Visible Light Communication Using TV Displays and Video Cameras

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***Abstract*—Visible light communication (VLC) is an attractive alternative to radio frequency communication for applications requiring a wireless short range link. A lot of research work has been done on this topic. Different concepts for VLC are specified in standard IEEE 802.15.7. An interesting feature is the application of existing infrastructures like LED lighting to carry data transmission on top. In this paper, we describe a new approach which applies a video display as transmitter and a digital camera as receiver. Due to a multi-parallel transmission based on individual modulation of all pixels of the screen, high data rates can be achieved. A special feature is the option to design the modulation such that data transfer runs on top of a video presentation without annoying the viewer.**

I. INTRODUCTION

Visible light communication (VLC) is an attractive solution for many applications which require short range links with line-of-sight path. In comparison to radio frequency communication, advantages are that occupation of scarce radio spectrum and interference problems are avoided. Eavesdropping and other security problems can be reduced easier, and users feel more comfortable, as no invisible radiation is introduced in their surroundings. At the same time, implementation cost can be very low. The option to re-use lighting equipment as transmitter is an approach resulting in ideas for innovative services. Many researchers have contributed to the development of optical free space communication. Standard IEEE 802.15.7 specifies successful concepts for different scenarios, introducing modulation of light emission of general lighting as well as e.g. of LED-based traffic signs and displays [1].

Data rate is a key parameter of all communication systems. A lot of work has been put on efforts to increase the rate of optical free space transmission schemes. Using one single LED limits the data rate, especially if this LED is primarily used for lighting purposes [2]. Information on recent developments in VLC can be found e.g. in [3].

In this paper, a completely new approach is described which is based on reuse of existing consumer electronics components. Given a certain performance of the involved equipment, optical free space transmission of data rates in the range of 100 Mbit/s appears to be feasible.

The concept introduces a multi-parallel transmission, using a video display as a spatial-temporal modulator. Decoding is based on a camera recording of the screen. If suitable displays are used in combination with specific modulation schemes, data transmission can be achieved simultaneously to a video reproduction on the same screen without annoying the viewer.

II. TECHNICAL CONCEPT

The basic concept is shown in Fig. 1. A flat display for TV reproduction such as an OLED- or LCD screen is used to show a live video, while hidden in the picture, many or all pixels are modulated to transmit data. The scene can be recorded by a camera, which e.g. might be a part of a smart phone. Considerations to use a smart phone camera to decode VLC signals have been published before [4]. However, in our case the high spatial resolution of the camera is exploited. The tendency to very high pixel count even in cheap CMOS cameras supports our concept. By processing of the video signal that is recorded by such a camera data can be decoded.

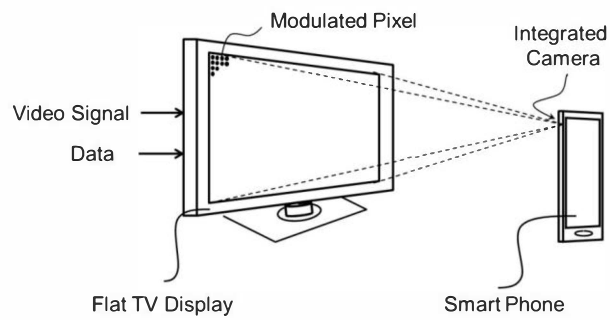

Fig. 1 Basic optical communication setup: TV display serves as the transmitter; smart phone is used as a receiver

Different modulation schemes can be used, depending on the parameters of the display. One approach would be a temporal modulation of all pixels individually. In order to achieve that the modulation is not visible or at least not disturbing the perceived video quality, a differential modulation scheme is proposed. If the display provides a frame rate of 50 Hz, one option would be to keep the picture content constant for two succeeding frames during a data transmission, like in film reproduction with simple picture repetition. Data is then encoded using a kind of manchester code in temporal direction, individually for each pixel in a pair of frames. The modulation sequence is $\{c,-c\}$ or $\{-c,c\}$ for a logical 0 or 1, respectively. The amplitude c is the modulation amplitude which should be selected small compared to the video amplitude range. The data rate per modulated pixel will thus become 25 bit/s in this example. If we apply a full-HD screen and modulate all colors simultaneously, we achieve a data rate of 1920 x 1080 x 25 bit/s = 51,9 Mbit/s. Higher frame rates as used in practically all modern displays allow for

978-1-4799-7543-3/15/$31.00 ©2015 IEEE

even higher data rates, and the introduction of 4K displays provides options for further enhancements.

Fig. 2 gives a simple example of a temporal modulation scheme, assuming an 8-bit representation of pixel amplitudes.

