Low-Power Tilt Sensor Using the MSP430F2012

John Fahrenbruch
MSP430 Applications

ABSTRACT

The MSP430 family of low-power microcontrollers are ideal for low-power smart-sensor applications. This application report describes a method for interfacing an accelerometer to an MSP430F2012, creating a microcontroller-based dual-axis tilt sensor. Using efficient hardware and software design practices, the MSP430 directly interfaces with an accelerometer and drives 12 LEDs with 6 port pins to illuminate the LED oriented at the highest point when the board is tilted.

1 Hardware Description

The MSP430F2012 is interfaced with an accelerometer to create a low-power 3-V tilt sensor. To demonstrate functionality, the LED oriented at the highest point is illuminated. Figure 1 shows a system block diagram of the interface between the MSP430, accelerometer, and LEDs. The accelerometer requires 0.45 mA at 3-V V_{CC}. This allows power to be sourced using a port pin from the MSP430 and further power savings by turning the sensor off when not in use. The ADC10 converts the accelerometer's analog output (Xout and Yout) to a binary value. This value is processed by software to determine which LED to illuminate.

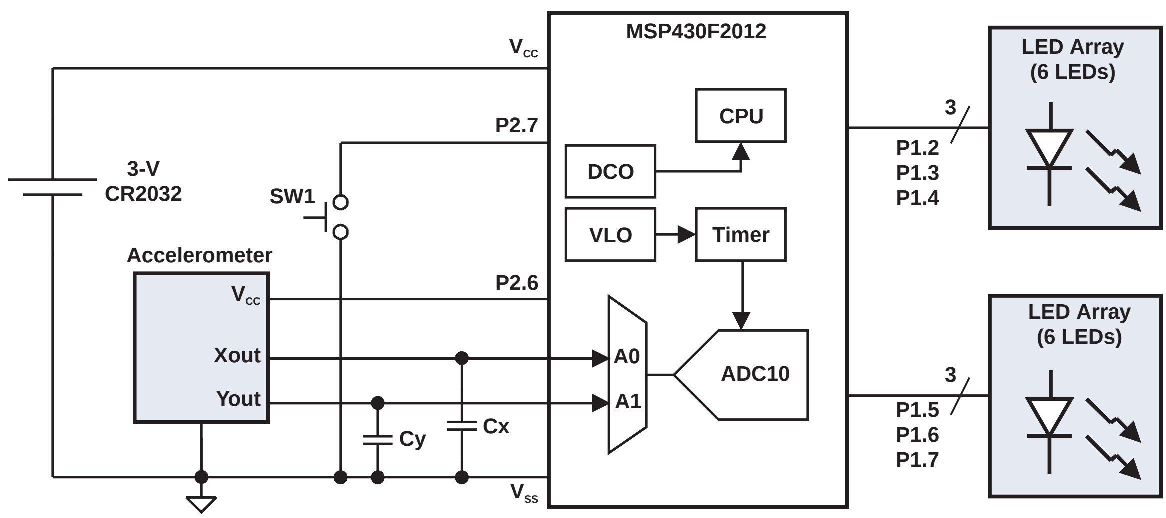

Figure 1. Block Diagram

The signals output from the accelerometer are converted two times per second, updating the 12 LEDs that are arranged in a circular pattern every 30 degrees on the circuit board shown in Figure 2.

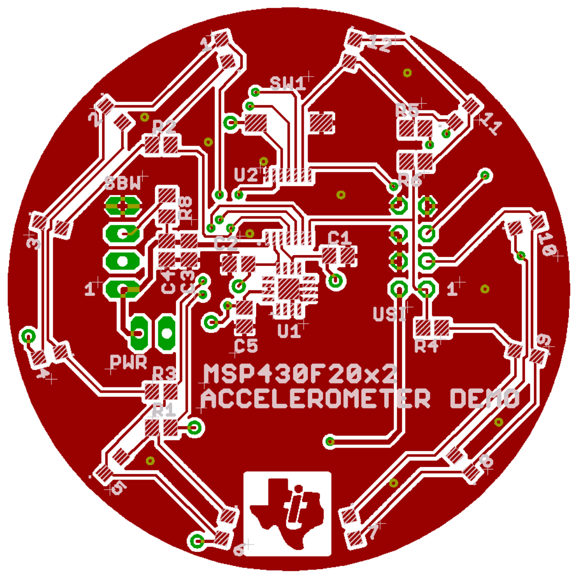

Figure 2. Circuit-Board Layout

Using multiplexing, it is possible to drive six LEDs with three port pins as shown in Figure 3 and Table 1. Reiterating this concept, 12 LEDs are driven with 6 port pins.

