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INTEGRATED DAYLIGHT HARVESTING AND OCCUPANCY DETECTION USING DIGITAL IMAGING

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Abstract *A case study of a catastrophic failure of a web marine crankshaft and a failure Analysis under bending and torsion applied to crankshafts are presented. A microscopy (eye seen) observation showed that the crack initiation started on the fillet of the crankpin by rotary bending and the propagation was a combination of cycle bending and steady torsion. The crack front profile approximately adopts a semi-elliptical shape with some istortion due to torsion and this study is supported by a previous research work already published by the authors. The number of cycles from crack initiation to final failure of his crankshaft was achieved by recording of the main engine operation on board, taking into account the beach marks left on the fatigue crack surface. The cycles calculated by the linear fracture mechanics approaches showed that the propagation was fast which means that the level of bending stress was relatively high when compared with total cycles of an engine in service. Microstructure defects or inclusion were not observed which can conclude that the failure was probably originated by an external cause and not due to an intrinsic latent defect. Possible effects of added torsional vibrations which induce stresses are also discussed. Some causes are analyzed and reported here but the origin of the fatigue fracture was not clearly determined.*

Keywords: *crankshaft failure, rotating bending, steady torsion, fatigue crack growth*

1.INTRODUCTION

As demand for lighting controls continues to grow, advanced solutions are becoming increasingly specified while also becoming increasingly sophisticated. This increasing sophistication translates to greater owner benefit but can also pose greater risk of design and installation mistakes.In a perfect world, designers create clear and detailed lighting control requirements that are easily installed by the installer and the owner. In the real world, however, the owner may not have clear expectations about their lighting. Further, the designer may not provide clear design intent, the installer may make errors and, if anything goes wrong, users will complain.

For the designer, the key is to clearly express the design intent, or the basis of design, so as to provide a common roadmap for the functionality of the lighting control system.

In California, the world's fifth largest economy, uses 265,000 GWh of energy each year, with peak demand growing annually at about 2.4%.**1** Total commercial electric consumption amounts to 67,707 GWh annually**.2** Nationally, the building sector's energy consumption is expected to increase by 35% between now and 2025, while commercial energy demand grows at an average annual projected rate of 4.7x1014 Wh.**3** In fact, commercial buildings consume 18% of the nation's annual energy use, and 35% of the nation's total electricity.**4** the many research has shown that lighting comprises 20% - 40% of total electric power consumed in commercial buildings.**5** Using California as an example, interior lighting is the highest primary electric end use (29%) as well as the highest overall annual end-use electric intensity (3.92 kWh/ft2). Lighting in the commercial office spaces alone consumes 4,997 GWh annually and accounts for 33% (5300 MW) of commercial peak demand.6 A review of building load databases has indicated that on an average, peak demand charges account for roughly 40% of total electricity expenditures and a 1% reduction in peak demand reduces annual electricity expenditures by 0.4%. An effective way to address this energy problem is to deploy automatic lighting control systems. Automatic lighting controls are capable of reducing energy consumption by up to 50% in existing buildings (in the case of an electronically ballasted lighting control system in an office building in San Francisco)7 and by 35% in new constructions.8 However, conventional lighting control technologies, partly due to their various technological drawbacks, have traditionally faced market barriers, leading to lower market penetration than some other building technologies. We believe any future market transformation in lighting control will be propelled by novel lighting control technologies that will overcome the drawbacks of conventional systems and demonstrate superior performance than what is currently feasible. This is the motivation behind this ongoing research.

In the first phase, methods and algorithms were developed for daylight harvesting using digital imaging technology.In this paper, we report the results of CamSensor-2 or CS-2, which integrates daylight harvesting and occupancy sensing into a single automatic lighting control system.

The lighting controls, including a sequence of operation, or description of system outputs in response to various inputs. Device settings include occupancy sensor time delay and sensitivity adjustments, integrated dimmer presets, time schedules for relays, and other programming and calibration. Control zoning visually reveals what control devices control what loads. One-line wiring diagrams visually reveal how all of the control devices connect and their relationship to each other. “In The interior lighting controls will enact two primary strategies intended to minimize energy consumption: 1) automatic shutoff via occupancy sensors in small, enclosed spaces and via a timeclock-based low-voltage control system in larger, open spaces, and 2) daylight harvesting in all spaces receiving high, consistent levels of daylight contribution, notably the main lobby and private and open office spaces. In certain spaces lacking daylight and where personal safety is an issue, such as corridors illuminated by electric lighting, select lights will remain ON at all times during normal hours of occupancy. In presentation spaces, notably the meeting and training rooms, flexibility will be provided to enable users to select preset light levels. Lighting controls will also turn exterior lighting ON/OFF using a photocell/timeclock based on curfew (grounds lighting) or dusk-to-dawn operation (security lighting).”

“The control system shall be programmable at a microprocessor-based central processing unit (CPU). The system shall provide weekly routine and annual holiday scheduling and automatically adjust for leap year and daylight savings time. Each program shall not exceed 25,000 sq.ft. or one floor, whichever is smaller. The control system shall have 10-year nonvolatile memory that stores all schedules. The system shall be able to reboot the program and reset the time schedule and current time, without errors, following power outages up to 14 days in duration. The system shall export lighting energy consumption reports by space and zone. The control system shall operate independently of but be capable of communicating with the building automation system, if present.” From there, we could also add performance testing and criteria for acceptance. For the above low-voltage relay control system, this might include ensuring that the general lighting in each zone turns OFF at the scheduled time, the sweep is properly preceded by a blink or other warning, and the overrides are properly zoned and working.

Finally, we could add references to other pertinent documents, such as wiring diagrams, control zoning and equipment specifications.

