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Research paper

Camera Based Occupancy Detection and Lighting Control

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Abstract

Artificial lighting accounts for a substantial percentage of total electricity consumption in commercial and residential complexes. It is prudent to make lighting systems as efficient as possible in order to reduce consumption of electricity, which, being largely dependent on fast-depleting fossil fuel reserves, severely impacts the availability and security of resources available to future generations. One aspect of energy conservation involves developing efficient luminaires. However, the untapped potential lies in better methods of lighting control. It is necessary to shift from traditional switch-based control to intelligent controls, which minimizes human effort, while improving accuracy and savings. This paper presents a camera based lighting control system, which detects human occupancy in the control zones and controls the luminaires accordingly.

Keywords: *Computer vision; lighting control; MATLAB; occupancy detection; raspberry pi; wireless control*

1. Introduction

Traditional lighting control systems employ various sensors such as passive infrared, acoustic, ultrasonic and dual-technology sensors for the purpose of occupancy detection. This paper advocates the use of a camera for visualizing the control zones and processing of the live feed to detect human occupancy.

In lighting control systems involving traditional sensors, multiple sensors with limited range and capability are required for a particular area, with a sensor dedicated to each control zone in that area. Due to drawbacks of using traditional sensors for occupancy sensing, such as false ON/OFF triggering, and logistical problems such as re-wiring during sensor or luminaire failure, high capital costs involved in establishing a lighting control system, it is important to delve deeper into this field of work and find simple, yet elegant solutions.

An algorithm to recognize human presence with a USB webcam is proposed by Yong Sam Kim et al. [1]. The algorithm detects movement of humans using the circle detection and morphological techniques. Under various experiments, the proposed method shows better performance in terms of recognition rate and speed. An experiment is undertaken to observe the usefulness of this technique with several people who come in and go out during daytime. The results showed 100 percent accuracy in detection from the image of entry and exit, however, if a person was wearing a cap, the one wearing a black cap was identified correctly while the person wearing a white cap was not detected. From here, it can be gathered that despite the advantages of using a camera for occupancy sensing, the quality of the video feed may not always be enough to detect human presence. Therefore, it is important that the images are resized, processed and customized according to the needs and specifications in order to enable high accuracy in detection.

Chakravartula R. et al. [2] in their paper compare three camera-based approaches for human detection in context of people counting. The performances are analyzed under different scenarios, camera orientations, density of humans in the space, variations in availability of light and daylight apertures. The approaches that employ classification over features in detecting humans work swifter and more accurately. Nevertheless, the paper also demonstrates the need for quicker and more accurate human detection techniques and algorithms, that involve less complicated machine learning and classification, so that it is possible to deploy them in real-time systems.

Shape-oriented, motion-oriented and texture-oriented methods to classify images obtained from surveillance video were studied by Manoranjan Paul et al. [3]. The process takes place in two steps: detection and classification of objects. All available object detection approaches are classified into background subtraction, optical flow and spatio-temporal filter methods. In conclusion, it is advised to exploit a multiple-view technique and implementing an improvised model based on specific aspects of the image.

A real-time computer vision system for human detection, tracking, and verification in uncontrolled camera motion environment has been presented in the paper by Mohammed Hussein et al. [4]. The major aspects of the system are its robustness and efficiency, which are achieved via amalgamation of multiple algorithms, each using a different visual feature to detect and track humans. The efficiency is attained via a multiple-threaded structure with efficient internal-thread communication, and taking advantage of highly sophisticated software libraries. The designed system managed to demonstrate a par performance on significantly challenging video clips.

Alok K. S. Kushwaha et al. [5] discussed the demand for creating effective CCTV surveillance systems in context of the increasing number of criminal and terrorist-related incidents. An automated multiple human detection system and tracking method using Haar-like features and simple particle filter is proposed. The human detector is trained using the Haar-like features extricated from the samples for classifier training consisting of the images of the humans and other background. Its working is fully automatic and does not require intervention as compared to various similar methods. Test results demonstrated that this technique is capable

of detection and tracking of humans in outdoors, under moderate to poor lighting and variable poses.
Susan G. Varghese et al. [6] employ camera as sensor for measuring the amount of daylight present, a combination of fuzzy logic and artificial neural networks for the lighting control, and use Wireless Radio Frequency transceivers which eliminates the need for physical wiring. A similar approach is employed by Panth Shah et al. [7]. Camera is used for image acquisition, computer vision on MATLAB for object detection and image tracking and Arduino as the interface between processing and output. Serial communication between a BS2 microcontroller and a PC with MATLAB has been used to create a GUI application for the BS2 microcontroller by Yan-Fang Li et al. [8]. The paper illustrates wide scope Simulink tool has to offer to enhance features of a microcontroller programming.

