Dryer Sensing Array

Design Document

Group: 18 –

***Lukas Janavicius**: Physical Design, R&V, Block Diagram*

***Drew Ingram**: High-level, Visual Aid, Schedule*

***Stephen Gioja**: Cost, Safety and Ethics*

NetIds: janavic2, andrewi2, and sgioja2

TA: Charles Ross

ECE 445 – Spring 2020

Contents

1 Introduction

1.1 Objective

Improper use and maintenance of laundry dryers lead to the accumulation of lint and fabric softener in the dryer vent. Without the removal of this debris, the internal temperature of the dryer would be too high, resulting in dryer fires that could cause substantial property damage and potential bodily harm. A thermocouple could be used to measure the internal temperature of a dryer during its operation and a temperature above 250°F indicates a large accumulation of lint that must be cleaned out. However, such a solution is rather pricey with units costing about $100.

We propose a novel, easy-to-install system that can be attached to the exterior of the dryer. The add-on will have a temperature sensor, a pressure sensor to sense air-flow, and an inductance coil around the dryer's power wires to sense if it is in use. An ESP32 microcontroller would read the sensor data and alert the user if either the dryer is running and air-flow is below the baseline, the dryer is running and the temperature is increasing at a rate above baseline, or some combination of the two.

Finally, we propose simplifying the user interface by adding a second ESP module to the system. The sensing ESP will detect when the dryer begins running, make an assessment on the dryers cleanliness, and send the status signal to the second ESP. The second ESP, located on the top of the dryer, will then display the dryers status with a green or red LED. In this manner, our solution is designed to work out of the box, with no additional hardware or software to install by the end user.

1.2 Background

Laundry dryers are used frequently by consumers around the world. Yet, they are not always perfectly made, and improper use or lack of maintenance can cause malfunction. Excess lint from clothing and fabric softener from dryer sheets can accumulate in various areas of the dryer. This can then lead to air vents becoming clogged, and eventually, this excess lint may even cause overheating. When air temperatures exceed 250°F, a fire hazard may occur since cotton and wool burn at those temperatures. Our goal is to monitor the state of the dryer, and alert the owner if potentially dangerous conditions arise. This will allow the owner to avoid danger, maintain peace of mind, and make dryer maintenance easier. By doing this, fires and property damage may be avoided.

1.3 High-Level Requirements

- Our system should be able to accurately measure the temperature in the dryer with an accuracy of 5°F.
- Our system must be able to detect when the dryer is running, but air is not flowing sufficiently. This indicates a lint build-up, and that the dryer should be cleaned.

- Our system should be durable and robust enough to operate in the conditions required for dryer operation. It should be able to withstand the vibrations and heat produced well enough to last several years.

