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Latest Trends in Building Automation and Control Systems

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ABSTRACT

This paper explains the basic concept of building automation and control system (BACS), examines the latest trends in the related technologies, and describes the challenges and future directions of the building control industry. It is believed that the development trend of BACS is greatly influenced by the advancement and blooming of information technology and communication networks. To achieve intelligent facility management and enhance the overall building performance, it is necessary to develop and implement the BACS in an effective manner, by considering appropriate technologies, actual project requirements and imaginations. It is also important to have effective system specification and proper education so that the knowledge from different disciplines can be integrated more efficiently in practice.

Keywords: Building automation, control systems, energy management systems.

1. INTRODUCTION

Building automation and control system (BACS) is also known as building automation system (BAS), building management system (BMS), energy management system (EMS) or central control monitoring system (CCMS). By definition, BACS comprises all products and engineering services for automatic controls, monitoring, optimization, for operation, human intervention, and management to achieve energy-efficient, economical, and safe operation of building services systems (ISO, 1999; ISO, 2005b). An effective BACS will provide lowest cost energy, avoid waste of energy by managing occupied space, and make efficient use of staff through centralized control and automation. Usually, the heating, ventilating and air conditioning (HVAC) system is the main concern of BACS because this system plays a major role in energy consumption and construction costs of commercial buildings (Honeywell, 1997).

In the past decade, automatic building controls has been developing and evolving very rapidly (CIBSE, 2000; EMSD, 2002; Gryzkewicz, 2004). The technology, both hardware and software, has advanced and changed significantly (ISO, 2004; ISO, 2005a). In general, the development trend of BACS is greatly influenced by the advancement and blooming of information technology and communication networks. Together with a growing demand for intelligent buildings and smart environments (Clements-Croome, 2004; Cook, and Das, 2005), the design and planning of BACS is becoming more and more sophisticated. It will also continue to evolve in the coming future.

This paper explains the basic concept of BACS, examines the latest trends in the related technologies, and describes the challenges and future directions of the building control industry. It also discusses the important issues for ensuring successful implementation of BACS projects in practice.

2. BUILDING AUTOMATION

Building automation is a programmed, computerized, intelligent network of electronic devices that monitor and control the building services systems in a facility. The aim is to create an intelligent, effective building and reduce energy and maintenance costs of the facility. Nowadays, modern buildings often implement the automation based on direct digital control (DDC) which consists of microprocessor-based controllers with the control logic performed by software. For further description about DDC for building automation, the website "www.ddc-online.org" provides unbiased information on it and would be a good information source for study.

2.1 System Architecture

Most building automation systems consist of a primary and secondary bus which contain programmable logic controllers, input/outputs and an operator interface (also known as a human interface device). Figure 1 shows a typical example of the system architecture.

