

# Dryer Diagnostic Unit

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Senior Design

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## **1. Introduction**

### **1.1 Objective**

The mechanical status of a clothes dryer is not directly available to its user. Our product is an external diagnostic unit that informs the user if a dryer needs service.

The diagnostic unit consists of a temperature sensor that is temporarily placed inside the dryer and a control box placed outside of the dryer.

The diagnostic unit will transmit temperature readings to a mobile app. Based on the temperature data, the mobile app informs the user about the mechanical conditions of the dryer.

### **1.2 Background**

The temperature inside clothes dryers has an optimal range of between 85 °C and 100 °C. However, mechanical failures inside dryers may cause dryers to overheat and induce safety concerns.

For example, the embedded temperature sensor inside a dryer may have worn-out metal contacts or have metal contacts covered by volatilized fabric softener; this type of failure causes the embedded temperature sensor to output inaccurate temperature readings and undermines the sensor's ability to prevent dryers from overheating. A clogged vent can decrease the dryer's heat dissipation rate; this type of mechanical failure also causes the dryer to overheat.

Typical household consumers are often unaware of the overheating issue and have limited knowledge of when their dryers may need service. Our product aims to provide a low-cost solution to inform users about the mechanical status of their dryers.

### **1.3 High-Level Requirements**

- (1) The sensor module measures the temperature inside a dryer with an accuracy of 5 °C.
- (2) The mobile app warns the user when the temperature inside the dryer is above 100 °C.
- (3) The mobile app refreshes temperature readings once per second.

## 2 Design

The dryer diagnostic unit has a power module, a sensor module, a control module, and a software module. The power module provides a steady 5 V voltage to the sensor module and the control module. The sensor module uses a K-type thermocouple to measure the voltage change that corresponds to temperature change inside a dryer. The control module converts the voltage measurements to temperature readings and sends the temperature readings to a database. The software module downloads temperature readings from the database and displays them on an app. The block diagram of the dryer diagnostic unit is shown in Figure 1. The PCB design of the dryer diagnostic unit is shown in Figure 2.

Figure 1 - Block Diagram of the Dryer Diagnostic Unit

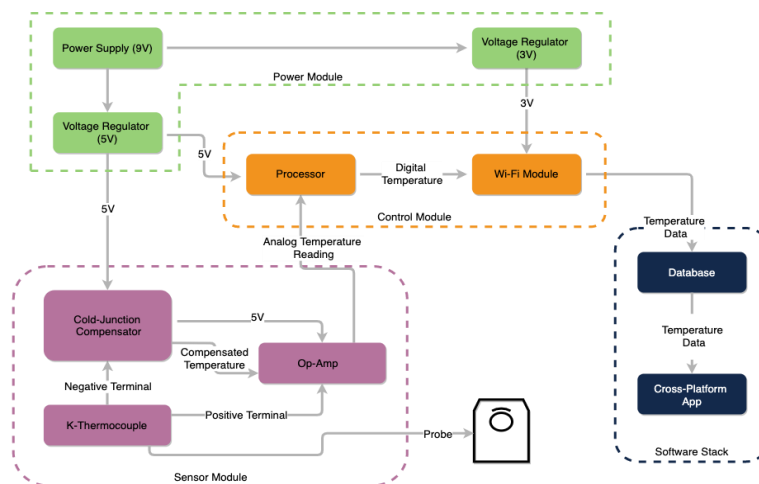
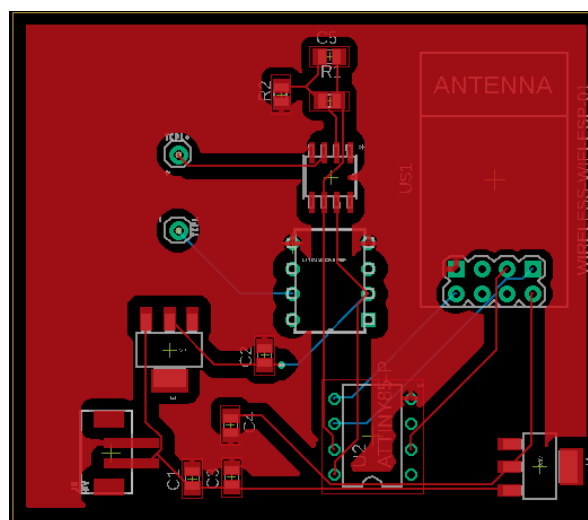


Figure 2 - PCB Design of the Dryer Diagnostic Unit



## 2.1 Power Module

### 2.1.1 Battery

The battery will provide power to the sensor module and the control module. The battery is a 9 V, PP3-sized battery. Table 1 outlines the requirement and verification of the battery.