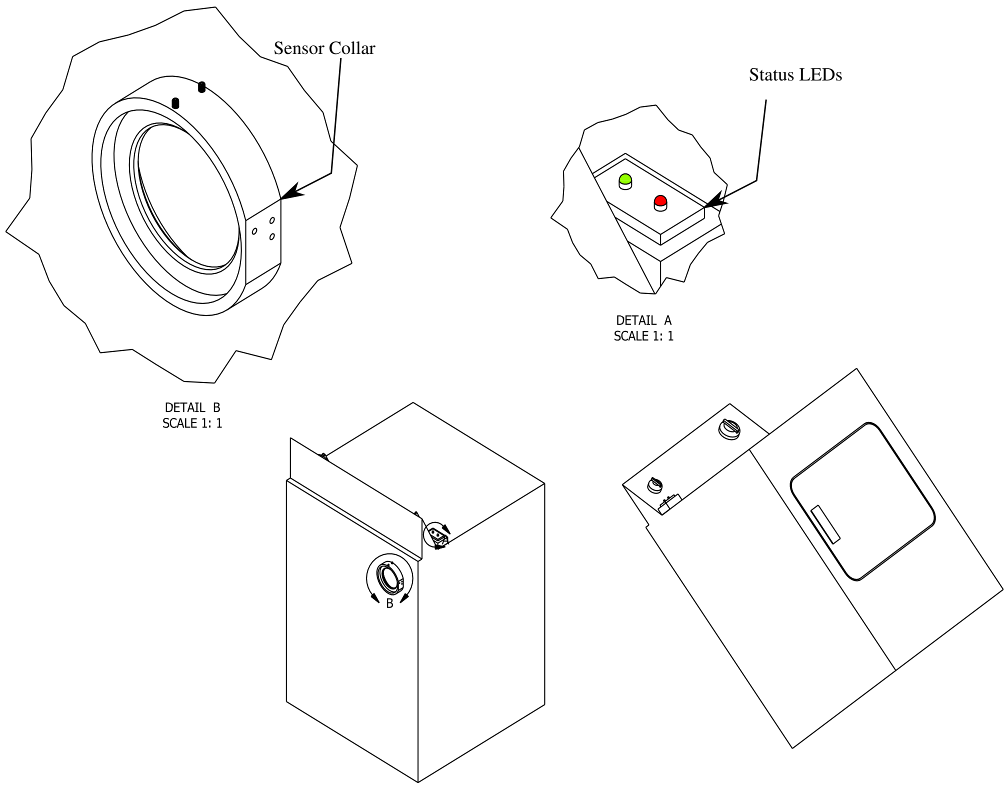

Figure 1. Sensors and status indicator mounted on the dryer. Detail A shows the indicator LED's, and Detail B shows the dryer collar.

2 Design

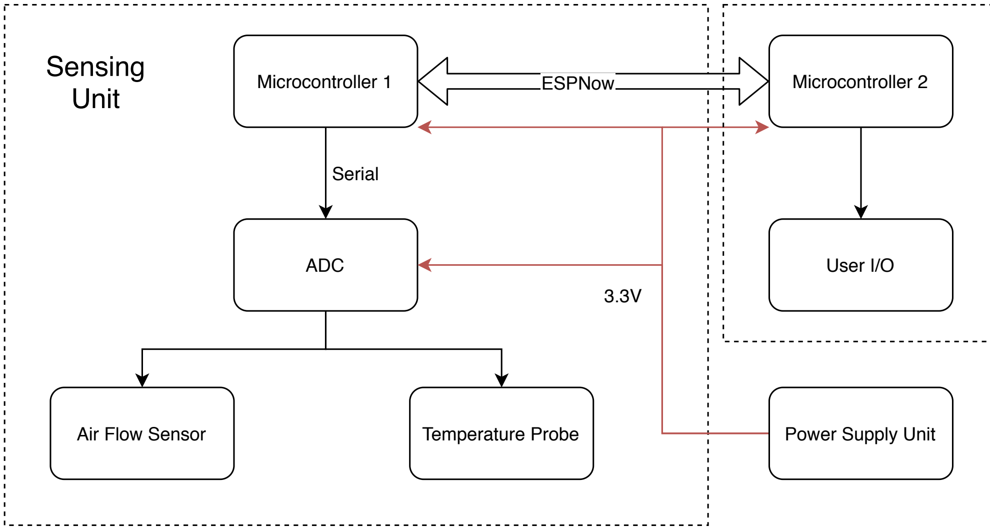

Figure 2. High-Level Block Diagram

The design requires three main components. The sensor block in-line with the dryer exhaust port which gathers flow and temperature data. The sending component consisting of an ESP microchip which collects the sensor data and sends it to the notification module using Bluetooth. The notification module consists of another ESP microchip and a status LED.

2.1 Sensing Unit

2.1.1 Microcontroller 1

This ESP32 controls the sensor array and communication to the user I/O. The ESP connects to the sensors either through serial or by reading their analog output with the ADC module. Communication to IO module will be over ESP-Now, a wireless communication protocol which allows for 1 master ESP to communicate with up to 20 slaves.
Requirement: Must host i2c, SPI, and ESP-now communications for the slave devices.

2.1.2 ADC

The ADC converts the analog output from the airflow and temperature sensors into digital format that be be read by the ESP32. Data should be sampled often enough to reflect real-time conditions in the dryer.
Requirement: Must sample data from both sensors at a frequency of 10 Hz's.