2. Proposed System

The aim of this paper is to develop an occupancy detection system which is used to control the lighting of a given space. The user should have control over creating control zones in the space. Zones normally depend upon the position of lighting fixtures in the room. Once the zones are made, camera, which acts as a sensor should be used to detect human presence in the created zones. Accordingly, the lighting fixtures of the zones must be triggered.
The use of camera overcomes many of the limitations of traditional sensor based system, as a single camera can cover a large area, while being able to demarcate separate zones and trigger the luminaire where occupancy is detected. All of the this can be achieved at minimal cost, with greater versatility and easier installation than traditional sensor based systems. The incorporation of the camera as an occupancy sensor may allow for further improvements in the system such as daylight harvesting, security surveillance, smoke detection, control of HVAC and other building automation systems.
The primary platform for implementation of this paper is MATLAB, as it offers a wide range of tools and features to enable the achievement of the key features proposed. The use of Computer Vision Toolbox allows for live feed from a camera to be used as a sensor input for the system. The various features in Image Processing Toolbox and Computer Vision Toolbox offers options to process the images from the live feed and enable human occupancy detection.

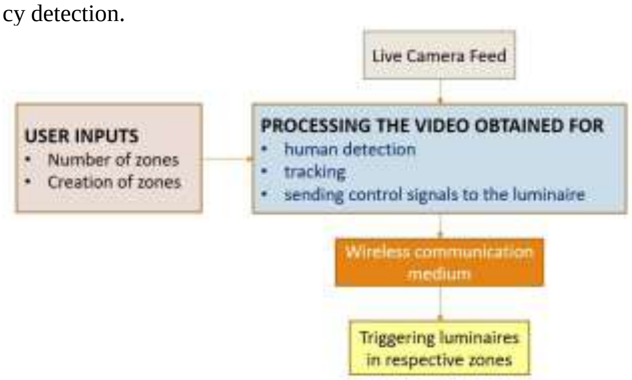

Fig. 1: Flowchart of the proposed occupancy detection system for lighting control

The flowchart of the proposed system is as shown in Figure 1. Realization of the system requires unification of MATLAB based GUI developed using App Designer along with raspberry pi camera module, raspberry pi controller, LED driver and fixtures.

3. Implementation

In this section, approach followed to realize the proposed system is discussed. During the execution of the work, MATLAB was installed in the PC. It is possible to export a MATLAB GUI to windows executable file for sharing of the GUI with systems which do not have MATLAB installed. This provision brings down the cost of the overall system for the end user.
Graphical User Interface (GUI) has a better aesthetic appeal and is easier to use compared to the text-based user interface. To allow the user/designer to have greater amount of control over, and to display the live video feed, object detection, control zones, tracking of humans and simulate triggering of luminaires, a GUI is created in MATLAB using the App Designer tool.

3.1. Human detection and tracking

For the purpose of occupancy detection and tracking from the point-of-view of the camera, the system employs the Viola-Jones object detection framework, which is a widely acclaimed and frequently used method for human detection in particular, and is easily available for use in MATLAB. The Viola-Jones algorithm was the first framework to provide competitive object detection rates in real-time. It has high detection rates and low false positive rates. At least 2 frames per second must be processed for practical applications. Its goal is to simply distinguish faces from objects which are not faces.
The detector available in MATLAB has a pre-trained classifier which is able to identify human faces by predicting the likelihood of a region of a video frame to harbour features of a human face, such as eyes, nose, forehead, cheekbones, etc.
An algorithm is developed such that a bound box is placed on the region of the video frame in which the human face is detected, and its co-ordinates are extracted. As the live feed is a series of static video frames displayed at a high frame rate, it appears that the bound box which encloses the region of detection is tracking the human face as he/she moves.

