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High Dynamic Range Imaging system for Energy Optimization in Daylight – Artificial Light Integrated Scheme

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Abstract- This paper explains High Dynamic Range Imaging (HDRI) technology for the control and optimization of visual comfort, thermal comfort and energy consumption in daylight-artificial light integrated scheme. The objective of this work is to incorporate image sensors, Wi-Fi and ZigBee to make an economical solution for reducing energy consumption while improving visual comfort levels. The camera based fuzzy model presented determines the position of blinds ensuring visual and thermal comfort by reducing glare and maintaining uniformity. MATLAB – SIMULINK technical computing and visualizing environment is used to obtain the complete system including making HDR images, calibration of camera, formulation of control algorithm for artificial light and window blind control as well as to analyse the quality aspects of daylight-artificial light integrated scheme.

Keywords- Light Emitting Diode (LED) lighting control, Daylight-Artificial light integration, Fuzzy Logic Control, High Dynamic Range Imaging, Energy saving.

1. Introduction

In commercial buildings, air-conditioning and artificial lighting accounts for the majority of total energy consumption[1]. Though lighting represents about 17.5% of all global electricity consumption only a small percentage of lighting in commercial buildings is controlled by anything other than an on/off switch[2]. Recent studies indicate that image data captured by photographic sensors of image acquisition systems can also be used to measure photometric quantity. If the luminance of a scene can be accurately measured using a digital camera, a novel system of building automation can be developed ,in replacement of occupancy and photo-sensor[3]. Research in this area is progressing in the direction of calibration of camera for luminance measurement, experimentation and analysis towards photometric measurement[4-7]. For improved occupant comfort and to increase energy savings, automated artificial light control in combination with window blinds is an efficient method[8]. To ensure energy efficiency in daylight-artificial light integrated schemes a coordinated control strategy is required for providing occupant comfort.

2. Literature Survey

Analyzing daylight information from high dynamic range image is a new method in which luminance information is extracted[9]. Luminance measurement with digital cameras, which are freely available at reasonable price, is more desirable for lighting control applications[10].

High dynamic range imaging is a technique used in imaging and photography to reproduce a greater dynamic range of luminosity than that is possible by using standard digital imaging or photographic techniques. “Reference [3]”, explains the process of creating HDR photographs, achieved by capturing multiple standard photographs using exposure bracketing and then merging them into an HDR image. PHOTOSPHERE is used to find luminance at each point of an HDR image. HDRI technology can be used to calibrate a digital camera with the help of a luminance meter[11]. **“**Reference [12]”, suggests HDRI for luminous intensity and light output measurement. Many researchers have demonstrated Fuzzy logic based window blind controller for visual comfort, thermal comfort and for minimizing energy consumption through slat angle variation as well as position control[13-16].

In daylight-artificial light integrated scheme, control over artificial light and window blinds can be made partially or fully automated[17]. For local task areas, manual dimming of light with a remote control can be used based on user preference and in case of large spaces, flexibility of setting different light levels depending on usage of space can be ensured with manual operation. “Reference [14]”, describes a PC based system with wired automatic control of artificial light and window blinds using Artificial Neural Network Fuzzy Inference System (ANFIS) and fuzzy controller. A digital addressable lighting interface based wireless system described by **“**Reference [18]”, uses sensors inputs and generates an analog dimming signal to the ballast.

3. Significance

The proposed HDRI based daylight-artificial light integrated system operates with low dynamic range camera photographs as input for artificial light control, window blind control, luminance spatial distribution, uniformity, glare and contrast analysis. For the purpose of demonstration, the lighting control signal is transmitted through ZigBee to the dimming electronic ballast / LED driving circuitry for controlling the lighting level. This system has the advantage over other traditional systems in a way that it eliminates conventional sensors like photo sensor and occupancy sensor[14, 19]. Considering the application of HDRI technology in lighting control, flexibility and programmability are much simpler when using MATLAB to design an automated system for daylight harvesting and dimming of lamps. Moreover, it is easy to analyze glare and adjust window blinds for effective control of daylight, providing visual comfort, thermal comfort and reduced load on air condition.

4. System Description

Low Dynamic Range (LDR) images are taken by Nikon Digital Single Lens Reflex (DSLR) D5100 with 35mm f/1.8 G prime lens using exposure bracketing method and the images are sent to PC using Eye-Fi Connect X2 SDHC, Wi-Fi Memory Card as shown in “Fig. 1”.

