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# TOWARD AN INTEGRATED PLATFORM FOR ENERGY EFFICIENT LIGHTING CONTROL OF NON-RESIDENTIAL BUILDINGS

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**Abstract**

Net energy import of Switzerland corresponds to about 13 BCHF (petroleum, uranium, etc.) each year. According to the energy perspective 2035 defined by Swiss Federal Office Energy, the energy import should be reduced to 7.3 BCHF. Meeting the goals defined by this perspective can be envisaged by mitigating the energy demand of buildings since the built environment consumes 40% of the total primary energy. In Switzerland; 20 % of the buildings' energy consumption is moreover related to electric lighting. Therein, integrated building automation technologies, such as automatic regulation of sun shadings and electric lighting can play an important role in reducing lighting energy demand while maintaining user comfort. For this purpose, a rapid, reliable, accurate evaluation of the lighting conditions in a building is essential. In this paper, a control platform installed in two offices of the LESO experimental building on the EPFL campus in Lausanne, Switzerland is presented. This data acquisition and actuation platform hosts two motorized sun shadings per office, a dimmable lighting system, a presence detector, energy meters, ceiling mounted luminance-meters and two novel High Dynamic Range (HDR) vision sensors. A sample controller is implemented in the platform to evaluate its robustness and performance. This platform is currently ready for integrating novel controllers for testing several energy efficient control scenarios/algorithms.

**Keywords:**

Integrated lighting control platform; visual comfort; HDR vision sensor; user centric approach; daylighting and electric lighting, energy savings

## 1 INTRODUCTION

Although a lot of building automation equipment and technologies are developed with the aim of reducing the consumption of energy, and although the application of *sustainability rating systems* (e.g. Green Star in Australia or BREEAM in UK and LEED in US) is encouraged, in practice, the contribution to the mitigation of energy demand in the residential and non-residential buildings has remained marginal [1], [2]. A couple of reasons lead to these adverse outcomes. Firstly, the designers and manufacturers of these technologies consider mostly the energy consumption in a building from an individual "component-level" viewpoint in spite of the "system-level" complexity. In other words, the integration of sensors and actuators as a part of the whole building automation system is overlooked. Moreover, the dynamic of the building modifications, once the building is commissioned, is often underestimated; the occupants starting to interact with the building. This new dynamic does not necessarily correspond to the one on which the building and its automation systems were once conceived. On the other hand, the acceptance of new technologies, and their coherence with the existing one for the users are not sufficiently taken into account due to the market pressure for rapid commercialization. Finally, and more specifically, the existing commercialized technologies do not allow for fast, an accurate on-the-fly reliable evaluation of the visual discomfort sensations of the users.

It is an emerging trend for providing facilities and test-benches for pre-validating building

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automation technologies and addressing these issues before commissioning them to the market. Several research communities have opted for alike approaches allowing for human-building interact monitoring, reconfigurable lighting and envelope (Living Lab [3]), rotating test-beds (FLEXLAB [4]), green Star rated commercial buildings[5]. In the LESO solar experimental building located on the EPFL Campus (Lausanne, Switzerland), a *system level*, *user centric* approach is adopted thanks to a new integrated platform for testing the global performance of a High Dynamic Range (HDR) vision sensor. This platform was developed as an ad-hoc platform to the existing building communication system (established on 2000), a comprehensive system that can monitor and log the data of more than 700 sensors and actuators of 14 offices rooms

In this article, the physical layout, communication topology as well as sensors calibration procedure of the proposed ad-hoc platform are exposed. The performance results of an integrated daylighting and electric lighting controller are presented and discussed.

## 2 EXPERIMENTAL SETUP

Two identical south-facing office rooms (Fig. 1) of the LESO solar experimental building were set-up in order to carry-out field-test experimentations. Both were equipped with a conventional window on the lower part and an *Anidolic Daylighting System* (ADS) on the upper part. This system collects direct and diffuse daylight issued from the sun and the sky vault through a zenithal collector, composed of an anidolic element protected by a double glazing [6]. The floor area of each test room is identical and equal to *15.7 m*$^2$; the room height is *2.8 m*. The two office rooms are equipped with the sensors and actuators described here.

