Application Report
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Designing a Dual-Ray Smoke Detector Analog Front-End With MSP430FR235x MCUs

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ABSTRACT

This application report provides an overview of a single-chip solution for a dual-ray analog front end (AFE) for smoke detectors using the highly integrated analog circuitry of the MSP430FR235x MCU.

Demo source code and schematics are provided to accelerate the development of a smoke detector application. The files can be downloaded from http://www.ti.com/lit/zip/slaa930.

An optional graphical user interface (GUI) allows developers to configure the AFE and observe the system response in real-time. The GUI is published in the TI Cloud Tools gallery.

This document also includes test data showing low-power performance and measurements under smoke and water vapor conditions.

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1 Introduction

There are two methods of smoke detection used in current smoke detectors — photoelectric and ionization detection. Photoelectric detectors use LEDs and photodiodes to detect the presence of smoke, while ionization detectors use a radiation source (typically americium-241) for smoke detection. Ionization has been historically used for better detection of flaming fires, while photoelectric responds better to smoldering. However, this report focuses on a dual-ray photoelectric solution intended to improve detection of both types of fires.

Photoelectric detectors can use single or multiple LEDs in their smoke detection circuits. Photoelectric detectors use a smoke chamber enclosure to house the LEDs and photodiode. The smoke chamber reduces the ambient light exposed to the photodiode and allows smoke to enter if it is present. The smoke chamber should be designed so that the LEDs do not shine directly on the photodiode. This smoke chamber design is based on a light scattering principle (light is scattered when smoke is present) as opposed to a light obstruction principle (light is reduced when smoke is present). A microcontroller will take a photodiode current measurement when the LEDs are turned off, and another when the LEDs are turned on. When smoke is not present in the chamber, there should be little variance between the two measurements as depicted in Figure 1. However, when smoke is present, the LED light is diffracted throughout the chamber causing the photodiode to detect more light as seen in Figure 2). This increases the current output, thus allowing for the detection of smoke.

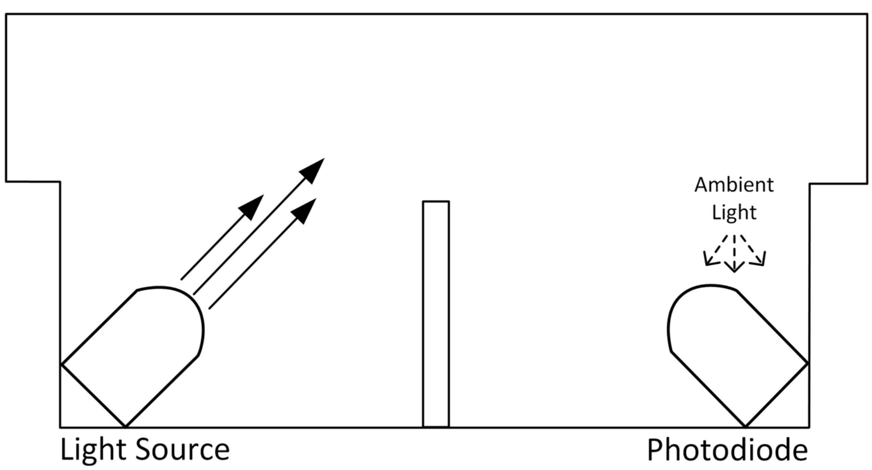

Figure 1. Light Scattering Smoke Chamber With No Smoke Present

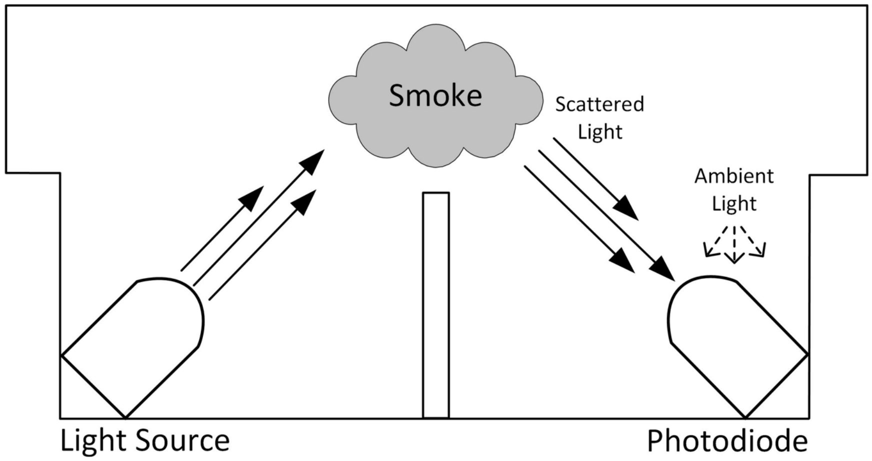

Figure 2. Light Scattering Smoke Chamber With Smoke Present

The photodiode current is converted into voltage by a transimpedance amplifier (TIA). This voltage is then fed through a gain stage to allow for proper sampling by an analog-to-digital converter (ADC). Using multiple LEDs provides the benefit of leveraging different wavelengths (such as with IR and blue LEDs), which can improve the detection of different types of smoke and rejection of false detections. Figure 3 shows this dual-ray solution.