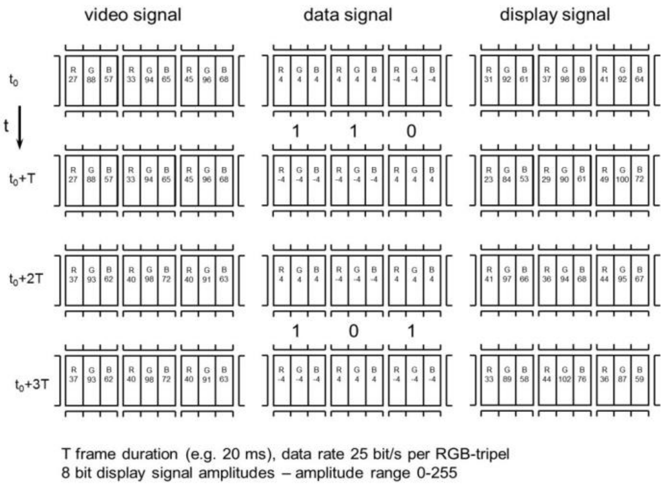

Fig. 2 Example of pixel amplitudes in temporal differential modulation

The figure shows the amplitudes of a small part of the screen with three pixels, each consisting of RGB sub pixels. The amplitude of the video signal is kept constant for t_0 and t_0+T, with T being the frame duration of the display. In this simple example, data is modulated with c=4, equally for the three colors. The resulting amplitudes are given in the right column of the figure.

Different modulation schemes are possible, e.g. spatial differential modulation of luminance, temporal differential modulation of color, spatial differential modulation of color, and combinations thereof. Depending on the characteristics of the display, i.e. resolution and temporal filtering, a good compromise has to be found between data rate, noise sensitivity and visibility to viewers. Temporal modulation requires a short impulse response time. OLED devices will be an excellent choice due, whereas the response time of LCD screens has to be considered carefully in the design of the complete system.

Decoding based on cheap consumer camera elements like those built into smart phones requires temporal and spatial synchronization. The video camera has to provide the frame rate of the display as well as frame synchronization. A user can be supported to adjust the camera to the video screen by the camera monitor. When using a smart phone, this will be its display. In order to simplify this task, a high resolution camera with automatic zoom function is recommended. In order to reduce the requirements on spatial synchronization, spatial filtering can be introduced at the transmitter side. In this case, a small group of pixels will be modulated with the same amplitudes. Thereby, scanning of the pixel raster can be simplified. Of course, this advantage has to be paid with a data rate reduction.

Although the idea of a system transmitting high data rates as an add-on to video representation is pushed by the ubiquitous fast technological improvements in consumer electronic devices, a lot of details still have to be considered to achieve a robust system design which guarantees Quality of Experience. One aspect is the synchronization procedure which might be supported by reference data. Powerful error protection can help to increase the reliability. Nonlinearities of the screen as well as the procedure to add the data modulation to dark black or peak white image content must be taken into account.

III. Application Areas

Based on a video display and a camera, a high rate optical communication can be set up, supporting data rates in the range of 100 Mbit/s. It is a line-of-sight transmission for short links. Suitable ranges are defined by the size of the display and the camera optics.

The implementation requires some modifications in the display. A data interface and modulation signal processing have to be introduced. Although the additional cost is very low due to the availability of powerful computing resources in modern TV sets, the application of the concept in home environment appears to be not the first choice. Here, WLAN based communication is an alternative which is well established in the market.

A preferred application of the proposed concept will be in public areas, e.g. for kiosk systems. Without registration in a network, users can pick up data at high rates by simply directing their smart phone camera to the display. An App could provide necessary processing and synchronization support. As an example, a real time HD music video might be reproduced on a public screen, while the audio data of the music are transmitted to viewers on top of the presentation without any additional hardware costs.

IV. Outlook

In the final paper, the technical concept will be discussed in detail with a focus on modulation options and synchronization procedures. First practical results of a demonstrator system built at the Communication Technology Institute at TU Dortmund University will be given. Future work will comprise the refinement of signal processing, evaluation of technical limits as well as specification of higher layers of data transmission for a variety of applications.

V. References

[1] IEEE Std. 802.15.7-2011, "Short-Range Wireless Optical Communication Using Visible Light", 6 September 2011

[2] J. Gancarz, H. Elgala, and Th. D.C. Little, "Impact of Lighting Requirements on VLC Systems," *IEEE Communications Magazine*, Vol. 51, No. 12, pp. 34-41, December 2013

[3] L. Grobe et al., "High Speed Visible Light Communication Systems," *IEEE Communications Magazine*, Vol. 51, No. 12, pp.60-66, December 2013

[4] C. Danakis, M. Afgani, G. Povey, I. Underwood, and H.Haas, "Using a CMOS Cmaera Sensor for Visible Light Communication", *3rd IEEE Workshop on Optical Wireless Communications*, 2012, pp. 1244-1248