Proceedings of the 2016 IEEE 20th International Conference on Computer Supported Cooperative Work in Design

Smart Phone Based Occupancy Detection in Office Buildings

Weiming Shen and Guy Newsham
Intelligent Building Operations, Construction Portfolio
National Research Council Canada
Ottawa, Ontario, Canada
weiming.shen@nrc-cnrc.gc.ca; guy.newsham@nrc-cnrc.gc.ca

***Abstract*—A recent literature review shows that approximately 20-50% of energy/cost savings are possible in office buildings when accurate occupancy information is applied to the control of building energy systems. Implicit occupancy sensing, by extracting occupancy data from systems already in the building rather than from those explicitly designed to collect occupancy information, has the potential to provide high-enough accuracy for building energy management with lower costs compared to traditional explicit sensing approaches. Since more and more office workers today carry smart phones, we conducted a proof-of-concept study to explore the feasibility of using smart phone Bluetooth signals for office occupancy detection. The objective is to use existing IT infrastructure to detect occupancy to enhance building control functions while protecting office worker privacy. This paper presents some preliminary results of our recent investigation in this direction. The experimental results are very promising.**

Keywords—office buildings, energy conservation, occupancy detection, smart phone, Bluetooth

I. INTRODUCTION

According to the results of a comprehensive literature review [10], approximately 20-50% of energy savings are possible for lighting and HVAC systems in office buildings when accurate occupancy information is applied to ensure that building services are provided only when and where they are needed. Implicit occupancy sensing, by extracting occupancy data from systems already in the building rather than from those explicitly designed to collect occupancy information, has the potential to provide high-enough occupancy accuracy for building energy management with lower costs compared to traditional explicit sensing approaches.

This paper presents our recent investigation on using smart phone Bluetooth signals for office occupancy detection (i.e., detecting when an office worker is in his/her own assigned workspace) with the objective of using existing IT infrastructure to detect occupancy while protecting office worker privacy. The paper is organized as follows. Section II provides a brief review of existing solutions and the related research literature. Section III describes the proposed approach on using smart phone Bluetooth signals for office occupancy detection. Section IV presents some implementation results. Section V concludes the paper and discusses the limitations and shortcomings of the approach.

II. REVIEW OF EXISTING SOLUTIONS AND RESEARCH LITERATURE

This section provides a brief review of the existing solutions for office occupancy detection and related research literature. A detailed review can be found in [10].

A. Conventional Approaches

Three types of motion detectors have been commercially available for a long time: passive infrared (PIR), ultrasonic (acoustic) emitters, and microwave emitters. They are combined with various devices to make six types of occupancy sensors:

- Passive Infrared (PIR) Detector
- Active Ultrasonic Detector
- Passive Ultrasonic Detector
- Microwave Occupancy Detector
- Combined PIR and Ultrasonic Detector
- Combined PIR and Microwave Occupancy Sensor

Traditional occupancy sensors such as PIR sensors and acoustic sensors output a binary value indicating whether people are in the area being monitored; these data are often used for lighting control. Typically, a single sensor is deployed to determine control over an entire zone.

Because of the uncertainty associated with the determination of occupancy using single-point sensing, a network of linked, cheaper conventional occupancy sensors [3][11] was proposed to offer more accurate and robust occupancy measurement, and greater energy savings than can be achieved with a single sensor.

These traditional occupancy detection approaches have a number of limitations:

- Cost: A high-quality, wired, standalone occupancy sensor can cost $200 or more installed. Wireless devices may offer lower installation costs, but are not completely reliable regarding data communications, and must be powered by batteries (that eventually need to be changed), or by energy-scavenging systems that add cost and have their own reliability issues
- Field of view (restricted to visual line of sight)
- Low occupant resolution without information on count, identity, and activity.

978-1-5090-1915-1/16/$31.00 ©2016 Crown

- False detection: a shadow or a flash (e.g., headlight from a passing car) can trigger PIR sensors; any other noises can trigger acoustic sensors
- Robustness: if the single sensor fails, drifts out of calibration, or is physically compromised, control for the zone becomes sub-optimal or is lost entirely.