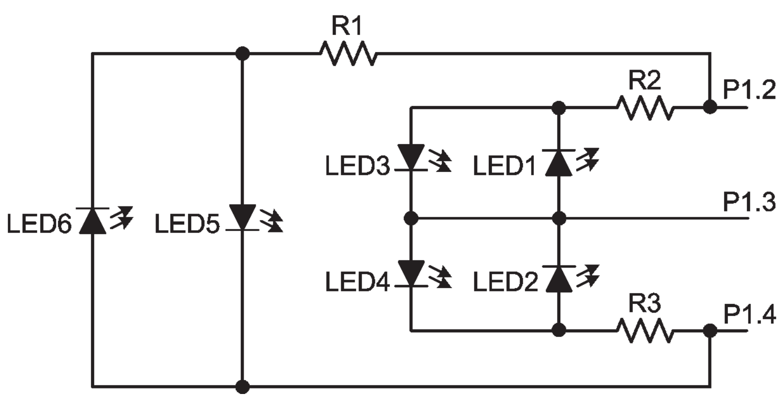

Figure 3. LED Network

Table 1. LED Multiplexing[1]

LED STATUS	P1.7	P1.6	P1.5	P1.4	P1.3	P1.2
All Off	0	0	0	0	0	0
#1 On	0	0	0	Z	1	0
#2 On	0	0	0	1	0	Z
#3 On	0	0	0	Z	0	1
#4 On	0	0	0	0	1	Z
#5 On	0	0	0	0	Z	1
#6 On	0	0	0	1	Z	0
#7 On	Z	1	0	0	0	0
#8 On	1	0	Z	0	0	0
#9 On	Z	0	1	0	0	0
#10 On	0	1	Z	0	0	0
#11 On	0	Z	1	0	0	0
#12 On	1	Z	0	0	0	0

(1) 0 = low output, 1 = high output, Z = high impedance (pin configured as an input)

Clocking the MSP430 core is accomplished with the internal digitally controlled oscillator (DCO) at a factory-calibrated frequency of 1 MHz. The built-in very-low-power/very-low-frequency oscillator (VLO) is designed to operate at 12 kHz (typical) and is used to clock the Timer_A module.

Using the factory-calibrated DCO as a time base, the VLO frequency can be calculated so that appropriate values can be loaded into Timer_A to achieve accurate timing. This is described in further detail in Section 2.

The MSP430F2xx devices have internal programmable pullup/pulldown resistors on each port pin that have been utilized in the switch circuitry to pull to V_{CC} internally.

2 Software

By taking advantage of the hardware architecture, the MSP430 family of microcontrollers can be optimized for low power consumption. Peripherals are turned off whenever possible, and the MSP430 is placed in low-power modes that shut down the DCO clock and CPU whenever possible. In this application, the VLO is used to clock peripherals to further conserve power, without the need for a 32.768-kHz watch crystal. Figure 4 shows the software flow chart for the provided code.

