are used to correctly distinguish between them.

where A and B is a low or high brightness level frame. There is no need to have a unique correspondence between “A” and “B” and the low or high brightness frames. The receiver would look only after the corresponding transitions. This behavior is easily explained by taking an example. Let us consider that when the camera starts, the first frame it acquires is a low brightness frame. This would represent the “A” frame. Let us consider that the next frames follow in this order, from the brightness point of view: low, high, high, low, high. Now the decoder just identified an “AABBAB” sequence, where “A” was the first acquired frame, in this case a low brightness frame. This means that the transmitted symbol was “1”. If another case is considered, when the camera is started the first captured frame is bright, this would also represent the “A” frame. If the next sequence is: bright, dark, dark, bright, bright, an “AABBAB” sequence is identified and the decoder can decide that the “0” symbol was sent, even if in this situation the first frame was bright, contrary to the previous example. Those two examples considered the case in which the camera is started at the beginning of a symbol. If the camera was started in the middle of a symbol transmission, the receiver will not identify as a known sequence the frames that correspond to the symbol that already started but will be able to resynchronize with the next symbol. The easiest way to show that the code is invariant to the sample moment is to illustrate all the possible sampling situations in Fig. 3 and Fig. 4. It can be observed that the “AABBAB” sequence is found

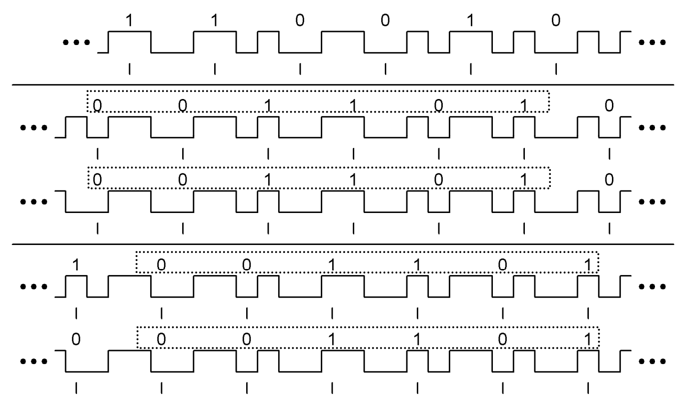

Fig. 3. The illustration of all the possible sampling points for the first code symbol, preceded by each of the two code symbols. Dashed rectangles show the correctly identified sequence.

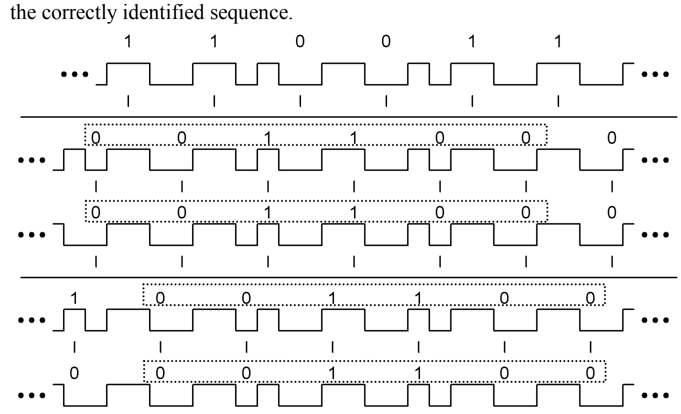

Fig. 4. The illustration of all the possible sampling points for the second code symbol, preceded by each of the two code symbols. Dashed rectangles show the correctly identified sequence.

in the case of the first symbol, no matter where the sampling point falls. The correctly identified symbol was marked with dashed rectangles. In the case of the second symbol it can be seen that the sequence is “AABBAA”, still invariant of the sampling point, also highlighted by dashed rectangles.

IV. Results

The prototype for the proposed low frame rate VLC system was implemented. In Fig. 5 a captured video sequence is shown, and the extraction of the code is exemplified. The video sequence was captured by holding the camera in hand and so a small upward movement can be observed especially by checking the top of the image and its lower right corner. This is a real-world recorded video sequence. The images in Fig. 5 are all different, not only two images duplicated for exemplification. The bight and dark frames can be identified even with the naked eye. The overall brightness of the image was computed in Matlab and the decision regarding dark and bright frame occurrence was done by comparing the brightness of the frame with a threshold. The threshold is adaptively computed by averaging the brightness of 120 frames (the first second of the recorded video signal). In Fig. 6 can be observed the waveform applied to the LED and the first symbol of the code is highlighted. The results confirm the functioning of the proposed system. The symbol rate (which is equivalent to the bit rate because there are only two symbols in the code) is 20 symbols per second. This could be increased by using a matrix of transmitting LEDs, resulting a parallel transmission.

V. Conclusion and Future Work

The paper proposes a VLC system that uses a LED as a transmitter and camera with a frame rate of 120 fps as a receiver. The challenge of using a camera with a low frame rate is to find a communication code that would assure robust decoding, would not produce flicker and does not need a synchronization between the transmitter and the receiver. The code is thoroughly described in the paper.

