Demo Abstract: ThermoSense: Thermal Array Sensor Networks in Building Management

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ABSTRACT

Buildings are often inefficiently conditioned. Rooms that are empty are needlessly conditioned and partially filled rooms are conditioned assuming maximum occupancy. In this demonstration, we describe a system that reduces energy consumption by opportunistically reducing energy consumption based on room usage; we only condition rooms currently occupied and condition the space based on real-time occupancy measurements. We will show how a thermal sensor array can be used measure occupancy in real-time and how this occupancy information can be integrated with a real building management system in order to control the heating, cooling, ventilation and lighting of a building to optimize energy usage.

Categories and Subject Descriptors

J.7 [**Computers In Other Systems**]: Command & control; C.3 [**Special-Purpose and Application-Based Application Systems**]: Real-time and embedded systems

1. INTRODUCTION

Energy usage has increased significantly within the past two decades. Room conditioning now consumes a substantial amount of energy; in 2010, 42% of the energy in the United States was consumed by heating, cooling, and ventilation. Reducing this load is critical for moving toward sustainability. Optimizing room conditioning based on usage is a major opportunity for reducing energy consumption. Most rooms are conditioned based on static schedules based on assumed periods of occupancy. Operationally, however, rooms are not always consistently occupied. For example, a conference room used once a week is conditioned even when unoccupied. Rooms are also often conditioned assuming maximum occupancy. Again, rooms are rarely fully occupied and can be conditioned more optimally if the number of people occupying a space is known.

Heating, cooling, and ventilation (HVAC) systems have two different points of control; temperature and ventilation. Several design considerations need to be accounted for when choosing an occupant sensor for control. Temperature depends only on a binary indication of occupancy. The strategy for setting temperatures only depends on whether a room is occupied or not, and does not depend on the number of occupants. Sensors such as passive infrared (PIR) and ultrasonic sensors are sufficient for temperature control. However, rooms need to be conditioned ahead of time in order to ensure the room can reach the appropriate temperature. A prediction model can be used to achieve this. However, these binary occupancy sensors are not suitable for ventilation control. This requires either the number of people occupying a space or the CO_2 levels. While a CO_2 sensor is able to directly measure the CO_2 levels in a space, these sensors are slow to respond since time is required for the gas to collect to measurable levels. CO_2 sensors are also prone to error, require regular calibration, and are sensitive to placement [8]. Cameras can be used for quantifying occupancy [6] but are sensitive to lighting conditions and sudden background changes. Depending how they are deployed, cameras also have privacy issues to be considered [1].

In this paper, we demonstrate a novel approach of measuring occupancy using a low cost low resolution thermal sensor array in combination with a PIR sensor. Thermal sensors are not sensitive to other issues such as background changes or lighting and are able to quickly measure changes in occupancy. In addition, we show how this sensing platform can be integrated with a building management system (BMS) to actuate a building.

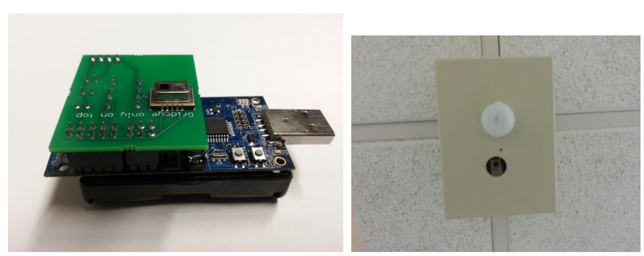

Figure 1: Grid-Eye and Tmote Sky (left). Enclosure containing both the Grid-Eye and PIR (right).

2. PROPOSED SYSTEM

2.1 Hardware

For our system we utilize the Tmote Sky platform [3] with a thermal sensor array and a PIR sensor. The mote has 48k Flash memory with a CC2420 radio chip and operates at

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Figure 2: 8x8 grid overlay taken with a webcam. Squares over a temperature threshold shown in red.

8Mhz. The PIR used is a Panasonic VZ long distance PIR motion sensor. It has a range of 12 m and has a detection range of 102° x 92 ° (width x height). The Grid-Eye [2], developed by Panasonic, is an 8 by 8 thermal sensor array capable of outputting temperatures to the Tmote through the I2C interface. It has a sample rate of 10 samples/sec and has a temperature range of -20°C to 80°C. It is capable of detecting objects in a 2.5m x 2.5m area when placed at a height of 3m. Figure 1 shows the Grid-Eye attached to the Tmote. Data from the Tmote is transmitted back to a base station, where the occupancy is estimated using a classifier. Occupancy can then be passed to WebCtrl, which is a commercial BMS developed by Automated Logic [9].

2.2 Software

The Grid-Eye makes up an 8x8 matrix, with 12 bits resolution. We can lower the range by truncating part of the data. Negative values and values that are above 50°C can be removed. Overall there is 64 bytes of data per sample. Due to the relatively small amount of data we are able to transmit the entire sample and process the data off-site. In order to get the number of people occupying a room we perform the following:

1. Create a thermal background based on known zero occupancy values using the PIR to help determine when no one is present.

2. Apply background subtraction with a threshold to create a 8x8 binary matrix of sufficiently "hot" pixels.

3. Apply connected components to the 8x8 binary matrix

4. Use a K-Nearest Neighbors classifier (KNN) to determine occupancy using the total active pixels, the number of connected components, and size of the largest component for the feature vector.

Because of the low resolution, connected components alone cannot be used to categorized the number of occupants. Instead, we use several features for our classification using KNN; the total number of "hot" pixels, the number of connected components, and the size of the largest component. The output of the KNN is the total number of occupants, which is then used to conditioned the room according to ASHRAE standards: thermal comfort (ASHRAE Std. 55 [4]) and outside air ventilation effectiveness (ASHRAE Std. 62.1 [5]). Along with this information, a scheduling model can be created to effectively predict room occupancy [7] and change temperature and ventilation to minimize energy usage while maximizing comfort.

3. DEMO DESCRIPTION

In our demonstration, we plan to show how our novel multi-sensor platform can estimate occupancy in real-time and can then be utilized in a working BMS. In our demonstration we use an LGR1000 BACnet router with a ZN141 actuator, which is the same equipment used in commercial buildings. To demonstrate this system, we will have a single zone room represented using a tent where people are able to enter and thereby trigger conditioning actuation (ventilation, lights, and temperature) based on the number of occupants within the space. The lights are actuated in real-time and illuminated based on the areas occupied within the tent. Similarly, a ventilation unit and fan are actuated based on the number of occupants within the space. As more people enter, the airflow produced by the unit increases. The following outlines the components of our demo:

1. Occupant actuated temperature control

2. Ventilation will be followed using ASHRAE standard 62.1 as follows:

$$V = R_p P + R_a A \tag{1}$$

   where V is the ventilation rate, R_p is the minimum CFM/person, P is the number of people, R_a is the minimum CFM/ft^2, and A is the floor area. Thus, as people enter the tent area, occupancy is sent to the BMS, which will adjust the air-flow through the vent unit. Occupancy information coming from the Grid-Eye/PIR and the air-flow will be displayed with a monitor.

3. For lighting control, we will demonstrate that our system is more robust than traditional PIR only systems and are able to cope with stationary occupants without having to "wave" on lights. In addition, we plan to show that the Grid-Eye is able to control area lighting based on occupant position.

4. REFERENCES

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