DETECTION OF AMBIENT LIGHT LEVEL FOR CONTROL OF LIGHT INTENSITY WITHOUT POSITIVE FEEDBACK

Dag Andreas Hals Samuelsen, Olaf Hallan Graven
Buskerud University College
Frogs vei 41, 3611 Kongsberg, Norway
Dag.Samuelsen@hibu.no, Olaf.Hallan.Graven@hibu.no

ABSTRACT
Applying artificial illumination of indoor objects can in some situations be difficult, when a uniform illumination of the objects and their surroundings is required. This often comes as a result of large changes in the light intensity of natural sources of light, such as daylight. This can be regarded as a disturbance to the controlled light environment. The system presented in this paper allows for a simple, low cost solution which uses a special measurement algorithm in order to estimate the amount of ambient light falling onto an object or area. The measured amount of light emanating from controlled light sources is separated from the measured amount of light emanating from other, uncontrolled sources. The controlled light source can then be increased or decreased as desired in step with the changing surrounding light levels. This can be achieved without introducing positive feedback from the controlled light source or other instability problems due to interference between the control law and the surrounding light sources. The control structure allows the system to be integrated into a single unit with existing LED lighting products and thus does not require expensive or intrusive installation of extra photo sensors. The system is designed to operate autonomously, without user interaction at any time, aside from turning the lights on and off. The performance of the system has been verified by implementing the system and using it in both a laboratory and a real environment.

KEY WORDS
Continuous and Discrete Methodologies, Model Development, Controlled Illumination, Estimation.

1. Introduction
The introduction of LEDs for lighting is by most people driven by a desire for low power usage lighting, it has however also opened large opportunities for advanced control of lighting. There are many reasons for this, e.g. ease of control of LEDs as opposed to incandescent light sources, in the sense that LEDs can be switched on and off extremely fast, and that the light level can be controlled in a much broader range than what is possible using traditional light sources. The authors’ area of interest is the automatic control of light levels according to user preferences and activities.

The controlled illumination of people’s surroundings by LED lights has been the focus of researchers for several years, and the number of publications is large. In [1], wireless sensor networks (WSNs) are utilized in the control of LEDs to give an individual a preferred level of light in hers surroundings. The requirement is that each individual must carry a wireless sensor with position tracking imposes limitations on the practical usability of this system, particularly if used in offices or private homes. Others, like [2] and [3] focus on the energy saving potential of smart or intelligent control of LEDs rather than control tailored to users.

In [4] Bhardwaj et al a system controlling the light levels in a room according to user preferences by adjusting the light level of LEDs, is presented. The illumination is controlled using a grid-based system, where photo sensors are used to measure the illumination levels of separate areas within the room. Ambient light from external sources, e.g. TV, outside daylight, etc, will influence the actual light levels produced by the LEDs in the system. The measurement system is then used to track the light levels so that the light intensity of the individual LEDs can be set to either achieve a uniform light level in the room, or to have a light profile as requested by the user.

This approach requires careful installation of the photo sensor network, so that the lux level perceived by each photo sensor is only affected by a limited area of the room according to the grid defined. This imposes limitations on the placement of photo sensors, as only reflected light should be measured. As a result, his requires the system to be tailored to each individual room and the personal preference of the user, which could be a complex task.

The system described in [5] have equal restrictions on the placement of the photo sensors, but the objective here is on energy saving, and not the quality or the user’s desire of luminance. Yet another approach is described in [6] where behavioral patterns, rather than photo sensor networks is used to estimate what light configuration the user want in various situations.
A highly integrated solution is found in [7] where the photo sensor is integrated within the LED driver for use with portable equipment. The backlight intensity of an LCD should be adjusted according to the level of ambient light, in order to keep the light intensity perceived by the human eye relatively uniform in the visible area. The problem description in this publication is similar to the challenge presented in this paper: The artificial illumination of objects must be adapted so that a perceived uniform illumination is achieved regardless of the amount of external light, for which the user or system has no control.