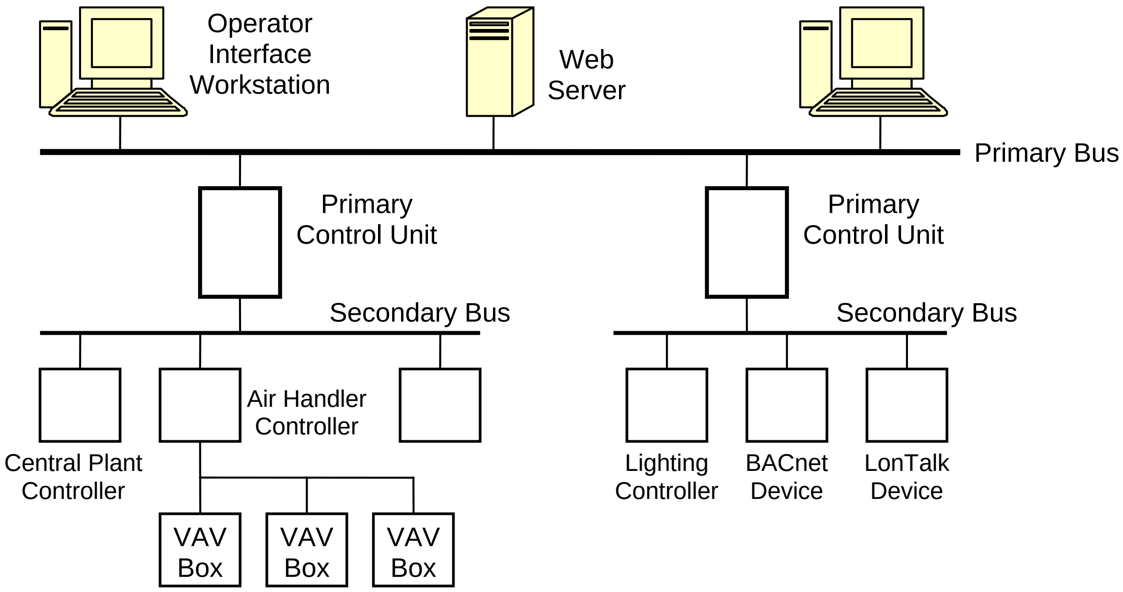

Figure 1. System architecture of building automation system

For large buildings, the automation process would cover many aspects of the building operation, including the following functions:

- HVAC
- Lighting
- Security and access control
- Life safety (such as fire services)
- Vertical transportation (lifts and escalators)
- Energy management and power distribution
- Tenant telecommunications
- Communications within public spaces
- Building structure monitoring

Nowadays, efforts to make buildings smarter are focusing on cutting costs by streamlining building operations like air conditioning and lighting. Building automation is crucial to these efforts, mainly because it could reduce the annual operating costs of buildings through effective monitoring and optimization. Most of the recent developments in building automation are on the system integration part (EMSD, 2002) and the automation trends in large buildings are affected by communication technologies (Sinclair, 2001). Yesterday's hierarchical systems with vertical information flows are being replaced by systems that have a flatter structure and more diverse information flow patterns.

2.2 Communication Standards

To facilitate the control functions, communication standards are needed for specifying control system capabilities on data collection, archiving, networking and remote annunciation. Two standards or protocols appear frequently in the building automation media are BACnet (www.bacnet.org) and LonWorks (www.lonmark.org).

(a) *BACnet*

The Building Automation and Control Networking Protocol (BACnet) was developed as a data communication standard specifically to address the needs of BACS of all sizes and types (ASHRAE, 2004). In 1995, the American Society of Heating, Refrigerating and Air-conditioning Engineers (ASHRAE) first published the BACnet protocol and it was later adopted in Europe and approved by International Organization for Standardization as both a CEN and ISO standard 16484-5 in January 2003. It has also been adopted as a national standard by Korea and is currently under active consideration in many other countries such as Russia, China and Japan (Kastner, et al., 2005).

The BACnet standard stresses an open protocol and allows for the integration of different protocols from different vendors. It helps to define how multiple BACnet systems may share the same communication networks and may inter-communicate to request various functions from each other (CABA, 2002). Nowadays, BACnet has grown beyond HVAC and can be applied to any type of building system including lighting, security and access control (Turner, 2006). In principle, it is also forward compatible with future generations of systems.

BACnet can communicate over local area networks such as Ethernet, ARCnet, MS/TP, PTP and LonTalk. The data on the BACS can also be routed through some IP (Internet Protocol) routers, so that remote monitoring and control can then become possible (via a BACnet/IP device).

(b) *LonWorks*

LonWorks is an open platform designed by Echelon Corporation for connecting building systems to each other and the Internet ("Lon" stands for "local operating network," a play of words on the term "local area network, LAN"). The system consists of the LonTalk communication protocol, a dedicated controller (Neuron Chip) and a network management tool (Loy, Dietrich and Schweinzer, 2001).

Basically, LonWorks describes products, software and hardware, that utilize LonTalk (now published as a formal standard, ANSI/EIA-709). It is an embedded technology that is suitable for most types of electronic devices used for automation and control. LonTalk supports a variety of different communication media and different wiring topologies. Since it was designed as a generic control network, many protocol parameters are free to choose for the designer (Kastner, et al., 2005).

