HIGH RELIABILITY SAFETY SYSTEMS FOR EMERGENCY RESPONSE IN THE BUILDT ENVIRONMENT

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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 of the building. The infomation 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 modem 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 infomation 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 must be consistent so that dissimilarities from the perspective of the user don’t cause more confusion than help..

The range of uses for modem transducers covers building management and indoor air quality, as well as 1st responders. While building management information display will be available on high resolution monitors, 1st responders 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.

The National Fire Alarm Code **(NFPA 72-1996)** requires that,

> ***"The primary purpose of fire alarm system annunciation is to enable responding personnel to identify the location of a fire quickly and accurately and to indicate the status of emergency equipment or fire safety functions that might affect the safety of occupants in a fire situation."***

In light of this requirement it **is** surprising that many fire departments report they seldom use the features provided by alarm panels. The root cause appears to stem from inconsistent interfaces, displays and controls. This paper describes an improvement in the type of information that is made available from buildings, describes a means to achieve that end and proposes an interface protocol that meets the diverse range of the needs of the fire service.

Background

As transducers become more commonplace in the built environment, it is desirable to utilize this infomation 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.

Taken together, we are trying to understand what transducers actually tell us about the environment in a building. In order to predict the environment, we must first understand the meaning of the data that is delivered. Then we can use the information in a system which is sufficiently faster than real time that the predicted information is useful.

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.

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 further in time; 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 a warning if not 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 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. Further **we** need a way to interpret sensor signals to know what the environment being detected is.

The second part of the problem is being able to modify the model "on the fly" to change the parameters being used **as** the initial conditions. CFAST has been able to do this since its inception (using the restart function) but the process 1) assumes a well defined consistent state, and **2)** is not 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. Figure (1) shows a two compartment calculation with a constant 100kW fire. The first calculation is a normal predicted time-temperature curve. The second curve is the result of starting the model later, but with the compartments at elevated temperatures which correspond to those predicted from the first calculation. The results do not (and should not) track exactly, but over a long time should come pretty close, as they do. This indicates that we have overcome the hysterisis involved in introducing real data into a model.

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 and simple text messages'.

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.

This information should be available whenever and where ever it is needed, and to whomever will benefit from the knowledge. The stakeholders range from the building owner, to the maintenance service contractor for the fire systems, to the firemen responding to emergencies.

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.

The ability to provide remote monitoring, even at reduced resolution (specificity of information) from the chief's car or mobile command post or even headquarters is of interest. This is because the obvious point of entry to a building is not always the best location from which to direct operations, and the incident commander usually wants to be free to go to where there is the best view of ongoing operations. If the attack is largely exterior that may be outside the building or across the street.

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.

What needs to be done

In order to extract information from both current and the next generation of transducers, it is crucial to calibrate these sensor(s). There are two regimes of sensing: low level which is appropriate to ignition and early fire growth, and high level which occurs during the later phases of a fire, perhaps extending to full room involvement and complete (visual) obscuration.

NIST has developed the fire emulator and detector evaluation (FE/DE) test chamber to calibrate sensors at extremely low signal levels. The FE/DE has been designed to evaluate fire detection technologies such as new sensors, multi-element detectors, and detectors that employ complex algorithms. The FE/DE is a flow tunnel that can reproduce velocity, temperature, smoke, and combustion gas levels to which a detector might be exposed during a fire. It is being upgraded to include low temperature operation and moisture variations. In addition, environmental sources such as dust and humidity can be produced to assess the level of immunity to nuisance alarms.

The FE/DE is useful for calibrating transducers at low levels. These are important in early detection. However, in order to provide information and tactical aids during an entire incident, the calibration of the sensors to more extreme conditions must be accomplished.

There is a cost/benefit tradeoff in asking for such extensions. For example, with current sensors, there is an limit to how well they can be expected to perform without hardening. While use of current technology for hardened sensors is more expensive, as the new technologies come online, this cost disadvantage will disappear. And as the expectation for reliability grows, there will be a greater demand for such transducers.

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 their occupants. In the residential end, 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 providing this information at the appropriate place in a timely manner.

