Gas Stove Safety Device

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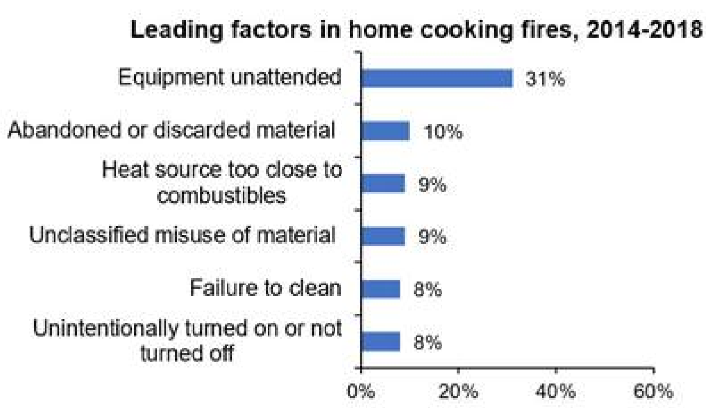
Introduction

Objective

172,900 homes burn down per year due to cooking-related fires, the leading cause of which were unattended stoves. Additionally, many gas leaks in a home are not caused by broken pipes. Rather, it is also because of these unattended stoves boiling over and putting out the flames, causing gas to start leaking from the now-unlit stove. Based on studies performed by the NFPA (National Fire Prevention Association), about 39% of the fires per year can be attributed to human negligence (unattended or unintentionally turned on/not turned off) of the stove itself, while 36% of the fires can be attributed to human negligence of materials around the stove, and only a very small percentage are various forms of failures. However, human negligence of the stove itself are by far the most costly, totalling $620 million dollars in property damage (52% of the total property damage caused in a year), as well as the deadliest, totalling in at 340 deaths (61% of the total deaths) that home cooking fires cause. [1]



Clearly, then, it stands to reason that we cannot depart from gas stoves any time soon. Our goal is to make stoves safer to use by the creation of a safety device. This safety device must alert the user in the event of a fire risk rather than an actual fire, as when the fire breaks out, it will be too late. In order to determine when a risky scenario is occurring, the device must make sure to alert the user periodically that the stove is on, alert the user when the user walks away too far, and alert the user when the stove's flame is put out but the stove is still running.

Background

While there exist many safety measures for electrical appliances, very few devices exist for gas stoves.[2] [3] [4] During preliminary searching, we could only find two while searching for electric safety devices yielded many. The ones that do exist also require professional installation as they attempt to shut off the flow of gas, and as a result they can be costly to install. Additionally, it is very unlikely that people will give up on using gas stoves, whether it is due to the instantaneous and controllable nature of the heat, or the commonly-stated anecdote of "food cooked on gas stoves just tastes better."

Due to the reasons listed above, we have come to the conclusion that our device must be easy to install and maintain. Many of the people looking for these devices will likely have the funds necessary to purchase a $200 appliance that keeps their homes safe, but they may not have the physique, skill, or patience necessary to install something directly into their gas lines. They also may not be willing to wait for someone to come install it for them, and would rather prefer it be usable almost immediately.

High Level Requirements

- The device must be able to detect when the stove is on and issue a short alert every so often.
- The device must be able to detect the distance between the stove and the user, issuing an alert when the user walks away too far.
- The device must be able to detect the presence of a flame on the burners. If it detects no flame, but the stove is on, the device must issue a critical alert as this is a high risk of a gas leak, and if other stoves are on, risk a gas explosion.

