Portland State
UNIVERSITY

Erebus Labs

STEM SENSORS

DESIGN SPECIFICATION

Version 1.2

2/1//2014

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VERSION HISTORY

Version #	Implemented By	Revision Date	Reason
1.2	Scott Lawson	2/1/2014	Fixed header typos Added Engineering Requirements to Introduction
1.1	Scott Lawson	1/30/2014	Changed data sample format Changed Appendix A name to “Glossary” from “Terminology”
1.0	Scott Lawson	1/28/2014	Initial Release Converted from Software Plan V1.0

NOTE TO READER

This is a template obtained from:
http://www2.cdc.gov/cdcup/library/templates/default.htm

Template Name: Product Design

UP Template Version: 12/31/07

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1 INTRODUCTION

1.1 PURPOSE OF THE DOCUMENT

This document describes plans for both the hardware and software components of the Erebus Labs STEM Sensor. It does not include any design files such as schematics, layout files, or source code. Rather, it is intended to guide the team members in their creation of such files and describe how various system components interact with each other.

1.2 OVERVIEW

1.2.1 Objective Statement

Encourage an interest in STEM in K-12 students by delivering a working prototype of an affordable, simple and flexible device to collect environmental data.

1.2.2 Theory of Operation

The Erebus Labs STEM Sensor system is an open-source electronic device for collecting environmental data over a period of time and presenting it for analysis. The system is comprised of the following components:

Base Unit

The central device that manages power, communication, and data storage, and has one or more sensors attached to it.

Sensor

The individual data collection devices such as VOC detectors and thermometers that are attached to the base unit.

User Interface

The program that will be run on a laptop or desktop computer that allows the user to view and interact with the data collected.

The base unit will have one or more sensors attached to it and will passively collect data without being attached to a computer system. The data collection site will be chosen by the user. The user interface will be a simple GUI for displaying collected data and exporting the data to a CSV file for analysis with a third-party program.

1.3 ENGINEERING REQUIREMENTS

See proposal for marketing requirements.

