Multicriteria Detection: Leveraging Building Control and Comfort Sensors for Fire State Determination

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Abstract

The ultimate goal of placing fire detection systems in buildings and structures is to allow for the rapid detection of fire and accurate, faster than real time, prediction of ensuing fire behaviour so that relevant information can be delivered to the appropriate stakeholders. In the near-term, development of detection systems with decreased detection time, better discrimination against nuisance and false alarms, and real-time monitoring of the fire state is a critical interim step. Buildings are increasingly incorporating a greater quantity of sensors for a variety of uses, focused primarily on optimizing building efficiency, occupant comfort, and intrusion detection. These sensors are typically installed at a much higher density than standard fire sensors and the density is increasing as greater efficiencies in cost and quicker return on investment can be achieved. While currently used primarily for building management purposes, the application of these, or similar types of sensors, for rapid fire detection, real-time fire monitoring, and potentially fire forecasting offers great potential. This paper summarizes the results of nearly 100 tests aimed at quantifying what standard building environmental sensors "see" and whether a fire can reliably be detected based on the sensor signals. The experimental results indicate that building sensors can be leveraged for fire state determination.

Keywords: multi-criteria, detection, fire state determination, multivariate analysis, building comfort sensor

Introduction

Even with significant advancements in fire detection and protection, as well as changes in human behaviour, specifically a drastic reduction in smoking, fire remains a costly event worldwide. The total cost of fire in the U.S. has been estimated to be as high as \$350 billion or 2.5 % of the U.S. gross domestic product (including monetary equivalents for deaths and injuries). Fires are pervasive, yet rare and uncertain events;

the probability of a fire occurring in any given structure during its lifetime is relatively low. The unforeseeable nature of fire and its ability for rapid growth requires timely sensing and the transfer of useful information for effective mitigation (prevention or response). The greater the delay in sensing a fire, the larger the potential loss. In order to advance the state of fire detection and response, typical fire signatures, as discerned by a wide range of sensor typologies, must be better characterized and understood.

Analogous to the human detection process, any effective fire detection system must be able to detect a change in a monitored condition, decipher its meaning, ensure that the interpretation is correct and that it indicates a fire, and then finally to provide notice to the interested parties in a sufficient amount of time that a safe egress can be effected. This is a non-trivial task to which a large portion of the field of fire research has been dedicated [1-7].

Limitations in the current state of the art in fire sensing technology, coupled with a general lack of information on useful sensor signals that might arise from a developing fire environment, both in the near and far field, provide ample opportunity to advance science in the areas of fire characterization, sensor signatures, detection algorithms, and multi-criteria sensing systems, in particular as it relates to "non-standard" fire sensors.

Thus, the present day challenges with fire detection may be summed into several distinct areas: a lack of understanding and definition of the characteristics of the fire environment; how these characteristics can be positively identified against any background signals in order to minimize the current high false/nuisance alarm rate; what sensors provide useful information at what stages of a fire; lack of fire sensor density; and what sensor combination and density can provide the highest reliability of detection.

Objective and Methodology

An exploratory study was conducted to examine the potential for leveraging building environmental and comfort sensors for rapid fire detection and fire growth determination, or more generally fire-state determination. Temperature, relative humidity, light, pressure, and a number of gas species were measured during the testing. The research conducted to date examined small, medium, and large-scale testing of fuels and sensor response including nuisance source identification and the potential for fire-state determination. The experiments were designed to systematically evaluate sensor performance for a range of fire locations and sizes [8].

The initial testing leveraged off-the-shelf sensors while the complex living room fires expanded the sensor suite to include a custom sensor block which incorporated a series of inexpensive electrochemical gas sensors to monitor the environmental conditions in the fire room [9]. These were introduced as an increasing number of commercial, residential, and other environments and consumer devices are incorporating air quality sensors for comfort and health monitoring, though they have yet to be leveraged for fire state determination purposes.

The fire tests were conducted at the University of Waterloo Live Fire Research Facility "Burn House", a two-story steel structure designed to accommodate large scale fire experiments. The structure is fire hardened with a 120 m^2 floor area per floor and a total structure volume of approximately 290 m^3. For the small scale experiments a room nominally 3.3 m x 3.3 m x 2.5 m tall was utilized with a standard size open door, while the large scale testing involved the entire burn structure, Fig. 1.