3.2. Creating zones

The camera plays a central figure, being the sole sensor in the system. This makes its positioning and orientation within the space where the system is implemented, a prime importance. The camera should be able to see as wide an area of the room as possible, preferably facing the entrances. Mounting at heights greater than 6 feet is recommended.
In this system, it is intended to give complete freedom to the user in making the zones. The user of the lighting systems operator is given the interactive tools to create control zones as well as modify them, by which complete command and flexibility over the lighting controls can be achieved with little or no subsequent human intervention.
A graphical user interface (GUI) has been developed, where the user is asked to take a snapshot of the space as seen through the camera. If satisfied with the captured scene, one can select the number of zones intended to be created. After selecting the number of zones, the control zones can be created by dragging interactive rectangles on the image of the space captured earlier. Once the zoning is completed by the user, the process of detection and tracking of the human presence can be initiated at the click of a button.
After the zones are created, lighting control of the zones contains multiple stages which include coordinate extraction of the zones, human detection, checking where the coordinates of detected human face lie and sending signals to the respective zone lighting fixture.
If the user draws N zones or N rectangles, since each rectangle has four coordinates, a total of 4N coordinates are extracted from all the zones created. The extracted 4N coordinates are stored in an array which will remain constant throughout the detection process.
Once human face is detected, next step is to check if the coordinates of the human face lie within any of the zones which were created. If any of the coordinates of the human face lie within any of the zones created, the luminaires of the respective zones are turned ON. Luminaires of the zones with no human faces are turned OFF or dimmed.

3.3. Dimming LED fixtures

Dimming of lighting fixtures is a feature which contributes to the visual aesthetics, acuity and comfort within a space, and also offer significant energy savings. Incorporating manual dimming in the lighting control systems offer the user/designer greater flexibility to control the illuminance of a particular zone depending on its occupancy, or the nature of working being conducted.

LED dimming is possible by two methods: (i) Analog modulation (ii) pulse-width modulation. Analog dimming changes lumen output by simply adjusting the DC current to the LED, while PWM dimming involves changing the duty cycle to adjust the average current to the LED. Analog dimming is considered inappropriate for several applications as it loses accuracy at modern dimming ratios and skews the colour of LEDs. In contrast, PWM dimming offers greater dimming ratios without loss of accuracy or lowering the quality of the LEDs.

To implement PWM dimming, it is necessary that the LEDs be supplied constant current. This is achieved by using a PicoBuck LED driver. It is an economical driver that allows up to three LED fixtures to be controlled individually on different channels. To change the duty cycle of the driving current, a PWM control signal is sent from raspberry pi, which receives commands from MATLAB.

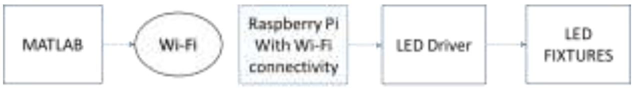

Fig. 2: Block diagram showing interconnection between components of the system

It is intended to send the command signals from MATLAB to the raspberry pi wirelessly. Therefore, a raspberry pi module with Wi-Fi is used to interface with MATLAB based GUI. Depending on the commands from MATLAB, PWM signal with necessary duty cycle is generated by raspberry pi which is given as input to the LED driver, which in turn controls the output lumens of the LED fixture. Figure 2 is the block diagram of the above mentioned concept.

4. Result Analysis

The system was set-up and tested in a test room. The LED fixtures were mounted at 8 feet above the ground and connected using wires to the PicoBuck LED driver. The PicoBuck LED Driver was powered up using regulated DC power supply. PWM dimming signals from the Raspberry Pi module were given to the input channels of the driver.

The Raspberry Pi module was wirelessly connected to the MATLAB GUI using a Wi-Fi network. The camera, Raspberry Pi and PicoBuck LED driver were contained within a single container and mounted strategically at 7 feet above the ground facing the zone where light fixtures are mounted.

Fig. 3: Snapshot of graphical user interface to capture the space to have lighting control

On powering up the drivers and executing the MATLAB GUI, the user is allowed to confirm the orientation of the camera after viewing a snapshot of the space from the camera's point of view as shown in Figure 3. Following this, an option to select the number of zones is provided, and zones are created subsequently.