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2. DAYLIGHT SENSING AND PROCESSING UNIT

2.1 Block diagram

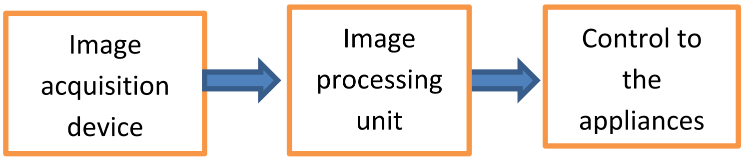


Fig2.1: block diagram of daylight sensing and processing unit

2.2. Occupancy sensors and their drawbacks

With typical energy savings ranging from 52% - 58% for classrooms and 28%-38% for private offices occupancy ,sensors are often viewed as one of the most energy and cost-effective lighting control technologies. However, even after being around for over 20 years, occupancy sensors do not have as high market penetration as some other building technologies (less than 10% commercial floor space served nationally), partly due to the difficulty in definitively predicting and demonstrating savings. Occupancy sensor performance is also dependent on the user occupancy, lighting control patterns, sensor selection and finally, commissioning, leading to varied savings estimates by the industry. Recent research has shown that reducing the time delay in the occupancy sensors can increase the energy savings in spite of a potential increase in lamp maintenance cost due to higher switching frequency. It has been found that the activity level is different for different users of a common space and even changes over the time of the day for a given user. However, a typical occupancy sensor only allows a single time delay setting based on the application, which can vary from several seconds to more than 30 minutes, and remains constant once set. The time delay is commonly maintained at a higher level than necessary to minimize false offs (when no motion is detected in presence of occupancy), thus reducing energy savings. Once calibrated, the sensitivity of the device to room movement cannot be changed as well. Most occupancy sensors used in commercial applications use passive infrared or ultrasonic motion-sensing technologies. Many use dual technologies, which combine the two technologies or others, such as microwave, in one sensor.

2.3. Photo Sensors and their drawbacks

In comparison to occupancy detection, daylight harvesting is a significantly less successful and somewhat less popular lighting control strategy. The use of photosensors to control interior lighting is nontrivial. Since a photo sensor signal greatly depends on the position of the sensor relative to room surfaces and daylight apertures, as well as on room surface material properties, commissioning and calibration play a pivotal role in photo sensor applications. Various problems associated with calibration and commissioning contribute to the fact that photo sensor-based systems have seen limited application and have traditionally faced market barriers.

Fig2.2:day light harvesting module

Further, a new paradigm in lighting control has started with the introduction of digital, addressable ballasts. Dimming of individual ballasts permits such a lighting control system to achieve different electric light output levels across a space, providing more flexibility and precise control of the illuminated environment. Digital Addressable Lighting Interface (DALI) is one such technology.20 Very recently, DALI has been used in a major field study of the performance of automated roller shades and daylight controls in a mock-up of the day lighting system in The New York Times Headquarters.3 DALI continues to mature as a technology with increased affordability ($30-$75 per ballast3), while other digital technologies continue to gain ground. Thus, there is a need for an advanced daylight sensor that can reap the benefits and flexibility that these technologies offer and achieve a better control of the light distribution within a space, improving the overall light quality.

Daylight harvesting is an advanced lighting control strategy used to minimize ongoing owner energy costs. It occurs when a sensor measures daylight levels and signals a control to adjust electric lighting system output to maintain a desired task light level. Variable daylight levels are automatically harvested as energy savings through electric lighting reductions. Because energy savings will be dependent on factors such as type of available daylight, control response and space and task characteristics, actual savings can be difficult to predict,although studies suggest strong potential.

Because of the strong energy savings potential offered by daylight harvesting, coupled with advancing technology, codes and standards are now beginning to address daylight harvesting—specifically, International Energy Conservation Code (IECC) 2009, ASHRAE/IES 90.1-2010, ASHRAE 189.1 and Title 24-2008. In review, IECC 2009 and ASHRAE/IES 90.1-2010 are energy standards offered as model energy codes for states and other jurisdictions. ASHRAE 189.1 is a green building standard. And Title 24-2008 is California’s unique energy code.

All of these codes and standards are different and yet have similar major themes. First, they define daylight availability as zones around side lighting (e.g., windows) and top lighting (e.g., skylights and roof monitors) daylight apertures. Second, they require separate control for general lighting in these daylight zones. The standard may also specify whether the control must be manual or automatic, switching or dimming, stepped switching or simple ON/OFF. And the standard may reward aggressive daylight harvesting with power adjustment credits that can be used to acquire greater design flexibility with the controlled load, Side lighted daylight zones are defined as depth x width adjacent to the aperture, and top lighted daylight zones are defined as length x width under the aperture.

Side lighted spaces: If the side lighted daylight zone is larger than 250 sq.ft., then the control method must be automatic and multilevel (or continuous dimming), providing one step between 50% and 70% of the design lighting power, and another between OFF and 35%. ASHRAE/IES 90.1-2010 encourages more aggressive daylight harvesting strategies in side lighted office, meeting, classroom, retail sales and public space types with credits that can be used to increase the power allowance for the controlled lighting load. Recognized strategies include continuous dimming control and automatic control of general lighting in secondary (deeper) daylight zones in side lighted spaces.

Top lighted spaces*:* In top lighted spaces, if the total daylight area under skylights plus the total daylight area under rooftop monitors is larger than 900 sq.ft., the general lighting must be separately controlled using either a stepped switching or continuous dimming controller, with some exceptions. As with side lighted spaces, more aggressive daylight harvesting control in top lighted areas is rewarded with power adjustment credits.

Additionally, perimeter lighting in parking garages is required to be automatically reduced in response to daylight, with some exceptions.

Demand for daylight harvesting controls has grown dramatically in recent years, driven largely by sustainability initiatives such as LEED. Since 2005, California’s energy code required daylight harvesting in certain spaces. Now the major energy standards—IECC and ASHRAE/IES 90.1—contain significant requirements for daylight harvesting control, signalling widespread acceptance and adoption of this control strategy in the future.

Lighting Controls: The Lighting Controls Association published a guide to the new ASHRAE/IES 90.1-2010 standard, focusing on its prescriptive lighting power requirements as well as significant changes to its scope and administrative requirements.

In this series on the new standard, we will focus on its extensive new mandatory and optional lighting control requirements. Regarding controls, the changes are nothing short of historic .The Lighting Subcommittee, says the dramatic lighting control-related changes in ASHRAE/IES 90.1-2010 are a sign of the times and a vote of confidence for the reliability and utility of advanced lighting control technology. “Lighting controls have come a long way,” he says. “Lighting controls are a critical component for saving energy in buildings; they are now a ‘must have’ in buildings instead of a ‘nice to have.’ These controls can eliminate 60% or more of the wasted lighting energy in buildings while enhancing occupant comfort and productivity.”

ASHRAE/IES 90.1-2010 requires

- automatic shutoff of indoor and outdoor lighting when not in use;
- automatic lighting shutoff now required in buildings <5,000 sq.ft. unless specifically exempted;
- automatic lighting shutoff requirements of code now required for lamp plus ballast retrofits impacting 10+% of the connected lighting load;
- occupancy sensors required for a broader range of applications
- manual-ON or auto-ON to 50% operation required for automatic controls;
- multilevel lighting in spaces using manual space controls;
- automatic multilevel lighting in certain stairwell, parking garage and other spaces;
- automatic daylight harvesting control;
- power credits providing additional lighting power allowances as an incentive for using advanced control strategies;
- functional testing of controls; and
- documentation requirements including a control narrative and maintenance schedule.

