Sustainable Cities and Society 44 (2019) 85–98

Contents lists available at ScienceDirect

Sustainable Cities and Society

journal homepage: www.elsevier.com/locate/scs

Development and implementation of novel sensor fusion algorithm for occupancy detection and automation in energy efficient buildings

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ARTICLE INFO

Keywords:
Occupancy detection
Sensor fusion
Image processing
Energy management
Distributed computing
Internet of things

ABSTRACT

This paper deals with achieving both energy efficiency and comfortness in a particular room by controlling lighting and cooling appliances of a building by deploying modern sensors like Thermal sensors and Camera for accurate mapping of the environment parameters. The unique part of this paper is that a Sensor Fusion algorithm has been used in different segments of the room which combine the sensory output from the Thermal Sensor and Camera to ensure that the occupancy detection is done accurately with least amount of fluctuations without any delay. The two algorithms, namely, image processing algorithm and sensor signal processing runs in distributed computing environment in two different processors and the outputs of processing algorithms are received in the master controller through IoT cloud platform. The proposed image processing algorithm is effective in detecting both static and dynamic event changes using background subtraction and ROI based segregation models. The system develops the use of this sensor fusion algorithm to provide an intuitive control of the environment and improve the efficiency of the decision making process using National Instruments MyRIO 1800 and cRIO 9082 processors in LabVIEW platform which also reduces the chances or consequences of any fault occurring in the system.

1. Introduction

The building automation system not only regulates the building functions but they acquire data to determine ways and means to cut costs and increase energy efficiency. The Global Construction 2030 forecasts (https://www.ice.org.uk/ICEDevelopmentWebPortal/media/Documents/News/ICE%20News/Global-Construction-press-release.pdf, 2018) the building construction will grow by 85% around $15.5 trillion all over the world, with three countries namely China, US and India accounting for 57% of all global growth. Moreover, the US Department of Energy Hua, Chen, Ye, and Tan (2016) states that 70% of the electricity is consumed by buildings every year. With the rapid growth of the construction market and energy consumption in the buildings, it is evident that building automation is essential to focus the energy conservation by automation of appliances and users comfortness. The existing building automation systems faces problems due to incompatibility with the new techniques. This leads to immense wastage of electrical energy due to mismanagement of appliances and devices and the system lacks in accuracy and reliability. Apart from the knowledge of the appliances to be automated, various environmental parameters must be assessed in order to decide the next state of the elements under control, which is done with the help of sensors. These environmental parameters are compared by the control system with the current state of the elements and then a decision is taken so as to maintain or change the state of the appliances under consideration. In addition to that, the reduction of human inputs leads to a more reliable system which is free from errors. The building automation mainly relies on effective control of lighting and cooling system which is dependent on identifying the number of occupants in the building and setting the parameters in the control system.

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https://doi.org/10.1016/j.scs.2018.09.031
Received 7 July 2018; Received in revised form 20 September 2018; Accepted 24 September 2018
2210-6707/

Several authors have studied the area of occupancy detection in an attempt to find the most effective solutions to cater the high demand of energy conservation while maintaining comfortable environment inside the building. The research work on occupancy detection approach is widely classified into sensor based and image based methods. Nowadays, in building automation, occupancy detection and actuator activation is done with the help of Passive Infrared (PIR) sensors (Guo, Tiller, Henze, & Waters, 2010) which are primarily used for energy efficient lighting systems. Similarly in Kim, Moon, and Yoon (2017), the occupancy detection is achieved by combining PIR sensors and door sensors. But these PIR sensors are unable to detect occupancy when the target is in static position which leads to decrease in comfort levels of the occupants of the building.

The detection of occupants based on temperature and CO_2 concentration using sensors at the air return and supply vents is proposed in Jin, Liberis, Weekly, Spanos, and Bayen (2018). In this work, spatial and temporal features of the system to detect the occupancy is investigated using environmental sensors. An indoor environmental data driven model for occupancy prediction using machine learning techniques is presented in Rya and Moon (2016). In this work, decision tree and Hidden Markov Model (HMM) algorithms were implemented to detect the occupancy. Occupancy prediction based model is developed to detect occupancy at the current state based on indoor environmental data such as CO_2 concentration, energy consumption of the lighting system and appliances which were obtained from sensing networks in buildings using decision tree algorithm. Based on the results of occupancy detection, the authors developed a model for occupancy prediction through indoor environmental data and estimated occupancy data using Hidden Markov Model. Although CO_2 is a good indicator for occupancy detection, the CO_2 process equations need complete information about the room conditions which varies with time and hence leads to uncertainity.

A novel plug and play method is presented in Pedersen, Nielsen, and Petersen (2017) which applies a set of rules on the trajectory of sensor data to determine the probability of occupancy. The rules are developed from sensor data such as PIR, noise, temperature, humidity, CO_2 concentration and Volatile Organic Compounds (VOC). This paper does not need the information of physical conditions of the room. The count of occupants is detected using a fusion of environmental sensors from an indoor air quality measurement system (Zimmerman, Weigel, & Fischer, 2017). The authors developed an indoor air quality measurement system with CO_2, VOC, air temperature, and air relative humidity sensors to detect the number of occupants inside smart homes.

