University of Connecticut Department of Electrical and Computer Engineering

ECE 4901: Fall 2017 – Spring 2018

Team 1817 (Hubbell):
Electrical plug, connector, and receptacle temperature sensor

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Abstract

The electric plug, connector, and receptacle temperature sensor project is sponsored by Hubbell Wiring in Shelton, CT. Hubbell is the manufacturer of Twist-Lock plugs, connectors, and receptacles. High temperatures may indicate faults in components. The project goal is to optimize a temperature sensing system by miniaturizing a sensor array. These sensors will need to communicate wirelessly with a microcontroller to transmit temperature information.

Background

Excessive temperatures in wiring devices can indicate faults and contribute to a shorter than expected lifespan. Due to the size of plugs, connectors, and receptacles and the potential for high voltage, currents and temperatures, a temperature sensor must be developed that is robust, yet discreet. In the development, the optimization of existing temperature sensing technology is essential for the miniaturization of the sensor. The two technologies most fitting for the design are Resistance Temperature Detectors (RTDs) and Infrared Devices (IR devices).

RTDs detect temperature by changing their internal resistance in the presence of heat. They must be contact or in close proximity to the object being measured. They are highly accurate and have a very wide operating range.

IR devices detect temperature by measuring the radiation coming off of an object in the long-wave infrared region (8-15 micrometers). The IR device does not have to be in contact or even close proximity to measure temperature. However, the ambient temperature must be known. This problem can be overcome by using an RTD to measure the ambient temperature.

To increase accuracy and to improve reliability, the prototyping stage will be very important. Testing the existing technology under different conditions and configurations will lead to the most successful device.

Proposal

Objective

The goal of our design is to revolutionize the market with a unique approach to sensing the temperature of high AC voltage products using market available components in an optimal fashion. Specifically, to do so in a 1 inch by 1 inch component density with the implementation of temperature readout. Our sensors should have an accuracy within 1 degree celsius and have a temperature reading range of -20 degrees celsius to 80 degrees celsius. This is to be done with a microcontroller that can read from multiple temperature sensors. Overall, the implementation of our final design cost should fit under our $8 USD budget.

Budget

Hubbell Inc. has provided the team with a final product cost of $6 to $8 USD per module. This budget does not include testing material costs. Most testing materials are purchased in quantities of 3 in order to evaluate manufacturer deviations of the same product and the impact this will have on our design. Therefore the testing cost is almost triple that of our expected cost.

Solution

General

Based on the sponsor's requirements and specifications, our team has decided that the most viable options for our project is Infrared (IR) sensing technologies and Resistance Temperature Detectors (RTDs). IR technologies are the best option for noncontact temperature measurement. The best option for contact measurements are the RTDs which provide incredible accuracy, stability, and repeatability.

RTD

A resistance temperature detector (RTD) measures temperature by correlating the resistance of the RTD element with temperature. The relationship between resistance and temperature is given in the equation shown below.

$$R = R_o(1 + \alpha(T - T_{ref}))$$

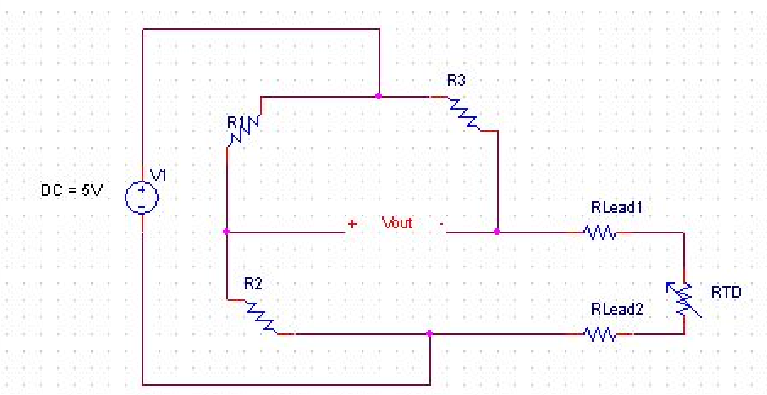
The paraments R_o , α , T_{ref} are all known based on the RTD element. Therefore, at a temperature T, resistance can be determined. RTDs are generally used for close proximity purposes or in contact with the surrounding or object. The typical temperature range that they operate range from -60℃ to 600℃. This temperature range will depend on the RTD element. RTDs provide incredible accuracy within 1℃ or better. The most common RTD composition materials are Copper, Nickel, and Platinum.