2.3 Intelligent Building Concepts

In the past decades, the scope of BACS is expanding to include information from all kinds of building systems, moving toward the goal of "intelligent buildings", a buzzword in the market (Clements-Croome, 2004). Gray (2006) found that discussions about building intelligence now extend well beyond building automation to issues such as security, communication, user friendliness and environmental monitoring and control, and focus as much on how facilities use their technology as whether they possess it.

In principle, the intelligent building of today not only boasts systems automation and control, but is also able to generate data and share it among systems to enhance the efficiency and effectiveness of the whole facility. In a study report, CABA (2002) defines an intelligent building as "a building and its infrastructure that provides the owners, operator and occupant with an environment that is flexible, effective, comfortable and secure through the use of integrated technological building systems, communications and controls". In fact, people's concepts and expectations on intelligent building and BACS are changing, under the influence of various social and economic factors.

3. MAJOR TRENDS IN TECHNOLOGIES

The development of BACS are also influenced by construction methods and the current market situation. As building technologies are breaking down some conventional barriers and there is growing concern with environmental impacts and building security (after the 9-11), the functionality of intelligent buildings and BACS is driven by these market forces (CABA, 2002).

3.1 Web-based Control Networks

Sinclair (2001) has pinpointed 11 revolutionary automation trends in large buildings and he put the World Wide Web as the first point. Needless to say, the Web is influencing every other industry in the world and affecting many aspects of our everyday life. Generally speaking, the Web can act as a catalyst for accelerating the process of system integration and standardization, because technologies for all businesses are converging on the Web and taking advantage of the market potential that it represents (McGowan, 2001).

Current trends to work from home and to have more global traveling encourage remote interaction with building communications and services. Even within the same territory or campus, Web-based control networks that communicate over the Internet using standard Web browsers can offer a convenient access and a familiar, effective interface to building managers, operators, users and visitors. It is believed that the Web is transforming the interface of building control and will have a significant impact on the way the building owners manage facilities and building equipment.

The Web interface capability makes building data available to everyone in the organization and this function will enable a host of management advances. Control based on real-time data that may come from anywhere in the Web is exciting, and the only limitation is creativity (McGowan, 2001). Having said that, the potential of Web-based BACS has not been fully explored at present. Some pilot research studies have been done in Hong Kong on integrating BACS and facilities management on the Internet (Wang and Xie, 2002; Wang, S., et al., 2007). It is believed that future BACS will make frequent use of the IT (information technology) or IP network as a backbone network.

3.2 Fieldbus Technologies and Synergy

Originated in the process automation industry, fieldbus technology began in the 1970s with the first attempts to distribute control functionality to the field level. With the introduction of the Distributed Control System (DCS), processing plants were able to distribute intelligent control throughout process facilities. After some considerable efforts to develop digital communication standards for field devices, the industry formed the Fieldbus Foundation (www.fieldbus.org) in 1994, with the aim to provide an open and neutral environment for developing a single, interoperable fieldbus. New initiatives to enhance the fieldbus capabilities, robustness and data structure are now on the way and will bring performance improvements and business benefits to the developers and end-users.

It should be noted that the fieldbus development in process control and instrumentation has significant implications to BACS because distributed control and distributed diagnostics will ensure that the functionality of all building systems is respected, and any single fault cannot invoke a generalized building failure. Also, intelligent field devices can easily perform simple control functions and enable more effective design and management of building systems and components.

Moreover, the synergy of fieldbus technologies is possible by combining fieldbus protocols with LAN technologies to better utilize an existing LAN infrastructure (Kastner, et al., 2005). Most approaches follow the principle of running the upper protocol layers of the fieldbus protocol over the lower layers of a typical LAN protocol such as IP over Ethernet. For example, many companies and organizations have established their own Intranet and are now able to leverage this infrastructure for managing their buildings. By doing this, all the device profiles developed before can be reused. Also, technicians trained on particular tools will not find their existing knowledge rendered worthless despite the switch to IP-based building automation networks.

