Day-light Occupancy Detection and energy saving by CS-2 camera and light control using MATLAB

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Abstract

The most waste of energy comes from the inefficient use of the electrical energy consumed by artificial light devices. This paper presents the digital system with a design for saving electrical energy by controlling the intensity of artificial light to a satisfactory level and getting use of the day light when possible with the best effort for energy saving. Day lighting will provide tremendous operating cost reductions if properly integrated with an electrical lighting control system. This is traditionally called "daylight harvesting.".This system shows light harvesting in day time by using the image processing in MATLAB tool and high dynamic range CS-2 camera, this proposed work decreases the energy consuming in day time as well as in night. The proposed system includes the prototype involves three algorithms, daylight estimation, occupancy detection and lighting control. These three prototypes runs sequentially one by one. The occupancy detection algorithm includes the image colour processing in YcbCr space has been developed. The hardware control the lights depending upon the values obtained from the occupancy detection algorithm, this is based on least squares technique. The result is obtained by Pilot test process in room used.

1. Introduction

We use more energy each year than we used the previous year. In fact, during the 20th century, the amount of energy our Nation uses has doubled about every 20 years. We used twice as much energy in 1955 as in 1935 and nearly twice as much in 1980 as in 1960. The rates of increase in our energy consumption have slowed somewhat, but we continue to use more and more energy.

Energy conservation—the wise and efficient use of energy—was not thought of before the energy crisis of the 1970s. When a shortfall in imported oil shipments and a dramatic rise in oil prices caused energy costs to skyrocket, we became concerned about saving energy. Today, energy costs have stabilized and the economy is stronger, but we still need to think about and practice energy conservation. Not only does energy conservation save us money on our energy bills now; it saves us (and consumers in the future) money in the long run by making our irreplaceable energy resources last longer. Today's students are tomorrow's consumers. Developing energy conservation skills will serve them well in the future, when prices are certain to be higher than they are now. Additionally, students may be able to help their families conserve energy at home, benefiting themselves and others both now and in the future. 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.

Daylight Harvesting is an energy conservation term used to describe the process of actively managing the amount of artificial light in a room when natural sunlight is available. Daylight harvesting can substantially decrease lighting power consumption depending on the amount of natural light available and the accuracy of the daylight harvesting device. Such day light harvesting building module shown in figure 1.

Figure 1:Daylight harvesting building module

Daylight harvesting systems are designed to maintain a minimum recommended light level in a room. Although the commonly recommended light level for offices in North America is 500 Lux (50 foot-candles) on the desktop, many commercial lighting installations typically exceed this level due to design obstacles or an abundance of natural light. With the increasing demand for environmentally sustainable buildings on the rise, daylight harvesting has become a common feature of green buildings. 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. 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.

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%. Review Process

- Total commercial electric consumption amounts to 67,707 GWh annually.
- 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.
- In fact, commercial buildings consume 18% of the nation's annual energy use, and 35% of the nation's total electricity.
- The many research has shown that lighting comprises 20% - 40% of total electric power consumed in commercial buildings.
- 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.
- 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%.

Faced with the skyrocketing cost of energy and environmental concerns, builders, architects and lighting specialists are increasingly turning to day lighting as a primary source of illumination in mainstream construction. Day lighting will provide tremendous operating cost reductions if properly integrated with an electrical lighting control system. At the same time, proper day lighting can increase the comfort and productivity of a building's occupants. It provides superior quality light for a wide range of tasks in the workplace. Windows, skylights and other clearstories used for daylight integration can also improve ventilation, lower air conditioning costs, and provide workers with visual stimulation. Exposure to both daily and seasonal cycles of natural daylight has also been shown to positively affect both the mood and stress levels of occupants. For successful daylight integration, cer tain principles need to be followed in terms of optimum building placement: the location, design and selection of materials for fenestration (windows, skylights, etc.) and electrical lighting design. In general, the earlier in the design process of new buildings that day lighting issues are addressed, the more successful the daylight harvesting project will be. To take full advantage of daylight integration, buildings should have automated controls that either turn off or dim ar bifacial lighting in response to the available daylight in the space. This is traditionally called daylight harvesting.

2. Proposed system

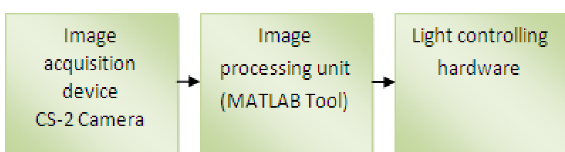


Figure2: Block diagram of daylight sensing and processing unit

2.1 Image Acquisition Device

The proposed system block diagram for day light harvesting and sensing system shown in figure1. For private offices occupancy ,sensors are often viewed as one of the most energy and cost-effective lighting control technologies. 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. In comparison to occupancy detection, daylight harvesting is a significantly less successful and somewhat less popular lighting control strategy.