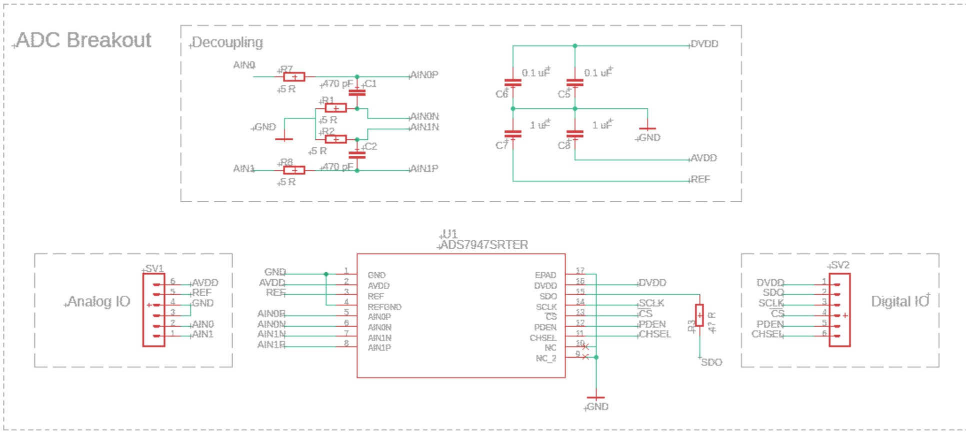

Figure 3. ADC Device Schematic

2.1.3 Air Flow Sensor

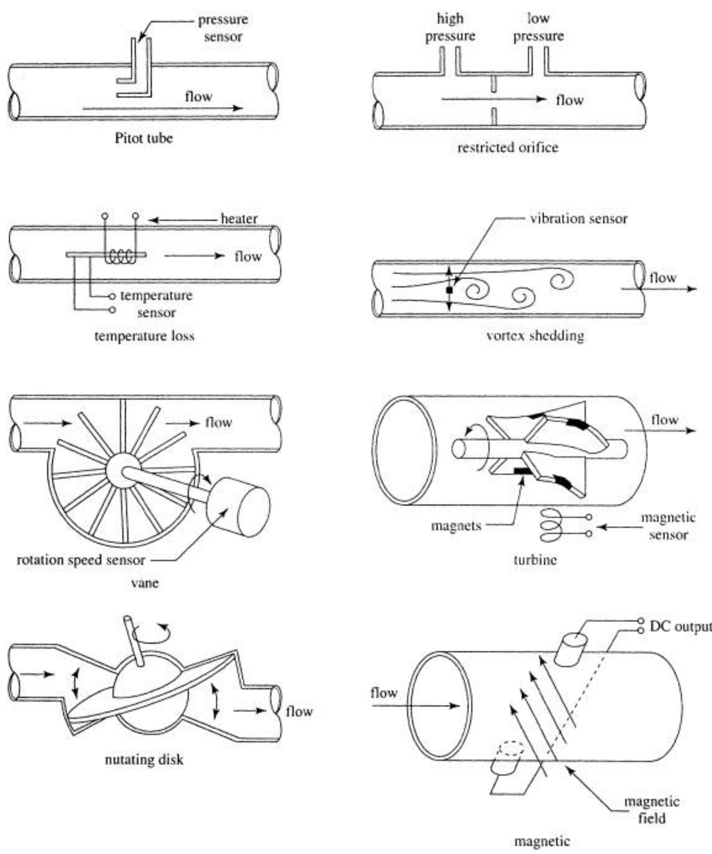

Figure 4. Reference, different configurations of air-flow meters [1]

A typical hot wire air-flow meter will not be safe in this scenario due to the flammable lint present in the dryer exhaust and a wire in the duct may cause further blockages. Instead we will use a dual-pressure sensor, either in a pilot tube or restricted orifice configuration, Figure 4. The restricted orifice configuration offers the advantage that the pressure inlet and outlet are shielded and perpendicular to flow, preventing accumulation of lint in the sensors.
Requirement: Must detect flows from 0-200 cfm, to accommodate the typical 100 cfm flow rate in commercial dryers [2].