Fig. 1. HDRI system for automatic lighting control

A single window venetian blind of dimension of 1.3m×1.3 m is mounted in the interiors. The semi specular white aluminium type venetian blinds with horizontal slats are uniformly spaced 2.1cm apart. The shafts of the blinds are equipped with small 12V Direct Current (DC) motors, each dedicated to blind up/down movement. The system developed is an integrated scheme for efficient utilization of daylight by controlling the window blind.The additional illuminance required in the work plane is provided by the control of the artificial luminaire in the room.

4.1. Canon DSLR Camera calibration and Luminance Calculation

In colour checker chart method of camera calibration, the actual luminance of each colour in the colour chart is measured using a luminance meter at specific lighting condition. At the same lighting condition the LDR images of the chart is taken and the software luminance is found out from the image using MATLAB software.

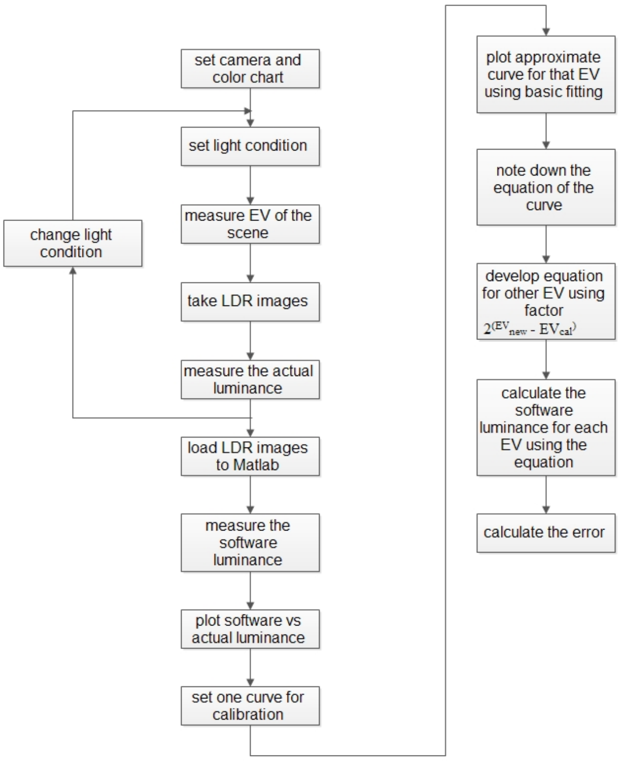

Fig. 2. Flow chart for luminance measurement with different exposure values

The flowchart for luminance measurement of a task area is shown in "Fig. 2". The Exposure Value (EV) can be obtained from the details of the image corresponding to zero exposure compensation. EV_{new} is the EV calculated for any new lighting condition and EV_{cal} is the exposure corresponding to the reference curve selected for minimum error[20].

4.2. *Occupancy detection*

The frames from the camera are periodically extracted and analyzed for occupancy detection using Sum of Absolute Differences (SAD) block available in Matlab.

4.3. *Window blind control for visual and thermal comfort*

The HDR images developed in MATLAB using photographs taken with an interval of 1hour is used for glare estimation and thereby adjusting blinds to optimize visual and thermal comfort and energy consumption. A fuzzy based scheme shown in "Fig. 3" is simulated where the inputs are the photographs taken by camera and temperature sensor.

