CRITICAL INFORMATION FOR FIRST RESPONDERS, WHENEVER AND WHEREVER IT IS NEEDED

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ABSTRACT

Most commercial and industrial buildings have fire detection systems that supply limited information from detectors to fire alarm panels. The information available today, and likely in the future, can be used to improve the fire service effectiveness and improve safety of the fire fighting effort. We need to improve the type of information that is made available to the fire service, the means by which it is presented, and the channels through which it is distributed. This will provide a higher level of information for monitoring the environment in buildings, including early warning of system malfunctions, hazardous environments, in-situ monitoring and prediction for building managers as well as real-time assessment of fire fighter conditions. The paper discusses the technology to accomplish this task, the standards and science needed, and provides an example of the implementation as a guide for future development.

INTRODUCTION

Reliable fire detection is an essential aspect of fire protection in all constructed facilities, first for the safe evacuation of occupants and second as a means to initiate manual suppression for control and extinguishment of unwanted fires.

However, fire fighting in buildings is complicated by lack of information about the environment inside the building. Even residential buildings (one and two family dwellings) are equipped with detection and alarm devices, that provide early warning for occupant evacuation. As technology for device interconnection, such as embodied in the the IEEE 802.11b standard, becomes more wide spread, the capability for communication even within residences increases and reporting such signals over a residential network will provide increased reliability.

Most commercial and industrial buildings have fire detection systems that supply limited information from detectors in the building to fire alarm panels, generally located in a designated area of the building. The information available today, and likely to be available in the future in new buildings with advanced sensors, can be used to improve the fire service effectiveness and improve safety of the fire fighting effort.

In order to enhance the safety and effectiveness of fire fighting operations in buildings containing modern fire alarm systems, we need to improve the type of information that is made available to the fire service, the means by which it is presented, and the channels through which it is distributed. More timely information on the state of the fire and the building environment will lead to better tactical decisions by the fire service.

The technology to demonstrate this vision exists, as do the numerical methods and measurement capability. The primary difficulty is that they have never been combined in a uniform and efficient way. In addition, the paradigm must provide for scalability, reliability, ruggedness, new sensors and new algorithms. At the same time, the view for the user (firefighter, security officer, maintenance personnel) must be consistent so that dissimilarities from their perspective don't cause more confusion than help.

The range of uses for modern transducers covers building management and indoor air quality, as well as first responders. While building management information display will be available on high resolution monitors, emergency service personnel need a much wider range of devices from laptops for vehicles use to handheld devices such as "pagers." The delivery of information must scale across this wide range of input and output devices, obviously with the detail available on small footprint displays being much less than on the high resolution devices.

BACKGROUND

As transducers become more commonplace in the built environment, it is desirable to utilize this information in a more complete way to assure safety. There are two facets to doing this, incorporating our knowledge of fires and other extreme events into the measuring and reporting capability, and insuring that all systems are functioning the way in which they were intended. The former is commonly referred to as smart sensing, while the latter deals with fault detection and redundancy. Combining the two is an information delivery infrastructure. These are the prime components of a system which will allow reliable real-time prediction of the environment in a building.

To accomplish this objective, it is important to have access to information about the building and its environment. The shortcoming in understanding what the information implies is transcended by providing sufficient computing and memory capacity to allow reasonable algorithms a chance to work in real time.

A necessary first step is having a model for sensors. The plural is used in this case to indicate that although each generic type of transducer would require a different model, these all could be used by a predictive model to provide a complete picture of the building environment. The physical implementation would behave as a filter on the data. What is needed is an understanding of the measure that the sensor itself takes and effect that the surrounding environment has on the data. Essentially this means understanding entry characteristics of the sensing element, and the response of the transducers themselves, such as the thermal lag of thermocouples, accumulation of dust on optics, and similar instrument functions.

The second part of the problem is being able to modify a predictive model "on the fly" to change the parameters being used as the initial conditions. CFAST has been able to do this since its inception but the process assumes a well defined consistent state, and is not yet fast enough for this application. We have developed a method to start (in the real sense of *ab initio*) the model with (almost) arbitrary values.