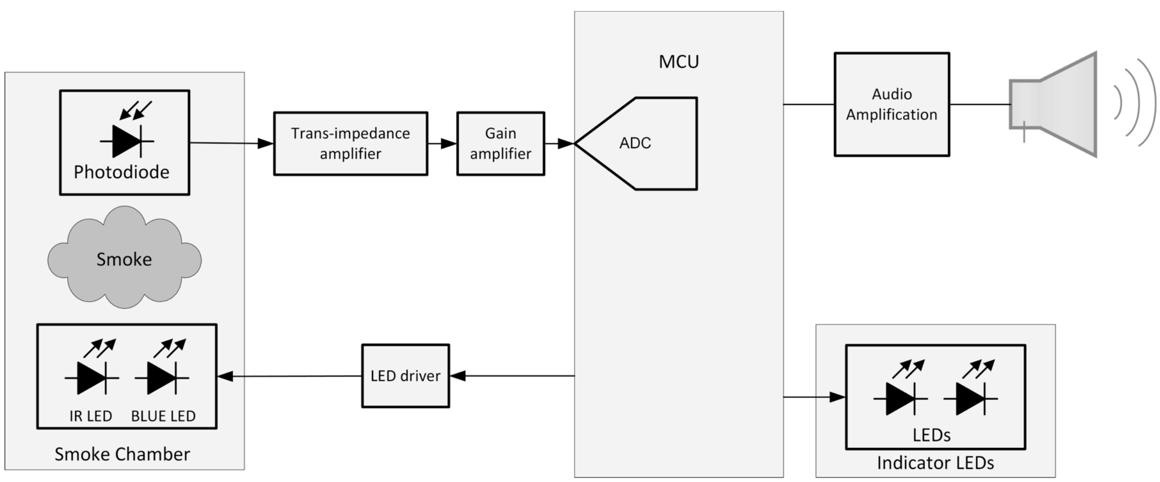

Figure 3. High-Level Residential Smoke Detector Block Diagram

The MSP430FR235x microcontroller enables an integrated dual-ray analog front end solution for smoke detectors by integrating four smart analog combo (SAC) blocks on-chip. Each SAC includes a flexible low-power operational amplifier (OA), a programmable gain amplifier (PGA) with gain up to 33 V/V, and a 12-bit digital-to-analog converter (DAC). This configurable analog signal chain can be operated in various modes, it can be cascaded together, and it can be connected to other peripherals as explained in the *How to Use the Smart Analog Combo in MSP430™ MCUs* application report.

Some other important features of MSP430FR235x MCUs that can be used in a smoke detector application are:

- One 12-channel 12-bit successive approximation (SAR) ADC with precise internal references (1.5, 2.0, or 2.5 V), which allows for fast, flexible, and accurate photodiode and battery measurements.
- Ferroelectric RAM (FRAM) gives nonvolatile storage comparable to flash or EEPROM but with lower power consumption and faster write access comparable to RAM. This allows for easier, faster, and lower-power data logging and updates of nonvolatile parameters and firmware.
- An on-chip temperature sensor that can be used for temperature compensation of LED current strength and photodiode temperature drift.

- Two enhanced comparators (eCOMP) with integrated 6-bit DAC that can be used for one-wire bus communication or for an alternate method to monitor voltage.

2 Single-Chip Solution

Figure 4 shows the proposed block diagram of an integrated dual-ray smoke detector analog front end design using the MSP430FR235x MCU. All four SACs are used: two for the LED drive stages (IR and blue) and other two for the photodiode signal conditioning (TIA and gain stage). Internal clocks and voltage references are selected to minimize the use of external components thus reducing the overall bill of materials (BOM) cost and the footprint of the design.

The schematic included in this application report can be referenced when designing dual-ray system hardware.

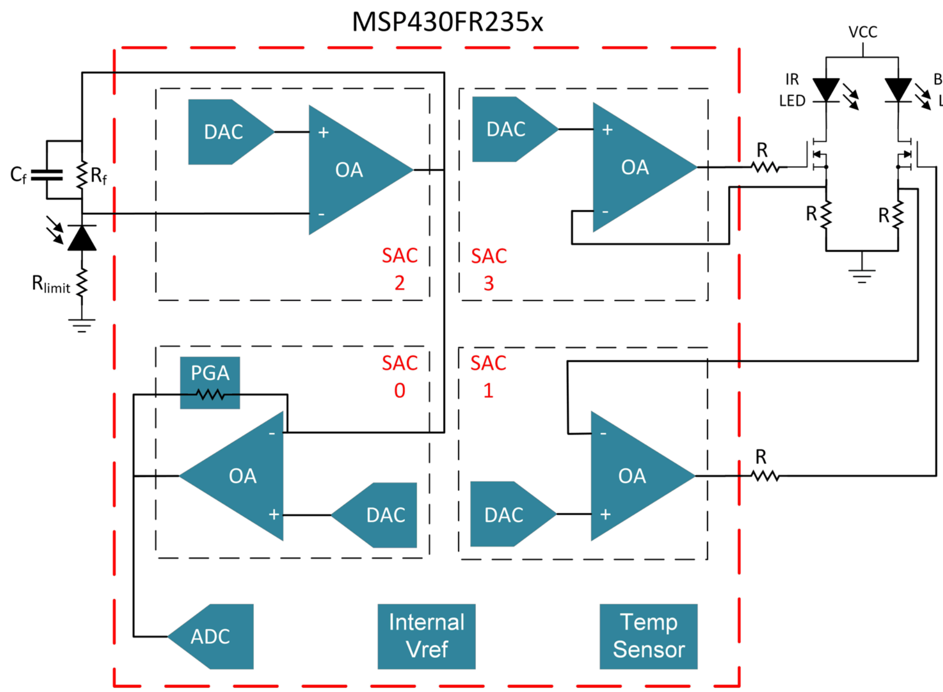

Figure 4. Single-Chip Analog Front End Solution for Dual-Ray Smoke Detector

2.1 Driving LEDs With SAC

The proposed solution was tested with LEDs in the infrared and blue spectrums; however, depending on the characteristics of the selected diodes and chamber, different drive strengths might be required. A SAC block is configured in a DAC output configuration, directly controlling the gate voltage of the MOSFET and ultimately, the LED drive current. Figure 5 shows this implementation.

Extra IR LED and capacitor footprints (D7 and C18) are included the design to allow for an alternate chamber design. To configure the SAC as a DAC output configuration, the internal register settings should be PSEL = 01, NSEL = 00, and MSEL = xx.

