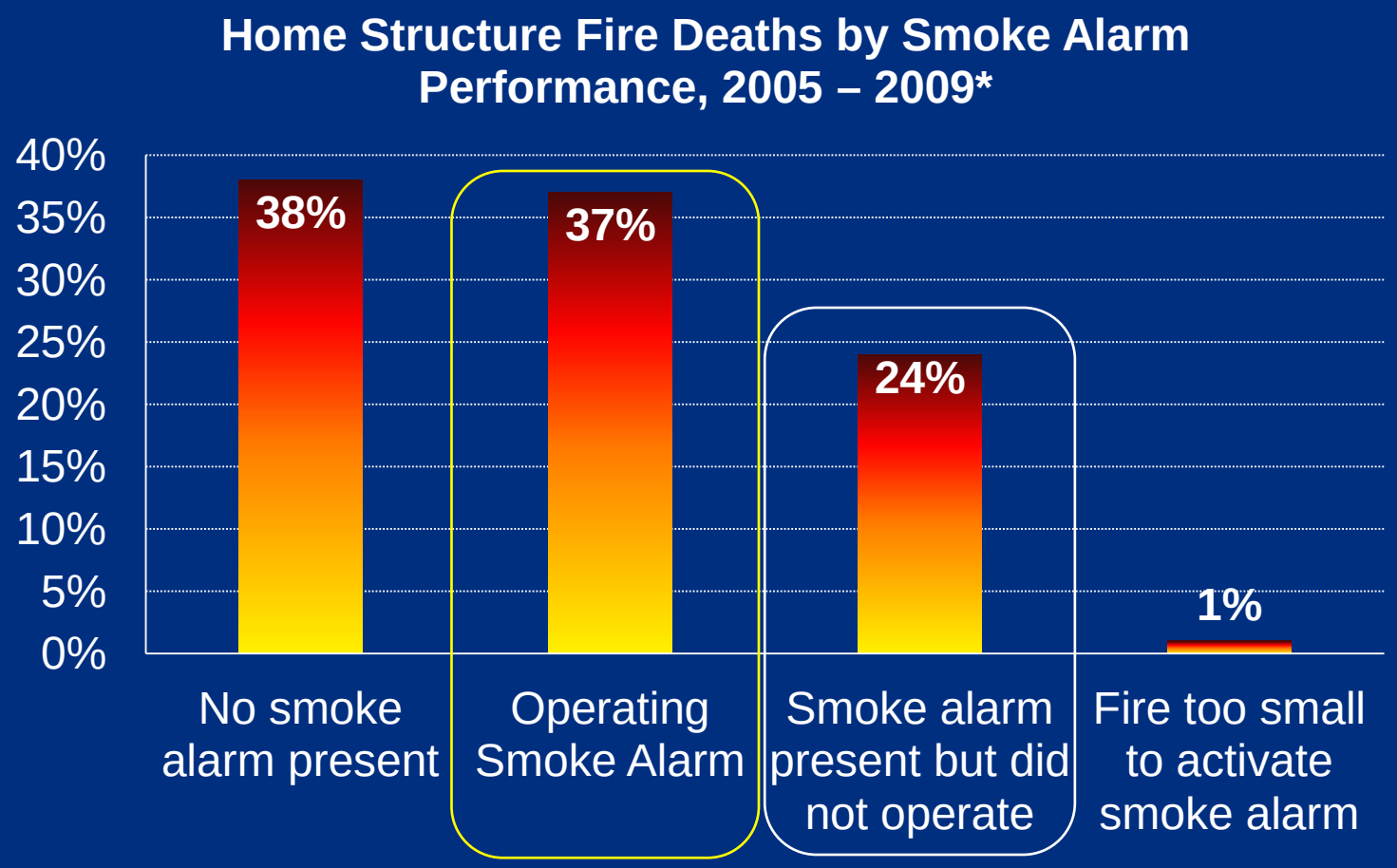
A People–Friendly Smoke Alarm

Motivation

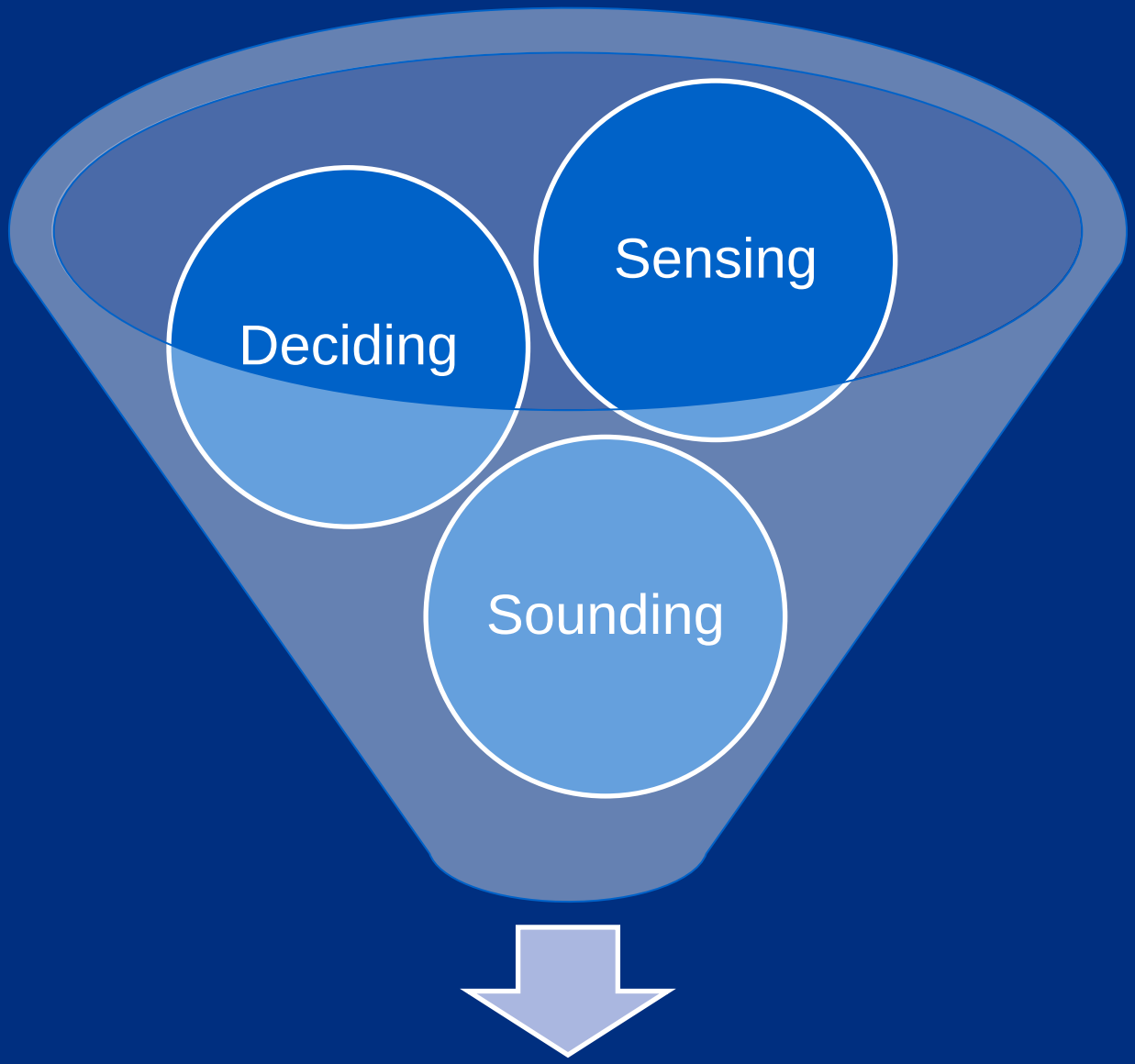
- Increasing fire risk in homes.
- Ionization vs. photoelectric alarms.



* Ahrens, Marty, "*Smoke Alarms in U.S. Home Fires*," NFPA, Quincy, MA 02169-7471, September 2011.

Project Goals

- Functional – earlier alarm than existing products.
  – improved awakening performance.
- Reliability – improved resistance to nuisance alarms.
- Power – capable of battery operation.
- Cost – mass-produced product < $30 per unit.
- Size – production unit should have a form factor similar to current products.
- Durability – extended service life.



