Ultra-Low Power Motion Detection Using the MSP430F2013

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ABSTRACT

Motion detection using pyroelectric passive infrared, or PIR, sensor elements is a common method used for such applications. An implementation of such a system using the 16-bit Sigma-Delta ADC integrated into the MSP430F2013 in order to detect motion is presented in this application report.

1 Hardware Design

A system capable of detecting motion using a dual element PIR sensor is shown in Figure 1 using the MSP430F2013 microcontroller. Using the integrated 16-bit Sigma-Delta analog-to-digital converter (ADC) and built-in front-end PGA (SD16_A), the MSP430F2013 provides all the required elements for interfacing to the PIR sensor in a small footprint. With integrated analog and a 16-MHz 16-bit RISC CPU, the MSP430F2013 offers a great deal of processing performance in a small package and at a low cost.

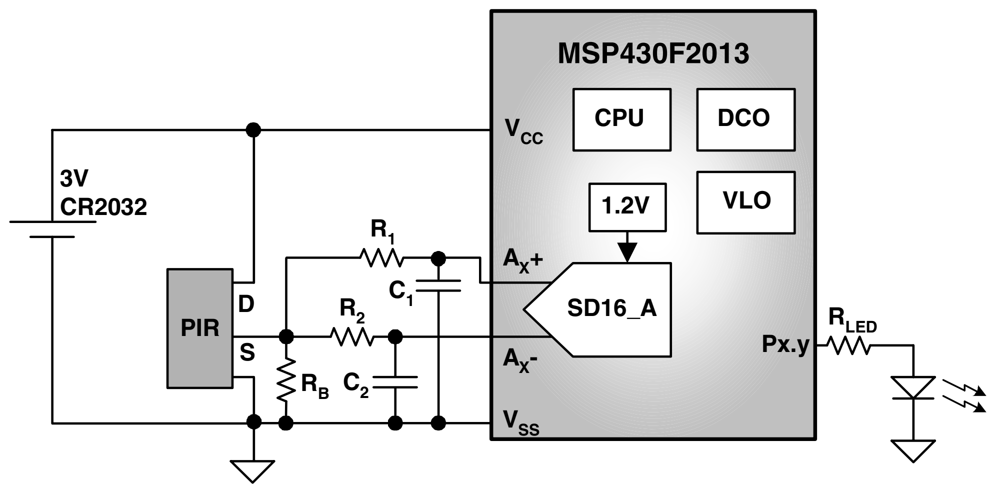

Figure 1. MSP430F2013 Motion Detection System

Figure 1 shows a simplified circuit that is used to process the PIR sensor output signal. The external components consist of the bias resistor, R_B, required for the sensor and two RC filters formed by R_1/C_1 and R_2/C_2.

The two filters serve two different purposes. Since the input to the SD16_A is differential, both a positive and negative input must be provided. R_1/C_1 serves as an anti-aliasing filter on the A_X+ input.

The second RC filter made up of R_2/C_2 serves to create a DC bias for the A_x- input of the SD16_A. This is required due to the large offset of the PIR source output with respect to V_{ss} with relation to the input range specification for the SD16_A. Figure 2 shows the respective signals in the circuit during detection of a motion event.

