PolyEnvi

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Abstract

Poor indoor air quality is a problem that is recognized by the Environmental Protection Agency (EPA) to cause health issues. In order to raise awareness of this problem, this document outlines the construction of a device that economically measures air quality through five metrics: dust, smoke, ozone, humidity, and temperature. The device integrates with a router to provide users access to information about their indoor air quality anywhere over the internet as well as local access to the data via an LCD mounted on the router. By increasing indoor air quality awareness, this device will aid users in making adjustments to their homes to improve quality of life.

The end product is an effective and low-cost solution. With a production cost of $150, it can provide as much usable information to residential users as a higher-end commercial sensors.

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Chapter 1 - Project Objectives

Introduction

Our project consisted of designing and developing an inexpensive air quality sensor for residential use. It measures dust, smoke, and ozone in the ambient air surrounding a sensor enclosure; in addition, it measures levels of humidity and temperature. We chose to measure dust and smoke because these are particles commonly known to trigger allergic reactions or asthma, and are otherwise unhealthy to breathe even for people who do not suffer either condition. We also chose to measure ozone because it is a by-product of smog, which is another pollutant that is unhealthy for anyone to breathe, and humidity because high-humidity conditions are known to exacerbate allergic and asthmatic reactions [1]. Finally, in order to retain the functionality of the client's base product, we added a temperature sensor. We, team PolyEnvi, brainstormed, designed, and developed this project on our own as a solution to the common problem of poor air quality.

The key component of the project is a sensor unit, which houses the sensors and acts as an add-on to an existing wireless router platform developed by the company Temperature@lert, our project's client. Our product has the capability to display sensor data on a LCD screen which is mounted to the wireless router. Users of this product are be able to remotely configure the sensor unit via a personal computer through the wireless router; in addition, the device allows for graphical displays of the sensor data through a website hosted by the router.

The key user group for this product is anyone concerned with health issues related to the air quality of their home, such as those with allergies. Our product provides an easy-to-use tool for people who desire to decrease the amount of pollutants in their home. Users are able to act once they have been notified by our product that an air quality problem exists. Emphasizing the significance of the problem we our solving, the U.S. Environmental Protection Agency (EPA) recognizes that poor indoor air quality may be hazardous to people's health. The EPA states, "Indoor pollution sources that release gases or particles into the air are the primary cause of indoor air quality problems in homes" [2]. These sources typically result from the use of combustion sources such as oil, gas, kerosene, coal, wood, and tobacco products. They also result from building materials like asbestos-containing insulation and home furnishings like cabinetry or furniture made of certain pressed wood products. The EPA recommends diluting the indoor air with outdoor air when air quality becomes a health problem. The EPA website states, "Some health effects can be useful indicators of an indoor air quality problem" [2]. Our air quality sensor provides an alternative and safe method to indicate problems with air quality. The website also states that "high temperature and humidity levels can also increase concentrations of some pollutants" [2]. Our product has been designed to measure temperature and humidity in addition to particle hazards. Furthermore, prolonged exposure to poor air quality may result in respiratory diseases. Symptoms of these diseases consist of asthma, hypersensitivity, pneumonitis, and humidifier fever. An air quality sensor in the home serves as a tool to help prevent avoidable health conditions. The EPA has identified a problem, and we have a solution to help combat it.

Background

Many air quality sensors exist on the market today, but very few are geared toward home-use, and even fewer are offered at as low of a cost as ours is. The highest-quality sensors on the market exist as particle counters, and are useful for highly-controlled environments, such as cleanrooms and HVAC applications. These products, such as the

Lighthouse 2000-series and the Kanomax 3000-series particle counters, cost thousands of dollars and would be impractical to purchase for home use. More comparable products to our own are the Dylos DC1100 Air Quality Monitor ($199) and the Fantech Air Quality Sensor ($119). Both products are lacking in data resolution and precision: the DC1100 can only distinguish between large and small particles, and the Fantech only measures aggregate particles as a whole. Our product not only informs users about the quality of the air, but more specifically about what kinds of particles are affecting it. Furthermore, while the DC1100 does save historical air quality data, the UI only allows users to scroll through previous values, instead of allowing them to view data graphically as ours does.

Objectives

Our goal for the project was to design and prototype a low-cost home-use air quality sensor that will function as an add-on to the Temperature@lert router and integrate into the Temperature@lert system.

Functional Requirements

Our sensor array must measure dust, smoke, ozone, humidity and temperature in the air. It must output this data to the user on an LCD display attached to the Temperature@lert router, as well as on a web page hosted by the router.

Performance Specifications

The values for temperature and humidity must be displayed in a quantitative manner. This means that a displayed value of 40% for humidity must mean that the relative humidity of the air is actually 40%. This value must be a whole number, and it must be accurate to within 5%. The measured smoke, ozone, and particle amounts, however, must be displayed qualitatively. The data will be displayed as a ranking from 1 to 10, 1 being close to the sensor's lowest possible reading, and 10 being close to the sensor's highest possible reading.

Physical Dimensions

The sensor unit enclosure must be less than eight inches cubed (or 512 cubic inches) in size. The only requirement for operating space is that nothing must block air flow to the device. This means that nothing can completely surround the top of the device. There are no requirements for clearance around the base of the enclosure. The sensor unit must also weigh less than 2 pounds.

Operating Environment

The ambient temperatures during operation must be between 0 and 50 degrees Celsius. The ambient temperatures during shipping and storage must be between -10 and 60 degrees Celsius. These temperature thresholds were determined from the highest minimum and lowest maximum temperature ratings of all of the electrical components in the system. We have no quantitative requirements for shock and vibration, but it must be able to withstand a US Mail shipment without any damage. Lastly, the input voltage of the sensor unit must be 12V, and the maximum current draw must be less than 1.5A.

Reliability and Product Life

The product must be reliable for 15 years. Also, it must require no more than monthly maintenance, which involves disassembly to wipe off the sensors and enclosure, to prevent dust buildup which may interfere with the readings.

Health, Safety, and Environmental Requirements

This product has no health, safety, or environmental requirements.

Marketing and Business Requirements

We estimate that 500 units will be sold per year (5000 units total, with an estimated ten-year lifecycle). The product will be targeted to US customers, but it will be available to customers all over the world. We require that the total cost of production is no more than $150, so that we can sell it for $200 and make a profit of $50 per unit sold. Finally, we do not have a specific launch date for this product.

Chapter 2 - Management Plan

Team Members & Primary Responsibilities

The members of PolyEnvi strive to participate on every aspect of the project; nonetheless, our members have taken specific roles and responsibilities. Stephen acts as our main contact with the company Temperature@lert. He also acts as the lead for the router's software integration. Paul leads the development for the project's website and router's communication with the website. Joshua, Diego and Alvaro manage the manufacturing considerations for the project. Joshua has also been leading the team's effort to arrange the testing plans for the sensors. Diego has focused his efforts on the design of the project's sensor enclosure design. Alvaro's tasks focuses on the projects material and procurement plans. This also includes arranging prototype fabrications by using a rapid prototyping machine. Miguel's responsibilities lie in managing the project's electronic sensor array and schematics. The team as a whole maintains a Gantt chart to track progress and to identify activity dependencies.

Major Tasks and Milestones

Obtaining the sensor components for the project became a very important step to complete at the beginning of the Winter Quarter. This allowed us to begin initial testing and project integration. During this quarter, we also identified the resources to perform the product verification tests for the project. This will allow for the team to smoothly conduct tests in the Spring Quarter because no time will be spent hunting down testing resources. This quarter also involved developing initial designs for the sensor enclosure. Completing this allows the team to focus on more important tasks regarding sensor and router integration. Obtaining router information from Harry, our contact for Temperature@lert, consist of obtaining an expansion board.

Upon receiving Temperature@lert's new expansion board, we will continue the integration of the project's router and sensor array. The specific method to build the project relies on having the client's updated expansion board. Completing the assembly of the first prototype is the Winter Quarter's most important milestone. The will allow for final product testing and verification. Please refer to Appendix G for Gantt Chart.

Expenses and Projected Budget

The following consist of a summary of our project's current incurred expenses and projected budget required to complete the project's prototype development:

Table 2.1 -

Project Expenses

Part	Supplier	Qty	Total order cost
Seeedstudio MQ2 Smoke Detector	www.robotshop.us	2	$35.46
Seeedstudio MQ2 Smoke Detector	www.seeedstudio.com	1	$7.53
Futurlec MQ131 Ozone (O3) Gas Sensor	www.futurlec.com	3	$60.70
Honeywell HIH 4000-01 Humidity Sensor	Mouser	3	$67.56
PIC18F24K20 (3x -I/SP version, 1x -I/ML version)	Microchip Direct	1	$20.49
CFA632YMCKS	www.crystalfontz.com	2	$82.00
Mesh	Home Depot	1	$9.19
DSM501A	Shenzhen HYC Electronic Technology CO. Ltd	3	$98.95
*some "Total order costs" include shipping and services charge		**Current Project Total Expense:**	**$381.88**

Table 2.2 -

Project Budget for Other Expenses

Part	Budgeted cost
Miscellaneous wires and supplies	$20.00
Sensor enclosure prototype	$0.00
Equipment and testing supplies	$0.00
Total:	**$20.00**

The projected budget to complete the project is very minimal because of the resources available to students working on senior projects. For rapid prototyping, the Industrial and Manufacturing Engineering Department at Cal Poly allows for students working on projects to build project parts at no cost. Martin Koch, an equipment technician, provides our group assistance with using the rapid prototyping machine. As students, we also have free access to labs such as the Air Quality and Control Lab. This access provided by Associate Professor Thatcher serves as an example for why our project testing costs will result in no additional cost. We are also getting help from the San Luis Obispo Air Pollution Control District to conduct testing with our ozone sensor. Equipment availability is highly available for student projects at no cost.

