A Low-Cost Experimental Testbed for Energy-Saving HVAC Control Based on Human Behavior Monitoring

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ABSTRACT

Heating, ventilation, and cooling (HVAC) is the largest source of residential energy consumption. Occupancy sensors' data can be used for HVAC control since they indicate the number of people in the building. HVAC/sensor interactions show the essential features of a typical cyber-physical system (CPS). However, there are communication protocol incompatibility issues in the CPS interface between the sensors and the building HVAC server. Through either wired or wireless communication links, the server always needs to understand the communication schedule to receive occupant values from sensors. This paper proposes two hardware-based emulators to investigate the use of wired/wireless communication interfaces for occupancy sensor-based building CPS control. The interaction scheme between sensors and HVAC server will be discussed. The authors have built two hardware/software emulation platforms to investigate the sensor/HVAC integration strategies. The first emulator demonstrates the residential building's energy control by using sensors and Raspberry pi boards to emulate the functions/responses of a static thermostat. In this case, room HVAC temperature settings could be changed in real-time with a high resolution based on the collected sensor data. The second emulator is built to show the energy control in commercial building by transmitting the sensor data and control signals via BACnet in HVAC system. Both emulators discussed above are portable (i.e., all hardware units can be easily taken to a new place) and have extremely low cost. This research tests the whole system with YABE (Yet Another BACnet Explorer) and WebCTRL.

KEYWORDS

Cyber-Physical Systems (CPS), Energy Saving, HVAC, Real-Time Emulators, Wireless Sensor Networks

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1. INTRODUCTION

The Heating, ventilation, and air conditioning (HVAC) system provides thermal comfort and acceptable indoor air quality. It is the single largest contributor to a home's energy bills, accounting for 43% of residential energy consumption in the U.S., and 61% in Canada and the U.K., which have colder climates (E. P. B. S. Energy 1997; Rathouse & Young 2004). Studies have shown that around 25% of this energy could be saved by turning off HVAC system in residential/commercial buildings when nobody is inside (I. E. Center 2010). An 20%-30% reduction in HVAC energy translates to the savings of about $15 per month for the average households in the U.S. In order to improve HVAC systems and save energy at the same time, several communication protocols among HVAC units have been developed, such as Building Automation Control Network (BACnet), Modbus, Local Operating Network (Lon Works) and Lon Talk.

To observe the impacts of sensors-HVAC communications on the energy savings, we have used real hardware to emulate two scenarios in this work: energy saving control in *commercial* or *residential* buildings. Commercial building consists of multiple single offices and classrooms, while residential buildings refer to individual houses. Inside each room, different occupancy sensors are used to count people. The sensors include but not limited to: CO_2 sensors, PIR sensors, image sensors, and accumulated sensors. The communications between sensors can be built via wired or wireless links. The wireless connections could use different types of communication protocols, such as Wi-Fi, Bluetooth, etc. In contrast, wired communication can be achieved by using Ethernet or USB connection, etc.

The interactions between occupancy sensors and HVAC controllers have the essential features of a typical Cyber-Physical System (CPS): (1) *Physical-to-Cyber*: The physical objects (occupants in the building) need to be counted in real time in order to better control the fan/temperature levels of the HVAV systems. Such *physical* parameters (i.e., the number of occupants in any region/room of a building) can be captured by using *cyber* units (i.e., computing hardware/software). Here we use wireless microsensors to serve as cyber units. The sensors can report the *physical* status to a HVAC server in real time. (2) *Cyber-to-Physical*: The *cyber* units can be used to change the physical world. In this case, the sensor data will be processed to find out the distributions of occupants in different regions of a large building. Thus, we can change the *physical* objects based on cyber data. For example, we can tune the fan/air circulation levels of HVAC units in these regions.

The architecture of such a building CPS is illustrated in Figure 1. There could be various uses of occupancy sensors. In particular, they can improve the security levels of homes and offices. They can also save energy by efficiently controlling the room temperature, lighting and appliances. Occupancy sensors generally use a human motion detector with a timer. Some others measure CO2 level, acoustic signals, or human images.

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