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Liu, Z.G.; Makar, J.M.; Kim, A.K.

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Development of Fire Detection Systems in the Intelligent Building

Z. Liu, J. Makar and A. K. Kim

Institute for Research in Construction

National Research Council of Canada, Ottawa, Canada, Email: zhigang.liu@nrc.ca

Abstract

Fire detection and its corresponding safety systems are crucial parts of an intelligent building. This paper reviews the current state of development of fire detection and alarm systems in the intelligent building. New technologies and concepts developed in intelligent buildings, such as advanced multi-function sensors, computer vision systems and wireless sensors, real-time control via the Internet, and integrated building service systems, have also been reviewed and discussed. These new technologies and concepts will improve the capability of fire detection systems to discriminate between fire and non-fire threats and will increase the time available for property and life protection. However, much effort is still needed to remove barriers to the further development of these new technologies.

Introduction

An intelligent building can be defined as one that combines the best available concepts, designs, materials, systems and technologies to provide a responsive, effective and supportive intelligent environment for achieving the occupants' objectives over the full life-span of the building [1-6]. Compared with traditional buildings, intelligent buildings should be able to reduce energy consumption, reduce maintenance and service operation costs, provide improved security services, improve ease of layout planning and re-planning, and increase the satisfaction of building occupants [4-7]. Other benefits should include its adaptability to changing uses and technology and its environmental performance in providing safer, healthier and more comfortable working conditions. Intelligent building proponents also believe that these buildings will improve worker productivity through improved work environments. Over the last two decades, the intelligent building concept

has become an important consideration in the planning of many new or upgraded office buildings [3-6]. It has also been further developed to embrace other types of living and working environments such as homes, factories and education facilities.

Fire detection and the corresponding safety systems are crucial parts of an intelligent building. Billions of dollars are spent annually to install and maintain fire detection systems in buildings to assure safety from unwanted fires [8]. Intelligent systems developed in the intelligent building offer opportunities to meet this task more effectively, efficiently and economically. New sensors will produce earlier and more reliable fire detection. Wireless systems will eliminate the need for cabling and offer opportunities for fire fighters to work out fire fighting strategies before arrival at the fire scene. Integrated building systems hold the potential for reducing false alarms, speeding building evacuation and assisting in fire fighting. These changes will create new ways to provide fire safety and new markets for fire detection, alarm and fighting systems [9]. As these technologies mature, changes to building practices may also result.

This paper reviews the current state of the art for fire detection and alarm systems in intelligent buildings. It identifies new technologies and concepts developed for intelligent buildings that could be used to improve the capability of fire safety systems. The potential effects of integrated building service systems and barriers to the development of fire detection and alarm systems in intelligent buildings are discussed. The paper concludes by examining how these new systems may be combined to provide the next generation of intelligent fire safety systems.

Emerging Sensor Technologies

New sensor technologies will be key components in the next generation of intelligent buildings. Current intelligent buildings often have embedded processors and dedicated information networks. The new generation is expected to add the capability to learn about the building's circumstances and its occupants' needs and change the behaviour of its control systems accordingly [10]. The employment of a large number of sensors within

the building will allow it to operate in a responsive manner, rather than using pre-programmed control models as are employed in the first two generations of intelligent building. The information provided by sensors includes changes in both internal and external environments of a building, such as smoke, temperature and humidity, air quality, air movement, and the number of building occupants as well as a host of other properties. The system will use sensors to identify how a particular person tends to react to particular circumstances and to learn different behaviours for different people.

The number of sensors required to obtain this type of functionality is quite high, especially since one of the major goals of intelligent buildings is to allow individualized control of an environment. This need will increase the cost of intelligent buildings and make it difficult to manage the resulting large amount of data. Development of cost-effective sensors has consequently been identified as a key need for intelligent buildings [11]. Fortunately, many of the properties that need to be monitored can be used for multiple purposes. Security systems that can track the entry and exit of occupants from an office building can also be used to ensure complete evacuation of a building during a fire or even, in more advanced forms, determine where occupants may be trapped and unable to escape. Similarly, parameters such as temperature and air movement are as relevant to fire detection as the maintenance of the indoor working environment. Dual use sensors and sensor systems that are flexible enough to interpret data from different events will be key to making cost efficient intelligent buildings.