Chapter 3 - Design Concept Development

When thinking of possible concepts for the enclosure of our product, our team wanted to identify what the users would find appealing. Since our sensor is intended to be used indoors, more specifically in American homes, we began to sketch up designs we felt were stylish and curvy as well as more conservative and straight forward designs. We created six potential mock up designs, all inspired from everyday objects, using the CAD program SolidWorks (figure 3.1). Our final designs included the following:

- The Bubble- Resembles the shape of two soap bubbles stacked on top of each other.
- The Flying Saucer – Resembles a flying saucer as depicted in older science fiction movies.
- The Mushroom - With a large head and stem this design resembles a common mushroom.
- The Eraser – Resembles the erasers commonly given in elementary schools.
- The Sphere - Basically a sphere with a flat bottom for stability when placed on a flat surface.
- The Hockey Puck – A short cylindrical disk that resembles a hockey puck in shape (but not in size).

The functional requirements stated that our enclosure must be black in color, as small as possible, attractive, etc. but did not mention any specific requirements surrounding shapes or sizes. To choose one design a survey was created to allow the general public to pick the design they felt they would like to see in their homes. The three dimensional image of each design was displayed and a group of questions regarding preferences in design shape and size were drafted and included in the survey. A link to the survey, hosted on surveymonkey.com, was sent out to various people using the online networking site "Facebook". After two weeks, 69 people had taken the survey; of those people, 44.8% agreed that the "flying saucer" was the most aesthetically appealing design. The second closest design was the "hockey puck" with only 17% of the votes, so the selected design far surpassed the second choice by more than 5%. The feedback we obtained from the survey advised us the most people like a design that with circular curves and that this product should be no larger than a cubic foot.

To examine the feasibility of our enclosure, a SolidWorks model of each subcomponent was created. Using a SolidWorks assembly drawing, our team was able to place each subcomponent inside the enclosure to examine how everything could be arranged. It was concluded that our design was too flat, since our subcomponents often stuck out of the enclosure. The only way to have all subcomponents fit within the enclosure would be to either increase the overall size of the enclosure or to modify the design so that there was more space in the top region of our "flying saucer". We decided to modify the design since our survey feedback indicated that most people would like a design that had curves. Furthermore, the design modification could save material by increasing the surface area to volume ratio; instead of simply making a bigger part, we would design more space in the top region of our enclosure while keeping the size relatively the same. The top of the enclosure was expanded out to increase the overall height while still maintain two curved regions for this portion. With this design modification, we were able to fit all subcomponents in an enclosure with a base diameter of 6 inches and a height of approximately 1.5 inches, well below our engineering requirement of an 8" cube. To ensure that our enclosure does not impede sensor readings and that the ambient air is able to easily flow to the sensors, we decided to use a mesh to create the top portion. More specifically a black aluminum mesh to provide increase protection against oxidizing as well as increased strength and durability.

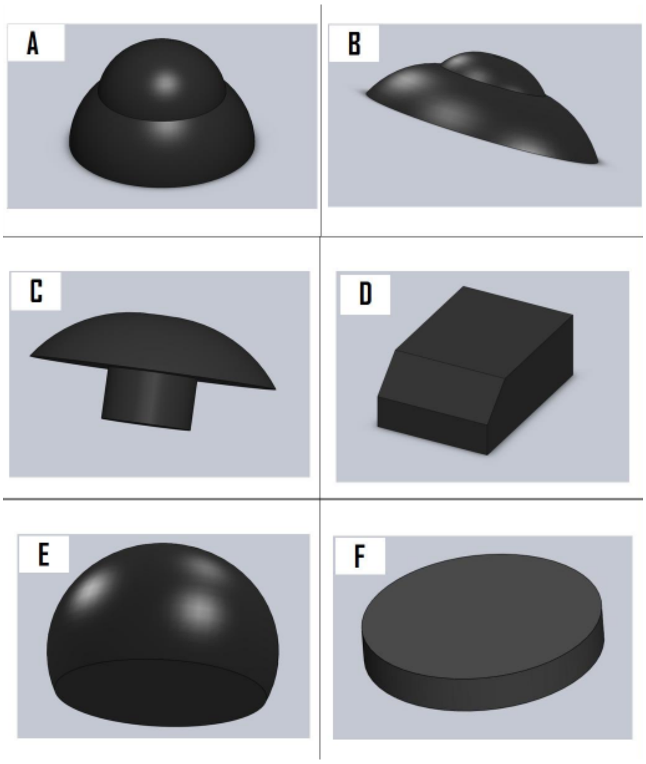


Figure 3.1 - The mock up drawings of six concept designs

Final Concept Drawings

Our final concept has a black aluminum mesh dome, which falls into a black polyethylene petri dish shaped base (Figure 3.2). The mesh will be secured onto the base with three screws and nuts. The polyethylene base is 6” in diameter, and the top of the mesh is approximately 1.5” high from the bottom of the base. Inside the enclosure you will find a dust, smoke, ozone, and humidity sensor embedded on a circuit board (Figure 3.3). Each sensor will be approximately 5mm from any nearby sensor. A wire connect to the circuit board will extend from the enclosure to the Temperature@lert router which will receive the data output by the sensors.

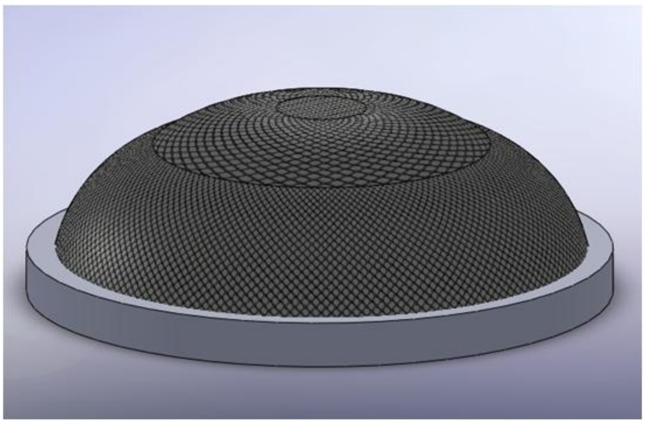


Figure 3.2 - Final enclosure design

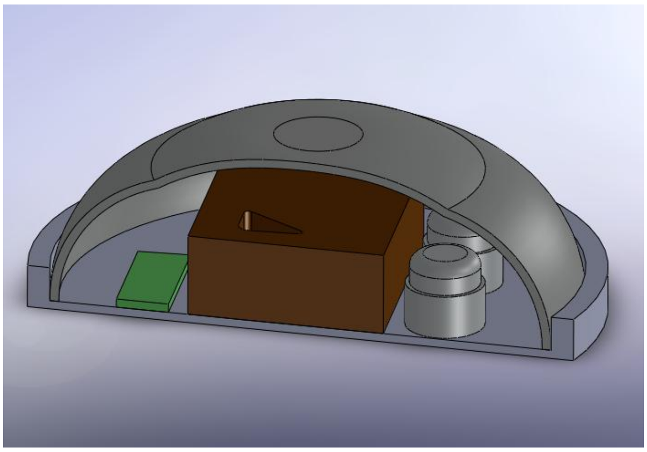


Figure 3.3 - Sectional view of enclosure with internal components shown

Interface Specifications

As seen in Figure 3.4 below, the system will have two main inputs, an Ethernet and WiFi connection. The system will also output to a LCD display, as well as to any device connected to the web server.

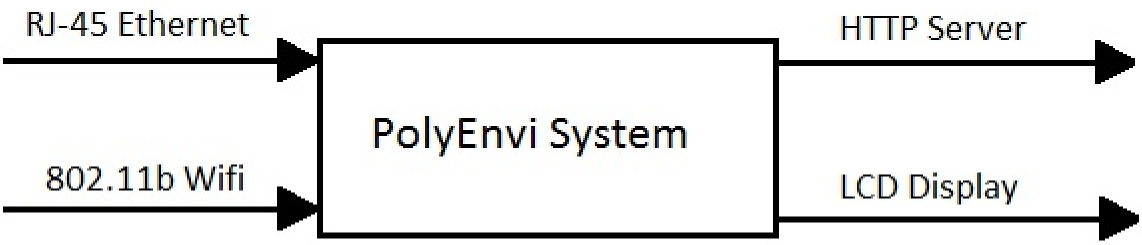


Figure 3.4 - Interface Block Diagram

Definition of User Interfaces

The web server will provide access to a number of user settings, including: network settings; e-mail address, to receive status updates; sensor reading intervals; alarm ranges; temperature notifications in Celsius or Fahrenheit; and time settings.