ALARM

Sensing

- Aerosol Sensors
  - Ionization
  - Photoelectric
- Material-Based Sensors
  - Sorbent Sensors
  - Heated Metal Oxide (Taguchi) Sensors
  - Catalytic Sensors
  - Electrochemical Sensors
- Physical-Based Sensors
  - Solid-State
  - Electrochemical
  - Nondispersive Infrared (NDIR)
  - Hydrocarbon

Deciding

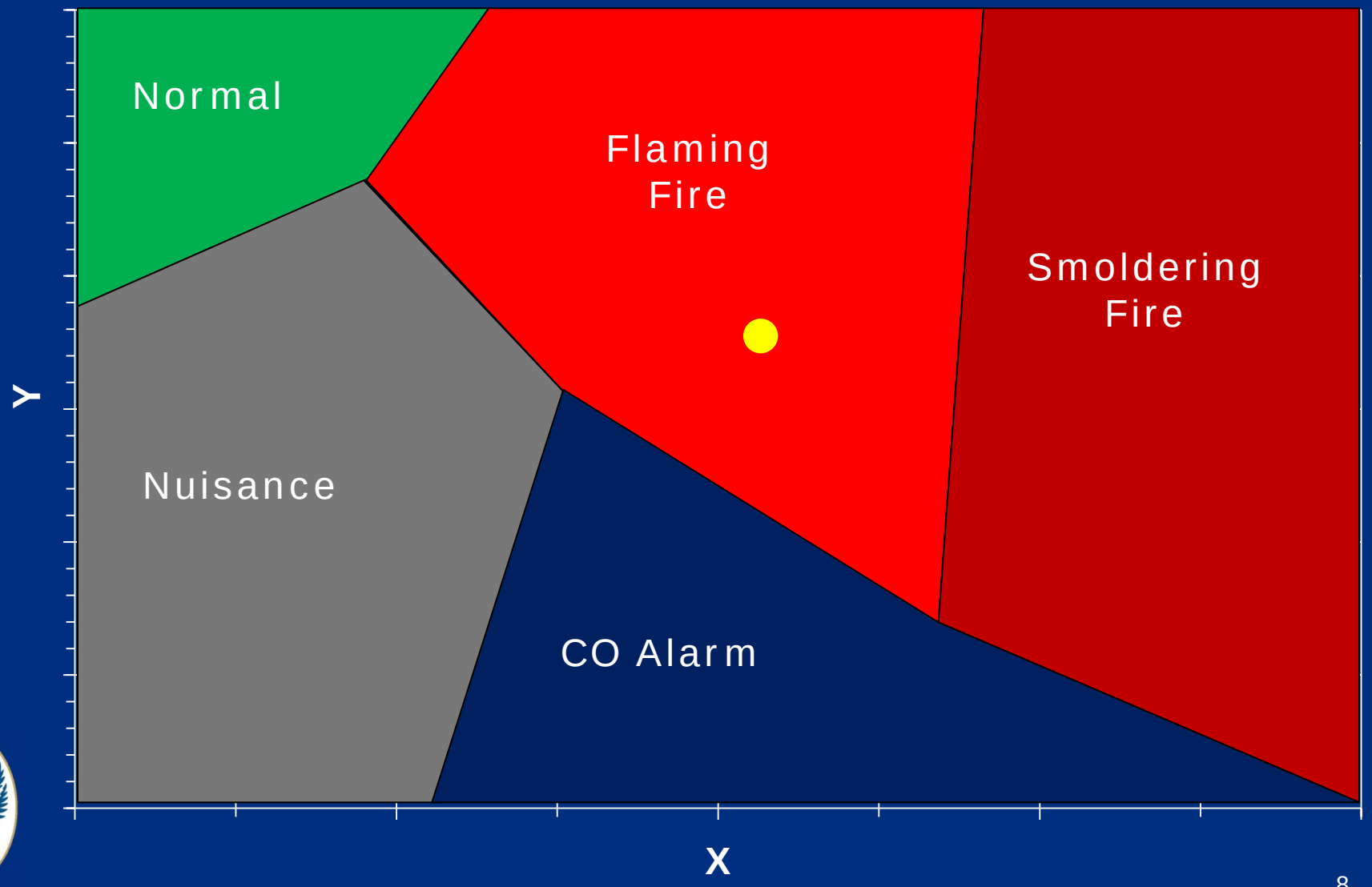
- Set Point
- Rate of Rise
- Simplified fuzzy logic (*i.e.*, if – then adjustments)
- Principal Components Analysis[1]:
  - Captures information about data variation but not necessarily to classify.
- Curve Matching or Neural Networks[2]:
  - Recently proposed, shows promise.

