Building and Environment 142 (2018) 472–483

Contents lists available at ScienceDirect

Building and Environment

journal homepage: www.elsevier.com/locate/buildenv

Smart and dynamic route lighting control based on movement tracking

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ARTICLE INFO

Keywords:
LED
Smart lighting
Street lighting
Dynamic
Energy saving
Sensing

ABSTRACT

Intelligent LED lighting pilot was carried out along a light traffic route in a housing area in Helsinki. The goal of the research was to develop and test a lighting control system with an optimal lighting behavior, which saves energy without lessening safety and security of route users during the dark. The developed lighting control solution was based on tracking route users' movements and location along the route with passive infrared (PIR) sensors. Using this information, the system could create lighting conditions where the illuminated area reaches further in front of the user than behind. This was considered as an optimal solution from the perspectives of energy savings and user comfort.

The control was implemented on a real life test site used by pedestrians and cyclists consisting of 28 lighting posts with controllable LED luminaires. The recorded PIR data was analyzed to evaluate the performance of the developed system in northern outdoor conditions and to compare different lighting control schemes and their influence on energy consumption. The experiences gained during the piloting showed that the system could operate in outdoor conditions, but strong wind in a cold environment caused false sensor activity. The used arrangement of the three PIR sensors with wide field of view made the system sensitive to false detections, especially as installed high in lighting poles surrounded by foliage. The relative energy saving compared to the existing control solution of the area was 60–77% depending on the used smart control scenario and the calendar time.

1. Introduction

Driven by the rapid uptake of light emitting diodes (LEDs), applications of intelligent or smart street lighting are spreading to various types of urban context [1]. Besides the energy efficiency and long lifetime of the LEDs, easy control compared to the traditional street lighting technologies has generated new opportunities for smart features in lighting. Smart systems with increased functionality can change the lighting behaviour with dynamic functionality and the ability to adjust spectral content and light distribution for example [2]. If designed wisely, smart street lighting can, besides energy savings, offer added value for urban environments on various levels of experience [3,4].

Lighting infrastructure is centrally located in city, close to people and activities. It provides excellent opportunity to collect and deliver information and services also beyond lighting. In this paper, we introduce smart lighting control system capable of tracking people movement in urban environment. Here, the information is used for dynamic street lighting control, but could be used for other services as well. Contrary to our previous work [5], the system can detect the direction of the movement and track the route that the person is taking enabling more sophisticated lighting behaviour with improved energy savings and user acceptance. The developed system is validated in real use environment along a light traffic route lighting in Siltamäki in city of Helsinki in which 28 control modules were installed. The performance of the system in real use environment is discussed and simulations and measurements are used to study the energy consumption of the developed system. Also, the data collected by the system is analyzed in the lighting design context as well as in use for other possible beneficiaries.

2. Background

The traditional way to control street lighting is based on a clock and/or daylight sensor adjusting the operating time. An active control of the light levels has not been feasible due to the difficulty to dim traditional light sources [6,7] but with current LED luminaires software-controlled street lighting systems have emerged to the market

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https://doi.org/10.1016/j.buildenv.2018.06.048
Received 23 March 2018; Received in revised form 20 June 2018; Accepted 21 June 2018
Available online 22 June 2018
0360-1323/

[8,9]. Sensors are typically used as part of the control system to deliver information about the use conditions. Office type indoor lighting is a typical example of wide-spread application of using sensors to turn the lighting on and off according to the presence of people. Depending on the control features of the system energy savings of 20–70% have been reported [10–13]. In street lighting, simple on-off functionality is generally not acceptable for safety and aesthetic reasons [6,14–16] and more sophisticated controls with advanced dimming are required [6,9,15–17].

Currently, energy savings with smart control in street lighting have already been demonstrated in many case studies. Lau et al. [9] introduced a remarkable 90% energy saving simulation compared with conventional control schemes with an adaptive street lighting algorithm based on traffic sensing to progressively control the brightness of street lighting. Ouerhani et al. [18] showed 56% savings in his real-world installation of dynamic street lights compared to classical static, time-based street lighting control, and Sun et al. [19] proposed a multi-sensor system with the average energy consumption reduction of 40% for solar powered street lights. Although savings are impressive, they are often based on case studies rather than normal use installations, which would be rather complicated to execute as street lighting levels are often strictly regulated [7].