3.3 Wireless and Mobile Technologies

Wireless technology can offer many conveniences and be a cost effective solution for BACS (Edler and Wang, 2006). For example, with wireless mobility, building operators and maintenance personnel can track building operations wherever they are. Also, wireless connectivity can save wiring, simplify future changes and enhance system performance. With careful planning, using one wireless backbone for several systems can reduce engineering, construction, commissioning and operating cost over the entire life of the building. Of course, to make this control network convergence possible, the wireless network should provide sufficient bandwidth and Quality of Service (QoS) required for all the related applications.

There are many scenarios where wireless is a viable and preferable option, such as locations which are difficult or expensive to wire, interconnecting multiple buildings, and need for mobility. Usually, wireless sensors and transmitters are deployed for inaccessible or hazardous areas or special aesthetical requirements. Also, wireless access is interesting for management functions like log file access for service technicians or presenting user interfaces to tenants on their personal mobile devices.

Today, mobile telephones are well established, allowing mobile communications in many other forms. This technology has value for in-building applications. In particular, for the occupants/tenants and the operators, mobile technologies can yield substantial efficiencies. As mobile devices are changing fast, these evolving concepts will lead to BACS applications that are not yet on the drawing board. More creative ideas are needed for exploring the potential of mobile technologies in BACS.

3.4 Integrated Building Systems and Facility Management

Building control has traditionally been organized into autonomous subsystems such as lighting and HVAC control. As buildings are automated, these formerly independent subsystems are interconnected to deliver integrated services. Interconnection among subsystems is enabled by equipping each subsystem with facilities for data communications. In fact, when developing new addenda for the BACnet protocol, ASHRAE has expanded its coverage of building systems to include access control, lighting, life-safety and network security (Turner, 2006).

To integrate these systems and exchange information effectively, a ubiquitous and reliable communications infrastructure is needed (CABA, 2002). Integration is obviously far easier when systems that shall be joined talk the same language. For example, unified presentation is achieved at no additional engineering effort this way, potentially reducing investment cost. Other benefits of systems integration include sharing of information, space, infrastructure and operating staff among different building systems. For instance, a single operator interface will recognize status and control information of all available systems.

In theory, benefits both in terms of life-cycle cost and functionality will be maximized as more systems are combined (Kastner, et al., 2005). This requires that expertise from different fields is brought together. Integrating fire alarm and security functions is particularly challenging due to the high demands made on their reliability. Engineers and consultants who used to work separately are required to collaborate with each other and the design engineer as an integrated team.

Hartman (2001) believed that an integrated facility network (IFN) will generate many benefits for building owners, managers and operators. It will also enable effective remote operation & maintenance (O&M) management of the whole building and multiple buildings.

4. CHALLENGES AND FUTURE DIRECTIONS

Wang, et al. (2007) has pointed out two major challenges in intelligent building (IB) integration research: (a) how to overcome the incompatibilities and limited opportunities for the integration of BACS among products of different vendors, and (b) how to integrate BACS with the Internet and enterprise applications. To respond to these challenges, three key aspects of future BACS developments and their practical design considerations are described below. It is believed that future directions and implementation of BACS will be dictated by appropriate technologies, actual project requirements, and imaginations.

4.1 Interoperability

"Interoperability" is defined as the ability of two or more systems or components to exchange information and to use the information that has been exchanged. It is an ideal for BACS and has been widely promoted (Newman, 2001). A well-designed interoperable system that is matched to the requirements of the facility can improve performance and reduce operating costs. The major advantages of interoperable systems include the followings (Piper, 2006):

- Lifecycle cost is lower due to more competition between system and component vendors.
- The use of a single user interface reduces training costs while increasing data accessibility.
- Greater access to data allows better management of resources and facilities.
- Integrating independent functions into a single, interoperable system makes operations more flexible and efficient.

