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Review

Automated point mapping for building control systems: Recent advances and future research needs

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ABSTRACT

This paper presents a review of recent research and development on methodologies relevant to automating mapping of points in building control systems and between building control systems and external or replacement software and hardware. Manual point mapping is labor intensive and costly, presenting a major impediment to innovations in building control (e.g., automated fault detection and diagnostics, self-healing, and automated commissioning for existing building control systems). The methods reviewed focus on classifying building control system points, especially sensor classifications by sensor type. Fewer publications address other important aspects of the point mapping problem, such as discovering spatial and functional relationships among points, relationships between control system points, physical systems, and equipment, and between various equipment and the systems of which they are part, and discovering metadata, normalizing it to a common namespace, and assigning the metadata to control system points. To motivate further development of new automated point mapping approaches, we identify many research questions organized into four key technical needs: 1) a complete solution and underlying problem formulation, 2) alignment of methods with the actual point mapping problem, 3) test cases, data sets for testing, explicit test procedures, and consistent performance metrics for reporting testing and evaluation results, and 4) understanding of the applicable data space to ensure future adaptability of automated BAS point mapping.

1. Introduction

Building automation systems (BASs) serve buildings that represent about 42% of the total floor area in the U.S. commercial buildings sector [1,2]. Seventy-nine percent of this floor area is in buildings with areas > 4645 m^2 (50,000 ft^2) [1]. Furthermore, the fraction of floor area served by BASs significantly decreases as the size of buildings decreases; however, 75% of the number of U.S. buildings with BASs are buildings with floor areas of 4645 m^2 and less, and the average size of buildings with BASs is 4407 m^2 (47,440 ft^2) [1,2]. Still, only 11% of all commercial buildings with floor areas ≤ 4645 m^2 have BASs compared to 70.3% of all buildings with floor areas > 18,580 m^2 (200,000 ft^2) [1,2]. To address the absence of BAS technology in commercial buildings smaller than 4645 m^2, work is currently underway to extend BAS functionality cost-effectively to these smaller commercial buildings, which generally do not have BASs presently (see, for example, [3,4]).

A significant effort has been underway for > 3 years by the U.S. Department of Energy and others to bring BAS technology at significantly lower cost than previously possible to such smaller buildings. This effort is centered around the flexible, low-cost, modular, open-source controls platform, VOLTTRON™ [5,6], for which several building control and analytic applications have already been built (c.f., [4,7], and http://www.bemoss.org/).

Extension of BAS technology to small commercial buildings will be necessary, if as many researchers, policy analysts, and utility personnel believe, buildings will serve as active participants in managing the emerging modernized electric power grid by controlling loads in response to conditions on the grid or incentive signals sent by the grid, such as prices [8–13]. Success of these developments should lead to the emergence of many third-party applications for commercial buildings of all sizes that rely on building control systems for data.

BASs consist of hardware and software integrated into a single architecture and are intended to keep building occupants comfortable, control systems and equipment (primarily for heating, ventilating and air-conditioning), monitor and track the performance of various systems, and provide notifications to building operators of device and

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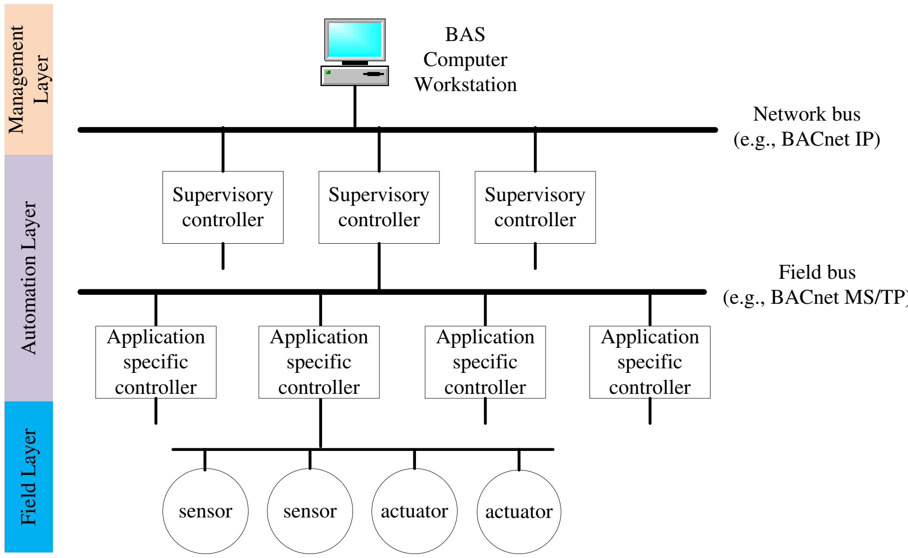

Fig. 1. Building automation system architectural structure.

system faults and failures through alarms (e.g., alarms indicating that a zone air temperature is outside its normal range and that air filters are clogged with dirt).

