Micro-controller based Heater Control for Gas Sensors

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Abstract

Semiconductor Metal Oxide (SMO) Gas Sensors have emerged as a dominant sensor technology in recent years. These sensors are now able to detect compounds ranging from greenhouse gasses to chemical weapon agents. The behavior of the sensor is temperature dependent and the sensor typically operates at elevated temperature (200 °C to 600 °C). Laboratory temperature controllers used high cost, high power, large size electronics and limited the potential usefulness of the sensor. In conjunction with a local company, The University of Maine Instrumentation Research Laboratory has developed a small, low power, cost effective heater controller. The solution utilizes Pulse Width Modulation (PWM) to control the average power dissipated by the heater. Interestingly, the heater changes conductivity as a function of temperature, so the heater element is also used to measure sensor temperature. This eliminates the need to affix an external temperature measurement device (such as a thermocouple) to the sensor. The temperature controller can be used stand-alone or with a host computer. When used stand-alone, a bank of DIP switches specifies the desired temperature, making this system very portable for deployable applications. When used with a host computer, this platform is able to communicate via RS-232 to receive commands and relay feedback about the system performance. Additionally, the temperature controller communicates over a Serial Peripheral Interface (SPI) bus to an LCD display unit. The ability to "mix and match" temperature controllers, display units, and host computers provides for a flexible, low cost, deployable solution suited to a variety of needs.

I. Introduction

Problem Description

A local company designs, produces, and tests Semiconductor Metal Oxide (SMO) Gas Sensors and needs to simplify the heater control requirements of these sensors. SMO sensors are highly temperature dependent and need to operate at an elevated temperature of 200 to 600 degrees Celsius. Due to this temperature dependency, each sensor is mounted on top of a heating element. The resistance of the heating element is temperature dependant, and can be used to accurately measure the temperature, eliminating a separate temperature measuring device, such as a thermocouple.

Unfortunately, the heater has a relatively large power consumption (several watts) and needs specialized equipment to drive the analog power to the heater. The analog signal is generated by a high power analog PC card that resides inside a full tower desktop PC case. This analog card is able to determine both the voltage and the current that is being supplied to the heater. The PC utilizes a virtual instrument package to calculate the heater resistance (and from the resistance the temperature), perform control calculations, and determine the new analog output value.

Obviously, this setup is far from optimal for several reasons:

1. The analog PC card needs to dissipate a fairly large amount of power while controlling the heater.
2. The entire setup is non-portable and expensive.
3. In order to test multiple sensor arrays at once, multiple control PCs must be built and maintained.

The instrumentation Research Laboratory was approached to find a solution that solved some of the inadequacies of the current heater control methods.

The Solution

The solution being implemented replaces the PC and the analog output card with a PIC micro-controller controlling the duty cycle of a Pulse-Width Modulated (PWM) output that drives the average power to the heater. While the PIC is driving the heater with the full power available, an A/D reading is taken that allows the PIC to perform simple PID controller calculations. During the output pulse, the PIC adjusts the duty cycle to reflect an adjustment that will help correct for errors between the desired and actual heater temperature.

Concerns

The client had several concerns that needed to be addressed in the implementation of the heater controller.

Size – The controller should be small enough to help promote the portability of the entire system.

Portability – If the controller requires little external equipment, then the ability to easily move it to remote locations will be possible.

Reliability – The controller needs to be reliable enough to leave for extended periods of time unattended and perform properly.

Power Consumption – The controller should consume and dissipate as little power as possible, further contributing to the size and portability concerns.

II. Implementation

This section focuses on the concerns raised in the previous section and how we addressed them to produce a reliable system.

Heater Temperature Measurement

The heater temperature measurement is performed using a simple voltage divider circuit as seen in Figure 1. When the PWM output is driving the power transistor, the voltage seen across the sense resistor allows us to determine the current passing through the heater. Knowing the current enables us to determine the heater resistance using Ohm's Law. Once the heater resistance is

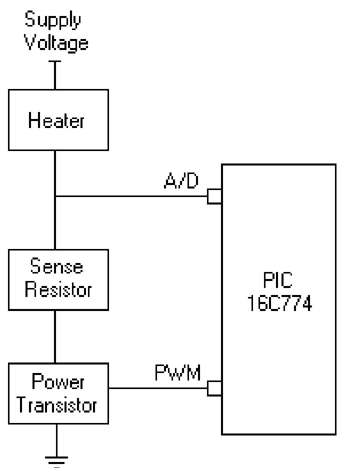

Figure 1. PIC 16c774 Control/Measurement Circuit

determined, the controller is able to make changes to the duty cycle to eliminate errors in the temperature.

Pulse Width Modulation (PWM)

PWM is a technique of applying power to a load in a very efficient manner[3]. Instead of having a controller that changes the output voltage seen by the load, the controller changes the percentage of time that the load sees the full input voltage provided to the system. This greatly simplifies the circuitry needed to drive the output to the heater. For example, the current implementation uses the analog output PC card to drive the heater voltage. This analog card has a large amount of circuitry designed to drive the output with only a portion of the input voltage. This voltage drop technique causes some of the circuitry to dissipate a large amount of power depending on the desired output of the controller.