Automatic shutoff: ASHRAE/IES 90.1-2010 requires that all lighting systems be turned OFF when not in use, with some exceptions.

Indoor: For indoor lighting systems, this could be satisfied through use of a schedule-based control device, occupancy sensor or signal from another control or alarm system indicating the area is unoccupied. Previous versions of the standard limited its automatic shutoff requirements to buildings larger than 5,000 sq.ft.

The 2010 standard requires these controls in all buildings, with exemptions limited to lighting required for 24-hour operation, where patient care is provided, and where they might endanger safety or security. “This change is a direct result of the realization that with the reduction in cost for controls in general that include building system controls and the options available for compliance—e.g., occupancy sensors—the rationale for application only to larger facilities was no longer compelling,”. . “Of course, this will increase initial control costs in some smaller facilities, but they should also see energy benefits over the life of the facility.”

Occupancy sensors: In previous versions of ASHRAE/IES 90.1, occupancy sensors began to be required in certain applications. The 2010 version expands this list: Occupancy sensors (or timer switches, per approval by the authority having jurisdiction) that turn the lights OFF within 30 minutes of the space becoming unoccupied are required in:

- class rooms and lecture halls;
- conference, meeting and training rooms;
- employee lunch and break rooms;
- storage and supply rooms between 50 and 1,000 sq.ft. in size;
- rooms used for document copying and printing;
- office spaces up to 250 sq.ft.
- rest rooms; and
- dressing, locker and fitting rooms.

“Since the first requirement for this technology in the 2004 standard, the intent has always been to explore the addition of more space types to the list where it can be found to be an effective energy-saving option,” says Richman. “These new additions to the list are based on the latest research and case studies for different space types. Occupancy sensing control is considered one of the most effective methods for reducing lighting energy usage, and supporting its installation in as many spaces as possible—where it is a practical application—will have a large and immediate impact on lighting energy savings.”

Exceptions include shop and laboratory classrooms, spaces with multi-scene (e.g., dimming) control systems, lighting required for 24-hour operation and spaces where automatic shutoff would endanger safety or security of people or property.

Occupancy sensing is also required in guestroom bathrooms in hotels, motels, boarding houses and similar buildings. The sensor must turn OFF the lighting, with the except for night lighting not exceeding 5W, within 60 minutes of the occupant leaving the space. (In addition, bathroom lighting is now exempt from the requirement that all lighting in the guestroom must be controlled by a master control at the entry door.)

Outdoor: The previous version of 90.1 requires outdoor lighting to be controlled by a photo sensor (daylight) or astronomical time switch (scheduling) for dusk-to-dawn lighting and either a time switch or combination photo sensor/time switch. It also required that building grounds lighting fixtures >100W either use lamps with an efficacy of 60+ lumens/W or be controlled by a motion sensor, with a long list of exceptions.

The new standard simplifies these requirements. First, all outdoor lighting must be controlled by a photo sensor. Second, building façade or landscape lighting must also be controlled by an astronomical time switch that turns the lights OFF between midnight or business closing (whichever comes first) and 6AM or business opening (whichever comes first) (or at times designated by the authority having jurisdiction).

Multilevel lighting: Previous versions of ASHRAE/IES 90.1 do not require multilevel lighting; the current version embraces it broadly for indoor and outdoor automatic shutoff and space controls, with special requirements for specific applications.

Manual-ON or auto-ON to 50%: Previous versions of the standard allowed automatic control devices to activate the lighting system as well as turn it OFF. In 90.1-2010, no longer: Automatic shutoff controls must be manual-ON or automatically turn the lighting ON to not more than 50% power. Exceptions include public corridors and stairwells, restrooms, primary building entrance areas and lobbies, and areas where manual-ON would endanger safety or security. Manual-ON and auto-ON to 50% occupancy sensors, for example, have been demonstrated to save energy compared to auto-ON to full occupancy sensors, while eliminating nuisance false-ON triggering. Allowing auto-ON to 50% also increases flexibility in choice of light levels for users.

Space controls: The lights in each enclosed space in the building must be independently controlled by a conveniently located manual control device or automatic occupancy sensor with manual-ON or auto-ON to 50% operation. Certain enclosed spaces, identified in the previous section of this whitepaper, require occupancy sensors (or timer switches if approved), while designers have a choice of manual control or occupancy sensors in all other spaces. Regardless if using manual controls or occupancy sensors, the lighting must be configured for multiple levels enabling users to select at a minimum OFF, a step between 30% and 70% (inclusive) of full lighting power, and 100% of full lighting power. Exceptions include corridor, electrical/mechanical room, public lobby, restroom, stairway and storage room lighting.

"This change was made primarily to provide users with light level options that have been shown in some studies to have energy-saving benefits," says Richman. "While the benefits are generally always smaller than automatic controls, the application of bilevel-type manual control has become common practice in a lot of commercial construction, and this requirement encourages the use of occupancy sensors that can be more cost-effective than the wiring needed for bi-level control."

Parking garages: Parking garages must comply with the standard's automatic shutoff requirements but also be controlled so that lighting power can be reduced by at least 30% when there is no activity detected for no longer than 30 minutes, with some exceptions. To satisfy this requirement, the lighting must be grouped in zones no larger than 3,600 sq.ft.

"The 2010 version of the standard includes specific parking garage control requirements," Richman says. "These include reducing lighting power for luminaries by 30% when the area is unoccupied, providing separate control for daylight transition zones—entrance/exit—and daylight-responsive control of luminaires within 20 ft. of effective daylight openings. This is a new area for the 90.1 standard but one where there is typically a lot of lighting use when spaces are unoccupied and therefore ripe for effective controls."

Daylight harvesting: Previous versions of ASHRAE/IES 90.1 do not address daylight harvesting control, an advanced control strategy that has matured due to strong demand in projects requiring high levels of sustainable design, such as LEED projects. The new standard now includes the most aggressive and complex daylight harvesting control requirements in current codes.

The code first distinguishes between primary side lighted areas directly adjacent to daylight apertures and secondary areas in proximity but not directly adjacent to daylight apertures. These areas are strictly defined by the standard using helpful diagrams and are intended to define zones in which consistent, unblocked, high levels of daylight availability is typically expected.