The use of photo sensors 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. In the proposed system contains a small camera for image acquisition, The main component of CS-2 is a color XAECK100 Automotive Evaluation Kit based on Small camera technology from Cypress Semiconductor Corp (now owned by Sensate Technologies).

Figure3: Image acquisition room in use

The kit consists of an imager module (or camera head), an FPGA Processing Box and Small image capture Application Programming Interface (API). The imager is a CMOS sensor with the following specifications.

- High dynamic range up to 120 dB.
- A resolution of 640x480 pixels.
- 8 or 12 bit image capture modes.
- Up to 60 fps variable frame rate.
- Progressive scan mode with rolling shutter.
- A spectral range of 400- 1100 nm.
- 45 dB digital signal-to-noise ratio.
- 0.09% fixed pattern noise. and
- 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).

2.2 Image processing unit

The Processing Box contains a 2 million Gate Xilinx FPGA video controller board, which is connected to a PC through a IEEE 1394/Fire wire 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, auto exposure, Automatic Gain Control (AGC) and gamma control were disabled by modifying appropriate registers. Obtaining raw image data is important for this application. the spectral reflectance of each gray patch being known, CIE tristimulus value Y was computed for each patch using Eq (1).

$$Y = K \sum_{\lambda} S_\lambda R_\lambda \bar{Y}_\lambda \Delta_\lambda \qquad 1$$

$$K = \frac{100}{\sum_\lambda S_\lambda R_\lambda \bar{Y}_\lambda \Delta_\lambda} \qquad 2$$

Where S! is a spectral power distribution of the light source 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. 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 were obtained using Eq(3)

$$\begin{bmatrix} Y \\ C_b \\ C_r \end{bmatrix} = \begin{bmatrix} 0.299 & 0.587 & 0.114 \\ -0.168736 & -0.331264 & 0.5 \\ 0.5 & -0.418688 & -0.081312 \end{bmatrix} \begin{bmatrix} R \\ G \\ B \end{bmatrix} \qquad 3$$

First, absolute YCC image difference between the last frame and the current frame is computed. The last two components of YCC contain chromatic information independent of the intensity. These are used to derive an rms difference metric as per Eq (4).

$$rms = \sqrt{(C_{b2} - C_{b1})^2 + (C_{r2} - C_{r1})^2} \qquad 4$$

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.

2.3 CS-2 camera 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.

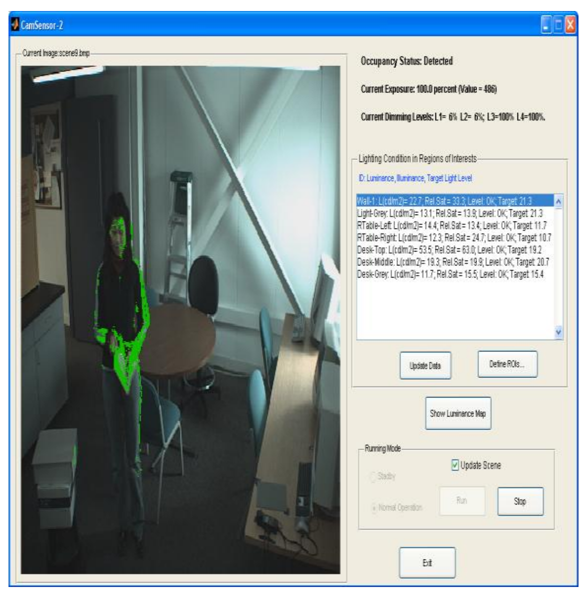


Figure4: Graphical User Interface for the CS-2 Software

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 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. As the CS-2 software detects motion, it is highlighted on the image in green (Figure 4). During the system setup/commissioning process, the software allow s 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.

2.4 System flow

STEP1: Start;
STEP2: Frame Acquiring;
STEP3: Convert RGB image to grayscale
Convert the colormap to a grayscale colormap;
[X,map] = imread('trees.tif');
gmap = rgb2gray(map);
figure, imshow(X,map), figure, imshow(X,gmap);
STEP4: Find Threshold Intensity of Grayscale;
STEP5: Is <required intensity? (check if is this required intensity or not);

If no switch off the appliances

STEP6: If YES then check for occupancy of light for room in use;

STEP7: Check for occupancy and if not occupied switch off the appliances;

STEP8: If YES switch on the Appliances;

This operation Repeat and repeat

STEP9: Stop;

3. Test for Proposed CS-2 Setup

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,

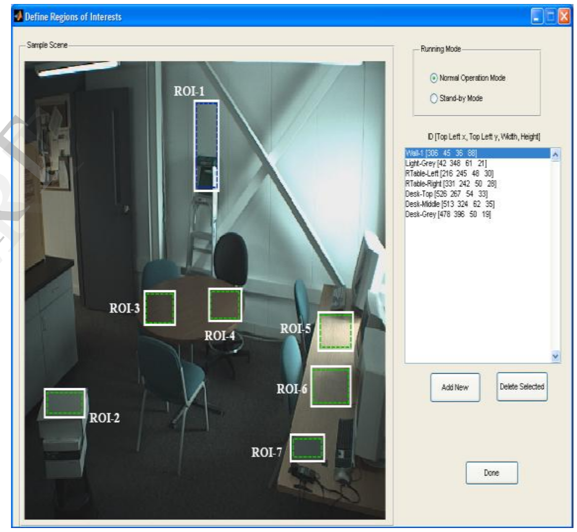


Figure5: A screen-shot of the window with ROIs marked and labeled.

