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Lighting as a Service that Provides Simultaneous 3D Imaging and Optical Wireless Connectivity

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***Abstract*—Light-emitting diodes enable optical wireless data transmission and advanced imaging methods such as photometric stereo-imaging. Both, wireless communications into a scene and 3D imaging of that scene is enabled in parallel using the same set of LEDs thus providing lighting-based infrastructure *e.g.* for automated agents.**

I. Introduction

As incandescent and fluorescent lighting is increasingly replaced by Gallium-Nitride based solid state luminaires, exciting developments have been made in the field of visible light communications (VLC). Through the dual use of visible light sources as luminaires and optical wireless transmitters at the same time, VLC promises to alleviate the capacity crunch in wireless networking at low energy consumption.

The fast modulation response of solid-state luminaires such as light-emitting diodes (LEDs) has not only sparked a frenzy of activity in VLC, but it also had impact on imaging. The projection of fringe-patterns by structured light sources enables increased performance in microscopy [1] and can be used for 3D imaging [2]. LEDs have also been used for photometric stereo-imaging, which enables 3D imaging using a single camera and illumination from different angles [3], [4].

Here, we demonstrate that both VLC and LED-assisted imaging can usefully be done at the same time using the same LEDs. We show that a scene can be monitored in 3D, while a VLC data link is established to receiving devices within the scene. Such a system could for example be employed in public spaces or manufacturing halls, allowing automated monitoring of the activity within the area through the 3D imaging and providing wireless connection to robotic agents that navigate the space. The simplicity of the components and setup yield potential for wide employment of such LED-enabled infrastructure.

II. Experiment

The experimental setup follows our earlier work [5] where four LEDs were placed around the camera in an X-shaped geometry, see Fig. 1. The camera was run at a frame rate of 60 fps and the LEDs were synchronized such that during each frame only one of the four LEDs was active. The scene monitored by the camera contained a white cardboard box for evaluation of the 3D imaging capability and a photodiode with

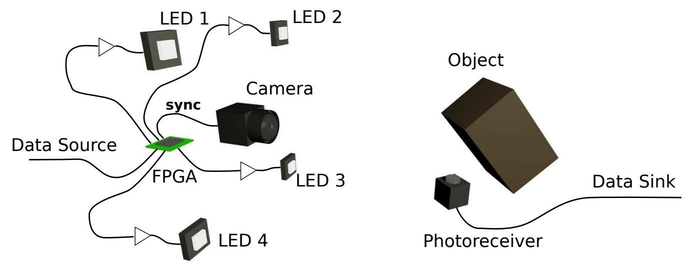

Fig. 1. Schematic of the experimental setup.

1 MHz bandwidth at a distance of 0.5 m from the LEDs that received the data signal.

Each LED was driven by an npn power transistor (BCX54) in emitter-follower configuration providing a luminous flux of 200 lm and a bandwidth of 8.6 MHz. The synchronisation signal from the camera to the LEDs was superimposed with a data signal. A field programmable gate array (FPGA) was used to combine the synchronisation signal with a data stream such that the LED that was active during one frame was not just constantly on but transmitting an on-off keying (OOK) data signal. The digital output from the FPGA was amplified to the LED drive voltage using an operational amplifier with 1.6 MHz bandwidth. Eye diagrams and bit error rate (BER) were measured on the basis of a pseudo-random bit sequence with 2^{19} bits.

III. Results

The photometric stereo method allows to calculate the surface normal vectors $\vec{n}$ of the imaged objects once four frames with illumination from different angles have been recorded. The components of the surface normal vectors are shown in Fig. 2. The spatial orientations of the three visible surfaces of the cardboard box are correctly identified. The position of the receiving photodiode within the scene is also visible.

The optical signal received by this photodiode is plotted in Fig. 3. On a slow (millisecond) timescale, it can be seen how the average intensity varies according to which LED is active during the current camera frame. This average intensity is seen by the camera and used for photometric stereo-imaging. On a faster (microsecond) timescale, the individual bits of the on-off keying data signals can be identified.

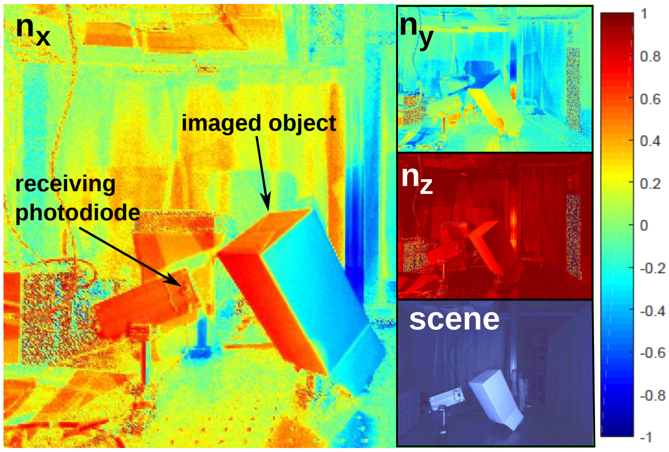

Fig. 2. Components of the surface normal vector. The position of the photodiode that receives the data signal in the seen is indicated in the plot of n_x, and n_y and n_z are plotted in the insets. A camera image of the scene with illumination from all four LEDs is also shown in an inset.