1. Cestari, L.A., C. Worrell & J.A. Milke, *Advanced fire detection algorithms using data from the home smoke detector project*. Fire Safety Journal 40 (2005) 1–28
2. Jones, W.W., *Implementing High Reliability Fire Detection in a Residential Setting*, Fire Technology, 48, 233–254, 2012, 233-254.

Deciding

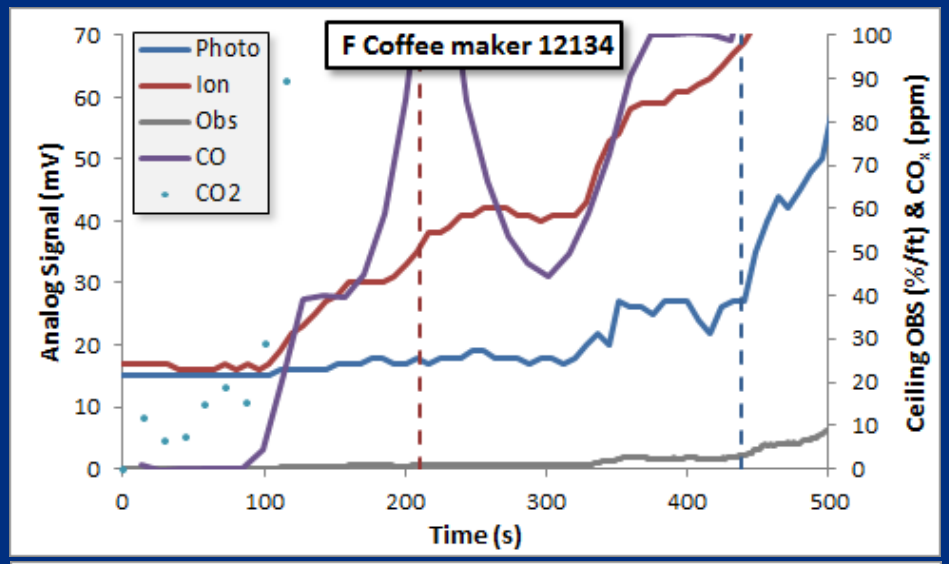
- Linear Discriminant Analysis:
  - A proven technique to classify objects into groups based on a set of observations that describe the objects.
  - A supervised pattern recognition technique.
  - Training data is used to formulate rules to sort new observations as belonging to specified groups.
  - Useful for a small number of signal channels.