The web server will also be used to display graphs of historical sensor data. The user may also use the web server to view sensor and error logs.

An LCD will be used to display current sensor readings.

Overall System Architecture

Figure 3.5 below shows a breakdown of the system architecture.

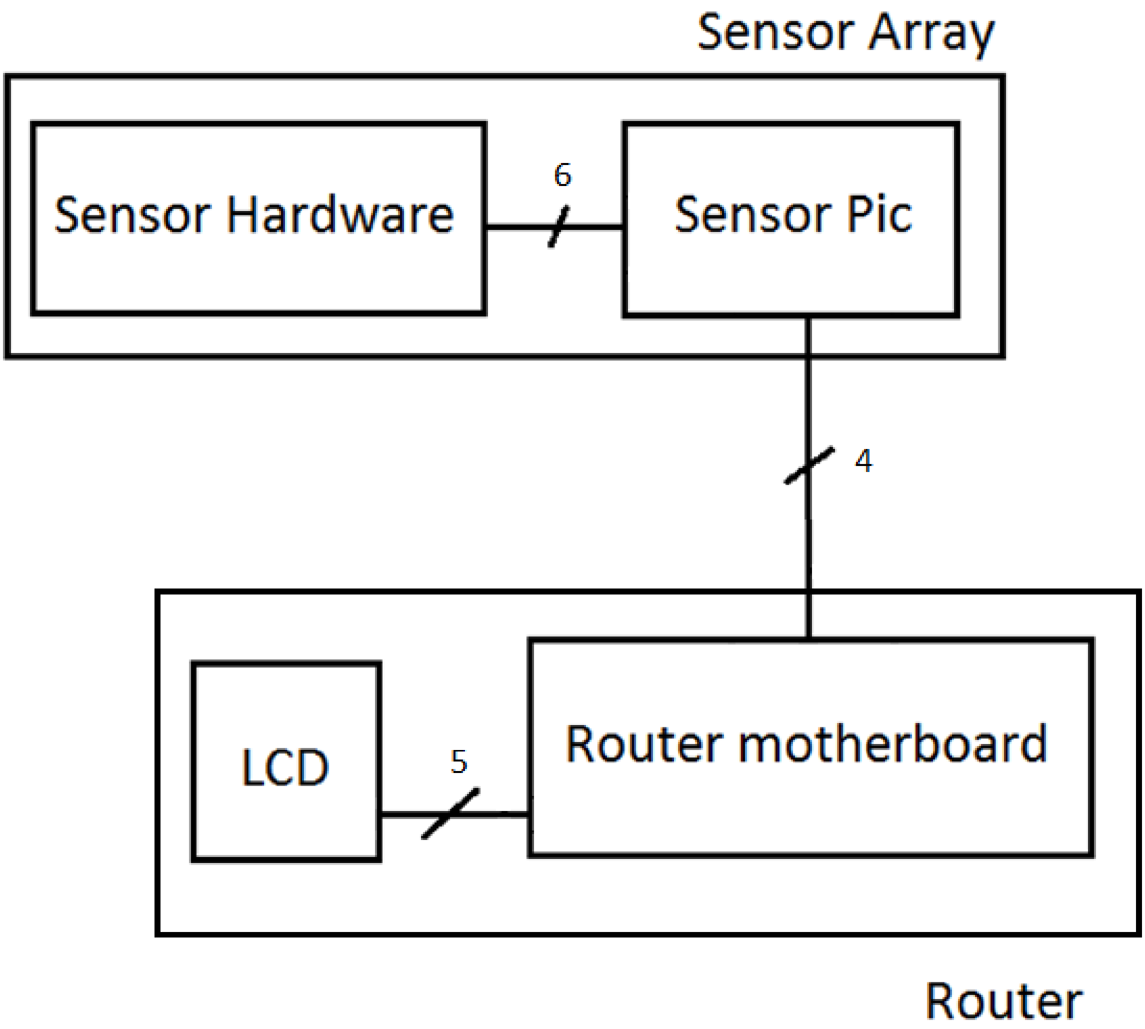


Figure 3.5 - Functional System Block Diagram

Physical Implementation and Packaging Plan

This system is expected to draw approximately 5W from a 12v DC power adapter. The router itself will consume 4.5W idle, and 8.5W under full load. The LCD runs at 5v and will consume 1.9W of power with back light. The sensors also run at 5v, while the PIC will run at 3.3v, and combined will consume approximately 400mW (**F3)** under normal operation.

The communication line to the sensor array will possibly require shielding, since it will be running data and power lines together across a distance of approximately three feet.

Chapter 4 - Design Details

Chapter 4 will go into more details on each of the three main components of the project, the router, sensor array, and sensor enclosure.

Router

The router software can be divided into two logical categories: hardware-dependent software, which is responsible for communicating with the sensor PIC and the LCD, and hardware-independent software, which is responsible for logging the data and running a web server.

Hardware-Dependent Software

The hardware-dependent software consists of two drivers, one to facilitate the PIC-to-Router communication, and one to control the LCD display.

PIC-to-Router Communication

This is the program that requests data from the sensors, processes the data, and then outputs its results to stdout. This mirrors the way that the current Temperature@lert temperature driver works. Figure 4.1 below shows the data flow.

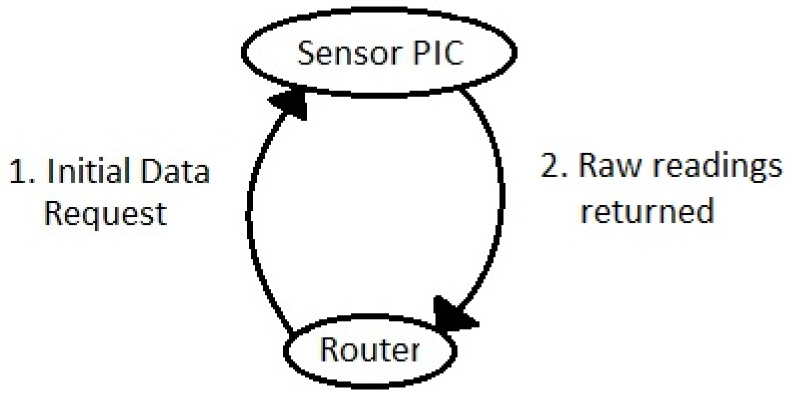


Figure 4.1 - Sensor Data Flow

The driver will receive the raw 10 bit ADC reading from the sensors. The driver will take an optional command line integer argument that is number of readings to perform and average. This will be used to smooth out any irregularities caused by unclean signals coming from the sensors. If no parameter is given, the driver will take one reading. After gathering the readings and performing the averages, if appropriate, the driver will output the five readings as a string in the following order dust, smoke, ozone, humidity, temperature. The driver can either be used to manually view sensor readings at any point, for debugging purposes, or can be called by a script that captures its output.

The communication between the router and the sensor PIC will take place using the router's serial interface and the PIC's UART lines. See Appendix C7 for wiring information.

LCD Display Driver

The LCD will be controlled by a driver program that will take in a string as a command line argument, and then display this string on the LCD. The LCD will be attached to three general purpose input output, GPIO, pins on the router. These GPIO lines will be used to interface to the LCD panel using a custom SPI library written for this project. See Appendix C6 for wiring details and Appendix E for the relevant data sheets.

The LCD driver has three modes of operation that use one, two, and six command line parameters. With one parameter, the LCD will display the input string and is used to momentarily display a message indicating the router has successfully completed the boot procedure. With two parameters, -brightness <0-100>, the LCD will adjust the back light brightness to the specified value. Finally, the six command line parameter version will take in the following values: dust, smoke, ozone, humidity, temperature, temperature units (C or F). These values will then be displayed on the LCD.

Hardware-Independent Software

The hardware-independent software is responsible for logging the sensor data and hosting a web page that provides the users with a visual interface into the system that is more detailed than the LCD display.

Data Logging Software

Upon initialization, the router runs a ruby script which loops infinitely, calling the program to retrieve the data from the sensors, passing that data to the program that writes the data to the LCD display, formatting and logging that data to a log file, and sleeping for a configurable interval.

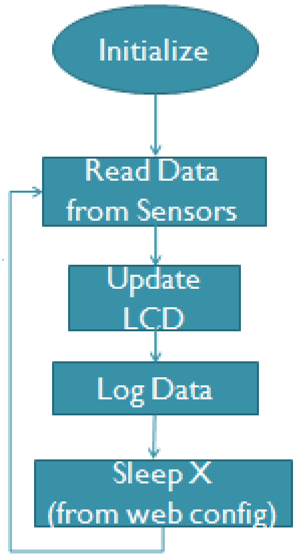


Figure 4.2 - Data logging program flow

These log files are parsed by the script run by the web page to display the data in graphical format.