The third is information delivery. The majority of the effort is in developing consistent controls and icons which convey the critical information and allow meaningful response. It is generally accepted that suitable graphics convey a great deal more information than simple text messages[1], and are preferred whenever possible.

The overall goal of the project is to estimate the environment in a building and to provide this information to all interested parties in a timely manner. The scope spans environmental monitoring for building owners to tactical decision aids for on-scene commanders. In the middle are alerts and reporting for troubles which develop in buildings from unsafe working conditions to conditions which would be serious should such extreme conditions occur. An example of the latter would be lack of water pressure in the sprinkler system.

The means by which it is provided should provide for multiple transmission media, from low band wireless to broadband wired lines. In the former, alarm prioritizing must occur and in the latter, video can be provided. The amount of information delivered must be commensurate with the delivery capability.

FIRE SERVICE NEEDS

The immediate focus of this project is information delivery for those who respond to emergencies. The fundamental questions that must be asked are 1) what information is needed, 2) when is the information needed, and 3) how can it best be presented to be most useful? The first two are closely linked. Though the fire service information needs differ with time, most relate to the most effective allocation of resources. There are three distinct operation times, dispatch, arrival and deployment and incident management.

Initially, the most important item is to provide some metric for the likelihood that the alarm is genuine – particularly when it derives from a single device. Perhaps a three level metric of low, moderate and high confidence would be enough. The basis for assessing confidence is currently unclear but may involve heuristic algorithms based on sensors keeping history data and reacting to excursions from that history. There is significant concern among the fire service over liability for damage they cause by forced entry when an incident turns out to be false. They would also like information they could use to decide what resources are required. For small fires growing slowly a single unit may be enough. For a fast growing major incident, additional units dispatched early can be of great help in minimizing losses and assuring firefighter safety.

At arrival, the most important information is (1) the location and size of the fire within the building, (2) the location of occupants, (3) how to get to the fire, (4) a safe location to stage, location of standpipes, and other points of interest (hazardous materials, locked areas), and (5) how fast is the fire growing. In addition, there are specific bits of information that are needed to make good choices about resource deployment, including temperature, carbon dioxide and monoxide concentrations, and whether conditions are conducive to full room involvement. The initial decisions about tactics and resource deployment for search and rescue, ventilation and suppression can have a significant impact on the effectiveness of the attack. The more information available upon which to base these decisions is better.

Finally, during the incident, information on (1) location and rate of spread of smoke/gas and of fire, (2) measures of operational effectiveness and safety of crews, and (3) potential benefits or dangers of ventilation.

These ideas extend to the less extreme environment found during normal conditions. Improved information gathering and processing could provide building owners and managers with more cost effective ways to maintain conditions which are acceptable for the occupants. The primary difference is the range of sensor input, and their concomitant calibration.

WHY WE NEED TO DO IT

From residential housing to complex office buildings, active technology is playing a greater and greater role in assuring the well being of occupants. In the residential market, refrigerators which “know” about their contents as well as maintenance needs are the bases for using technology to improve the living conditions of the occupants. In the complex office building, eliminating “sick building” syndrom is a desirable end. All of these advances are fueled by monitoring and sensing of the environment and the desire to provide this information at the appropriate place in a timely manner.

Much of this change is inspired by the availability of information appliances, *e.g.* Tivo television, but there is a large element of making life better through active technology. Sharing information is a natural outcome of the availability of such information. These same ideas apply to managing resources for emergency response personnel. As buildings become more complex, as first responders are stretched to their limits in response capability, and as the expectations of the populace grow, utilizing this type of information will be critical to satisfying the higher expectations.

In the specific case of firefighting, the availability of tactically significant information across a wide range of media facilitates the delivery of this information to the hands where it can be used to best advantage. For example, information on the current location and intensity of the fire delivered wireless to pagers or personal digital assistants (PDAs) could prove lifesaving to truck companies doing ventilation on a roof, or search and rescue teams already inside a building. Detailed information on the fire monitored at dispatch could indicate the need for special units or additional resources before it becomes critical to the "on scene" commanders. Critical information could even be shared with Fire Wardens in high rise buildings undergoing partial phased evacuation.