Although interoperable systems offer tremendous benefits, they have sometimes been overpromoted, resulting in unrealistic expectations as to what the systems can do and the level of support needed to make them perform (Piper, 2006). It is important for the BACS designers, specifiers and contractors to understand the underlying wants and needs of facility managers and what is required to get a fully functioning system that meets the needs of the facility (Hoffmann, 2003).

Moreover, it should be noted that interoperable systems do have one significant drawback: complexity. While some proprietary systems are fairly simple in their selection and installation, the interoperable applications often have more choices available. These choices mean flexibility, but also complexity. In order to ensure an interoperable system is successfully implemented, it is necessary for the end-users and facility management staff to be actively involved in the BACS development process. At present, proprietary solutions still permeate the BACS industry. If the future will require full interoperability, there is an opportunity for middleware technologies that translate protocols and conventions so that systems are fully interoperable (CABA, 2002; Wang, et al., 2007).

One approach to ensure interoperability among the systems is to provide common interfaces based on open systems protocols and architecture. But even when open protocols like BACnet and LonWorks are fully adopted in the system, BACS designers should not overlook some key details for specifying and applying the related devices. For example, the actual BACS implementation may still require special purpose gateways (Fisher, 2002); each vendor's equipment will require separate means to program; and additional on-site personnel training will be needed.

4.2 Information-rich World

An important trend in control is the move from low-level control to higher levels of decision making. In the past, because the building control systems lack information about the performance of existing equipment and building systems, managers often miss cost-effective retrofit opportunities (Gryzkewicz, 2004). Nowadays, modern BACS has better capabilities and robust data structure to allow continuous building-performance measurements, and support information processing, detailed analysis and data visualization. These advances can help to diagnose problems in the performance of building energy systems and provide reliable, decision-oriented information.

Continuous performance-monitoring and automated diagnostic systems, similar to those that you already have in your car, are possible in BACS. Combined with building simulation techniques, they can be used to model and assess the impact of control strategies even before systems are deployed. It also allows proactive instead of only reactive control strategies to be used in BACS and facility management. By integrating simulation data and local feedback loops into the systems, sophisticated evaluations of building energy, environmental and operating performance can be made and this will greatly enhance the quality of building design and management.

Nevertheless, if we have access to enormous amounts of data and information about building performance and control strategies, then the demand on computing and communication will also become very high. To manage the information effectively and provide efficient computation and feedback, an innovative approach to computing, communication and sensing systems will become a critical factor in such an information-rich environment.

4.3 Pervasive and Ubiquitous Computing

"Pervasive and ubiquitous computing" is about moving beyond the traditional desktop computing model, into embedding and integrating computing into everyday objects and everyday activities, so that intelligence can be built into the things we already use (Dillon, 2006). The vision is that the virtual (computing) space will be seamlessly integrated with our physical environment, such that we as people cease to take notice of computing artifacts. Sensor webs and microelectromechanical systems (MEMS) are two application examples of its concepts. Supporters of this idea think that embedding computation into the environment and everyday objects would enable people to interact with information-processing devices more naturally and casually than they currently do, and in ways that suit whatever location or context they find themselves in.

Supported by the wireless revolution and mobile technologies as mentioned in section 3.3, this future computing approach is revolutionary (Sinclair, 2001) and innovative (Doherty, 2002). Just imagine, eventually, building materials and components may become "smart" themselves, with for example wall paint and ductwork itself being able to measure temperature and light level for environmental control purpose. Future buildings could also be aware of the tenants and their actions, taking appropriate measures for their comfort and safety, possibly using an agent-based model. Chips could be embedded in pipeworks and light fittings for monitoring fire risk, health hazard and security.

In practice, some pervasive devices have already been used in the commerce, such as palm-tops, personal digital assistants (PDAs), wireless sensors, wireless monitoring systems, radio-frequency identification (RFID) and global positioning system (GPS). When they are applied to BACS and related fields, it will offer enormous opportunities for improving efficiency, productivity, safety, and reliability. On the other hand, they may also bring up some conflicting issues with technical, social and ethical implications. For instance, software infrastructure, battery lifetime, mobility handling, data security, privacy protection are issues likely to come up.

