Evaluating Sensor Algorithms to Prevent Kitchen Cooktop Ignition and Ignore Normal Cooking

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This presentation will include:

**Background and Methods:** Motivation, kitchen setup, conditions, quantities measured, pan temperature

**Classification of Data:** Defining normal cooking conditions based on pan temperature, food temperature, or duration of cooking

**Threshold Analysis:** False alarm rates for thresholds of sensors and sensor ratios

**Machine Learning Analysis:** False alarm rates and missed ignition rates for individual sensors and for all sensors as training input
We investigated ways to robustly and reliably prevent cooktop ignition, applicable to all cooktop types.

UL 858 “abnormal cooking test”
- Applies to new electric-coil cooktops

Investigate feasibility of a retrofit device for ignition-prevention for:
- Older electric-coil cooktops
- Gas cooktops
- Ceramic/glass cooktops
- Induction cooktops, etc.
Experiments in a mock kitchen measured various quantities for cooktop ignition and normal cooking.

- CO$_2$
- CO
- Hydrocarbons
- Alcohols
- H$_2$
- Natural gas
- VOC’s

Sensors in the duct:
- Smoke detectors
- Air quality
- Dust/aerosols
- Temperature
- Humidity
- Velocity

Exhaust hood

Flow ~ 3 m/s

Looking along the duct:

- Flow
- 3.4 m/s
- Sensors in the duct:
- Smoke detectors
- Air quality
- Dust/aerosols
- Temperature
- Humidity
- Velocity

Exhaust hood

84 cm

Flow ~ 3 m

76 cm

68 cm
New experiments included cooking chicken, French fries, bacon, multiple pans, and a gas (methane) cooktop.
IR and thermocouple temperatures showed that the center was cooler than other locations on the pan:

- Center: 319 °C
- Other locations: 327 °C, 330 °C, 343 °C, 370 °C

IR images of cast iron pans calibrated using surface thermocouples:
- ε: 0.88 – 0.96
- Calibration uncertainty: ± 8 °C

50 mL of canola oil in 20 cm cast iron pan
When pan temperature was only measured in the center, the hotter, edge temperature was estimated.

Temperature Corelations for Cast Iron Pans

\[ T_{5cm} = 0.972 \, T_{\text{center}} + 23 \, ^\circ\text{C} \]
- 20 cm cast iron pan, 1.1 kW electric coil burner (15 cm burner)

\[ T_{6cm} = 1.07 \, T_{\text{center}} + 16 \, ^\circ\text{C} \]
- 25 cm cast iron pan, 1.8 kW electric coil burner (20 cm burner)

\[ T_{7.5cm} = 0.967 \, T_{\text{center}} + 31 \, ^\circ\text{C} \]
- 25 cm cast iron pan, 4 kW gas burner
Ignition occurred at a pan temperature of 429 °C on average for different foods, pans, and cooktops.

<table>
<thead>
<tr>
<th>Quantity</th>
<th>Type</th>
<th>Pan Diameter</th>
<th>Heat Source</th>
</tr>
</thead>
<tbody>
<tr>
<td>100 mL</td>
<td>oil</td>
<td>25 cm</td>
<td>4 kW gas</td>
</tr>
<tr>
<td>50 mL</td>
<td>oil</td>
<td>20 cm</td>
<td>4 kW gas</td>
</tr>
<tr>
<td>50 mL</td>
<td>bacon</td>
<td>20 cm</td>
<td>1.1 kW electric</td>
</tr>
<tr>
<td>110 g</td>
<td>bacon</td>
<td>20 cm</td>
<td>1.1 kW electric</td>
</tr>
<tr>
<td>50 mL</td>
<td>fries in 500 mL oil</td>
<td>25 cm</td>
<td>1.9 kW electric</td>
</tr>
<tr>
<td>100 mL</td>
<td>fries in 500 mL oil</td>
<td>25 cm</td>
<td>1.9 kW electric</td>
</tr>
<tr>
<td>100 mL</td>
<td>salmon, 43 g butter</td>
<td>20 cm</td>
<td>1.1 kW electric</td>
</tr>
<tr>
<td>100 mL</td>
<td>salmon, 43 g butter</td>
<td>20 cm</td>
<td>1.1 kW electric</td>
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<tr>
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</table>

**Oils:**
- canola oil
- corn oil
- soybean oil
- olive oil
- sunflower oil
- butter

**Diagram:**
- Pan Temperature at Ignition, °C
- Experiments with Ignition (39 out of 60)
Many of the sensor values increased throughout an experiment and at a faster rate approaching ignition.

50 mL of canola oil, 20 cm cast iron pan, 4 kW gas burner
To evaluate algorithms, both normal cooking conditions and a ignition prevention window must be defined.