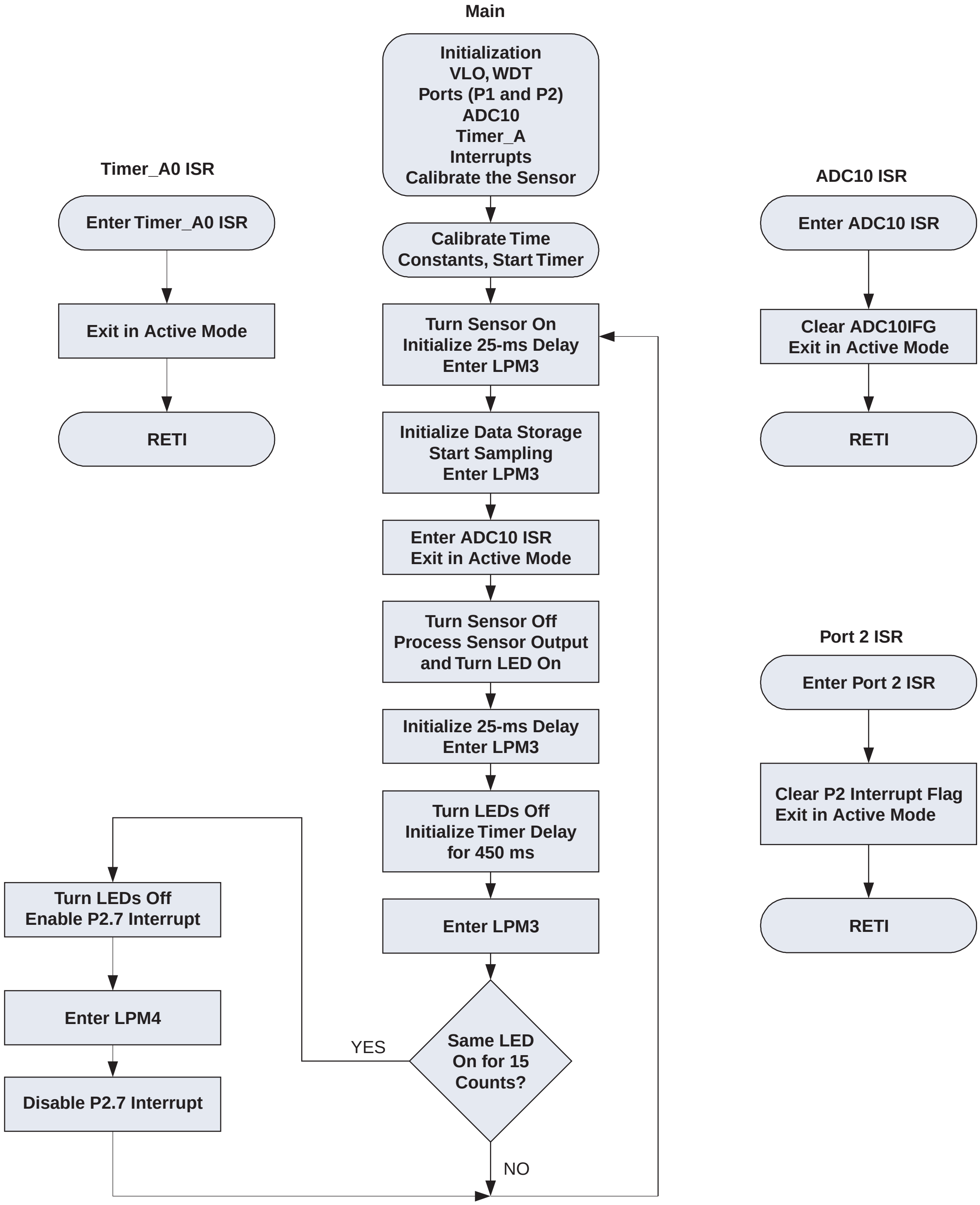

Figure 4. Tilt Sensor Software Flowchart

Upon power up, the system is initialized and must be placed on a level surface to establish a positional reference. The zero-tilt reference position is used to calibrate the accelerometer at power-up. Timer_A is clocked with ACLK = VLO to determine time constants for delays. Utilizing the 1-MHz factory frequency calibration for the DCO, the VLO frequency can be internally measured, and timer constants for the required delay periods can be calculated. This is done by counting the number of DCO clock cycles per VLO period with Timer_A.

After the VLO measurement is complete, the program enters an endless loop of sampling, processing the samples, and flashing the LEDs at two times per second. Initially, the accelerometer is turned on and given 25 ms to stabilize. The minimum time required is 21 ms; however, 25 ms has been used to simplify timing and optimize the delay constant calculations in software. During this time, the MSP430 enters Low Power Mode 3 (LPM3), waiting to wake from a timer interrupt to trigger the ADC10 to begin acquiring X- and Y-axis samples. After the ADC10 is triggered, the MSP430 again enters LPM3 until the ADC10 completes acquisition and storage of the two samples into RAM. Once this is complete, the ADC10 sets the ADC10IFG bit, triggering an interrupt and causing the MSP430 to resume operation in active mode within the ADC10 ISR. The stored conversion data is analyzed, and the appropriate LED is turned on for 25 ms. After 25 ms, the MSP430 enters LPM3 for 450 ms with all LEDs turned off to complete the 500-ms period.