Web Page

The router's web page allows users to view current and historical data on graphs, as well as configure the logging interval and alarm conditions. The web page consists of HTML code, which controls the user interface, and embedded ruby scripts, which perform the functions of building graphs of data, and presenting and saving user-configured options. The web page was designed according to the model of the current Temperature@lert web page, and replaces the "Status" tab with a tab labeled "Air Quality". Because our project will conform to the current Temperature@lert model of alarming users by email when certain environmental conditions are met, it was necessary to move the configured email address field previously present in the "Status"

tab to a common location usable by users of both the original Temperature@lert functions and our "Air Quality" add-on. We moved the option to the "Preferences" tab, which is the most logical location.

Sensor Array

The sensor array consists of the various sensors which gather environmental data. Their outputs are connected to a PIC microcontroller which essentially handles gathering data and sending it to the router.

Power Requirements

The sensor array taps off an unregulated 12V line on the router which in turn is supplied by a 12V wall transformer. The unregulated line contains noise and is a higher voltage than the 12V specification. Since most of the sensors require 5V, the microcontroller and dust sensor requires 3.3V, the line must be regulated using LM7805 and PQ3RD13 linear voltage regulators. Regulation ensures system stability as well as accurate sensor measurements. The combined current draw for the system is 400mA, obtained by summing the typical current draws for each component from their datasheets.

Of note is the presence of 5V and 3.3V regulators already available on the router. These regulators were not used for the sensor array due to their poor regulation. An accurate reference voltage is necessary for a precise analog to digital conversion by the microcontroller. Additionally, the router's regulators were already very hot and adding an additional load may damage them.

Microcontroller

The microcontroller (MCU) model is a Microchip PIC18F24K20 which was originally chosen to match the router’s daughterboard MCU in order to facilitate communication between the sensor array and the router. The two devices would use I^2C, which is a standard serial communication protocol. Additionally, using one type of MCU simplifies manufacturing by requiring fewer components to purchase. However, Temperature@lert never provided us with the final specification of their daughterboard, so a direct interface from the sensor's MCU to the router was implemented via UART as a contingency plan. UART is another standard serial protocol common in many digital devices.

The MCU’s role is to gather the data from the sensors on command from the router. After receiving the command, the sensor MCU multiplexes between each sensor and samples its voltage output. Then the MCU performs an analog to digital conversion (ADC) to prepare the raw data for processing in software. This raw data is then sent to the router which can then begin higher level processing and interpretation of the data. Converted values are stored as a 10 bit integer, which provides a resolution of 3.2mV for each bit. Figure 4.2 shows the microcontroller schematic and its relevant pinout.

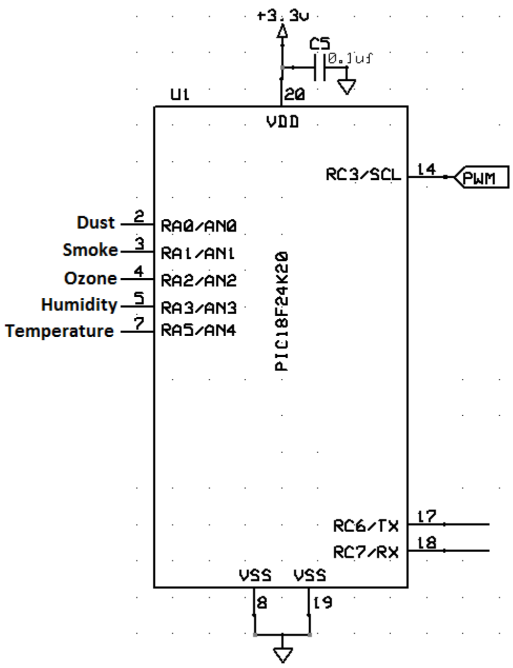


Figure 4.3 - MCU Pinout

Sensors

The sensors can generally be modeled as a variable resistor which changes resistance depending on the presence of their target vector, with an exception being given to the dust sensor. For the other sensors, they can be put in series with a minimum load resistance R_L specified by each sensor's datasheet to form a voltage divider where output voltage measurements can be taken. Figure 4.4 shows a schematic for gathering sensor outputs in the basic configuration.

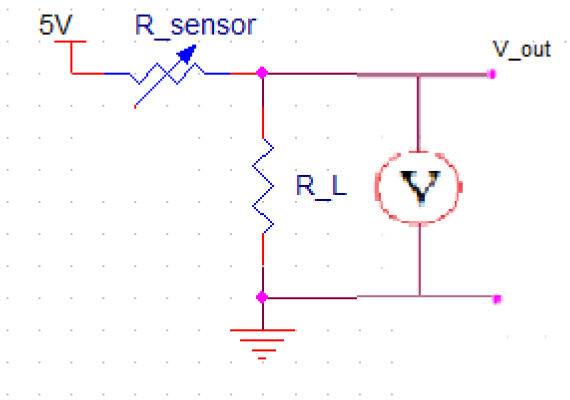


Figure 4.4 - Basic Sensor Output Model

Dust Sensor

The dust sensor uses photometric principles in its operation. The circuit model given in its datasheet consists of an LED, a photodiode, and an amplification circuit. This circuit is shown in figure 4.5 for reference.

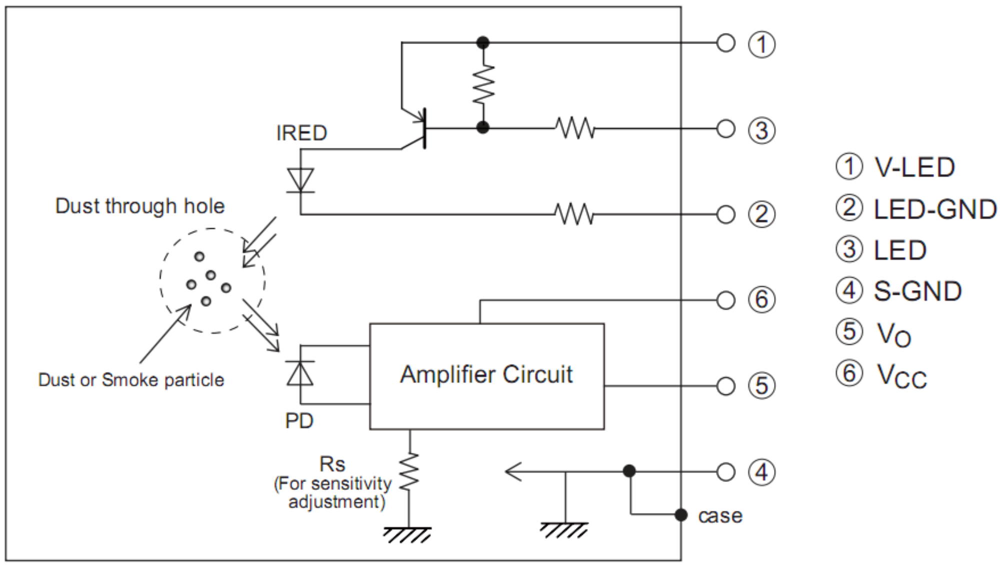


Figure 4.5 - Dust Sensor Circuit Model

The LED (IRED) is sent a pulse from the microcontroller. The LED briefly lights up and illuminates any dust inside of the sensor. The amount of light that passes through without being blocked by dust is detected by the photodiode (PD), whose response is passed to the amplifier circuit before being output.

The LED pulse is specified by the datasheet as having a 10 ms period with a 0.32 ms pulse width. This is generated using the PIC's internal timer peripherals. Also of note is that the pulse width is active low, since pin 3 on the dust sensor is hooked up to the base of a PNP transistor.

The implemented dust sensor circuit is shown in figure 4.6.

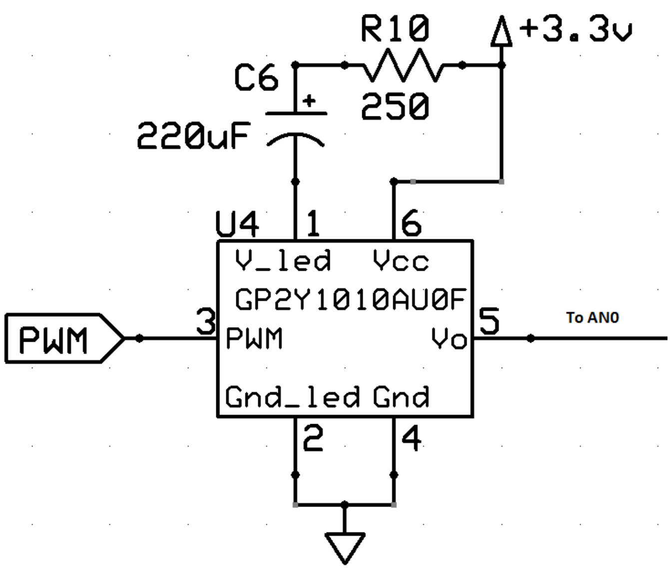


Figure 4.6 - Dust Sensor Circuit Implementation

The resistor and capacitor were provided in an example circuit in the datasheet. They serve to smooth the output of the dust sensor. Output of the dust sensor recorded on the oscilloscopes in the Cal Poly electrical engineering senior project lab is shown in figure 4.7.