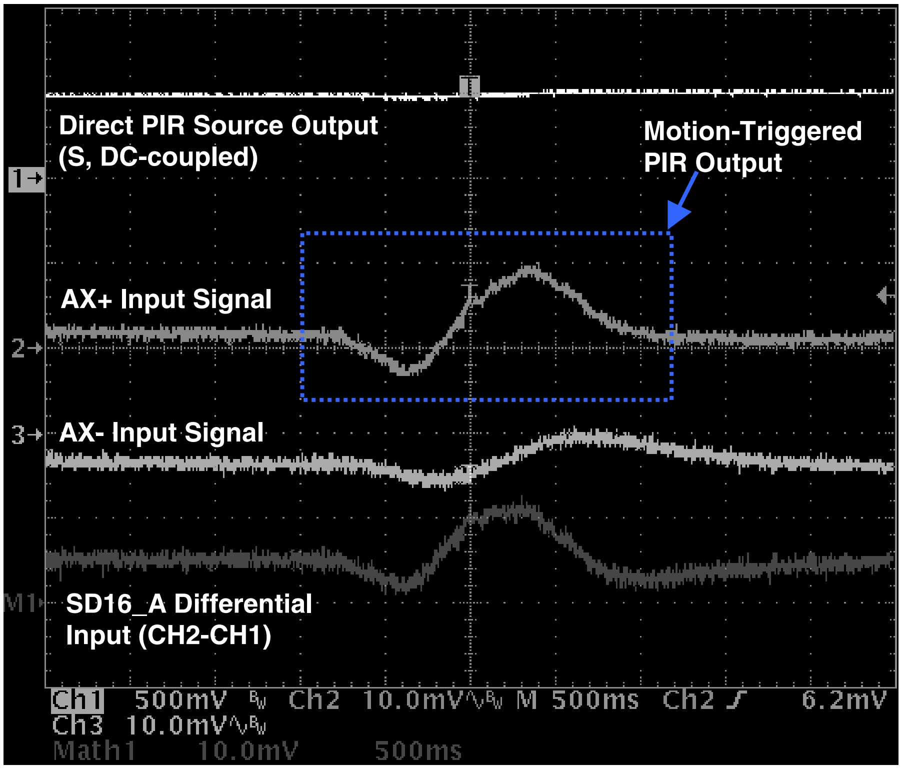

Figure 2. PIR Sensor Output & Signal Conditioning

In Figure 2, channel 1 is the direct output of the sensor. With a sensor drain voltage of 3V, the output offset is approximately 500 mV. Connecting A_x- directly to V_{ss} and the sensor source output to A_x+ would be valid only if the internal SD16_A PGA gain setting is 1. With such a small peak-to-peak sensor output, as seen on channel 2, a higher gain setting is required eliminating the possibility that A_x- can be tied directly to V_{ss}.

Alternatively, a DC bias voltage can be generated to drive the A_x- input. This is created from the R_2/C_2 low pass filter. This signal is shown on channel 3. The sensor output signal after the anti-aliasing filter connected to A_x+ is shown on channel 2. By heavily low pass filtering the sensor output before connecting to A_x- as well, a simple DC bias is established, maintaining the input range requirements of the SD16_A. The mathematical difference, CH2-CH3, is shown on M1. This is the differential voltage seen at the differential input pair, A_x, of the SD16_A.

A PGA gain of 4x with an oversampling rate (OSR) of 256 has been used in this implementation. Additional gains and OSRs up to 32 and 1024, respectively, are possible for systems requiring additional sensitivity. See the MSP430F2013 data sheet (SLAS491) for possible SD16_A PGA settings and appropriate analog input ranges.

In addition to the PIR sensor and the analog signal conditioning, a port pin is used to drive an LED. The LED is illuminated to indicate to the user that motion has been detected. This signal could also be used to drive an analog switch or relay to turn on a lamp or otherwise indicate motion in a real-world system.

As a final aspect of the hardware design, use of a Fresnel lens is critical to establishing good directionality of the sensor detection field. The internal architecture of the dual element sensor provides good noise immunity and false trigger rejection but also creates a limited directionality of the sensor's sensitivity. Use of the lens widens this field, making the final solution more robust.

2 Software Design

With low power as an essential goal in this application, analog sampling and data processing is kept to a minimum required to reliably detect motion. Figure 3 shows the software flow of the software implementation described.