### 2.1 HDR vision sensor

The introduction of an HDR vision sensor to the building automation is the principal innovation of this research work. The reader is encouraged to refer to [7] for ample information regarding the robustness and accuracy of the sensors. They were used to measure two variables: the Daylight Glare Probability ($DGP$), and the workplane horizontal illuminance ($E_h$). The first variable, measured by the first HDR vision sensor, quantifies the probability of experiencing discomfort glare for the scene captured by the vision sensor and is used for sake of protecting the occupants against glare sensations. The second one was used for assuring the required illumination on the work plane for specific work based on lighting norms ([8]). The second sensor was mounted on the ceiling (Fig. 1) and by predefined zone from its luminance mapping, an estimation of $E_h$ is obtained (section 4.1). The sensor was attached to a metallic plate mounted on a roller so that its position can be modified if needed. On the other hand, since the HDR vision sensor is equipped with a fisheye lens, the horizontal illuminance on one or several work station(s) located in the office can be monitored at each snapshot.

The other vision sensor is located as close as possible to the user's view point and mounted on a tripod to monitor the main photometric variables (e.g. pupilar illuminance, average luminance, etc.) as well as all well known glare indices, such as the Daylight Glare Index ($DGI$) and the Daylight Glare Probability ($DGP$). Nevertheless, only $DGP$ was the one used for the control platform. The exact sensor location and orientation will be explained in Section 4.1 Both sensors have their own fixed sampling frequency and as soon as the required data are obtained, they are available for the telemetry (LAN line). The data remains there till the next sampling iteration is done; the calculated data are not registered on the sensors' embedded platforms.

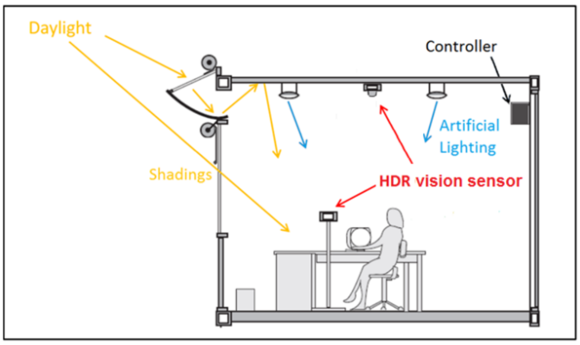


*Fig. 1: Physical layout of an office room used as a test bench for the novel controller.*

### 2.2 Illuminance sensor and presence detector

A conventional illuminance sensor is permanently mounted on the ceiling and looking downward in the second office room; it measures an average luminance in a given cone which can be translated in work plane illuminance, assuming a constant desk reflection factor. The data is captured and stored in a 4 bytes format to the KNX system. The calibration process is explained in section 4.2. The data is generally saved when a data variation equal or larger than a certain threshold (currently 15 lux) is observed. Thus the illuminance records in the database do not have fixed sampling rate.

### 2.3 Energy metering

A 3-phase energy meter (*hager TE360)* was installed in each office room to monitor the following energy consumptions per phase: (i) electric lighting; (ii) electric heating and motorized shading and (iii) plug loads. The latter measures instant power consumptions (W) as well as partial and total active energy consumption (KWh) on each phase.

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### 2.4 Motorized external shading

Each office is equipped with two external motorized fabric blinds. Each blind can be driven by two manual switches inside the office room. The upper blinds cover the ADS window and are occasionally used to reduce the rooms' workplane illuminance when the users feel that the daylight flux is too large in the office; they are also used for glare control (i.e. to prevent direct sunlight from falling on the VDT). The lower one, however, are used less frequently by most users and serve mainly for thermal reasons. The sun shadings can also be controlled through a KNX communication network: the shadings do not have position sensors, thus, they are fully retracted for initialization at the beginning of each experimentation. During the latter, a command is sent to the shadings by defining the "duration" of their raising or lowering at a constant speed. The total time required for lowering/raising each sun shading was previously measured. The final position after each movement was recorded and used as initial position for the next movement.

### 2.5 Lighting

The LED lighting installation (Regents Lighting SA 78H14L1224JA) consumes 23W with a 2400 lm luminous flux, a 4000K correlated color temperature (CCT), a, color rendering index (CRI) of more than 80 and Unified Glare Rating (UGR) lower than 22. The lighting system is dimmable and controllable either through a DALI protocol or manual switchers. The dimming functionality is possible through 4-bit large data. The status of the lighting system (comsumed electric power and on/off status) is accessible through the KNX communication network.