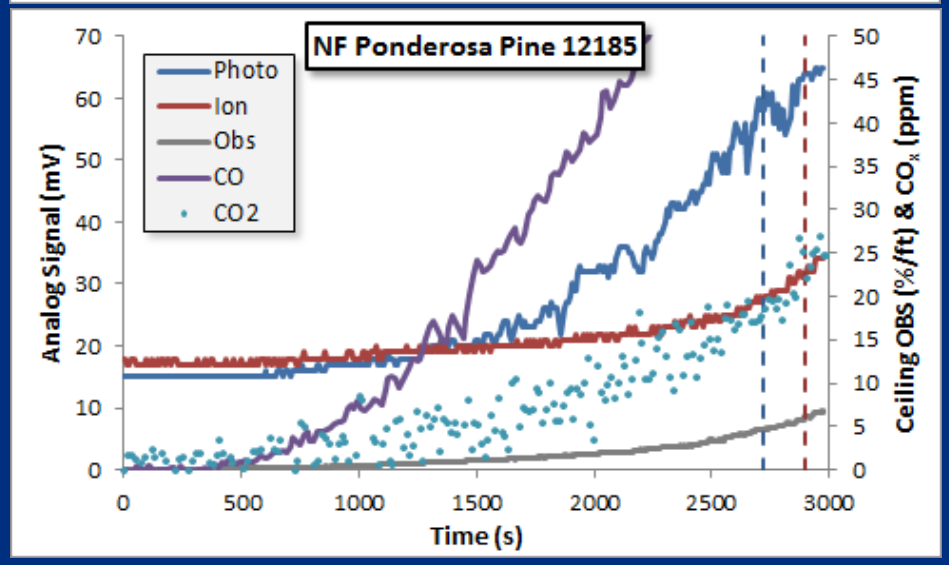
LDA Concept



Training Data

- UL data[1] from 18 fire tests in the UL217/UL268 Fire Test Room
- NIST data[2] from 21 fires each with multiple sensor locations (67 total) in a manufactured and a two-story home plus 25 nuisance tests
- Sensors common to both: ion, photo, temperature and CO





1 Fabian, T.Z. and Gandhi, P.D. 2007. "Smoke Characterization Project." Northbrook, IL: Underwriters Laboratory Inc.
2 Bukowski, R.W. et al. 2008. "Performance of Home Smoke Alarms." NIST TN-1455-1 (Rev. 2008)

LDA Development

- First two LDs show good segregation of fire events from normal and even nuisance conditions
- Ion, CO and temperature sensors provided the most valuable sensor data for classification
- LDA processing improves alarm performance

Trial	Smoldering	Flaming	Grease	Nuisance
Ion + Photo + CO + Temp	Earlier Alarms	Similar times to alarm	Slightly Slower	50% elimination, others slower to alarm
Photo + Temp	Earlier Alarms	Similar times to alarm	Slightly Slower	17% elimination, others slower to alarm
Photo only	Earlier Alarms	Similar times to alarm	Similar	Similar

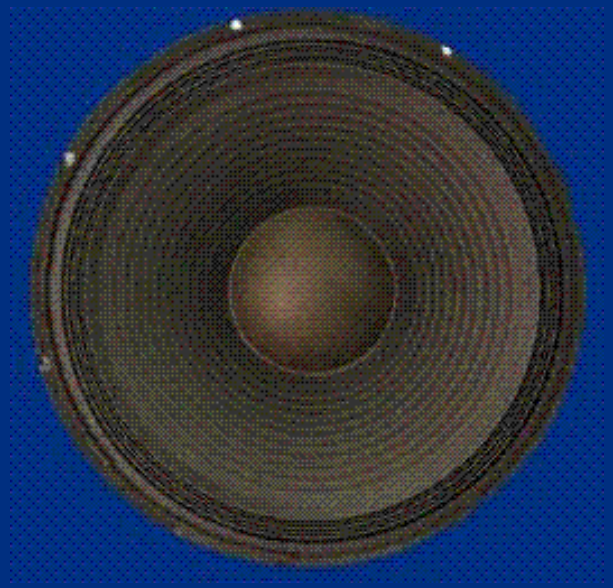
Alerting

- 37% of fire deaths occur while people are sleeping in homes with working alarms (CPSC 2004).
- Arousal is limited with sleep deprivation, alcohol/drugs, children, old age, hearing impaired.
- Standard 3100Hz T-3 alerting tone is substantially less effective than low frequency or female voice.
- 520Hz square wave much more effective than 3100Hz for all at-risk groups.