The classic BAS architectural structure defines three layers (Fig. 1), which from bottom to top are the field layer, automation layer, and management layer [14]. The field layer consists of various sensors and actuators that interface to physical processes. The sensors (e.g., thermistors and flow meters) measure the condition or status of physical processes and devices. The measured data are gathered at direct digital control stations, which are usually application-specific controllers in the automation level. These controllers process the sensed data and command the actuators to take appropriate actions (e.g., regulating the position of a valve to control a water flow rate). The automation layer may also include supervisory controllers, which generally perform global control functions such as scheduling, alarming, and recording data. Field buses are used to communicate between application-specific controllers and supervisory controllers, while networks based on the Internet Protocol (IP) are used for communication between supervisory controllers. The management layer has computer stations or portable devices used to manage and monitor the entire system. Through a unified user interface, building operators can modify schedules and control loop parameters, archive data for long-term historical analysis, and generate reports. In the context of building automation systems, sensor measurements, actuator outputs, and adjustable parameters in control algorithms are often called BAS points. Fig. 1 shows a classic BAS architecture normally seen in the field, but other configurations exist, including some with sensors connecting directly to field buses or application specific controllers using IP.

Correctly installed and well-operated BASs can bring many benefits to building owners and operators, such as increasing occupant comfort, reducing occupant complaints, lowering utility costs, decreasing maintenance costs, and enhancing property values [15–17]. However, control systems are currently largely installed by an error-prone manual process, during which the associations among sensors, actuators, and their connected controllers, between application-specific controllers and their supervisory controllers, and between different peer controllers must be correctly established. High costs for installation, programming, and commissioning of BASs ($1.0 to $6.0 per square foot [17]), especially for specialized labor, have historically been one of the major reasons why many commercial buildings – and in particular the many medium and small commercial buildings – do not have BASs. Automating the point association (i.e., mapping) process will help ensure error-free, less labor intensive, consistent, and complete implementation of control algorithms during installation and thereby significantly lower the total installation costs.

BASs can provide a platform on which new energy-saving technologies can be deployed, first as external software connected to them and later as capabilities integrated into BASs. Software applications using data from BASs have shown substantial benefits in enhancing building operational efficiency, occupant comfort, and grid services [18,19]. These software applications provide functionalities, such as remote monitoring of building and equipment operation, energy information management, fault detection and diagnostics, adaptive control, self-correcting control, and other innovative functions. These applications usually connect to and rely on BASs as their source of data and a means of implementing control actions so as to avoid the expense of a separate network. Connecting to BASs though leads to the need to *map* BAS points to points in these external software applications, which is ordinarily done manually or using a customized semi-automated process.

Points in a BAS ordinarily have little, if any, computer readable metadata that identify point functions, characteristics, and relationships to other points in the control system, devices in the physical (e.g., heating, ventilation and air-conditioning [HVAC]) systems, and spaces in the building. When metadata are available, they are often embedded in point names or in extended text descriptions in fields associated with a point. This suggests that metadata could be automatically retrieved from BAS point names or other text associated with them by simple parsing of text strings. However, because no naming convention is yet widely used, point names and extended descriptions are inconsistent across buildings and BASs (even those on a specific campus). Point naming is often ad hoc with names differing in the information included, terminology used, and abbreviating of terms. Even though some work towards the use of standardized point tags is ongoing (e.g., [20]), current tagging schemes cannot represent all information required by third-party software applications [21]. Tags can be embedded in point names or captured in a table, for example, associated with each point. The present chaotic naming makes the process of parsing text to determine metadata difficult to automate and often requiring involvement of an expensive expert (e.g., control system implementer or building engineer). The resulting high cost of implementing software that relies on mapping of BAS points often makes the software applications prohibitively expensive and unable to penetrate the marketplace. For example, it took 3 days for a building expert to manually map 9820 BAS points from 6 buildings to an enterprise energy management system [22].

Successful automation of the BAS point mapping process would overcome a key barrier to the cost-effective use of third-party devices and software that require data communication to and from existing