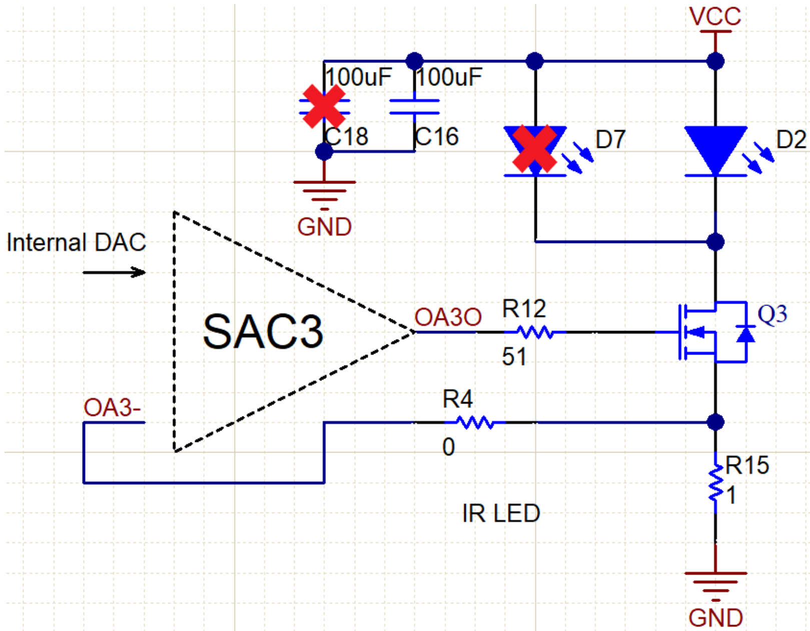

Figure 5. IR LED Driving Circuit With SAC

In the SAC3 block, the 12-bit DAC is configured with a reference voltage of 2.5 V. The DAC output voltage (V_{DAC}) is connected to the noninverting terminal of the SAC3 op-amp. The DAC voltage directly sets the voltage across R15, which sets the current flowing through the IR LED. The current flowing through the IR LED is calculated as Equation 1.

$$I_{LED} = V_{DAC}/R15 \quad (1)$$

A V_{CC} value should also be chosen that can sustain the voltage drops across the LED, the transistor, and R15.

$$V_{CC} \geq V_{LED} + V_{MOSFET} + V_{R15}$$

where

- V_{LED} = 2.7 V to 3.6 V for blue LEDs, and 1.3 V to 1.8 V for IR LEDs
- V_{MOSFET} = the voltage drop from drain to source of the MOSFET
- V_{DAC} uses a reference of 2.5 V, which makes it programmable from 0 V to 2.5 V in 4096 steps. (2)

2.2 Using SAC for Photodiode AFE

Figure 6 shows the analog front end circuit for the photodiode. SAC2 is configured as a transimpedance amplifier (TIA) converting the photodiode current into a voltage. This voltage is then fed to SAC0, which is configured as a gain stage with a default gain = 2. The gain can be adjusted in software based on the characteristics of the external components. This amplified signal is then fed to the internal 12-bit ADC for sampling. Figure 6 shows a DC implementation for the photodiode AFE. However, the full schematic shows additional passives that can be added for an AC-coupled circuit or to fine tune the circuit.

To configure the SAC as a TIA, set PSEL = 01, NSEL = 00, and MSEL = xx, and connect the photodiode, external resistor, and capacitor (for filtering). For the subsequent gain stage, the SAC can be put in:

- General-purpose mode (PSEL = 00, NSEL = 00, MSEL = xx) using external resistors to set gain, or
- Inverting PGA mode (PSEL = 01, NSEL = 01, MSEL = 00) using internal programmable gain values

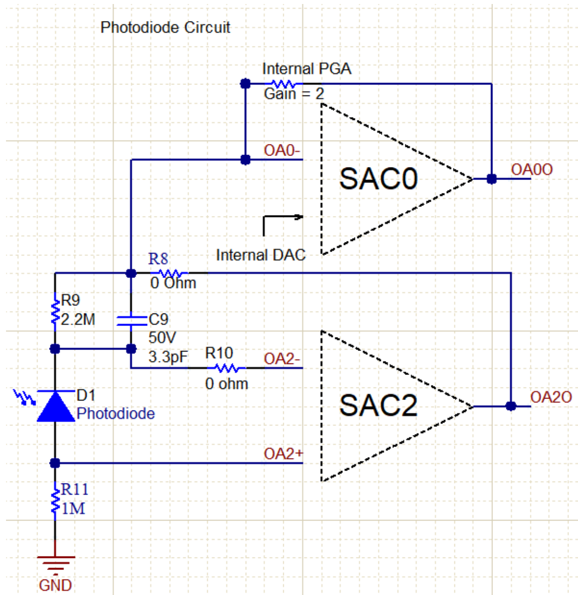

Figure 6. Photodiode Analog Front End Circuit

3 Demo Software

This application reports includes source code for libraries and a demo application intended to accelerate the development of a smoke detector application. This software is only a part of a complete system and is intended to be used only as a reference.

Figure 7 shows the architecture of the demo software.

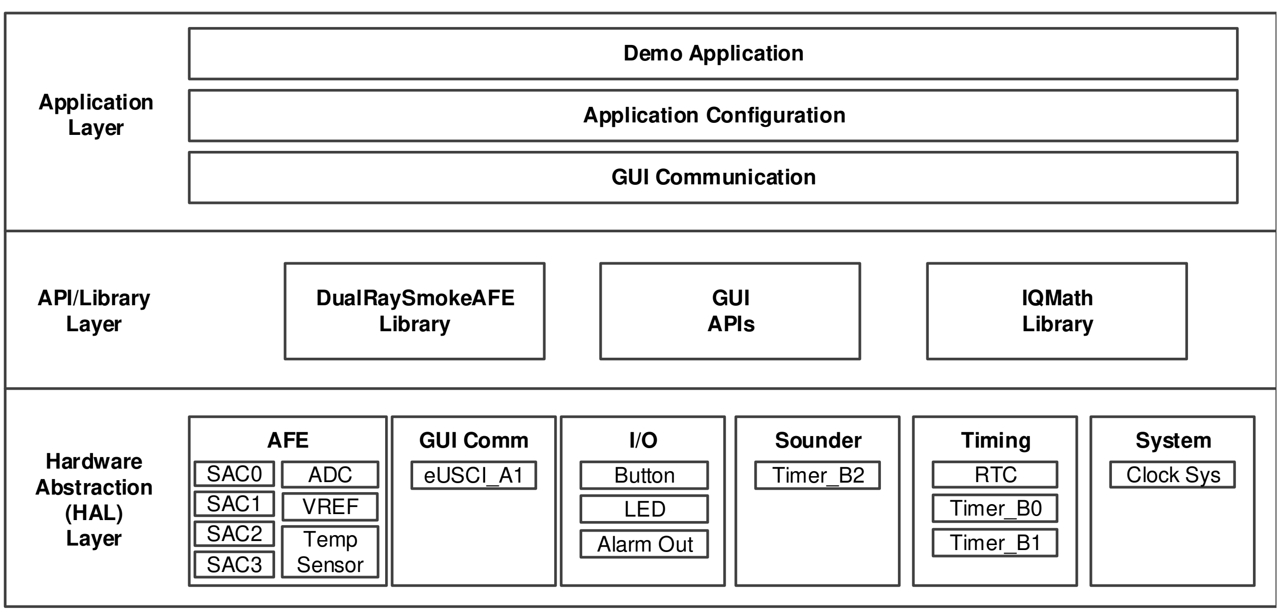

Figure 7. Demo Software Architecture

The software was architected in 3 layers:

- The application layer implements the demo functionality, defines the default configuration, and handles the commands to and from the GUI.