If the primary side lighted area (defined in the standard and based on space geometry and window effective aperture characteristics) in an enclosed space is 250 sq.ft. or larger, the general lighting in that area must be separately controlled using either a stepped switching or continuous dimming controller, with some exceptions. More aggressive daylight harvesting in primary and secondary side lighted areas is rewarded with power adjustment credits described later in this whitepaper.

In to plighted spaces, if the total daylight area under skylights plus the total daylight area under rooftop monitors is larger than 900 sq.ft., the general lighting must be separately controlled using either a stepped switching or continuous dimming controller, with some exceptions. As with side lighted spaces, more aggressive daylight harvesting control (i.e., automatic continuous dimming) is rewarded with power adjustment credits.

Additionally, perimeter lighting in parking garages is required to be automatically reduced in response to daylight, with some exceptions.

"Day lighting control has been an elusive item for energy codes and standards because of its natural complexity, which makes it very difficult to write a code requirement that is practical and enforceable," notes Richman. "The requirements in 2010 include control of electric lighting when sufficient side lighting from windows or top lighting from skylights or roof monitors is present. A second part of the requirements makes the installation of skylights mandatory but only when there is sufficient open area available to make good use of day lighting. The trick with these requirements is the determination of an effective daylight capability."

While ASHRAE/IES 90.1-2010 endeavours to simplify the process, its approach to daylight harvesting control will increase the complexity involved in compliance. Of particular concern is the fact that daylight harvesting control, particularly zoning, is now treated differently in ASHRAE/IES 90.1-2010, ASHRAE 189.1, IECC 2009 and California's Title 24-2008.

"This will not be the easiest energy code requirement to apply but the diagrams do a good job of clarifying the requirements," says Richman. "This is the most aggressive and involved day lighting requirement in current codes and is expected to help increase the use of day lighting control as standard commercial construction."

2.4. An image sensor

An image sensor can be thought of as a cluster of photo sensors. Unlike photo sensors, they do not give us a single electrical signal, but rather provide luminance as well as colour information at thousands of points within the space. A sequence of digital images of the space thus gives us a wealth of information that we can use to estimate daylight availability in various parts of the space simultaneously, as well as detect occupancy. Thanks to the tremendous growth and development in CMOS technology, today digital imaging is pervading every sphere of our life, providing us with cost-effective and innovative solutions.

Recently, high dynamic range CMOS video sensors have been introduced in the market, primarily for various automotive applications, whose technical constraints are somewhat similar to those of interior lighting applications. In both cases, the imaging system needs to work under a wide dynamic range, have a fast (more time critical in some real-time automotive applications) but affordable image processing functionality, and finally, have integrated image acquisition and image processing modules that continuously interact with each other.23 Real-time operation might involve adjusting the image acquisition system based on the lighting condition. However, the lighting product will have a more stringent budget constraint than a product for an automotive application. Here, by automotive applications we mean lane recognition, parking control, obstacle/traffic sign recognition etc.

2.5. Proposed concept: an integrated lighting control sensor

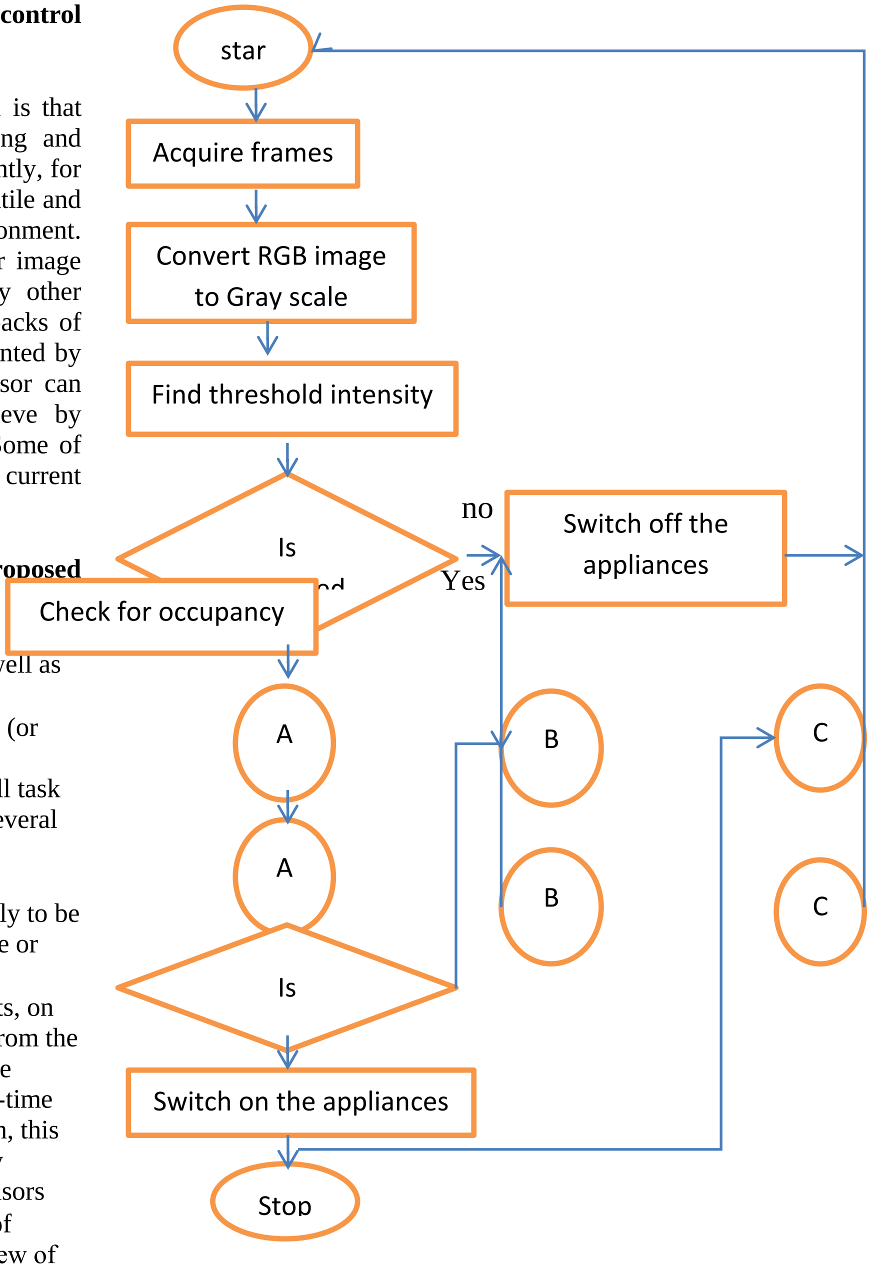
The fundamental hypothesis of this research is that we can use an image sensor for daylight harvesting and occupancy sensing at the same time, but more importantly, for developing a lighting control system that is more versatile and that offers a far better control of the illuminated environment. Our approach is significantly different from the prior image sensor based lighting control devices envisioned by other researchers.24-26 We demonstrate that several drawbacks of conventional lighting control sensors can be circumvented by the proposed concept. In addition, an integrated sensor can provide functionalities that are impossible to achieve by conventional photo sensors and occupancy sensors. Some of these features have already been implemented in the current work.

