REAL-TIME OBJECT DETECTION SYSTEM FOR BUILDING ENERGY CONSERVATION: AN IP CAMERA BASED SYSTEM

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In the contemporary world, there is a rapid introduction of automated and intelligent building systems. These technologies offer new and exciting opportunities to increase the connectivity of devices in built environments, particularly for energy conservation. Most of the developed building energy conservation systems are based on sensors, thus, the application of those systems is limited to small spaces due to maintainability issues. The reliability of these sensor-based systems is still argued as sensors are not capable enough for multi-person tracking and real-time object detection. Giving emphasis to these limitations, the current study introduces a real-time object detection, tracking and counting system for building energy conservation particularly, for HVAC and lighting based on IP CCTV cameras. An experimental research design was employed for the study. Initially, CCTV images from three objects: human heads, lighted vehicles, and non-lighted vehicles were collected from 12 offices. Subsequently, these objects were trained using the machine learning and the real-time object detection was performed using a Single Shot Detector model. The proposed system was developed using the Python programming language. The developed system comprised of three basic features namely, object detection, object tracking and counting, and HVAC and lighting control. This system enables real-time object classification for human heads, lighted vehicles, and non-lighted vehicles, therefore, reduces excessive energy consumed by air conditioning and lighting depending on the nature and movements of the objects. With the use of this system, facility managers can make built environments much comfortable for occupants while deducting excessive energy consumption and human effort taken to manage comfort levels of buildings.

Keywords: energy conservation, IP CCTV camera, detection, real-time tracking

INTRODUCTION

Energy consumed in buildings is a significant fraction of that consumed in all end-use sectors. Although percentages vary from country to country, buildings are responsible for about 30 to 45% of the global energy demand (Asimakopoulos *et al*., 2012). For instance, buildings consume approximately 41% of total primary energy use by sector in the US (United States Department of Energy [USDOE] 2012) and particularly, 18% (17.4 out of 97.4 quadrillion Btu) from commercial buildings (USDOE 2012). Further, a significant share of energy is consumed by Heating, Ventilation and Air

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Conditioning (HAVC) systems (Sane *et al*., 2006) and lighting (Yun *et al*., 2012) systems in buildings. According to Perez-Lombard *et al*., (2008), energy consumption from the HVAC system and lighting requirements in a typical building range between 45 to 55% and 20 to 35% from its operational energy consumption respectively.

Giving this dramatic increase in energy consumed by HVAC and lighting systems, the energy efficiency of system components for HVAC and lighting have improved considerably over the past 20 years (American Standard Inc. [ARI] 1999). In contrast to energy conversion equipment, less improvement has been achieved in optimum control in terms of energy efficiency distribution for conditioned air and peak load reduction potential. Therefore, advancements are also needed to improve the control systems and systems integration from a whole building perspective while meeting occupant comfort and performance requirements (National Energy Technology Laboratory [NETL] 2000).

Referring to lighting systems, daylighting strategies have been studied and proposed in order to reduce artificial lighting energy demands (Mardaljevic *et al*., 2009; Yun *et al*., 2011). Further, Yun *et al*., (2010) study concludes that lighting controls in connection to daylighting can save lighting energy demands by 20 to 40%. In a different point of view, Lindelöf and Morel (2006) investigations on light switching patterns during working hours revealed that lights are 'ON' although daylight is enough to provide adequate illumination.

Despite these simple energy saving techniques, the world has taken a move towards advanced building energy management systems. Accordingly, the implementation of a combination of various technologies under the title of “Building Automation”, “Smart Buildings”, and/or “Building Management System (BMS)” are increased (Jan Bozorgi and Ghannad 2009). Since monitoring the accuracy of any controlling system in industrial, commercial, and residential environment separately requires time, energy and presence of manpower in the place, it is necessary to implement an integrated management system, which is able to display information and arrange all smart controlling systems in a short time. BMS as a unique and modern way to fulfil this need have been applied in most of the developed and developing countries and it has proven its abilities in the field of managing all kinds of smart controlling systems applying in industrial and non-industrial environments.