2.1.4 Temperature Probe

The temperature sensor will be a thermocouple that can sense temperatures up to 400°F. Thermocouples require a dedicated sensing circuit, as traditional ADC neglect the junction effect of multi-metal systems, the operating principle behind thermocouples. A dryer should never go above 250°F, anything higher than that would indicate a problem.
Requirement: Must detect temperatures up to and exceeding 250°F in order to monitor safe dryer operation and detect hazardous conditions.

2.2 Microcontroller 2 and User Interface

The two ESP units will communicate with one another using their native ESP-now protocol. The dryer's ultimate status is reported through a green LED for normal operation, and a red LED for required cleaning.
Requirement: Must communicate real-time dryer status to owner through a simple, intuitive interface.

2.3 Power Supply Unit

The ESP32s will be powered by a typical wall socket 5v adapter with a USB cable, avoiding the battery change required in the original design.

3 Physical Design

Our physical design serves as a convenient sensor mount, and as a critical component to the airflow sensing. The chamfered central spine serves to restrict airflow, allowing for us to measure the pressure drop caused by the dilation, and therefore the flow. The third mounting point samples the inlet temperature.

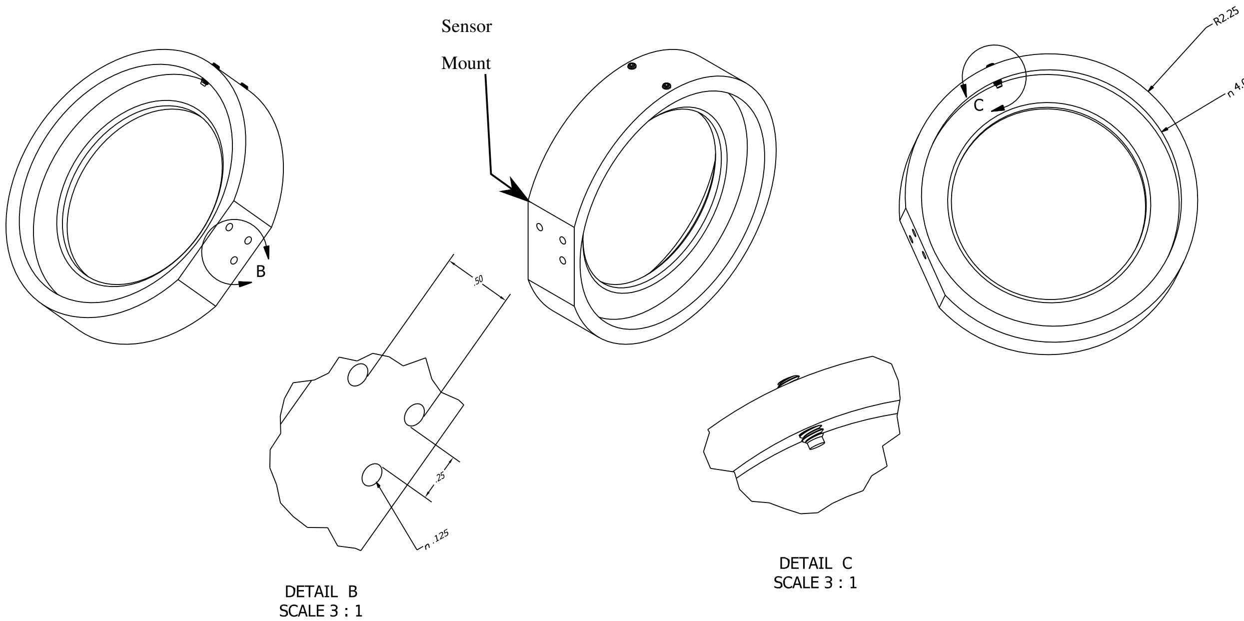

Figure 5. Standard dryer collar with sensor mount. Detail B shows the three sensor mounting holes, and Detail C shows the set screw mechanism.

3.1 Risk Analysis

The most challenging design component will probably be modeling the flow and temperature at the duct to find the internal temperature withing the dryer. Then standardizing it across every dryer within a reasonable amount. We will have to test in multiple dryers with varying amounts of flow blockage, varying internal temperatures, and different external temperatures.

There is also a possibility of the flow meter becoming blocked over time. We will have to test our meter with differing moisture and lint contents over a long period of time to ensure this doesn't occur.