Efforts are being made to develop multi-function sensors for simultaneously detecting fire and monitoring indoor air quality (IAQ). Multi-function sensors that combine inputs from several different chemicals or physical processes would be expected to reduce the rate of false alarms and increase the speed of detection of real problems. They should therefore enhance fire safety while at the same time lowering total system costs. The chemical gas sensor has potential for this type of application. Chemical sensor techniques are now available for measuring almost any stable gaseous species emitted from materials and prior to or during combustion [12]. Chemical species can be sensed through a multitude of interactions, including catalytic, electrochemical, mechanic-chemical, and optical

processes. In one square inch, several hundred individual sensors can be placed in an array. By coating each sensor with a different semi-conducting material, several hundred different readings for gas signatures can be made by an expert system [13]. Recently, one olfactory sensor array system has been developed for environmental monitoring and for fire and smoke detection [14]. Such a system consists of an array of broadly-selective chemical sensors coupled to microprocessor-based pattern-recognition algorithms so that the changes in environmental conditions, such as CO, CO₂ and smoke, can be detected.

A major issue in any sensor system is differentiating between different causes of the event being detected. Higher than expected levels of CO₂, for example, may be the signs of a fire, but may also be a sign of poor air circulation within a room. When separate sensors installed in the building for fire safety, thermal comfort control and environmental monitoring can be integrated, sensitivity to fires and false alarm immunity can be significantly enhanced [15]. These sensors are located in different positions in the building. Once a fire occurs, the system can take multiple fire signatures and the spatial relationship and status of adjacent detectors into account in making decisions. Separate fire sensitivity information produced by these sensors would be transmitted to a control panel where fire signal processing and alarm and fault determinations are made. The use of a powerful central processing unit (CPU) in the control panel would also allow the system to use complex algorithms and advanced signal processing for fire signature identification.

The role of the control panel in improving fire detection capability has already been recognized, with a system using control panels for decision making being one of two main versions of intelligent fire detection systems [16]. Modern control panels are much more powerful and flexible because of the widespread use of integrated circuits and digital components that allow functions to be fully computer controlled. These control panels have powerful signal processing capability and use artificial intelligent techniques, to improve fire detection system reliability, response times to incipient fires, false alarm rates and maintenance requirements. The Building and Fire Research Laboratory at NIST has

recently initiated a project to further develop advanced fire detection and alarm panels [8]. This project aims to use information provided by sensors and advanced models of fire growth and smoke spread in buildings to discriminate between fire and non-fire threats, identify the exact location of a fire in a building, and provide continuous estimates on the short and long term behavior of fire growth and smoke spread in the building. Such fire information will allow building operators and fire fighters to make a more accurate and responsive evaluation of any fire-related incident in the building, to control fires and supervise the evacuation from the building.

Computer vision systems can also be used as a type of multi-function sensor. Computer vision applications have included building security, improving response rate and energy saving for HVAC systems by identifying occupant numbers and their locations [17], monitoring electrical power switchboards and control panels [18] and lighting level sensing and control [2]. Computer vision also has strong advantages for use in sensing and monitoring a fire. Cameras and corresponding facilities required in the computer vision system are already standard features of many buildings for other applications. Additional fire detection capability can therefore be added with minimal cost through changes in software and correlating results between the computer vision system and other sensors. One such application is the machine vision fire detection system (MVFDS), which uses a combination of video cameras, computers, and artificial intelligence techniques [19-22]. It processes multiple spectral images in real time to reliably detect a small fire at large distances in a very short time. It can also identify the location of a fire, track its growth and monitor fire suppression. For some applications, the MVFDS is further combined with radiation sensors (UV and IR) to enhance its detection capabilities or a CCD camera to automatically evaluate the scene through identification of bright regions associated with the fire radiation and increase system reliability [21, 22]. The development of this computer vision system is still ongoing and is viewed as being restricted due to the need for expensive and sophisticated software and hardware components.