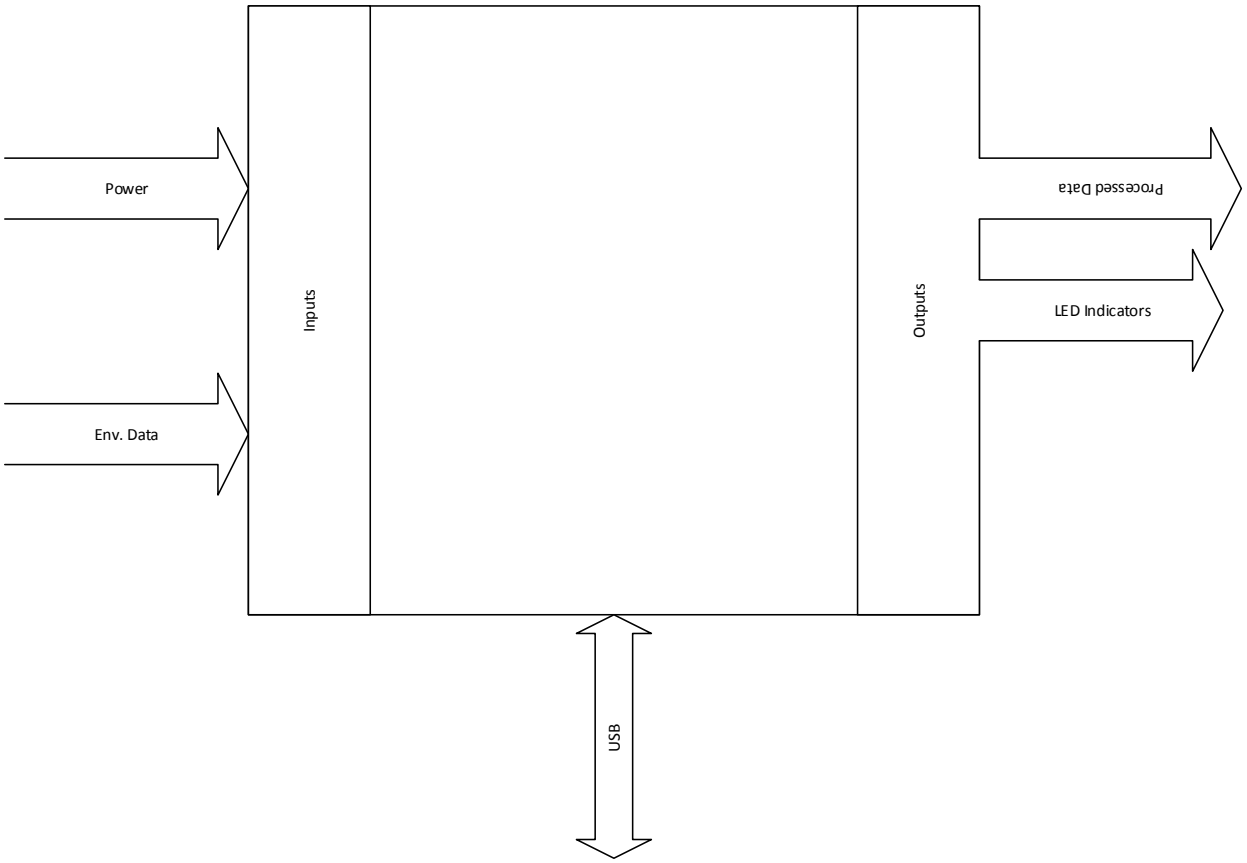
Marketing Requirements	Engineering Requirements	Justification
1, 2, 3, 4	All sensors must use the same interface to connect to the base unit	Minimizes cost and complexity for users while increasing versatility
4	The user interface must provide a method for the user to access the raw data collected	Allows advanced users to perform their own data analysis
7	A publicly-accessible repository must be used for code and documentation hosting	Encourages exploration and experimentation by students
2, 7	If third-party software is used, it must be open-source	Encourages exploration and experimentation by students, minimizes cost
5, 12	The base unit with sensors attached must operate when exposed to temperatures between -10°C and +70°C	Temperature range required for outdoor operation
2, 3	If the system is does not use a rechargeable power source, it must not use proprietary battery types	Using widely available batteries minimizes cost
2	BOM for base unit should not exceed $20.00 each	Necessary for adoption by K-12 classrooms with limited budgets
2	BOM for sensors should not exceed $5.00 each	Necessary for adoption by K-12 classrooms with limited budgets
3, 4, 9	The base unit should identify the sensor(s) attached and configure itself appropriately	Simplifies operation for younger users
1, 4, 6	The system should be able to collect data points at rates between 1 Hz and 1 per day	Accommodates a wide variety of data collection applications
4, 10	The system should be able to coordinate data collection between 6 base units simultaneously	Accommodates a wide variety of data collection applications
5, 12	The base units and sensors should be operational after a 1.5m drop-test	The system needs to survive daily use by K-12 students
5, 12	The base unit with sensors attached should operate when exposed to temperatures between -20°C and +80°C	Temperature range suggested for outdoor operation
3, 8	The base unit should be able to collect data points for 90 days without user interaction	Simplifies operation for all users
11	A wireless data dump interface should be utilized by the base unit	Provides a convenient method for users to retrieve data
11	If a wireless data dump interface is utilized by the base unit, it should not require the user to be closer to the base unit than 3 meters	Provides a convenient method for users to retrieve data
5, 12	The base and sensors may be constructed with a water-resistant case	The system needs to survive daily use by K-12 students
2, 4, 14	The base unit may contain multiple attachment points to enable multiple sensors to be used simultaneously	Enhances versatility for advanced data collection
3, 13	The base unit may use sockets and connectors to attach the controller, power, and communications devices to the PCB	Further modularity provides hardware interactivity and learning opportunities for younger users