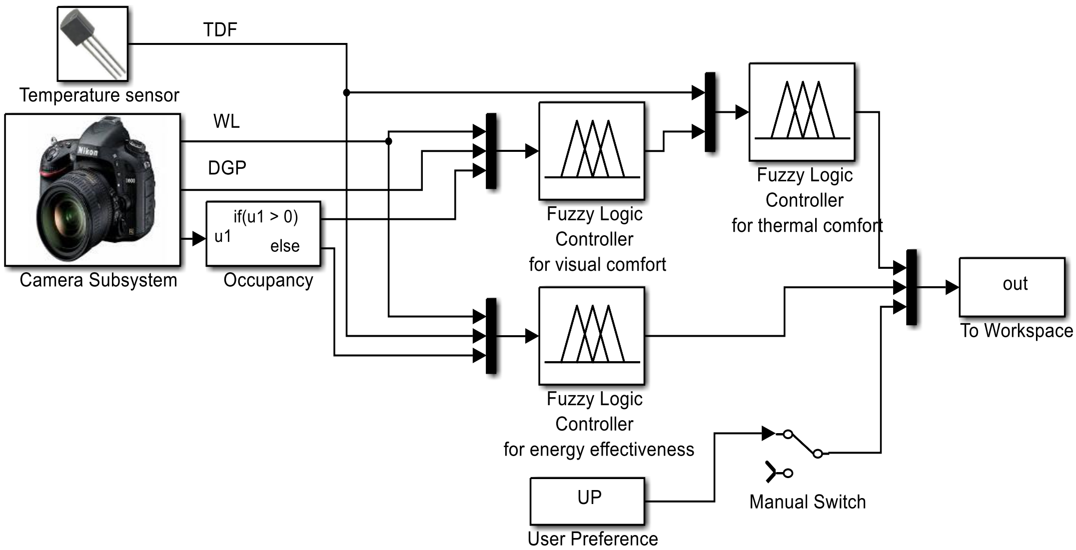

Fig. 3. SIMULINK model for window blind control

The window blind algorithm described by "Reference 13", is modified with input parameters Temperature Difference (TDF), Window Luminance (WL) and Dominant Glare Position (DGP), where WL is the average luminance of the window and DGP takes the value from 1 to 3, wherein 1 is the lower 1/3rd, 2 being the middle and 3 being the upper 1/3rd of window. TDF is calculated by subtracting the measured temperature from the set temperature (25°C). "Fig. 4" shows the membership functions and the surface plots of individual fuzzy controllers.

Fuzzy controller for energy effectiveness: When the user is absent in the room, the controller optimizes the energy consumption by providing half the required illuminance in the interior and by reducing the load on air conditioning system. “Fig. 4(a) and Fig.4(d)” show the fuzzy input variables daylight on window and room internal temperature difference. “Fig. 4(c)” shows the blind position for energy optimization algorithm when the user is absent.