Duarte, Van Den Wymelenberg, and Rieger (2013) proposed occupancy sensor for occupancy detection under several scenarios with better simulation parameters using data mining techniques. The lighting control based on occupancy detection is proposed in Peruffo, Pandharipande, Caicedo, and Schenato (2015) in which light and occupancy sensors determine the net illuminance and occupant presence. Based on the information, the controller controls the dimming level of the lighting system. The prediction of occupancy based on light, temperature, humidity, CO_2 sensors and a digital camera to establish ground occupancy has been investigated in Candanedo and Feldheim (2016) using different statistical classification models. An IoT based occupancy detection system using change patterns of dust concentrations such as particle matter using point extraction algorithm is proposed in Jeon, Cho, Seo, Kwon, and Park (2018).

In D'Oca and Hong (2015), the authors developed a data mining method to learn occupancy schedules. Decision tree model is applied on the collected data sets to predict the occupancy presence. Rule induction algorithm is used to mine a pruned set of rules on the results of the decision tree model. Cluster analysis is employed to obtain the patterns of occupancy schedules. In another paper Diraco, Leone, and Siciliano (2015) the authors demonstrated the feasibility of people counting in medium crowded environments using depth data that is sensed through 3D depth sensors which could simplify computer vision tasks for occupancy detection. The Gaussian average background model is used to work with depth distances in crowded scenes. Clustering and edge-based constraints are designed for people segmentation in depth data.

The image based techniques such as video analysis using surveillance video data to detect the occupancy is reported in Zou, Zhao, Yang, and Wang (2017). The algorithm implements a cascade classifier to detect human head and hence predicts online detection of occupancy by video surveillance. An image based method with infrared depth frame images to detect persons counting the number of occupants in the room is discussed in Petersen, Pedersen, and Nielsen (2016). The algorithm is able to detect and track multiple persons of various heights in different directions but only in the camera point of view. An occupancy prediction model using real time occupancy model from smart camera estimation system using the Markov chain model is proposed in Erickson, Carreira Perpinan, and Cerpa (2012). This paper considered inter room relationship and sensor network data to model the occupancy. A stochastic inhomogeneous Markov chains in multi occupant under different zones to detect the occupancy is discussed in Chen, Jinming, and Soh (2010). Stochastic inhomogeneous Markov chains was used to model building occupancy through Multi-Occupant Single-Zone (MOSZ) and Multi-Occupant Multi-Zone (MOMZ). MOSZ defined the state of the inhomogeneous Markov chain as the increment of occupancy in the zone and the MOMZ dealt with the interactions among zones. Through inhomogeneous Markov chain vector, the increment of occupancy in each zone was detected. A sensorless system for providing occupancy details of a commercial building that leverages pre-existing opportunistic context sources and supervised learning algorithms are provided in Ghai, Thanayankizil, Seetharam, and Chakraborty (2012). The results from this sensor would also help validate the mapping of the Environment by image acquisition devices.

A virtual reality integrated approach was developed in Niu, Pan, and Zhao (2016) to get the occupancy information. Virtual reality along with pre-occupancy evaluation design framework were used to collect occupancy information and the design patterns for the occupants to follow in the most energy-efficient way were identified. Ekwevugbe, Brown, Pakka, and Fan (2017) discussed genetic based feature selection for building occupancy. Occupancy measurement was estimated through fusion of low cost non-invasive indoor environmental sensors and data processing. The occupancy-based scheduling to perform start/stop operation of HVAC system in an office building were developed in Capozzoli, Piscitelli, Gorrino, Ballarini, and Corrado (2017). The occupancy profiles were analyzed using data mining techniques to detect the occupants for the optimized HVAC start/stop schedule.

The PIR sensors which has been widely used in existing leading automation systems is only able to detect the dynamic events i.e., it will only be able to detect changes in the environment if some movement has been registered, otherwise the PIR sensor would detect lack of movement as absence. The thermal sensor which has been presented in this proposed work overcomes the main problem of PIR sensors by giving out temperature readings across 16 sections along a 44° Field Of View (FOV) in both X and Y direction. All the existing algorithms provided in the literature lack in accuracy and effectiveness in occupancy detection under different environments. Hence the proposed work will concentrate in accurate occupancy detection by combining two sensory inputs which is suitable in different real time environments. The main contribution of this work is as follows: This paper proposes novel sensor fusion algorithm for occupancy detection by combining two sensory inputs such as camera and thermal sensors which are deployed in a room of the building. The output of camera is processed by background subtraction based image processing algorithm for detecting dynamic events and ROI based segregation algorithm for detecting static events and the output of thermal sensors is processed to detect the human presence in different segments of the room. The two sensory processed inputs are performed in a distributed computing platform in different processors and the outputs of these processing algorithms through IoT are obtained in the master controller and