Resistive Sensors

EE241: Electonics I
Laboratory Report

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Abstract

Photoresistors and thermistors were examined to determine their response to changes in light and temperature, respectively. Photoresistors were then placed into a voltage divider circuit and into a Wheatstone bridge circuit in order to produce a voltage change in response to lighting variation. Both circuits produced a voltage signal that depended on lighting level. The voltage divider circuit had the advantage of simplicity, while the Wheatstone bridge circuit has the advantage of allowing the user to independently set the output offset level.

Introduction

Resistive sensors such as photoresistors and thermistors are inexpensive and are used in many common systems such as street lamps and fever thermometers. This lab explores these sensors as well as methods for translating resistance change into a voltage signal that could be used in a larger system.

Theory

The resistance for a thermistor varies inversely with temperature. For example, for the Panasonic ERT-D2FGL102S thermistors used in this lab, the expected resistance at room temperature was 1 kΩ, while the expected resistance at 50 °C was 383 Ω [1]. Similarly, the resistance of a photoresistor varies inversely with light intensity level. For the Advance Photonics CdS photocell used in this lab, the expected resistance in typical office lighting conditions was expected to be about 1 kΩ, while the expected resistance in total darkness was expected to be greater than 1 MΩ [2].

In order to translate a resistance change into a voltage signal, the resistor must be placed into a circuit. Two examples of circuits that could be used to this purpose are shown below in Figures 1 and 2. Figure 1 shows a simple voltage divider while Figure 2 shows a Wheatstone bridge.

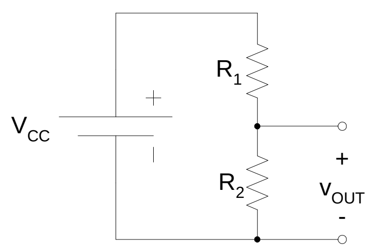

Figure 1: Voltage Divider Circuit

For the voltage divider, the output voltage is given by:

$$v_{OUT} = V_{CC}\left(\frac{R_2}{R_1 + R_2}\right)$$

For this circuit to be used with a resistive sensor, one of its resistors must be replaced by the sensor and the other by an appropriate balancing resistor. For the case of a "dark sensor," a photoresistor would be used that would have R_{low} in its ambient state, and R_{high} in its darkened state. This photoresistor must then replace R_2 in the voltage divider circuit in order to create a system where the output voltage increases in darkness. With this change the voltage signal in ambient conditions would be given by:

$$v_{OUT,ambient} = V_{CC}\left(\frac{R_{low}}{R_1 + R_{low}}\right)$$

The total voltage change between dark and light would be given by:

$$\Delta v_{OUT} = v_{OUT,dark} - v_{OUT,ambient} = V_{CC}\left[\left(\frac{R_{high}}{R_1 + R_{high}}\right) - \left(\frac{R_{low}}{R_1 + R_{low}}\right)\right]$$

If the value of R_1 is either too large or too small, the total voltage change will be very small. Thus the value of R_1 should be between R_{high} and R_{low}. For a light sensor with the same circuit, one need only interchange R_1 and R_2.

One disadvantage with the voltage divider is that it is not possible to maximize Δv_{OUT} and at the same time minimize v_{OUT} in the ambient condition, which would require R_1 to be as large as possible and therefore result in a negligible voltage change in response to darkening. In contrast the Wheatstone bridge, shown below in Figure 2, allows for both maximal voltage change and a zero default condition.

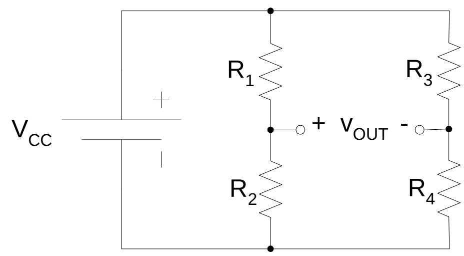

Figure 2: Wheatstone Bridge Circuit

The equation for the output voltage for the Wheatstone Bridge is given by:

$$v_{OUT} = V_{CC}\left[\left(\frac{R_2}{R_1+R_2}\right)-\left(\frac{R_4}{R_3+R_4}\right)\right]$$

To create a dark sensor, R_3 and R_2 should be replaced by photoresistors. To create a balanced condition at ambient conditions, R_1 and R_4 should be equal and of the same value as the photoresistors in ambient light. Theoretically, the output voltage would then be 0V in ambient conditions and large in darkened conditions.