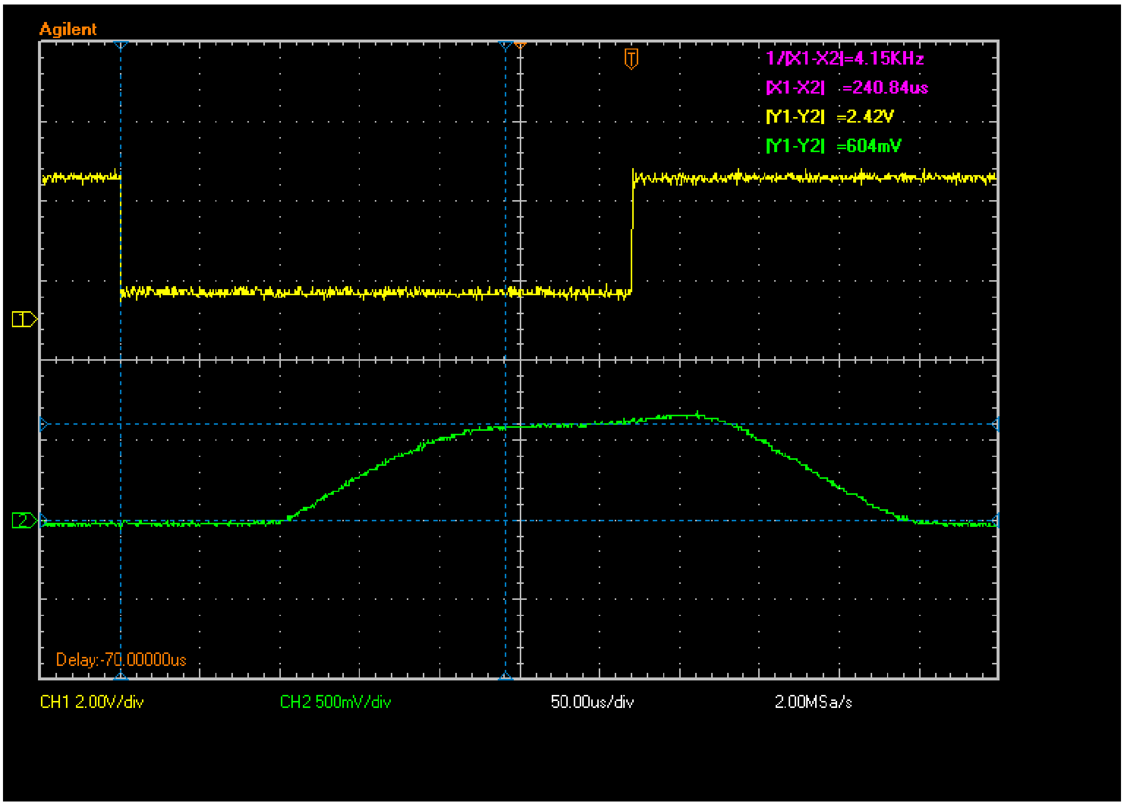


Figure 4.7 - Dust Sensor Idle Output

Smoke and Ozone Sensors

The MQ2 smoke and MQ131 ozone sensors come from the same manufacturer and have the same operating principles. They are made of materials whose electrical resistance change when in the presence of their respective stimulus. A heating element is also present in both sensors, which takes up a large portion of the sensor's power draw to dissipate as heat. The current draw with the heating element hooked up was recorded as about 150mA for each sensor. Without the heating element, current draw was less than 5 mA. These two sensors comprise over 90% of the power draw on the sensor array, so a consideration for any future revisions is to incorporate more efficient sensors.

The sensor output behavior follows the basic model of figure 4.4. Figure 4.8 shows the circuit of the MQ2 smoke sensor.

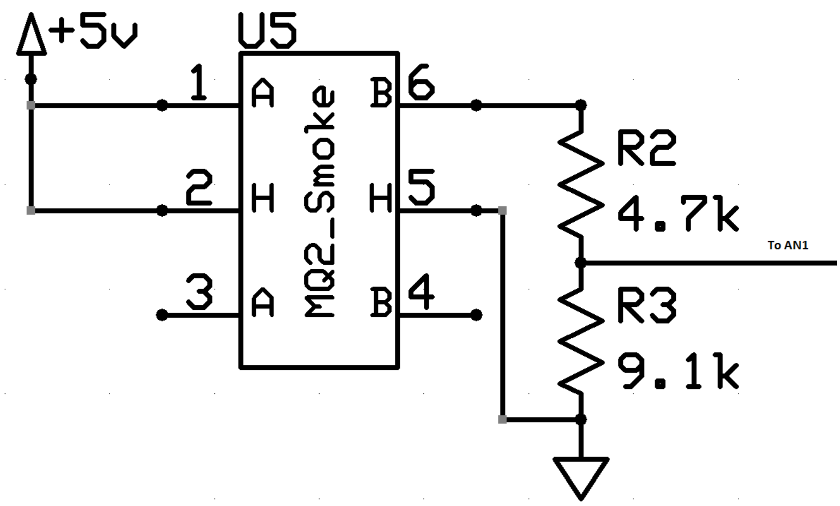


Figure 4.8 - MQ2 Smoke Sensor Circuit Implementation

Humidity Sensor

The humidity sensor also follows the basic sensor operation shown in figure 4.4. It's supplied by 5v and outputs a voltage from roughly 0-5V which corresponds to a relative humidity from 0-100%. The voltage output is temperature dependent, but is linear for a constant temperature. Figure 4.9 shows the output characteristic of the humidity sensor and was used to derive an equation for the software calculation of relative humidity.

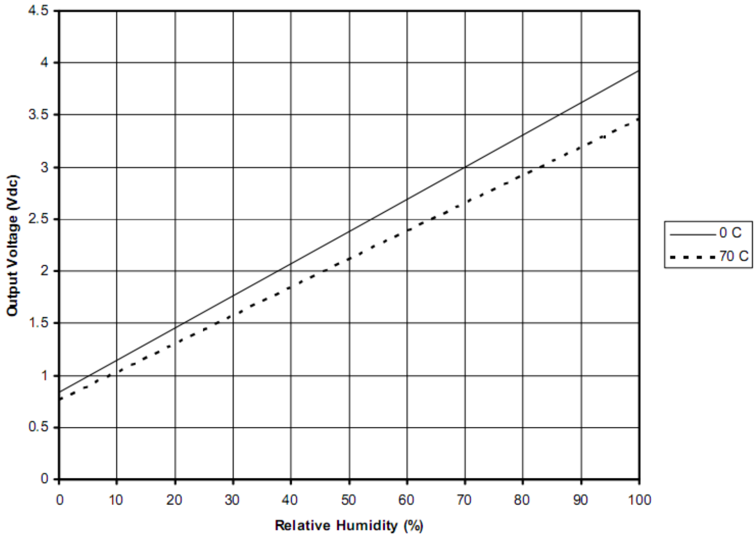


Figure 4.9 - Humidity Sensor Output Characteristic at 5V

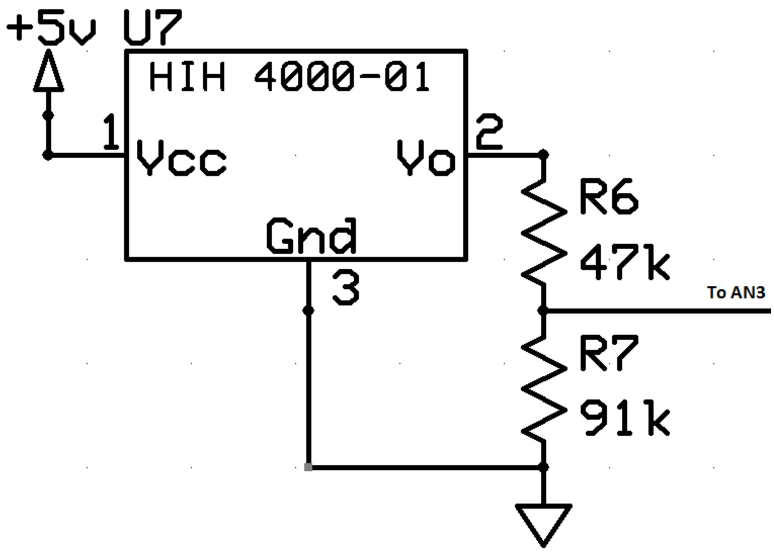


Figure 4.10 - Humidity Sensor Circuit Implementation

Temperature Sensor

The temperature sensor acts as a Zener diode with a 3V Zener voltage. This voltage varies predictably with temperature, and translates to one degree Kelvin per 10 mV.

Figure 4.11 shows the circuit implementation of the temperature sensor. The resistors are for current limiting to an acceptable level specified by the datasheet.