Different technologies are currently employed for BMS with different benefits and evaluations. Amongst, hard-wired networks have long been used in BMS (Dinh and Kim 2012). However, authors further posit that this approach is inflexible in design due to high cost and difficulty in renovations. Later, advances in Wireless Sensor Networks (WSN), including hardware, software and emergent standards have demonstrated the strength of WSNs. WSNs as a key solution are alternatives to a wired approach in the BMS field (Brambley *et al*., 2005). WSNs are used in many kinds of application in BMS including HVAC, lighting, air quality and window controls, and security and safety systems, which use different types of sensors such as light sensors, gas sensors, movement, motion sensors and more. However, the WSNs for BMS is still challenged due to its interoperability, integration failures, overhead and low bandwidth problems of the constrained environment (Dinh and Kim 2012).

Besides, many pieces of research have been carried out on predictive controllers and real-time control models for building energy conservation over the years. For instance, Henze *et al*., (2011) have been introduced a model-based predictive optimal control for active and passive building thermal storage inventory. The second category of research uses also the predictive control but it introduces real-time control model in order to give more benefits contrary to Henze *et al*., (2011). For example, Mishra *et al*., (2013), Kimbley *et al*., (2016), and Yuganandhine *et al*., (2017) have been proposed automatic room light and fan controller with bidirectional visitor counter systems using IR sensors over the years. Furthermore, Kastner *et al*., (2005) introduced a basic requirement, services and application model for BMS, and Ploennigs *et al*., (2006) analysed a network in BMS and proposed an automated model. A fuzzy logic control is implemented for building illumination and temperature control in Lah *et al*., (2005). A novel multi-agent control system for managing the comfort level of the building environment is proposed in the research of Dounis and Caraiscos (2009). From the literature, it is observed that most of the theoretically developed and practically implemented systems for building energy conservation especially for HVAC systems and lighting have been based on sensor technologies, which subject to practical limitations such as

- Inflexibility in design: sensors are only capable of detecting objects within a limited space where the sensor is installed
- No object classification: sensors are only capable in object detection but unable to classify objects (i.e. if an object moves across the infrared rays, the system just count it as an object without knowing whether it is a live object or not)
- No real-time object tracking: unable to identify the exact location of a moving object
- Expensive in implementation: building owners have to install an excessive number of sensors, which is costly. Therefore, not appropriate for large-scale buildings

Giving emphasis to these limitations, very recently, Akkaya *et al*., (2015) have opined that CCTV systems as an improved way of object detection, tracking and counting in real-time for energy conservation in open building spaces despite the common goal of using CCTV systems for the prevention of crime and disorder by tracking and observation. However, this approach still has not been converted into a system design or implemented within buildings for the purpose of energy conservation. Unlocking this potential constitutes the motivation for this work. Occupant behaviour is a crucial factor in determining HVAC and lighting energy use in buildings (Masoso and Grobler 2010). With this motivation, this paper introduces a novel building energy conservation system based on real-time object detection, tracking and counting using IP-based CCTV cameras in order to tackle several of these needed advancements.

RESEARCH METHODS

The study employed an experimental research design to develop the proposed building energy conservation system. Initially, CCTV images of three selected objects including human heads, lighted vehicles, and non-lighted vehicles were collected from 12 office buildings (i.e. working areas and car parks). A sample image taken for the study is shown in Figure 1. The selection of 12 office buildings was based on the convenient sampling as the requirement is just to collect a possible amount of CCTV images within office premises. Then, a list of bounding boxes (xmin, ymin, xmax, ymax) were defined for all the objects within collected CCTV images in order to prepare the input .csv formatted file for the analysis. Next, the collection of coordinates defined CCTV images were divided into two as images taken for the object training (90%) and for the model testing (10%).