A prototype of the proposed system was implemented using a development board based on an Atmel microcontroller equipped with a microcontroller and a LED as the transmitter and a uEye UI-1485LE-M-GL camera as the receiver capturing 120 frames per second. The luminance of each captured frame is analyzed to determine if the LED was on or off. The total bit rate of the proposed system is 20 bits per second.

Future work would aim the increase of the bit rate by using a LED matrix as transmitter, where each LED would represent a separate communication channel. This involves LED localization in the frame. Given the small resolution in this case, the LED filled almost the whole frame and identifying its position is not needed. If greater resolution cameras are used, the position of the LED in the frame could be determined by subtracting consecutive frames.

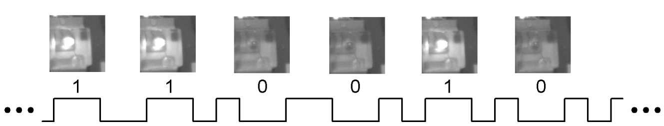

Fig. 5. The recorded video sequence corresponding to the first symbol of the proposed code. The hand movement can be observed by examining the top part and the lower right corner of each frame.

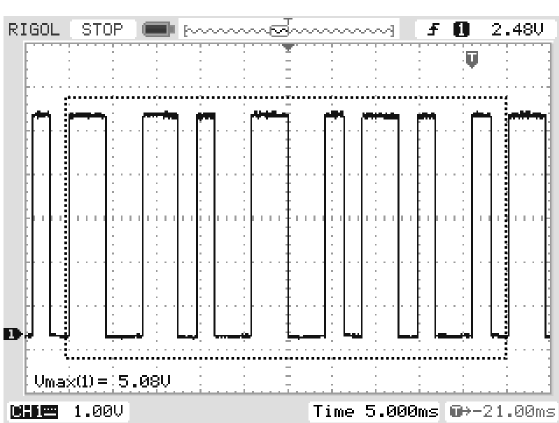

Fig. 6. The signal applied to the LED captured using an oscilloscope. The first symbol from the proposed code was marked with a dashed rectangle.

References

[1] H. P. Pathak, X. Feng, P. Hu and P. Mohapatra, “Visible Light Communication, Networking and Sensing: A Survey,” in *IEEE Communications Surveys & Tutorials,* vol. 17, no. 4, IEEE, 2015, pp. 2047-2077.

[2] J. J. George, M. H. Mustafa, N. M. Osman, N. H. Ahmed and D. M. Hamed, “A Survey on Visible Light Communication,” in *International Journal of Engineering and Computer Science,* vol. 3, no. 2, 2014, pp. 3805-3808.

[3] C. Medina, M. Zambrano and K. Navarro, “LED Based Visible Light Communication: Technology, Applications and Challenges – A Survey,” in *International Journal of Advances in Engineering & Technology*, vol. 8, no. 4, 2015, pp. 482-495.

[4] A. E. Marcu, R. A. Dobre and M. Vlădescu, “Key Aspects of Infrastructure-to-Vehicle Signaling Using Visible Light Communications,” in *Future Access Enablers for Ubiquitous and Intelligent Infrastructures. FABULOUS 2017. Lecture Notes of the Institute for Computer Sciences, Social Informatics and Telecommunications Engineering,* vol. 241, Springer, Cham, 2018, pp. 212-217.

[5] A. M. Cailean and M. Dimian, “Current Challenges for Visible Light Communications Usage in Vehicle Applications: A Survey,” in *IEEE Communications Surveys & Tutorials,* vol. 19, no. 4, IEEE, 2017, pp. 2681-2703.

[6] T. Yamazato, I. Takai, H. Okada, T. Fujii, T. Yendo, S. Arai, M. Andoh, T. Harada, K. Yasutomi, K. Kagawa and S. Kawahito, “Image-sensor-based visible light communication for automotive applications” in *IEEE Communications Magazine,* vol. 52, no. 7, IEEE, 2014, pp. 88-97.

[7] C. Premachandra, T. Yendo, M. P. Tehrani, T. Yamazato, H. Okada, T. Fujii and M. Tanimoto, “Outdoor Road-to-Vehicle Visible Light Communication Using On-Vehicle High-Speed Camera,” in *International Journal of Intelligent Transportation Systems Research,* vol. 13, no. 1, Springer US, 2015, pp. 28-36.

[8] S. Iwasaki, C. Premachandra, T. Endo, T.i Fujii, M. Tanimoto and Y. Kimura, “Visible light road-to-vehicle communication using high-speed camera,” in *2008 IEEE Intelligent Vehicles Symposium*, Eindhoven, NL, 2008, pp. 13-18.

[9] T. Kondo, R. Kitaoka and W. Chujo, “Multiple-access capability of LED visible light communication with low-frame-rate CMOS camera for control and data transmission of mobile objects,” in *2015 IEEE/SICE International Symposium on System Integration (SII)*, Nagoya, JP, 2015, pp. 678-683.