## 3 CONTROL PLATFORM

### 3.1 Communication platform layout

An ad-hoc control platform was set-up to guarantee the proper data acquisition and logging, flawless initialization as well as actuators commanding. The topology of this system is shown in *Fig. 2*; It is installed on a PC labeled "*control platform*" (#1 in *Fig. 2*). This PC performs the on-the-fly data acquisition, hosts the controller, sends the commands to the actuators and finally, logs the corresponding data. In other words, the whole procedure described in *Fig. 3* is hosted in this *control platform*. The data transfer between relay units and the control platform is carried out through the "mapped drive" technique provided by MS Windows; it is the most robust method for data synchronization between different platforms which are all connected to the internet.

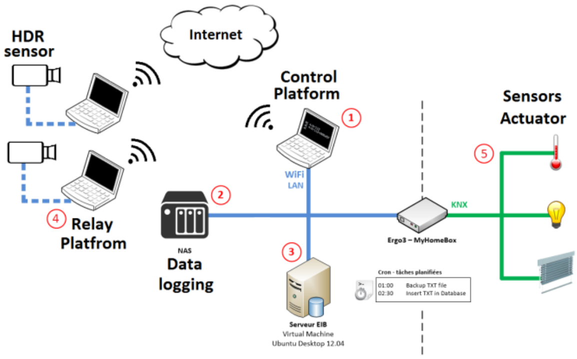


*Fig. 2: Communication platform layout.*

### 3.2 Control Platform execution block diagram

The control platform was established based on the following principal strategies:

- Data should be registered as received by the master platform in order to avoid a loss of information if any unforeseen problem occurs. They should be stored in a folder with an easily recognizable label.
- The controller's commands (output values) are applied to the actuators if the "*actuation conditions*" are met. As an example, the shading positions are amended if the new position differs from more than 15/30% (lowering/raising) from the current position. Similarly, the actions are applied only if 15 minutes and more are elapsed from the previous actuation (inspired by [9]).
- The platform should be designed flexible enough to allow for the introduction of any type of new control strategy. In other words, the platform should manage the input data to the controller and retrieve the output data from the controller in a structured standard format. This flexibility allows the platform user to introduce his controller in a time efficient manner by including only one file (the controller) in the predefined location and to readily evaluate its functionality. On the other hand, masking the physical and logical addresses of the actuators and the sensors with "user-friendly labels" would ease the utilization and reduce ambiguity.
- The platform should be flexible enough to accommodate a timely efficient introduction or elimination of a sensor or an actuator.
- The control platform should have a "control board" with an accessible code location (evidently at the beginning) so that the user has the possibility to modify the key parameters of the platform in a straightforward way without exploring the whole platform.
- Finally, proper structure and classification for the files managing sensors and actuators would lead to a faster debugging and tuning of the control platform.

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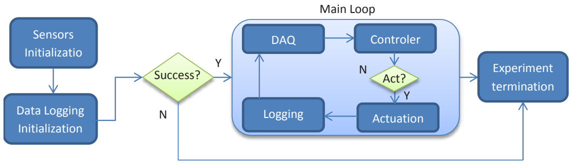


*Fig. 3: Control Platform execution block diagram.*

The *sensor initialization* block illustrated in *Fig. **3***, allows the platform verifying if all the sensors are functional and if there is an access to the sensor readings. Control platform requests for a sample from the relay platforms and by examining it determines whether the HDR vision sensors are properly functional. On the other hand, the shading system is initialized and fully raised to mark the initial state. The status of the electrical lighting is also recorded.

The *main loop* block contains four action blocks and a conditional one. The DAQ block prepares the input data for the control block. This block verifies the data correctness by comparing them with the expected ranges. In the next step, the control block generates the appropriate command for the building actuators based on the algorithm loaded in the initialization section.

In the next step, a decision-making procedure is carried out to find out if the generated command should be actually executed or not. This process is based on several principles, such as:

(i) The actuation should be carried out more than a certain number of times per day, since too many amendments of the lighting and sun shading would annoy the office occupant.