2 HARDWARE PLAN

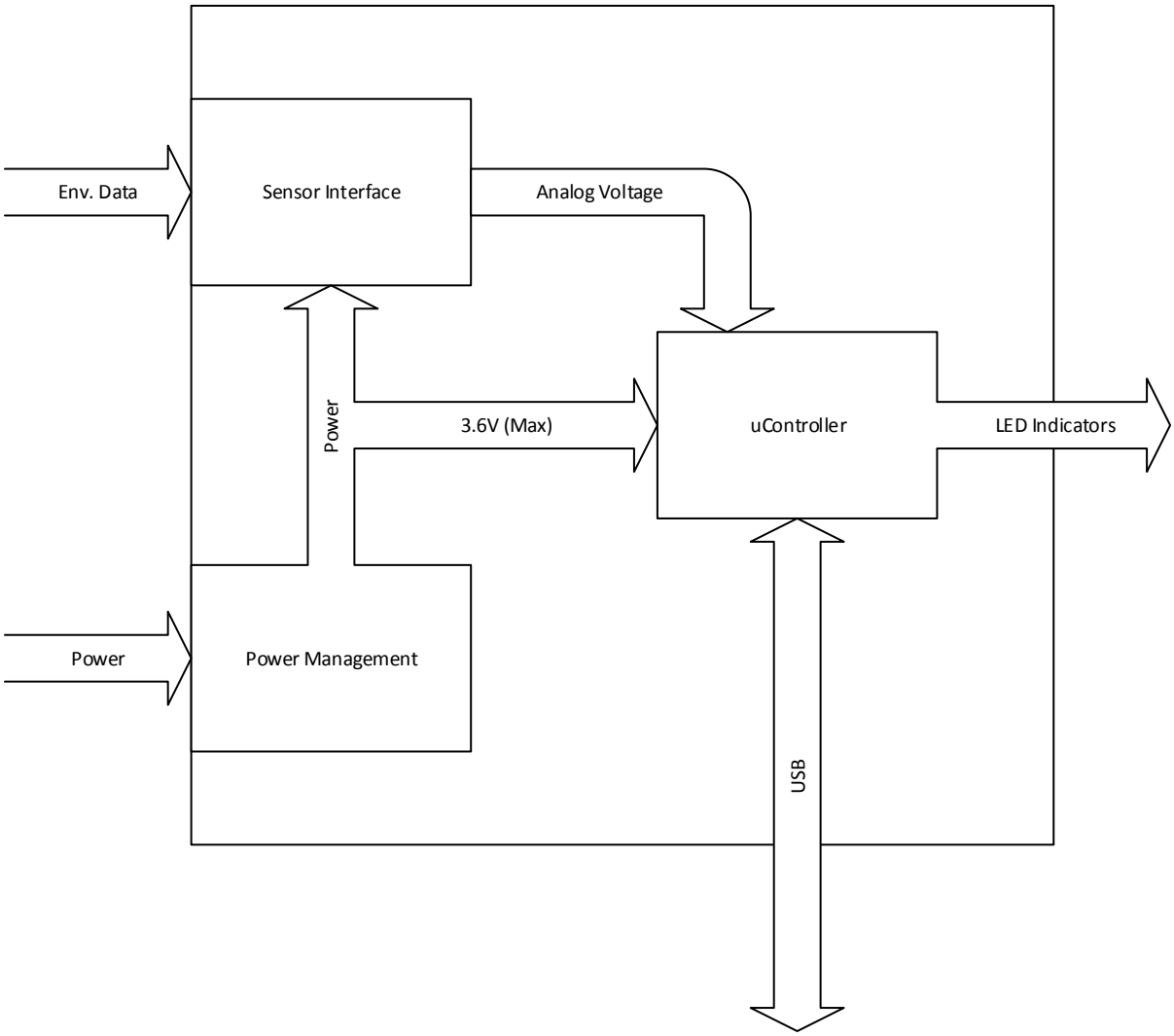
2.1 OVERVIEW

The base unit will be comprised of a Cypress PSoC 3 microcontroller, a voltage regulator, a sensor interface and a USB bus, along with miscellaneous passive and capacitive components.