In our previous work, luminaires incorporated with sensors and low energy two-way wireless communication were installed on a pedestrian road in Helsinki. The system was able to deliver different lighting modes and record data including ambient temperature, LED board temperature, light reflected from the road, direct light from the LEDs, pedestrian presence sensor activations and, most importantly, energy consumption. This data were delivered to a web page that also served as a user interface for remote control of the pilot installation. Reduced power levels of more than 40% were demonstrated for pedestrian street lighting in this installation. With light level sensing approximately 45% less power could be used during the night with fresh snow compared with the previous night with no snow on the road while maintaining the same measured reflected light level. In the pedestrian sensing mode the luminaires operated on average at 40% lower power than in the passive use mode during the five-day test period of pedestrian sensing. In this study, the luminaires were dimmed to 50% drive current and raised back to passive use mode when an approaching pedestrian was detected. Due to the inability to detect the direction of the person's movement, the lighting was symmetrically increased around detected person [5].

In this work we present passive infrared (PIR) sensing solution for movement tracking. Human bodies are good sources of infrared radiation with some 100 W power emission in wavelength range of 5–14 μm [20]. Today, PIR sensors are commonly incorporated with lighting due to their low cost, small size and practical function to detect human presence by the thermal power emitted. Also, the detection does not depend on the amount of visible light and sensing does not need much computation. In many applications it is also appreciated that as the sensing provides only thermal characteristics of the objects it avoids privacy concerns. The drawback of the PIR sensing is that the detection can be disturbed by other sources of thermal energy, like engines and temperature changes in the ambience [21]. Also, as the detection is based on the change in temperature the target must move or special techniques, like chopping of infrared radiation or sensor rotation, must be used [22,23]. Similar to our work reported in this paper, Lukkien and Verhoeven [24] used PIR sensor based system for dynamic street lighting control in their pilot installation in Eindhoven, Netherlands, and used collected PIR sensor data to simulate energy consumption of different lighting controls. Comparing dynamic lighting behaviour to static control of the same system the energy savings up to 28–38% were shown. Though the energy saving is significant, Lukkien and Verhoeven stated that the direct economic advantage per pole is limited due to the relatively low energy prices. Consequently, they proposed more versatile usage of the collected data to balance the extra investment [24].

In this paper, the movement direction and people tracking was detected using low cost PIR sensors. Movement direction could be detected with vision-based camera recognition. However, compared to the proposed system such an installation is expensive. Also, operation of image recognition is affected by the surrounding illumination and the processing of a visual material requires a lot of computation capacity. In addition, people generally dislike camera installations for privacy reasons [25]. Sophisticated human tracking has also been realized with depth sensor (Microsoft Kinect) [26]. However, most of the reported applications are made indoors as the first version of the Kinect sensor was not suitable for sunlight conditions due to the structured light technique used in the detection [27]. Compared to such advanced detection systems installed in few critical locations, our system introduced in this paper is designed as part of street lighting infrastructure that would cover the environment widely. As such, the weaker detection accuracy could be compensated with the redundancy of the repeated installations. The approach is analogous to the results of Lovett et al. [28] stating that sensing value can be maximized by using multiple low-cost, less valuable sensors rather than fewer high-cost, more valuable ones. The luminaires acting as a communicating, sensing and reacting individuals is a classical example of 'Internet of things' combining many individual devices of everyday life into one communicating network [18]. It can be assumed that in future a significant number of these devices will be related to lighting as they already exist all around urban areas. Our research is one step towards this vision.

3. Objectives and methods

The objective of the research was to develop and test control method capable of providing sufficient illumination for safety and security of the route users while minimizing the energy consumption of light traffic route lighting. The research hypothesis was that this could be achieved with adaptive lighting control, which keeps the lighting at low level when nobody is present, and when a person appears, brightens the lighting around the user and dims it again after he/she has passed. Optimally from the perspective of comfort and energy savings, the illuminated area would reach further in front of the user than behind. For this task, a system able to detect the direction of the movement and track the route that the person is taking was needed. The system should also be able to manage several road users at the same time. Furthermore, as the system is installed at every lighting pole, it should have low device cost and wireless communication to keep the infrastructure and installation costs minimal. As the dynamic lighting behavior could disturb the users [15], the control scheme needed to be designed so that the changes of the lighting level could not be perceived. In practice this would mean soft, low speed dimming ramps and wide enough brightened area around the road user. The area would be non-symmetrical extending further away towards the direction of the movement for optimized energy savings. The objectives of testing of the system were to evaluate its performance in northern outdoor conditions and to estimate energy saving potential with the developed system.

3.1. Research context and test installation

A sensing and control system able to fulfill the research objectives was developed and tested in real life pilot installation that situated along a light traffic route in Siltamäki housing area in Helsinki. The route was used by both pedestrians and cyclists. The route runs besides two and three story blockhouses and a kindergarten on the other end, then crossing a road, continues to run past another kindergarten, and finally runs alongside a park. The image of the pilot site is shown in Fig. 1. There are some elevation changes along the route. The length of the walkway with pilot installation is in total 750 m. The lighting control and movement detection was limited to only one dimension, and people entering and leaving from the crossing road and paths could only be detected when moving along this route. In the 6 m high lighting