Figure 1: A sample CCTV image

Subsequently, these images were trained using the machine learning: TensorFlow framework integrated with the Single-Shot Multibox Detector (SSD) mobile net software to export the inference graph. Compared to other object detection methods such as Region-Based Fully Convolutional Networks (R-FCN), You Only Look Once (YOLO), and Deeply Supervised Object Detector (DSOD), SSD has much better accuracy and faster even with a smaller input image size (Liu *et al*., 2016; Shen *et al*., 2017). SSD is simply relative to methods that require object proposals as it completely eliminates proposal generation and subsequent pixel or feature resampling stages and encapsulates all computation in a single network (Liu *et al*., 2016). The code is available at http://download.tensorflow.org/models/object_detection/ssd_mobilenet_v1_coco_2017_11_17.tar.gz

The TensorFlow framework provides an iterative machine learning process until the user breaks the process once it resulted in the optimum inference graph considering the total loss value provided. The total loss represents the percentage of failure in object classification and localization with test data. Although there is no exact number or rule of thumb to determine the number of images required for the object training, TensorFlow framework itself determined the ideal number of images required depending on the total loss of test. Accordingly, the analysis resulted in a total loss lower than 1% with the use of 1000 CCTV images indicates that there is a greater accuracy in the inference graph developed. Therefore, it was taken as the optimum trained model for the object detection in this study.

The building energy conservation system is constructed using the Python programming language. And also, the system comprised of a number of components that every component has its own function integrated to each other for completing the whole system to functioning. The system further includes a MySQL Database in order to store configuration data relating to pre-defined building zones and customised standards for HVAC and lighting control.

Finally, the proposed system design was validated through few discussions held with seven experts in the fields of building operations and Information Technology (IT). This approach for software validation has been approved by Boehm (1984). In detail, three experts are Chief Engineers who possess more than twenty years of experience in building operations while the other is a Facility Manager whose experience is eight years. In addition, all three IT experts are Senior Software Engineers who have more than seven years of experience in the field of software development.

PROPOSED SYSTEM DESIGN

The system introduced for the building energy conservation in this study basically consists of 03 features. They are real-time object detection, object tracking and counting, and controlling of HVAC and lighting devices.

Real-Time Object Detection

The inference graph obtained through the object training process mentioned in the research methods was input to the proposed system design, which configured to the SSD. Hereafter, this SSD configured inference graph is called as the SSD model within the proposed system that provides the classification of objects for real-time CCTV stream images. The output provides a label and coordinates for each object together with its probability of being that particular object. A sample image derived by the real-time object detection function within the proposed system is shown in Figure 2 and 3.

Figure 2: A sample output of object detection (Humans)

Figure 3: A sample output of object detection (Lighted vehicle)

As shown in Figure 2 and 3, the SSD model has been perfectly functioned to classify the objects (i.e. human heads and lighted vehicle) in CCTV images taken from the CCTV video streams.

Real-Time Object Tracking and Counting

With the use of aforementioned SSD model, a number of objects from each category were calculated and determined the exact building location, where it is located at the very time. In order to proceed this, a MySQL Database was developed and it includes coordinates for each and every pre-defined zone. A sample diagram of the developed database is presented in Figure 4.

Zone Mapping	
PK	zone_id
	lb_coordinates
	lu_coordinates
	rb_coordinates
	ru_coordinates
	ea_zoneid
	su_zoneid
	we_zoneid
	nt_zoneid

Figure 4: Zone mapping table structure

As shown in the zone mapping table structure, each zone has four coordinates such as lb - left bottom, lu - left upper, rb - right bottom, and ru - right upper. These coordinates help to determine the exact zone of the detected object. Furthermore, it includes outer boundaries for each zone namely, ea - east, su - south, we - west, and nt - north.

Accordingly, Figure 5 shows a sample of an integrated image of two camera streams together with pre-defined zoning coordinates.

Figure 5: A sample of an integrated image of two camera streams

At the same time, the system counts the number of objects for each category for all zones.

HVAC and Lighting Controlling

As the next step, the developed system calculates percentages for the amount of HVAC and lighting requirements within each specific zone. For example, the number of lights to be turned on or/and the degree of air conditioning dampers to be opened for a given zone is calculated according to the number of objects detected and their behaviour. These calculations are based on the data stored in the developed database and Figure 6 shows the table structure of setup data for HVAC and lighting controls.

