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Adaptive Modulation and Lighting State Control in VLC Systems

MS Project Proposal

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1. Abstract

Intensity and color control of light-emitting diode (LED) luminaires pose a challenge to the integration of visible light communication (VLC) systems. While such control systems enable dynamic illumination environments, most VLC schemes assume static lighting conditions. For the completion of a M.S. project, the synthesis of VLC and lighting state control will be investigated with an analysis of the tradeoffs between the bit-error ratios, data rates, LED chromaticity shifts, and energy use of modulation techniques. An adaptive modulation scheme will be proposed for improved efficiency given a dynamic user-defined lighting state and transmitter/receiver configuration. The scheme will be implemented on a software-defined radio VLC system.

2. Problem Statement

In order to surpass the personalization capabilities and energy efficiencies of past lighting technologies, next-generation light emitting diode (LED) luminaires feature superior light intensity and color control. However, the ability to flexibly adjust the lighting state results in additional complications for an illumination system integrated with visible light communication (VLC). VLC systems, which stream data wirelessly by high frequency modulation of the LED drive currents, must incorporate novel modulation schemes for compatibility with lighting control. These usually result in increased complexity and performance losses as compared to systems designed for unvarying lighting conditions. In particular, dimming schemes inherently limit the transmitted optical power and place restrictions on the modulated waveform. Additionally, reducing light intensity may result in an undesired chromaticity shift of the emitted light. Energy consumption is another system attribute which is dependent on the modulation scheme. While a number of modulation schemes compatible with dimming requirements have been proposed to mitigate data rate and light quality losses, a comprehensive assessment of such techniques is lacking.

For the completion of a M.S. project, modulation schemes compatible with lighting state control will be compared by an assessment of the tradeoffs between bit error ratios (BER), data rate, output color integrity, and energy consumption. Leveraging the research results, an adaptive modulation scheme will be proposed for improved performance in next-generation illumination control systems, i.e. "Smart Lighting" systems. Adaptive modulation has been commonly used in other communication settings, such as 3G cellular networks, but has been hitherto unexploited in VLC. The gains of the technique over traditional fixed modulation schemes will be quantified. Ultimately, the adaptive scheme will be empirically tested in a software-defined radio VLC communication system.

3. Prior Work

Optical communication has become a vital technology for data transmission in the twenty-first century. While fiber-optic communication is the most prevalent, free-space optical (FSO) communication has also progressed as LED and laser diodes have improved since the 1970s. A significant body of research work exists for wireless infrared (IR) communications; industry standards for wireless infrared technologies have been specified by the Infrared Data Association (IrDA) since the early 1990s [1]. The field of indoor visible light communications, emerging as it is known today within the last decade, shares considerable characteristics and challenges as wireless IR. "Fundamental Analysis for Visible-Light Communication" by Komine and Nakagawa in 2003 proved to be one of the first comprehensive assessments of VLC. Its potential and feasibility has since been studied by several research groups worldwide [2-6].

Numerous modulation schemes have been proposed for and implemented in VLC systems. Each has characteristic energy and bandwidth requirements. Many of these schemes coincide with those popular for wireless infrared communications, such as on-off keying (OOK), pulse position modulation (PPM), and differential pulse position modulation (DPPM) [1]. Pulse-amplitude modulation (PAM), an additional baseband communication technique, has also been utilized [4]. Single subcarrier modulation and multiple subcarrier modulation schemes have additionally been exploited; orthogonal frequency division multiplexing (OFDM) has achieved the highest data rates for VLC systems [6].

A number of schemes also exist with dimming compatibility. These schemes are mainly variants of the types named above. A user can select a dimming percentage within a given range, which will adjust the modulation accordingly. The IEEE 802.15.7 standard specifies several modulation methods with dimming support including OOK with compensation time, and variable PPM (VPPM). More complex schemes such as multiple pulse position modulation (MPPM) [7], overlapping pulse position modulation (OPPM) [8], and a hybrid of discrete multitone modulation and pulse-width modulation [9] have also been proposed.

A number of the modulation and dimming methods reduce the DC bias point of the LED in order to achieve a desired lighting intensity. This has the unintended consequence of a chromaticity shift, whereby the color emitted from the LED varies from its intended hue due to the LED being underdriven. The extent of the shift is dependent on the dimming level, the employed modulation technique, and the LED model utilized. Debyle et al. conducted a preliminary study on the color effects of dimming due purely to dimming mechanisms (no communication) [10].

While the modulation options are plentiful, typical systems employ only one particular scheme for a communication session based on a particular lighting state. On the contrary, in radio frequency (RF) communications, it has become increasingly popular to vary the modulation scheme and/or other communication parameters according to the channel conditions [13]. Simple implementations can be performed using software defined radio systems, which flexibly allow transitions between different schemes. Adaptive modulation catered to VLC will be modified from the techniques utilized in RF thus far. A "software defined visible light communications" setup has already been designed by Rahaim et al. and is available for use in the Smart Lighting laboratory [11].

4. Approach

The approach to be taken for the completion of the M.S. project will have three components – analysis of current schemes, development, and implementation.