Table 1: Requirement and Verification of the Battery

Requirement	Verification
(1) The battery outputs a voltage of 9 V $\pm$ 5%.	(1a) Connect the positive end of the battery to the red probe of a multimeter; connect the negative end of the battery to the black probe of the same multimeter. (1b) Set the multimeter to measure the voltage in the 20 V (dc) range. (1c) Verify that the measured voltage is within the range of 9 V $\pm$ 5%.

### 2.1.2 Voltage Regulator

Two voltage regulators are planned. The first voltage regulator will provide a steady 5 V voltage to the cold junction compensator (LT1025). The second voltage regulator will provide a steady 3.3 V voltage to the controller (ATtiny85). The two voltage regulators are low-dropout linear regulators (LM1117). Table 2 outlines the requirements and verification of the voltage regulators.

Table 2: Requirement and Verification of Voltage Regulator

Requirement	Verification
(1) The first voltage regulator outputs a voltage of 5 V $\pm$ 5%.	(1a) Connect the positive end of the 9 V battery to the input pin of the voltage regulator; connect the negative end of the battery to the ground pin of the voltage regulator. (1b) Connect the red probe of a multimeter to the output pin of the voltage regulator; connect the black probe of the multimeter to the ground pin of the voltage regulator. (1c) Verify that the measured voltage is within the range of 5 V $\pm$ 5%.
(2) The second voltage regulator outputs a voltage of 3.3 V $\pm$ 5%.	(2a) Repeat (1a) and (1b) using the 9 V battery and the 3.3 V voltage regulator.

	(2b) Verify that the measured voltage is within the range of $3.3 \text{ V} \pm 5\%$ .
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## 2.2 Sensor Module

### 2.2.1 K-Type Thermocouple

The K-type thermocouple is placed inside the dryer near the lint filter, which is the area inside the dryer the has the highest temperature. The K-type thermocouple is selected because its accurate measurement in the range of temperatures that occur inside a dryer (20 °C - 150 °C). Table 3 outlines the requirement and verification of the K-type thermocouple.

Table 3: Requirement and Verification of K-Type Thermocouple

Requirement	Verification
(1) The thermocouple has a resistance of less than $10 \Omega$ between the positive lead wire and the negative lead wire.	<p>(1a) Connect the two leads of the thermocouple to a lead connector that has a positive lead wire and a negative lead wire.</p> <p>(1b) Connect the two lead wires of the lead connector to a multimeter using alligator clips.</p> <p>(1c) Use the multimeter to measure the resistance. The measured resistance is the resistance between the positive lead and the negative lead of the thermocouple.</p> <p>(1d) A measured resistance of less than <math>10 \Omega</math> indicates that the thermocouple has no internal disconnection.</p>
(2) The thermocouple, when connected to the amplifier, has a 100 mV increase in output voltage when temperature increases by 10 °C.	<p>(2a) Connect the thermocouple to the lead connector.</p> <p>(2b) Connect the positive lead wire to an operational amplifier.</p> <p>(2c) Connect the negative lead wire to the cold junction compensator.</p> <p>(2d) Increase the temperature of the hot junction of the thermocouple by 10 °C.</p> <p>(2e) Observe the measured voltage on the multimeter and verify that the measured voltage increases by 100 mV.</p>

### 2.2.2 Cold Junction Compensator

The thermocouple measures the temperature difference between its hot junction and cold junction. In practical settings, the cold junction is at room temperature. If we directly measure the temperature difference between the two junctions, the measured difference is the difference between the temperature of the measured object and the room temperature, rather than the actual temperature of the measured object.

The cold junction compensator (LT1025) simulates a 0 °C environment at the cold junction of the thermocouple. Using the cold compensator, the measured temperature difference is the actual temperature of the measured object. Table 4 outlines the requirement and verification of the cold junction compensator.