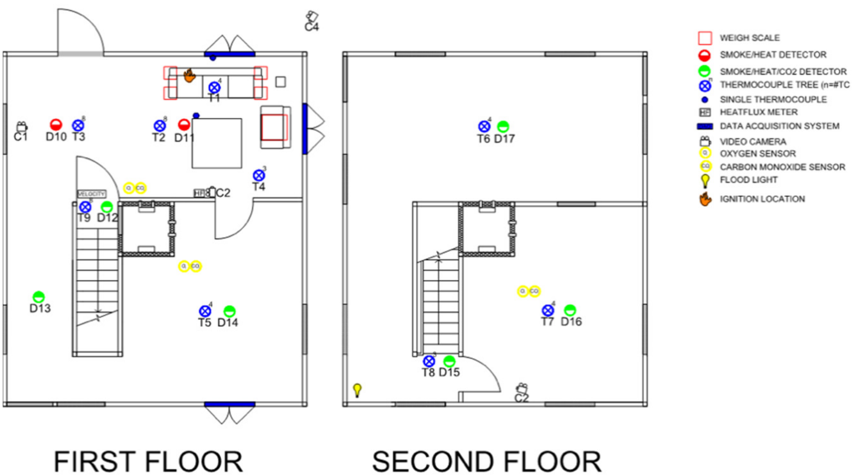


Fig. 1. Floor plan of the large scale test facility.

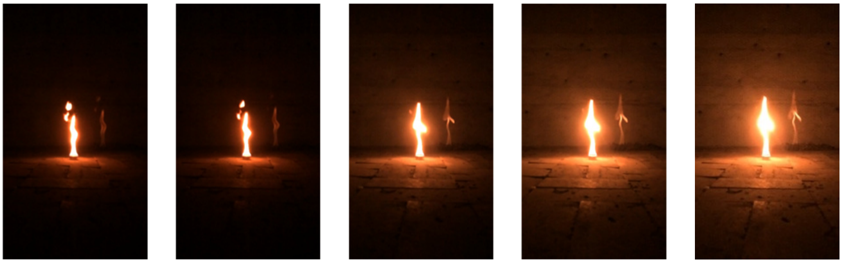
The small scale testing utilized heptane and ethanol pool fires of various sizes to ensure a consistently repeatable fire source. The pool diameters corresponded to heat release rates ranging from approximately 3 kW to 100 kW (32 mm - 200 mm diameter pools) with sufficient fuel depth to achieve a steady state burning period.

Additionally, a range of nuisance sources were included in the test series to determine the sensor response to typical potential nuisance sources. While traditional nuisance sources include items that may create particulates (i.e. dust, steam, or others) or other products that might produce a false alarm, the range of potential nuisance sources expands when humidity, light, pressure, and other variables are introduced. As such the traditional nuisance sources were expanded to include constant and flickering light sources, heat sources, steam sources, smouldering newsprint, and other potential sources of stray signals that might be encountered in an early fire situation.

Nine large scale tests were conducted with identical fuel arrangements, though the specific fuel composition varied. For this study a representative sample of data is provided covering the tests which were analysed. The primary fuel load consisted of an upholstered sofa. While additional fuel load was present in the form of an upholstered chair and coffee tables, the fire did not spread to these items and thus they are not addressed further in this study.

Results

The experimental program indicated that the range of sensors tested were capable of detecting and discerning fire and non-fire scenarios and also providing additional information on the fire state rather than simply the binary fire-non/fire signal provided by most standard detectors. The light intensity standard responded in the shortest timeframe and also reflected the dynamic nature of the flame. Even for a fixed pool fire the flame flickering was observable in the measured light intensity, Fig. 2. In the "simple" fuel experiments the rate of change of temperature, humidity, and light all allowed for differentiation between fire and non-fire scenarios, Fig. 3. In addition, when the signals for each parameter are examined in conjunction with each other, threshold values and logic can be applied to further reduce false alarms.



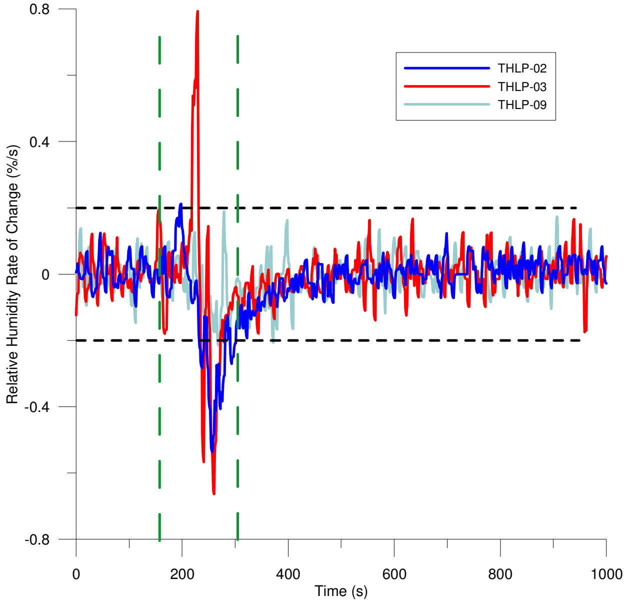
(a) (b) (c) (d) (e)

Fig. 2. Variation in light intensity from flame flickering at 0.25 s increments.

