Demo Abstract: Building Energy Management Systems Actuated Using Wireless Camera Sensor Networks

Siddharth Zaveri*, Shane Ross*, Varick Erickson, Ankur Kamthe, Tao Liu and Alberto Cerpa
Electrical Engineering and Computer Science - University of California, Merced
{szaveri,sross3,verickson,akamthe,tliu5,acerpa}@ucmerced.edu

Abstract

Heating, cooling, ventilation, conditioning and lighting currently account for approximately 60% of the energy consumption within buildings [4]. The conditioning of these areas, however, are not controlled optimally. Rooms that are empty or only partially occupied are conditioned assuming maximum occupancy rather than actual occupancy. In order to optimize conditioning, room usage must be considered. In this demonstration, we show the interplay between a wireless camera sensor network, which is used for detection and tracking of people entering/exiting rooms, and building energy management infrastructure, which controls the heating, cooling, ventilation and lighting for a room/area.

1 Introduction

Heating, cooling, ventilation, conditioning (HVAC) systems in residential and commercial buildings account for 50% of the total building energy. Lighting adds on an extra 10% in energy consumption [4]. Current HVAC system do not condition based on actual usage. Rooms that are empty are needlessly conditioned. Conditioning strategy also typically does not change for partial occupancy. In order to condition spaces optimally, we need a means of determining room usage. Several different methods have been used for determining room usage. Passive Infrared sensors (PIR) have long been used for controlling lighting have recently been used for controlling temperature [5]. Although PIR has some use for binary indication of occupancy, there are limitations to this sensing paradigm. PIR is unable to determine the precise number of people within a space. This information is necessary for proper ventilation. Efficient ventilation increases the energy efficiency of thermal conditioning since less outside air needs to be brought to temperature. In [6], it has been shown that efficient ventilation has a significant impact on the total energy efficiency of an HVAC system. CO_2 sensors have also been used for measuring occupancy. However, they are prone to calibration errors and slowly react to occupancy changes as CO_2 buildup is a slow process.

In order to precisely measure occupancy, we propose an optical sensing solution via a wireless camera sensor network. Using occupancy data from the camera sensor network, we propose a closed-loop system that can regulate heating, cooling, ventilation and lighting based on real time occupancy and the resulting occupancy schedules.

Figure 1. The upper left image shows an Imote with an IMB400 camera and a fisheye lens. The upper right shows several cameras deployed in a hallway. The bottom image shows an ventilation damper actuator made by Automated Logic.

2 Proposed System

2.1 Hardware

The Imote2 [1] is a sensor mote developed by Intel and can be connected to an IMB400 camera board [1]. The mote has an XScale processor that runs 13–416MHz and has 64MB of memory; this mote is capable of basic image processing. The camera is capable of capturing 32fps at 640x320 resolution. By combining this camera with a fisheye lens (see figure 1), we were able to monitor an area of roughly $400ft^2$. Data from the Imote2 is transmitted back to a base station, where control signals are passed to BACnet-

*Co-primary authors.

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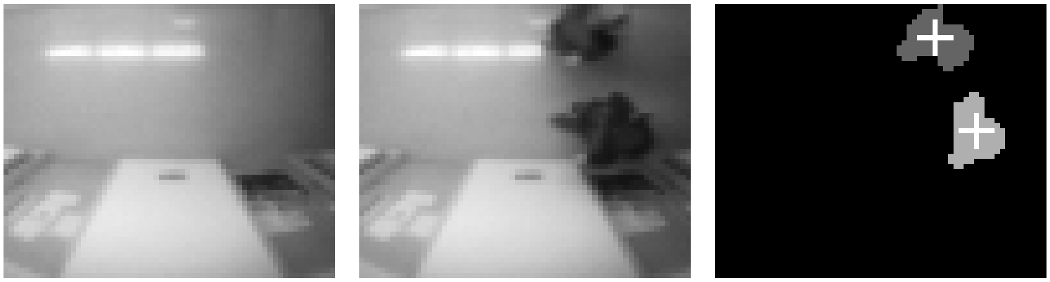

(a) Background Image (b) Occupied area (c) Components

Figure 2. This figure shows the basic process used to detect occupancy. 2(a) is the background image for the target area and 2(b) is a frame with occupants within the area. After applying the connected components algorithm, we can see the two occupants in 2(c) along with the centroids.

based Automatic Logic (ALC) building energy management system. Inside buildings, such systems are comprised of several ALC routers, each of which can support several sensor devices (temperature sensors, air flow sensors, damper actuators, etc). Figure 1 shows the ALC actuator to be used in conjunction with a damper.

2.2 Software

As the onboard 802.15.4 radio has very low bandwidth (250kbps), it is impractical to transmit a video stream or even images to detect people. Instead, we perform on-board image processing in order to count the number of occupants. The following series of operations (see Figure 2) are used to count occupants within an area:

1. Background subtraction to detect presence of people.
2. Apply thresholding to the background subtracted image to create a black and white image.
3. Apply connected components algorithm to the black and white image to count the number of blobs (people within the image area).

The number of occupants is simply the number of components found. Based on the number of occupants, the room/area is conditioned according to ASHRAE standards: thermal comfort (ASHRAE Std. 55 [2]) and outside air ventilation effectiveness (ASHRAE Std. 62.1 [3]). In addition to basic user comfort, the system will also be able to adjust lighting based on real time occupancy and learned schedules.

3 Demo Description

In our proposed system, we plan to demonstrate the control of temperature, ventilation, and lighting using a combination of pre-learned occupancy schedules and real time occupancy estimates from a wireless camera sensor network within a mock up of a conditioned room (tent). In order to convey the full operation of the system, we compress the day cycle into 12 minute intervals to show details such as night time setbacks and time based lighting control. During these compressed timelines, people will be able to enter a mockup of room and observe the real time response of the conditioning system. The room (tent) will contain an IntelMote2 based camera sensor node for detecting occupancy. A run through of the demo comprises of the following steps:

1. Optimal temperature control based on actual observed occupancy and learned occupancy schedules. The room is pre-conditioned based on occupancy prediction estimates; a setback temperature is used when the room is likely to be empty. However, the room is always conditioned when occupants are present.
2. We follow the ventilation requirements defined by ASHRAE standard 62.1 as follows:

$$V_{bz} = R_p P_z + R_a A_z \tag{1}$$

   where z denotes the zone, V_{bz} is the ventilation rate, R_p is the minimum CFM/person, P_z is the number of people, R_a is the minimum CFM/ft^2, and A_z is the floor area. For our demo, we plan to control the ventilation to the space via occupancy determined from our hardware setup. As seen in the above expression, ventilation (air-flow) is a function of the number of occupants in a room. As occupants enter the room, the camera sensors will relay the occupancy count to the energy management system which will adjust the air-flow through the vents. In the demo, we will visualize the occupancy information coming from the camera and display the airflow (in CFM) proportional to the current occupancy.
3. We will demontrate that unlike PIR sensors, camera based occupancy detection is robust against static objects. Occupants do not have “wave on” lights if sitting still for a period of time. In addition to demonstrating this feature, we plan to show how position based lighting can be achieved to selectively turn on lights based on occupant location.

As the occupancy of the space changes, we will demonstrate the performance of camera based occupancy detection system and the effect of the occupancy information feedback loop to the building energy management system.

4 References

[1] Intelmote2 and IMB 400 sensor board. http://www.memsic.com/.

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