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System Architecture for Road Lighting

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Abstract—Traditional road lighting systems consume a large amount of energy. When the ambient light falls under a certain threshold, all the luminaries are turned at full-power without considering user perception and interaction. The feeling of safety experienced by users and user-lighting system interaction via consumer electronics (CE) devices should be investigated. For this study, we establish a software-controlled testbed that allows changing the brightness level of each street luminary remotely. In this paper, we describe the system architecture of this testbed deployed on a street along with the future work directions.

I. INTRODUCTION

The last decade witnessed a change in the trend from conventional incandescent lights to solid-state lighting, which uses LED (light-emitting diode) luminaries for illumination. The high efficiency of solid-state lighting provides several benefits, in terms of energy consumption, overall carbon footprint, cost per lumen and lifetime [1]. Furthermore, it is possible to control the spectral, spatial, temporal polarization and color properties of the light using a solid-state light source [2]. Considering the relationship between such properties of light and human body chemistry [3], the controllability of the light source provides a new playground.

A lighting solution can be fully automated where an intelligent system reacts to changes using several sensors and actuators. Besides, the system can be interactive where users interact with the system using CE devices, such as their mobile phones, as in Dial4Light 2. Such an interactive design not only enables individuals to communicate with the system using a variety of CE devices but also provides a road lighting solution satisfying the user needs. There are certain requirements for such a system to work properly. Firstly, the system must be efficient in terms of latency. Secondly, the communication protocol used in the system should support necessary bandwidth to execute the commands properly even under heavy load. Finally, the installation should be as simple as possible while keeping the costs as minimum as possible.

Recently, various efforts have been made to design intelligent road lighting systems [4], [5]. In particular, realizing a road lighting testbed is of crucial importance to perform various experiments, which has not been done in any of the aforementioned efforts.

In this work, we present the technical details of a road lighting testbed installation on a street. The aim is to investigate the relation between road lighting and safety feelings of pedestrians using static scenarios, where different brightness levels are compared, on our testbed [6]. This testbed will enable us to analyze dynamic scenarios, where the system adjusts the brightness levels of individual luminaries according to the changes in the environment, as a future work.

II. PROBLEM DESCRIPTION

Consider pedestrians walking on a road, where a number of luminary poles are evenly placed. Assuming an average pedestrian walking speed of 1.25 m/s and a separation of 25 m between every two adjacent luminary poles, it takes 20 seconds for a pedestrian to walk from one pole to a neighboring pole. The road lighting system is required to adjust the brightness level of each luminary in this interval of 20 seconds based on the position and direction of the pedestrian subject. Light brightness adjustment commands need to propagate to the individual poles faster than this. As a worst case scenario, assume the system needs to adjust 10 poles simultaneously and it needs to turn each luminary from a fully off state to a 100% on state. It requires 10 messages per pole to do this using a fine quantization with step sizes of 10% brightness. Therefore, the system needs to support successful transmissions of 100 messages in 20 seconds in the worst case scenario, such that an area of 125 meters in both forward and backward directions can be lit within the specified time.

III. SYSTEM MODEL

Following the above analysis, we use power-line communication for sending commands to the luminary poles. The bandwidth of power-line is theoretically limited to a maximum of 8 messages/sec 3. Due to transmission errors and packet losses, power-line operates at an average throughput of 5 messages/sec in practice, which is sufficient for the worst case scenario described in Section II. This also reduces the installation costs significantly, since no additional wiring is required for communication to the luminary poles.

We establish the testbed with a PC, a segment controller (SC), 10 outdoor luminaire controllers (OLCs), i.e., 1 per luminary, and 10 luminaries. SC and OLC communicate through power-line wires while the PC connects to SC via Ethernet. The PC provides GUI for monitoring and sending commands to SC. The system model is depicted in Figure 1.

SC is responsible for monitoring and controlling the OLCs. Although various built-in functions, such as scheduling, alarming and logging come with SC, we use only the two basic parameters required to control the luminary brightness levels. These parameters are ‘state’ and ‘value’. The former is a boolean variable that defines the on-off state of the luminary while the latter is an integer value in the range 0-100, defining the brightness percentage of the luminary. The brightness of

1 This work is a part of the ENSURE initiative, which is supported by the Dutch Ministry of Economic Affairs.
2 Available online at http://www.dial4light.de
3 According to PLT-22 Power Line Transceiver by LonWorks.
An OPC - Object Linking and Embedding (OLE) for Process Control - server is required for the communication between the SC and the PC in the control room. We use a commercially available OPC client/server application in our testbed. Although one can access the SC using a web-based GUI via HTTP, we use LabView for building a GUI as it includes an OPC client and allows a human operator to switch between different scenarios effectively. Each luminary used in the testbed includes 84 LEDs with a total power consumption of 106 W and light output of 8820 lm at 100% brightness.

IV. EXPERIMENTS

The experiments have been done on De Zaale street on the Eindhoven University of Technology campus where 10 luminaries are approximately evenly placed. The LED luminaries have been installed using a metal fork along with the traditional HID luminaries as seen in Figure 2.

The schematic of the experiment is given in Figure 3. The small circles and squares denote the positions of the LED luminaries used in our experiments and the interfering luminaries, respectively. The star in the center shows the location of the subjects who rated different scenarios according to the perceived safety [6]. After some initial experiments, we observed that the interfering luminaries in the surrounding degrade the reliability of the questionnaire. In order to avoid external light interference, we installed additional OLCs to each interfering luminary and connected them to a second SC. Before doing an experiment, they are turned off via the PC GUI.

In the experiments, all the possible combinations of three different scenarios for both sides of the street are compared: flat (all luminaries at 40% dimming), increasing/decreasing (with 20% step sizes) [6].

V. CONCLUSIONS & FUTURE WORK

This paper presents the technical details of a preliminary testbed for intelligent road lighting. This testbed is used for investigating the relationship between the brightness levels of road lamps and the feelings of safety at night. Currently, users can interact with the system using a computer interface.

Following the result of this study, sensor boxes (including various sensors, such as camera, microphone, passive infrared and radar) will be placed on each lamp post. Additional questionnaires will be administrated while participants are walking through the street and the results will enlighten us further on how to utilize the sensory data efficiently. Using the inputs from these sensors, the system will adjust the luminance levels of each luminary. Our goal is a fully automatic, interactive and intelligent road lighting system where luminaries react to changes in the environment. The system should adjust brightness in real-time using both the sensory data and the feedback from the users through their CE devices.

REFERENCES


4 SC, OLC, OPC and the luminary used in the testbed are Philips LFC7065, Philips LLC7020 OLC, Marcom OPC and Philips CitySoul LED – BGP431, respectively.