- The API/Library layer defines a set of APIs and libraries to perform fixed-point math operations (IQMath), take AFE measurements and calculations, and interface with the GUI.
- The HAL layer provides hardware-abstraction to interface with different peripherals and allow for a modular, flexible and portable solution. A description of the peripherals and I/Os used in the application is included in Section 3.3.

3.1 Dual-Ray Measurements and Alarm Detection

The demo application performs periodic measurements of the Dual-Ray AFE and implements a simple threshold algorithm to detect if an alarm should be triggered.

In the setup routine, the internal digitally controlled oscillator (DCO) is configured to run at 8 MHz and is stabilized by a frequency-locked loop (FLL) which uses the internal 32-kHz RC oscillator (REFO) as a clock reference. An internal real-time clock (RTC), used as an ultra low power timebase to trigger measurements, is configured to use the internal 10-kHz very-low-power low-frequency oscillator (VLO). The rest of the setup routine includes default configuration of the MCU pins and initialization of the state machine, internal timers, software library, and GUI communication, when enabled.

The main loop includes calibration of the internal RTC, the sampling routine, averaging routines, determining if IR or blue LED thresholds have been reached, sending and receiving information from GUI if enabled, and entering low-power modes. The loop requires either IR or blue reflection to be detected three times before sounding the alarm (see Figure 8) and adjusts the timing interval of the sampling.

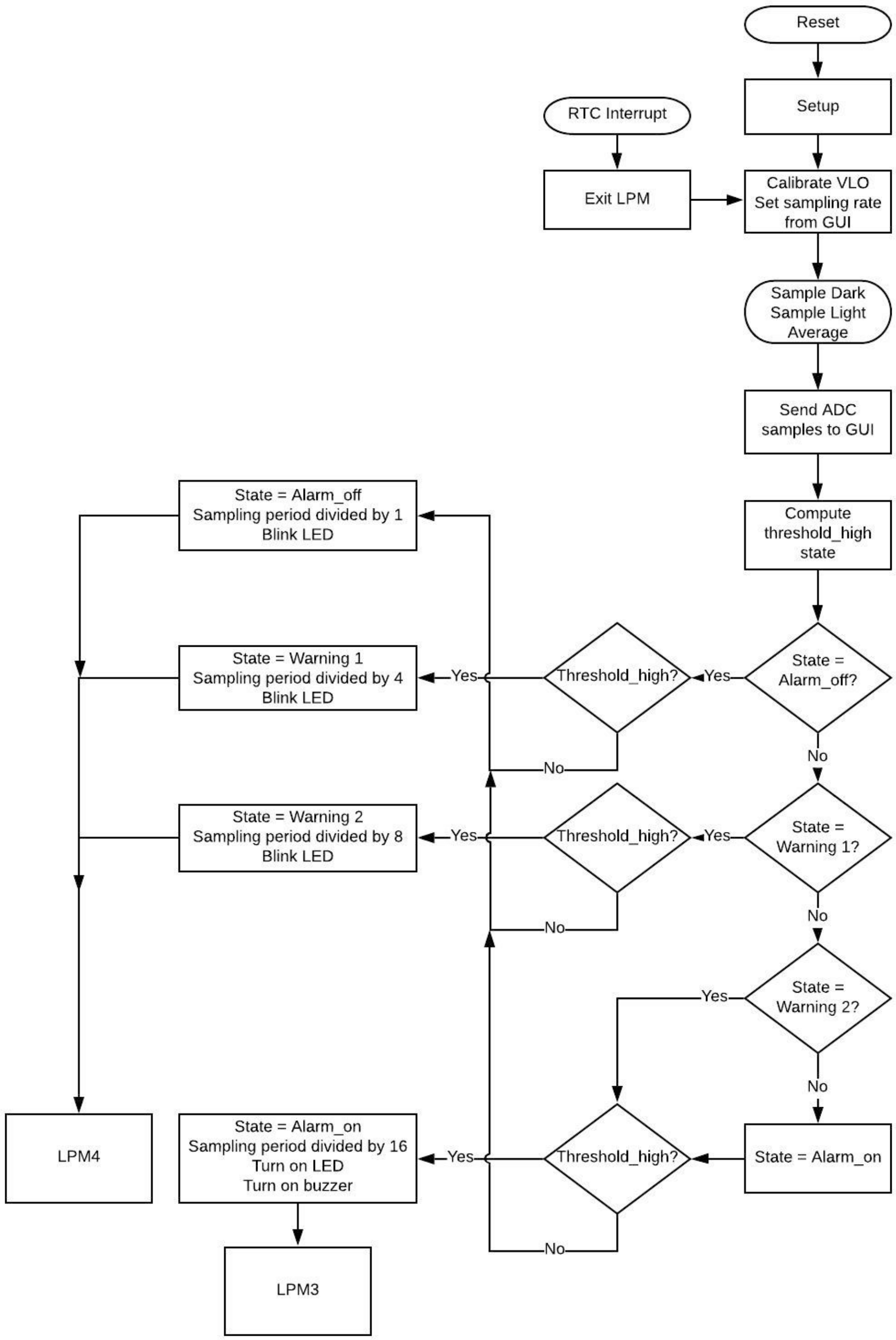

Figure 8. Software Flow Chart of Light Measurement and Alarm Detection in Demo Application

As Figure 9 shows, the routine first samples the photodiode output with the IR LED turned off. The two SAC amplifiers for the photodiode AFE circuit and the SAC block driving the IR LED are turned on and enabled. The ADC12 is turned on and configured to take continuous conversions of the photodiode channel in repeat single-channel mode. After allowing a brief settling time for the SAC peripheral, the ADC12 starts and takes four ADC conversions. These photodiode measurements are taken with the IR LED turned off and stored as "dark" measurements. Next, the IR LED turns on, and after a brief settling time, the 4-conversion process repeats and the results are stored as "light" measurements. After sampling, the ADC and amplifiers are turned off and the averaging routine is called. The averaging routine averages the four dark samples and the four light samples for comparison in the main routine. This entire process is then repeated for the blue LED. Gathering samples for both IR and blue LEDs enables the system to implement a dual-ray detection algorithm.