Design

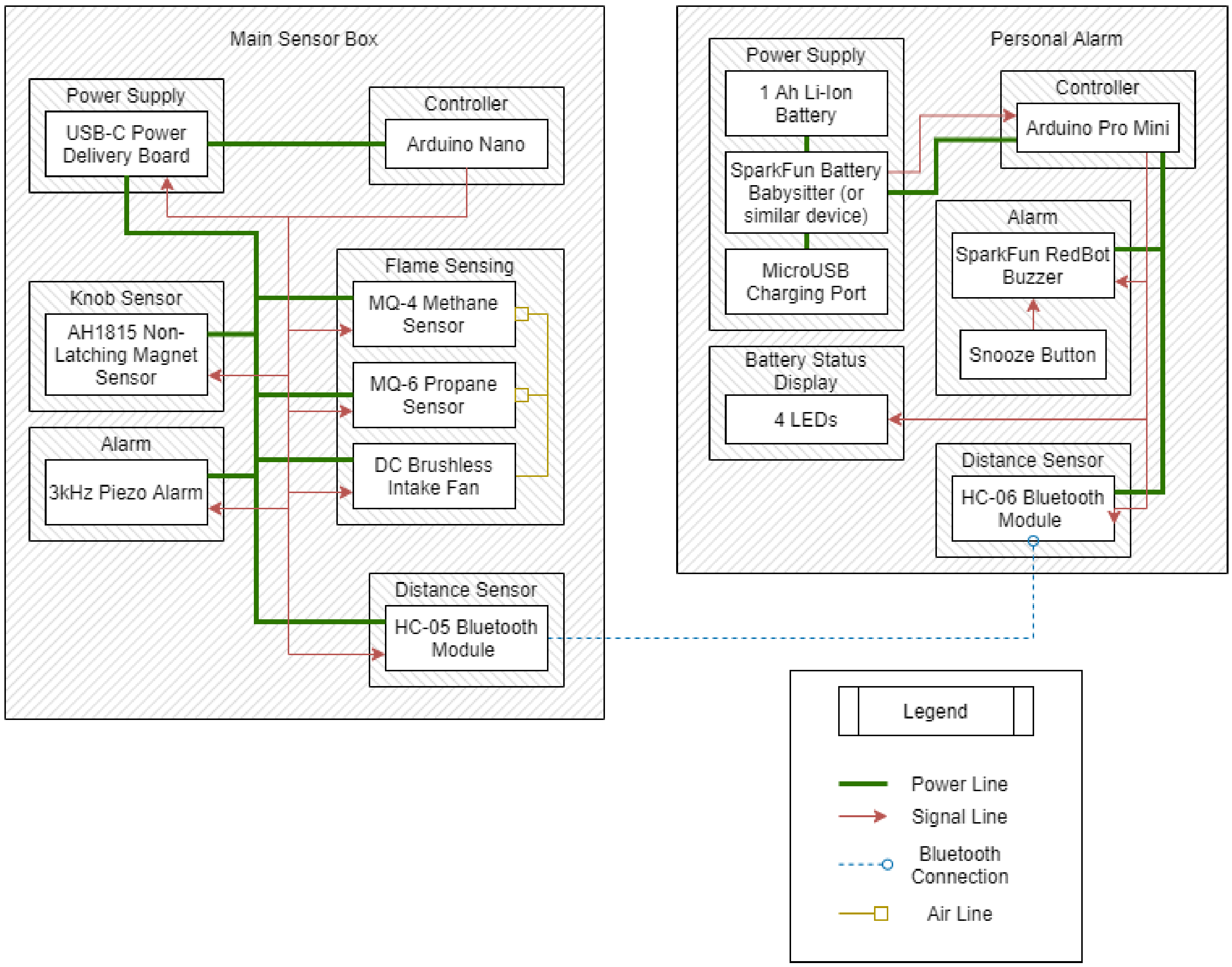
In the device's entirety, we need two separate units. One unit, the main sensor box, serves as the hub everything works from. The other unit, a small alarm unit carried by the user, serves as the method the main sensor box uses to determine how far the user is via Bluetooth.

The main sensor box consists of five modules: a power supply, an alarm unit, a controller, a knob sensor, a gas sensor, and a distance sensor. The power supply plugs into the standard 120V AC wall outlet and delivers 5V power to the controller, which serves a double purpose as a power distributor. The knob sensor serves to detect whether or not the user has turned the stove on or not. The gas sensor is built to detect propane and methane gas, two common fuel sources used for gas stoves. The distance sensor utilizes a Bluetooth signal, which supports

RSSI (Received Signal Strength Intensity) and can send a notification if connection is lost. We use both of these properties to detect approximately how far the user is from the main sensor. The controller takes in the information from the sensors and sounds the alarm module when certain conditions are met, which is built using a small buzzer for local notices and a piezo alarm to notify the user over longer distances.