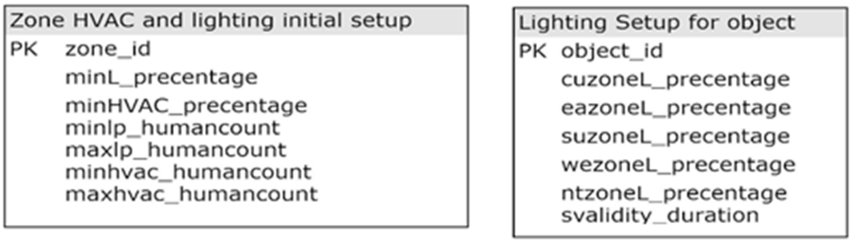

Figure 6: Table structure of setup data for HVAC and lighting controls

The fields shown in the table structure of setup data for HVAC and lighting controls are defined as follows.

Zone id - unique identity for the zone
minL - minimum lighting percentage required for the zone
minHVAC - minimum degree of air conditioning damper to be opened for the zone
minlp_humancount - the minimum human count that minL should apply
maxlp_humancount - the maximum human count that 100% of lights to be turned on
minhvac_humancount - the minimum human count that minHVAC should apply
maxhvac_humancount - the maximum human count that 100% of AC required

Compared to HVAC, lighting behaves in a different way. Therefore, lighting percentage required for a zone should be mapped according to the detected object: human or lighted vehicle or non-lighted vehicle. As shown in Figure 6, there is a separate table structure for lighting setup for objects and fields of the given table are defined in below.

object_id - unique identity for the object
cuzoneL - lighting percentage for the object in the detected zone
eazoneL - lighting percentage for the east zone of the detected zone.
suzoneL - lighting percentage for the south zone of the detected zone.
wezoneL - lighting percentage for the west zone of the detected zone.
ntzoneL - lighting percentage for the north zone of the detected zone.
svalidity_duration - the period of time that the generated control signal to be kept

The control signals generated for each and every zone will be transferred to HVAC damper controllers (ATMEGA microcontroller) and lighting controller devices using the Wireless Transceiver Module. These controlling signals will provide the necessary level of illuminance and conditioned air to pre-defined zones based on the real-time object detection, tracking and counting. For example, an air conditioning damper installed within a zone will rotate as per the calculated percentage.

In addition to aforementioned explanations, a process chart illustrating the entire system procedure is presented in Figure 7. The validity of the proposed system design shown in Figure 7 has been evaluated via informal discussions held with experts in the fields of building operations and IT. Accordingly, four experts engage in buildings operations confirmed that the implementation of this system will meet user requirements and ultimately leads to reduce excessive energy consumed by HVAC and lighting systems installed in office buildings. Further, the credibility of the proposed system design is assessed by three experts in software development and confirmed that the system meets user requirements.

