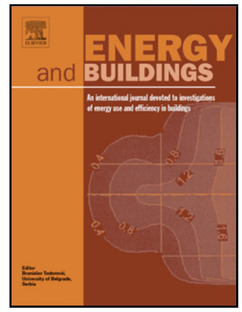
Accepted Manuscript



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PII: S0378-7788(17)30509-1
DOI: http://dx.doi.org/doi:10.1016/j.enbuild.2017.07.077
Reference: ENB 7817

To appear in: *ENB*

Received date: 22-2-2017
Revised date: 6-6-2017
Accepted date: 27-7-2017

Please cite this article as: Muhammad Aftab, Chien Chen, Chi-Kin Chau, Talal Rahwan, Automatic HVAC Control with Real-time Occupancy Recognition and Simulation-guided Model Predictive Control in Low-cost Embedded System, *<![CDATA[Energy & Buildings]]>* (2017), http://dx.doi.org/10.1016/j.enbuild.2017.07.077

Automatic HVAC Control with Real-time Occupancy Recognition and Simulation-guided Model Predictive Control in Low-cost Embedded System

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Abstract

Intelligent building automation systems can reduce the energy consumption of heating, ventilation and air-conditioning (HVAC) units by sensing the comfort requirements automatically and scheduling the HVAC operations dynamically. Traditional building automation systems rely on fairly inaccurate occupancy sensors and basic predictive control using oversimplified building thermal response models, all of which prevent such systems from reaching their full potential. Such limitations can now be avoided due to the recent developments in embedded system technologies, which provide viable low-cost computing platforms with powerful processors and sizeable memory storage in a small footprint. As a result, building automation systems can now efficiently execute highly-sophisticated computational tasks, such as real-time video processing and accurate thermal-response simulations. With this in mind, we designed and implemented an occupancy-predictive HVAC control system in a low-cost yet powerful embedded system (using Raspberry Pi 3) to demonstrate the following key features for building automation: (1) real-time occupancy recognition using video-processing and machine-learning techniques, (2) dynamic analysis and prediction of occupancy patterns, and (3) model predictive control for HVAC operations guided by real-time building thermal response simulations (using an on-board EnergyPlus simulator). We deployed and evaluated our system for providing automatic HVAC control in the large public indoor space of a mosque, thereby achieving significant energy savings.

Keywords: Automatic HVAC control, embedded system, occupancy recognition, model predictive control

1. Introduction

Heating, ventilation, and air-conditioning (HVAC) units, which are a primary target of building automation, make up almost 50% of the energy consumed in both residential and commercial buildings [1]. In general, building automation systems aim to intelligently control building facilities in response to dynamic environmental factors, while maintaining satisfactory performance in energy consumption and comfort. The primary functions of a building automation system include: (1) sensing of the environmental factors by measurements, and (2) optimizing control strategies based on the current and predictive states of building and occupancy. These tasks require an integrated process of sensing, computation, and control.

Traditional building automation systems rely on fairly inaccurate occupancy sensors, which hinder the responsiveness of automation systems. For example, passive infrared and ultra-sound occupancy sensors produce poor accuracy, because they are unable to determine the occupancy state adequately when occupants remain stationary for a prolonged period of time. They also have a limited range which hinders their performance, especially in a large area. More accurate sensing technology, such as cameras that use visible or infra-red lights, can significantly improve the accuracy of occupancy recognition.

On the other hand, model predictive control, by which the future thermal response and external environmental factors are anticipated to make control decisions accordingly, has been considered in a number of studies [2, 3, 4, 5, 6, 7] which are shown to be more effective than classical PID and hysteresis controllers that do not consider anticipated events. However, these studies are often based on time-invariant, first-principle linear models (also known as lumped element resistance-capacitance (RC) models [8]), considering only simple building geometry and single-zone in near-future time horizon. Although these linear models are easier for calibration (e.g., using frequency domain decomposition, or subspace system identification methods [8, 9, 10]), the error accumulates considerably when a longer time horizon is considered in model predictive control. While non-linear models are rather complicated and impractical, other alternatives based on physical models of building thermal response can provide a feasible solution.

Recently, there have been remarkable advances in embedded system technologies, which provide low-cost platforms with powerful processors and sizeable memory storage in a small footprint. In particular, the emergence of *system-on-a-chip* technology [11], which integrates all major components of a computer into a single chip, can

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