Prevention of Casualties and Property Damage Due to Kitchen Fires By Using Thermal Imaging and Software Based Occupancy Detection

Introduction

Kitchen fires cause casualties and property damage, with **thousands of lives lost each year** in the United States. Studies show that **smoke detectors often detect fires too late** and may not be reliable enough. To address this problem, I wanted to construct an early fire detection system that would warn of kitchen fire hazards **much before normal smoke detectors** do, hence saving lives and reducing property damage.

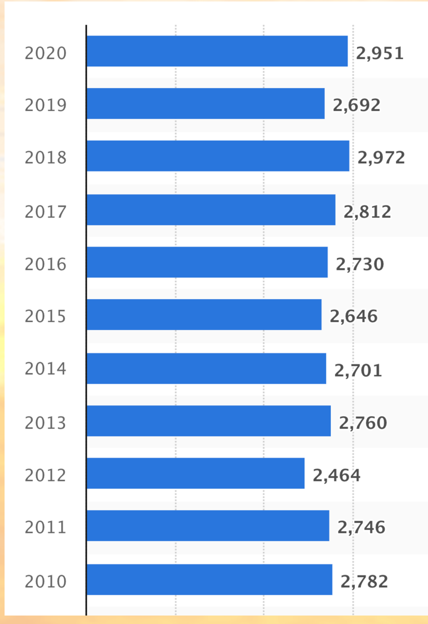

Fig 1. Number of deaths due to fire, flames, or smoke, in the United States from 2010 to 2020. (Source: Statista)

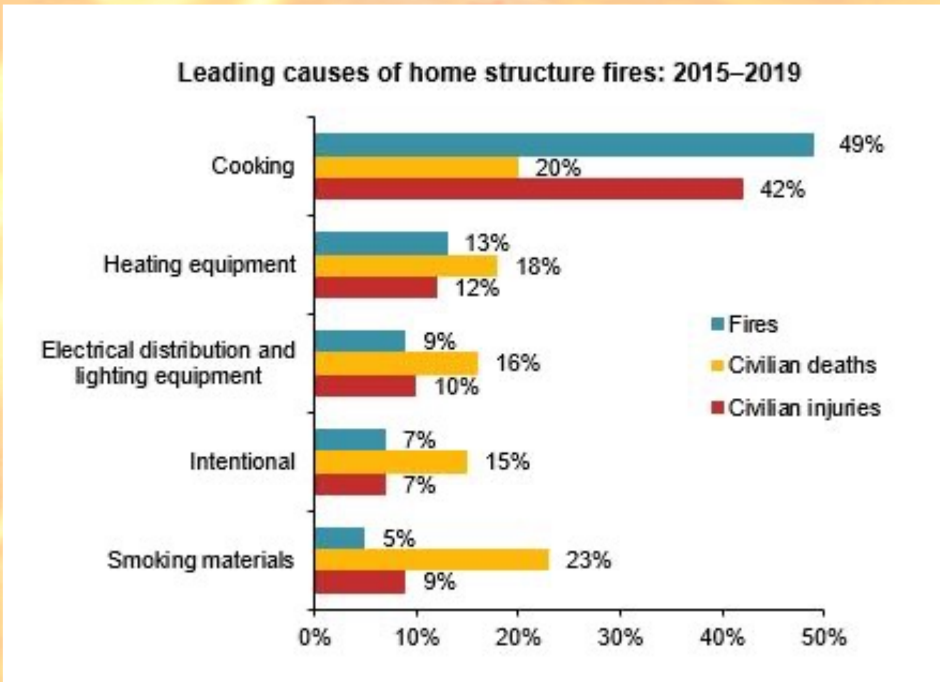

Fig 2. Common causes of home fires. (Source: NFPA)

I have created an affordable and efficient device for **early fire detection** in homes and **improved kitchen safety**. This device utilizes a Raspberry Pi, a **thermal camera**, and Python code to identify heat sources and humans present in a kitchen. This innovative device **outperforms conventional smoke detectors** in terms of **accuracy**, **affordability**, **speed**, and **functionality**. It has the potential to either replace or supplement existing smoke detectors in kitchens, ultimately improving safety and reducing the number of casualties and property damage caused by house fires.