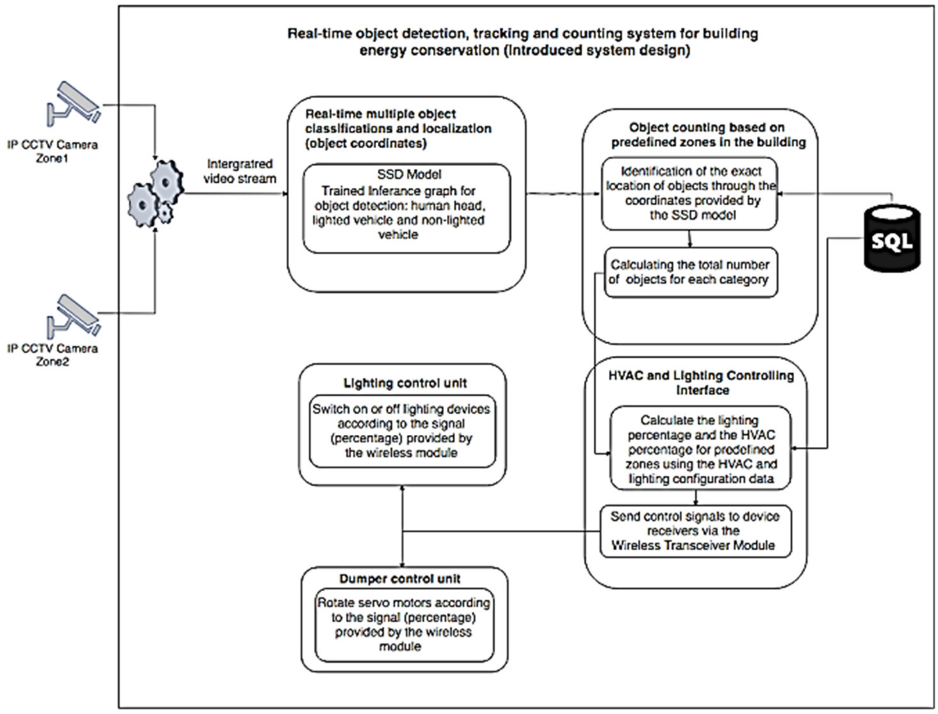

Figure 7: The process chart of the system design for building energy conservation

DISCUSSION AND CONCLUSIONS

This study introduces a novel system for building energy conservation through real-time object detection, tracking and counting using IP- based CCTV cameras. The objective function selected for the system designed in this study is the minimisation of building operating costs while optimising energy consumed by HVAC and lighting devices. Unlike previous systems developed by Mishra *et al*., (2013), Kimbley *et al*., (2016), and Yuganandhine *et al*., (2017), this system enabling energy conservation by optimising the energy requires for both HVAC and lighting systems as those are dominant energy consuming end-users in buildings. Furthermore, the system is based on IP-based CCTV cameras, therefore, eliminates the limitations exits in currently using sensor-based systems. Very importantly, the developed system featured with the real-time object detection, classification, tracking and counting, which cannot be achieved via sensors. Simply, this system enabling changing the comfort levels of the building environments within few milliseconds.

Moreover, the cameras used for this system can be alternatively used for the security purposes as well thus, effective in cost aspects. In addition, the wireless network proposed for the system makes it convenient for the implementation and flexible in design. Refereeing to the advanced features used in this system, the system keeps the pre-defined minimum lighting and HVAC percentage as the default value for a given zone and then it is changed according to the signal provided by the wireless module depending on the real-time results of object detection, tracking and counting. This control signal will keep only for a pre-defined signal validity duration and once it expires it is back to the default minimum percentage. This feature leads to reduce an excessive amount of energy consumed by HVAC and lighting systems consequently, cause a significant reduction in the cost of building operations.

Despite having many improvements compared to the existing building energy conservation systems, the application of the developed system is limited to the open spaces in buildings due to privacy features violated with the use of cameras. The system can be easily implemented to any place where IP CCTV cameras are in operation and this will be a steadfast system to track the real-time occupancy and energy consumption of buildings, which is a challenging task to Facility Managers. In addition, although the figures mainly show objects identified in office environments, this technology and system design will prove useful on construction sites and for construction management, particularly in the management of operatives, and plant and equipment.

REFERENCES

Akkaya, K, Guvenc, I, Aygun, R, Pala, N and Kadri, A (2015) IoT-based occupancy monitoring techniques for energy-efficient smart buildings. *In*: Wireless Communications and Networking Conference Workshops (WCNCW), 9-12 March, IEEE, New Orleans, LA, USA, 58-63.

American Refrigeration Institute (ARI) (1999) *Statistical Profile of the Air Conditioning, Refrigeration and Heating Industry*, 28, 4301. North Fairfax Drive, Arlington, VA.

Asimakopoulos, D A, Santamouris, M, Farrou, I, Laskari, M, Saliari, M, Zanis, G, and Zerefos, S C (2012) Modelling the energy demand projection of the building sector in Greece in the 21st century. *Energy and Buildings*, 49, 488-498.

Boehm, B W (1984) Verifying and validating software requirements and design specifications. *IEEE software*, 1(**1**), 75.

Brambley, M R, Kintner-Meyer, M, Katipamula, S, O'Neill, P (2005) Wireless sensor applications for building operation and management. *Web-Based Energy Information and Control Systems: Case Studies and Applications*, 341-367.

Dinh, N T and Kim, Y (2012) RESTful architecture of wireless sensor network for building management system. *KSII Transactions on Internet and Information Systems*, 6(**1**), 46-63.