B. Existing Implicit / Ambient / Soft Sensing Approaches

Implicit occupancy sensing refers to extracting occupancy data from systems already in the building rather than from those explicitly designed to collect occupancy information [9]. Such approaches are also called soft sensing [6][11] and ambient sensing [8].

Sources of implicit occupancy data include data that are already collected but not used for building control purposes, and data which are potentially available, but not yet collected. In the former category are things like computer network activities, security card access systems, and detection of mobile devices at WiFi access points. In the latter category are things like keyboard and mouse activity, webcams, and PC microphones. The advantage is that these sensors are already present for other purposes, are powered and capable of communication so that they can be accessed by the building control system, and thus come at little or no incremental cost. Although these individual channels might have limited accuracy independently, their aggregated data may carry more precision, and certainly more robustness, than any one high-end sensor [4][5][6][7][12].

C. Observations

According to our literature review [10], there are only a small number of projects / systems in the research literature using the existing IT infrastructure to collect occupancy information. More researchers have proposed and developed systems using supplementary devices and systems including Wireless Sensor Networks, sensor arrays, RFID (Radio-frequency identification), motion sensors, and other dedicated sensors.

Occupancy detection accuracy indicates how far from the ground truth any measurement is. Almost all reviewed systems [10] report an overall accuracy of 80%-98% which is believed to be "good enough" for building automation. As argued by many researchers, the accuracy requirement is really dependent on various control applications. Since high accuracy requirements also bring high implementation cost, the key issue is to have "good enough" accuracy with minimal cost, at the same time ensuring occupant comfort and protecting occupant privacy.

Note that any analysis of occupancy accuracy in the context of building systems control should discriminate between false positives and false negatives. False negatives (concluding there is no-one in the zone when, in fact, the zone is occupied) are more problematic than false positives (concluding there is someone in the zone when, in fact, the zone is unoccupied). For example, a false negative might lead to lights being automatically switched off, leaving a person in darkness.

The most relevant work related to this investigation is by Balaji et al. [1] on the use of existing WiFi infrastructure in commercial buildings along with smartphones with WiFi connectivity carried by building occupants. Their experimental results show an accuracy of 86% with 6.2% false negative errors. The inaccuracies were attributed primarily to the aggressive power management by smartphones, i.e., WiFi is turned off when a phone is not in use. In fact, 86% was only achieved when all the smart phone users were requested to turn on WiFi permanently during the test period.

III. Occupancy Detection based on Smart Phone Bluetooth Signals

A. Brief Introduction to Bluetooth Technology

Bluetooth is a wireless technology standard for exchanging data over short distances (using short-wavelength radio transmissions in the range of 2400–2480 MHz) from fixed and mobile devices, creating personal area networks (PANs) with high levels of security. Bluetooth was standardized as IEEE 802.15.1. It can connect several devices, overcoming problems of synchronization.

Bluetooth uses a master-slave or server-client structure. A master Bluetooth device can communicate with a maximum of seven slave devices. The devices can switch roles: a slave can become a master, and vice versa. At any given time, data can be transferred between the master and one other device. Bluetooth devices can communicate with a distance of up to 100 meters (Class 1) in open space, but smart phone Bluetooth signals are usually detectable within about 10 meters (Class 2) inside a building. There are also Class 3 Bluetooth devices that have a range of only one meter, but such devices were not available for this initial work.

Bluetooth has been embedded in all smart phones and almost all recent laptop computers. Even though existing desktop computers are not equipped with Bluetooth, a USB Bluetooth adaptor costing less than $10 can render a desktop computer Bluetooth ready.

Compared with WiFi, which is intended as a replacement for high speed cabling for general local area network access in work areas, Bluetooth is intended for portable equipment and applications. It is a replacement for cabling in a variety of personally-carried applications in any setting. WiFi is usually access point-centered, with an asymmetrical client-server connection with all traffic routed through the access point, while Bluetooth is usually symmetrical, between two Bluetooth devices. Bluetooth serves well in simple applications where two devices need to connect with minimal configuration, while WiFi is better-suited in applications where some degree of client configuration is possible and high speeds are required.