A counter variable is used to determine if there is no board movement for 15 simultaneous flashes of the same LED. Should no activity be sensed, the sensor is turned off, LEDs are turned off, P2.7 interrupts are enabled, and the MSP430 is placed in LPM4 (the lowest power mode). To wake from LPM4, the external push-button switch must be depressed, causing an interrupt on port pin P2.7 to resume normal operation.

There is a window variable defined in the program. This is used to define the voltage threshold to turn on the middle LED in each quadrant grouping (i.e., LEDs 2, 5, 8, and 11). From the sensor data sheet, the sensitivity is 420 mV/g, meaning that, at rest, the maximum/minimum voltage output is 1.5 V ± 420 mV. By dividing 420 mV by 3, a "voltage window" of 140 mV for each LED is defined. Using quadrant 1 as an example, when tilted off level, LED 10 illuminates between 1.5 V and 1.64 V. LED 12 illuminates between 1.78 V and 1.92 V. By default, any value not falling within the ranges defined illuminates the middle LED, which is LED 11 in this case. Refer to Appendix A: *Accelerometer Sensor Operation* for additional information concerning the typical usage and implementation.

3 Results

The system is powered from a standard CR2032 3-V lithium battery. Using the software flow chart shown in Figure 4, an estimate of average system current consumption (I_{CC}) can be calculated and is approximately 138 µA over a period of one second. Assuming a safe margin of 80% of the typical 220-mAHr battery life is usable, an estimated system battery life of approximately 1275 hours can be achieved. Further analysis shows that the sensor and LEDs consume 99.5% of the power, while the MSP430 consumes 0.5%. Table 2 shows a breakdown of the current calculations.

Table 2. Typical System Current Consumption (for 500 ms)

FUNCTION	DURATION	ACTIVE CURRENT	AVERAGE CURRENT
MSP430 in active mode (1-MHz DCO at 3 V)	0.15 ms	300 µA	0.05 µA
MSP430 in LPM3 with VLO	499.8 ms	0.6 µA	300 nA
ADC10 On	10 µs	600 µA	0.01 µA
Sensor On	25.05 ms	450 µA	11.27 µA
LED On	24.9 ms	2.3 mA	57.28 µA
Average system current over 500 ms: 68.9 µA			
Average system current over 1 s: 137.8 µA			

When the MSP430 has not detected any change in orientation over a period of 15 consecutive samples, the system is powered down, and the MSP430 placed into LPM4. Average current consumption for the entire system in this powered-down state is approximately 0.5 µA.

4 References

1. MSP4302xx Family User's Guide (SLAU144)
2. MSP430F20xx Mixed Signal Microcontroller data sheet (SLAS491)
3. Analog Devices ADXL322 data sheet

Appendix A Accelerometer Sensor Operation

Accelerometers are used for many applications in addition to measuring tilt. A few examples are: vibration, shock, motion, security, and surface leveling. In any case, the accelerometer measures acceleration from the force of gravity (g) and/or actual acceleration. The accelerometer alone cannot differentiate the difference between a static and a dynamic force. A static force would be the force of gravity when the device is at rest and tilt is measured. A dynamic force is measured when the accelerometer is in motion. The output of the accelerometer is the vector addition of the static force (g) plus the dynamic force.

Figure A-1 shows the axis orientation for the two-axis accelerometer used in this application report. Figure A-2 is the ideal output voltage when the device is level. The Analog Devices ADXL322 data sheet specifies the typical 0-g bias level to be 1.5 V, measured at the Xout and Yout pins when V_{CC} is 3 V.