The small alarm unit also has five modules which allow it to function, all of which must be designed with portability in mind. The power supply has an emphasis on portability, but must be able to supply a constant 3.3V to the entire small alarm unit for many hours on end between recharges. The distance sensor once again functions similarly to the one found in the main sensor box, utilizing RSSI and the state of the connection (connected/not connected) to determine how far the user is from the main control box. The controller takes input both from the distance sensor and the power supply, and outputs two different signals. The power supply input is processed in the form of a battery status display, telling the user how full the battery is so the user knows when to start recharging. The distance sensor input is processed and output into an alarm which has a snooze button to acknowledge that the user is aware of the stove still potentially being on.

Block Diagram



2.1 Main Sensor Box

The main sensor box is built to be a sensor package and a hub for the entire device's function. This module does all the heavy lifting and important functions, such as alerting the user of the stove being on, providing the bluetooth master for the distance sensor, and detecting and alerting the user in case of methane or propane gas leakage.

2.1.1 Power Supply (Main)

A power supply is required to keep the entire control box functioning at all times. Reliability is an emphasis, as many of these components are critical and any lapse could create its own danger. The entirety of the main sensor box can be run on 5V, so we realistically only need a power supply that can support 5V to the whole board.
We can use the SparkFun Power Delivery Board that supports USB-C input, as USB-C to wall outlet cords and converters are easy to obtain. The SparkFun Power Delivery Board supports anywhere from 5-20V output, and requires I^{2}C adjustment to function properly.

Requirement: Power Supply (Main) must provide consistent 5V at >0.8A to the rest of the components. Must also stay below 105 degrees Celsius (maximum operating temperature) at all times, even when an open flame is nearby.

2.1.2 Controller (Main)

In order to best process all of the incoming information, we have decided to use an Arduino Nano microcontroller due to its small form factor. While barebones, it also provides all the functionality required. It will take in analog and digital data, processes the data, and use that data to determine whether or not the alarm should be triggered. There are two conditions where the alarm should be triggered:

1. If the stove is turned on, the user must be reminded every so often that the stove is in fact still on. This is best tuned to be 1 minute in length, as the desired consumer response is awareness, not annoyance.
2. If the stove is turned on, but there is no flame, then there is a potential leakage of flammable gas. This must be dealt with urgently.

Requirement 1: The controller must be able to process analog voltage data as well as digital voltage data.
Requirement 2: The controller must either include a side module, or internally maintain an internal timer that sends out a signal every minute.
Requirement 3: The controller must be able to actually drive the alarm.

2.1.3 Flame Sensing

We know the flame of a stove will be powered mostly by methane, or failing that, will be powered through propane. Occasionally some will be powered by butane as well. Therefore, instead of detecting for the presence of a flame, we can detect the presence of dangerous gases, which allows us to conclude the absence of a flame.

2.1.3.1 Methane Sensor

The MQ-4 Methane Sensor allows us to sense a major component of natural gas, methane. This methane sensor outputs an analog signal in the form of increasing resistance. While we have a graph of the voltage in certain ppm (parts per million), we don’t know how sensitive it is to gas simply running past it.
Requirement: The methane sensor must be able to detect and output a reasonably large signal in the concentration of gas that a leaking stove would output.

2.1.3.2 Propane Sensor

The MQ-6 Flammable Gas Sensor allows us to sense two other components of natural gas, propane and butane. As it was made by the same manufacturer as the MQ-4 Methane Sensor, we find the same issues with tuning.
Requirement: The propane sensor must be able to detect and output a reasonably large signal in the concentration of gas that a leaking stove would output.

2.1.3.3 Intake Fan

As the control box will be sitting off the side of the stove instead of above the stove, we will have to pull gas to the side and past the two sensors in order to get a reasonable reading. We use a DC brushless fan to pull air through a tube containing both sensors to get a good reading of the gas in the air.
Requirement 1: The intake fan must run a reliable >15 CFM at 5V over the methane and propane sensors for them to pick up the presence of harmful gases. It must also have a strong enough suction force to pull in a plume of methane rising slowly in the air.
Requirement 2: The intake fan must be able to push the gas through a thin tube in order to nullify as many effects of turbulence and gas density as possible.
Requirement 3: The intake fan must dispose of measured gas into a safe location, the user's kitchen fume hood vent path.