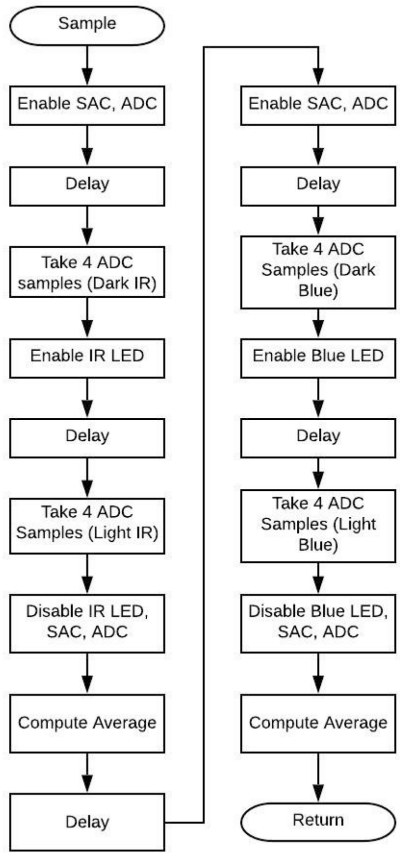

Figure 9. Sample Dark, Sample Light, and Average Functions

3.2 Additional Demo Functionality

In addition to measurements of the dual-ray AFE and the basic smoke detection demo algorithm, the software includes the following features:

- Test button: a short press turns off the alarm after being activated, while a long-press activates the alarm in self test mode.
- Temperature sensing: an internal temperature sensor is measured periodically and the information is sent to the GUI. This information can be used by developers to perform temperature calibration of the LED drive current and photodiodes.
- GUI communication: provides a visual representation of the measurements, and allows developers to adjust parameters - such as PGA gain, bias voltage, or sampling period- in real time.

The software implemented for this design is only a part of a complete system and is intended to be used as a reference. A complete dual-ray reflection detector will require more functionality, such as: algorithms for improved detection of smoke and nuisance rejection, monitoring voltage and temperature, system calibration, and so forth.

3.3 Peripherals and I/Os Used by Demo

Table 1 shows the peripherals and I/Os used by the application. These peripherals are defined and can be customized in the software HAL layer.

Table 1. Peripherals and I/Os Used by Demo Software

Peripheral	I/Os	Description
RTC	N/A	Ultra-low power timer active in LPM4 to trigger measurements.
Timer_B0	N/A	General purpose wide frequency timer to calibrate RTC and implement delays.
Timer_B1	N/A	Low-power periodic timer active in LPM3 triggering periodic events.
Timer_B2	P5.0/TB2.1	Generate PWM for sounder.
SAC0	P1.1/OA0O/A1	Programmable gain amplifier (PGA) to ADC.
	P1.2/OA0-	
	P1.3/OA0+	
SAC1	P1.5/OA1O	DAC controlling blue LED.
	P1.6/OA1-	
	P1.7/OA1+	
SAC2	P3.1/OA2O	Transimpedance amplifier connected to photodiode.
	P3.2/OA2-	
	P3.3/OA2+	
SAC3	P3.5/OA3O	DAC controlling infrared LED.
	P3.6/OA3-	
	P3.7/OA3+	
ADC	P1.1/OA0O/A1	Measure photodiode current after PGA and internal temperature.
eUSCI_A1	P4.2/UCA1RXD	UART communication to GUI (optional).
	P4.3/UCA1TXD	
GPIOs	P2.3	Alarm output set high when alarm is on.
	P2.5	Test button to turn off alarm or activate self test mode (long press).
	P3.4	LED indicator indicating periodic measurement or alarm activation.

4 Dual-Ray Smoke Detector Demo GUI

To improve the evaluation of dual-ray smoke detection systems, a graphical user interface (GUI) developed with TI GUI Composer is included with this application report.

TI GUI Composer is a tool for rapid development of customer user interfaces to interact with your target application. For more information about it, visit https://dev.ti.com/.

To use the Dual-Ray Smoke Detector Demo GUI:

1. Visit the TI Cloud Tools Gallery.
2. Click on the DualRaySmokeGUI_FR235x GUI.
3. Connect the PC to your MSP430FR235x design using a UART bridge such as the back-channel UART included in MSP-FET or the MSP-EXP430FR2355 LaunchPad.
4. Select the corresponding COM port at 19200 bps.
5. GUI Composer will automatically detect when the hardware is connected after receiving data from the device.

Figure 10 and Figure 11 show the Dual-Ray Smoke Detector Demo GUI and its features:

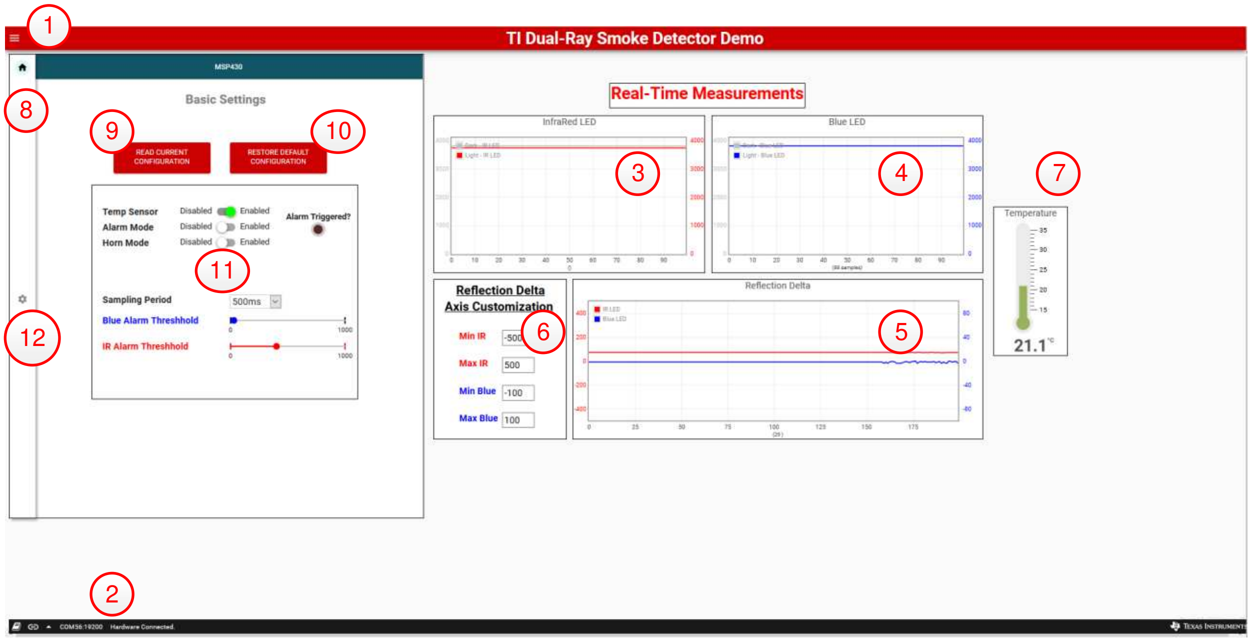

Figure 10. Dual-Ray Smoke Detector Demo GUI - Basic Settings and Real-Time Measurements

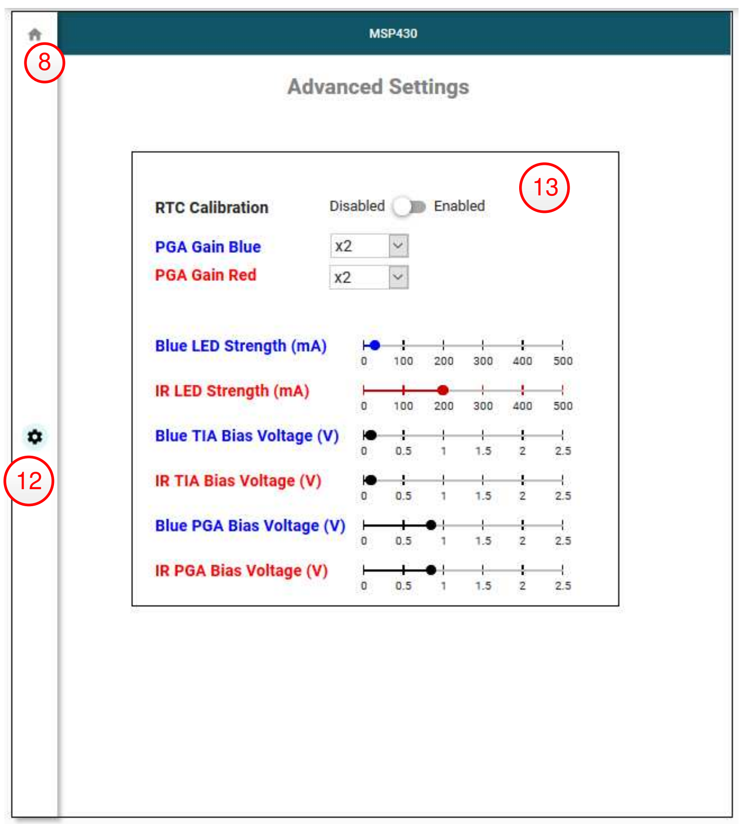

Figure 11. Dual-Ray Smoke Detector Demo GUI - Advanced Settings

The features included in the GUI are:

- Menu: used to configure port and baudrate.
- Connection Status: shows the current hardware connection and its status.

- Infrared LED plot: shows the real time ADC data for the IR LED. The "dark" IR ADC data (measurements taken with the IR LED turned off) are plotted in grey while the "light" IR ADC (taken with the IR LED turned on) are plotted in red.
- Blue LED plot: shows real time data for the blue LED with the "light" data plotted in blue and "dark" data plotted in grey.
- Reflection Delta plot: shows the difference between the "dark" and the "light" measurements for both the blue and IR LEDs. Plotting these deltas makes it easy to evaluate how intrusive substances influence the system.
- Reflection delta axis customization: adjusts the axis of the reflection delta plot.
- Temperature sensor: shows the temperature measured using the MCU internal sensor.
- Selects the Basic Settings window (default).
- Read Current Configuration button: press to update the GUI with the current configuration of the device.
- Restore Default Configuration button: press to restore the default configuration of the device.
- Basic Settings panel, including:
  - Temp Sensor: enables/disables reading the temperature sensor.
  - Alarm Mode: enables/disables the alarm detection functionality. Disable to take measurements without triggering alarm unnecessarily.
  - Horn Mode: enables/disables the horn/sounder.
  - Alarm Triggered LED: shows if the alarm is activated.
  - Sampling Period: adjusts the period of AFE measurements.
  - Blue/Red Alarm Threshold: adjusts the threshold at which the blue/IR LED reflection delta will trigger the alarm.
- Advanced Settings tab: select to view advanced settings shown in Figure 11.
- Advanced Settings panel, including:
  - RTC Calibration: enables/disables periodic RTC calibration.
  - PGA Gain Blue/Red: adjusts the PGA gain when measuring each LED.
  - Blue/Red LED Strength: adjusts the drive strength of each LED.
  - Blue/Red TIA Bias Voltage: adjusts the bias voltage of the TIA when measuring each LED.
  - Blue/Red PGA Bias Voltage: adjusts the bias voltage of the PGA when measuring each LED.

4.1 GUI Commands and Customization

Table 2 shows the commands implemented in the demo application.

"In" commands are sent by the GUI to the device to trigger actions or request a parameter update. "Out" commands are sent from the device to the GUI to transfer data or current configuration.

Table 2. Implemented GUI Commands

Command	In	Out	Description
bReadConfig	X		Requests current configuration from device
bRestoreConfig	X		Restores default configuration
tSample	X	X	Sampling period
RTCCalibEn	X	X	Enables RTC periodic calibration
tempSensorEn	X	X	Enables temperature sensor measurements
alarmEn	X	X	Enables alarm detection
hornEn	X	X	Enables horn (sounder)
bLS / irLS	X	X	Blue / IR LED strength
bPGAGain / irPGAGain	X	X	PGA gain when driving blue/IR LED
irtiaBias / btiaBias	X	X	TIA bias voltage when driving each LED

Table 2. Implemented GUI Commands (continued)

Command	In	Out	Description
irpgaBias / bpgaBias	X	X	PGA bias voltage when driving each LED
bLEDTh / irLEDTh	X	X	Threshold triggering the alarm for each LED
dR / dB		X	"Dark" IR / blue LED measurement
IR / IB		X	"Light" IR / blue LED measurement
fR / fB		X	Reflection delta (difference between "dark" and "light") for IR / blue LED measurements
tempC		X	Temperature measurement
aS		X	Indicates if alarm is activated

The GUI and commands can be customized as needed by importing the project to GUI Composer.

