

Discriminant Analysis for Home Fire Alarms

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Multisensor technology has long been recognized as a valid approach to improve fire detection. Though commercial systems have incorporated multiple sensors through control panels, multisensor integration for home fire alarms has only become practical with the availability of inexpensive microcontrollers. The challenge then becomes the development of recognition algorithms that improve the performance for fire detection and nuisance rejection. Simple thresholds (logical “OR”) for individual alarms can be replaced with rules-based decisions (logical “ORs,” “ANDs,” and “IF” comparisons). However, the complexity of fire-recognition logic can increase geometrically with additional sensor channels. An approach is needed that can distinguish conditions requiring alarm, preferably even sooner than present smoke alarms, while reducing or eliminating false or nuisance alarms.

Discriminant analysis is a mathematical technique of supervised pattern recognition that can be used for optimal classification of conditions based upon any number of sensor channels. The basis for pattern recognition is supplied by actual field data of smoke, temperature, and combustion products for stimulating prescribed sets of sensors to be incorporated in a system. Principal component analysis (PCA) has been used to develop fire-detection algorithms that have shown improved performance for fire sensitivity and nuisance immunity.¹ Unlike PCA which does not take into account the differences between classes of events, the goal of linear discriminant analysis (LDA) is to separate classes of events. LDA classifies each observation of all sensor channels, including their rates of change, using a simple linear transformation to obtain the discriminant coordinates, i.e., the observation’s position in discriminant space. The closeness of the discriminant coordinates to each of the prescribed classes or groups (e.g., “normal,” “nuisance,” “fire,” “toxic,” etc.) can then be easily calculated and sorted – even by inexpensive microcontrollers.

In this study, training data for LDA transformations were supplied by Underwriters Laboratory, Inc. (UL)² and National Institute of Standards and Technology (NIST)³ and taken from historical tests of fire and nuisance situations in home dwellings. Various

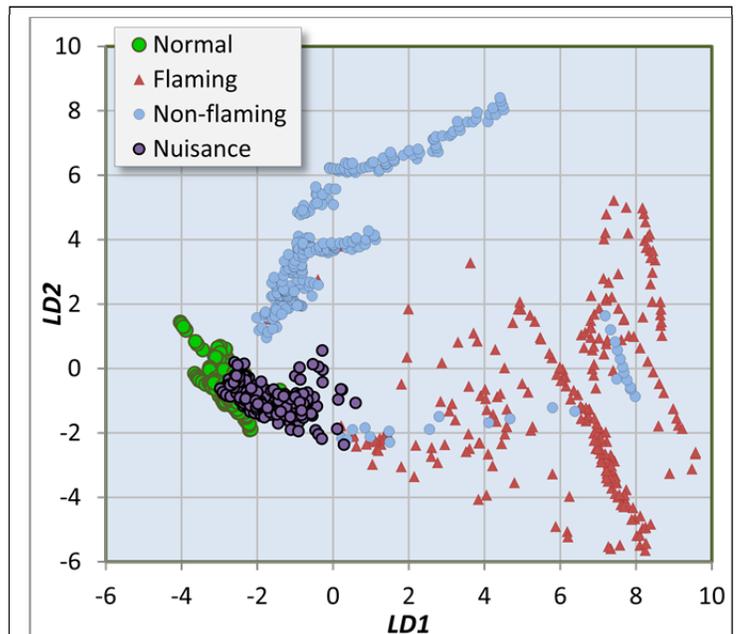


Figure 1. Illustration of LDA transform of UL fire and NIST nuisance data into discriminant coordinates, $LD1$ and $LD2$. Flaming and non-flaming fire conditions are generally separated from normal and nuisance conditions.

combinations and subsets of sensor signals, including baseline corrected sensor outputs and their rates of change, were analyzed and transformed into discriminant coordinates. An example with the first two discriminant coordinates is shown in Figure 1, which illustrates reasonably good segregation between fire and non-alarming situations. For each set of sensors chosen, LDA of the training data yields a set of linear transformation coefficients that are permanently stored in the microcontroller. Using these, the microcontroller readily transforms real-time sensor data into discriminant coordinates to determine when an alarm is warranted.

Prototype

A prototype battery-powered home fire alarm has been fabricated and incorporates multiple sensors, a microcontroller, battery power, and a speaker for alerting (Figure 2). The sensors in this model include ion and photo aerosol detectors, a thermistor, and a carbon-monoxide cell. The microcontroller can be programmed to select all or part of the sensor suite and to alarm according to conventional rules-based or advanced discriminant algorithms. In the latter case, the microcontroller computes the rates-of-change for each of the sensors and combines these data with baseline-corrected sensor data to calculate the discriminant coordinates and to determine the need for alarm.

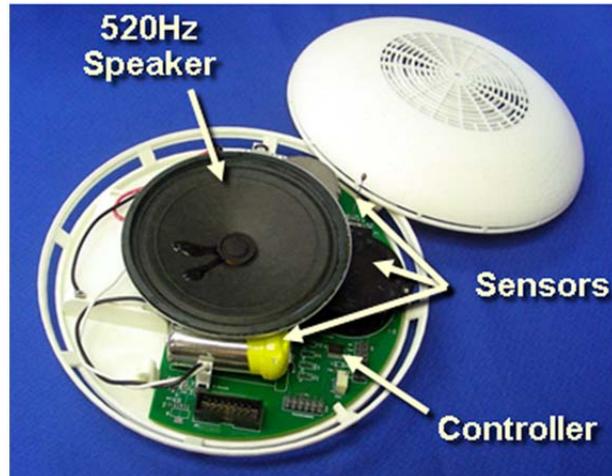


Figure 2. Prototype multisensor home fire alarm. The enclosure is 6.5" in diameter and 1.7" tall.

Besides the possibilities for improved fire recognition, the prototype demonstrates additional benefits for protecting occupants. At low concentrations, the carbon monoxide sensor is used to enhance discrimination for fire detection but also doubles as a toxic sensor for dangers of carbon monoxide at 70ppm or more according to UL2034. The most noticeable component under the top cover is the 3.6-inch-diameter speaker, required to generate a 520Hz square-wave alarm that has been shown to be much more effective for awakening people than the standard 3100Hz alarm.⁴ It is hoped that manufacturers will continue to improve home fire alarms by incorporating some of these inexpensive sensors and features into their new products.

Research sponsored by the U.S. Fire Administration (USFA) and the Consumer Product Safety Commission (CPSC).

¹ Cestari, L.A., Worrell, C., Milke, J.A. 2005. "Advanced fire detection algorithms using data from the home smoke detector project." *Fire Safety Journal* **40**:1-28.

² Fabian, T.Z. and Gandhi, P.D. 2007. "Smoke Characterization Project." Northbrook, IL: Underwriters Laboratory, Inc.

³ Bukowski, R.W. et al. "Performance of Home Smoke Alarms." National Institute of Standards and Technology Technical Note 1455-1, February 2008 Revision.

⁴ Thomas, I, and Bruck, D. 2010. "Awakening of Sleeping People: A Decade of Research." *Fire Technology* **46**:743-761. Note: InnovAlarm Corp. has produced battery powered alarms meeting the UL217 standard of 85dBA at 10 feet (David Albert, private communication).