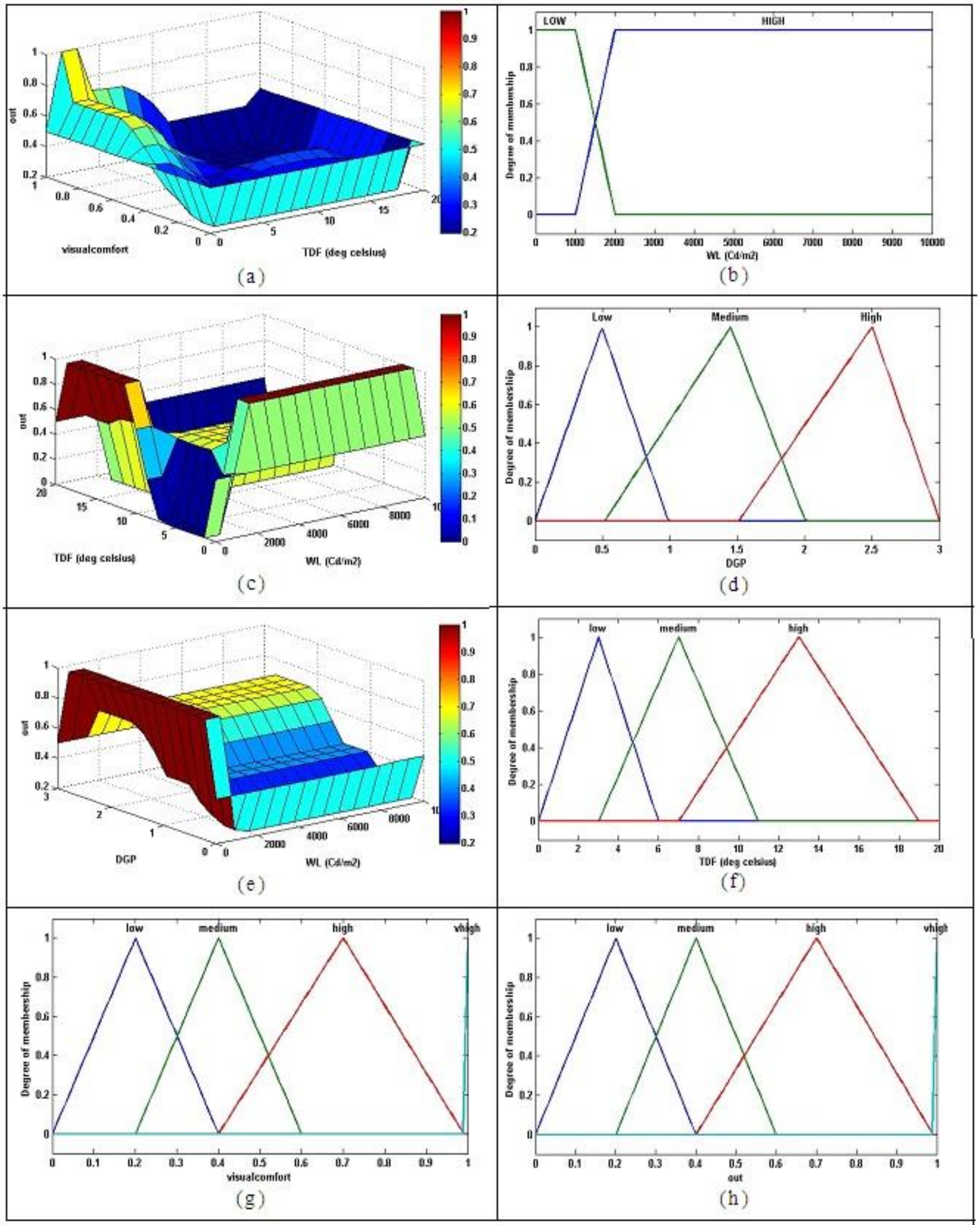

Fig. 4. Surface plots for fuzzy controllers and membership functions (a) surf plot of thermal comfort fuzzy controller, (b) input membership function of window luminance, (c) surf plot of energy effectiveness fuzzy controller, (d) input membership

function of dominant glare position, (e) surf plot of visual comfort fuzzy controller, (f) input membership function of temperature difference, (g) output membership function of visual comfort and (h) output membership function of thermal and energy effectiveness fuzzy controller.

4.4. Wireless communication and dimming control

Fluorescent Tube Light (FTL) dimming control: If occupancy is detected in a zone, the illuminance calculated is compared with the desired illuminance level. When zone luminance control is executed, a control signal proportional to daylight availability is generated and sent to the serial port of the computer. If the actual illuminance has not reached the required range then the control signal is incremented in steps and this variable is send to the serial port. ZigBee based wireless communication system is established for the transmission and reception of control signal, which can be used for energy efficient communication. Since ZigBee is a low power networking technology, for short range communications many organizations have been using it for energy management and efficiency[21]. The ZigBee transmitter receives input from the serial port of the computer through Programmable Integrated Circuits (PIC) 16F873A. At the receiver side ZigBee is connected to another PIC16f873A. High frequency electronic dimming ballast, HF-R 236 TL-D 220-240V 50/60Hz is used for the operation and control of two 36watt FTL lamps and use analog protocol (1-10V) for dimming. The lamp power output can be controlled from minimum output to 100% output via the analog control input in accordance with the 1-10V control signal. This PIC is programmed to generate digital values at port B for each signal received by the ZigBee module. For each of these digital value received, the Digital to Analog Converter (DAC) generates a corresponding analog voltage ranging between 0 and 10V. This analog voltage is given to the control input of the electronic dimming ballast and different dimming levels are generated by each of these analog voltages. MATLAB performs the illuminance calculation after the average luminance of task area is found. E_{set} be the desired illuminance and E_{task} the present illuminance of the task area, control signal for FTL is generated as per the control scheme given in the "Table 1" [9]. The control signal obtained is approximated to the nearest integer and is transmitted wirelessly using ZigBee communication.

Table 1. Control signal generated for different lighting conditions

Relation between E_{task} and E_{set}	**Control Signal**	**Artificial Light Condition**
$0.2\ E_{set} < E_{task} < E_{set}$	$\left(1-\frac{E_{task}}{E_{set}}\right)\times 7$	20% to 100% output
$E_{set} < E_{task} < 1.25\ E_{set}$	No change in control signal	20% to 100% output
$E_{task} > 1.25\ E_{set}$	Zero	All lights off
$E_{task} < 0.2\ E_{set}$	7	100% output

LED dimming control : For LED dimming control PWM signal is generated by the PIC 16F873A in accordance with the control signal received by the ZigBee module.

The LM3047 EVM evaluation module controls the led brightness in proportion to the Pulse Width Modulation (PWM) signal. The PWM signal for control signal from 1 to 6 received by the ZigBee is shown in "Fig. 5".

