Improving Building Energy Efficiency by Kinect-based Occupancy Tracking and Mobility Detecting System

Haleimah Al Zeyoudi, Yanan Xiao, Chi-Kin Chau

Masdar Institute of Science and Technology
{hzeyoudi, yxiao, ckchau}@masdar.ac.ae

ABSTRACT

Nowadays, most building air conditioning systems often operate on a fixed schedule rather than based on real-time occupancy. In this paper, we develop an occupancy tracking software based on MS Kinect to capture the number of people in an open lab. We then employ a Markov Chain (MC) model for its occupancy transitions. We apply our occupancy model to simulate a dynamic HVAC schedule on eQuest, and obtain up to 22.1% energy reduction in HVAC.

1. INTRODUCTION

The majority of energy consumption in modern buildings is due to Heating Ventilation and Air Conditioning (HVAC) systems, which are often designed to operate at full capacity most of the time and it is often assumed a maximum occupancy [3]. Although the current HVAC systems are equipped with presence sensors, their sensitivity is problematic for management and control systems, and cannot accurately capture the dynamic occupancy patterns in buildings. In addition, they are unable to proactively adjust to occupants' comfort levels. Understanding human mobility and occupancy patterns is a key factor in order to successfully manage HVAC systems in buildings. The main contribution of our paper is to develop an energy-saving system based on accurate occupancy patterns of human mobility in buildings. The most important features of the system are as follows: a) A real-time detection and tracking of human mobility in buildings based on Kinect. b) An occupancy prediction mechanism using Markov chain model.

2. IMPLEMENTATION

2.1 Kinect-based Occupancy Counting Software

Our occupancy counting software is developed using Microsoft Visual C# 2010, project WPF application in C# and XML. Both types of Kinect are used and tested to insure that it works properly, i.e. Xbox Kinect and Kinect for Windows.

Kinect can capture RGB and depth images with the help of color sensor as well as infrared (IR) sensor. The depth image as shown in Figure 1. For each depth image captured, a corresponding blue box with unique ID is drawn to detect the movement of multiple people at the same time. We implemented a system that can count occupancy based on head tracking and skeletal tracking with a high accuracy.

2.2 Testbed Setup

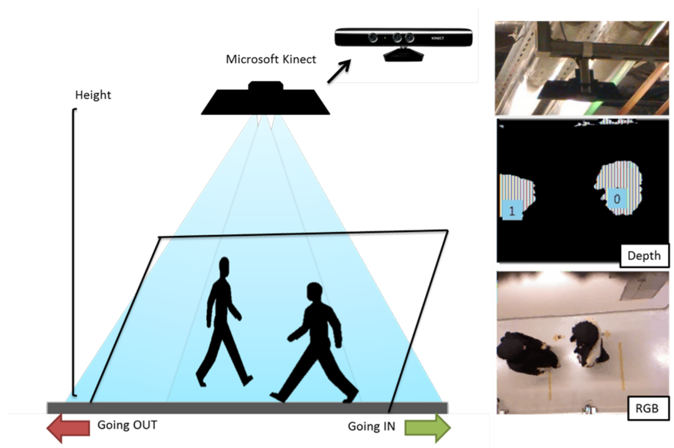

Figure 1: Architecture of human mobility tracking system

The testbed environment in our experiment is an open laboratory with no walls. Therefore we divide this lab into 4 zones and deployed 8 Kinect sensors attached to a laptop running Windows at key areas of each zone, i.e. the conceptual entrance and exit. The image of In/Out is captured by Kinect and processed by our system to track mobility. All mobility data is recorded by offline processing. A selection of deployments is shown in Figure 2.

2.3 Markov Chain Prediction Model

We employ a Markov chain model for a prediction model of mobility across different zones, which is built on the work in [1, 2]. We parse mobility data and fit the distribution of occupancy data, i.e. number of people at a specific time slot in each zone. We use a time slot as 30min and divide the states of occupancy into 4 occupancy states: E for empty, F for few, M for medium and C for crowded. For each time slot, an occupancy state is assigned with respect to the number of people in that zone. For example, when the number lies in between 8 and 14, then the state is assigned to be M.