Although GUI Composer allows for a more advanced configuration of widgets and components using Java Script, HTML or CSS, the Dual-Ray Smoke Detector Demo GUI was created with simple binding of variables. This approach is shown in Figure 12.

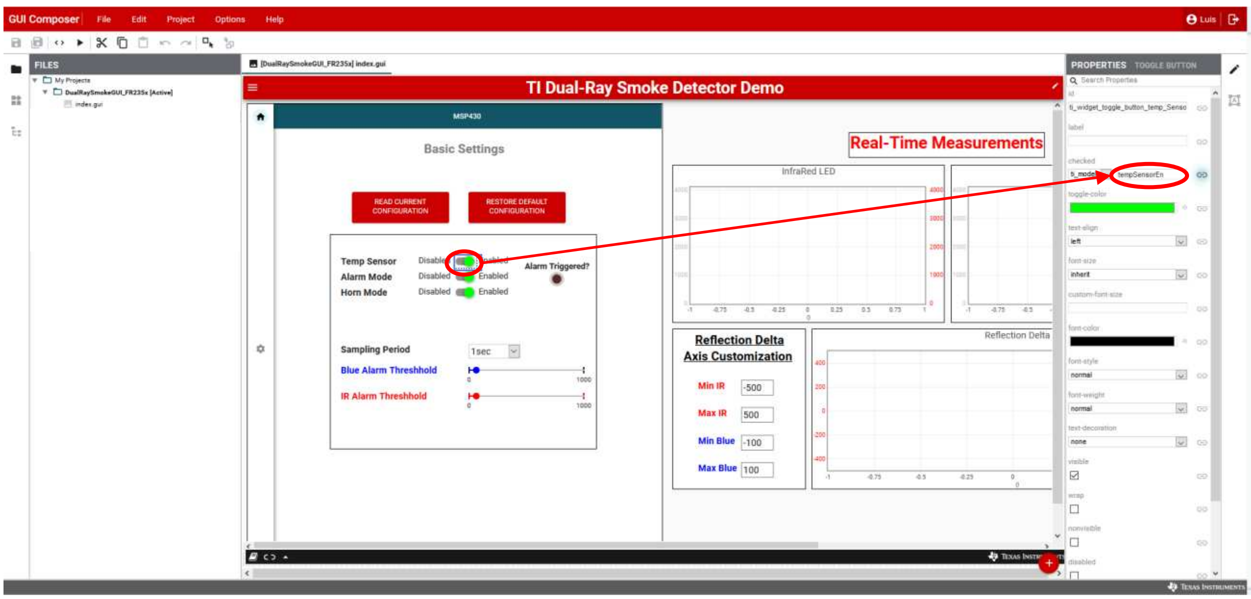

Figure 12. Binding of Variables in GUI Composer

As observed, the switch to enable/disable temperature sensing functionality is implemented with a Toggle Button widget labeled "ti_widget_toggle_button_temp_Sensor_En", and this widget is bound to the "tempSensorEn" variable. GUI composer will either automatically update the status of the switch if the variable is received from the device, or it will use this variable to send the status of the switch when the state changes.

Using this simple approach, more variables and widgets can be easily added to the application.

5 Test Results

The following tests were performed using a demo board based on the schematics included with this application report. A custom prototype chamber was used to demonstrate the capability to implement a dual-ray smoke detector AFE with MSP430FR235x; however, the results can be optimized based on the performance of the smoke chamber used by the designer.

An optimized smoke chamber and more advanced algorithms would be required to implement a final application. These topics are outside the scope of this document.

5.1 Smoke and Water Vapor Tests

Four smoke-in-a-can and four water vapor tests were separately conducted with the MSP430FR2355 dual-ray solution. For all test cases, the IR LED was driven with 100 mA, and the blue LED was driven with 20 mA. The testing procedure included placing the system in a box, filling the box with either smoke spray or water vapor, and then recording the measurements.

The difference between dark and light measurements is used to detect the presence of a foreign substance in the smoke chamber.

Table 3 shows the results of smoke and water vapor tests using four units.

Table 3. Consolidated Test Data for Smoke and Water Vapor Tests

Test Number:	1		2		3		4	
Material:	Vapor	Smoke	Vapor	Smoke	Vapor	Smoke	Vapor	Smoke
IR delta	2926	3005	2720	2991	2684	2946	2995	3040
Blue delta	878	1016	834	1078	741	1003	823	1121
Ratio IR:blue	3.33	2.95	3.26	2.77	3.62	2.94	3.64	2.71

The results of the smoke-in-a-can test show higher delta values for both IR and blue LEDs. This is due to the difference in particle size between the canned smoke and water vapor. An average IR-to-blue ratio of 2.84 was observed for the smoke-in-a-can tests, while the vapor tests had an average ratio of 3.46.

The water vapor ratio is greater than the smoke aerosol ratio for the four tests, showing the capability to detect and classify smoke with the MSP430FR235x dual-ray AFE.

5.2 Power Consumption Tests

The power consumption of the system was estimated and tested with the GUI disabled, and using a measurement period of 10 seconds, an IR LED drive current of 100 mA, and a blue LED drive current of 20 mA.

The analysis is depicted in Figure 13 (not in scale).