RTDs come into two basic styles: Wire-wound and Thin Film. Wire-Wound RTDs are constructed using a wire wound around a ceramic or glass bobbin in one of two configurations: birdcage or helix. The birdcage configuration keeps the RTDs wire loose and enables the wire to expand and contract freely with changes in temperature. This configuration reduces long-term stress-induced resistance change, but the downside to this configuration is the susceptibility to vibration. In helix configuration, a bifilar winding is wound around the bobbin and then sealed with some non-conductive coating. This configuration helps protect against vibration, but is prone to long-term stress induced resistance change depending on the RTD element.

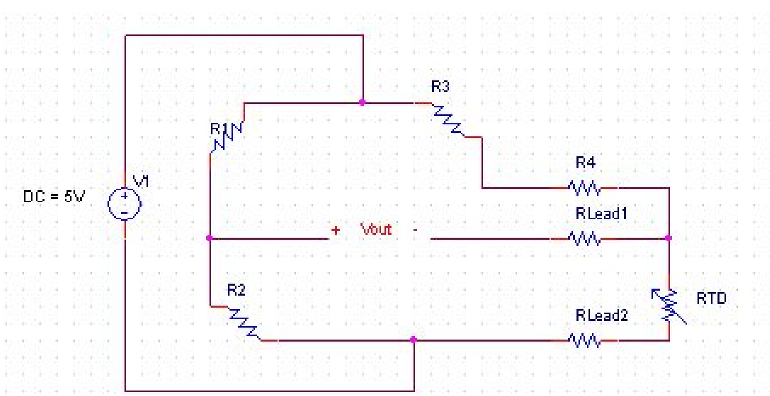
Thin-Film RTDs are constructed by depositing some metal alloy film onto a substrate, etching the shape of the resistive element, and then sealing the sensor. These types of RTDs are smaller, faster, and much less expensive than Wire-Wound RTDs. The drawbacks to Thin-film RTDs include poor long-term stability and narrower temperature range.

As far as the circuitry is concerned, RTDs have three circuit configurations: 2-Wire, 3-Wire, and 4-Wire. 2-wire configuration is the least accurate of the 3 types. In the 2-wire configuration, lead wire resistance is not eliminated from the sensor measurement which results in its measurement error. 3-Wire circuit configuration is the choice for industry purposes, where the third wire enables a method for removing the error from 2-wire configuration from sensor measurements. 4-wire configurations is the best option for high-accuracy results while it can also provides the resistance of the lead wires.

2-Wire and 3-Wire circuit configurations are shown below.



2-wire configuration



3-wire configuration

Infrared (IR)

For the specifications provided by Hubbell, some infrared technologies could be utilized for the given temperature range. For the range of -20℃ to 80℃, the long wave infrared spectrum can be used. The long wave spectrum includes the wavelengths from 8 micrometers to 15 micrometers. The measurement of temperature using IR technology is based off of the Stefan-Boltzmann law:

$$P = \varepsilon\sigma A(T - T_c)^4$$

where P is the net power radiated in watts of the object being measured, ε is the emissivity of the object being measured, σ is Stefan's constant, A is the area being measured on the object, T is the temperature of the object being measured, and T_C is the ambient temperature of the environment where the object is. From this it can be seen that the ambient temperature is necessary to find the absolute temperature of the object. One of the great benefits of the IR technology is that it is a non-contact method allowing no damage to occur to both the temperature sensing device and the object being measured if the temperature is extreme.

Some current components utilizing IR technology are the bolometer and IR thermopiles. The bolometer is extremely accurate, however, it far exceeds our final budget. Thermopiles, on the other hand, fall within our budget as well as requirements for the temperature range and accuracy. Thermopiles utilize the IR radiation in a different way in that they do not measure the power radiated directly.