As mentioned in the previous section, using WiFi for occupancy detection requires smart phone users to turn on WiFi permanently during the test period. Using Bluetooth, smart phones need to be in discoverable mode for an initial registration with their owner's office computers. There is no subsequent need to change Bluetooth settings (as long as the Bluetooth capability is switched on, which it is usually by default). Bluetooth also consumes much less smart phone battery energy than WiFi [2].

B. Two Approaches

The basic idea of smart phone-based occupancy detection is to detect a smart phone within range of the phone owner's office computer using Bluetooth signals, with the assumption that the office worker always carries the smart phone with him/her. The implication is that if the phone is within the typical 10m range of the "home PC" that the office worker is inside their office (and consequently in the context of this work, that building services may be delivered as appropriate).

The first step is to pair a smart phone with its owner's office computer, which can be done like pairing any two Bluetooth devices. During the pairing process, the smart phone must be in discoverable mode (once only).

We have developed a software module in C# to detect / discover the registered smart phone. The Service Discovery Protocol (SDP) is used for this purpose. Two different approaches have been investigated to check whether the smart phone is within range (about 10 meters):

Approach 1: Try to make a connection with the smart phone with any data transfer. A service Universally Unique Identifier (UUID) is required to achieve this. Some sample UUIDs are listed in Table I.

Table I. UUIDs of Sample Smart Phones

Smart Phone	UUID
iPhone 4	00001101-0000-1000-8000-00805F9B34FB
Samsung Galaxy	00001112-0000-1000-8000-00805F9B34FB
HTC Desire C	00001112-0000-1000-8000-00805F9B34FB
LG Nexus 4	00001112-0000-1000-8000-00805F9B34FB

Approach 2: Discover the smart phone using a fake UUID. This discovery process seems to take longer than a connection (Approach 1), since it may compare the UUID with all available services of the smart phone. The advantages of this approach include: (a) no real connection; (b) no need of UUIDs.

The implementation of the Bluetooth communication uses the 32feet.NET - Personal Area Networking for .NET. In particular, *InTheHand.Net.Personal.dll* needs to be included.

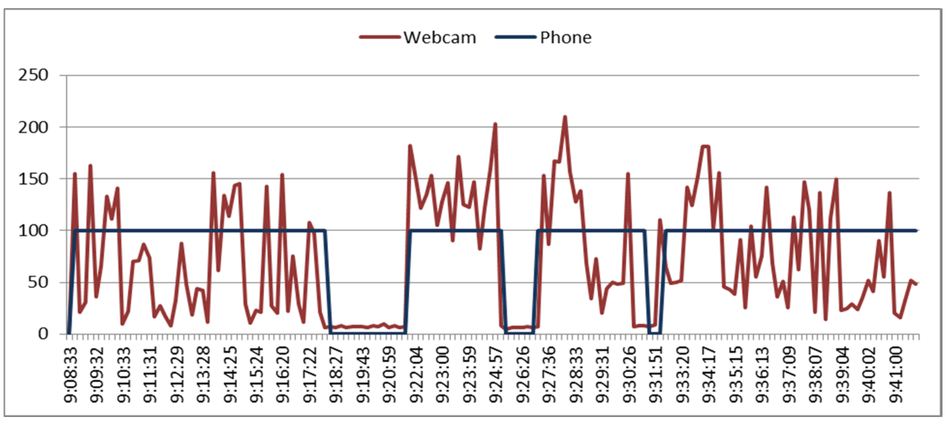

Fig. 1. Short period results using the real connection approach (Approach 1)