Following are some advantages offered by the proposed solution over conventional systems

- A single sensor can function as a photo sensor as well as an occupancy sensor
- A single sensor can be used for different task areas (or control zones) with different target light level requirements, as long as the sensor has a view of all task areas. A conventional system will typically need several photo sensors for this purpose
- Compared to a conventional photo sensor, the performance of the proposed system is far less likely to be adversely affected by a direct view of a light source or direct sunlight
- The sensor is capable of detecting small movements, on the order of a couple of inches, several feet away from the camera as long as it has an adequate resolution. The sensor sensitivity to motion can be adjusted in real-time based on the activity level or other criteria. As such, this approach can offer a better capability in occupancy detection compared to conventional occupancy sensors
- Algorithms can be developed so that the problem of people or objects partially blocking the sensor's view of the task areas can be circumvented (not implemented in CS-2)
- Real-time energy monitoring and performance analysis of the actual system is possible, which is unique to this application
- Image processing techniques can be employed to achieve enhanced functionalities like automatic calibrationand detecting areas for selective scanning of the scene to ensure low response time (not implemented in CS-2)
- CMOS technology can provide an attractive and cost effective solution (cost analysis has not been conducted for CS-2)

3.TECHNICAL DETAILS OF THE PROTOTYPE

flowchart.



3.1. Hardware

The main component of CS-2 is a color XAECK100 Automotive Evaluation Kit based on SMaL camera technology from Cypress Semiconductor Corp (now owned by Sensata Technologies).27 The kit consists of an imager module (or camera head), an FPGA Processing Box and SMaL image capture Application Programming Interface

(API). The imager is a CMOS sensor with the following specifications: i) high dynamic range up to 120 dB, ii) a resolution of 640x480 pixels, iii) 8 or 12 bit image capture modes, iv) up to 60 fps variable frame rate, v) progressive scan mode with rolling shutter, vi) a spectral range of 400-1100 nm, vii) 45 dB digital signal-to-noise ratio, viii) 0.09% fixed pattern noise, and ix) 5V/lux sec sensitivity. We used the standard 1/3" C-Mount lens with a nominal field-of-view of 50°. The electronics in the camera head transports the digital sensor data to the processing box through Low Voltage Differential Signaling (LVDS) serial interface (CAT-5 cable).

The Processing Box contains a 2 million Gate Xilinx FPGA video controller board, which is connected to a PC through a IEEE 1394/Firewire interface. The controller includes various image processing features like dark current removal, column fixed pattern noise correction, defective pixel correction, 3x3 general sharpening etc. It also allows automatic and manual control of the integration period and the dynamic range. The dynamic range can be controlled by selecting one of 29 pre-defined response (or gamma) curves. All image processing features and parameters are programmable and can be manually controlled by setting the appropriate registers in the FPGA. This is accomplished by the virtual addressing mechanism implemented in the image capture API. All automatic processing features like white balance, autoexposure, Automatic Gain Control (AGC) and gamma control were disabled by modifying appropriate registers. Obtaining raw image data is important for this application.

It must be pointed out that the above specifications are not the recommended configuration for this application, but-merely the configuration of the hardware available for this work. Determining the minimum system requirement or a cost analysis was out of the scope in this phase of our research. CS-2 also includes a Digital Addressable Lighting Interface (DALI) controller that helps control the DALI dimming ballasts by sending digital commands from the computer to individually addressed ballasts. The controller has an RS-232 serial interface and follows DALI communication protocol.20 The master control of CS-2 was a windows-based computer with modest hardware configuration (1.8 GHz, 512 MB RAM, WinXP).

3.2. Daylight-sensing with CS-2.

The camera was calibrated to generate the response curves for the three channels so that luminance (in cd/m2) could be estimated directly from the digital counts. A brief description of the calibration process follows. A Colorchecker DC color chart and a gray card were imaged by the camera. Only the grayscale patches in the colorchecker were used in this calibration. The gray card data was used to correct for the spatial non-uniformity of lighting. Three different exposure settings were used to ensure proper sampling of the full 8-bit range.

A sample of Halon (Polytetrafluoroethylene or PTFE) was placed near the chart before the image capture. Halon has a spectral reflectance factor close to unity with very high spatial uniformity and is nonselective across wavelengths. Thus, it is used as a perfect reflecting diffuser (PRD). Absolute luminance (in cd/m2) of the brightest patch in the colorchecker and the spectral reflectance of the PRD were measured using a spectroradiometer. Now, the spectral reflectance of eachgray patch being known, CIE tristimulus value Y was computed for each patch using Eq (1).

$$Y = k\sum_{\lambda} S_{\lambda} R_{\lambda} \bar{y}_{\lambda} \Delta\lambda$$

$$k = \frac{100}{\sum_{\lambda} S_{\lambda} \bar{y}_{\lambda} \Delta\lambda}$$

Where S! is a spectral power distribution of the light source (obtained from the spectral reflectance data of the PRD), R! is the object's spectral reflectance factor, y is the CIE 10° standard observer color matching function and k is a normalizing constant. X and Z tristimulus values can be found similarly. The summation is performed over the wavelength range of 380-780 nm at 10 nm intervals. Eq (1) can also be used to compute Yn, tristimulus value of the light source, assuming R! = 1 for the PRD. To obtain the absolute luminance values, normalized Y values of each patch were multiplied by the measured absolute luminance of the white patch. Figure 1 shows the calibration measurement and the response curves for the three channels. In this case, only the green channel response was used for obtaining absolute luminance. Note that the hardware takes care of the dark current correction. A digital count of zero corresponds to 0.75 cd/m2 and a maximum digital count of 255 corresponds to 91 cd/m2.