HOW IT CAN BE DONE

A typical building with a modern alarm system and environmental monitoring will have in excess of 10 000 transducers. This argues for using relatively simplistic filtering techniques to extract significant deviation, and utilizing the readings from a dozen nearby sensors as initial conditions for a predictive model. We have demonstrated that such filtering can be done on a real-time basis with current microprocessor technology[2]. A decision to model the environment can be a relatively frequent occurrence, perhaps one per second per zone in an occupied building. An example of appropriate filtering would be the exceeding a nuisance alarm threshold for smoke detectors. At this point in time, an quick estimate of the heat release rate or carbon monoxide buildup could be extracted as an initial fire signature and posed as the initial conditions for estimating the time to a notable event. As computers become faster (Moore's law[1]), and the science of environmental prediction improves, constraints of computation will lessen and filtering will become less critical.

Layering

The level of detail available is closely related to the resolution of the display devices. This also affects the possible interaction. At the "high" end of technology, one would expect screen resolutions of 1280x1024. Pointing devices such as touch screens or trackballs would complement this technology. At the laptop ("in apparatus") level, the amount of information which can be conveyed becomes constrained. The need to accommodate a wide range of lighting conditions renders fine detail found in graphic display unsuitable. Similarly, the freedom to point is constrained by vibration, distractions and possibly inclement weather which necessitates gloves. Further reductions in information availability and interactivity

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[1] Gordon Moore, a Scientist at Intel, postulated in 1965 that microcomputer processing speeds would continue to double approximately every 18 months.

occur at the personal level, exemplified by beepers and PDAs.

A possible layout would put the basic information, such as size of the fire, time since the first or major alarm, and floor and time to full room involvement, in the the basic text display. At the next level, a basic building diagram would be appropriate. In this view, relative location of compartments and stairwells could be indicated. For the highest resolution, a building schematic would be appropriate. This would indicate the location of the fire and provide some indication of "wayfinding."

The browser paradigm, shown in figure (1), is an example of an implementation. It would include the basic panel information as elements. We would propose three layers, corresponding to three resolutions of devices: layer 1 for palm pilot, beeper, cell phones; layer 2 for basic panels and fire service interaction; and layer 3 for building management, dispatch and similar protected displays. In the example, layer 1 is represented by the "Elevation" information, layer 2 by the "Fire Service Controls," and layer 3 by the building schematic, "Plan view, 3rd Floor."

The touch screen concept for interaction works well, allowing access to objects where additional information is needed, by pointing, using a stylus, pushbutton or touch screen.

Displays and resolution

In order to achieve the goal of "information anywhere, anytime," it is important that display of building conditions be possible across a wide range of technologies, and through a wide range of conduits.

At the "high" end, for example in a building management or security center, one would expect the luxury of high resolution displays with detailed drawings and schematics of building components. In these cases, fragility of the hardware, and ambient lighting conditions can be controlled. However, as one takes even this same display capability to remote locations, prioritizing of signals is necessary.

A similar push comes from lower resolution and ruggedized requirements, such as would be imposed on information centers which might be carried in command vehicles or even on-scene. In these cases, ruggedness must be considered, as must the lack of control of ambient lighting.

In the extreme case of portable systems, i.e., Palm Pilots, beepers and hand-held browsers, it will only be possible to convey a very limited amount of information. Not only must the most important information be display first, there will be only limited capability of interaction so in general the information shown must be relevant to immediate needs, i.e., announcement, location and so on.

One might envision the four levels of display to be in 1) a building management office, 2) a command vehicle, 3) a small building annuciator panel, and 4) a personal information manager. In each case, it is crucial to provide information about the location and size of the *fire* . As the display capability improves, additional layers of information can be accommodated. In the realm of simple annunciator panels, the capability to access other systems, such as the status of the elevators, would be possible. At the highest end, devices such as CCTV would be available.

One of the basic concepts deals with the actual display of information. Graphical displays are recognized as being a compact and efficient way to transfer information from electronic signals to humans, at least if used properly. Although we are not intending for this to be "intuitive," the closer the symbols are to commonly accepted notions of signals that are of interest the more reliable the information transfer to the user.

An initial set of icons was developed from icons used for similar purposes in Japan and from standard symbols for engineering drawings from NFPA170. An example of a set of icons is shown in figure (2). The set and style chosen were dictated by scalability and the desire to allow information to be displayed in monochrome.