4 Requirements and Verification

4.1 Sensing Unit [40 Points]

Requirement	Verification
Must accurately monitor dryer conditions in real time through use of sensors.	(a) Temperature sensor can be tested and calibrated using a heat source of known temperature, such as an oven. (b) Accurately measure air flows relevant to dryer operations (100 cfm) (c) Use sensor information to accurately determine the operating conditions inside the dryer.

4.2 User Interface [30 Points]

Requirement	Verification
Must display dryer status through a simple, intuitive interface.	(a) LED can be controlled in order to indicate status of dryer. (b) LED will indicate if an error has occurred in our monitoring system. (c) LED will indicate if hazardous dryer conditions are detected.

4.3 Microcontroller Communication [30 Points]

Requirements	Verification
1. Microcontroller units must be able to wirelessly communicate real-time dryer status. 2. SPI communication must support atleast 10 communications each second or atleast 30kbps.	1. (a) Configure the ESP to PWM 0-40 MHz on all clock related GPIO. (b) Confirm all clock pins can output at least their respective maximum frequencies with an oscilloscope. 2. (a) Establish SPI communication with the ADC (b) Generate a 500 KHz sine wave with a function generator. (c) As before, if the microcontroller reconstructs the signal, the data-rate exceeds 30 Kbps.

5 Project Differences

Original Solution: "A more cost-effective user-friendly dryer temperature probe can be created by utilizing three components. The temperature probe would be a k-type thermocouple that can withstand and measure temperatures of up to 350°F inside the dryer while it is running. The hardware unit would physically be placed on top of the dryer while it is running to read the data, convert it from analog to digital, and transmit the data via BlueTooth. A smartphone would then be used to view the temperature data in real-time and indicate whether or not the temperature is potentially dangerous. This interface would be more user-friendly compared to the LCD display commonly found on handheld thermocouple temperature sensors."

Most people will not want to or be able to take apart their dryer to install a thermocouple into the lint trap. Additionally, the single sensor approach may lead to false positives because of ambient temperature changes; the lint trap of a dryer, gas or electric, should always connect to the outside through an air duct [3]. To combat the ambient temperature effects, we recognize that the heat removed from the dryer, by air, is directly proportional to the mass flow of the air through the dryer [4]. Hence, we are interested in the rate of temperature change in the dryer once it has started, or the airflow through the output.

6 Cost and Schedule

6.1 Cost Analysis

We estimate the hourly rate at approximately $42/hr using Engineering Illinois's calculated average salary of $84,250 for the year 2014-2015. The number of hours each of us spend per week will vary throughout the semester, but we estimate 10hrs/wk average for the three of us and be able to complete the prototype design within the remaining 8 week semester, Equation 1

$$3 \times \frac{\$42}{\text{hr}} \times \frac{10\text{hr}}{\text{wk}} \times 8\text{wk} \times 2.5 = \$25,200 \tag{1}$$

Our parts and prototype creation costs are estimated to be $2.98 per unit.

Part	Cost
ESP32 dual core microcontroller breakout board (mouser)	$10.00
TI Analog to Digital converter ADS7947SRTER (mouser)	$3.59
Board Mount Pressure Sensor 403-SDP31 (mouser)	$34.10
Thermocouple 1286-1099-ND (digikey)	$9.99
Assorted Resistors, Capacitors, ICs, Sockets	$10.00
PCB (PCBWay)	$4.60
Total	$72.28

We plan to build 5 prototypes with a total production cost of $25,561.