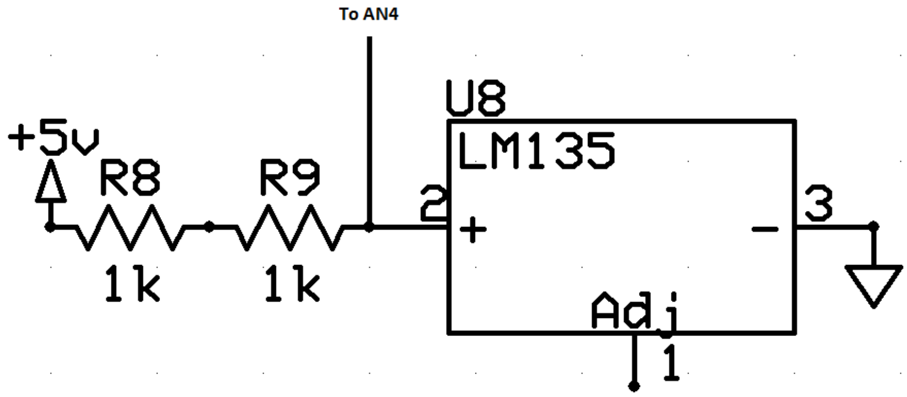


Figure 4.11 - Temperature Sensor Circuit Implementation

Sensor and Microcontroller Interaction

The sensors in the basic configuration have a theoretical output voltage of 5V which is beyond the maximum input value of 3.3V of the microcontroller's ADC. Since the ADC can only handle 3.3V, any sensor outputs above this will saturate the ADC and give erroneous measurements. Therefore, the sensor outputs require scaling down from 5V to 3.3V. This can be accomplished using a two resistor divider network. Resistor selection was restricted to common standard values to simplify manufacturing. The resistor values chosen are some decimal multiple of 4.7kΩ and 9.1kΩ, which has a side effect of scaling 5V down to a non ideal value of 3.297V, a -0.087% difference from nominal. However, since common resistors also have tolerances of ±5%, this gives a worst case variation of 3.183V to 3.4076V, a difference of -3.55% and +3.26% respectively (see appendix F1 for detailed analysis).

Another issue concerns the input impedance presented to the ADC. Figure 4.4 shows the input model of the ADC which is figure 19-5 taken from the PIC18F24K20 datasheet.

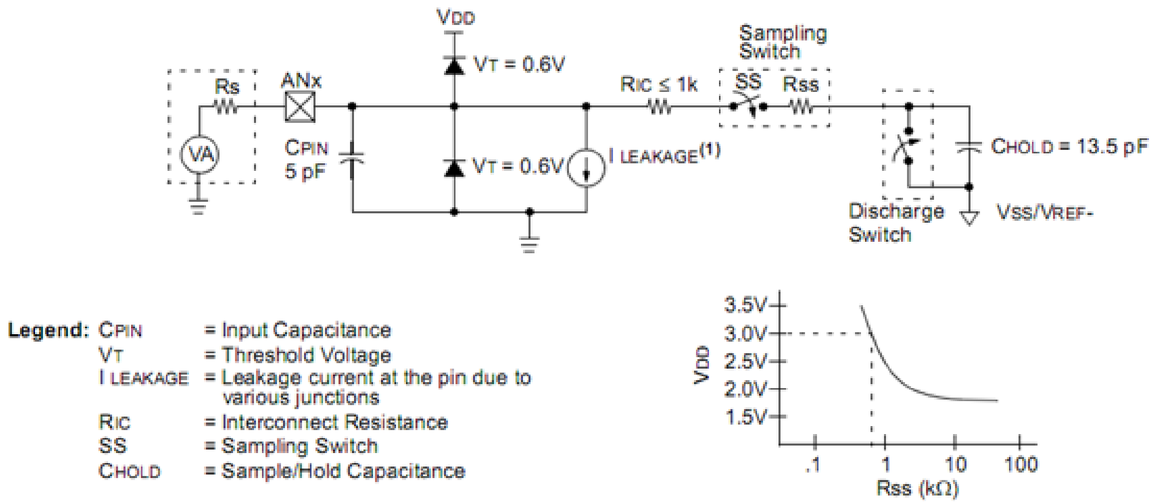


Figure 4.12 - ADC Input Model

The ADC works by first selecting a sensor input with the multiplexor on the corresponding ANx port. The sensor's output voltage VA charges the capacitor C_{HOLD},

which is then sampled by the ADC. There is a minimum delay required for the C_{HOLD} capacitor to charge to its steady state, which is determined by the resistances R_S, R_{IC}, and R_{SS}. R_{IC} and R_{SS} are resistances inherent to the ADC, while R_S is the input impedance of the sensor circuit presented to the ADC. If the charging time is too long, the ADC will take a sample from the C_{HOLD} before it has charged to the actual voltage output from the sensor which results in errors. This means that R_S must be small enough so that C_{HOLD} can charge up for proper measurements. Appendix F2 shows the calculation for the delay of the worst case R_S value and verifies that the delay is within specification for correct ADC readings.

Enclosure

The enclosure was created to protect the sensors and other electronic testing equipment from being damaged by the local environment as well as when handled by customers. Since our client was going to use this enclosure for a product that will be sold in relatively low volume production (about 500 units/year). To meet the needs of our client, this enclosure was created to have only two simple to manufacture parts, an aluminum mesh, and a polyethylene petri dish shaped base put together through the use of three screws and nuts.

The Aluminum Mesh

The aluminum mesh will be manufactured in the shape of two overlapping radiuses with the overall look of a dome. The purpose of using this mesh is to represent the ambient air in the room by allowing air to freely flow into an out of the enclosure; using a mesh allows us to eliminate the use of an internal fan thus making manufacturing easier. This mesh still protects our sensors by blocking insects and large debris from entering and damaging any sensors. By using aluminum, we have the ability to color our mesh and reduce the possibility that our enclosure will oxidize. Preventing our product from oxidizing is important because this process would give off small particles which would be picked up by our particle sensor and skew the data collected by our system.

The dimensions of our aluminum mesh design can be found in the appendix C. As indicated previously, our client will need to purchase relatively small quantities of these fabricated aluminum meshes, so we are going to suggest that he work with Banker Wire, a company that specializes in manufacturing metallic meshes. The aluminum 5154A that will be used for prototyping our enclosure mesh has square holes that are 1.0 mm^2 in size. For our design, the shape of the holes is not super critical because of device is not intended to be used in areas with high air velocity; our enclosure is intended to mimic the ambient air in a home. The dimensions of the hole can be problematic if the holes are made either large enough such that insects can still crawl/climb through our mesh or if the holes are small enough to act like a filter and prevent particles from reaching our sensors. For this reason our mesh holes should be maintained at a size of 1.0 mm^2 with a tolerance of ±0.25 mm in either the mesh hole length or height (but not both). The other critical dimension associated with this enclosure is the bottom portion of the mesh that is open with a circular radius of 60mm. Given that this portion of the mesh will make contact with the base of the enclosure we require a radius tolerance of ±2.0mm^2. This tolerance is not too strict since we understand that the mesh has the ability to stretch slightly and because we know that a design with lower tolerances is easier and cheaper to manufacture.

Given that our aluminum mesh allows air to freely flow into the enclosure, we expect that over time dust may accumulate around the sensor and begin have an effect on the sensor readings. Therefore we will recommend our customers to turn off their system once every six months and use a vacuum on the mesh to pick up loose dust within the

enclosure. This process may be repeated as needed depending on the conditions of the home in which our product is being used.

Polyethylene Base

Our sensor will be mounted onto a black polyethylene (PE) base which will resemble the shape of a petri dish. Polyethylene was chosen due to its low cost ($1.30/kg), ease of manufacturing/coloring and current use in electronic housings. Additionally, polyethylene is strong and stiff enough to hold our components securely, but is not brittle. In terms of thermal properties, PE has a melting temperature and maximum operating temperature of 130°C and 100°C respectively; much higher than our enclosure will ever be exposed to even when taking into account the heat given off by during operation or transportation. The glass transition temperature, or the temperature below which this material begins to exhibit brittle behavior, of PE is -100°C; once again this temperature is much lower than what our system is being designed for. Lastly, we are looking to an outside vendor to purchase this base given that the shape, and material we require, are fairly common and our client only requires approximately 500 enclosures per year. We do not recommend that our client attempt to create a custom made part since the initial cost for an injection molding mold, for example, can run up wards of $100,000. Purchasing prefabricated enclosures seems to be the only viable option for our client.

The dimensions of our enclosure base are provided in Appendix C, however we have two critical dimensions associated with this design: the wall thickness and inner diameter of the enclosure base. The wall thickness of our base varies from 2.0 to 5.0 mm. We used a larger wall thickness in the areas were we plan to drill holes to ensure there was enough material to drill through. Although 2.0mm is enough to support the contents of our enclosure, we must have a tolerance of ±0.10 mm to make sure that our base never has an area that is so thin that it will fracture from a three foot drop (one of our requirements). Our other critical dimension is the inner diameter on the top of our base, this in the area where our mesh will be in contact with the base. Since our PE base is not as easily flexible as our aluminum mesh we will need an inner radius tolerance of ±0.50mm to insure that our mesh and base will fit properly without having to stretch out our mesh.

Final Design

We made several failed attempts to design the enclosure at the beginning of the process. The one which was dubbed "the skeleton" was a wire frame outline of our product design, this allowed for proper air flow, but was presumed to have improper structural integrity. The skeleton also was considered costly to reproduce and we were told by Cal Poly Industrial engineering lecturer Martin Koch that it may experience difficulties in rapid prototyping. Another design that was dubbed "the dome" was a complete mesh top with a circular ring at the bottom to connect to the base of our enclosure. The issue with this was that we believed our mesh did not provide enough rigidness for this design to work. We then looked into a design where the top of the dome was mess and the bottom half plastic, this seemed like the most practical design structurally however we came to a conclusion that not enough airflow was available for the sensors to give an accurate reading do to the fact that the cut was to small. We attempted several other designs with more cuts for airflow however we could not find a balance between structural integrity and airflow.