(ii) The control actions are applied to the controllers provided that the amendment of the shadings' position is larger than a given threshold. For instance, if the newly proposed sun-shading position differs from the current one by more than 30%, the new command is passed to the shading actuators.

(iii) In the actuation phase, the commands are sent through the KNX network insuring that they are properly executed.

(iv) In any case, the whole acquisition data and the input and output variables of the controller are stored into a local hard disk.

(v) As soon as the conditions for ending the experiment are met, the main loop ends and the whole data registered on the local hard disk are copied into a database located on an EPFL server so that the risk of data loss is minimized.

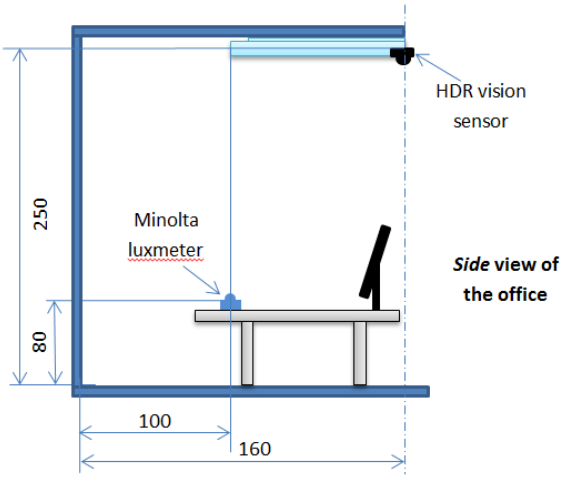


*Fig. 4: HDR vision sensor mounted on the ceiling with a work plane illuminance meter calibration setup.*

## 4 CALIBRATION

### 4.1 Ceiling mounted HDR vision sensor

An HDR vision sensor, mounted on the ceiling and facing downward, was used for estimating the work plane illuminance (*Fig. 4*). This technique is based on the assumption that all surfaces in the office room are Lambertian meaning that their apparent brightness is constant whatever the observer's angle of view. This means that the surface's luminance is isotropic and that the luminous intensity obeys to a cosine law. In other words, the surface illuminance is linearly proportional to the observed luminance. On the other hand, since it is equipped with fisheye lens, the illuminance of one or several work spaces located anywhere in the office can be monitored at each sampling (Fig. 5).

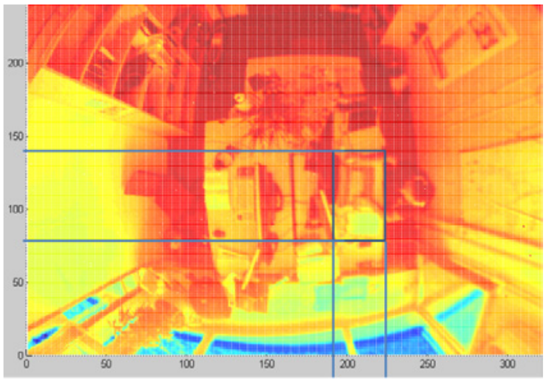


*Fig. 5: View from the ceiling mounted HDR vision sensor with a defined zone corresponding to the work plane.*

### 4.2 Illuminance meter

The ceiling mounted luminance meter has been calibrated using a conventional illuminance meter. A Minolta illuminance meter was placed for that purpose directly underneath the ceiling

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mounted HDR vision sensor to measure the horizontal illuminance on that table; 160 samples were recorded leading to the calibration illustrated on Figure 6.

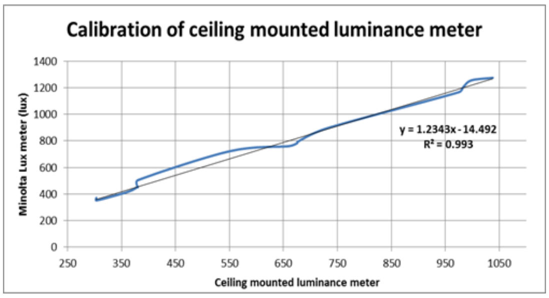


*Fig. 6: Calibration of the ceiling mounted luminance meter by means of Minolta CL-200A illuminance meter.*

