A Proof-Of-Concept Application of Digital Imaging in Lighting Control – Integrating Daylight and Occupancy Sensing

An Innovative Graduate Student Research Proposal

Principal Investigator
Abhijit Sarkar, Graduate Student (MS Color Science)
Chester F. Carlson Center of Imaging Science
Rochester Institute of Technology, NY
e-mail: axs4458@cis.rit.edu

Faculty Advisors
Dr. Mark D Fairchild, Advisor; e-mail: mdf@cis.rit.edu
Dr. Carl Salvaggio, Co-Advisor; e-mail: salvaggio@cis.rit.edu

Abstract

Conventional photosensor-based lighting control systems can only respond to the overall illuminance level within a space and is calibrated to address performance at a specific critical task point. Various calibration and commissioning issues contribute to the fact that photosensor-based systems have seen limited application and have traditionally faced market barriers. The purpose of this proposal is to obtain funding for a proof-of-concept research that seeks to overcome some of these difficulties by exploiting the latest advances in the field of digital imaging. Using an imaging system and the latest imaging technology, it is possible to develop an integrated sensor with the capabilities of both a photosensor and an occupancy sensor. Such sensor can provide enhanced functionalities by taking full advantage of the powerful features of the state-of-the-art digital technologies, including both digital imaging and Digital Addressable Lighting Interface (DALI) ballasts. This proposal focuses on a short-term collaborative research between the members of the Munsell Color Science Laboratory (MCSL) and the Digital Imaging and Remote Sensing Laboratory (DIRS) with the goal of demonstrating the feasibility of this futuristic technology. It also summarizes the scopes and prospects of future research and development that may follow.

Dollar Request: $5500

Desired Funding Dates: June 1, 2006 – August 31, 2006
PROPOSAL

Scientific justification

Photosensor-based lighting control is a common method for daylight harvesting in buildings. However, the use of photosensors to control interior lighting is nontrivial. A photosensor signal greatly depends on the position of the sensor relative to room surfaces and daylight apertures, as well as on room surface material properties. Various problems associated with calibration and commissioning contribute to the fact that photosensor-based systems have seen limited application and have traditionally faced market barriers. (Kim and Mistrick 2001; Mistrick and Sarkar 2005)

Further, a novel non-proprietary digital communication technology called Digital Addressable Lighting Interface (DALI) is now available for automatic lighting control that provides a lot more flexibility, enabling dimming of individual luminaires to different levels (DALI–AG 2001). Dimming of individual ballasts permits a DALI-based lighting control system to achieve different electric light output levels across a space providing for more precise control of the lighted environment. There is a need for an advanced daylight sensor that can reap the benefits and flexibility that DALI offers, and provide details of the light distribution across a space.

This PI has recently completed a master’s thesis research (Sarkar 2005) that used an inexpensive CMOS image sensor coupled with High Dynamic Range (HDR) imaging algorithm as an alternative to a photosensor. It was concluded that some problems associated with a single integrating photosensor could be circumvented using the hardware and software associated with this kind of solution. However, the need for further research on this application, including the imaging system itself, was apparent. The solution, named as CamSensor, was a proof-of-concept for the application of HDR imaging in the field of lighting control. The strength of such a solution lies in the fact that it can take full advantage of the available digital technologies, including digital imaging and digitally controlled ballasts. The proposed research will be an extension of the previous work and will investigate the imaging aspect of such application more thoroughly. The prototype will hereafter be described as CamSensor-2 in this document.

A major goal of CamSensor-2 will also be to explore the possibility of integrating occupancy sensing with daylight sensing. It is anticipated that such an integrated sensor will have high market demand considering the combined market size of these two types of lighting control products. Using image sensors for motion detection is commonplace, but their use in lighting control applications is still unknown. Thus this research will serve as a proof-of-concept for a new application of digital imaging.
Major goals of the proposed research:

- Develop a prototype that will be cost-effective and yet demonstrative of the capability of an image sensor to act both as a photosensor and an occupancy sensor. Selection of the imaging system will be based on criteria like resolution, heat dissipation (due to continuous operation), high dynamic range, high signal-to-noise ratio etc
- Develop software for image acquisition and processing
- Develop software that allows the camera to act as an occupancy sensor with low response time
- Test the accuracy of luminance estimation and also the ability to detect occupancy at low light levels
- Develop a smart algorithm that allows the system to operate even when the view of the imager is partially occluded

An outline of the research procedure:

The sensor will capture images of the work plane, with target points covered with diffuse surfaces. This will eliminate the need to calibrate the system (Sarkar 2005), since the target point illuminances will be proportional to corresponding luminances. The advantage of this technique is that it will effectively segregate the imaging aspect from the lighting aspects. From the images, luminance at the target points will be estimated at various light levels and will be compared with the readings of an illuminance meter. Further, if an object like a book or paper covers a target point on the work plane or its view from the camera vantage point is obstructed, the system should be able to detect such occurrences. In such cases it should automatically look at a nearby alternative point and estimate the luminance of the original point as if it was unaltered. An algorithm will be developed for this purpose.

