Towards Efficient Illumination Control for Underground Parking

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Abstract. Increasing the illumination efficiency of underground parking is challenging mainly because traditional control strategies have limited applicability to this type of spaces. LED illumination is making its way into underground parking due to their greater lighting efficiency. However, LEDs bring along new control possibilities that are yet to be explored and can further increase the energetic efficiency of underground parking. In this paper we address this problem and propose new illumination control strategies that leverage the unique features of LEDs and take into account the specificity of parkings and their usage patterns.

1 Introduction

On a variety of facilities the illumination of underground parking is a great spender of electricity. For example, the illumination of a commercial mall consists of thousands of points of light, half of those are installed in underground parking. Thus, improving the illumination efficiency of underground parking is of utmost importance. Although conceivably simple, improving the illumination efficiency of underground parking can be quite challenging due to the constraints posed on the lighting scheme by safety and marketing. Efficiency is frequently sacrificed to make the customers feel welcome. It has been observed that to feel safe, people need to be able to see clearly the surroundings and recognize a face as friendly or unfriendly at a distance of 60m and, moreover, there should be no dark or shadowed corners. Technically speaking, the illumination of underground parking requires *(i)* a comfortable average horizontal luminance level with *(ii)* a good light uniformity and *(iii)* a good chromatic restitution [5]. To meet these requirements in a cost effective way fluorescent illumination has been prevalent in underground parkings.

LEDs are slowly making their way into underground parking, mostly in *lamp retrofitting* energy efficiency initiatives. Studies show that LED light sources at the same brightness can save up to 50% of energy. However, to achieve the same uniformity as a fluorescent lamp, the placement of LED luminaries must be reconfigured which is very labour intensive. Although this issue will be overcome in the coming years with technological advances in the optic components of luminaries, we believe that it is possible to take illumination efficiency in these spaces one step further.

Another way to increase energy efficiency of illumination is to take advantage of *automated control* techniques [1]. Illumination systems performing daylight harvesting or occupancy detection have been shown to achieve reductions of energy consumption around 30% [2]. In underground parking there is virtually no daylight, which prevents daylight harvesting technique from working, and spaces are usually ample with hundreds of meters in line of sight, that undermine occupancy detection. Thus, traditional illumination control strategies do not apply to underground parking or apply only to a very limited extent.

We conjecture that some features of LEDs open an array of control possibilities: LEDs start instantaneously, they can be dimmed at a very low cost and their color characteristics can be controlled digitally. Moreover they have a good chromatic restitution, which helps in identifying faces and activities at a distance for safety purposes requiring lower luminance. Finally, developments in LED technology also point to the possibility of installing a large number of low cost units that will lend themselves to computerised individual control.

Our paper is organized as follows. In Section 2 we present the background concepts related to illumination control and then, in Section 3 we briefly overview the traditional illumination control strategies. Section 4 discusses the new techniques we propose and finally Section 5 closes with challenges and directions for further research.

2 Zoning and Flow control

A *visual task* is any task that can be assessed according to lighting requirements. It can be parking a vehicle, walking on the parking, or deciding to buy a product at a shop. Different visual tasks require distinct lighting. Illumination control systems are capable of creating lighting scenarios with varying degrees of detail through two fundamental control strategies[1]. Controlling groups of luminaries arranged into zones independently from one another, a technique is known as *zoning*, and they are also capable of creating light scenarios with varying levels of intensity, a technique known as *flow control.*

Since lighting of different areas (zones) can be controlled independently, instead of illuminating the whole space, only the area where a visual task is taking place is lit while surrounding areas can save energy. Zoning can be coarser or finer. The coarser type of zoning control consists of allowing the control of only large sets of luminaries at once, while the finest type of zoning consists of allowing the individual control of each luminary. Finner zoning is more flexible and enables higher energy savings.

Flow control consists of changing the amount of light in a given space. There are basically two types of flow control: discrete and continuous. Common implementation of discrete flow control consists of simple on/off control. Another form of discrete control is bi-level dimming obtained by actuating on dual-lamp luminaries or interleaving luminaries on and off. Continuous flow control is obtained

[1] For now, we are leaving color out of our discussion.

by dimming lighting intensity using specific electronic ballasts. Unoccupied areas can be dimmed down. Discrete flow control often results in a weak light uniformity with annoying shadows. Thus to achieve a comfortable light level, the space has to be illuminated in excess. Therefore, continuous flow control is more energy efficient.

To be cost effective, fluorescent lighting control currently deployed are coarse zoned and more discrete in terms of flow control. LEDs are more akin to fine zoning and continuous flow control.

3 Traditional control techniques

Daylight harvesting refers to controlling illumination, i.e., artificial light to take advantage of natural light. By definition, underground parking has little or no natural light available, which makes this technique impracticable.

