USING SENSOR DATA TO PREDICT THE ENVIRONMENT IN A BUILDING

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Introduction: 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 they were intended to. The former is commonly referred to as smart sensing, while the latter deals with fault detection and the needed redundancy. These are the prime components of a system which will allow reliable real-time prediction of the environment in a building.

In order to accomplish these tasks, it is important to have access to information about the building and its environment. This requires a common protocol to provide the data from a multitude of sensors and sufficient computing capacity to utilize the data to provide some indication of future events. The former problem is exacerbated by the wide variety of sensors and the confounding problem that sensors have traditionally been used to signal a specific event. The BACnet protocol is designed to allow a wide variety of manufactures of sensors such as heat and smoke detectors to collaborate with traditional building transducers such as velocity probes and door-closure indicators. The protocol has the virtue that many types of events, including analog signals, bimodel information, reset states and many others, exist or can be defined, allowing a great flexibility in communication while enforcing deterministic behavior on a potentially chaotic system. The shortcoming in understanding what the plethora of information means is transcended by providing sufficient computing and memory capacity to allow reasonable algorithms a chance to work.

Taken together, we are trying to understand what transducer actually tell us about the environment in a building. The technical perspective is the most fascinating. 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 could be understood by a predictive model in the same sense as is embodied in the concept of a love-seat versus a sofa or chair. 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 chamber, and the response of the transducers themselves, such as thermocouples, optical detectors and infrared detectors, photon scattering characteristics and so on.

Theoretical approach: Over the past decade we have developed a model of fire growth and smoke spread (CFAST[1]) 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. CFAST 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.

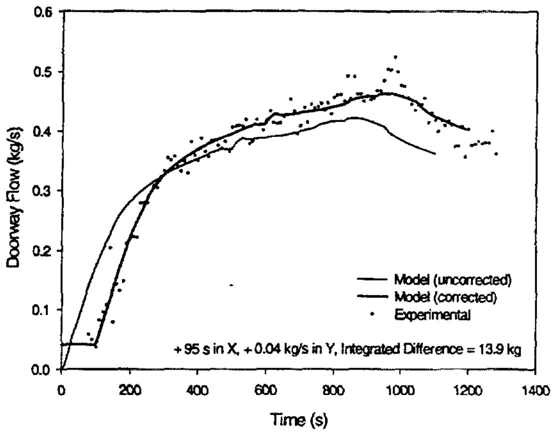
If we can presume sufficient information to make a prediction with sufficiently small error bounds, an example of an approach that might be taken would be the following: use transducer data to start a simulation of a building; predict the environment for the next 10 seconds (30 seconds, ...); gather the actual conditions for this period of time; 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 negatives (false alarms) or false positives (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.

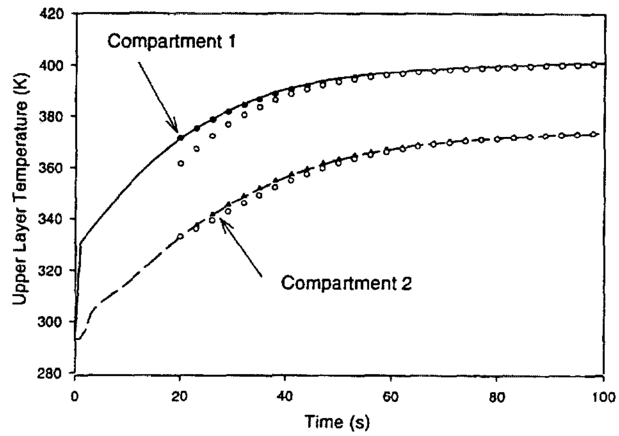
In order to implement such a paradigm, there are three areas in which we need to make improvements: a real-time environmental response model of fire growth and smoke transport, we must be able to make a very quick assessment of how good a comparison there is between a prediction such a model makes, and the actual data which is 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 1 shows an example of modifying a pair of time-velocity curves to bring them into the "best" agreement. This is only a first step, and provides a match based only on the 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. We have developed a method to start (in the real sense of *ab initio*) the model with (almost) arbitrary values. Using the previous example, this means starting with a non-zero velocity. Figure 2 shows a two compartment calculation with a constant 100 kW fire. The first calculation (lines) is a normal time-temperature curve. The discrete points are the result of stating the compartments with elevated temperatures which correspond to those prediction 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 leg of the knowledge triangle will be the understanding of actual sensors, so that we might put an appropriate filter between the raw data and what is to go into the model. We are beginning as is discussed in the paper by Bukowski and Averill[2], to develop an *ab initio* model of transducers. Part of this effort will be to





survey the current state of the art, and test these detectors in a suitable facility. This research will provide the instrument function which will relate a transducer signal to the actual sensible variable being measured: a millivolt reading from the sensor head will correspond to a specific temperature being measured.

Conclusion: We are using our knowledge and practical experience in computer 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 thread 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.

1. A Technical Reference for CFAST: Engineering Tools for Estimating Fire Growth and Smoke Transport, Walter W. Jones, Richard. D. Peacock, Glenn P. Forney, and Paul A. Reneke, NIST Technical Note (in review).

2. Methods for Prediction Smoke Detector Activation, Proceedings of the NFPRF Conference on Suppression and Detection, R.W. Bukowski and J. Averill, Orlando, Florida (1998).