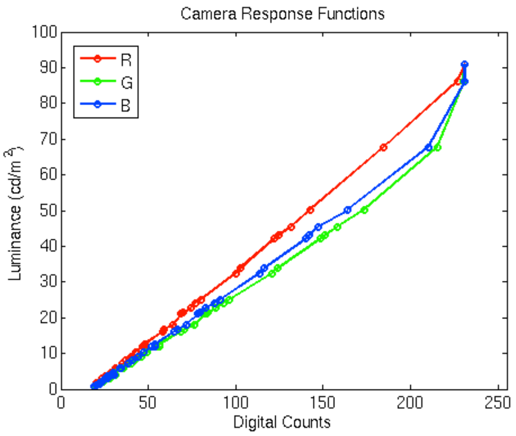


Fig 3.1: Calibration to determine response functions for the three channels of the video camera

Luminance is used throughout the daylight-sensing algorithm. Current and target light levels were determined by estimating luminance values from digital images of the space under present and ideal lighting scenarios respectively. This, although an approximate method, avoids the complicated calibration process to estimate luminance from luminance as proposed earlier. It is important to avoid specular reflection due to daylight coming from a task area by positioning the camera appropriately. Contributions from individual fixtures were determined during night time calibration. A lighting control algorithm was implemented to determine the dimming levels of individual fixtures required to reach the target light levels for different task areas simultaneously based on the daylight contribution. Details of the algorithm have been published earlier. The algorithm, based on least squares technique, tries to minimize the difference between target and current light levels for all task areas simultaneously. This is one of the most important advantages of this application. Please note that instead of absolute luminance, relative luminance can also be used for daylight sensing.

3.3. Occupancy sensing with CS-2

Our occupancy detection algorithm uses digital color imaging technique. The algorithm, based on reference image method, uses YCC color space instead of RGB. YCC values v

$$\begin{bmatrix} Y \\ C_b \\ C_r \end{bmatrix} = \begin{bmatrix} 0.299 & 0.587 & 0.114 \\ -0.168736 & -0.331264 & 0.5 \\ 0.5 & -0.418688 & -0.081312 \end{bmatrix} \begin{bmatrix} R \\ G \\ B \end{bmatrix} \quad (2)$$

obtained using Eq (2)

First,absolute YCC image difference between the last frame and the current frame is computed. The last two comp of YCC contain chromatic information independent intensity. These are used to derive an rms difference m per Eq (3).

$$rms = \sqrt{\left(C_{b2} - C_{b1}\right)^2 + \left(C_{r2} - C_{r1}\right)^2} \quad (3)$$

Where, (Cb1, Cr1) are the chromatic components at a given pixel in the last frame, and (Cb2, Cr2) are the corresponding values in the current frame. The metric is simply the Euclidean distance in the Cb - Cr plane. The difference image (pixel differences between any frame and the reference frame) and the thresholds are based on this metric. There are two userspecified thresholds, one for the pixel difference, and one for the spatial extent (in terms of a fraction of total number of pixels in a frame). These thresholds are programmable, thus allowing a real-time adjustment to the motion sensitivity of the sensor based on the operating requirements. The detection area is controlled through the specification of regions of interests, otherwise the whole frame is considered.

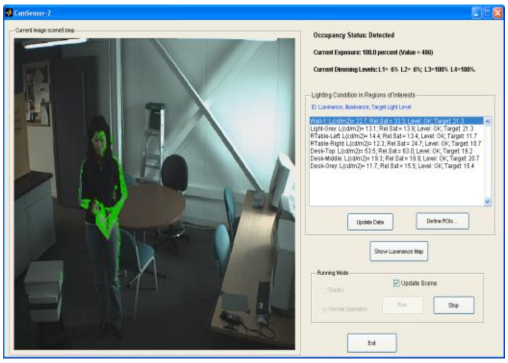
There are three advantages of using such an approach. Firstly, since YCC data format is very common in video processing, additional transformations may not be needed if YCC format is used throughout the processing chain.

Secondly, the detection of changes between frames is more robust against pixel noise. The pixel noise is likely to be introduced during various stages of the processing chain, including compression and transmission, and is predominantly present in the intensity channel. This metric is also less likely to be seriously affected by minor changes in the space illumination level than a metric based on raw RGB values. This is convenient because a change in the light level in the space does not typically cause a false alarm, unless the change is significant. Finally, this method is fast and inexpensive, which is a critical requirement for this application. Preliminary test showed CS-2 could detect very small head movement, on the order of 3-5 inches from a distance of feet. However, occupancy detection under low light level was not very satisfactory.

This is unlikely to be a hardware limitation, as the sensor works at a luminance as low as 0.88 cd/m2.29 One probable cause for this problem is that our occupancy detection method uses only the chromatic information in the image, and at low light levels, there is not much chromatic information present in the scene. The occupancy detection method needs to be more robust at low light levels as well as in rapidly changing daylight situations. Considering connected regions during occupancy detection may help in differentiating between daylight change and human motion. The performance of the occupancy detection algorithm could not be thoroughly evaluated because of a software constraint described below. Nonetheless, the initial results are promising.

3.4. CS-2 software

CS-2 software contains three modules developed in various programming environment. The code and algorithm for the Image Acquisition Module was developed in C++, built around the Small Image Capture API. The Processing Module, containing the daylight sensing, occupancy detection and lighting control algorithms as well as the graphical user interface, were developed in Matlab. The code for the DALI Communication Module was written in C. The operation of these modules is synchronized by updating parameter values in configuration files, which imposes a constraint on the system response and operating speed. The system performance should significantly improve under an integrated development environment.



Occupancy Status: Detected

Current Exposure: 100.0 percent (Value = 486)

Current Dimming Levels: L1= 6% L2= 6%; L3=100% L4=100%.

Lighting Condition in Regions of Interests

ID: Luminance, Illuminance, Target Light Level

Wall-1: L(cd/m2)= 22.7; Rel.Sat = 33.3; Level: OK; Target: 21.3
Light-Grey: L(cd/m2)= 13.1; Rel.Sat = 13.9; Level: OK; Target: 21.3
RTable-Left: L(cd/m2)= 14.4; Rel.Sat = 13.4; Level: OK; Target: 11.7
RTable-Right: L(cd/m2)= 12.3; Rel.Sat = 24.7; Level: OK; Target: 10.7
Desk-Top: L(cd/m2)= 53.5; Rel.Sat = 63.0; Level: OK; Target: 19.2
Desk-Middle: L(cd/m2)= 19.3; Rel.Sat = 19.9; Level: OK; Target: 20.7
Desk-Grey: L(cd/m2)= 11.7; Rel.Sat = 15.5; Level: OK; Target: 15.4

☑ Update Scene

Fig 3.2: Graphical User Interface for the CS-2

Software

The image acquisition module in CS-2 configures the imager and then runs in a continuous loop, in which it captures and stores 10 frames in pre-defined time intervals and overwrites them in the next cycle. If the Processing Module does not detect occupancy for a given amount of time, the system goes to standby mode where daylight dimming is not operational. Normal operation is resumed only when the thresholds discussed earlier are exceeded multiple times in successive frames. This reduces the probability of false alarms. It is critical that the system response time is minimized in the standby mode, so that it can react to occupancy detection within a fraction of a second. This underlines the importance of having a fast and efficient occupancy detection algorithm. The timing aspect could not be properly tested in CS-2 because of the software constraint described above.