Our designs were also met with connectivity issues. We decided that we did not want the bottom to come off easily due to the fact that it would impact the drop test, but the enclosure also needed to be able to come apart with relative ease for the sake of setup. Screws provided the issue that they may not exactly cut right in rapid prototyping and

they would also make it difficult for us to take apart the enclosure. A screw on lid provided problems, because if the thread count was off then the enclosure would not fit together. Finally we were told by Martin Koch that a twist lid may have problems breaking.

We also were unsure that the plastic in the rapid prototype machine would provide any static that would interfere with our sensors. This turned out to be an unfounded as the plastic in the prototype machine was used in our router. Never the less this was a factor in our decision at the beginning of Spring quarter in the design of our enclosure.

After considering these problems we had come to conclusion that it maybe simpler to use other methods of design. A fire alarm was an easy fix because it was already structurally sound, it is designed to allow air flow, and can be taken apart while still allowing us to protect the sensors. The circular frame allowed us to maintain our shape and thus all we needed to do was add a circular incision on the top to provide us with a mesh dome and enough airflow. Figure 4.12 is a picture of the fully assembled enclosure with all sensors inside.

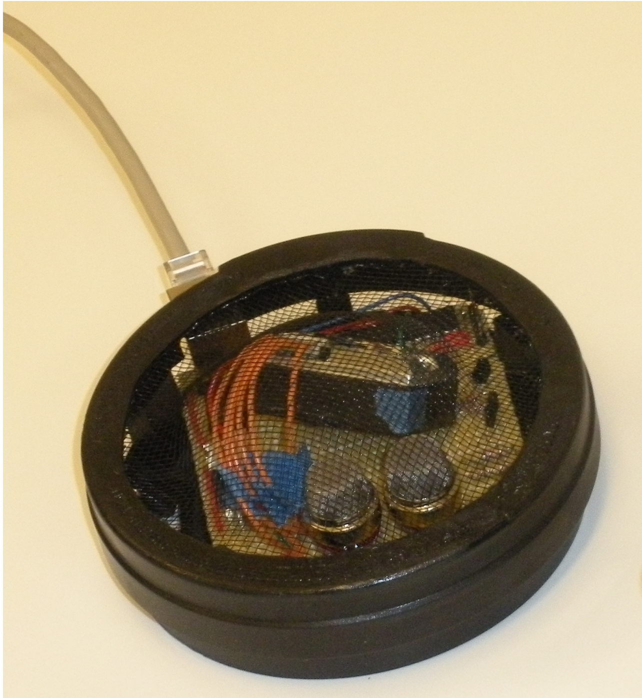


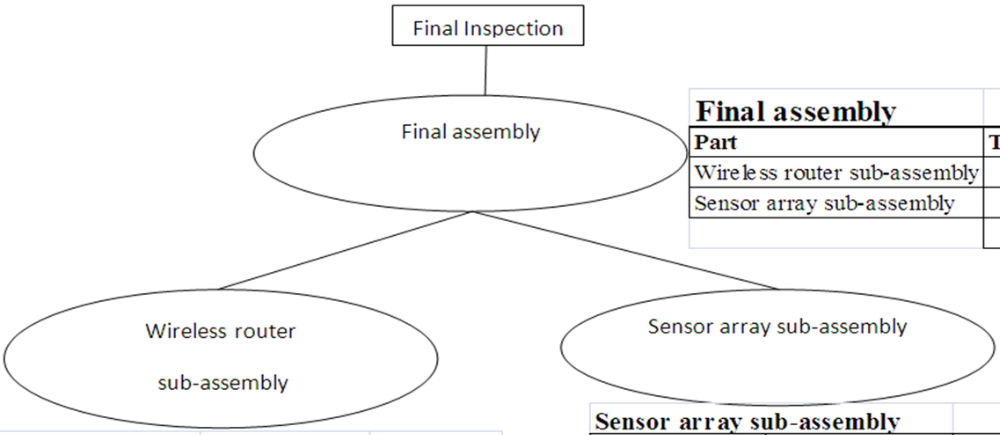
Figure 4.13 - Assembled Prototype Enclosure with Sensors

As mentioned above the enclosure prototype was created using a fire alarm purchased at a hardware store and not a rapid prototyped model. Overall we believed this would could fabricate a more solid prototype that better represented our final design. This was also a good choice given that it already contains electronic sensors much like our device is intended for. One draw back to this choice is that we did go over our proposed enclosure budget. The enclosure cost approximately $28.00 to prototype when you consider the cost of the fire alarm, paint, and the mesh used. Since originally we intended to use a rapid prototyping machine on campus that was free of use, we surpassed our budget by $28.00.

Chapter 5 - Manufacturing and Procurement

Product Procurement and Material Cost Analysis

The following is a summary of the bill of materials and the assembly process for the air quality sensor:



Final assembly

Part	Total order cost
Wireless router sub-assembly	$76.00
Sensor array sub-assembly	$131.95
	$207.95

Wireless router sub-assembly

Part	Supplier	Total order cost
LCD	www.crystalfontz.com	$41.00
Wireless Router	Temperature@lert	35
	Total:	**$76.00**

Sensor array sub-assembly

Part	Supplier	Total order cost
Smoke Detector	www.seeedstudio.com	$7.53
Ozone Gas Sensor	www.futurlec.com	$20.23
Humidity Sensor	Mouser	$22.52
DSM501A	Shenzhen HYC Electronic Technology	$32.98
PIC	Microchip Direct	$20.49
Mesh	Home Depot	$9.19
2 linear voltage regulators	www.digikey.com	$4.00
Sensor enclosure	estimated cost	$15.00
	Total:	**$131.95**

Figure 5.1: Estimate for Bill of Materials

Note: Lead time for all ordered components from warehouses is about two weeks for delivery for all products unless extra is paid to expedite delivery.

Manufacturing Process Employed

PolyEnvi suggest a simple assembly method for this product's production process. Our design objectives do not include creating many new components. The project merely integrates existing products and internet functionality. Assembly will consist of a single build station for the product to be assembled. We have a desired design for the sensor enclosure; however, this production method best suits Temperature@lert's need due to the company's history of low volume sales.

Recommendations for Future Manufacturing

The only recommendation for future manufacturing is to find a company that produces a product that can replace the need to order specially designed sensor enclosures. This will greatly reduce the money spent on the enclosure because the product will more than likely sell in low volume based on the company's history.

Chapter 6 - Project Verification Test Plan

System Functions and Performance Verification

Smoke Sensor

We built a gas chamber made of a plastic container that is 1 ft cubed with valves that allow us to control the flow of gas into the chamber. A fan is on top of the chamber to mix the particles so the gas can saturate the entire chamber. We placed the smoke sensor in the chamber along with a calibrated digital Carbon Monoxide sensor (Fluke Airmeter). The Fluke reads Carbon Monoxide, temperature and relative humidity. First we flushed out the chamber by opening the valves and pumping in nitrogen, which served as our substitute for purified air. Once the sensors inside the chamber read minimal levels the testing began. We then closed one valve in the chamber and pumped in smoke from a jar with burning paper inside. We performed this step until the data showed the chamber was completely saturated. We monitored the levels of the smoke sensor and the calibrated sensor each time smoke was filtered in. We then placed the enclosure over the smoke sensor and performed the same test. Since the setup differs in every enclosure the amount of time it takes is unknown, but it is done when the sensor reach a steady level of saturation.

After collecting data, we placed the data in Minitab to verify if the sensor readings differed by more than 5%. The sensor readings in the enclosure did not differ by more than 5%; thus, it did not fail the test to see if the enclosure impeded sensor readings. While we were testing the carbon monoxide levels, none of the other sensors gave readings that they should not be, such as changing levels; therefore, the feedback test did not fail. This required at least 4 team members: one to monitor and record our sensor data the other to monitor and record the calibrated sensor data, another to monitor and record the levels of the other sensors, and finally one team member made sure the gas stays inside the chamber. The only cost of this experiment was the purchase of the plastic chamber and valves. The IME department supplied to nitrogen for this test.

The problem with this test was that the smoke filled the gas chamber too fast and the smoke sensor read more than just Carbon Monoxide. However, as the readings on the carbon monoxide sensor rose the readings on our smoke sensor did the same (see Figure 6.1). The result of this was a .8 correlation. Since we can show our graph was working appropriately but could not obtain accurate values we decided it was appropriate to go with a qualitative value. Only when we decided to use cigarettes did this test show fluctuations, this was because cigarettes give off NO_x which our ozone sensor reads. We burned other substances and realized that this was only a phenomenon that occurred with cigarettes, and decided that it was appropriate to say that we were not getting any inappropriate readings from our sensors. Our enclosure did not impact the sensors ability to read smoke in anyway passing the enclosure test. Finally, the LCD displayed the same values as the webpage and thus the LCD was working appropriately.