Similar to the trends observed in the small-scale testing, the large scale testing yielded conditions with changes in room characteristics that could be observed by the sensors and thereby allowed for the identification of a fire. The sensors observed the fire state at different times in the experiments, Fig. 4. Typically, the light sensor was the first to notice an observable change in signal followed by the relative humidity sensor, gas sensors for O_2 and CO, and finally the temperature sensor. The pressure sensor did not observe any noticeable repeatable changes during the tests.

Equally significant, the nuisance sources tested resulted in different sensor signals being observed, thus it appears possible to decipher a fire vs. non-fire signature using the specified sensors as well as to ascertain information on the fire state.

(a)



(b)

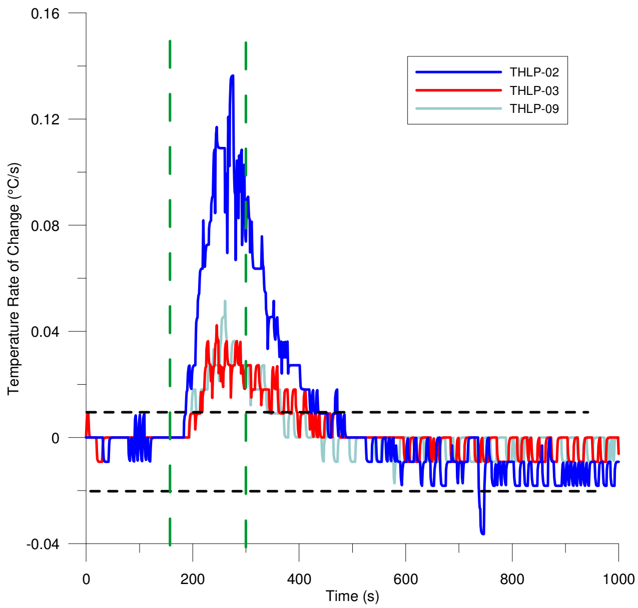


Fig. 3. Rate of change observed in Relative Humidity (a) and Temperature (b).

It was observed that as the HRR increased the observed light intensity and heat flux trended with the HRR. The products of combustion similarly increased while the O_2 was observed to decrease. The light intensity from the building sensor showed the quickest response to a change in HRR. The observed light intensity declines as the sensor is obscured, consistent with the smoke layer heights observed in the testing.

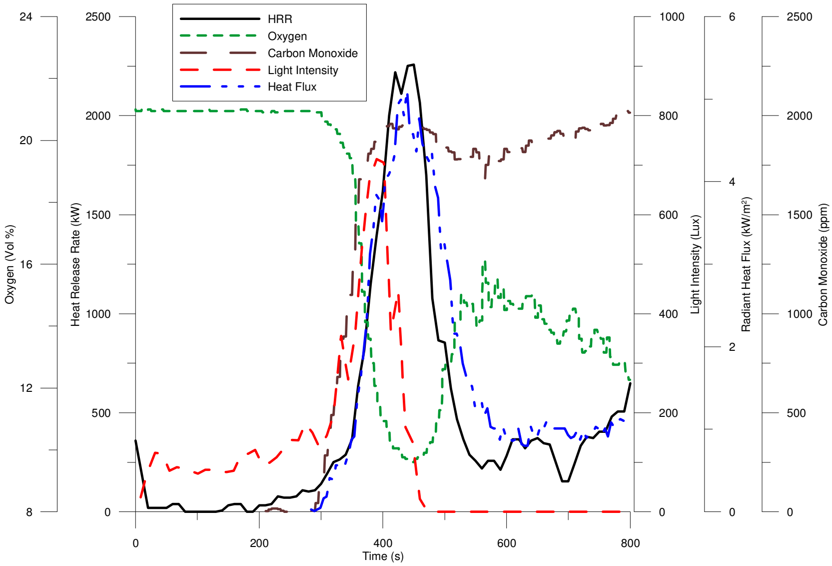


Fig. 4. Measured heat release rate, light intensity, heat flux, O_2 and CO concentration during full scale test.

Summary and Conclusion

This study showed the promise posed by existing and future sensors to be leveraged for fire detection and monitoring purposes. The commercial sensor packages showed that they were capable of detecting fires as small as 5 kW and reliably could differentiate fires as small as 15 kW. Additionally, nuisance sources and smouldering sources could be distinguished from flaming fire scenarios.

With sensor systems being integrated into new and existing structures, the availability of sensors which may be leveraged for fire state determination will only increase in time. The initial success of this preliminary test series indicates that they show promise as an additional information source for fire detection purposes.

Future Work

The present work should be expanded to further refine the sensor selection and should determine the minimum sensor set required for successful fire state determination. Additional testing of smouldering sources and other fire situations should be conducted. Furthermore, work should be performed to determine a suite of algorithms to support successful detection from the device.

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