As the CS-2 software detects motion, it is highlighted on the image in green (Figure 3.2). During the system setup/commissioning process, the software allows the user to specify different regions of interest (ROI) where different target light levels need to be maintained. The software adjusts the camera exposure in real-time until the light levels in each ROI can be properly estimated. If needed, the exposure is adjusted for one ROI at a time. This ensures that local glare does not cause system malfunction. After resuming normal mode operation or after the exposure is updated, adequate wait time is allowed for the lighting condition and/or the imaging system to stabilize.

4. PILOT TEST OF CS-2

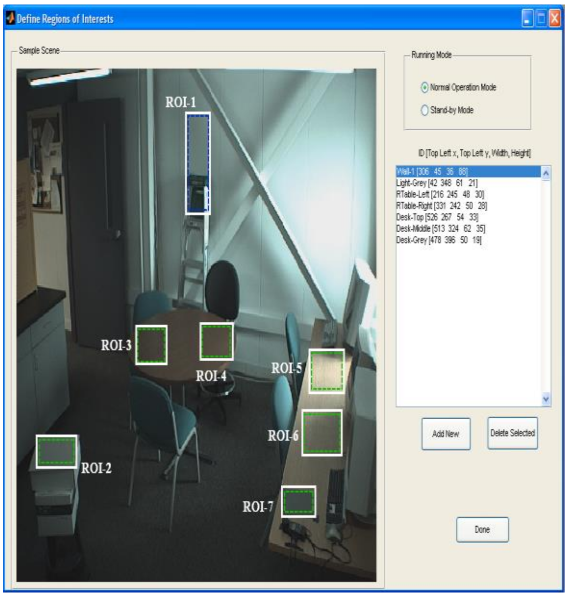
CS-2 prototype was run continuously for 4-6 hours on three separate occasions to evaluate the daylight sensing and lighting control functionalities. Results presented here are from one of these tests conducted from 12 noon to 4 PM on February 24, 2006, which was a partly sunny day in Rochester, NY. Four bare strip lights (F32-T8) with DALI ballasts were fitted into a room with adequate daylight. Figure 5 shows views of the room with the complete setup. The setup included several non-dimmable recessed troffers. Each troffer had three F40-T12 lamps, with the middle lamp on a separate circuit from the outer ones. These fixtures were turned on or off to simulate different lighting conditions inside the room. All lamps had a color temperature of 6500K. The camera was installed at one corner, looking away from the windows, but with a direct view of a bare lamp. Window blind positionswere changed from time to time to simulate different. daylight conditions.Fig.4.1

Fig 4.1: Experimental Setup

Figure 4.2 shows the seven Regions of Interests (ROIs) used in this experiment. To give an idea about the locations of the dimmable fixtures, L1 is almost right above ROI-5, L2 (visible in Figure 4.2) is closest to ROI-3, L3 is very close to ROI- 7 and L4 is right above ROI-2. The ROIs were dispersed throughout the room and covered areas with varied surface reflectance. For example, ROI-1 was on the white wall and was at times partially covered with a black cardboard, ROI-2was on a gray paper with close to 30% reflectance, ROI-3 and ROI-4 were on a round table with low surface reflectance,ROI-5 and ROI-6 were on another table with higher reflectance, and lastly, ROI-7 was on a 18% gray card. Thus, the luminance values corresponding to these ROIs varied widely during the experiment. It is, however, unlikely in a real-life application that task areas so close to each other will have different illumination requirements. Daylight and electric light availability varied quite drastically from one ROI to the other, making it a somewhat challenging application in terms of lighting control. This test setup was for demonstration purposes only. Large commercial spaces will likely have multiple control zones with various illumination requirements. Each ROI can be treated as a control zone in this application.

Every two minutes, all the data at each of the seven ROIs were recorded and automatically logged, including the illuminance measured by a luxmeter at a point close to the gray card (ROI-7). Since the gray card was fairly diffuse, the ratio of illuminance to luminance was assumed to be constant and independent of the direction of incident light. Thus measuring the illuminance on the gray card would give an indication as to how well the daylight could be estimated by CS-2 in case of diffuse surfaces. In presence of specular reflection, the relationship between illuminance and luminance is directional, resulting in a potential error in estimating illuminance from luminance. Images were saved at the same time the data were recorded. This allows us to do a detailed performance analysis and monitoring (and possibly system diagnosis).

The high dynamic range of the sensor and software controlled exposure allowed the system to operate normally even in the presence of direct sunlight and with a bare fluorescent lamp in the field-of-view, as shown in Figure 4.3. Both these conditions are likely to be problematic for conventional photo sensors.



Running Mode: ● Normal Operation Mode ○ Stand-by Mode

ID [Top Left x, Top Left y, Width, Height]

Wall-1 [306 45 36 88]
Light-Grey [42 348 61 21]
RTable-Left [216 245 48 30]
RTable-Right [331 242 50 28]
Desk-Top [526 267 54 33]
Desk-Middle [513 324 62 35]
Desk-Grey [478 396 50 19]

Fig 4.2: A screen-shot of the window with ROIs marked and labeled

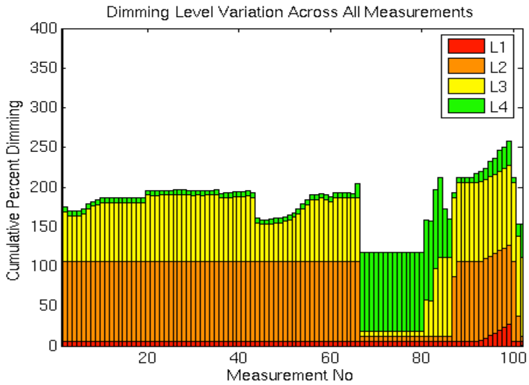


Fig 4.3: System functionality is not affected by a view of direct sunlight patches and a bare lamp

5. RESULTS AND ANALYSIS.

This section contains a brief discussion on the results obtained from the pilot test. A detailed performance analysis is beyond the scope of this paper. Figure 6 shows the variation in estimated luminance for different ROIs over time. Target luminance levels are plotted as dotted lines. Abrupt rises and falls in the graphs show the times when the blinds were operated to drastically change the daylight entering the room. However for ROI-1, the changes during 65th and 85th measurements were due to the black cardboard being removed and reintroduced respectively. A general tendency for most graphs is to slowly move toward the target light levels over time.