The analysis of current schemes in light of communication theory will reveal the salient differences that determine the optimal scheme for a given lighting state. The energy requirements, bandwidth requirements, and the data rate performance of these schemes (for a given BER) will be compiled. The effect of these methods on the output chromaticity of a given LED will be estimated using the characteristics of a particular LED. Tradeoffs between schemes will be identified. The modulation schemes under consideration will be simulated in MATLAB in order to effectively compare schemes under a variety of different lighting state constraints.

The developmental phase of the project will entail the formulation of an adaptive VLC modulation scheme. This will take into account parameters such as energy consumption, bandwidth, dimming percentage, and data rate. As a parameter is varied to the extent that another modulation method would yield improved performance, the adaptive technique will change to the superior scheme. This will additionally be simulated in MATLAB with the communication and lighting emulation software (CandLES) designed by Rahaim et al. [12]. CandLES assesses overall VLC performance for a given system design and environment.

The implementation of the project will be in programming and testing the adaptive modulation scheme using the software defined VLC setup (SDVLC) in Boston University's Smart Lighting lab. Like previously implemented modulation methods, the adaptive scheme will be a modification to the open source GNURadio platform utilized in the system. This entails reprogramming the FPGA of the device using the hardware description language Verilog. Once programmed, the adaptive scheme will be empirically tested. Results will be compared to the predicted theory.

5. Plan and Schedule

- *Mid-Late January*: During this phase, the relevant modulation/dimming schemes will continue to be researched. These will be simulated using MATLAB. The performance of the techniques given relevant environmental and user preference parameters (such as data rate and dimming percentage) will be theorized. The parameters will be incorporated into the simulations. Tradeoffs between the modulation techniques will be identified.
- *Late January – Mid February*: In this time period, the effects of any additional parameters of interest (such as color control and energy use) on VLC schemes will be researched and simulated. A summary will be produced which highlights the pros and cons of each scheme under different circumstances.
- *Mid February – Mid March*: An adaptive modulation model will be formulated. This will leverage the results of the analysis performed in the earlier weeks. If necessary, multiple schemes will be proposed with advantages and disadvantages noted. The model will be simulated in MATLAB using the CandLES software. This will theoretically test the performance of the technique. The data rate and/or quality gains of using the adaptive technique over traditional approaches will be quantified.
- *Mid March – Early April:* The software defined visible light communication (SDVLC) setup will be programmed with the formulated adaptive modulation scheme. The code will be debugged and optimized for performance. Experimental testing of the modulation scheme will ensue. Additional adjustments to the technique will be made to optimize performance.
- *Early April – Late April*: The experimental results using the SDVLC setup will be compared to the predicted theoretical results. Deviations between empirical data and theory will be explored and explained.
- *Early April-Early May*: The final report describing research, implementation, and testing will be written and edited. The work will be presented.

6. References

[1] Kahn, Joseph M., and John R. Barry. "Wireless infrared communications." Proceedings of the IEEE 85.2 (1997): 265-298.

[2] Komine, Toshihiko, and Masao Nakagawa. "Fundamental analysis for visible-light communication system using LED lights." Consumer Electronics, IEEE Transactions on 50.1 (2004): 100-107.

[3] O'Brien, Dominic C., et al. "Visible light communications: Challenges and possibilities." Personal, Indoor and Mobile Radio Communications, 2008. PIMRC 2008. IEEE 19th International Symposium on. IEEE, 2008.

[4] Grubor, Jelena, et al. "Broadband information broadcasting using LED-based interior lighting." Journal of Lightwave technology 26.24 (2008): 3883-3892.

[5] Cui, Kaiyun, et al. "Line-of-sight visible light communication system design and demonstration." Proceedings of Communication System Networks and Signal Processing, CSNDSP (2010): 621-625.

[6] Afgani, Mostafa Z., et al. "Visible light communication using OFDM." Testbeds and Research Infrastructures for the Development of Networks and Communities, 2006. TRIDENTCOM 2006. 2nd International Conference on. IEEE, 2006.

[7] Lee, Kwonhyung, and Hyuncheol Park. "Modulations for visible light communications with dimming control." Photonics Technology Letters, IEEE 23.16 (2011): 1136-1138.

[8] Bai, Bo, Zhengyuan Xu, and Yangyu Fan. "Joint LED dimming and high capacity visible light communication by overlapping PPM." Wireless and Optical Communications Conference (WOCC), 2010 19th Annual. IEEE, 2010.

[9] Ntogari, G., et al. "Combining illumination dimming based on pulse-width modulation with visible-light communications based on discrete multitone." Journal of Optical Communications and Networking 3.1 (2011): 56-65.

[10] Dyble, Marc, et al. "Impact of dimming white LEDs: chromaticity shifts due to different dimming methods." Optics & Photonics 2005. International Society for Optics and Photonics, 2005.

[11] M. Rahaim, A. Mirvakili, T. Borogovac, T.D.C. Little, and V. Joyner, "Demonstration of a Software Defined Visible Light Communication System," Mobicom 2011, Poster and Demonstration Competition, September 2011.

[12] Rahaim, Michael B., Tarik Borogovac, and Jeffrey B. Carruthers. "CandLES: communication and lighting emulation software." Proceedings of the fifth ACM international workshop on Wireless network testbeds, experimental evaluation and characterization. ACM, 2010.

[13] Chung, Seong Taek, and Andrea J. Goldsmith. "Degrees of freedom in adaptive modulation: a unified view." Communications, IEEE Transactions on 49.9 (2001): 1561-1571.