Several constraints on the icons have been identified. First, the icons need to represent three states – function not present, function present but not active (no additional information available), and function present and active (more information is available). It is important to be able differentiate functions not present and functions present but not active. Thus, simply having an icon shown or not shown is insufficient.

MODELING THE BUILDING ENVIRONMENT

Over the past decade we have developed a model of fire growth and smoke spread (CFAST[3]). This model is used by specifying the geometry of the building, characteristics of the fire and the venting available for combustion. It is based on solving a set of equations that predict state variables (pressure, temperature and so on) based on the enthalpy and mass flux over small increments of time. The equations are derived from the conservation equations for energy, mass, and momentum, and the ideal gas law. The perspective has been understanding the environment for a specified building. In this context the overall computation time is paramount. However, in order to use the model in a real-time mode, the time required for initialization is the dominant consideration.

If we can presume sufficient information to make a prediction with sufficiently small error bounds, an example of an approach that might be taken would be the following: use transducer data to start a simulation of a building; predict the environment for the next 10 seconds (30 seconds, and so on); gather the actual conditions for this period of time, then compare the curves. If these curves are close (the meaning of which is to be determined) and the imputed heat release rate is indicative of a fire, then an alarm is sounded. There are several other possibilities. One is that the prediction and measurements do not agree. This would indicate that some assumption in the building model is incorrect, or that a transducer is giving an incorrect reading. Another is that the cause of the discrepancy is from some cause other than a fire. Either scenario would trigger an alarm. Another is, of course, that prediction and measurement are in agreement and no untoward event is happening. The latter is, hopefully, the case the majority of the time. An implied acceptance criterion is that there be no false positives (false alarms) or false negatives (missed fires). Actually, any extreme event is a candidate for an alarm, and some thought will need to be given to the various conditions that warrant intervention.

In order to implement such a paradigm, there are three areas in which we need to make improvements: a real-time environmental response model of fire growth and smoke transport, we must be able to make a very quick assessment of how good a comparison there is between a prediction such a model makes, and the actual data which are subsequently measured and we need a way to interpret sensor signals to know what the environment being detected is. There are several component to such an endeavor. The natural evolution, at least for a first try, is to improve upon our current framework of models, verification and sensor modeling.

RELIABILITY, CONFIDENCE, AND A METRIC FOR COMPARISON

An issue which has come up repeatedly is the ability to say how close two curves are, that is whether a value extrapolated from a model of the process agrees with the actual progression of events. In the alarm industry, this is manifested in the Underwriters' Laboratory Test Standards for smoke detector suitability, UL 268. The assumption is that if the time series sensed by smoke detectors were found in habited compartments, this would indicate that a fire existed and is in such a state that there is a high likelihood that dangerous conditions would exist, absent corrective action. This is an implicit statement of reliability, indicating a high level of confidence that this series of fires is indicative of conditions which will become extreme.

The paper by Forney[4] has examined the mathematical robustness of fire models using the CFAST model as an example. While the ability to compare a fire model with experimental data is the thesis of the paper, the issues are the same for comparing real time measurements from multiple sensors, and making an assessment of parameter extraction. Key to both sensitivity analysis and fire model comparisons is the ability to quantify the difference between two time series.

Functional analysis is a generalization of linear algebra, analysis, and geometry. It is a field of study that arose around 1900 from the work of Hilbert and others. Functional analysis is becoming of increasing importance in a number of fields including theoretical physics, economics, and engineering to answer questions on differential equations, numerical methods, approximation theory, and applied mathematical techniques. Functional analysis allows problems to be described in vector notation and defines appropriate operations on these vectors to allow quantitative analysis of the properties of the underlying physical system[5].

A simple sample of experimental data and a model prediction is shown in figure (3). An obvious question arises comparing these two data sets: that is, how close are the actual conditions to those predicted by the model? At present, there is not a sufficient mathematical foundation for how best to quantify the comparison between model predictions and experiments. The necessary and perceived level of agreement for any variable is dependent both upon the typical use of the variable in a given simulation (for instance, the user may be interested in the time it takes to reach a certain temperature in the room), the nature of the experiment (peak temperatures would be of little interest in an experiment which quickly reached steady state), and the context of the comparison in relation to other comparisons being made (a true validation of a model would involve proper statistical treatment of many compared variables). For this simple example, a comparison of peak values would yield a difference of 6.9 or a relative difference, using the usual sum of squares of the difference between the experiment and model, (experiment – model) / experiment, of 0.055.