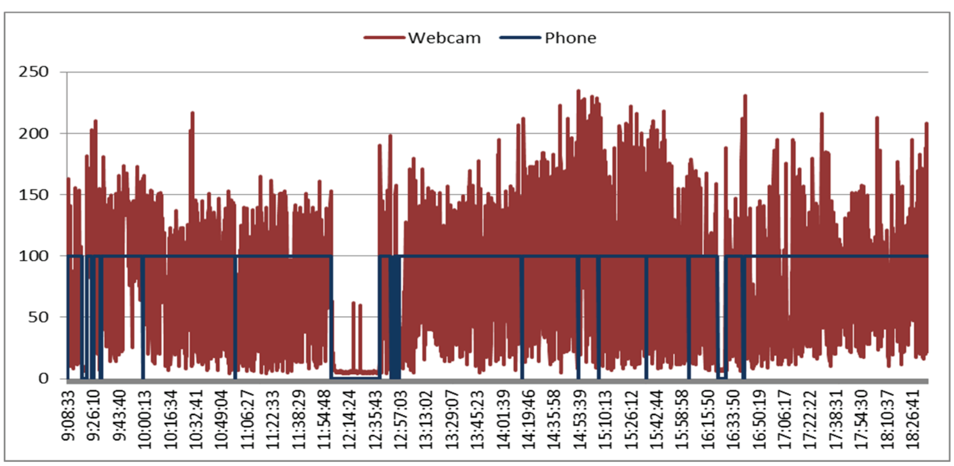

Fig. 2. Full day results using the real connection approach (Approach 1)

IV. IMPLEMENTATION RESULTS

A. Approach 1: Real Connection

Fig. 1 and Fig. 2 show some implementation results using the real connection approach, all under the assumptions that:

- The smart phone has been paired with the office computer;
- The smart phone is always with the office worker;
- The smart phone has enough battery to function;
- The smart phone Bluetooth service is turned on.

No specific ground truth data source was installed during

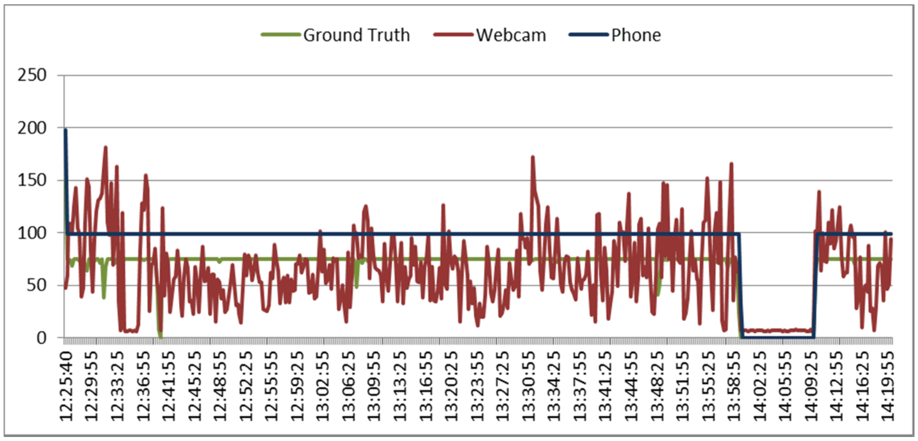

Fig. 3. Short period results using the fake UUID approach (Approach 2)