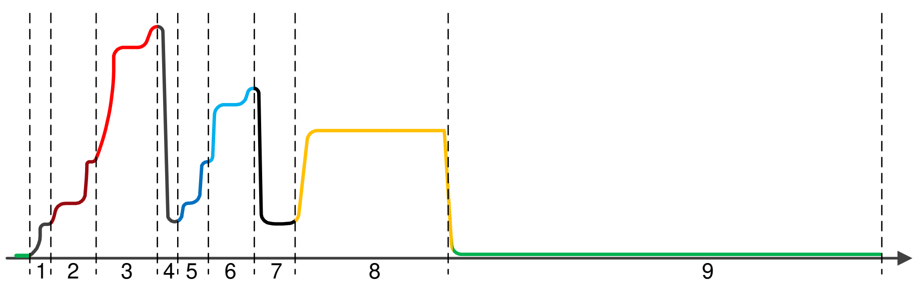

Figure 13. Power Profile of Demo Application

The power profile consists of the following stages:

1. Pre-processing: device wakes-up and initializes system for a new measurement. The device is in active mode with AFE and LEDs turned off.
2. IR dark current measurement: device takes ADC measurements with IR LED off in two steps:
   a. The AFE is turned on with both LEDs off while the CPU is in LPM0 waiting for circuitry to settle.
   b. The AFE stays on with both LEDs off, while the ADC takes four measurements with the CPU going in and out of LPM0 waiting for measurements and storing the results.
3. IR light current measurement: device takes ADC measurements with IR LED on in two steps:
   a. The AFE is turned on with IR LED on, while the CPU is in LPM0 waiting for circuitry to settle.
   b. The AFE stays on with IR LED on, while the ADC takes four measurements with the CPU going in and out of LPM0 waiting for measurements and storing the results.
4. Post-processing IR LED: AFE and ADC are turned off and the MCU processes the IR data in active

mode. The timing shown in Table 4 also includes system configuration during stage 2 and 3.

5. Blue dark current measurement: same as stage 2.
6. Blue light current measurement: same as stage 3 but turning blue LED on.
7. Post-processing IR LED and detection algorithm: AFE and ADC are turned off, the MCU is in active mode processing the data and running an algorithm to detect if alarm should be activated. The timing shown in Table 4 also includes system configuration during stage 5 and 6.
8. Indicator LED toggle: the red indicator LED is turned on for 10 ms to indicate a new measuement. The AFE is off while the CPU stays in LPM3 using REFO.
9. Sleep: the MCU goes to LPM4 using VLO with AFE and LEDs off.

Table 4 shows estimated timings and power consumption for each one of the stages.

Table 4. Power Consumption Estimates

Stage	Time (approximate)	MSP430 CPU and Digital Current (approximate)	MSP430 AFE Current (approximate)	LED Current (approximate)	Average MSP430 Current Over 10 s	Average Total Current Over 10 s
1	3 µs (1)	1 mA (2)	–	–	0.3 nA	0.3 nA
2.a	120 µs (3)	324 µA (4)	1.07 mA (5)	–	16.7 nA	16.7 nA
2.b	30 µs (6)	662 µA (7)	1.58 mA (8)	–	6.7 nA	6.7 nA
3.a	120 µs (3)	324 µA (4)	1.07 mA (5)	100 mA (9)	16.7 nA	1.21 µA
3.b	30 µs (6)	662 µA (7)	1.58 mA (8)	100 mA (9)	6.7 nA	306 nA
4	180 µs (1)	1 mA (1)	–	–	18 nA	18 nA
5.a	120 µs (3)	324 µA (4)	1.07 mA (5)	–	16.7 nA	16.7 nA
5.b	30 µs (6)	662 µA (7)	1.58 mA (8)	–	6.7 nA	6.7 nA
6.a	120 µs (3)	324 µA (4)	1.07 mA (5)	20 mA (10)	16.7 nA	256 nA
6.b	30 µs (6)	662 µA (7)	1.58 mA (8)	20 mA (10)	6.7 nA	67 nA
7	188 µs (1)	1 mA (2)	–	–	18.8 nA	18.8 nA
8	10 ms (11)	16 µA (12)	–	7.5 mA (13)	16 nA	7.52uA
9	10 s (11)	1 µA (14)	–	–	0.99 µA	0.99 µA
TOTAL	10 s	–	–	–	1.145 µA	10.45 µA

(1) Estimated according to CPU cycles and 8 MHz frequency
(2) Approximate current consumption of device in active mode at 8 MHz = 1 mA
(3) Defined by DUALRAYSMOKEAFE_HAL_AFE_DELAY_MEASUREMENT1 and DUALRAYSMOKEAFE_HAL_AFE_DELAY_MEASUREMENT2 = 120 µs
(4) LPM0 current at 8 MHz = 324 µA
(5) 3 SAC current + VREF = (350 µA x 3) + 19 µA = 1.069 mA
(6) Based on 4 12-bit ADC conversions using interval VREF, ADCSHT=8 cycles, and internal MODOSC between 3.0 MHz and 4.6 MHz.
(7) Average between active mode and LPM0 at 8 MHz = 662 µA
(8) 3 SAC current + VREF + ADC = (350 µA x 3) + 247 µA + 280 µA= 1.577 mA
(9) Defined by DUALRAYSMOKEAFELIB_DEFAULT_IR_CURRENT_MA = 100 mA
(10) Defined by DUALRAYSMOKEAFELIB_DEFAULT_BLUE_CURRENT_MAA = 20 mA
(11) Defined by demo application.
(12) LPM3 current using REFO = 16 µA
(13) Indicator LED current set by external components = 7.5 mA
(14) LPM4 current usng VLO = <1 µA

As observed, the MSP430 MCU is expected to consume approximately 1.145 µA when taking measurements every 10 seconds. The total system is expected to consume 10.45 µA, but the indicator LED blink consumes approximately 72% of the power. Skipping this functionality or reducing the LED current or the blinking time can drastically reduce power consumption.

Figure 14 and Figure 15 show the actual results of power consumption tests.

Figure 14. Measurement of System Power Consumption

Figure 15. Measurement of MSP430FR235x Power Consumption

As observed, the power consumption of the system was measured at 8.75 µA, while the MSP430 MCU alone consumed only 1.21 µA.

6 Conclusion

This application report describes a highly integrated, low-power, cost-efficient solution for a dual-ray AFE that can be used to accelerate the design of a smoke detector. The test results show the ability of this solution to detect and classify smoke and nuisance substances.

Other factors can be taken into consideration to improve smoke classification and detection with this MSP430FR235x solution, such as adjusting for input/output optical power. Different components will yield different optical responses; for example, photodiodes can have different sensitivities, and diodes can have different wavelengths and optical output levels. Taking the output power of the LEDs and photodiodes into account can allow these variances in optical responses to be adjusted. Performance can also be improved through algorithm modification, optimal smoke chamber design, and optimal LED and photodiode component selection.

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