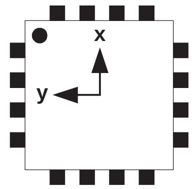

Figure A-1. X-Axis and Y-Axis Orientation

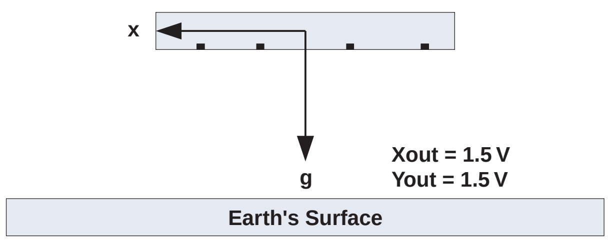

Figure A-2. Sensor Output When Level

Figure A-3 shows the device oriented at some angle that is not parallel to the force of gravity. From the data sheet, the typical sensitivity is 420 mV/g when Vs = 3 V for the ADXL322.

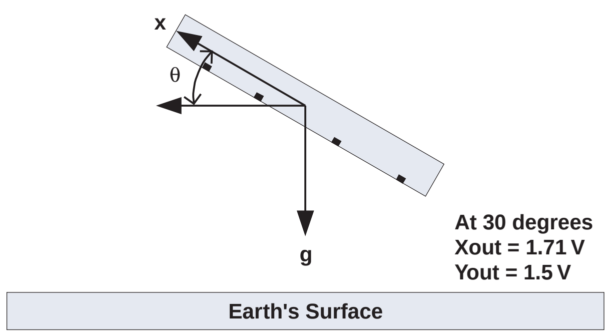

Figure A-3. Sensor Output When Not Level

Equation 1: Calculation for 30° Tilt

θ (degrees) = arcsin[(*sensor_output* – 1.5 V) × (1/0.420)]

θ (degrees) = arcsin[(1.71 V – 1.5 V) × (1/0.420)]

θ (degrees) = arcsin(0.5)

θ (degrees) = 30

IMPORTANT NOTICE

Texas Instruments Incorporated and its subsidiaries (TI) reserve the right to make corrections, modifications, enhancements, improvements, and other changes to its products and services at any time and to discontinue any product or service without notice. Customers should obtain the latest relevant information before placing orders and should verify that such information is current and complete. All products are sold subject to TI's terms and conditions of sale supplied at the time of order acknowledgment.

TI warrants performance of its hardware products to the specifications applicable at the time of sale in accordance with TI's standard warranty. Testing and other quality control techniques are used to the extent TI deems necessary to support this warranty. Except where mandated by government requirements, testing of all parameters of each product is not necessarily performed.

TI assumes no liability for applications assistance or customer product design. Customers are responsible for their products and applications using TI components. To minimize the risks associated with customer products and applications, customers should provide adequate design and operating safeguards.

TI does not warrant or represent that any license, either express or implied, is granted under any TI patent right, copyright, mask work right, or other TI intellectual property right relating to any combination, machine, or process in which TI products or services are used. Information published by TI regarding third-party products or services does not constitute a license from TI to use such products or services or a warranty or endorsement thereof. Use of such information may require a license from a third party under the patents or other intellectual property of the third party, or a license from TI under the patents or other intellectual property of TI.

Reproduction of information in TI data books or data sheets is permissible only if reproduction is without alteration and is accompanied by all associated warranties, conditions, limitations, and notices. Reproduction of this information with alteration is an unfair and deceptive business practice. TI is not responsible or liable for such altered documentation.

Resale of TI products or services with statements different from or beyond the parameters stated by TI for that product or service voids all express and any implied warranties for the associated TI product or service and is an unfair and deceptive business practice. TI is not responsible or liable for any such statements.

Following are URLs where you can obtain information on other Texas Instruments products and application solutions:

Products		**Applications**	
Amplifiers	amplifier.ti.com	Audio	www.ti.com/audio
Data Converters	dataconverter.ti.com	Automotive	www.ti.com/automotive
DSP	dsp.ti.com	Broadband	www.ti.com/broadband
Interface	interface.ti.com	Digital Control	www.ti.com/digitalcontrol
Logic	logic.ti.com	Military	www.ti.com/military
Power Mgmt	power.ti.com	Optical Networking	www.ti.com/opticalnetwork
Microcontrollers	microcontroller.ti.com	Security	www.ti.com/security
Low Power Wireless	www.ti.com/lpw	Telephony	www.ti.com/telephony
		Video & Imaging	www.ti.com/video
		Wireless	www.ti.com/wireless

Mailing Address: Texas Instruments
Post Office Box 655303 Dallas, Texas 75265