Procedure

The first part of the lab focused on the sensors themselves. The resistance of a Panasonic ERT-D2FGL102S thermistor was measured at room temperature and at 50°C using a multimeter. The high temperature was achieved using a hot plate set to 50°C. Due to space limitations, the resistance in the hot condition wasn't measured while the thermistor was directly on the hot plate but rather it was measured at the lab bench after sitting on the hot plate for approximately five minutes. An Advance Photonics CdS photocell was also studied. Its resistance was measured in the ambient room light and also when darkened by a midshipman cover.

The results of these measurements were then used to guide the choice of resistor values for the different circuits. The voltage divider circuit shown in Fig. 1 was built using a 100 kΩ resistor for R_1, a photocell for R_2, and a 5 V source for V_{CC}. The circuit was then tested in ambient conditions and in the dark, simulated again by a midshipman cover, and the results are shown in Table I. The two resistors were then swapped in order to create a light sensor and the test was repeated. The results for the light sensor are shown in Table II.

The Wheatstone bridge was built using photoresistors in the place of R_2 and R_3 and 1.1 kΩ resistors in the place of R_1 and R_4. V_{CC} was again 5V. The voltage was measured in ambient light and in darkened conditions, again simulated by a midshipman cover.

Results

The thermistor was measured to be 1.02 kΩ at room temperature and about 450 Ω when heated. There was nearly 10 Ω of variation noted in the heated result over the course of the measurement. The photoresistor resistance was 1.15 kΩ in the ambient light of the classroom and 2 MΩ in the darkened condition.

The results for the different circuit configurations are shown in Tables I and II below. The expected values were calculated using the resistance measurements for the sensors described above and the equations given in the theory section for the respective circuits.

Table I: Results for Dark Sensor

Circuit	Measured		Expected	
	$V_{OUT,light}$	$V_{OUT,dark}$	$V_{OUT,light}$	$V_{OUT,dark}$
Voltage Divider	85 mV	4.5 V	57 mV	4.76 V
Wheatstone Bridge	103 mV	4.6 V	0 mV	4.99 V

Table II Results for Dark Sensor

Circuit	Measured		Expected	
	$V_{OUT,light}$	$V_{OUT,dark}$	$V_{OUT,light}$	$V_{OUT,dark}$
Voltage Divider	4.1 V	420 mV	4.95 V	238 mV

Discussion

The resistance measurements were generally consistent with what was expected from the datasheets for the sensors. The thermistor resistance was a little higher than the datasheet value, but this is likely due to the thermistor not being at 50 °C because of the conditions of the measurement. The photoresistor results are consistent with typical office lighting conditions of hundreds of lux [3].

The voltage divider circuit performed well. Better performance might have been possible by experimenting with other values of R_1 but this was prevented by time constraints. The Wheatstone bridge also performed well but did not have the expected zero default condition. This was likely due to variation in the values of resistance between the photoresistors and could be improved by finely tuning the matching resistors (R_1 and R_3) to establish a balanced circuit in ambient conditions. Thus, while the Wheatstone bridge has the advantage of permitting a zero volt default condition with a large output signal, it has the disadvantage of complexity and requires more fine tuning to meet its performance expectations.

Conclusion

Thermistors and photoresistors were investigated and found to be useful sensors for temperature and illumination conditions. Two circuits were explored for translating resistance changes into voltage signals. Both circuits performed well and could be useful in larger sensor systems. The Wheatstone bridge promises better performance than the voltage divider but at the cost of greater complexity, and so the choice of circuit depends on the requirements of the particular system.

References

[1] Panasonic NTC Thermistors Datasheet, http://www.panasonic.com/industrial/components/pdf/arg0000ce2.pdf, Accessed 08 February 2008.

[2] Advanced Photonix CdS Photoconductive Photocells Datasheet, http://www.advancedphotonix.com/ap_products/pdfs/PDV-P9003.pdf, Accessed 08 February 2008.

[3] Wikipedia entry for “Lux,” http://en.wikipedia.org/wiki/Lux, Accessed 08 February 2008.