2.1.4 Knob Sensing

The knob sensor at its barebones is built to detect whether or not the stove is running. We can achieve this through the use of a non-latching Hall effect sensor, which outputs high when a magnet is nearby and outputs low when the magnet is removed. By attaching a magnet to the knob of a stove and securing the Hall effect sensor close to the magnet, we can then detect the state of the knob.
Requirement 1: The Hall effect sensor must be able to detect the presence of the magnet on many different configurations of stove knobs. This is best possibly achieved through the use of a specialized mount.
Requirement 2: The Hall effect sensor should be implemented with unobtrusiveness in mind.

2.1.5 Alarm

The alarm sounds when the main controller decides that the user is at risk of the dangerous conditions it is coded to detect.
Requirement: The alarm must be able to sound at 70-80 dB. Fire alarms sound at minimum 65 dB, and as such we do not want the alarm to be any louder to protect the user's hearing.

2.1.6 Distance Sensor

The distance sensor utilizes the HC-05 Bluetooth Master/Slave Transceiver, which supports both Received Signal Strength Intensity (RSSI) tracking and state of the connection. This makes it perfect for our purposes, as we can simply monitor how far someone is judging by the connection integrity.
Requirement 1: The Distance Sensor must detect when a person has stepped beyond a certain threshold of distance.
Requirement 2: The Distance Sensor must automatically reconnect once back in range.

2.2 Personal Alarm

The personal alarm serves primarily as a portable extension of the distance sensor on the main sensor box, but also has additional functionality such as the ability to "snooze" the alarm, and the ability to show the current charge left in the battery. Due to the portability requirement, the personal alarm must stay at a compact, easy to carry size.
Requirement: The Personal Alarm must not exceed these dimensions. 6in length x 3in width x 2.5in depth.

2.2.1 Power Supply

A good power supply is required to keep the personal alarm functioning at all times. Input from a micro-USB or USB-C port will charge a Li-Ion battery, which can be then regulated to output 3.3V for the rest of the system.

2.2.1.1 Battery Babysitter

The Sparkfun Battery Babysitter is not a total requirement. It is only a stand-in for what will be a battery management system. All system power goes through the battery management system, such that when the battery is being charged, the system takes power from the charger outlet. When the battery is not being charged, the system takes power from the battery instead. This system is also used to measure the charge of the battery itself, outputting into the controller.
Requirement 1: The Battery Babysitter must be able to both charge the battery and discharge the battery to the system between 3.3V-3.7V while staying below 45 degrees Celsius (maximum safe battery temperature when charging). This either means a bidirectional power bus or two separate power buses.
Requirement 2: The Battery Babysitter must include a method to measure the battery charge and output it in the form of a data bus.
Requirement 3: The Battery Babysitter must accept some form of 5V charger input and convert it to a safe voltage for the battery to charge from. This can be either USB-C, micro-USB, or mini-USB.

2.2.1.2 Li-Ion Battery

The battery will be one of the heavier components in this project, so a balance must be achieved between capacity and portability. As Li-Po batteries are known to explode, caution must be taken with how it is handled.
Requirement 1: The battery must be able to store enough charge to provide at least 200 mA of current (30mA from Bluetooth + 150mA from controller + some spare) at 3.7V for 4 hours at a time.
Requirement 2: The battery must not be at risk of exploding if left on the charger.

2.2.2 Controller

Due to the strict size and power requirements of the personal alarm, we opted to use the Arduino Pro Mini 3.3v. This controller is built to interface with all the data buses on the device and perform the hard reset necessary for the Bluetooth controller.
Requirement 1: The controller must handle the hard reset on the HC-06 Bluetooth chip, if necessary. This is linked to the snooze button function of the alarm; as the controller must maintain an internal timer that counts down how long it's been since the Bluetooth chip has been disconnected. If this timer runs out, the controller must signal the alarm until the snooze button is pushed.
Requirement 2: The controller must be able to process the information from the battery babysitter and output information to the status display in the form of some battery percentage measurement.

2.2.3 Alarm

Being close to the user at all times, the alarm does not need to be as powerful as the siren on the main sensor box. However, this alarm will need to be reset by the user, as when the distance sensor detects that the user has walked too far from the stove, every 30 seconds the alarm on the user will sound until the user presses a snooze button, acknowledging that they do in fact remember the stove is still on.
Requirement 1: The alarm must output any form of audio between 50~60dB, the average range of a person speaking.
Requirement 2: The alarm must output its alert when the Bluetooth has been disconnected for 30 seconds, resetting its 30 second timer when the user presses the snooze button.