Wireless sensors are another important emerging technology for intelligent buildings. Wireless fire detectors are already available in the market. An alarm signal is transmitted

to the control panel by radio, infra red transmission, ultra sonic and microwaves when smoke or rapid temperature changes are detected. Their significance comes not from their ability to measure new parameters, but because they do not require a hardwired connection to the data acquisition system that will record their readings. This capability not only allows wireless sensors to be located anywhere inside a room, but also means that they can be installed in the exterior envelope or other locations that would be too expensive or physically impossible to monitor in any other way [2]. Wireless technology may also be a necessity for retrofitting intelligent building technology in older buildings, where the difficulty and cost of installation is a significant barrier. In many cases installing intelligent building systems in older buildings requires major renovations. It can rarely, if ever, be done without damage to existing walls, floors and ceilings. It is likely that wireless networks will need to be developed to retrofit older buildings. Without such techniques, these older buildings will gradually become uncompetitive with new construction, reducing the value of the existing built environment.

In large buildings, wireless sensors communicate with other building systems through wireless networks in the building. Intra-office data networks based on 10 GHz wireless networks are already becoming widely available [23]. Wireless networks are expected to become the dominant media for low to medium bit rates for many intelligent building network applications. However, significant further development will be necessary for them to reach their full potential, and to overcome attenuation problems, such as absorption by office partitioning and reflection from wall, windows and other surfaces. Other major problems include the need to significantly lower the cost of wireless sensors, and the requirement for the development of suitable power supply systems that will allow the long-term operation of these sensors.

Development of Remote Monitoring and Control Techniques

There is increasing interest in remotely monitoring building service systems. Intelligent remote monitoring can significantly increase efficiency and reduce costs for building management operations. They may be especially important for small facilities where

skilled technical supervision would otherwise be too expensive to consider. These systems could let a single person supervise a number of buildings.

Most commercial monitoring systems use a modem and remote dial-up to access the building's operating system. Alarm messages from the building systems can also be directly sent to the equipment's manufacturer without intervention from the building's operator. More recently, studies have been carried out using the Internet for real-time control of a building automation system [24, 25]. Compared to "voice/touch-tone" interface, the Internet is able to provide more information (text, images and sound clips). Researchers at the University of Essex in the United Kingdom are developing an embedded-internet within a building that will allow building users or manufacturers to directly communicate with the building service systems [24]. The City University of Hong Kong has carried out an initial research project to use the Internet for real-time control of building automation systems [25]. Their studies have shown that the Internet has the potential to extend the monitoring and control of a typical building automation system out of the building so that users can gain access to it at anytime and from anywhere. Their work also shows that one central 24-hour management office is able to manage a real estate portfolio with hundreds of buildings.

Remote monitoring and control also has the potential to improve fire safety. It is estimated that 67 percent of all fires occur outside of office hours [26]. Remote monitoring of fire detection and alarm systems can reduce response time and improve response effectiveness by providing adequate fire information to the building supervisor, activating fire suppression systems and immediately summoning the appropriate fire brigade.

Some current advanced fire control panels have already incorporated a modem for remote access control. With the development of real-time control via the Internet, fire detection systems will perform automatic fault detection and diagnosis with early warning of sensor contamination before the overall integrity of the system is affected. Human intervention at the first sign of a warning should permit more efficient discrimination between fire and non-fire threats. When a fire occurs, detailed and adequate local fire information could be

directly sent to the appropriate fire department. Firefighters could also access information from the Internet to identify the locations of potentially hazardous materials or occupants who will need special assistance to leave the fire location. Fully integrated remote access systems will allow planning for fighting fires to take place enroute to the fire, rather than at the building's fire panel. Remote access systems should therefore provide valuable additional time for property and life protection.

However, real-time control via the Internet, is still in its infancy [25]. Development of the advanced, Internet based remote access fire protection systems described above has not yet begun. In addition, significant issues, such as real-time control of security and safety, still need to be considered. Internet access to fire safety systems also creates its own unique fire safety issues concerning computer and network security. The full implementation of Internet based monitoring systems will require strong assurances of data integrity and resistance to computer hacking. Without these protections, fire fighters may receive false information about the existence, location or size of fires.

Integrated Building Service Systems

Today's fire detection and alarm systems have been partially integrated with other building systems. Once a fire occurs in a building, fire detection and alarm systems in some buildings activate various fire safety systems, such as smoke control, and various pressurization and smoke exhaust system. They also activate elevator recall, the door release system, flashing exit signs and fire suppression systems [27]. Currently, however, the level of integration of all the disparate building systems is still limited. Even though building service systems that have similar functionality, such as fire safety systems and security systems, or HVAC systems and lighting systems, have been integrated together [5, 6], there is a limited level of information-sharing among the systems. Systems on the same cabling backbone are all provided by the same manufacturer. Various building service systems involving HVAC, lighting, fire safety and security monitoring in the building are not integrated together on the basis of a common communication protocol. This is mainly due to fragmentation of the building and communication industries, a

reluctance to change established practices as well as the lack of standardized, broadly-based communication protocols that allow different types of building service systems to communicate with each other. Many tenants and developers also prefer to have a lesser degree of systems' integration due to fears of excessive complexity, potential total system failure and possible slowdown of the central control [28, 29].