Dounis, A I and Caraiscos, C (2009) Advanced control systems engineering for energy and comfort management in a building environment-A review. *Renewable and Sustainable Energy Reviews*, 13(**6-7**), 1246-1261.

Henze, G P and Neumann, C (2011) *Building Simulation in Building Automation Systems. Building Performance Simulation for Design and Operation*. London: Spon Press.

Jan Bozorgi, A, Ghannad, Z (2009) Building smart system. *Kaison Quarterly*, 43.

Kastner, W, Neugschwandtner, G, Soucek, S and Newman, H M (2005) Communication systems for building automation and control. *Proceedings of the IEEE*, 93(**6**), 1178-1203.

Kimbley, R, Mehrotra, S A, Khan, S K and Pawar (2016) Automatic room light controller using microcontroller and visitor counter. *International Journal of Research in Engineering and Technology*, 5(**3**).

Lah, M T, Zupančič, B and Krainer, A (2005) Fuzzy control for the illumination and temperature comfort in a test chamber. *Building and Environment*, 40(**12**), 1626-1637.

Lindelöf, D and Morel, N (2006) A field investigation of the intermediate light switching by users. *Energy and Buildings*, 38(**7**), 790-801.

Liu, W, Anguelov, D, Erhan, D, Szegedy, C, Reed, S, Fu, C Y and Berg, A C (2016) SSD: Single shot multibox detector. *In*: *European Conference on Computer Vision*, 21-37.

Mardaljevic, J, Heschong, L and Lee, E (2009) Daylight metrics and energy savings. *Lighting Research and Technology*, 41(**3**), 261-283.

Masoso, O T and Grobler, L J (2010) The dark side of occupants' behaviour on building energy use. *Energy and Buildings*, 42(**2**), 173-177.

Mishra, R, Raza, S, Zulquarnain, R A and Kumar, P (2013) Development of automatic person detection system to control AC fan and room lights. *International Journal of Innovative Research in Science, Engineering and Technology*, 2(**3**), 587-589.

National Energy Technology Laboratory (NETL/DOE) (2000) *Federal Assistance Solicitation for Energy Efficient Building Equipment and Envelope Technologies Round II*. 'PS No. DE-PS26-00NT40781, 4. US Department of Energy.

Pérez-Lombard, L, Ortiz, J and Pout, C (2008) A review on buildings energy consumption information. *Energy and Buildings*, 40(**3**), 394-398.

Ploennigs, J, Buchholz, P, Neugebauer, M and Kabitzsch, K (2006) Automated modelling and analysis of CSMA-type access schemes for building automation networks. *IEEE Transactions on Industrial Informatics*, 2(**2**), 103-111.

Sane, H S, Haugstetter, C and Bortoff, S A (2006) Building HVAC control systems-role of controls and optimization. *In*: *2006 American Control Conference*, 14-16 June, *(IEEE)*, Minneapolis, MN, USA, 1121-1126.

Shen, Z, Shi, H, Feris, R, Cao, L, Yan, S, Liu, D, and Huang, T S (2017) Learning object detectors from scratch with gated recurrent feature pyramids. Available from https://arxiv.org/abs/1712.00886 [Accessed 15th July 2018].

United States Department of Energy (2012) *CBECS 2012: Energy Usage Summary*. Available from https://www.eia.gov/consumption/commercial/reports/2012/energyusage/ [Accessed 15th July 2018]

Yuganandhine, R R, Kiruthika, J, Manju, S, Mythili, K and Manikandan, R K (2017) Automatic room light and fan controller with bidirectional visitor counter. *International Journal of Recent Trends in Engineering and Research (IJRTER)*, 20-24.

Yun, G Y, Hwang, T and Kim, J T (2010) Performance prediction by modelling of a light-pipe system used under the climate conditions of Korea. *Indoor and Built Environment*, 19(**1**), 137-144.

Yun, G Y, Kim, H and Kim, J T (2012) Effects of occupancy and lighting use patterns on lighting energy consumption. *Energy and Buildings*, 46, 152-158.

Yun, G Y, Shin, J Y and Kim, J T (2011) Influence of window views on the subjective evaluation of discomfort glare. *Indoor and Built Environment*, 20(**1**), 65-74.