A linear correlation between the ceiling mounted luminance meter readings ($L_{sensor}$) and the workplane illuminance ($E_h$) was obtained; the average mean square error is $\pm 27\ lux$. Thus:

$$E_h = 1.2343 \times L_{sensor} - 14.492 \pm 27 \quad \text{[lux]} \qquad (1)$$

## 5 RESULTS

In order to verify the robustness and the performance of the platform, a controller based on fuzzy logic was set-up and tested during the afternoon of October 9 2015 (partially cloudy). The input data to the controller are: $DGP$, $E_h$, height and azimuth of the sun. The outputs are: relative coverage positions of the two sun shadings (for ADS and normal windows) as well as electric lighting status (0/100). The reference for defining comfort zone for horizontal work plane illuminance and $DGP$ are 200/1500 lux and 30%. The set point value for $DGP$ is derived from [7].

*Fig. 7* shows the $E_h$ and $DGP$ ranges during the almost 5 hours duration of the 'in situ' experimentation in the afternoon. Sun shadings positions as well as the electric lighting status are illustrated in *Fig. 8*.

One can observe that the workplane illuminance exceeded the comfort range boundaries at 13:50 and that the bottom and top shadings are moved respectively, to 17% and 52% window coverage positions. Consequently, $E_h$ is brought back to the visual comfort range. Since $DGP$ was in the comfort range (DGP lower than 30%), the controller was still not activated based on this variable. At 14:16, as the $E_h$ dropped below the comfortable range ($200\ lux$) the sun shadings were retracted to increase the daylight flux into the office through the windows. It is worth noticing that since this action was sufficient for providing enough illumination on the work plane, the electric lighting system was not activated.

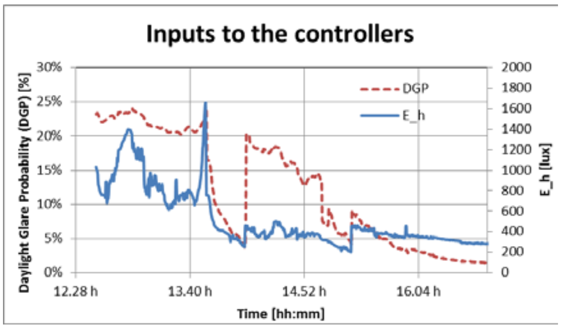


*Fig. 7: Input variables to the controller during a test-field on 9th October 2015.*

Finally, at 15:22, the interior illuminance reached the lower boundary of the comfort range for $E_h$, (i.e. 200 lux): the electric lighting was activated in order to compensate for the shortage of daylight. The lightings remained turned on till the end of the duration of the experiment.

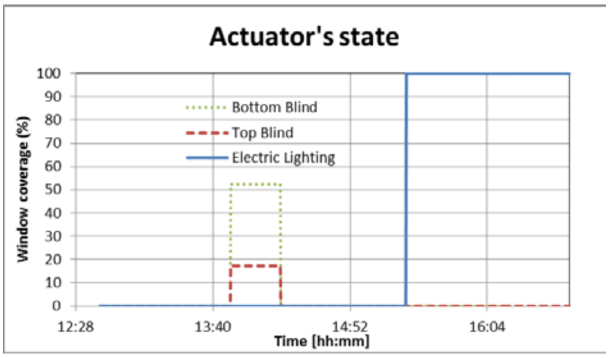


*Fig. 8: State of the actuators during a test run on 9th October 2015.*

During the test-field, the platform remained functional; the monitored data as well as the input and output variables of the controller are stored on the local disk of the control platform.

## 6 CONCLUSION

The setting-up of an ad-hoc control platform for the field-testing of a controller based on novel HDR vision sensors was presented. This platform was installed in two office rooms of the LESO solar experimental building on the EPFL campus in Lausanne, Switzerland. A data acquisition and actuation platform driving two motorized sun shadings per office, a dimmable electric lighting system, a presence detector, energy meters, a ceiling mounted luminance meter as well as two High Dynamic Range (HDR) vision sensors were set-up for that purpose. A controller based on HDR vision sensor was successfully implemented in an LESO office room in order to evaluate its robustness and performance. This platform is currently ready to operate with advanced controllers in order to test several energy efficient control scenarios/algorithms.

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