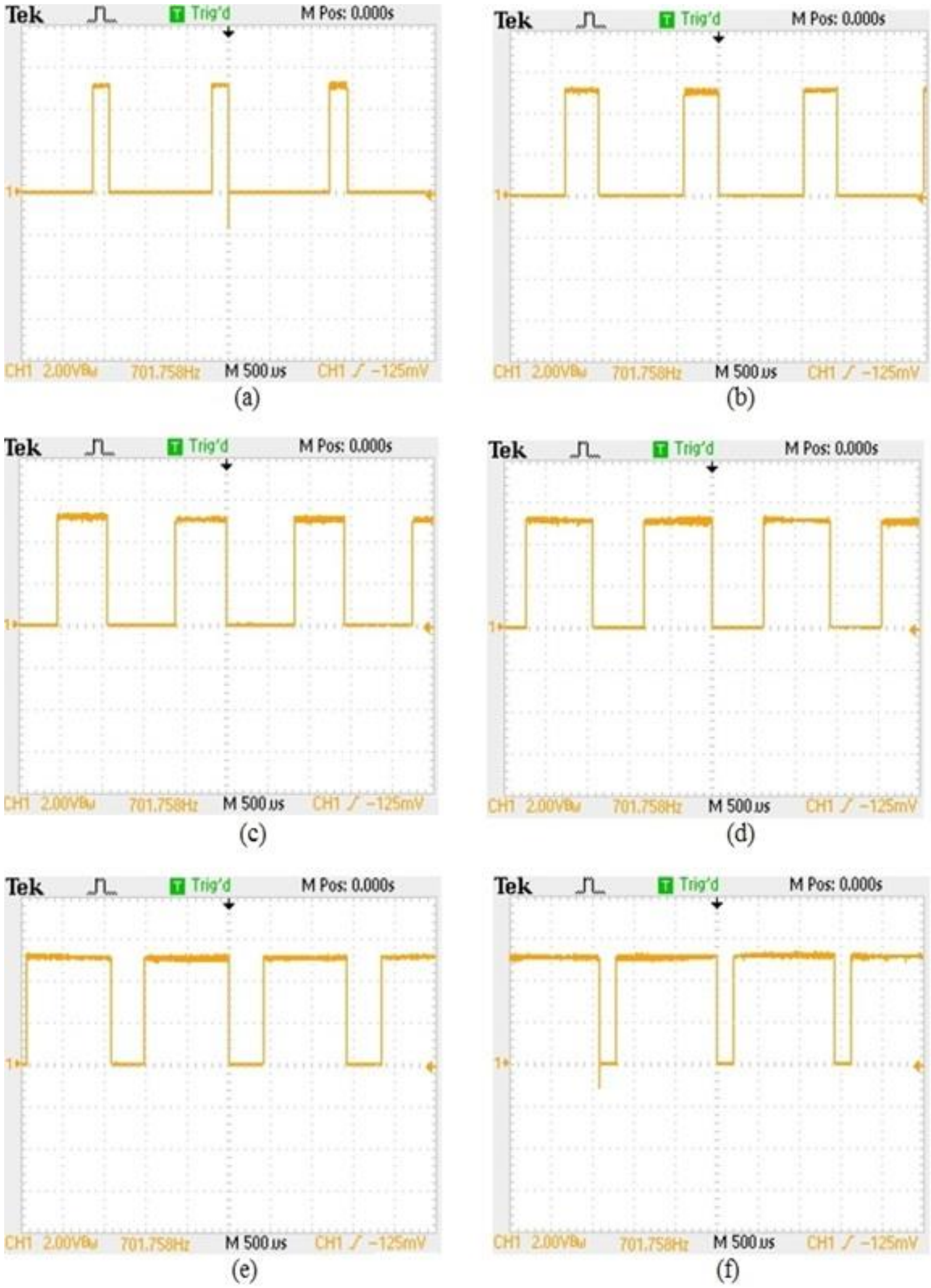

Fig. 5. PWM signal for LED dimming for 6 different lighting levels, PWM generated for (a) control signal 1, (b) control signal 2, (c) control signal 3, (d) control signal 4, (e) control signal 5, (f) control signal 6

4.5. Control signal for window blinds

"Fig. 6" shows the sample window blind control signal obtained in a test room where the readings are noted for an East-facing window in every one hour. For a set of readings from 9am to 4pm, the variation in WL, DGP and TDF can be noticed and the corresponding blind position is estimated using fuzzy logic algorithm. The control signal for this blind position is given to drive the DC motor to adjust blinds.