2.2 LEVEL 0 BLOCK DIAGRAM



2.3 LEVEL 1 BLOCK DIAGRAM



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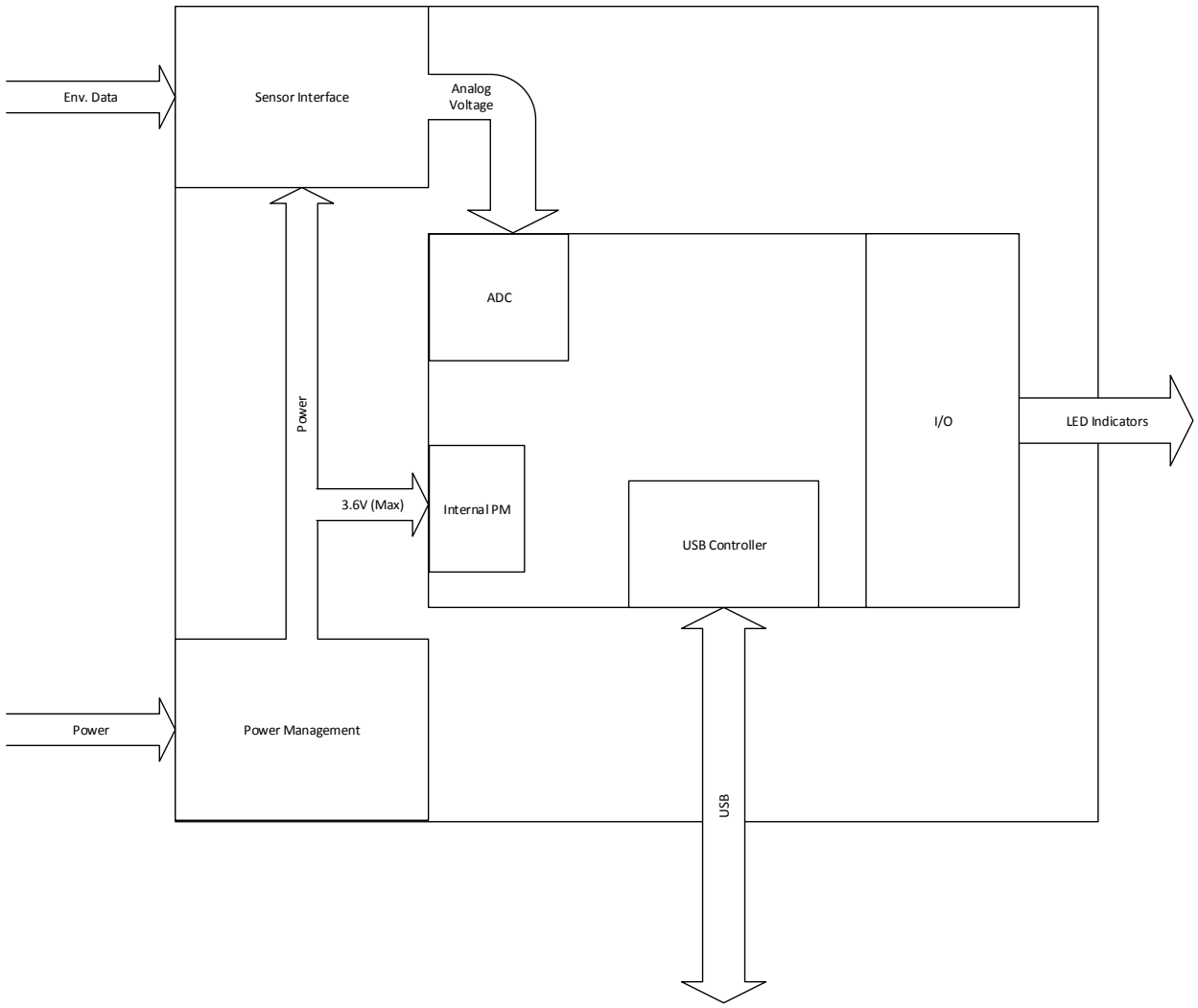
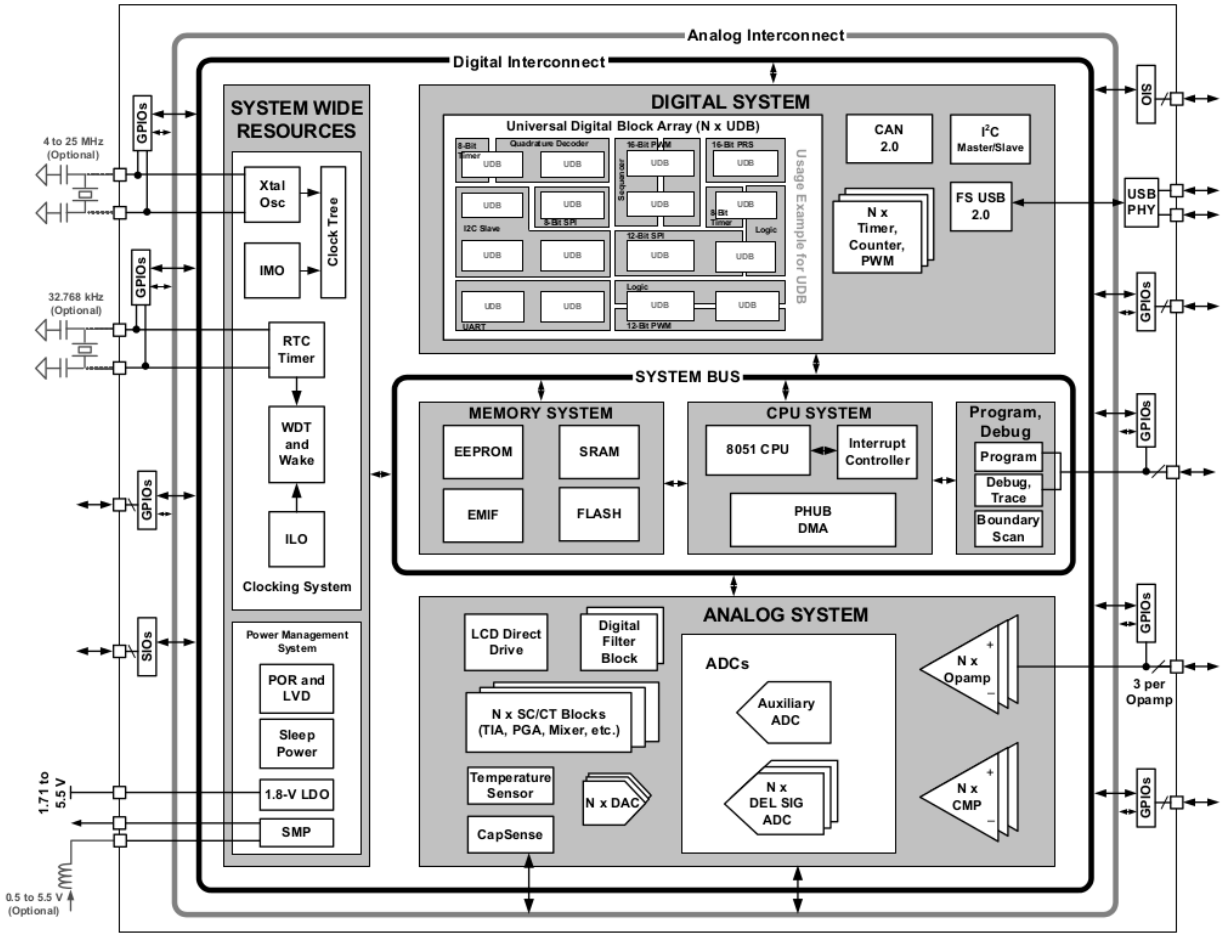