The specific case, for which the system presented in this paper is developed, is an installation of a bookshelf underneath a window. Two extreme cases can be identified: First, on a clear, sunny day, the amount of light coming in from the window will be large. Second, in the evening the window will appear as nearly black. The perceived illumination of the objects in the bookshelf, and the bookshelf’s surroundings should be equalized in the two cases. In the first case the LEDs must be set at their maximum in order to allow the objects in the bookshelf to be visible in spite of the large influx of light through the window. In the second case, the strong illumination of the objects that was used in the first case will be unpleasant for the viewer, and a lower amount of light should be used to obtain the same perceived uniform light level. Hence, there is a need to adjust or adapt the level of illumination from the LEDs to the ambient light.

Normally, a photo sensor would be placed separately from the controlled light source, preferably outside the window to measure the level of light outside the house. This would give a simple control scheme with accurate control of the light level in the bookshelf relative to the light conditions outside. The problem with this solution is the cost of the installation involved in mounting the photo sensor outside the window. Sometimes this is not desired or even impossible due to building restrictions, climate consideration, power source for the photo sensor etc.

The control solutions presented in the papers referenced in the introduction are all based on photo sensor networks that directly measure the light intensity of the objects where the illumination level should be controlled. In control theory terms, this means that it is possible to form a stable, negative feedback loop from the measurement to the controller input, and the design of both the measurement system and the controller itself is simple. For the problem presented in this paper such a simple system setup would create a positive feedback loop that leads to instability of the control system, as described in section 2.2.

The solution presented in this paper consists of a single unit that includes the photo sensor, the controller and the driver for the LEDs. The control unit is directly connected to the light source, controlling the light intensity of the LEDs. Typically an array of LEDs is used to illuminate the objects in the bookshelf. This LED array can be offered with an AC-DC adapter, making the installation cost very low. Adding the external photo sensor is not an option for most consumers, making the only feasible option to place the photo sensor inside the LED array together with a low-cost micro controller as the control unit. The system is also required to work autonomously, and configuration of the operation is limited to the use of possibly a single button on the LED array. Adding a wireless network interface for additional control is possible but would increase the cost of the controller, and is beyond the scope of this paper.

2. Estimation principle

2.1 Ambient light measurement

As described, the setup for the system presented in this paper is a single control and photo sensor unit connected to a LED array. In order to set the correct light intensity of the LEDs, the amount of ambient light must be measured. The placement of the photo sensor within the same unit as the LEDs will, despite shielding, cause the photo sensor to be at least partly illuminated by the light from the LEDs, either directly or indirectly by reflected light from the objects illuminated by the LEDs. In broad daylight, the amount of light coming in from the window will be relatively larger than the amount of light emanating from the LEDs. In the evening, this situation has turned, and the amount of light coming in from the window will be practically zero, and all the light measured will be that of the LEDs.

In the systems listed in the introduction, this is not a problem. In [1-5] the objective is achieved by measuring the lux level at specific areas and ensures that the sum of light from the controlled sources and the uncontrolled sources is kept at some predefined level. As stated in the previous section, in terms of control theory a negative feedback loop is formed, and both the open loop and the loop closed by the controller have a stable transfer function. This results in the system being stable, meaning that the output never will grow out of bounds by a limited input (disturbance) signal.

In [7] the problem is similar to the scenario described in this paper, however, the placement of the photo sensor and the capabilities of the controlled light source gives that the amount of light emanating from the light source will never have a significant impact on the lux level measured at the photo sensor. The feedback from the controlled light source will therefore have insignificant coupling to the control system, and the control system is in principle a feed-forward control loop. The open loop can then easily be designed to be stable, as shown in the paper[7].
2.2 Nonlinearities and positive feedback

As introduced in the previous subsection, there is a problem creating a stable feedback loop for this system. Normally, a control system is set to keep the output close to a reference signal. The output is then measured and compared to the reference, and any error here is fed to the controller, leading to a change in the process input, forcing the process output closer to the reference. Some processes are unstable and has to be stabilized by the controller, but a general rule is that the controller itself cannot be unstable.

The challenge in this system is that the control topology differs from the normal, having a control law stating that the light output from the LEDs should increase and decrease in step with the ambient light intensity. When the level of external light is reduced during the evening, the emitted light from the controlled light source should be reduced. When a controller is set to automatically control the light intensity, it relies on the measured light level, but now there is actually a positive, unstable feedback loop in this control system.