To obtain an overall comparison of the two curves, we can simply extend this single point comparison to multiple points. Each of these curves can be represented as a multi-dimensional vector, with each point in time defining an additional dimension. Using such a vector notation, a direct extension of the simple comparisons of maximums is the norm of the difference of the vectors of experimental and model data.

These examples are based on single point measurements and predictions. The mathematics can be extended to multiple sensors, multiple compartments and more than one sensible variable (temperature as well as smoke, for example). Then the data fusion implied by the national fire alarm code (NFPA 72[6]), chapter 2, section 3.4.5.1.1 would be rigorously defined. The implication is that more detectors mean higher reliability of the ability to detect and report fires. While the emphasis in existing codes and standards are for single compartments, the ideas can be extended to different types of transducers, placed in non-contiguous compartments and systems.

EMERGING TECHNOLOGIES

Current technology for common (widely used) sensors covers a wide range of measurement capability. The commonly used measures are sensors for

carbon monoxide, temperature (thermocouple) or thermister, opacity (photo detectors), smoke particle counters (ionization current),

We need to extend this to include carbon dioxide, oxygen and water vapor (moisture).

Two of the most promising technologies under development are the micro electro mechanical system (MEMS) (wide use in strain and acceleration applications), and microchemical sensor arrays because of the combinatorial nature of multiple sensors on a chip. These are an outgrowth of the chip" industry and have been under development as a separate entity since the middle 1970's.

Although they are of similar size and manufacture, MEMS are significantly different from electronic chips in that they incorporate miniature mechanical devices such as diaphragms, cantilevers, gears, etc. This industry has matured sufficiently that MEMS accelerometers act as "triggers" for most automotive air bags. MEMS have been used to control air intake rate to provide stoichiometric combustion in cars, as well. They are showing up in a wide variety of products of all levels of expense and sophistication, for example in gauges for checking air pressure in tires, and similar applications[7].

Much of the future development of sensors for these additional gases will be in the arena called “electronic noses.” These are sensors which detect small amounts of polymeric substances. The particular focus today is on detecting bombs and the vapors from organic materials (foods), but the principle should apply to any odor or VOC.

RECENT RESULTS

There are three separate thrusts: display of information, preprocessing to provide more understanding of the sensors data, and tactical tools. For the first, a proposal has been submitted to NFPA as a new appendix for the Fire Alarm Code. This will incorporate the display paradigm discussed earlier. We have demonstrated a prototype with new icon based display and reported on an assessment of techniques and technologies to the Interanational Association of Fire Chiefs. The proposal is for the 2002 Edition of NFPA 72.

CONCLUSION

We are using our knowledge and practical experience in developing predictive models of fire growth and smoke transport to develop the capability for making real time predictions in buildings using existing transducers. There are three research threads involved: developing a computer model which can make predictions in real time; understanding the instrument function in order to use data from building transducers; and finding a metric for the “goodness of fit” between two time varying curves. These avenues are being explored and there is progress in all three areas. This should allow for a prototype of such a tool in the near future. At present we are pursuing these concepts using tools we have developed, but if they are not suitable, or sufficiently robust, then we will develop ones that are.

This will provide a higher level of information to the building industry for monitoring the environment in buildings. The endpoint is to provide appropriate information whenever and where-ever it is needed. This includes early warning of system malfunctions, hazardous environments, in-situ monitoring and prediction for building managers as well as real-time assessment of fire fighter conditions.

The immediate application is to provide environment measurement and prediction for “first responders,” those who have to know very quickly where a fire is and how large it has become and what is likely to occur in the near future.

A possible future work would be to use data reported from Personal Accounting and Safety System (PASS) devices to indicate to scene commanders when a fire fighter is likely to be in conditions in which it is not possible to operate safely, even with appropriate gear.

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