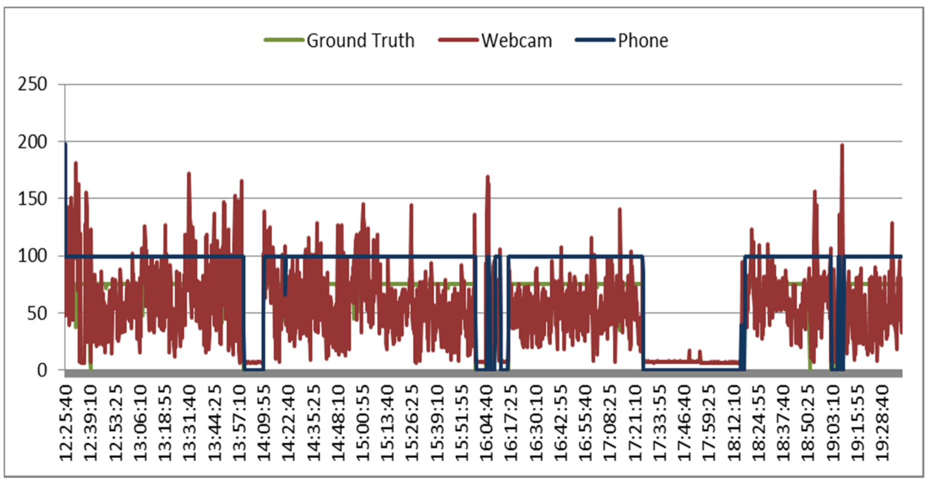

Fig. 4. Full day results using the fake UUID approach (Approach 2)

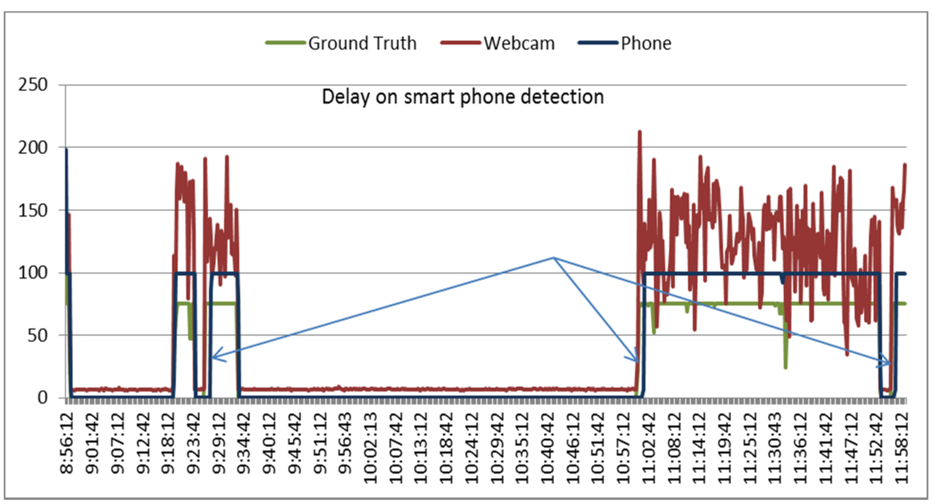

Fig. 5. Testing results showing the delay of smart phone detection (Approach 2)

the test of the real connection approach, so the smart phone based detection results (blue lines on Fig. 1 and Fig. 2) are compared with Webcam-based motion detection results (brown lines). Fig. 1 shows some delays in occupancy detection when the office worker leaves and comes back to the office. Fig. 2 shows some very short-lived false negatives which may be caused by the low battery of the smart phone or the slow response of the Bluetooth connection.

B. *Approach 2: Fake UUID*

Fig. 3 and Fig. 4 show some implementation results using the fake UUID approach under the same assumptions.

A pressure-sensitive floor mat was installed before the test of the fake UUID approach to provide ground truth information. The smart phone based detection results (blue lines) are compared with the ground truth (green lines) as well as the Webcam detection results (brown lines). The results shown in Fig. 3 and Fig. 4 seem to be better than those of Fig. 1 and Fig. 2, but another test (shown in Fig. 5) indicates some longer response delays (about one minute) when the office worker returns to the office.

V. Conclusion and Discussion

An investigation shows that it is feasible to use smart phone Bluetooth signals for office occupancy detection. Preliminary experimental results are very promising. The advantages of using smart phones for office occupancy detection include:

- It is an additional channel of occupancy-related information at (almost) no cost (assuming the occupant already has a smart phone), which may be used independently or as a supplement to other sensors;
- It is very reliable and accurate (according to our preliminary studies);
- It potentially carries fewer privacy concerns compared with some other data channels (e.g., webcam, keyboard, and mouse);
- It is particularly useful in cases where other sensors are compromised.