Table 4: Requirement and Verification of Cold Junction Compensator

Requirement	Verification
(1) When the cold junction compensator is connected to the thermocouple and the amplifier, the output voltage at the amplifier is within 5% of the expected voltage.	<p>(1a) Connect the circuit as described in the Requirement and Verification table for the K-type thermocouple.</p> <p>(1b) Connect the amplifier output to the positive end of the multimeter. Connect the ground to the negative end of the multimeter.</p> <p>(1c) Read the measured voltage on the multimeter.</p> <p>(1d) If the amplifier has a gain of 220 V/V, then the amplifier output at 25 °C should be 0.22 V.</p> <p>(1e) Calculate the percent difference between the measured voltage and the theoretical value of 0.22 V.</p>

### 2.2.3 Operational Amplifier

The operational amplifier (LTC1049) amplifies the output voltage of the thermocouple. The amplifier is necessary because the output voltage of the thermocouple is in the  $\mu\text{V}$  range, while the precision of the controller (ATtiny85) is in the mV range. If the output voltage were directly connected to the controller, then a change in output voltage is undetectable by the controller. Table 5 outlines the requirement and verification of the operational amplifier.

Table 5: Requirement and Verification of Operational Amplifier

Requirement	Verification
(1) The amplifier has a gain of 220 V/V.	(1a) Generate a sinusoidal waveform of 100

	<p>Hz and 0.05 V peak-to-peak using a function generator. Connect the sinusoidal waveform to the input of the amplifier.</p> <p>(1b) Power the amplifier as specified in its datasheet.</p> <p>(1c) Connect the output of the amplifier to an oscilloscope.</p> <p>(1d) A measured output voltage of 11.0 V peak-to-peak indicates that the amplifier has a gain of 220 V/V.</p>
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## 2.3 Control Module

### 2.3.1 Microcontroller

The output of the amplifier is connected to the analog input of the microcontroller. The microcontroller (ATtiny85) reads the changes in the output of the amplifier, and converts such changes into temperature values. Table 6 outlines the requirement and verification of the microcontroller.

Table 6: Requirement and Verification of Microcontroller

Requirement	Verification
(1) The size of the written code does not exceed the available memory of the controller.	<p>(1a) When uploading the written code to the controller, check the notification in the Arduino IDE.</p> <p>(1b) The IDE will not upload the code to the controller if the code reaches the size limit.</p>

### 2.3.2 Wireless Transmitter

The wireless transmitter (ESP8266) will transmit data from the controller to the database. Table 7 outlines the requirement and verification of the wireless transmitter.

Table 7: Requirement and Verification of Wireless Transmitter

Requirement	Verification
(1) The wireless module transmits data to a wireless network.	<p>(1a) After the database is set up, program the wireless module to upload a temperature value to the database.</p> <p>(1b) Check the database and verify that the</p>

	temperature value is uploaded successfully.
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## 2.4 Software Module

The database stores available temperature data from the sensor module. The app displays the stored data from the database. When multiple dryer diagnostic units are available, the temperature data from multiple diagnostic units can be aggregated for analysis. Table 8 outlines the requirement and verification of the software module.

Table 8: Requirement and Verification of Software Module

Requirement	Verification
(1) The app refreshes temperature display once per second.	(1a) After the database and the app are both set up, send several temperature values to the database. (1b) Observe the temperature display on the app and verify that the temperature refreshes once per second.
(2) The app sends a warning message to the user when the temperature is higher than 100 °C.	(2a) Send several temperature values higher than 100 °C to the database. (2b) Observe the app display to verify that a warning message shows on the app.

## 2.5 Tolerance Analysis

The risk comes from the thermocouple and the cold junction compensator. We found it difficult to unit test the thermocouple for accurate voltage output, and we found it difficult to unit test the cold junction compensator. If either the thermocouple or the compensator does not work properly, our product would not work.

## 2.6 Contingency Plan

If the university moves to online instruction, we will have to finish the product without accessing the labs. We will still be able to finish a prototype on breadboard, but we would need to find alternative resources to order the PCB. We intend to finish measurements as soon as possible, so we would not have to purchase additional instruments. Once we make the prototype, the testing can still be completed using a dryer. The software would remain unchanged, as we can finish the software development remotely.



### 3. Cost and Schedule

#### 3.1 Cost Analysis

Based on our research, a student graduated from the computer engineering program from the Urbana campus has an average starting salary of about 80-100k. This roughly translates to \$40/hour. The whole project is roughly 10 weeks, with three students working on it for roughly 8 hours per week. Therefore, the total labor cost are:

$$10 \text{ weeks} \times 3 \text{ students} \times 40 \text{ \$/hr} \times 8 \text{ hr/week} \times 2.5 = \$24,000$$

The component costs for the prototype are listed in Table 8.