Occupancy-based control aims at switching off illumination when the space is unoccupied and has proven to be an effective way to reduce energy consumption [3]. Occupancy is detected through passive infrared sensors which are know to be unreliable and fail to detect occupancy whenever a human subject stays idle. Therefore a timer is used to uphold the on state for a period of time estimated to be sufficient for the visual task to be completed. If the period is too long, illumination ends up staying on longer than needed; if the period is too short, illumination gets turned off leaving the occupant in darkness. This is known as a false off. In underground parking, pedestrians can be idle on a walkway, or simply stay in the car without leaving. Also it is difficult to assure a complete coverage of all the space. So, it is very hard in practice to be sure that the space is unoccupied. Since false offs are unacceptable, occupancy-based illumination control is somewhat limited.

Scheduled shutdown can be used to completely turn-off illumination at closing hours. The scope of this functionality is limited in our setting since illumination will be turned off only after the emptiness of the parking is verified by a human.

4 Innovative LED-based underground lighting control

The new control strategies that we propose take advantage not only of LED features but also of aspects related to the reaction of the human eye to light. A linear decrease in luminance is perceived logarithmic In fact people cannot reliably perceive reductions of 20% in luminance level [4]. Another observation is that we have a greater sensitivity to luminance level transitions (contrast) by comparison with a global luminance level (brightness). From the former observation we conjecture that it may be feasible to achieve interesting energy savings with marginal costs on visual comfort, while the latter points to the possibility of maintain lower luminance levels in some areas as long as luminance transitions are smoothed. We also note that the eye takes time to adapt when transitioning from a brighter environment to a darker environment. Hence, luminance levels along access paths should be set in progressive intensity to help the eye adapt. Finally, the perception of luminance decreases with the distance to the source of light (differences in intensity levels become indistinguishable at a distance). Conceivably, lower luminance can be applied to zones that are farther from the observer.

We envision implementing a fine zoning and continuous flow control illumination system consisting of a tight matrix LED luminaries driven by a distributed control system. This control system aggregates occupancy information from a mesh of inexpensive occupancy and car parking sensors installed trough out the space. The underlying idea is to minimize the overall illumination intensity while maximizing visual comfort for the users of the space. The system aims at creating the most adjusted visual scenario for each focus of activity such as a car arriving or leaving or pedestrians walking. The control system will take advantage of a set of illumination control strategies that can be summarised as follows:

Adaptive compensation consists of using progressive light levels to assist the eye adapting to luminance variance while commuting between spaces. Transitions between the inside and outside of the parking should be brighter during the day and dimmed during the night period, accompanying the variations of external light levels. The illumination of access walkways to the mall can be managed progressively to help the eyes adapt to the increased ambient light level of the mall. This feature enables the parking area to be maintained at a lower overall intensity level.

Occupancy prediction consists of predicting when a space is about to be occupied or unoccupied and create the appropriate illumination scenario, which will be dimmer when the space is unoccupied thus saving energy on vacancy. During certain periods certain zones of the parking alternate frequently between occupied and vacant and this technique takes advantage of short vacancy intervals frequent in parking that are not explored with fluorescent illumination to save the lamp lifetime. When someone is about to enter the space it should be instantly illuminated. For example, depending on the place where a car was parked may hold the illumination on that area until the guest crosses the access door. However, for some reason the guest may not cross the door. In that case the system, after a certain time, may start to dim slowly the illumination to save energy. Occupancy sensors may be spread on the parking to revert the dimming process whenever activity is detected.

Activity spotlight refers to illuminating with higher intensity the area where activity (a visual task) is taking place. We conjecture that users are more likely to accept a lower global intensity levels as long as the luminance level is higher near the place where they are standing. This feature has the benefit of highlighting any other activity in the parking making the persons feel safer. This technique saves energy by keeping the luminaries in between the areas of activity at a lower luminance level.

Progressive spacial dimming consists of progressively dimming the luminaries farther from the focus of activity. Since parkings are characterized by being open spaces with long lines of sight, in order to ditch shadows, a great number of luminaries have to be switched on whenever activity is detected. Dimming can be used to a greater extent if the structure of the space are highlighted. Users tend to feel more comfortable whenever they feel they can correctly read the space on visual contact. Energy savings will follow from dimming luminaries progressively with the distance to the source of activity.

5 Conclusions

Although the replacement of current fluorescent illumination by LEDs already offer efficiency gains, we argued that current illumination control techniques are of limited applicability to underground parking and proposed a new range of control strategies that can further increase the energy efficiency of LED-based underground illumination.

In this paper we championed illumination control systems for underground parking which explore the individualized control with dimming (fine zoning and continuous flow) features of LED illumination. We conjecture that using these strategies it is possible to reduce the overall luminance levels of parkings, with corresponding energy savings, while maintaining visual comfort levels.

Implementing on such system presents several challenges. Since there is no cheap way to accurately determine whether the space is vacant or occupied, we envision integrating information coming from parking sensors, passive infra-red sensors and door sensors. Another source of uncertainty is how to determine the minimum comfortable luminance levels and whether a minimum safe luminance must be kept at all times for security reasons. It is also unclear what will be the impact of these techniques in the perception of the users. These issues, we believe, will have to be determined experimentally.

We are currently in the process of formalizing a consortium some of the major national mall management companies to implement a pilot test of the ideas we have presented.

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