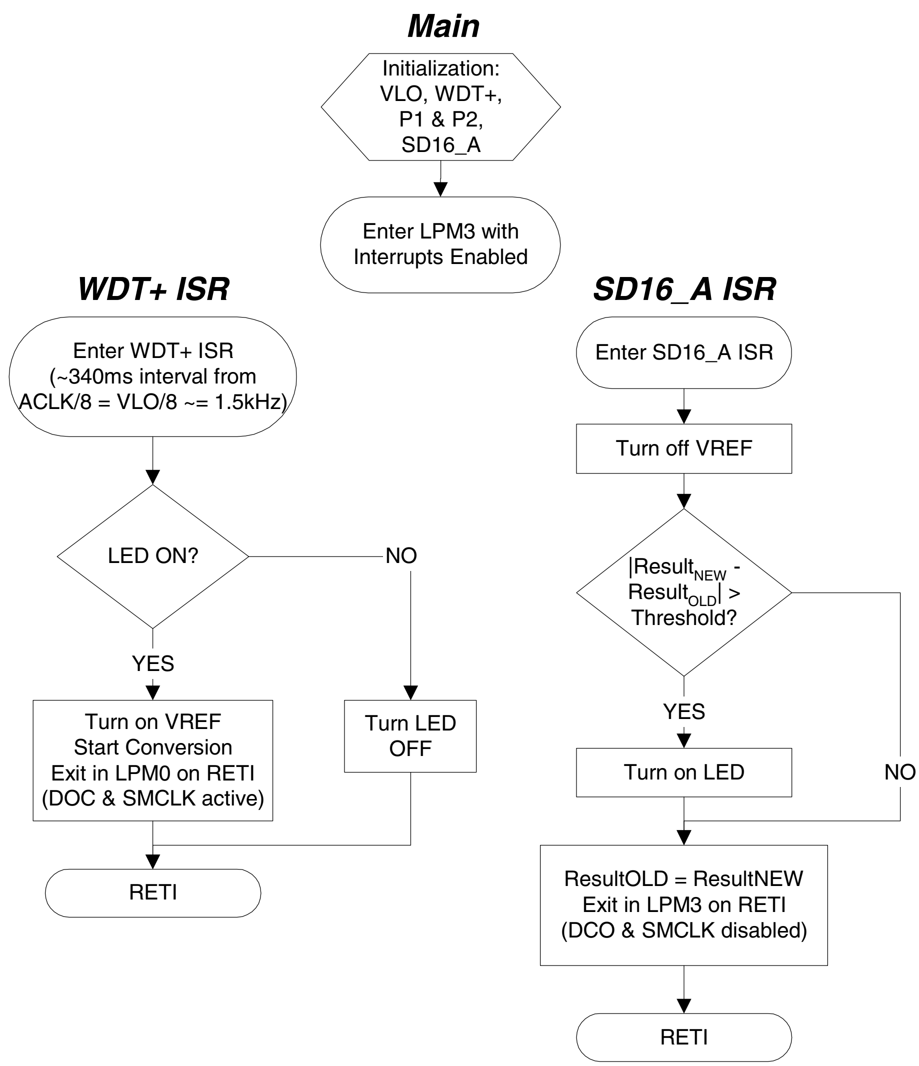

Figure 3. Motion Detection Software Flowchart

The software consists of three main elements: main routine, watchdog timer interrupt service routine and analog-to-digital converter interrupt service routine. The entire flow is interrupt driven using the internal very low frequency, very low power VLO oscillator. The VLO is approximately 12 kHz and provided internally on the ACLK clock line. This signal is then divided by 8 and drives the WDT+ to give the CPU an interval wakeup. With an interval divider of 512, this equates to a wakeup time of 512 clocks / (12 kHz / 8) = 341 ms. After initialization of all peripherals. the CPU enters into LPM3 via the VLO waiting for a WDT+ interrupt trigger.

After 341 ms, the WDT+ ISR is entered and serves two basic functions: first, to start a new SD16_A conversion and, second, to control the LED indicating motion. If no motion was detected in the last measurement (meaning the LED is off), the SD16_A internal reference is enabled and a new conversion is started. Before exiting the WDT+ ISR, the status register value to be popped upon RETI is modified so that the DCO and SMCLK used to clock the SD16_A will remain active. This causes the CPU to switch from LPM3 to LPM0 after RETI.

During this time, the SD16_A is completing the conversion process. This takes 256 clocks / 1 MHz DCO × 4 = 1.024 ms. The factor of 4 comes from the INTDLYx setting of the SD16_A. This setting allows the SD16_A to take up to four conversions before interrupting the CPU to allow for any potential analog input changes that might impact the SD16_A decimation filter, causing an invalid result. This is important, because the SD16_A is used in a single conversion mode in this application. See the *MSP430x2xx Family Users Guide* (SLAU144) for more information concerning this setting.

After the conversion is complete, the SD16_A ISR is entered and the internal reference is disabled. The absolute difference between the new result and the prior result is calculated, and compared against a preset threshold. When this threshold is exceeded, motion has been detected and the LED is enabled. The CPU exits the ISR back into LPM3 (DCO and SMCLK are disabled) and the next WDT+ interrupt is awaited.

3 Summary

Using this flow the average current consumption is maintained at a low level, low enough that the entire system can be powered from a standard CR2032 3-V battery at approximately 9.4 µA average I_{CC}. Table 1 shows the breakdown of operation versus current consumption.

Table 1. Typical System Power Budget (Over 1 second)

Function	Duration	Active Current	Average Current
PIR325 sensor	1 s	6 µA	6 µA
SD16_A and VREF + DCO	1.024 ms, ~2.94 times per second	810 µA + 85 µA	2.69 µA
CPU Active (1 MHz at 3 V)	262 MCLKs per second: 262 µs	300 µA	0.08 µA
MSP430 Standby (LPM3 with VLO)	996.7 ms	0.6 µA	0.598 µA
		Total	***9.37 µA***

The method shown here is quite simple in terms of the measurement and algorithm applied to detect motion. With up to 2-KB flash and up to 16 MIPs of processing power, the MSP430F2013 can be used to implement a much higher level of signal processing to add sensitivity as well as selectivity to a given PIR profile. The integrated analog and processing power of the MSP430F2013 family provides a low cost yet powerful MCU solution which can be used to differentiate custom motion detection applications.

4 References

1. *MSP430x2xx Family User's Guide* (SLAU144)
2. *MSP430F20xx Mixed Signal Microcontroller* data sheet (SLAS491)
3. "Infrared Parts Manual: PIR325 & FL65", GLOLAB Corporation, www.glolab.com, 2003