Table 9: Components and Costs

Component	Cost
9 V Battery x2 (MN1604)	\$4.46
Battery Connector Male (PRT-09749)	\$0.95
3 V Converter (LM1117MP-33-NOPB)	\$1.11
5 V Converter (LM1117DTX-5.0/NOPB)	\$1.44
K-Type Thermocouple (SEN-13715)	\$5.00
Thermocouple Connector Female (290-1986-ND)	\$6.75
Op-Amp (LTC1049CN8#PBF-ND)	\$4.82
Cold Junction Compensator (LT1025CN8#PBF-ND)	\$5.72
Microcontroller (OLIMEXINO-85-ASM)	\$6.91
Wireless Transmitter (1568-1235-ND)	\$6.49
Snap Connector (PRT-00091)	\$1.25

The sum of parts in total is \$44.90. The cost is an important factor in our project, and the current cost is still higher than what we expect. However, retail prices are usually much higher than bulk purchase prices. If we make hundreds or thousands of units in the future, the cost reduction amounts to less than \$10.

#### 3.2 Schedule

Table 10: Weekly Schedule of the Team

Week	Xiaobai	Chenlong	Supransh
9/28	Research and work on Design Document draft	Research and work on Design Document draft	Research and work on Design Document draft
10/5	Finalize the design	Finalize the design	Finalize the design

	and submit our part order to machine shop	and submit our part order to machine shop	and submit our part order to machine shop
10/12	Finish the Soldering Assignment and start ordering Wi-Fi and Bluetooth module	Design the circuit schematics and finish Soldering assignment	Design the circuit schematics and finish Soldering assignment
10/19	Start learning about Flutter, download Flutter on Windows	Finish the circuit schematics, and get all parts ready	Finish the circuit schematics, and get all parts ready
10/26	Have some basic understanding of Flutter and make the first flutter app	Build a first prototype on breadboard and refine the parameters of components	Build a first prototype on breadboard and refine the parameters of components
11/2	Finish the app of our project	Test the prototype Modify the prototype if needed	Test the prototype Modify the prototype if needed
11/9	Test and debug for the app	Test the prototype and the app	Test the prototype and the app
11/16	Finish the first version of our project and prepare for Mock Demo	Finish the first version of our project and prepare for Mock Demo	Finish the first version of our project and prepare for Mock Demo
11/23	Thanksgiving Break	Thanksgiving Break	Thanksgiving Break
11/30	Finalize our project and present our project	Finalize our project and present our project	Finalize our project and present our project
12/7	Finish the Final paper	Finish the Final paper	Finish the Final Paper

## **4. Ethics and Safety**

### **4.1 Ethics**

Since the project is designed for use by the sponsor in a real-world setting, we need to keep ethical considerations in mind.

Our project may have some safety issues. We need to make sure that our product is safe for the user, as mentioned in IEEE ethics code 1 [1]. Before we release the product, we must perform testing to make sure the product is safe to users. We could list all potential safety issues on the description and package it with the product. We need to present all our work to the public honestly, listing all potential danger or harm to users.

We need to listen to and respect all potential criticism of our product, and we must credit others' work in our projects, listing all parts we used and ideas we referenced from others, especially the team working on this project last semester. As mentioned in IEEE ethics code 5 "to seek, accept, and offer honest criticism of technical work, to acknowledge and correct errors, to be honest and realistic in stating claims or estimates based on available data, and to credit properly the contributions of others;" [1].

Some apps have limitations on regions, and to avoid these limitations, we plan to make our app available for free across different platforms, following the IEEE ethics code 7 [1].

### **4.2 Safety**

Safety is of utmost importance. To ensure the safety of our team members, we will follow the safety guide of ECE 445 when we work on the project in a lab. We will make sure at least two students work in the lab together, and every student will finish the safety training prior to entering the lab.

Also, we need to make sure that our users are safe when using the dryer diagnostic unit. First, we need to make sure that injury will not result from the high temperature inside the dryer and the electronics of our PCB. We will print a warning message on the external of our product to remind users that the thermocouple will operate at a high temperature when a dryer is running or just stops running. Also, we need to make sure that our app is safe to users, and it does not collect private information from our users.

## References

[1] "IEEE Code of Ethics", *ieee.org*, 2020. [Online]. Available: <https://www.ieee.org/about/corporate/governance/p7-8.html>.