Occupant-Centric Federated Cyber-Physical System for Building Management

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Abstract

Multiple operations inside the building, e.g. HVAC, elevators, fire system and access control, are managed by diverse systems, each providing centralized management and inflexible ways for external interaction. Limited interactions across these systems also limit the occupant experience towards personalized control, ability to selectively share data and control access and build custom applications that can integrate these systems to provide a holistic experience. This research focuses on developing an open-source, federated cyber-physical system for building management. Proposed system will allow the occupants to create sharing and control policies to guard the sensors, actuators and suppress their data to preserve occupant's privacy. We also propose to develop interfaces to external systems to support data integration and actuation based upon detailed analytics. Finally, we intend to develop and deploy low-cost sensing and control hardware for building management, using Commercial Off-The-Shelf (COTS) hardware, to demonstrate the diverse capabilities of the proposed system.

1 Introduction

Building management systems (BMS), used to manage, monitor, control and automate various building subsystems, have been in existence for a long time. Several diverse hardware subsystems and their corresponding software interfaces enable fine-grained monitoring and control of different building operations such as electrical distribution, water distribution, HVAC (Heating, Ventilation and Air Conditioning), safety and security, and access control, among others. Information and communication technologies from such diverse sub-systems pose unique challenges and opportunities for researchers and industry towards developing sustainable building infrastructure.

Many of these subsystems are managed and controlled by central utilities and often in isolation with other subsystems. Building occupants often have little insights into information collected about the environment around them and almost zero controllability of these subsystems. Such centralized management and isolated operations results in sub-optimal operations, taking into account the average occupant requirements rather than catering to specific individual preferences. Combining the collected information from several of these subsystems will result in richer information source, potentially leading to optimized resource usage. A common integration framework, together with occupant driven sensing and control will also enable the ecosystem for third party application development, currently non-existent. Several challenges exist in integrating these subsystems and corresponding unified information access and actuation control. An integrated framework should support:

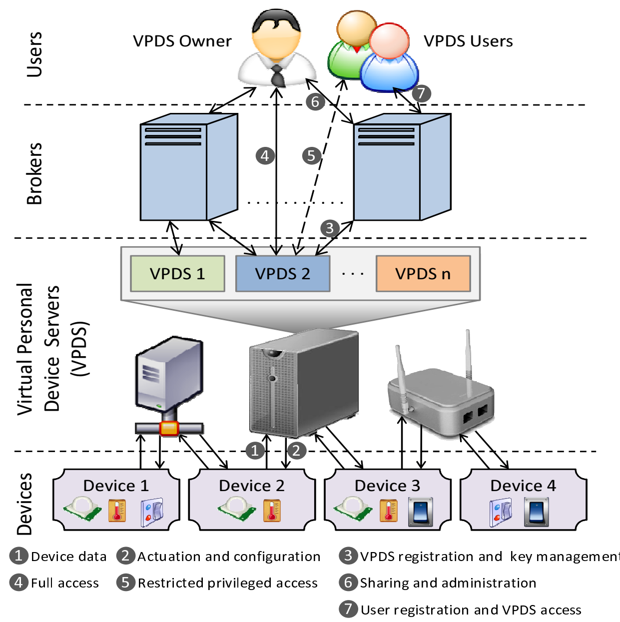


Figure 1: Layered architecture of SensorAct

1. Collection of information from diverse subsystems, supporting multiple protocols, such as BACnet, LonTalk, Modbus and proprietary sensor network deployments.
2. Participatory engagement of occupants to set policies guarding access to the sensor data and actuators and to define operations controlling actuators based on sensor data and time.
3. Simple and intuitive application interface, supporting diverse third party application development.
4. Data analytics, using aggregated information from diverse sources, leading to optimal usage scenarios.
5. Scalability for large number of users, devices, applications and support to manage them reliably.

Proposed research focuses on the design and development of such an integrated framework and addresses these gaps in the existing building support systems.