At a base level, a thermopile is made up of many thermocouples placed in series. A thermocouple is made up of two dissimilar metals that form a junction. If there is a temperature difference between the two junctions of the metals, a small voltage will be produced. This is the Seebeck effect. The Seebeck effect of a single thermocouple can be modeled as:

$$V_{Out} = S * (T - T_{Ref})$$

where V_{out} is in volts, S is the Seebeck coefficient in Volts per degree celsius, T is the temperature at the junction of the dissimilar metals, and T_{Ref} is a reference temperature (ambient temperature). This voltage tends to be extremely small in the realm of millivolts, however it can be increased by placing many thermocouples in series forming a thermopile. With thermopiles the output voltage is based off of:

$$V_{Out} = N * S * (T - T_{Ref})$$

where all of the values are the same as the thermocouple case, with the addition of N which is the number of thermocouples in the thermopile. This allows for a higher output voltage. The temperature difference observed is due to the location of the dissimilar metal junction.

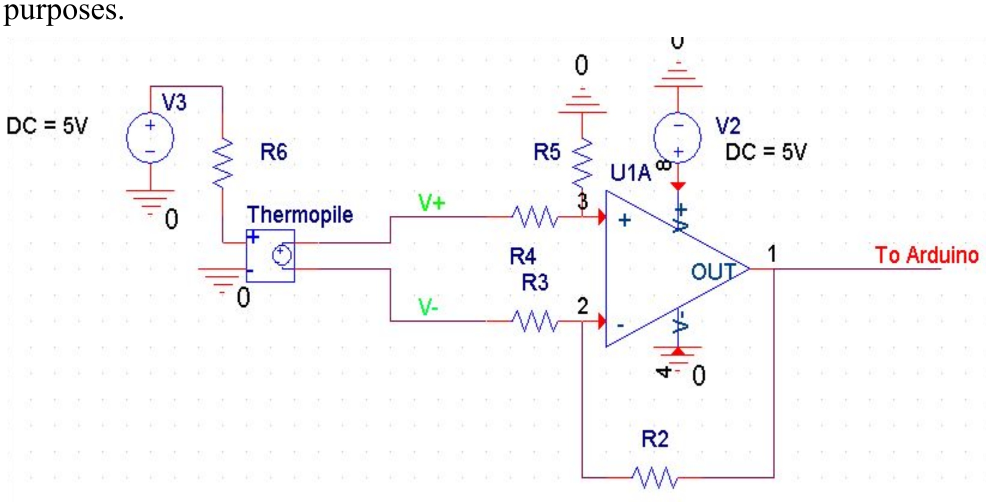
In the case of IR thermopiles, there is an IR absorber placed at the dissimilar metal junction. This IR absorber allows for the IR radiation to be absorbed and creates the temperature difference on the thermopile. Voltage is then output based on the aforementioned IR radiation.

Output voltage values are still within the millivolt range so the signal must be amplified to allow for proper reading at the output. This can be done utilizing a differential amplifier which will eliminate common mode noise, as the same noise will be on both the positive and negative terminals of the thermopile.

The ambient temperature is necessary for proper measurement with a thermopile. In many modern thermopile packages, a RTD element is included to allow for this measurement. If the voltage drop over the RTD is measured and the resistance is calculated, the ambient temperature can be obtained.

Some issues associated with IR thermopiles deal with the material of the object being measured. For those objects with extremely low emissivity or those materials that are extremely reflective will cause the thermopile to measure the IR radiation of the reflected object, not of the target object. Another issue with thermopile components is the possibility of a cold junction on the lead wires. However, this can be compensated for.

If utilizing a thermopile device, the following schematic can be used for prototyping purposes.



The leftmost part of the circuit is the RTD measurement for ambient temperature. The amplifier is used to amplify the small voltage output from the thermopile. The resistance values will be determined based on the physical thermopile used, as the output voltages can vary.