Note different scales for different ROIs. Note that target light levels cannot possibly be achieved for all ROIs. For example, ROI-5 and ROI-6 were quite close to the window and so had a high illumination level most of the time. ROI-2 received a strong daylight contribution from around 20th measurement through the 65th measurement, which caused the luminance level to far exceed the target level during this time. Toward the end, the luminance levels fell below the target levels for most ROIs because of inadequate daylight, but having a luminance on ROI-5 close to the target level prevented a rapid correction for other ROIs. As mentioned before, the least squares technique in the lighting control algorithm tries to minimize the difference between target and current light levels for all ROIs simultaneously. Rapid and abrupt change in the dimming levels is avoided by the algorithms, as evident in the graphs.

5.1.Applications

- Can be used in house, office and other commercial buildings.
- This system can be helpful in saving electricity and make the area energy efficient.

Automatic control over appliances such as light and other appliances depending on occupancy of the area

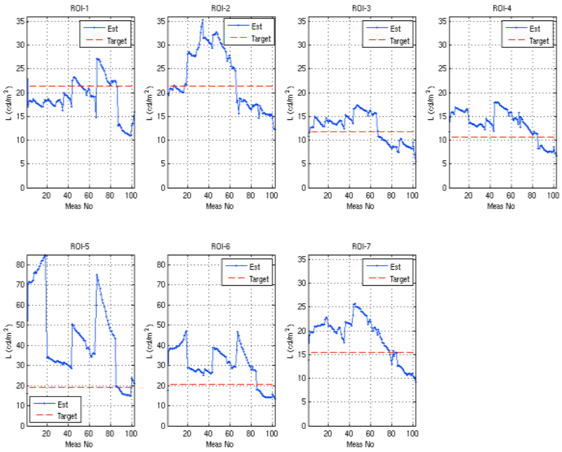


Fig 5.1: Light level (luminance) variation in different Regions of Interests

Fig5.1.shows the dimming level variation for individual fixtures. This illustrates how the system responded to changes in daylight availability within the room. The fixture L1 was the closest to ROI-5, which had a high illumination level due to its proximity to the window. So for the most part, L1 was dimmed to 1%. L4 was right above ROI-2, which received direct sunlight between the 20th and the 65th measurements. During this time, L4 was dimmed to 1% as well. L3 and L4 were not set at full output at the same time, as that would exceed the target illuminations for ROI-2 and ROI-7. On the other hand, with L1 being dimmed to 1%, L2 was mainly responsible for providing adequate illumination to ROI-1 and

ROI-3. L2 was kept at 100% for the most part. While the luminance level at ROI-3 exceeded the target because of L2, ROI-1 was below the target level for the most part, but in both cases, the deviation was not large. This shows that CS-2 performed reasonably well in addressing different daylight requirements of various regions, based on the luminance information available. Figure5.1 also illustrates that real-time energy monitoring and performance analysis can be achieved in this application. In this particular test, the average dimming levels for the four fixtures were 8%, 80%, 69% and 26% respectively, and average power savings were 54%.

Fig 5.2: Dimming level variation for each fixture over time

Figure 5.2 shows plots of target illuminance (in lux) for ROI-7 and the illuminance measured by the luxmeter. There was a significant deviation at times from the target illuminance. Abrupt increase in the illuminance level was caused by opening the blinds. Illuminance level started reducing slowly after each such increase. During the 65th measurement, there was an abrupt drop. Around the same time, the daylight contribution to ROI-5 and ROI-6 increased markedly (Figure 4.2), resulting in high luminance values. CS-2 responded by dimming L2 and L3 to 1%, which resulted in the drop in ROI-7's illuminance level. From the 65th through the 80th measurements, for about 30 minutes, CS-2 allowed this illuminance to fall further as the daylight contribution reduced, before increasing the light output of L3. Between the 85th and the 100th measurements, available daylight started reducing rapidly (between 3:30 PM and 4 PM). For all ROIs, the luminance levels were below the targets, and falling further. CS-2 responded by changing L2 output level from 1% to 100%, and slowly increasing L1 and L4 output levels. The performance probably would have been better had ROI-5 not have a strong daylight contribution. Assigning priority levels to various ROIs in the lighting control algorithm may address this problem.

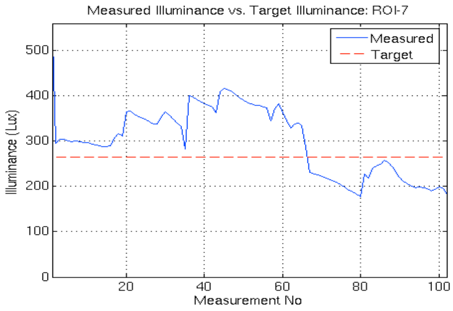


Fig 5.3:Target and measured illuminance (in lux) near ROI-7 as measured by the luxmeter

Considering wide changes in the daylight availability within the room, the performance of CS-2 seems acceptable. Precise daylight control is neither expected, nor achievable by any lighting control system in real-life applications. That said, a thorough performance analysis would require measuring the illuminance levels for each of the ROIs, and quantifying the accuracy of the daylight estimation method with luminance as the lighting metric. Neither of these could be undertaken because of time and resource limitations.

6. Conclusions

In this paper, we discussed a proof-of-concept implementation that uses a high dynamic range CMOS video sensor to integrate daylight harvesting and occupancy sensing functionalities into a single automatic lighting control system. We described a preliminary functional prototype, named CamSensor-2 or CS-2, which we developed during our research We also proposed a fast and inexpensive occupancy sensing method suitable for this application.

Future research on CamSensor must focus on customizing the image sensor and the hardware, with the application requirements and commercial viability of the concept in mind. The emphasis should be on making the system standalone, capable of functioning with or without a workstation. It should also be possible to interface the system with a standard lighting control panel. System setup (or commissioning) procedure needs to be further simplified to enable stand-alone operation, minimizing user intervention even further. An embedded system approach is foreseen. The software requirements will be governed by the hardware capability of the system, which in turn will be governed by its commercial viability. Cost-effectiveness will be a prime concern in future works in order to make this approach attractive to the lighting control market.

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