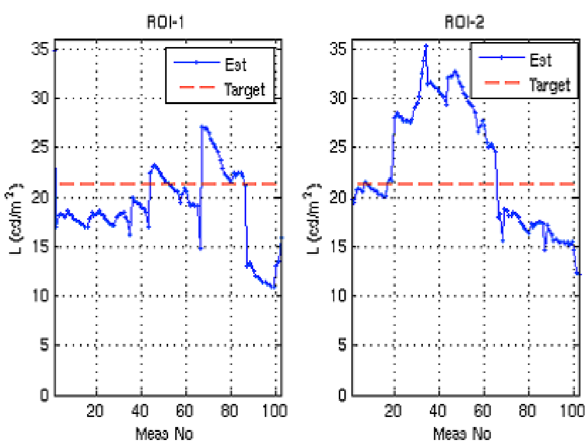
looking away from the windows, but with a direct view of a bare lamp. Window blind positions were changed from time to time to simulate different daylight conditions, Figure 5. shows the seven Regions of Interests (ROIs) used in this experiment. To give an idea about the locations of the dimmable fixtures, L1 is almost right above ROI-5, L2 (visible in Figure 4.) 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. 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.

4. Result And Analysis

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.



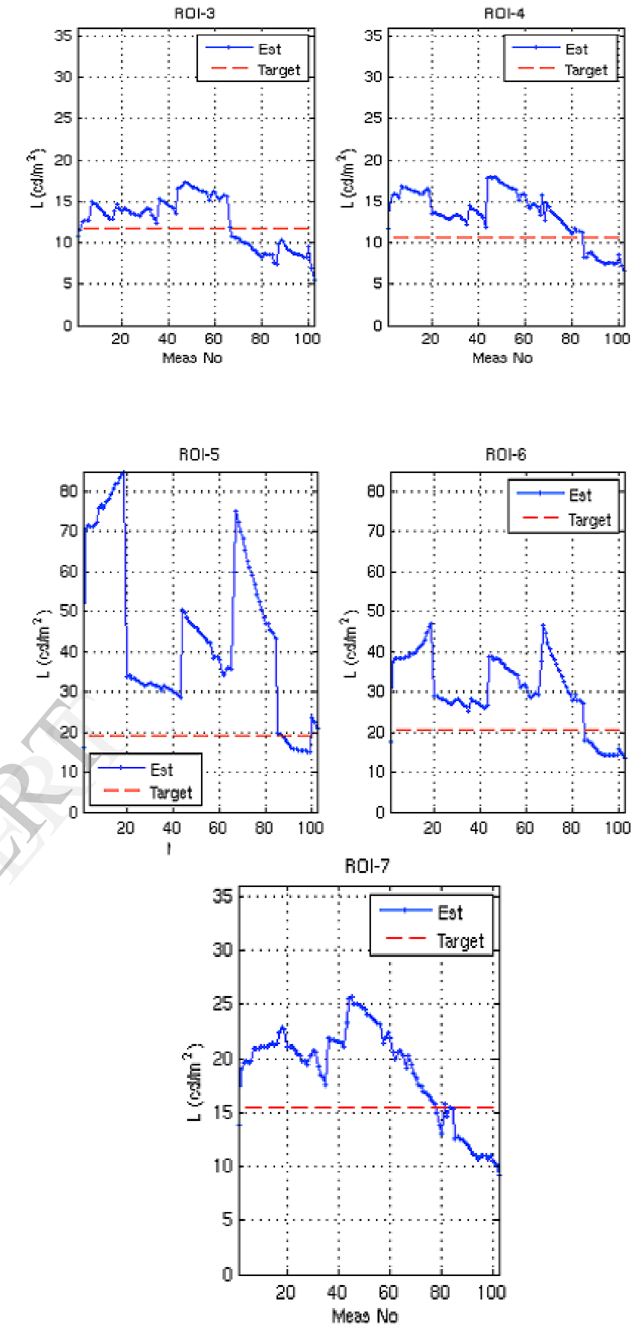


Figure6: The variation of Light intensity level (luminance) in different ROI

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. Above figure 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.

5. 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.

6. Conclusions

In this through this system we learnt and discussed a concept implementation that uses a high dynamic range CMOS video sensor to Day-light Occupancy Detection and energy saving by CS-2 camera 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. With this we can developed a control panel for System setup (or commissioning) and this procedure needs to be further simplified to enable stand-alone operation, minimizing user intervention even further. An embedded system approach is foreseen.

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