# Improved Home Smoke Alarms[1] – Achievable, Affordable, & Demonstrated

*U.S. Fire Administration and the Consumer Product Safety Commission, with Oak Ridge National Laboratory and Underwriters Laboratories*

Recognizing the documented longstanding performance and reliability concerns related to home smoke alarms, in early 2009, the U.S. Fire Administration (USFA) and the Consumer Product Safety Commission (CPSC) embarked on a project intended to improve home smoke alarms. The principal goals of the project were to:

1. Provide an earlier warning to occupants.
2. Improve awakening performance.
3. Improve resistance to nuisance sources – to reduce or eliminate nuisance alarms.

Research partners with expertise in sensor technology and integration in harsh environments were recruited to work on the project. An interdisciplinary team drawing experts from the Measurement Science & Systems Engineering, the Chemical Sciences, and the Computer Science & Mathematics Divisions of the Oak Ridge National Laboratory collaborated successfully to develop and demonstrate a smoke alarm that fulfilled the project goals.

An earlier publication, "*Home Smoke Alarms – A Technology Roadmap*," provided an overview of current and future technologies that could prove helpful in designing improved residential smoke alarms.[2] Several new sensor types were identified that could provide improved fire detection, but their potential use is presently limited by cost and availability. That report also described an advanced mathematical technique that has been successfully used in chemical detection in military and commercial safety systems. The report proposed the use of this Linear Discriminate Analysis (LDA) in home smoke alarms to improve decision making ability of the alarms.

It is commonly accepted that better decisions can be made if more complete relevant information is provided to the decision maker(s). The same is true with smoke detection. Multi-sensor smoke detectors have been available in the commercial marketplace for some time. Their extension into the residential, battery-powered market has been constrained by cost, processor limitations, and power limitations. These limitations have been minimized or eliminated by advances in semiconductor

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[1] This paper is extracted from: Warmack, R.J., Dennis Wolf, and Shane Frank, "Smart Smoke Alarm – Using Linear Discriminant Analysis." Publication pending. Report will be available on the U.S. Fire Administration website.
[2] Warmack, R.J *et al.* (2012) "Home Smoke Alarms – A Technology Roadmap." http://www.cpsc.gov//PageFiles/93425/homesmokealarm.pdf

sciences and related fields over the last 15 years or so. These advances can now be economically used in home smoke alarms.

A single sensor can provide a single data point; if combined with a clock and memory storage component, a time-dependent rate-of-change aspect can provide a second data point, improving decision making. This approach has been used in at least one commercial product to date, and has been shown to reduce nuisance alarms.[3] Adding additional sensors and, more importantly, an advanced classification technique such as LDA to process the signals from the sensors has been shown to greatly improve reliability of chemical detection systems. (LDA has not previously been used in fire detection to our knowledge.)

In this final phase of the USFA / CPSC funded project, a series of prototype smoke alarms were fabricated at Oak Ridge National Laboratories. These prototype smoke alarms were constructed using multiple sensors integrated by an inexpensive microcontroller that costs under $1 in volume. An electronic circuit was designed to allow up to four sensors to be populated and used for discrimination, including ionization, photoelectric, carbon monoxide (CO), and temperature sensors. A low-frequency speaker was added for improved alerting, consistent with findings that a 520-Hz square-wave auditory signal is much more effective than the currently used 3100-Hz T-3 alarm signal.[4] Figure 1 shows an assembled prototype with components mounted on a custom printed-circuit board and enclosed in a custom shell that includes a 3-AA battery chamber.


Figure 1. Assembled prototype incorporating multiple sensors, a microcontroller, power (3 AA batteries), and a speaker for 520Hz alerting. The enclosure is 6.5" in diameter and 1.7" tall.

The prototype smoke alarms were tested at Underwriters Laboratories following the protocols described in UL-217. Three suites of tests were used:

- The standard suite of UL-217 fire tests
- UL's proposed flaming and smoldering polyurethane foam tests, and
- UL's nuisance alarm tests.

The time to alarm for each Smart Smoke Alarm and for each fire test is given in Table 1. Each of the units responded well within the prescribed 4 minutes for the flaming tests. All units alarmed at beam-

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[3] Feng, Jewell T., and James A. Milke (2012). "Analysis of the Response of Smoke Detectors to Smoldering Fires and Nuisance Sources." Deportment of Fire Protection Engineering, University of Maryland, College Park, MD. January 2012.

[4] Thomas, I. and D. Bruck. "Awakening of Sleeping People: A Decade of Research." *Fire Technology* **46**(3): 743–61.

obscurance readings between 0.5%/ft to 2%/ft, well below the required 10%/ft limit, except for Unit 11, which alarmed at about 10%/ft. The cause for the late alarm in this unit is unknown at present.

A series of nuisance tests developed by UL was also performed. During the nuisance tests, none of the prototype units alarmed until dangerous conditions or ignition were reached, at which point both types of Smart Smoke Alarms triggered. The time to alarm for each unit and for each test is given in Table 2.

In Tests 16 and 19, a small or large skillet with approximately 3/8-inch-deep canola oil was located on an electric range that was set on high. The small skillet reached ignition temperature so quickly that the alarms sounded within seconds after ignition. In the case of the large skillet, the alarms sounded typically when the oil had reached about 310-320°C, above ordinary cooking temperatures but below the ignition point.

In Test 20, eight slices of toast were repeatedly toasted until heavily charred, accompanied by significant smoke emission and CO evolution, at which point the alarms properly sounded to indicate dangerous conditions. In Test 21, a pound of bacon strips covered the large skillet and was taken to ignition. The alarms typically sounded at about 250°C, which is above ordinary cooking temperatures but below the ignition point.

