Design of Automatic Program Control Gain Circuit for Infrared Gas Detection

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Abstract. When using infrared gas detection technology to measure gas concentration, due to the immobilization of parameters such as cell, detector and light source, the range of the detection gas concentration is limited. In order to achieve the wide range of infrared gas detection system, an automatic program-controlled gain circuit system is designed based on MCP42010. Through the MCU to determine whether the current photoelectric signal is saturated, the resistance of the programmable potentiometer is automatically changed to achieve wide dynamic range detection. The simulation results show that the auto-programmed gain module's amplified photoelectric signal is within the effective resolution range of the A/D converter and meets the actual requirements of infrared gas detection.

1. Introduction

Infrared gas detection technology is used to determine the composition and concentration of the tested gas by analyzing the infrared absorption wavelength and the changing of light intensity [1]. However, when the gas concentration is measured by this method, the measurement range is limited due to the fixed length of the cell, the light emission efficiency of the light source, and the performance of the detector [2]. Therefore, how to realize the wide dynamic range of gas detection is a problem that needed to solve urgently.

Automatic Gain Control (AGC) can control the output signal in a stable range by detecting the input signal [3, 4]. The automatic gain control system is used in various fields such as medical systems, radar receivers, electronic warfare technologies, multimedia devices, sensor networks, image processing, and so on[5,6]. It has the advantages of simple structure and good compatibility with digital processing units. For the weak signal amplification in infrared gas detection, there are mainly two methods at present, one is fixed gain, and the other is manual adjustment of gain. There are certain defects in the two methods. The first one fixes the measured gas range and second one are inaccurate and inconvenient. Obviously, it is necessary to use automatic program-controlled gain to automatically adjust the infrared detection signal.

Based on the infrared gas detection technology, an automatic gain control circuit system is introduced based on MCP42010 digital potentiometer in this paper. The circuit system mainly detects whether the photoelectric signal is in saturation by MCU, and automatically controls the digital potentiometer to change the magnification to ensure the detection of infrared gas. The system is in the best absorption position when measuring different concentrations of gas.
2. Measuring principle
When infrared light passes through the gas which to be measured, these gas molecules absorb infrared light of the specific wavelength, and the absorption relationship obeys the Lambert-Beer absorption law:

\[ I = I_0 e^{(-kxL)} \]  

(1)

Where, as shown in Figure.1, \( I_0 \) is the original intensity of the light source, \( I \) is the intensity of the light at the detector, \( k \) is the absorption coefficient at the wavelength \( \lambda \), \( x \) is the gas concentration entering the cell, and \( L \) is the length from the cell window to the filter.

![Infrared gas detection module](image)

**Figure 1.** Infrared gas detection module

The infrared light source emits 1-20\( \mu \)m infrared light. After being absorbed, it passes through a narrowband filter and the intensity of the infrared light is monitored by an infrared photodetector. In the practical applications, light intensity is not easy to be measured, and voltage ratio algorithms need to be used to eliminate the influence of light intensity factors.

For the output of the infrared photodetector, there is a corresponding voltage change \( \Delta V = V_0 - V \):

\[ FA = \frac{V_0 - V}{V_0} = \frac{I_0 - I}{I_0} = 1 - \frac{I}{I_0} = \frac{\Delta V}{V_0} \]

(2)

Where: \( FA \) is the fractional absorption, \( V_0 \) is the zero-gas voltage output, and \( V \) is the voltage output of the gas which to be measured. Finishing formulas (1), (2) to gain formulas (3):

\[ FA = 1 - e^{-kxL} \]

(3)

If \( k \) and \( L \) do not change, the \( FA \) can be plotted with the concentration \( x \). As shown in Figure.2 (where \( kL = 0.5, 1, 5, 8, 40, \) and 80), The \( FA \) increases as the concentration of the gas increases, but eventually saturates at high gas concentration.
From Figure 2, by adjusting $k$ and $L$, it can provide the best absorption for the gas concentration range. This means that longer optical paths are more suitable for low gas concentrations, while shorter optical paths are more suitable for high gas concentrations. When the length of the cell and the absorption coefficient are determined, the relationship between the zero gas and the output voltage difference $\Delta V$ of the gas and the concentration $x$ of the gas can be seen in the formula (4), so that the gas concentration can be inverted.

$$-\ln\left(1 - \frac{\Delta V}{V_0}\right) = kLx \quad (4)$$

The determination of the length $L$ of the cell and the absorption coefficient $k$ will result in a large voltage $V$ of low-concentration gas, and therefore it will be saturated after amplification; when measuring high-concentration gas, the voltage of the gas to be measured will be small and thus the resolution of voltage difference $\Delta V$ is too low. Therefore, this requires a smaller gain when measuring low-concentration gas, and a larger gain when measuring high-concentration gas.