Uniformity and contrast: Uniformity and contrast were evaluated from the luminance data obtained using the HDRI system. Illuminating Engineers Society of North America (IESNA) defines the luminance contrast as the relation between surfaces with greater and lower luminance as in "equation (1)" where C denotes contrast, L_g greater luminance and L_l being the lesser luminance. The result of this equation indicates a contrast between 0 and 1. The task area and background area is selected and average luminance is calculated to find the contrast luminance[10].

$$C = \frac{L_g - L_l}{L_g} \qquad (1)$$

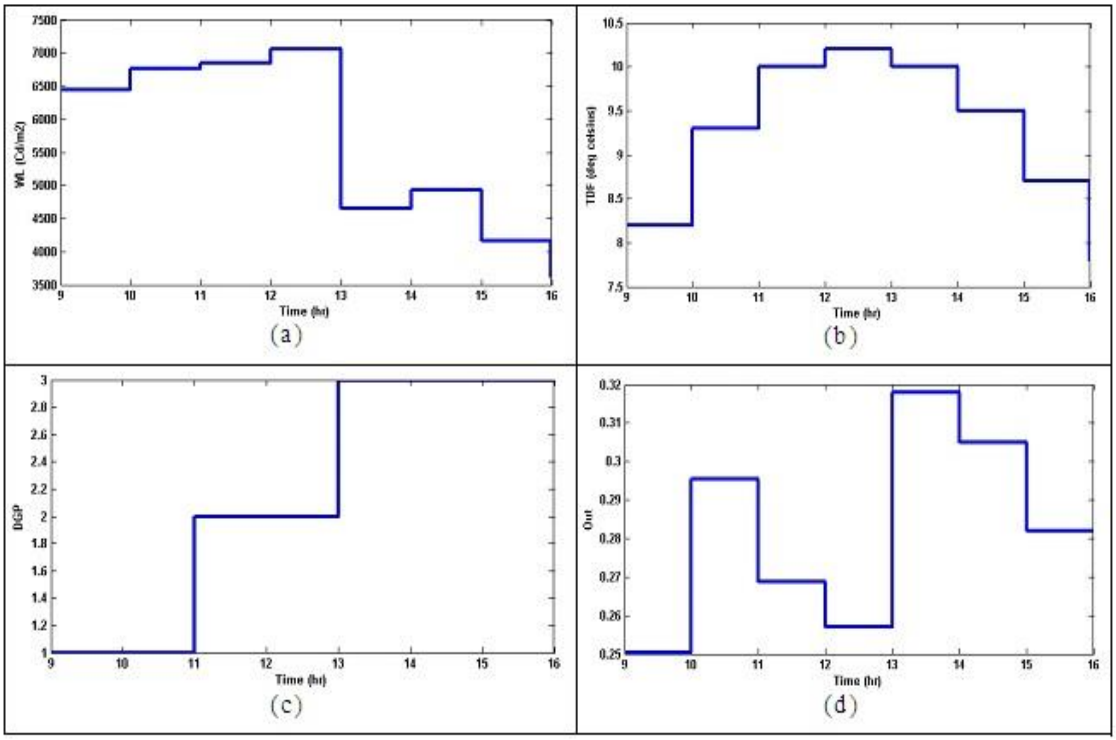

Fig. 6. Inputs and output of SIMULINK model (a) window uminance, (b) temperature difference (c) dominant glare position and (d) blind position

IESNA recommendations are that luminance of task area to adjacent surroundings and task area to remote surroundings must not exceed 3:1 and 10:1 respectively[22]. After the calculation of luminance matrix, the 8 bit image is displayed where the region of interest can be selected using *impoly* tool in matlab for the calculation of luminance contrast with the whole image considered as backgorund. To find the uniformity over a workplane where the reflectance of surface remaining the same, the luminance ratios were calculated. The spatial luminance distribution of the entire scene also was determined.

5. Conclusion

This paper demonstrates an HDRI based wireless system for the luminance measurement and subsequent analysis and control of an energy efficient daylight-artificial light integrated scheme. This system gives the distribution of luminance within an image and it can calculate contrast. The fuzzy controller optimizes visual comfort, thermal comfort and energy consumption and it gives the suitable blind position for daylight-artificial light integrated scheme. When the user is not present in the room,the control system minimizes the energy consumption by providing half the required illuminance in the interior and by reducing the load on air conditioning system. Energy saving can be achieved by dimming/switching of the artificial light . The HDRI system helps automation and is a promising approach for building energy management systems.

With the increased application of luminance scale in lighting analysis, this method is apt for the automated glare and uniformity analysis, blind control and also lighting control in buildings.

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