However, it also has some limitations/shortcomings:

- It will generate false positives if the smart phone is left behind when the person leaves the office;
- There is a risk of false positives due to the standard Bluetooth signal range (of about 10m) extending beyond the person's own office;
- Some false positives or false negatives due to the Bluetooth response latency (a couple of seconds);
- Smart phone low battery state seems to cause some false negatives;
- The requirement to leave Bluetooth always on will consume some additional smart phone battery life (but our initial estimates suggest this is only about 2%).

While some limitations mentioned above are difficult to overcome, a possible solution to address the second limitation would be a specially design Bluetooth adaptor with limited range of 2~3 meters.

After some further testing and debugging, the smart phone based occupancy detection module can be integrated into the office occupancy detection system currently deployed in pilot sites. Similar approaches can also be used for occupancy detection at the zone, floor, and building levels.

Acknowledgment

This work was funded by the ecoENERGY Innovation Initiative (EcoEII) administered by Natural Resources Canada (NRCan), and by the National Research Council Canada, and the Conservation Fund of the Ontario Power Authority.

References

[1] Balaji, B.; Xu, J.; Nwokafor, A.; Gupta, R.; Agarwal, Y. 2013, Sentinel: An Occupancy Based HVAC Actuation System using existing WiFi Infrastructure in Commercial Buildings, 11th ACM Conference on Embedded Networked Sensor Systems (SenSys 2013).

[2] Balani, R., 2007, Energy Consumption Analysis for Bluetooth, WiFi and Cellular Networks, Networked & Embedded Systems Laboratory (NESL), University of California at Los Angeles, Los Angeles, CA. http://nesl.ee.ucla.edu/fw/documents/reports/2007/poweranalysis.pdf

[3] Dodier, R.H.; Henze, G.P.; Tiller, D.K.; Guo, X. 2006, Building occupancy detection through sensor belief networks, Energy and Buildings, 38(9), 1033-1043

[4] Dong, B.; Andrews, B.; Lam, K.P.; Hoynck, M.; Zhang, R.; Chiou, Y.S.; Benitez, D. 2010, An information technology enabled sustainability test-bed (ITEST) for occupancy detection through an environmental sensing network. Energy and Buildings, 42 (7), 1038-1046.

[5] Dong, B.; Lam, K.P. 2011, Building energy and comfort management through occupant behaviour pattern detection based on a large-scale environmental sensor network. Journal of Building Performance Simulation, 4(4), pp. 359-369

[6] Ghai, S.K.; Thanayankizil, L.V.; Seetharam, D.P.; Chakraborty, D. 2012, Occupancy detection in commercial buildings using opportunistic context sources. Proceedings of PerCom (Lugano), pp. 469-472.

[7] Hailemariam, E.; Goldstein, R.; Attar, R.; Khan, A. 2011. Real-time occupancy detection using decision trees with multiple sensor types. Proceedings of SimAUD 2011 (Boston), pp. 23-30.

[8] Lam, K.H.; Höynck, M.; Dong, B.; Andrews, B.; Chiou, Y.; Benitez, D.; Choi, J. 2009, Occupancy Detection through an Extensive Environmental Sensor Network in an Open-Plan Office Building, 11th International IBPSA Conference on Building Simulation, 99. 1452-1459.

[9] Melfi, R.; Rosenblum, B.; Nordman, B.; Christensen, K. 2011, Measuring building occupancy using existing network infrastructure. Proceedings of the International Green Computing Conference (Orlando, USA), pp. 1-8.

[10] Shen, W., Newsham, G. Implicit Occupancy Detection for Energy Conservation in Commercial Buildings: A Survey, Submitted to CSCWD 2016, 2016.

[11] Thanayankizil, L.V.; Ghai, S.K.; Chakraborty, D.; Seetharam, D.P. 2012, Softgreen: towards energy management of green office buildings with soft sensors, Energy in Communication, Information, and Cyber-physical Systems (E6) Workshop, COMSNETS (Bangalore), pp. 1-6.

[12] Tiller, D.K.; Guo, X.; Henze, G.P.; Waters, C.E. 2009, The application of sensor networks to lighting control. Leukos, 5(4), pp. 313-325.