Much of this change is inspired by the availability of information appliances, 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 response personnel 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 providing 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 **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 infomation could even be shared with Fire Wardens in high rise buildings undergoing partial phased evacuation.

How it can be done

The best scheme is to examine the sensor input from a building in the normal (operating) state and look for deviations from this baseline. *An* anomaly at this level should trigger a closer examination. The closer examination would be to initiate a model of the environment using data from the transducers. In algorithmic terms, one would need an initial guess, followed by a prediction, followed by **a** comparison of the ongoing measurements with the output from the model.

Since we are interested in the full range of environmental conditions, sensing from very low levels is needed to extreme conditions is needed. While current sensor implementation, hardness and calibration, is suitable for the low level signals, decision aids for sustained fire fighting will require **a** much broader range of detection.

Filtering:

Generally, it is not feasible to run a predictive model continuously. Figure **(2)** shows the regions of current computational complexity[2]. Each of the islands of “current capability” is tackled by **a** separate algorithm and numerical implementation. *An* intelligent decision therefore will allow one to select the region for examination. **As** computers become faster, Moore’s law’, and the science of environmental prediction improves, these islands overlap more and more and the filtering will become less critical. Until such time, however, the predictive capability is constrained to specific instances of what is needed.

Indeed, most of the time such computing power could better be used for other purposes. The requirement is to filter signals including a means to detect any deviations. This would provide a starting point for a prediction of the environment. Even at this point, long term predictions are not useful. However, the reliability of confirming trouble or alarm signals through modeling is of great **use.** Even if a building cannot be specified completely, a calibration of nominal and expected conditions can be done as an empirical technique, much as a ventilation system is

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[1] Gordon Moore, Scientist at Intel, 1965 observed that microcomputer processing speeds doubled approximately every 18 months.

balance prior to occupancy. Such calibration and spot checking of sensor systems can be done relatively cheaply in terms of computer resources.

A typical building with a modem alarm system and environmental monitoring will have in excess of 10000 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[3]. **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.

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

In all cases, touch screens or similar “point and click” devices are available; toggles and similar switches are not scalable. Scaling both paradigms argues for layers of information. At the highest level of resolution, one can show building graphics and video signals to confirm **alarms.** Pointing at rooms would bring up additional information such as text showing temperature, geometry and other suitable data. At the laptop level, the channel bandwidth will nominally be lower and video confirmation is probably not feasible. At the level of a PDA, only a single text line will be available. The information on alarm size and location can be conveyed with such constraints, but details of the number of devices in alarm is beyond its capability. And interactivity with a stylus and total display size 1"x3" lends itself only to acknowledgment and requests for status information.

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. ***Also,*** status of basic systems would be shown. 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 (3), 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 infomation. Not only must the most important infomation 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 infomation 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. It is assumed that as the displays become simpler, they are further from the source of information, and there is lower bandwidth available to transmit the data. This necessitates prioritizing the information to be transmitted and subsequently shown.

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. For this current project it would seem to be natural to use a set of icons to represent the information that can be delivered, and which will be generally meaningful. 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. The unit of display is the icon.

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 **(4).** 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.

Three states could be shown by the use of color, but color acuity is a general problem so this does not seem to be appropriate. Thus we decided to use the logic that if a function is present but not active the icon would be presented with a diagonal slash as is done with traffic signs. Icons are not present for functions not provided. Active functions are indicated by the icon being displayed. Another approach would be to use a flashing icon for an active function and a steady icon for inactive, but flashing indicators have another meaning on fire alarm panels.

Modeling a hostile building environment

Over the past decade we have developed a model of fire growth and smoke spread (CFAST[4]) which has seen a wide variety of uses. 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. These 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 the first time step 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 perhaps longer); 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.