A CMOS based high dynamic range video camera evaluation kit, sMaL Camera Technologies, donated to the laboratory by the manufacturer (Cypress Semiconductors Corporation), has been identified as a suitable imaging system for this application [sMaL Camera 2004]. It can be interfaced to a PC through IEEE 1394 or serial communication interface and raw digital signals can be obtained from the imager. The kit is already in possession of MCSL.

USA TridonicAtCo Inc, a reputed lighting control company with headquarter in Europe, has agreed to supply the DALI controller and DALI dimming ballasts at a severely discounted price of $250. Software to control a DALI system was developed during CamSensor project. The software program needed for PC interface of the camera will be developed in CamSensor-2 project.
Some advantages of the proposed solution:

• CMOS technology will allow the system to be fast and cost-effective
• The system will operate even at a very low light level. For example even when the room is dark, the sensor will be able to respond when someone enters the room. Even in presence of direct sunlight in the room, the sensor will be able to correctly estimate work plane illuminance (a known problem for photosensors).
• Image processing techniques can be employed to achieve enhanced functionalities like automatic calibration and detecting areas for selective scanning of the scene (to ensure low response time while being used as an occupancy sensor).

Collaboration benefits

CamSensor-2 will have the potential to lead to a next-generation lighting control technology. This will also open up a new frontier for digital imaging. The flexibility and competitiveness of digital technology make this application an attractive and commercially viable solution.

The past experience of this PI in CamSensor project and the expertise of the faculty advisors in different areas of imaging science will be quite helpful in conducting this research. Given the interdisciplinary nature of the application and significant involvement of imaging science research, the Center of Imaging Science seems to be the ideal place to work on this application at this stage. It also resonates with the Center’s vision of promoting innovative, forefront research in novel application areas of digital imaging.

An initiative to establish a collaborative partnership between the Munsell Color Science Laboratory and Cypress Semiconductor Corporation is already underway. Using the equipment donated by this firm for the proposed research and demonstrating the feasibility of applying digital imaging technology in a new application area like lighting control will bolster this potential relationship. A successful completion of CamSensor-2 will increase the likelihood of industry sponsorship for further research and development. This also creates the potential for a whole new multidisciplinary research area within the Center.
BUDGET REQUEST

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<tr>
<th>Description</th>
<th>Amount</th>
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<tr>
<td>Summer stipend</td>
<td>$4,333</td>
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<tr>
<td>Tridonic DALI Busmaster and four DALI ballasts ($250) + shipping charges</td>
<td>$320</td>
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<td>Four fluorescent Fixtures, special wiring for DALI system and fixture supports</td>
<td>$250</td>
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<td>Tools and materials to build the test setup (e.g. materials to make diffuse surfaces, support to mount the camera, black curtain, toolbox etc)</td>
<td>$497</td>
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<td>Stationary, miscellaneous supplies and incidental expenses</td>
<td>$100</td>
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<td><strong>Total</strong></td>
<td><strong>$5,500</strong></td>
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PROJECT PLAN

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<th>Milestone</th>
<th>Timeline</th>
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<tr>
<td>Acquire PC (being procured using another project fund) and hardware accessories, setup software for the imaging system and build the test setup</td>
<td>June 2006</td>
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<td>Implement data communication software for interfacing the camera with the PC</td>
<td>June-July 2006</td>
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<td>Write and test code for automatic image acquisition and luminance information retrieval from the images</td>
<td>July 2006</td>
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<td>Implement code to operate the camera as an occupancy sensor</td>
<td>July 2006</td>
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<td>Test the accuracy of luminance estimation as well as occupancy detection at low light levels</td>
<td>July-August 2006</td>
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<td>Develop algorithm to take care of occluded view of target points while sensing light levels</td>
<td>August 2006</td>
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<td>Prepare a technical report on CamSensor-2</td>
<td>August 2006</td>
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As already pointed out, this research will demonstrate the feasibility of an integrated lighting control sensor developed by using digital imaging techniques. The test setup will be a permanent asset of the laboratory and can be used in future research as well. The results will be published in an imaging conference and will also be used to seek industry funding for future research and development.

REFERENCES