Background Research

Smoke detectors (photoelectric): Devices that sound an alarm when a fire has significantly progressed causing smoke to rise; this is too late in many cases. There are no fire detectors in the market that can detect unattended fires before they worsen into a dangerous situation.

Thermal cameras: Devices that capture the temperature of different parts of a scene using arrays of micro-bolometer.

Raspberry Pi: A small general-purpose computer that can be connected to peripheral devices like thermal cameras.

Engineering Goal

The engineering goal is to design and construct an **early fire detection system** that uses **thermal imaging** to detect unattended fires **before** they become a fire hazard.

This device should be able to:
Detect humans in the scene using thermal imaging at least 80% of the time.
Detect major heat sources in a scene like gas burners at least 95% of the time.
Send a text message when a heat source is left unattended for more than 10 minutes at least 95% of the time.

(Background image: pngtree)

Materials

1. Raspberry Pi for model B with boot up SD micro card
2. Thermal camera MLX90640-D55
3. Mouse
4. Keyboard
5. Computer monitor
6. Micro HDMI to HDMI cable (6 feet long)
7. 5V DC Power adapter
8. Kitchen cooking stove
9. Human volunteers
10. Small cardboard box to house the device.

Methods

Criteria 1: Able to detect humans in the scene using thermal imaging 80% of the time.
Testing Procedure: Ask volunteers to walk into the kitchen, and check if the message "human" appears on the monitor. Repeat this 30 times with volunteers entering from both left and right, during morning, afternoon, and evening and record the results.

Criteria 2: Able to detect major heat sources in a scene like gas burners 95% of the time.
Testing Procedure: Ask an adult to light different kitchen burners with and without a pan on top in the morning, afternoon, and evening. Check if the message "fire" appears on the monitor and repeat this for a total of 10 trials and record the results.

Criteria 3: Able to send a text message to the user 95% of the time when a heat source is left unattended for more than 10 minutes.
Testing Procedure: Leave a fire running for 11 minutes in the morning, afternoon, and evening. Record whether a text message is sent to the user if the fire is unattended. Calculate the overall success rate.

Hardware Design

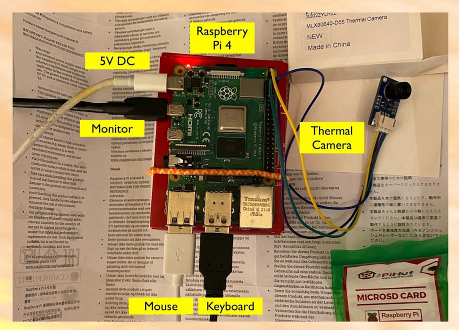

Fig 3. Assembled hardware.
(Photograph taken by Shanya Gill)

Fig 4. Device housed in a cardboard box.
(Photograph taken by Shanya Gill)

This early fire detection system uses a Raspberry Pi 4 and a thermal camera (MLX90640).

1. Connect the thermal camera to the Raspberry Pi by attaching the 4 wires to the correct pins.
2. Connect the mouse, keyboard and monitor to the Raspberry Pi
3. Insert the boot up SD card into the Raspberry Pi and connect it to the power supply.
4. Follow the instructions to connect to the WiFi network and install the operating system as directed on the monitor.
5. Take a cardboard box and place the Raspberry Pi and thermal camera in it.

Software Design

Prototype #1

1. Write a python program to continuously obtain temperature readings from the thermal camera.
2. Count the number of cells warmer than certain thresholds.

I found that the fire heated up the air around it to roughly human temperatures, resulting in a **high false positive rate** for detecting absence of humans.