2.5 PSOC3 BLOCK DIAGRAM



2.6 IMPLEMENTATION

2.6.1 Microcontroller

The PSoC3 microcontroller from Cypress Semiconductor was selected because of its balance between flexibility and cost. It contains several embedded programmable logic blocks that can be used to implement a Full-Speed USB controller and real-time clock. Additionally, the programmable blocks also provide an interface for utilizing the chip's on-board Flash memory in place of an external EEPROM chip. Therefore, the PSoC3 provides a one-chip solution.

Manufacturer	Cypress Semiconductor
Family	PSoC3
Model Number	CY8C3245PVI-150
Architecture	8-bit 8051
Clock Speed	48MHz
Operating Voltage	1.71V – 5.5V
Current Draw	0.8mA@3MHz, 1.2mA@6MHz, 6.6mA@48MHz
ADC	12-bit Delta-Sigma
Program Memory	32KB Flash
EEPROM	1KB
UDBs	20
Package	48-pin SSOP

2.6.2 Power Supply

No power supply details available at this time.

2.6.3 Sensors

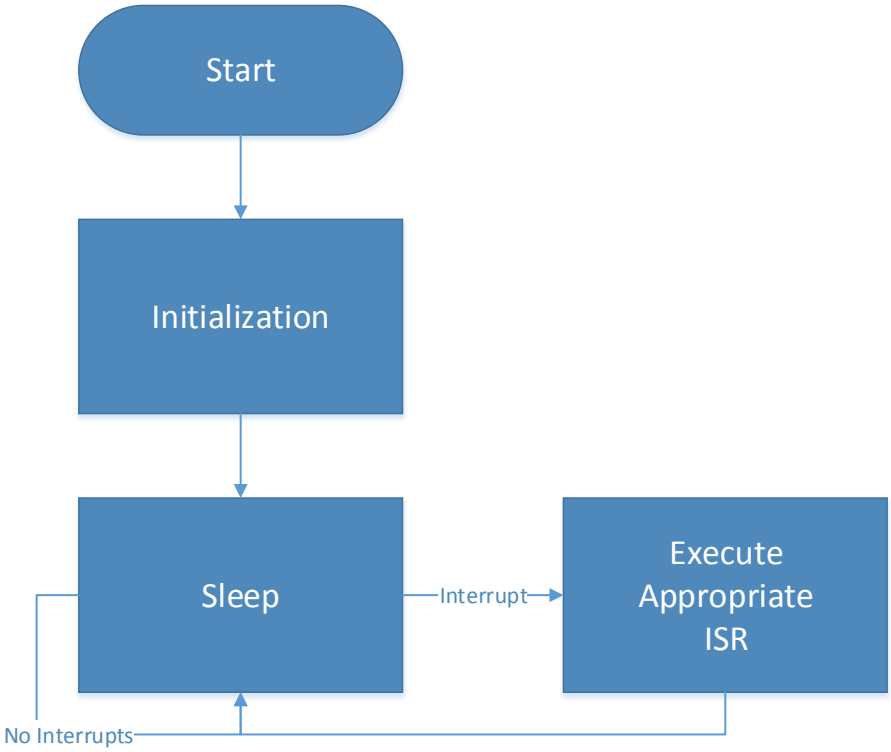
No sensor details available at this time.

3 SOFTWARE PLAN

3.1 FIRMWARE

3.1.1 Firmware Overview

The Erebus Labs STEM Sensors device firmware will be written in standard C compliant with ISO/IEC 9899:2011 and developed in Cypress' PSoC Creator 3.0. Upon reset, the controller will operate as follows:



The STEM Sensor will contain a null-body loop as its MAIN function. All functionality will be interrupt-driven. The system will remain in sleep mode except when connected to a computer via a USB interface, or when sampling the ADC. The system will be woken from sleep by the PSoC3's Central Freewheel Timer to drive ADC sampling.

3.1.2 Initialization Tasks

After a restart, the chip must be initialized. There are several individual components that will require register modifications:

General

- Clocks
- GPIOs including LEDs and buttons

PSoC Components

- USB
    - Set Device / Interface Descriptors
    - Enable USB interrupt assertions from USB controller
- Flash as EEPROM
    - Set wear-leveling pointers
    - Initialize pointers to key data points
- Real Time Clock

Analog to Digital Converter – Delta Sigma

- Enumerate Sensors or retrieve sensor IDs from EEPROM
- Configure clocks, capacitance, gain, and power settings

Central Timewheel

- Retrieve frequency settings from EEPROM
- Branches to ISRs
- Start timer

Power management

- Enable Sleep State
- Power down unused chip components
- Allow waking up from USB (PICU interrupts) and CTW
- Enable voltage monitoring