Normalized Signal

- Smoke
- Alcohol
- VOCs
- HCs low range
- HCs high range
- H2
- Natural Gas
- Dust
- iAQ
- CO cheap
- CO expensive

Pre-Ignition

Normal Cooking

50 mL of canola oil, 20 cm cast iron pan, 4 kW gas burner
Because bacon fat quickly coats the pan, the end of normal cooking was defined using the pan temperature.

- 4 oz bacon (110 g) in 4 slices
- 20 cm cast iron pan
- 1.1 kW electric burner

![Graph showing temperature and time relationship during cooking process.](image)
Normal cooking of chicken was defined by adding 10% to the time it took to reach a safe temperature.

2 chicken legs (282 g) in 200 mL canola oil
20 cm cast iron pan
1.1 kW electric burner

USDA safe temp for chicken = 74 °C

Chicken placed in pan

Chicken reaches safe temp.

Flipped chicken every 4 min

End of normal cooking

Chicken was 85 °C
Normal cooking for salmon filets in butter was over after cooking for 4 minutes on each side.

227 g (8 oz) salmon, 44 g butter
20 cm cast iron pan
1.1 kW electric burner

Pan Temp, test A
Food Temp, test A
Pan Temp, test B
Food Temp, test B

Salmon placed in pan
Flipped salmon
USDA safe temp for fish = 63 °C
Ignition, test A
End of normal cooking (8 min.)
The end of the hamburger frying recipe was about 10% longer than the time to reach a safe internal temperature.

2 x 230 g (0.5 lb) frozen hamburgers
25 cm cast iron pan
1.8 kW electric burner

USDA safe temp for ground beef = 71 °C

End of normal cooking (19:30)

Well done temp for beef = 77 °C

Meat reaches safe temp.
71 °C
77 °C

Pan Temp, test A
Food Temp, test A
Pan Temp, test B
For broiling hamburgers, the end of normal cooking was 10% longer than the time to reach the safe temperature.

2 x 230 g (0.5 lb) frozen hamburgers
broiler pan
electric oven on broil setting

USDA safe temp for ground beef = 71 °C

Meat reaches safe temp, 1020 s

Well done temp for beef = 77 °C

End of normal cooking (1122 s)

Oven Air Temp

Food Temp

77 °C
71 °C

After 1500 s
The end of normal cooking of French fries in oil was after 15 minutes, and the food ignited about 11 minutes later.

223 g (0.5 lb) frozen French fries,
500 mL canola oil
25 cm cast iron pan
1.8 kW electric burner
For each sensor, we compare the values 60 s before ignition and the peak values during normal cooking.
We determine the threshold values of each sensor that would detect all ignitions and find the false alarm rate.

Values at 60 s before ignition

- **False Alarm Rate (FAR)**: 1 false alarm / 60 experiments ≈ 0.02

**VOC sensor values**

- **Ignition**: 0.57 V
- **Normal Cooking**: Maximum values for normal cooking

**Graph Details**:
- X-axis: VOC sensor values
- Y-axis: Fire event
- Values at 60 s before ignition
- Ignition threshold: 0.57 V
False alarm rates were determined for each sensor and its ratio with duct T (K), humidity (vol %), and CO₂ (PPM)

![Graph showing best performing thresholds for sensors (FAR < 0.25) and sensor ratios](image-url)
With a few exceptions, the sensor ratios do not reduce the false alarm rate of the sensor alone.
The sensor data was also used to train a multi-layer perceptron neural network in machine-learning analysis.

Input data: 12,800 individual time points across 60 experiments.

Classification labels:
0 = normal cooking
1 = pre-ignition

Leave-one-out cross-validation:
Train with 59 experiments & test on 1 experiment,
Repeat for all experiments, and average results.
The neural network predicts the likelihood of pre-ignition at each time, and the probability is rounded to 0 or 1.
The machine learning performance was evaluated through the number of false alarms and missed ignitions.

False Alarm Rate = false alarms / 60 total experiments

Missed Ignition Rate = missed ignitions / 39 total ignitions
Single sensor cases and the case with 11 sensors as input predicted most ignitions, but had higher false alarm rates.
Conclusions and Future Work

Definitions of normal cooking conditions were based on pan temperature, food temperature, and duration of cooking.

The sensors with lowest false alarm rates were in agreement between the threshold and machine learning analyses (VOC, iAQ, and Dust).

Thresholds of the VOC sensor and of the ratio VOC/Duct Temperature had the best performance (1 false alarm).

Future work includes evaluating sensor rates of change and evaluating pairs of sensors with machine learning.