I concluded that this design did not work effectively, and I need to approach the solution differently.

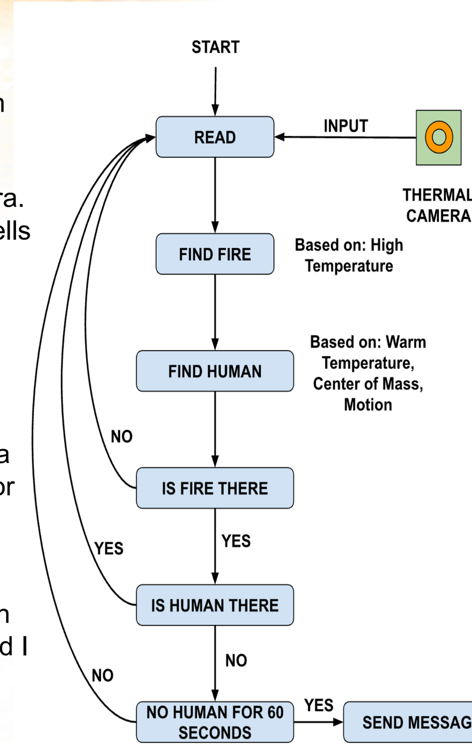

Fig 5. Software workflow diagram
(Diagram by Shanya Gill)

Prototype #2

1. Detect fire by counting the number of cells warmer than 60°C.
2. Detect humans by counting cells between 28°C - 33°C.
3. Remove cells in the vertical area of any cell hotter than 60°C. This ensures that the warm air above a fire is not mistaken as a human.
4. Detect **center of gravity** of the warm cells and track its movement
5. On 10% horizontal motion declare it as a human. This **removed false positives** as warm air does not move sideways like humans.

Data

Criteria 1

Time of Day	Person	Entry Direction	Person Detected
Morning	Person 1	Left	Y,Y,Y,Y,Y
		Right	Y,Y,Y,Y,Y
	Person 2	Left	Y,Y,Y,Y,Y
		Right	Y,Y,Y,Y,Y
	Person 3	Left	Y,Y,Y,Y,Y
		Right	Y,Y,Y,Y,Y
Afternoon	Person 1	Left	Y,Y,Y,N,Y
		Right	Y,Y,Y,Y,Y
	Person 2	Left	Y,Y,Y,Y,Y
		Right	Y,Y,Y,Y,Y
	Person 3	Left	Y,Y,N,Y,Y
		Right	Y,Y,Y,Y,Y
Evening	Person 1	Left	Y,Y,Y,Y,Y
		Right	Y,Y,Y,Y,Y
	Person 2	Left	Y,Y,Y,Y,Y
		Right	N,Y,Y,Y,Y
	Person 3	Left	Y,Y,Y,Y,Y
		Right	Y,Y,Y,Y,N

Fig 7. Detection of humans at various times of the day
(Data by Shanya Gill)

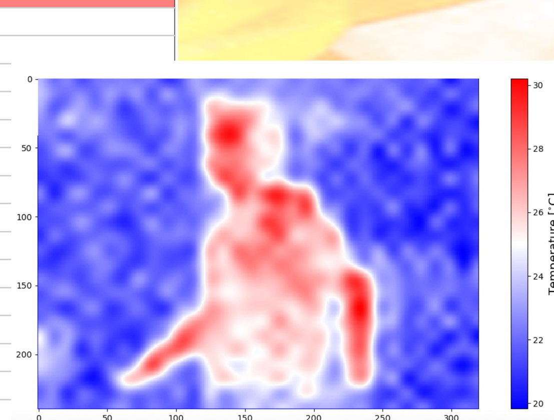

Fig 6. Human Thermal Image
(Photo by Shanya Gill)