Comparison of Technologies

For the technologies considered, RTD and IR, there are benefits and drawbacks for each. When looking at RTDs, the benefits are that the method of measurement is extremely accurate and requires minimal external circuits. The downside is that RTDs require extremely close proximity if not contact to measure temperature accurately, this can result in damage to the target as well as the sensor. For thermopiles, the great benefit is that it is a non-contact form of measurement. This minimizes the probability of damage to the sensor. The major drawbacks are that reflective substances will cause errors in measurements as well as the ambient temperature must be known for accurate temperature sensing.

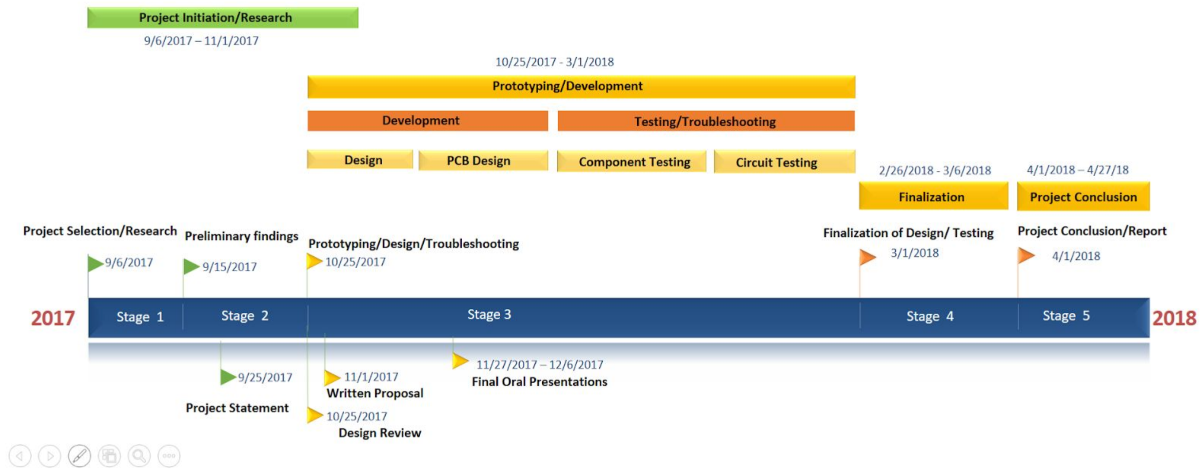
Solution options:

As Hubbell has imposed the task of minimizing or optimizing a temperature sensing system, both technologies are to be considered. Testing will be taken place to compare accuracy and range of both types of components. Multiple package sizes of the components will be tested. This is performed to determine the optimal method of measurement. Once results have been found, refinement of the circuits and components utilized will be performed and a PCB will be designed to fit within the specifications given. After the technology is decided on, the microcontroller will have to be programed and attached to the PCB.

Microcontroller

For our sensors and their components values to be interpreted as a temperature reading, a microcontroller is required. Incoming voltages will be connected to 2 pins and interpreted into a temperature value using C code and the data sheets for our sensors. For testing purposes, we have 3 ATMEGA328P-XMINI evaluation boards. There are 3 boards in order to control factory deviations in the atmega chip. The Atmega328p chip was chosen for its "...32KB ISP flash memory with read-while-write capabilities, 1024B EEPROM, 2KB SRAM, 23 general purpose I/O lines, 32 general purpose working registers, three flexible timer/counters with compare modes, internal and external interrupts, serial programmable USART, a byte-oriented 2-wire serial interface, SPI serial port, a 6-channel 10-bit A/D converter (8-channels in TQFP and QFN/MLF packages), programmable watchdog timer with internal oscillator, and voltage operation range", as specified by Microchip Technology Inc. The advantages of this chip over the competition is its numerous I/O lines, varias interfaces and ports, and large memory. For current testing, the UART communication over USB to a computer will be used to readout temperature values. This will be done at a 9600 Baud Rate. For our project implementation, an on-board version of the Atmega328P chip will be used without the evaluation board.

Timeline



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Work Cited

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