We started with the framework provided by **CFAST** and have modified it to read a sensor suite as might be delivered from an alarm panel, and compare this curve with **an** actual data set. Figure **(5)** shows **an** example of modifying a pair of time-velocity curves to bring them into the "best" agreement, which would then provide the basis for a restart at the "correct" time. This is only a first step, and provides a match based only on making the curves agree in shape and minimum difference between the curves. In this example, the fire in the prediction was started too soon, that is the fire was thought to have started earlier than the measurement data indicates. The procedure was done for a single sensor, using 120 data points in time. The time for this computation was 0.8 seconds. In order to make this practical, we need to be able to apply the technique to –5000 transducers using **–20** data points (in time), and the total computation time must be under one second. ***So*** the matching algorithm must be improved and the time to do the comparison must be reduced.

The second part of the problem is being able to modify the model "on the fly" to change the parameters being used as the initial conditions. **CFAST** has been able to do this since its inception (using the restart function) but the process 1) assumes a well defined consistent state, and **2)** is not fast enough for this application.

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[5] 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[6].

A simple sample of experimental data and a model prediction is shown in figure (6). An obvious question arises comparing these two data sets: How close are the actual conditions to those predicted by the model? How to best quantify the comparison between model predictions and experiments (generally two time series) is not obvious. 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.

Figure **(7)** shows another simple example of fictitious experimental data compared with three model predictions. Model 1 is simply the experimental data multiplied by 0.9. Model **2** has the same peak value as model 1, but with the peak shifted *-25* **s.** Model **3** has the same peak as Model 1 and Model **2,** but with a 20 **s** plateau centered around the peak of the experimental data. Weighted area comparisons would show that these three models are essential identical. Clearly this comparison fails to capture the differences. If such an algorithm were used, there would not be a high degree of confidence that an alarm would be justified.

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, 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 sensors covers quite a wide range of measurement capability. The commonly-used measures are sensors for

carbon monoxide sensors,
temperature (thermocouple) or thermister,
opacity (photo detectors),
smoke particle counters (ionization current),
beam (laser),
carbon dioxide sensors,
oxygen concentration,
and water vapor (moisture).

These are the types of measurements needed to understand the environment from normal operating conditions to the extreme environments found in hazardous situations. If the predictive model were to be extended to the baseline environment, volatile organics (VOCs), should be monitored as well.

One of the most promising technologies under development is the micro electro mechanical system **(MEMS)** because of the wide use in strain and acceleration applications. They 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 they 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].

Water vapor is listed above but is not generally available in commercial applications. Moisture in constructed facilities can cause a general degradation of the infrastructure. However, the most common type of moisture sensors are used primarily by the lumber processing and furniture industries to deduce the moisture content from electrical impedance measurements and empirical correlations, primarily for wood based products. Water vapor detection would be a very useful adjunct to detecting and monitoring fire initiation and growth because it is one of the primary products of combustion.

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 an 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 International Association of Fire Chiefs. The proposal is for the 2002 Edition of **'' P A72.** To implement the second part, we have developed a consortium with NEMA to acquire in-situ data from current buildings. The first example will be the NIST site, Building **224.** This information will be displayed on with our proposed panel and will be available through web browsers, either on site or remotely.

Tasks needed to achieve the goal of useful information delivery

The basic tasks to develop such **an** advanced information delivery systems are

1) Extract alarm signals from current sensing technology, based on specified criteria. This is similar to current detection algorithms **as** implemented in fire alarm systems, but uses filtering at the panel rather than at the detector. It needs to be done this way to ascertain patterns.

2) Extract growth curve from T, OD, and other types of sensors. From calculational studies, this will also determine what signals are needed to provide the highest reliability. This would allow a better plume model to extract the time of initiation and a better guess for the heat release rate or growth **of** toxicants.

3) Develop a panel display and define the appropriate level of interactivity based on the resolution of display and intended purpose.

4) Develop an adaptive model which will start based on estimate of HRR and change based on extracting δt from comparison **of** $T_p(t)$, $T_e(t)$

5) Define a figure of merit for one or more detectors, the number of compartments to be protected and information available on construction and thermophysical properties including the sensitivity to input, the uncertainty of plume impingement and heat release rate.

6) Validate adaptive model using NIST fire tests up to full room involvement.

7) Full scale building demonstration of real time prediction (tactical aid) and data delivery.

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.

An possible future development would be to use data reported from **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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