The results from the UL tests of these prototype units are encouraging. More extensive testing, especially with a broader range of nuisance sources and in side-by-side tests with conventional smoke alarms, would be helpful for performance comparison with existing technology. Including a larger number of units in the tests would provide better statistical data on response predictability using manufactured sensors. Nevertheless, the UL tests demonstrated very consistent responses for at least 9 out of 10 units tested.

The LDA technology is applicable for any combination of sensors in residential and commercial smoke alarms for which data has been recorded during anticipated situations, including ambient, nuisance or alarming conditions. Additional field data can be added to bolster the appropriate responsivity to conditions found in specific consumer environments. Data recorded during the UL tests of the prototypes can also be used, with appropriate calibration, to simulate how a particular set of aerosol, temperature and CO sensors would act in UL tests.

In the long term, new sensors may be developed that could be advantageously employed in addition to conventional ionization, photoelectric, CO and temperature sensors. Variants of existing sensors could be incorporated to improve performance. For example, a photoelectric sensor using different or multiple wavelengths and scattering angles could extend its sensitivity or provide additional information about smoke (or nuisance) aerosols. The LDA approach provides a straightforward means for incorporating these sensors in an optimal algorithm.

Table 1. Alarm times and averages for each unit in minutes after the start of each fire test. Units 5 and 10 were located on the side wall; units 9 and 15 were located on the opposing side wall; and the remaining five units were located on the ceiling.

| **Test number:** | **9** | **10** | **11** | **12** | **13** | **14** | **15** |
|---|---|---|---|---|---|---|---|
| **Unit** | **Flaming Liquid** | **Flaming Wood** | **Flaming Paper** | **Smoldering Wood** | **Flaming Foam** | **Smoldering Foam** | **Smoldering Wood** |
| 5 (Ion, PE, CO, T) | 0.57 | 2.53 | 1.53 | 46.00 | 1.67 | 35.10 | 30.32 |
| 7 (Ion, PE, CO, T) | 0.77 | 2.82 | 1.98 | 39.57 | 2.33 | 32.42 | 38.27 |
| 8 (Ion, PE, CO, T) | 0.78 | 2.98 | 1.93 | 38.05 | 2.52 | 33.45 | 41.10 |
| 9 (Ion, PE, CO, T) | 1.27 | 3.45 | 1.95 | 35.83 | 2.62 | 31.70 | 35.45 |
| 10 (PE, CO, T) | 1.60 | 3.03 | 1.87 | 39.68 | 3.17 | 30.32 | 43.35 |
| 11 (PE, CO, T) | 2.37 | 3.90 | 1.88 | 48.05 | 3.28 | 34.37 | 56.10 |
| 13 (PE, CO, T) | 2.42 | 3.23 | 1.95 | 41.92 | 3.20 | 32.45 | 41.30 |
| 14 (PE, CO, T) | 2.72 | 2.88 | 1.90 | 41.27 | 3.28 | 29.67 | 44.28 |
| 15 (PE, CO, T) | 1.52 | 3.27 | 1.83 | 29.75 | 3.07 | 32.80 | 30.00 |
| Units 5-9 avg (with ion) | 0.85 | 2.95 | 1.85 | 39.86 | 2.28 | 33.17 | 36.28 |
| Units 10-15 avg (w/o ion) | 2.12 | 3.26 | 1.89 | 40.13 | 3.20 | 31.92 | 43.01 |
| Overall Average | 1.56 | 3.12 | 1.87 | 40.01 | 2.79 | 32.47 | 40.02 |
| Standard deviation | 51% | 13% | 7% | 13% | 20% | 5% | 20% |

Table 2. Alarm times for each unit in minutes after the start of each “nuisance” test. Units 5 and 10 were located on the side wall; units 9 and 15 were located on the opposing side wall; and the remaining five units were located on the ceiling.

| **Test number:** | **16** | **17** | **18** | **19** | **20** | **21** |
|---|---|---|---|---|---|---|
| **Test:** | **Oil (small skillet)** | **Steam** | **Steam** | **Oil (large skillet)** | **Toast** | **Bacon** |
| **Time to ignition:** | 7.87 | - | - | 25.83 | - | 22.48 |
| 5 (Ion, PE, CO, T) | 7.95 | No alarm | No alarm | 14.70 | 7.35 | 11.78 |
| 7 (Ion, PE, CO, T) | 8.28 | No alarm | No alarm | 15.38 | 8.52 | 12.30 |
| 8 (Ion, PE, CO, T) | 8.33 | No alarm | No alarm | 15.48 | 8.67 | 12.25 |
| 9 (Ion, PE, CO, T) | 8.32 | No alarm | No alarm | 15.18 | 8.68 | 12.12 |
| 10 (PE, CO, T) | 8.05 | No alarm | No alarm | 14.28 | 7.53 | 11.93 |
| 12 (PE, CO, T) | 8.30 | No alarm | No alarm | 20.57 | 8.53 | 14.15 |
| 13 (PE, CO, T) | 8.32 | No alarm | No alarm | 15.07 | 8.47 | 12.10 |
| 14 (PE, CO, T) | 8.47 | No alarm | No alarm | 15.80 | 8.45 | 11.83 |
| 15 (PE, CO, T) | 8.02 | No alarm | No alarm | 14.13 | 8.55 | 11.23 |
| Units 5-9 avg (with ion) | 8.22 | - | - | 15.19 | 8.30 | 12.11 |
| Units 10-15 avg (w/o ion) | 8.23 | - | - | 15.97 | 8.31 | 12.25 |
| Overall Average | 8.23 | - | - | 15.62 | 8.31 | 12.19 |
| Standard deviation | 2% | - | - | 12% | 6% | 7% |