To see this, assume that the system is started in the evening. A light level above zero is measured due to other light sources used in the surroundings. Any infinitely small increase in the measured light level will cause the controller to increase the light intensity of the LEDs, in order to compensate for what is measured as an increase in the overall light level. Part of this increase in the light intensity of the LEDs will be picked up by the light photo sensor as this photo sensor “see” some of the light emanating from the LEDs. This increase is then fed to the controller which in turn causes a further increase in the light intensity of the LEDs, again to compensate for a measured increase in the overall light level. This continues until the maximum light level is reached, and the system will remain in this state regardless of what happens to the external light level.

The coupling factor or transfer function from the controlled light source (LEDs) is highly dependent on the amount of external light as well as the type and shape of the objects in the surrounding of the LEDs reflecting the light from the LEDs back to the photo sensor. This results in the failure of any attempt to create a transfer function eliminating the effect of the reflected light on the photo sensor, as the model error always will be large to the degree of complete system failure.

The solution to this problem is to create a way of measuring the light level, without the feedback from the LEDs to the disturbance input of the control system. There are multiple ways of performing this measurement. The method chosen in the system described in this paper relies on the difference in measured light levels when subject to minute changes in the light intensity of the LEDs, as described in the next section.

2.3 Measurement

In order to remove the positive feedback that causes the instability of the control system, a more complex measurement algorithm than the simple strategy of measuring the lux level directly, has been selected. There are a number of publications on how to measure light for special purposes. The algorithms presented in [8] relies on a combination of online and offline analysis, and the objects need to be known before the offline algorithms can be used. The main problem with this and the related methods described in [9][10][11] is the need for image processing, which requires far more processing power than is available in this application. Instead, the light intensity of the LEDs is programmed to periodically have a slight deviation from the set-point, so that the actual light intensity is increased or decreased by a small delta. Delta is here selected to be small enough so that the human eye do not notice the difference, but large enough for the photo sensor to detect the difference. This delta has been found via experiments where multiple human observers are directed to observe the light and report on any changes in light intensity. At the selected delta no change in the light intensity was observed by any of the human observers, but a difference was registered by the photo sensor.

The measured signal from the photo sensor is subject to large noise components, and filtering is necessary to achieve good measurements. For that reason, the light intensity is first increased for a short period while multiple samples are taken by the photo sensor, after which the light intensity is decreased to the previous level and a new set of samples are taken. The difference between the averages of the two set of samples are then calculated. The differences are also filtered by averaging to further increase the quality of the measurements.

The type of filtering selected here is the simple running average, which is not advanced when compared to, for instance [12], but is selected for mainly two reasons: First, calculating running average requires very little resources like memory and processing power, as opposed to more advanced methods. This is especially important in this context as the system is running on a low-cost small footprint micro controller that must fit within the LED-strip. Second, the extreme phase lag introduced by this simple filtering is of no importance as this is basically a feed-forward control system only. The ambient light conditions are assumed to be slow-changing, and the filter is more than fast enough to capture these changes.

The control algorithm for light intensity is currently set using a simple look-up table for selecting the light intensity from the measured differences. This means that the light intensity of the LEDs is set in steps according to the estimated intensity of the ambient light, as can be seen from figure 1-3. The very coarse resolution of the lookup table used in this experiment has a negative impact on the
user experience, but is chosen for a simple verification of the strategy suggested.

2.4 Adaptation to the surroundings
The method described here will only work when adapted to the surroundings. For the same lighting conditions, the amount of reflected light and hence, the values of the differences will have a significant variation, depending on the reflective properties of the objects in the surrounding of the LED-strips. The method therefore requires adaptation to the environment where the system is used. This may seem to be an obstacle for the low-cost, autonomous, easy installation requirements for the system, but a simple self-adapting scheme is proposed that remove the need for complex adjustments after installation.