3. Program-controlled gain circuit system

Figure 3 is a system block diagram of the automatic program-controlled gain circuit. The entire circuit system is divided into five modules: gain control module, micro control module, A/D sampling module, preamplifier and follower module. The MCU first receives the voltage signal acquired by A/D, and determines whether the output voltage difference of the zero gas and the measured gas is out of range. If the conditions are not met, the MCU adjusts the resistance of the digital potentiometer through the SPI communication, thereby adjusting the amplification factor and ensuring the
acquisition of the optoelectronic signals is in a suitable gain range.

4. System hardware design

In the hardware design of the entire system, the main content is the gain control module. The gain control module is mainly composed of digital potentiometer MCP42010, operational amplifier TLV2372IDR and analog-to-digital converter chip LTC1867IGN. The specific principle is shown in the Figure 4.

![Gain control module schematic](image)

**Figure 4.** Gain control module schematic

In the schematic above, the TLV2372IDR is a single-supply dual operational amplifier with input and output rail-to-rail functions. The first-stage amplifier is designed as a voltage follower to play the role of isolation, taking into account the effects of the input optoelectronic signal impedance. The second-stage amplifier is a program control amplifier using the MCP42010. The MCP42010 is a dual 10 kΩ digital potentiometer with 256 taps. The position of the taps is controlled by the MCU using SPI communication. The second-stage amplifier output is:

\[
V_{OUT} = V_{REF} \left(1 + \frac{R_{PBW}}{R_{PAW}}\right) - V_{IN} \left(\frac{R_{PBW}}{R_{PAW}}\right) \\
R_{PAW} = \frac{R_{PAW} (256 - D_n)}{256} \\
R_{PAW} = \frac{R_{PAW} D_n}{256}
\]

where \(V_{OUT}\) is the output of the second stage amplifier; \(V_{IN}\) is the input of the second stage amplifier; \(V_{REF}\) is the reference voltage of the photoelectric signal; \(R_{PBW}\) is the resistance value between the terminal taps and the terminal B of the digital potentiometer; \(R_{PAW}\) is the resistance value between the terminal taps and the terminal A of the digital potentiometer; \(R_{PAW}\) is the resistance value between the terminal A and the terminal B of the digital potentiometer; \(D_n\) is the setting parameters of the terminal taps (0 to 255).

The signal output from the secondary programmer amplifier is acquired by the 16-bit A/D chip LTC1867, which has a sampling rate of 200ksps and 8 composite channels (can be set to single-ended input or differential input), which is more used for industrial process control and high speed data...
collection. The LTC1867 communicates with the MCU through the SPI interface and transmits the collected data to the MCU for processing.

5. System software design
When the entire infrared gas detection system is working, the photodetector converts the light signal into a weak electrical signal and sends it to the preamplifier for amplification. The amplified electrical signal is sent to the automatic program-controlled gain module through a band-pass filter and a voltage follower. The A/D acquisition module outputs the signal and sends it to the MCU. The MCU determines if the signal value is out of range. If the signal is out of range, the resistance of the digital potentiometer is changed so that the optoelectronic signal is within the proper gain range. The entire system process is shown in the Figure 5.

![Flow chart of program-controlled gain system](image)

**Figure 5.** Flow chart of program-controlled gain system

6. Experimental verification
To verify that the designed program-controlled gain system can properly adjust the gain of the photoelectric signal output from the infrared gas detection system, this part of the circuit is verified by simulation as shown in the Figure 6.
Figure 6. (a) Input (blue) and output (powder) of the system for low-concentration; (b) Input (blue) and output (powder) of the system for high-concentration.

The selected photodetector is HEISMANN's HTS-E21-F3.91/F3.40, which outputs the signal voltage of 66-119 μV in the 3.40 μm band.

In the above simulation diagram, the blue line in Figure 6 is the preamplified signal, and the pink line is the output signal through the automatic program-controlled gain. Figure 6 (a) shows that when the low concentration photoelectric signal is detected, the output of the infrared detector is 118 μV. After the preamplifier, the signal reaches 300 mV. The gain of the automatic gain module which the MCU controlled is to be 10 times, so as to ensure that the amplified signal is in good linear range. Figure 6 (b) shows that when the high-density photoelectric signal is detected, the output of the infrared detector is 75 μV. After the preamplifier, the signal reaches 190 mV, and the automatic program-controlled amplification factor is selected to be 20 times, so as to ensure that the amplified signal is in a good linear range. Simulation experiments have verified that the photoelectric signals amplified by the automatic program-controlled gain module are all within the effective resolution range of the A/D converter.

7. Conclusion
This paper describes the measurement principle of the wide dynamic range infrared gas detection technology, the designed hardware scheme and software scheme based on the MCP42010 automatic program-controlled gain circuit system in detail. The results show that the programmable gain circuit system can achieve proper gain based on the input optical signal. The designed automatic program control circuit system can meet the actual requirements of the wide range and high precision of the infrared gas detection system.

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9. References
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