Criteria 2

Time of Day	Situation	Fire Detected
Morning	No Fire	N,N,N,N,N
	Open Fire	Y,Y,Y,Y,Y
	Pan on Fire	Y,N,Y,Y,Y
	Pot on Fire	Y,Y,Y,Y,Y
Afternoon	No Fire	N,N,N,N,N
	Open Fire	Y,Y,Y,Y,Y
	Pan on Fire	Y,Y,Y,N,Y
	Pot on Fire	Y,Y,N,Y,Y
Evening	No Fire	N,N,N,N,N
	Open Fire	Y,Y,Y,Y,Y
	Pan on Fire	Y,Y,N,Y,Y
	Pot on Fire	Y,Y,Y,Y,Y

Fig 10. Detection of heat sources at various times of the day
(Data by Shanya Gill)

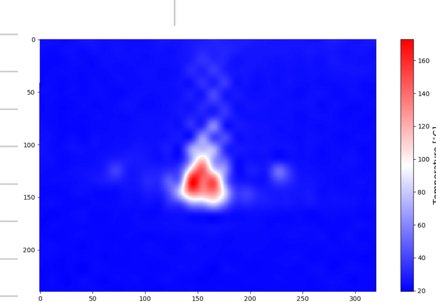

Fig 11. Unattended Fire Thermal Image
(Photo by Shanya Gill)

Criteria 3

Time of Day	Situation	Text Message Sent
Morning	Fire + Person (Attended)	N,N,N,N,N
	Unattended Fire	Y,Y,Y,Y,Y
Afternoon	Fire + Person (Attended)	N,N,N,N,N
	Unattended Fire	Y,Y,N,Y,Y
Evening	Fire + Person (Attended)	N,N,N,N,N
	Unattended Fire	Y,Y,Y,Y,Y

Fig 8. Detection of unattended fires.
(Data by Shanya Gill)

Fig 9. Text message on iPhone
(Photo by Shanya Gill)

The product exceeded all success criteria:
1. **Accuracy**: With an average accuracy of 97%, this product surpasses conventional smoke detectors, which typically have an accuracy rate of 82%.
2. **Affordability**: This product can be mass produced at a price similar to a regular smoke detector because it requires minimal computation and a low-end thermal camera.
3. **Response Time**: Capable of detecting fires within 10 minutes, this product is significantly faster than traditional smoke detectors, which often take up to 19.2 minutes to activate and only do so when the fire has already become hazardous.

Early Challenges & Lessons Learned

Fig 12. Kitchen with fire detector installed.
(Photograph taken by Shanya Gill)

Positioning of the Device

Initially, I placed the device on the table. Although the scene still displayed the entire kitchen, sometimes the fire **was obscured by an object** placed on the table, leading to inaccurate results. I realized that the root of this problem was the positioning of the device. To address this issue, I decided to place it on **top of the backsplash**. This ensured that the fire was guaranteed to be visible and that the thermal camera had an unobstructed view, preventing any obstructions.

Software Difficulties

One significant issue encountered was that the initial prototype's code failed to differentiate between a human and a fire in close proximity. The first code relied solely on temperature readings, causing it to misidentify situations where the **fire had heated the surrounding air to human-like temperatures**. To address this issue, the second prototype's code incorporated additional variables, such as **motion detection, which greatly improved its accuracy.**