PWM utilizes the only two conditions where the controller dissipates no power (see figure 1), 0% and 100% output power. The controller modulates the output, or turns it on and off, to achieve the desired average power seen by the load. For example, if the target output voltage is

Input Voltage	Power Dissipated by 100w Load	Power Dissipated by Controller
0	**0**	**0**
10	1	9
20	4	16
30	9	21
40	16	24
50	25	25
60	36	24
70	49	21
80	64	16
90	81	9
100	**100**	**0**

Figure 1. 100w Load Example

50% of the input, then we are able to apply full voltage to the heater for some period of time and then zero voltage for an equal amount of time. In this situation the load sees the input voltage 50% of the time, or is driven by a 50% duty cycle.

PWM only works well if the frequency of the signal is higher than the frequency that the system will respond to. We can see by inspection that the frequency of the PWM signal is highly dependant upon the application. In our case, the frequency for the heater PWM circuitry was arbitrarily decided to be 1 kHz. Some initial testing verified that the heater cooled an insignificant amount in the 1 millisecond (max) that the controller would ever be completely off, and produced satisfactory results.

PIC Micro-controller

The Microchip PIC 16C774[1] was chosen as the micro-controller that would control the PWM circuitry to drive the heater. The Microchip PIC brand was chosen due to many reasons:

1. Small minimum required circuit. Most PIC micro-controllers need only a power supply and an acceptable oscillator to operate. This was highly desirable since we were looking to have a smaller implementation than a PC board-sized controller.
2. Built-in PWM controller. PWM control is fairly straight-forward to accomplish in code, but works better with fewer chances for programming errors when it is supported in hardware. The 16C774 supports two separate PWM channels that share the same frequency.
3. 12-bit A/D converters. The 16C774 contains 8 12-bit A/D converters. It was determined early in the project that in order to have a +/- 0.5 degree Celsius temperature measurement, that we needed to have a 12-bit converter to achieve the desired controller resolution.
4. Synchronous/Asynchronous communication support. Even though the project was intended enable portable applications, there will still be a need to communicate with the controller from a PC or laptop to monitor operation during the testing phase.
5. On-board watchdog circuitry. The on-board watchdog circuitry automatically resets the processor if the processor hangs up or gets stuck in code that contains programming errors.

The micro-controller code utilizes each of these features that the Microchip PIC 16C774 provides.

Micro-controller Code

General Operation

The micro-controller executes a fairly straightforward program loop. First, the input and output pins of the controller are set up. Then, the PWM frequency and communication frequency are initialized, and the external DIP switches are read to determine the mode of operation in which we are currently operating. If the DIP switches are in a state that indicates a predetermined temperature value, then we set the desired temperature to the appropriate starting value and begin the PI controller. If the DIP switches indicate otherwise, the PIC sets the PWM duty cycle to the lowest setting, starts the PI controller, and waits for a command from the communications port.

Temperature Controller

The temperature controller is a piece of the code that performs adjustments in the PWM duty cycle to help eliminate error between the desired and actual temperature. The controller that we have implemented is a standard PI (Proportional-Integral) controller. A PI controller changes its output depending on the current error and the integral of the error over time. In order to tune the controller to provide fast response and low steady state error, the PI controller has two constants, Kp and Ki, that can be adjusted. Kp and Ki are variables that allow the user to adjust the gain of each component of the controller, in this case the proportional gain and the integral gain, respectively.

Command Set

In order to communicate with the micro-controller from a host PC, a robust command set was developed. The command set includes the following functionality:

- Set the desired temperature
- Change the controller constants…Kp, Ki
- Read the controller PWM value
- Read the measured heater temperature

Entire System

The entire system was designed to address each of the original concerns and develop a system that the client would find acceptable.

Size – The selection of the micro-controller and utilizing PWM were the biggest factors contributing to the small size of the final implementation. If a different micro-controller were used, then there could have been a more complicated support circuit required. This would have obviously contributed to the overall footprint of the final controller circuit. If PWM were not utilized, then the output circuit would have been much more complicated than it ended up. For example, the original analog output idea would have required a D/A circuit with a high power drive circuit to power the heater.

Portability – Choices were made selecting components from the actual micro-controller to supporting devices so that there would not be any degradation to the portability of the final unit. The bank of DIP switches was implemented to enable a completely stand-alone unit. This allows the package to be used for demonstrations or applications in unique environments where connection to a PC is not feasible.

Reliability – The biggest factor that helps to enhance reliability is the watch-dog circuitry in the PIC 16C774. The watch-dog virtually eliminates the possibility that the controller will stop working properly and either turn the power to the heater off permanently or turn the heater power on permanently. Of course, either of these situations is undesirable.

Power Consumption – Since we used PWM to minimize the component size, and the power consumption of the controller, the overall power consumption of the controller was minimized. Since there is no need to dissipate large amounts of heat in the controller, the size is further minimized and portability is enhanced.

II. Conclusion

We have developed a micro-controller based heater controller for the SMO gas sensors that helps the client achieve an implementation that is less expensive and more practical, without losing effectiveness. This project was developed by students in the Instrumentation Research Laboratory at the University of Maine and demonstrates some sound engineering design choices, while teaching students some practical applications of classroom ideas.

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