The simple adaptation scheme is based on the assumption that the LED-strip is bright enough for the brightest hours, and that the system must be running at least one time (not necessarily the first time), during the darkest hours and at least one time during the brightest hour. This need not be in sequence, and it even need not be on the same day. The maximum and minimum levels will automatically be recorded and saved in non-volatile memory in the micro controller. These values are then used to automatically re-calculate the look-up table used for setting the light intensity levels. If the darkest level is considered too dark, a single button can be implemented to adjust this level, by adjusting the brightest level during the brightest hours and the darkest level during the darkest hours.

3. Implementation

3.1 System setup
The system has been implemented and used for an extended period. In order to ease the debugging process a larger processor than selected for the final application is used. The system is developed using a PIC18LF2620 [13] from Microchip as the micro controller. This is used for running the control system and for performing the measurements. The system is also fitted with an SD-card slot for recording of sample data to flash memory readable from a normal PC. A photo diode [14] from Hamamatsu is chosen for its low cost, combined with the ability to capture visible light. The sensor photo diode is mounted directly next to the LED-strip, but is mounted inside a casing with a lens, in order to avoid direct light from the LEDs to affect the measurements. The 12V LED-strip is dimmed by PWM (Pulse Width Modulated) control of a single MOSFET transistor, with a switch-mode 230VAC-12VDC converter as power supply.

The final system has only one input and one output – the analogue input of the photo sensor and the PWM output for the transistor controlling the LEDs. This facilitates the utilization of 8-pin micro controllers that have two pins for power supply, possible one pin for power-on reset, and 5 I/O pins. One of these is used for the PWM output and one is used for the photo sensor input. No external crystal oscillator is needed as the system does not rely on accurate timing of any external system. One to three pins can then be used for external user input, if desired as explained in section 2.4. This allows for a very small footprint of the complete system, facilitating small devices that fit easily into small spaces.

3.2 Practical tests
The system has been tested under different conditions to verify the operation, both in a laboratory setup and in a real home. Figure 1 shows un-normalized values for a trial operation during early evening. The system is started with an initial value of 100 for the filtered difference, and the look-up table is set up with a very coarse 5-level light
intensities regime. The blue graph shows the unfiltered difference measurements, while the red graph shows the filtered values. The green graph represents the light intensity or dimming levels for the LEDs. Here it can be shown that the delta has been increased in the mid-levels in order to increase the accuracy of the estimation. This is incorporated into the look-up table, and does not affect the feed-forward control loop.

In figure 2 the stability of the difference method for estimating the amount of external light, disregarding the light emanating from the LEDs. The graph is made from un-normalised data and is recorded during bright sunlight, causing the difference to be close to zero (average around 10).

The delta has now been chosen to give the same level of difference for all dimming levels. The green graph shows the dimming level of the LEDs, while the blue graph shows the unfiltered difference and the red graph the filtered. It can be seen both from the filtered and unfiltered graphs that the estimation method gives predictable results in the presence of varying light intensity from the controlled light source.

Figure 3 shows the same setup as figure 2, but this time in the evening when there is very little light from the outside. The filtered difference is preset to a value of 1000. A slight increase in the measured difference can be seen as the light intensity from the LEDs is decreased. This is due to the non-linearity of the difference estimation method, but has not shown any significant problems.

4. Conclusion

A system is presented which allows for controlled illumination of objects by LEDs, using the control objective that the overall illumination of the surrounding and the objects are more uniform, despite changes in the light intensity of the surroundings. The uniformity of the light should be better than what is possible without control. This is done in a manner which allows for a low-cost, compact solution, and without expensive and intrusive installation of photo sensors at carefully selected locations, but rather relies on a single photo sensor that is placed inside the casing of the LEDs. This is made possible by the introduction of an estimation scheme and a simple filter algorithm for separating the part of the light measured by a single photo sensor into two components: the ambient light and the light from the controlled light source. The simple scheme and filter algorithms allows the system to run in a low-cost, small footprint micro controller. The controlled light source is made up of an LED array, which allows for a very simple dimmer circuit and is easy to control by PWM. The system operates autonomously and no extra user interaction is required before, during or after the installation procedure, except for a possible simple adjustment of the maximum and minimum dimming levels. Practical tests show the performance of the system to be satisfactory during changes in the dimming levels of the LEDs as well as during changes in the ambient light conditions.

References