Thomas & Bruck 2010. Fire Technology, 46, *743*

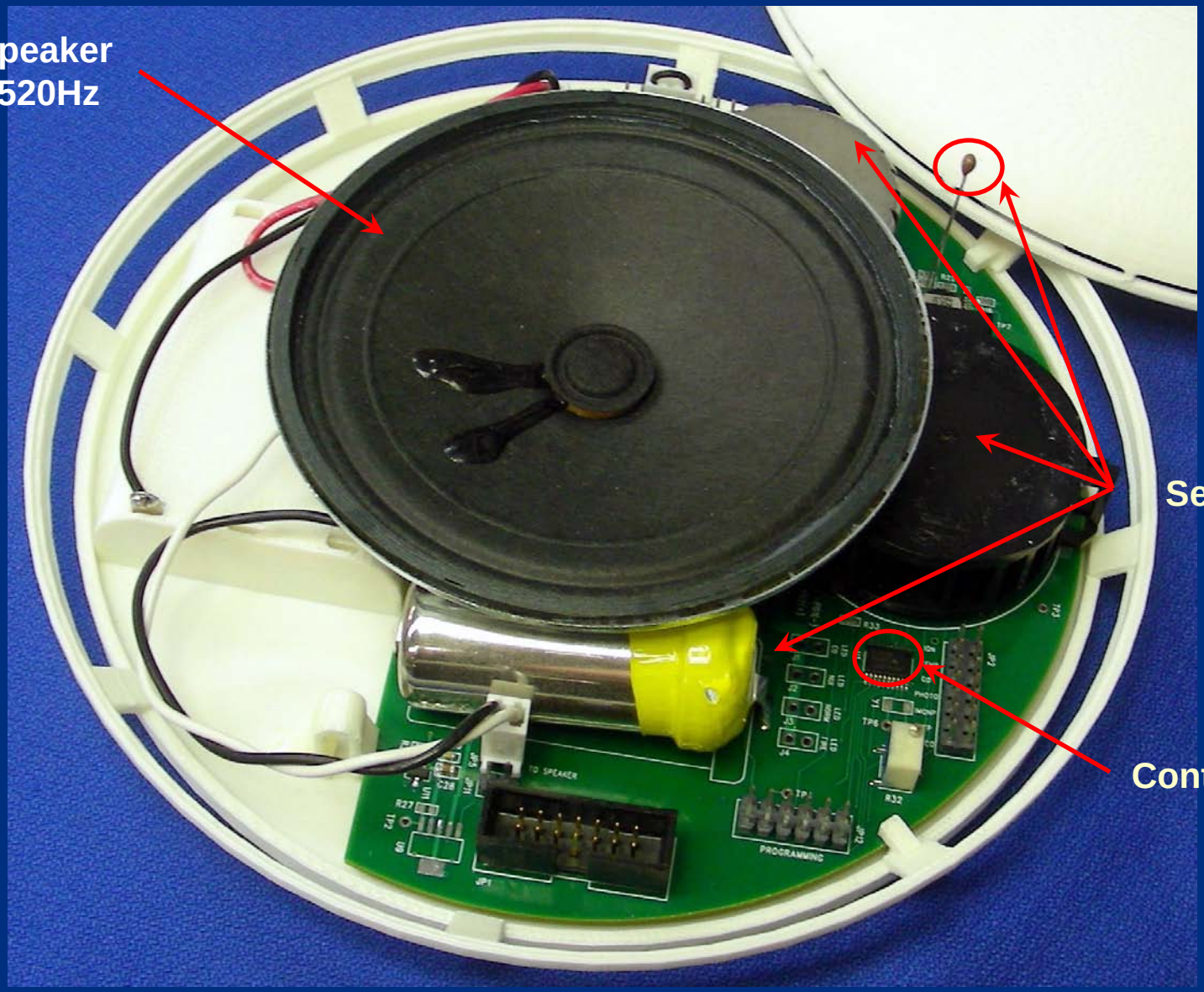
Sounder Technology

- Sound frequency currently used in residential smoke alarms is sub-optimal for some target audiences (3,000 Hz vs. 520 Hz).
- Piezoelectric horns have low energy requirements



Size is to scale.

LDA Alarm Prototype



Recommendations

- More data can yield better decisions!
  - more sensors
  - time dependent rate of change
- CO sensor – smoldering fires and CO poisoning.
- Upgrade Photoelectric sensing
  - blue LED, dual λ or dual angle.
- Microcontroller based decision making
  - LDA
- Alert Tone can be improved.
- On horizon: NDIR sensors – CO_2, H_2O, CO & HCs.

Take – Away

- Home smoke alarm performance can be improved to be more user – friendly:
  - Earlier alarms
  - Fewer nuisance alarms
- Cost will increase
  - Will still be a bargain
- Pending UL changes may prompt changes