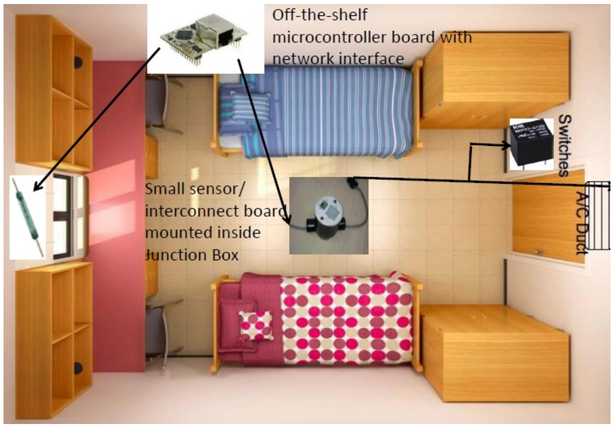


Figure 2: Illustration of the dorm deployment involving wired infrastructure planned during the construction phase

2 Related Work

Existing commercial building management[1] and home automation[2] systems are primarily centralized and limit the occupant participation in sensing and control decisions. While many of these systems support a standard protocol for external interface, such as BACnet, Modbus and LonTalk, there is limited support for extending these systems to support additional sensors and actuators, outside of what is already supported. Additionally, there is negligible support to set policies for sharing the sensor data and actuation control.

Several research systems have been developed in the recent past to address unified building management system. HomeOS [7], provides a PC like abstraction over networked devices as peripherals for both users and developers. HomeOS design broadly addresses the interoperability and usability issues of home automation systems with limited support for occupant centric functionalities. Proposed research derives motivation to use distributed and federated architecture from other systems such as Personal Data Vault [9] and SensorSafe [5], that allow users to own their data while still providing the flexibility for sharing the data and control with other system users. Several sensor based research systems, such as SenseWeb [12], SensorWeb [6] and GSN [1], have been developed and deployed. However, these systems are limited primarily to data aggregation, visualization and minimal sharing capabilities. Sensor Andrew [11] has similar goals as the proposed research but differ in many ways e.g. sensing and application layer interface is not lightweight, and sharing mechanism, supported in the system, follow "all-or-nothing" model without any fine-grained sharing.

On the hardware side, several novel building sensor systems [2, 8, 11] have been proposed. Of particular interest is Softgreen [13] that uses existing sensory information, such as Wi-Fi/Ethernet connectivity information, computer activity, IM status, on-line calender and access card information, inside an office environment as soft sensors providing useful information for building management without additional deployment of physical sensors. RESTful interface, integrated with CoAP[3], proposed in this work will allow for sensor data streaming from any of these diverse systems.

Several data analytic approaches have been proposed in the recent past [4, 10]. Generic application layer interface, supported in this research will support many of these approaches to be developed as third party applications that can then seamlessly interface with any building management system deployment. As a proof of concept, we provide some preliminary analytics from one of our deployments of low cost hardware systems for which the data collection and analytics were supported through the proposed research system.

3 Ongoing Research

Primary focus of this research is the development of a cyber-physical system for occupant-centric building management. Current focus is on the design and development of SensorAct [3], the software system that addresses many of the challenges specified in Section 1. SensorAct follows the classical layered architecture for the overall system design as shown in Figure 1. Layered architecture maximizes the interoperability, both with diverse sensing systems and third party applications, and reduces the overall system complexity. Moreover, each layer can be built independently and new functionalities can be designed in a modular manner and can be added incrementally.

RESTful interface between sensing layer and VPDS allows for supporting diverse devices. Data adapter tools can be easily built to interface with existing building system protocols and integrate the data and control of the other systems through RESTful SensorAct interface. A *Guard rule* engine within the VPDS layer supports for participatory engagement of occupants, allowing them to set the rules for sharing the data and actuation control. Proposed light-weight tasking framework, *tasklets*, allows occupants to perform rich forms of automated sense-and-control operations within the system. RESTful broker interface allows easy interactions with third party applications, enabling them to search for sensor data, that is accessible as per the guard rules set by the device owners, and perform visualization and analytics outside the SensorAct system.

Ongoing research involves support for several device management functions such as seamless integration of new devices, removal of obsolete devices, and location and context based device search and data query. Device management, together with integration of diverse devices and external systems in the sensing layer and third party applications allow SensorAct to support for optimal usage scenarios inside the Buildings. Distributed VPDS instances, federated by a common broker, allow SensorAct to scale for large deployments, potentially spread across multiple geographical regions. We implemented SensorAct using existing open source technologies and released the code in opensource[4].