Various methods and concepts have been developed to enhance integration of building systems and to increase reliability of the integrated systems [5, 6, 30]. Efforts are also being made to develop communication protocols that enable different manufacturers to "interoperate" together and allow the building systems to communicate with each other over a network [8]. These protocols include BACnet, LonWorks, CAN, NEST, EHSA and CAB [10]. They prescribe a detailed set of rules and procedures that govern all aspects of communicating information from one cooperating machine to another. BACnet prefers a hierarchical model in which the whole system is divided into a number of subsystems, each with a separate central processing unit [31]. The coordination of the subsystems is achieved by hardwired interconnection or software interconnection. This method simplifies installation and maintenance and the damage caused by the failure of the CPU to EMCS and the fire safety systems is only limited to the local level, instead of to the whole integrated system. BACnet is most suitable to the traditional processing and communications models used by current HVAC hardware. However, BACnet does not support dynamically structured networks, nor does it emphasize distributed processing. Efforts are being made to expand BACnet beyond the HVAC realm. The first commercial BACnet fire system products will be introduced within the next two years, and new features are also being added to the protocol that will enhance the use of BACnet in life-safety systems [8].

Other communication protocols, such as LonWorks, on the other hand, prefer "networking integration" in which there is no central processing unit, just intelligent field cabinets. Each intelligent field cabinet is a "node" on the network and has equal status to the other nodes. Each cabinet controls local or zoned all energy management functions, all fire alarm functions and smoke control functions. It does not depend on any remote central

processing unit or another intelligent field cabinet. The microprocessors in the field cabinet can support advanced diagnostics and manage all the local building functions. The nodes in the network can communicate with each other and can be approached and managed through a central station or by a personal computer. This type of network further simplifies installation and maintenance, and increases the reliability of the system. Once a fire damage or a fault occurs, only the immediate area is affected, and the fire command station or any other man/machine interface location could maintain communication with any other field cabinet on the network loop by transmission of data in two directions. Response of this type of network to a fire threat is very fast, because there is no need for a CPU to scan and process whole building systems. The intelligent field cabinet recognizes the fire alarm within its own area and acts upon that event within the cabinet.

Conclusion

New intelligent building technologies have strong potential to improve fire safety. Multi-function sensors (i.e., chemical gas sensors, integrated sensor systems and computer vision systems) and wireless sensors will not only reduce expenditure on sensors, but also reduce false alarms, speed response times and reduce fire-related losses. Real-time control via the Internet will extend the monitoring and control of building service systems and fire safety systems out of the building, which will increase the efficiency and reduce costs for building management operations, more efficiently discriminate between fire and non-fire threats, and increase the time available for property and life protection. The integration of fire detection and alarm systems with other building systems should also increase fire safety in the building.

However, the application of intelligent building technology may also create completely new risks. Sensor technologies will need to be robust enough to prevent false alarms, accurately discriminate between fire and non-fire threats, and ensure that vital information such as the location of occupants is not lost due to data overload during a fire. Internet based monitoring and control of building service systems will need to be completely secure to prevent false fire information being provided to building owners and fire brigades.

Integrated building systems will need to be designed not only to give fire safety priority over other building activities but also that fire emergencies do not crash the building service system. A close examination of the concept of system integration will need to be conducted as intelligent building systems become more prevalent in order to determine whether a full integrated building system has sufficient redundancy to provide adequate fire safety.

In addition to the need for further research in developing new fire safety systems and ensuring that intelligent building systems do not hinder fire safety, additional work is needed to overcome the problems that are common to all parts of the intelligent building industry. Fragmentation of the building and communication industries, a reluctance to change established practices, the complexity of intelligent building systems, and the lack of universal communication standards have all slowed intelligent building progress. Much effort is needed to remove these barriers.

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