Interrupts

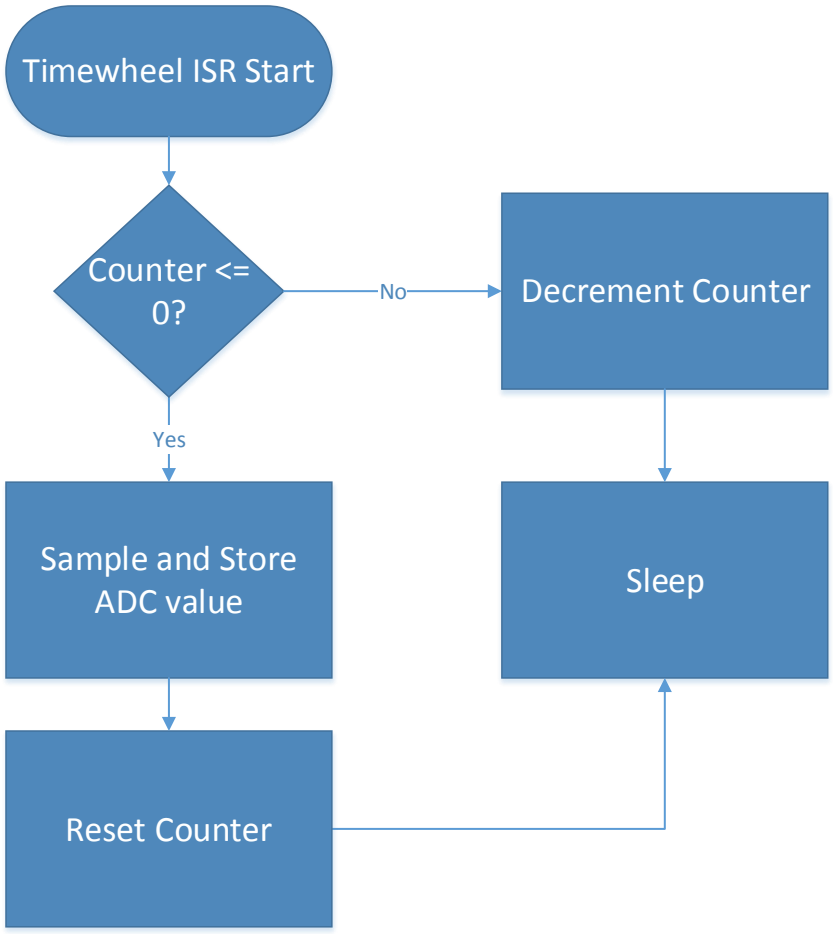
- Set USB (PICU), low voltage, and CTW interrupts in interrupt controller
- Map interrupt vectors to ISRs
- Enable global interrupts

3.1.3 Interrupt Service Routines

Central Timewheel ISR

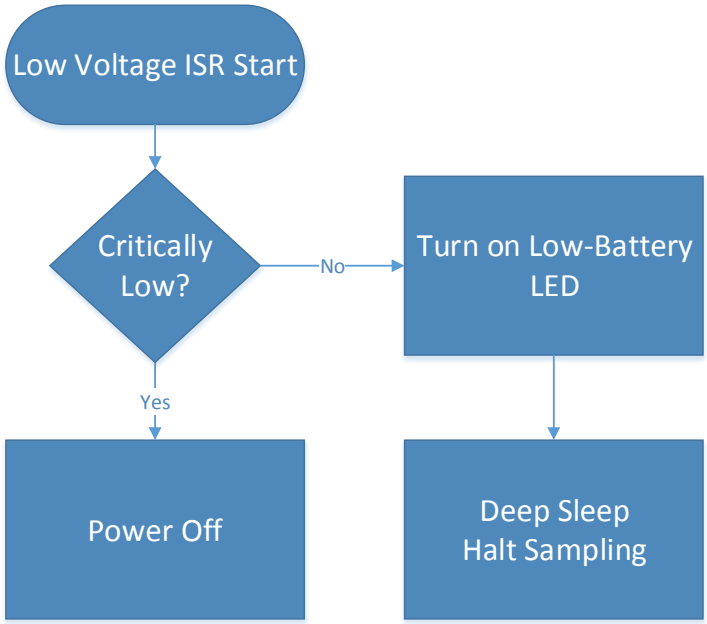
The PSoC3 employs a 1-kHz free-running clock to periodically wake the system up from sleep. The free running clock increments an interval counter that can be set as high as 4096, resulting in the counter rolling over every ~4.096 seconds and generating an interrupt, waking the system from sleep. This value will be adjusted based on the user's desired data sampling frequency.

The firmware will keep a software counter in memory, which will be decremented every time the system is woken from sleep. The value of the counter will be equal to Sample_Period / Wake_Period. See Pg 148 of the PSoC3 TRM for the Central Timewheel information.