To corroborate the accuracy of our Kinect detection system, we compare the processed occupancy data against the ground truth, which is collected by manually counting the number of people in captured videos. We observe over 90/

Next, we use the occupancy data to obtain a Markov chain model, which is a 256-by-256 matrix, representing the joint

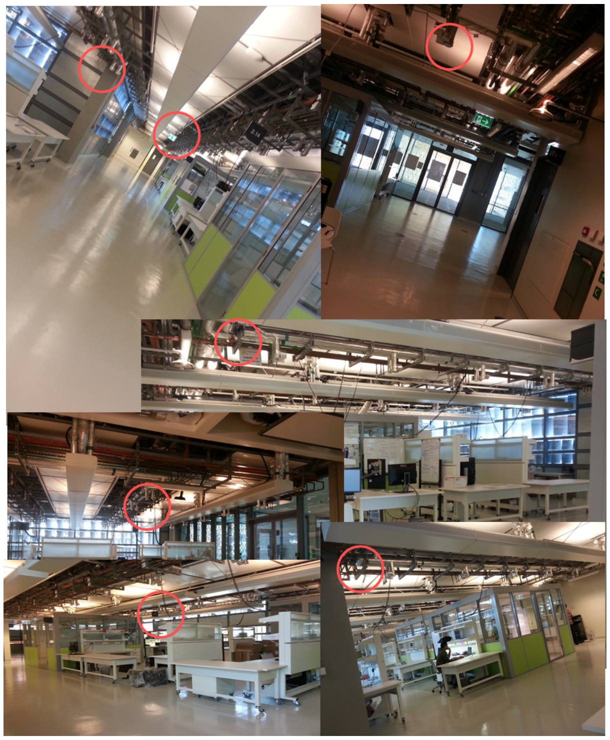

Figure 2: Kinect deployments in an open lab

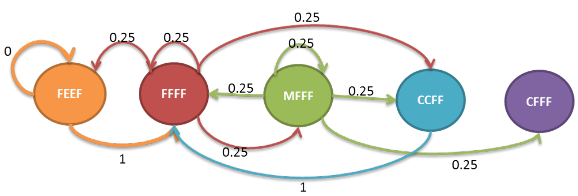

Figure 3: Transition matrix of occupancy states.

occupancy states in the four zones.

The matrix we obtain is very sparse, because many states has no transition probability as reflected from real mobility patterns. We present the Markov chain model in Figure 3. This transition matrix is then used to enable a dynamic control strategy for ventilation and air conditioning systems.

3. SIMULATION

We carry out simulation studies by eQuest by creating a building model and setting parameters to corresponding our buildings. The model is a two-floor office building with a total floor area of $232m^2$. Each floor is divided into four office zones with a floor area of $40m^2$ each. Windows are placed on the north, east and west walls of the building with overhangs having a projection factor (overhang depth/window height) of 0.6. Two doors are placed on the north and east sides of the building. Windows and doors are not specified on the south wall to minimize heat gain through radiation. The window to gross wall area is kept at 29%. The cooling system is configured to match practical office in our office.

4. RESULTS

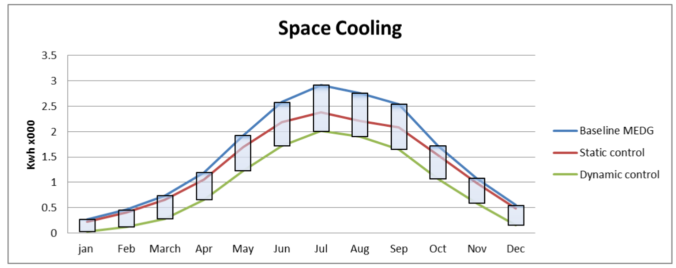

Figure 4: Energy consumption of 3 different control strategies

We adopt two control strategies to investigate their effect by our model. In the simulation, we use a fixed set-point for air conditioning system while applying a dynamic occupancy schedule generated from Markov chain model. We compare the energy consumption between HVAC schedule set according to the observed average occupancy with the original HVAC schedule set according a building design guide that assumes a maximum occupancy throughout the weekdays. We next apply a more realistic schedule with a dynamic set-point that varies according to the occupancy states. The more populated a zone is, the lower set-point it requires. Our simulation result is shown in Figure 4. The observed energy saving is up to 22.1% in July.

5. CONCLUSION AND FUTURE WORK

We aim to develop a system to improve the energy efficiency in our campus by making the building management systems smarter to dynamically adjust the HVAC system. Currently, we have developed a Kinect-based mobility tracking system to identify accurate the state of occupancy in an open lab. We devise a mobility model using Markov Chain to predict the likelihood of each zone's next occupancy state. Furthermore, we have conducted simulations to investigate the energy reduction. We plan to extend our Markov chain model to capture human activities besides of occupancy.

6. REFERENCES

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