2.2.4 Battery Status Display

While not a strict requirement to the functionality of the personal alarm, should the battery run out mid-operation, disastrous consequences could result. As such, a basic display of how much battery life is left is a suggested course of action for devices like this.
Requirement 1: The battery status display should display the battery left in easy to understand intervals (25/50/75/100% capacity could work).
Requirement 2: The battery status display should not consume much power.

2.2.5 Distance Sensor

To track RSSI and connection status with the main sensor box, which is what we are using for distance detection, we utilize the HC-06 Bluetooth slave module. This module can only accept connection requests, which makes it suitable for our purpose as we do not want it connecting to anything other than the main sensor box. However, in no example or datasheet is the HC-06 known to automatically reconnect to its original device once in range. In all examples of the HC-06 functioning, though, it has been shown that the HC-06 will automatically reconnect to the original bluetooth device it was connected to if its power is cycled. In this case, we will have to

cycle the power to the HC-06 every so often so it can reestablish connection to the sensor box once in range.
Requirement 1: The Bluetooth module of the distance sensor must be able to automatically reconnect to the sensor box.
Requirement 2: The Bluetooth module must be able to output its current state (connected/disconnected) to the controller. If possible, the Bluetooth module should also output its RSSI (Received Signal Strength Intensity) to the controller for finer tuning on distance from the main sensor box.

2.3 Risk Analysis

Currently the block that looks like it will cause the most problems is power supply for the personal alarm. With the use of a lithium polymer battery, highly intensive care must be taken to ensure that the charging and discharging stays within specs of the battery. This risk should be mitigated with the use of a battery management system, which would be able to prevent mischarging of the battery, but there may potentially be a need for an active thermal regulation submodule.
Another potential source of problem may be the bluetooth modules. Because of the wireless nature, making sure the devices get connected and stay connected will be a top priority. There is a risk that the module may not want to work as they should, or that the Bluetooth signal may be blocked by electromagnetic devices such as blenders, or by radiation, such as from a microwave. These issues can only be discovered during the testing phase.

Safety and Ethics

Since the first proposal of this project, safety has been the most important aspect of the design. This device is designed to improve the safety of gas stoves by making sure that the operator does not leave it unattended. With safety being the focus, it is important that this device itself is safe to use around a stove. This includes the dangerous cases where there is a gas leak, or the stove flame went out with the gas still flowing. The devices must be designed and created so that it has the smallest possible chance of igniting anything. Safety is the most important and applicable Ethics code that this design must follow [4].

To help reduce the chance of the devices from igniting any gas that may be in the air, the devices will be surrounded in a flame arrester, which is a fine wire mesh that would contain any flame from spreading outside the enclosed area. This idea has been applied on lamps used in mines to stop the lamps from igniting a flammable atmosphere.

As for the other main part of the ethics code, they don’t really apply to the devices itself, but to us working on it. We must strive to work together and be respectful. This code of ethics should be understood and practiced by every engineer.

Laboratory Testing Safety

Due to the nature of this project, it is important to come up with specific testing procedures for safety reasons. The device is meant to be for fixed gas stoves, but testing the device on an actual stove would be difficult to test in ECEB. So, as an alternative, a small portable camping stove will be used as a substitute. This will make it portable and make it easier for non-flame testing. Using the actual flame, and propane is not needed for many parts of the testing, so for those parts we can just use the stove with no propane. For testing the flame sensors and gas sensors, testing cannot be done in ECEB. The building does not have the facilities to be running open flames with the possibility of small gas leaks. Using a fume hood would allow for the safe testing with the stove. This would require access to fume hood used in other college departments, such as the chemistry department. If this permission is not given, the flame testing would be held outside in a large, empty area, such as a parking lot. A 10 meter radius clear area will be enforced to ensure that a gas leak cannot catch fire due to nearby objects. With the air currents of the outdoors, we have a suitable gas dispersion method. For more safety, while testing it, a fire extinguisher would be on stand by just in case a fire breaks out. For the safety of the person conducting the flame testing, safety goggles, flame resistant clothing, and gloves should be worn.

References

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[4] IEEE.org, “IEEE Code of Ethics,” June 2020. [Online]. Available: https://www.ieee.org/about/corporate/governance/p7-8.html. [Accessed Feb. 15, 2021].