Results

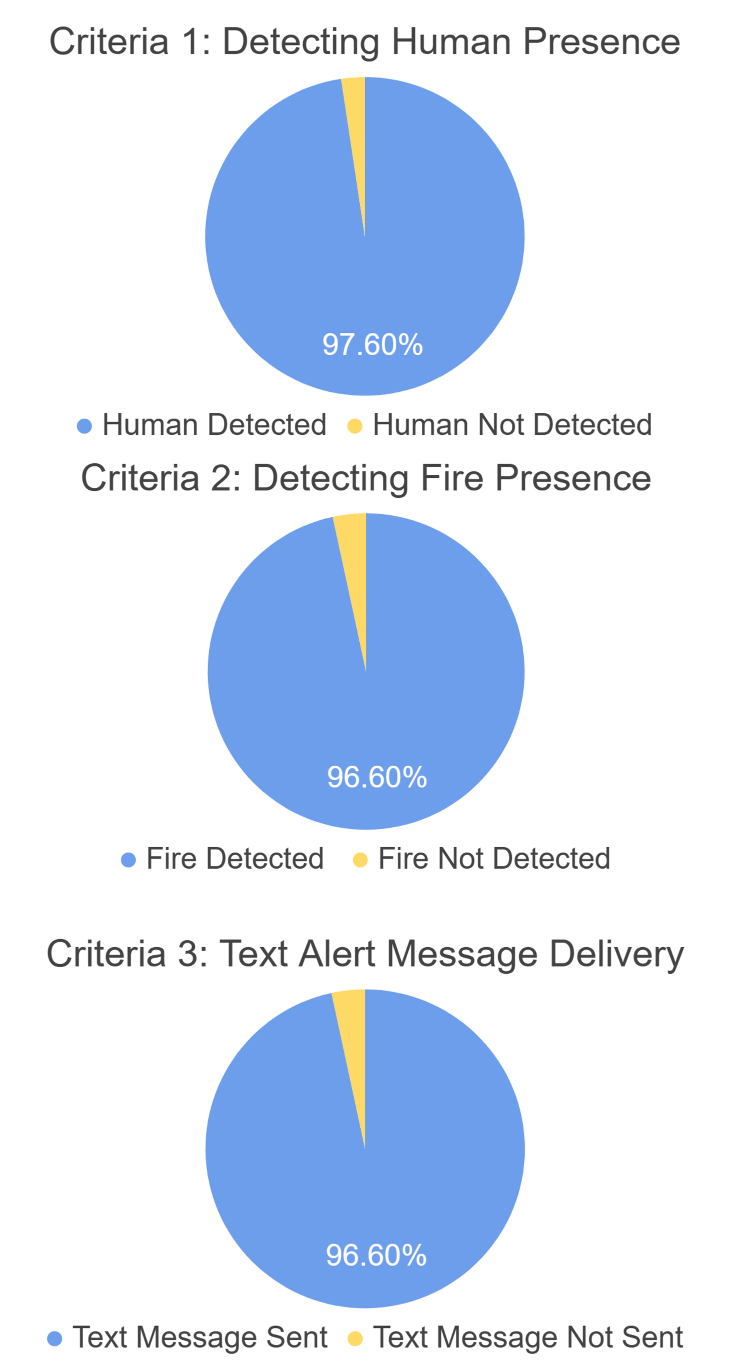

Fig 13: Summary of results for each criteria. (Diagram by Shanya Gill)

Further Research

I am continuing my work to productize this early fire detection system with the **following improvements**:

1. Ceiling mounting of the device for obstruction free detection of a larger area.
2. Making the product more affordable through mass production.
3. Enhancing detection accuracy by implementing AI-based human and fire detection algorithms.
4. Using a higher resolution thermal camera for more precise and reliable detection.
5. Developing a phone app that allows users to monitor their kitchen live.

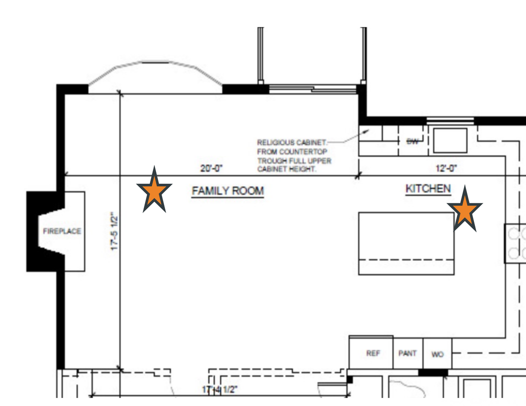

Fig 14. Potential placement locations for device.
Source: Room sketcher