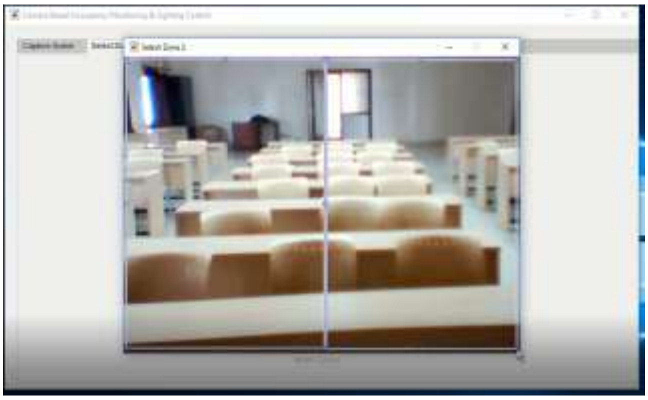

Fig. 4: Creation of two zones using interactive rectangular box in MATLAB GUI

Figure 4 shows how user can create zones for lighting control of a room. The entire space on the left side of the image (in Figure 4) can be considered as zone 1. Space on the right side of the image can be considered as zone 2. These zones may be reshaped and resized by the user.

Fig. 5: Creation of two zones using interactive rectangular box in MATLAB GUI

Figure 5 shows the dialogue box that appears after the user has created zones from the image. In the prototype, the user can create up to 4 zones. User can redo the zoning of the space by selecting 'No' in the dialogue box.

On the press of 'Yes' button, the detection, tracking and triggering process commences with little or no need for intervention by the user. The dimming feature is implemented by using a slider in the GUI to change the lumen output of the LED as per occupancy status.

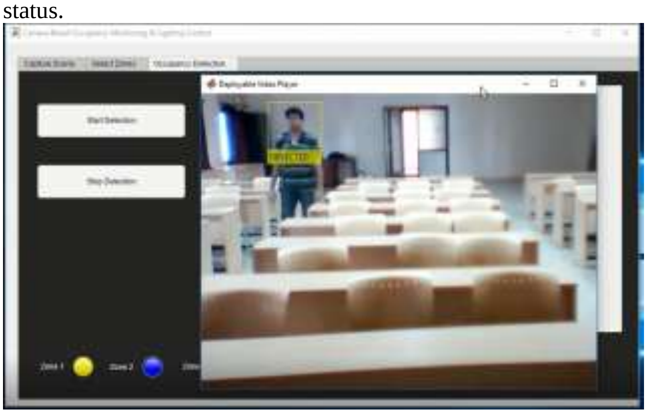

Fig. 6: Snapshot of graphical user interface tracking person in the left side zone

As shown in Figure 6, due to the presence of the person in zone 1, the fixture corresponding to zone 1 is turned ON. If the person moves from zone 1 to zone 2, the algorithm triggers the lighting fixture of zone 2.

Fig. 7: Snapshot of graphical user interface tracking people in multiple zones

It can be seen from Figure 7 that as people occupy zones, corresponding zone light fixtures gets triggered.
The challenges faced during the testing process were:

- Occasional false triggering of fixtures due to inaccuracies in human detection by the pre-trained classifier. This can be overcome by using deep learning techniques to re-train the classifier using test images taken in the same test group of persons.
- The lighting conditions and distance of the test subjects from the camera affect the ability of the classifier to detect features of the human face. It is advisable to use cameras with good resolution and wide viewing angles for the purpose of improving accuracy of the control system.
- Due to budget constraints, only a single camera with moderate resolution was deployed. This allows only a single sided view of the space to the user, thereby limiting the flexibility of control zoning to simply rectangular zones seen from the point of view of the camera. Further improvements can be made by incorporating multiple cameras to get a better model of the space and provide versatility to control zoning.
- Quick movements across the range of view of the camera can cause flickering of the LED fixtures. This can be overcome by incorporating a delay, i.e., a time interval for which a luminaire must remain ON once triggered after last detection.

5. Conclusion

This paper proposed a new smart lighting control using camera based occupancy detection. The system consisted of LED fixtures, Raspberry Pi, PicoBuck LED driver, Raspberry Pi camera module, a Wi-Fi dongle and a PC with MATLAB GUI.
The designed set-up was cost effective and easy to install with most of the tools available in the college laboratories. The savings made makes the system feasible for implementation at personal as well as commercial level. The feature of manual dimming can be further worked on to accommodate daylight harvesting, adaptive control and various other building automation systems.
The human detection algorithm makes it suitable for integration with face recognition and may further be used for security systems and surveillance.

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