5. DISCUSSIONS

Effective implementation of automated facility management technology requires culture and process change (Keller, 2005). In most of the successful projects, technology is treated as a catalyst and a tool for process improvement. Knowledge and skills from various disciplines are needed so as to understand the technology trends and manage the development process. There are no universal rules for selecting appropriate technologies and guaranteeing a successful project. However, the practical experience in BACS projects around the world shows that the knowledge from different disciplines can be integrated more efficiently in practice, if effective system specification and proper professional education are established.

5.1 System Specification

The process of specifying, designing, and installing BACS typically begins with the plans and specifications produced by the building services or mechanical engineer. After that, the control system integrator will create a configuration database for the control system, which establishes communication, network, and device parameters as well as input/output (I/O) configuration parameters. The control system integrator also develops control application programs for the controlled equipment based on the narrative “Sequence of Operations”. To ensure the design intent has been implemented correctly, the system should be fully checked after installation through a proper commissioning process.

Petty (2004) pointed out that the most effective BACS specifications are based on technical descriptions of minimum and maximum performance levels of hardware and software system components at their functional levels. Also, well-written performance specifications shall concisely and clearly describe what the user wants in system hardware and software functional performance, open communication protocols and communication applications. The desired levels of performance are achieved by carefully selecting system components with attributes that meet or exceed performance goals. Those goals are set to conform to specific recognized standards and regulations, thereby reducing technical conflicts between rival building automation system manufacturers and equipment suppliers while supporting a competitive bidding process.

5.2 Professional Education

More often that not, BACS is not well understood by the client and many stakeholders in the building project team. Up to now, a lot of the consulting design engineers are still relying on the control contractor or supplier for suggesting and developing the BACS requirements and details. In recent years, increasingly, the design engineer is put in the role of being a systems engineer, responsible for linking the many elements of a complex control product or system. This requires not only a solid grounding in the framework and tools of control, but also the ability to understand the technical details of a wide variety of disciplines, including building services, communication engineering, computer science, electronics, facility management, IT and operations research. Leadership and communication skills are critical too for coordination in these jobs.

Unfortunately, the current system of professional education and training for the design engineers and BACS designers is often broken down into discrete disciplines. There is a lack of integrated studies on BACS and intelligent facility management which could provide a holistic view on the system design and enough interdisciplinary exposure to keep abreast of the evolving technologies and trends. Perhaps, the best options we can have at present is to train up a building services engineer with suitable courses on IT and communication networks, or educate a communication/electronic engineer with enough building services knowledge.

6. CONCLUSIONS

The development of BACS is affected by many technical, managerial, human, social and economic factors. In fact, the trends of BACS and intelligent building technologies in the past two decades were driven mainly by the advancement and blooming of information technology and communication networks. By integrating and applying Web-based control, fieldbus capabilities, wireless and mobile technologies, the modern BACS is able to enhance its functionality and cost-effectiveness. Through development of open protocols (such as BACnet and LonWorks) and interconnection of building services sub-systems, an integrated facility network can be established for sharing of information and resources as well as achieving overall system optimization.

Nowadays, we have got BACS technologies that are much better and sophisticated, at costs that have been reduced substantially. What people are looking for in the future would include quantum leaps forward in the functionality of the systems and opportunities for linking them together to improve the performance of a building as a whole. It is expected that further enhancements on interoperable systems, building information diagnosis, building simulation and performance monitoring will come up soon. Innovative approach to apply pervasive and ubiquitous computing to BACS is also possible.

To achieve intelligent facility management and enhance the overall building performance, it is necessary to develop and implement the BACS in an effective manner, by considering appropriate technologies, actual project requirements and imaginations. It is also important to have effective system specification and proper education so that the knowledge from different disciplines can be integrated more efficiently in practice.

It is the right time for us to prepare a wish list for future control, automation technologies and develop a better understanding of BACS by interdisciplinary studies.

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