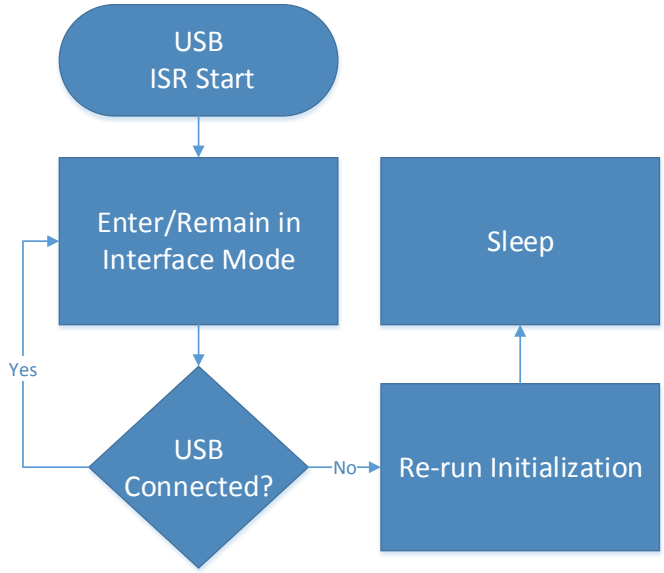
3.1.4 Low Power ISR

The actual power output of the supply batteries cannot be directly measured during operation, so the PSoC3's voltage monitoring capabilities will be utilized to detect low-voltage conditions. The Low Power ISR will determine if the system is critically low on power. If yes, the system will shut down entirely to protect the microcontroller from failure. If no, then turn on a warning LED to the user.



3.1.5 USB ISR

The system will enter an interface mode when plugged into a computer. The sampled data will be transferred to the host computer and interpreted by the user interface software.



3.1.6 Data Samples

Data samples will be stored in Flash memory along with program code by utilizing the EEPROM emulator component available for the PSoC3. Each section of data samples will begin with a 7-byte header. The header contains information about the sample period (SP) and a date/time stamp (DT) when data collection begins.

- 3 Bytes – Sample Period Information
    - SP[23:22] X
    - SP[21:17] Day of Month
    - SP[16:12] Hour
    - SP[11:6] Minute
    - SP[5:0] Second
- 4 Bytes – Initial Date/Time Stamp for the beginning of data collection
    - DT[31] X
    - DT[30:26] Year offset from 2014
    - DT[25:22] Month
    - DT[21:17] Day of Month
    - DT[16:12] Hour
    - DT[11:6] Minute
    - DT[5:0] Second

The data samples themselves will be recorded in a 2-byte bit-field (DA) comprised of the 12-bit ADC output and a 4-bit sensor signature, identifying which type of sensor the measurement was made from.

- DA[15:12] Sensor Identifier
- DA[11:0] Raw ADC output

3.2 COMPUTER INTERFACE

3.2.1 User Interface

The host computer user interface will be a simple GUI that performs three functions:

- Provide a method for the user to change data collection settings or reset the base unit.
- Allow the user export data from the device. When this occurs, the GUI will be responsible for translating the data from the 40-bit fields described in 3.1.6 into human-readable data.
- Allow the user to display simple graphs of previously collected and exported data when the base unit is not connected to the computer.

The interface will be written in Python, compatible with version 3.3 or later.

3.2.2 Program Installer

The user interface software will be packaged in an installer that allows the user's system to recognize the base unit when attached, and launch the GUI.

APPENDIX A: GLOSSARY

A.1 ACRONYMS

Acronym	Meaning
ADC	Analog-to-Digital Converter
BOM	Bill of Materials
CO	Carbon Monoxide
CSV	Comma-separated-value formatted file
EEPROM	Electrically Erasable Programmable Read-Only Memory
EPL	The Portland State University Engineering and Prototyping Lab
I^2C	The Inter-Integrated Circuit communication protocol
ISR	Interrupt Service Routine
K-12	Kindergarten through 12^{th} grade school
LED	Light Emanating Diode
PCB	Printed Circuit Board
PSoC	Programmable System On Chip
SI	Silicon
SPI	Serial Peripheral Interface Bus
STEM	Science, Technology, Engineering and Math
TRM	Technical Reference Manual
USB	Universal Serial Bus

A.2 SYSTEM ARCHITECTURE

Base Unit

The central device that manages power, communication, and data storage, and has one or more sensors attached to it.

Sensor

The individual data collection devices such as VOC detectors and thermometers that are attached to the base unit.

User Interface

The program that will be run on a laptop or desktop computer that allows the user to view and interact with the data collected.

System

The operational product comprised of base units with attached sensors and a user interface.