6.2 Schedule

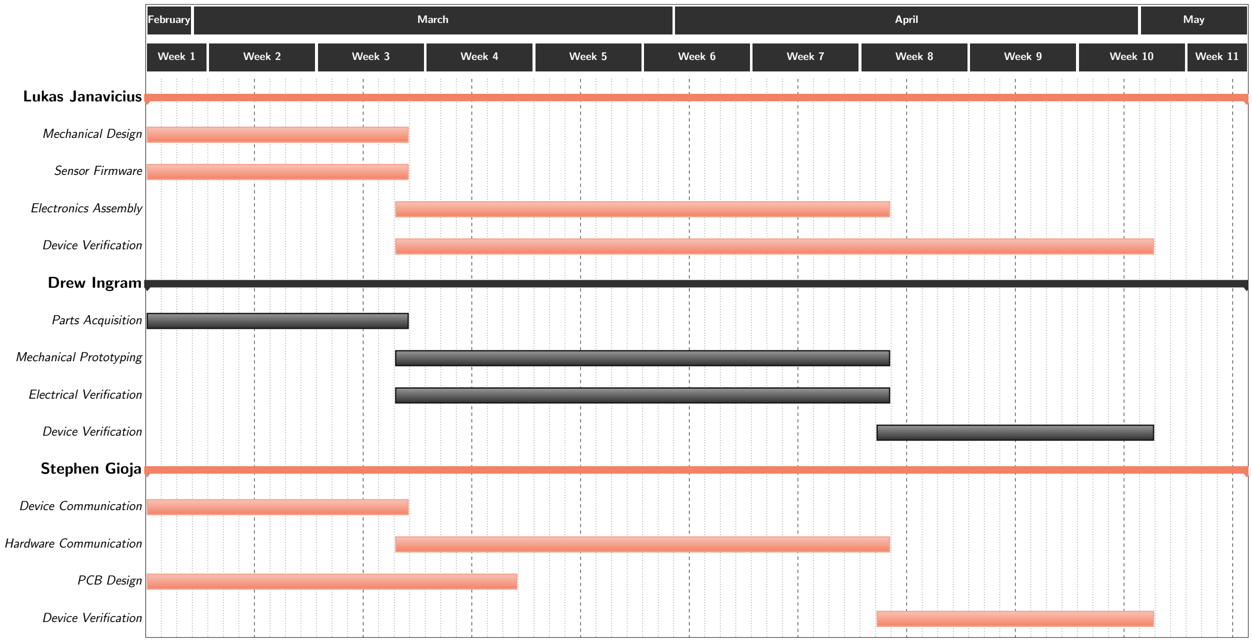

Figure 6. Project Schedule.

7 Safety and Ethics

7.1 Safety

The idea of this design is to improve safety, however there are a few things that could still be hazards. The sensors could break or stop functioning, resulting in a potential overheating situation that doesn't get noticed. Our code will ensure that the error light flashes red if a sensor fails. The connection between Microcontroller 1 and 2 could fail. We will ensure the light flashes red to notify the user there is an error.

7.2 Ethics

The primary goal of improving a product design is to enhance people's lives as seen in section 3.1 of the ACM Code of Conduct [5]. We will accomplish this by adding a safety device to any dryer which will notify the user if the dryer malfunctions. It will also alert the user if the lint trap needs to be cleaned.

This project is also going to be designed to prevent harm to others which is a large component to the ACM Code of Conduct section 1.2. [5] Fires caused by dryers overheating or getting clogged cause 2900 house fires in the US every year [6] with 34% of those caused by not cleaning the lint trap. Our sensor array will be designed to minimize the risk of dryer caused house fires.

We recognize that owners will rely on our product for the safety of their possessions and of themselves. We must be sure that our product is dependable in order to meet this responsibility.

References

[1] "Technology and Principles of Operation of Flow Sensors." [Online]. Available: https://www.pc-control.co.uk/flow_sensors.htm

[2] P. Pescatore and P. Carbone, "High Efficiency, High Performance Clothes Dryer." [Online]. Available: https://www.osti.gov/servlets/purl/888669

[3] "What Is the Danger of Running a Dryer Not Vented Outside? — Hunker." [Online]. Available: https://www.hunker.com/13410484/what-is-the-danger-of-running-a-dryer-not-vented-outside

[4] "Cooling Flow Calculation." [Online]. Available: https://www.rotron.com/tech-corn/cooling-flow-

[5] "ACM Code of Ethics and Professional Conduct." [Online]. Available: https://www.acm.org/code-of-ethics

[6] "Clothes Dryer Fires in Residential Buildings (2008–2010)," Tech. Rep., 2012. [Online]. Available: https://www.usfa.fema.gov/downloads/pdf/statistics/v13i7.pdf