3.1 Hardwares and Deployment Scenarios

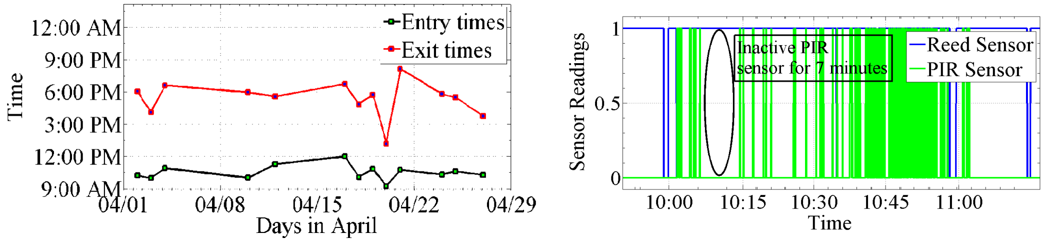
At the sensing layer, SensorAct maintains and supports *device* abstraction. A device can consists of hard and soft sensors and actuators with multiple channels. A device

[1] `http://www.trane.com`, `http://www.buildingtechnologies.siemens.com`, `http://www.johnsoncontrols.com`

[2] `http://micasaverde.com`, `http://www.homeseer.com`, `http://www.control4.com/residential`

[3] `https://datatracker.ietf.org/doc/draft-ietf-core-coap`

[4] `https://github.com/iiitd-ucla-pc3`



(a) Inferred entry and exit time of an occupant for a month (b) Limitation of motion sensor when observing small movement

Figure 3: Preliminary data analysis by combining motion and door status sensors data

is managed by its owner who also configures its various attributes such as location, identity, actuation key, data publish key and URL. A device consisting of an actuator should specify an IP address for its accessibility. A device's observed data point can be uniquely identified as *building:floor:room:device:id:[sensor/actuator]:id:channel:data*. Devices can be connected through both wired (Ethernet) and wireless (Wi-Fi, ZigBee and Z-Wave) interfaces to VPDS. Devices transmit their readings through upload API to VPDS. Interactions with the devices are authenticated using a key, issued by the VPDS and configured by the device owner. Figure 2 illustrates a deployment scenario in a dormitory room, including motion, temperature, light, door status and window status sensors and relays to control electrical fittings. This scenario is replicated across more than 400 rooms in the new campus of IIIT Delhi and will be supported using SensorAct system. Hardware system is custom built using COTS components.

SensorAct system will be further deployed across diverse environments supported by multiple collaborators, including two academic partners - IIIT Delhi and UCLA and an industrial research laboratory - IBM Research, India. Deployment at IIIT Delhi will include sensing deployment in dormitory rooms (as mentioned earlier), smart electricity and water meters across the campus, interactions with the commercial BMS (controlling HVAC) and access control and deployments across multiple faculty offices using both custom made Wi-Fi sensor nodes and Z-Wave commercial sensor nodes. Another academic deployment at UCLA involves a 1200 sq. ft. laboratory space with 30 electrical channels each and 10 event driven sensors for motion, door, and light. Proposed system deployment for Softgreen [13] testbed at IBM Research India involves temperature, motion and various soft sensors to infer employee occupancy information.

3.2 Application Integration and Analytics

SensorAct exposes most of its functionalities through web APIs allowing easy integration of custom third party applications (web, stand-alone and mobile) addressing specific user requirements such as visualization, dashboard, data analytics, among others. SensorAct APIs are RESTful HTTP requests to access various system resources. Each API request is authenticated using a unique secretkey which is generated when the user registers with the system. SensorAct uses JSON, a light-weight data interchange format, to receive and send API request and response data.

A prototype of deployment scenario illustrated in Figure 2 was deployed for four months in two faculty offices, monitoring temperature, motion and door status. Data collection and analytics were supported using SensorAct. Figure 3 illustrates our preliminary analytics performed with the data collected from this deployment. Such analytics can be used to infer utility of collecting multi-modal sensor data (combining motion and door status sensors to infer occupancy) and motivate privacy concerns arising from inference of behavioral patterns of the occupants. Extensive user studies will be done to evaluate several aspects of SensorAct such as performance, usability and ease of interface.

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Biographical Sketch

Pandarasamy Arjunan is a PhD student at IIIT Delhi, India since July 2010. He is working with Mobile and Ubiquitous Computing (MUC) group, under the guidance of Dr. Amarjeet Singh. Before joining PhD, he worked for three years as Software Engineer with HCL and IBM. He completed Master of Computer Applications from Madurai Kamaraj University, India in 2007.