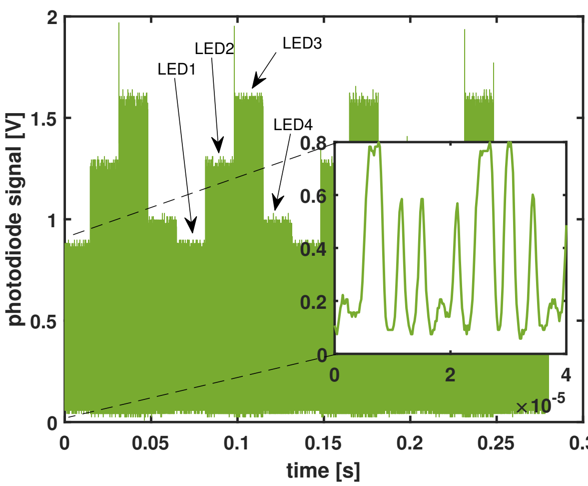

Fig. 3. Received signal of the photodiode at a data rate of 0.9 Mb/s. The main plot shows a time scale of several camera frames, indicating the times during which different LEDs are transmitting. The inset shows a time scale of several transmitted bits.

The corresponding eye diagram is shown in Fig. 4a). In the eye diagram, the '0'-level is constant because it corresponds to all LEDs being off, whereas the '1'-level is split into several sub-levels according to the intensity of the different LEDs at the position of the receiver. The BER was below detection limit up to a data rate of 0.9 Mb/s and increased above, limited by the bandwidth of the slowest components in the setup. At 1 Mb/s a high BER ($> 10^{-3}$) was found, which is thought to be caused by a parasitic resonance in the drive circuit.

IV. Discussion and Conclusion

We demonstrated the concept of imaging a scene in 3D and communicating to a receiver within the scene using low bandwidth ($\sim$1 MHz) components and simple on-off keying. In practical applications, the 3D information can be used to automatically identify targets of interest and direct a mobile unit towards them through the VLC link. Building on this intitial demonstration, higher bandwidth hardware and spectrally efficient encoding such as orthogonal frequency division multiplexing can be used to increase performance. Widely used VLC encoding methods should be applicable. Therefore, the demonstrated system has potential for wide employment as a surveillance system that includes VLC capability.

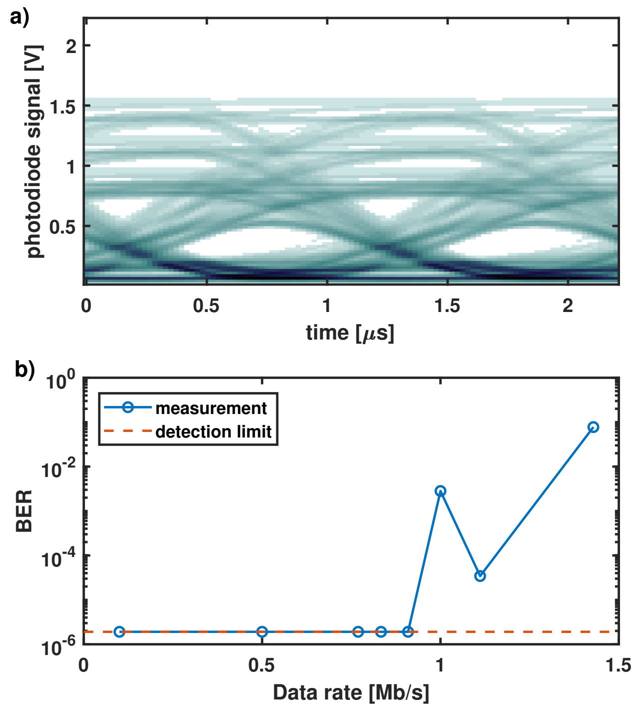

Fig. 4. *a)* Eye diagram at 0.9 Mb/s and *b)* BER as a function of data rate.

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References

[1] V. Poher, H. Zhang, G. Kennedy, C. Griffin, S. Oddos, E. Gu, D. Elson, J. Girkin, P. French, M. Dawson *et al.*, "Optical sectioning microscopes with no moving parts using a micro-stripe array light emitting diode," *Optics Express*, vol. 15, no. 18, pp. 11 196–11 206, 2007.

[2] T. Weise, B. Leibe, and L. V. Gool, "Fast 3d scanning with automatic motion compensation," in *2007 IEEE Conference on Computer Vision and Pattern Recognition*, June 2007, pp. 1–8.

[3] Y. Zhang, G. M. Gibson, R. Hay, R. W. Bowman, M. J. Padgett, and M. P. Edgar, "A fast 3D reconstruction system with a low-cost camera accessory," *SCIENTIFIC REPORTS*, vol. 5, JUN 9 2015.

[4] A. F. Martins, M. Bessant, L. Manukyan, and M. C. Milinkovitch, "(ROBBIE)-O-2-3D, a Fast Robotic High-Resolution System for Quantitative Phenotyping of Surface Geometry and Colour-Texture," *PLOS ONE*, vol. 10, no. 6, JUN 3 2015.

[5] J. Herrnsdorf, L. Broadbent, G. C. Wright, M. D. Dawson, and M. J. Strain, "Video-rate photometric stereo-imaging with general lighting luminaires," in *2017 IEEE Photonics Conference*, 2017.