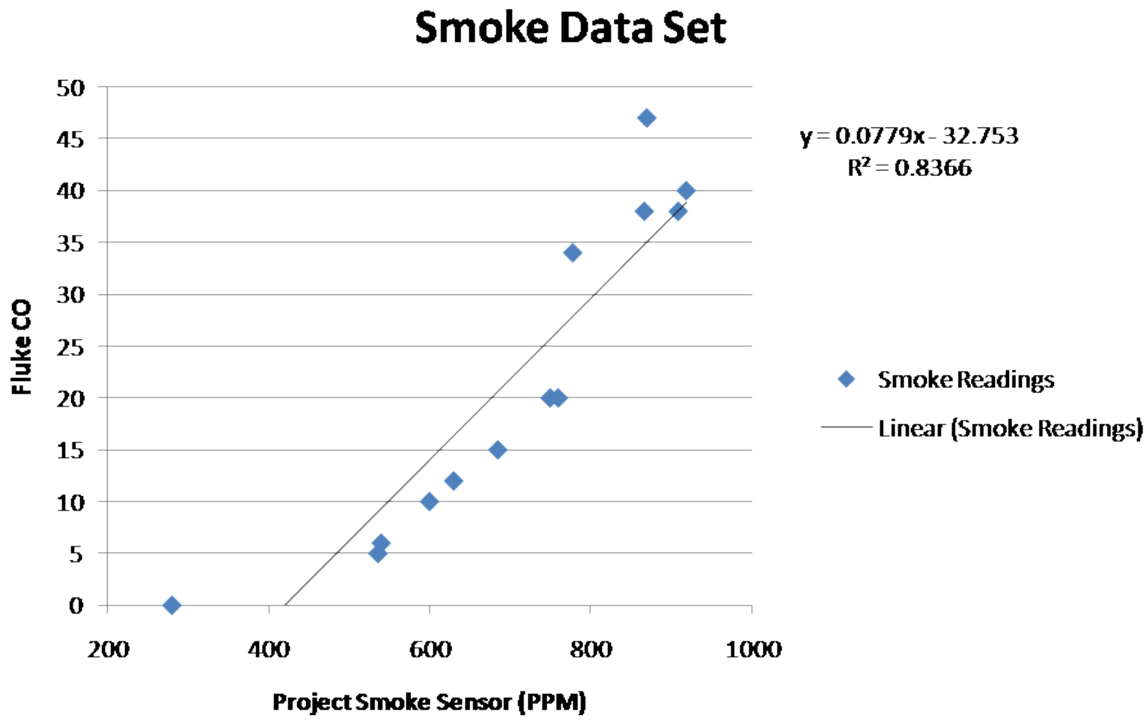


Figure 6.1 - Smoke Data

Particle Sensor

This setup steps was similar to that of the smoke sensor, the only difference is we used a shop-vac that has collected dust particles. It is more difficult to clean out the chamber after this test, thus this we performed it last. Since the particle sensor was difficult to compare to other dust sensors, the only test was to see if the particle sensor readings decreased to minimal levels when the chamber was flushed and increased as the dust was pumped into the chamber. The sensor followed the desired pattern; thus, we can state it does work properly. We then placed the sensor in the enclosure and repeated the test. The sensor worked properly in the enclosure. While we tested the particle sensor, none of the other sensors gave readings that they should not of, such as changing levels. The feedback test did not fail. This required 3 team members: one to monitor and record our sensor data the other to monitor and record the levels of the other sensors and another to make sure the dust continued to pump into the chamber. There was no costs of performing this test. The IME department had a shop vac available for our team to use.

The particle sensor went up as the levels of dust were increased. No other sensors were giving off inappropriate readings as we increased the levels of dust. Also, the enclosure did not impede the sensors ability to read dust.

Figure 6.2 - Box for Smoke and Particle Sensor Testing

Humidity Sensor

The humidity sensor can be tested and calibrated using a dual thermometer system, a wet bulb and a dry bulb, called a sling psychrometer to test the accuracy of relative humidity. This test is considered standard for measuring relative humidity. By locating the two temperatures given on a chart the relative humidity can be found. We can then compare the reading given by the sensor to the actual relative humidity if it is more than a 5% difference between them then it failed. If while in the enclosure the sensor readings differ by more than 5% and it did not fail the initial test the enclosure has failed. This test is quick and simple and was no cost to.

We decided that since this test would be needed to be done multiple times during the day to be considered accurate and would take too long, we used a digital humidity sensor on the Fluke Airmeter and compared it to the sling psychrometer to determine its accuracy. After it was determined the Fluke appropriately read the relative humidity we placed it in our gas chamber and lowered the humidity by flushing out the water particles using nitrogen. When the relative humidity hit 10% we allowed the levels of humidity to return to normal recording the humidity levels every 2 minutes. Then we increased the humidity to 75% using steam from a shower and allowed the levels to lower and level out by opening and closing a window. The result of this was our humidity sensor was within a 5% error of the calibrated sensor. No other sensor readings fluctuated during the test and the enclosure did not interfere with levels of humidity our sensor read. Our Minitab analysis resulted in the conclusion that our humidity sensor and Fluke sensor were highly correlated (.99). This allowed for our group to calibrate the humidity sensor and maintain an accurate humidity reading when compared to the Fluke sensor.

Figure 6.3 - Sling Psychrometer

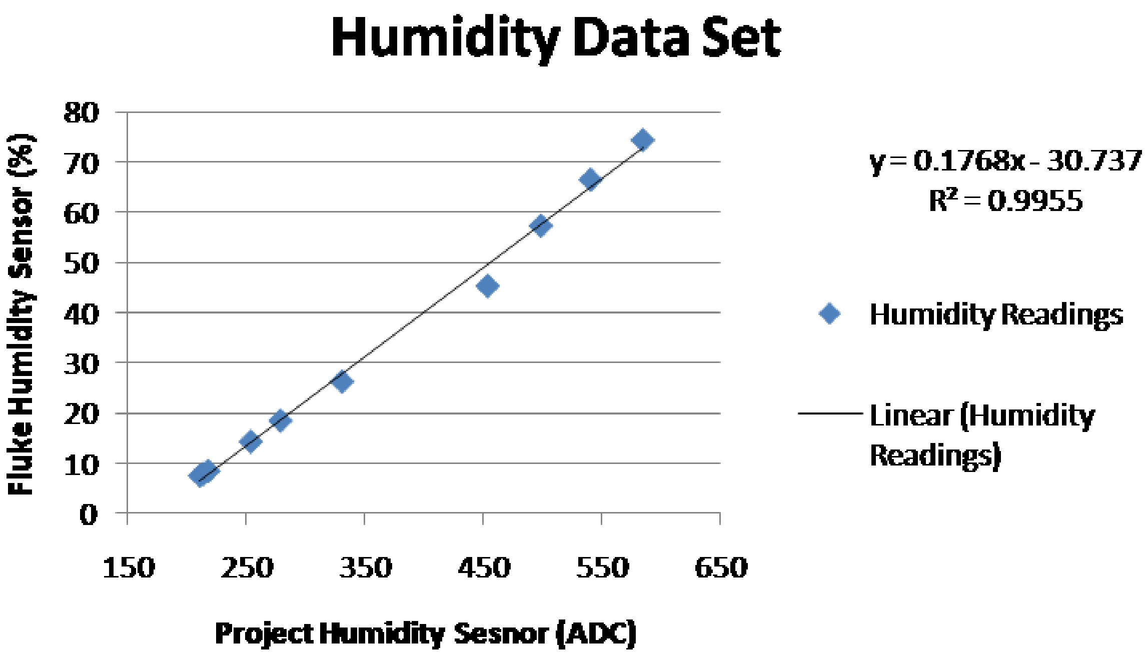


Figure 6.4 - Humidity Data Set

Ozone Sensor

For the Ozone Sensor, we scheduled an appointment with the San Luis Obispo Air Pollution Control District (SLOAPCD). The test will consist of putting our sensor in a glass gas chamber along with the calibrated sensor and pump ozone into the glass chamber. We then monitored the levels of both sensors every 2 minutes and recorded them. We then placed the data in Minitab to verify if the data correlated to the data from the calibrated sensor. The enclosure the did not show any evidence of impedance of the sensor. While we tested the ozone sensor, none of the other sensors gave readings that they should not be, such as changing levels; therefore, it passed the feedback test. This

test required 3 team members: one to monitor and record our sensor data the other to monitor and record the calibrated sensor data and another to monitor and record the levels of the other sensors.

The result of this test was that our sensor was within 5% error of the calibrated sensor and had a -.991, meaning that the sensors readings decrease as the ozone levels increase. Even though the sensor was accurate enough to give readings as parts per billion, as the SLOAPCD did, we decided that for home use qualitative values would be more reasonable. The majority of users would not understand what a reading of 30 parts per billion means for their health, while a one to ten scale is highly intuitive. This decision also allowed us to maintain the same levels functionality between the particle, smoke, and the ozone sensors. When monitoring the levels of the other sensors while performing this test no other sensors changed in values inappropriately. When the sensors were encased by the enclosure, the ozone reading did not change.

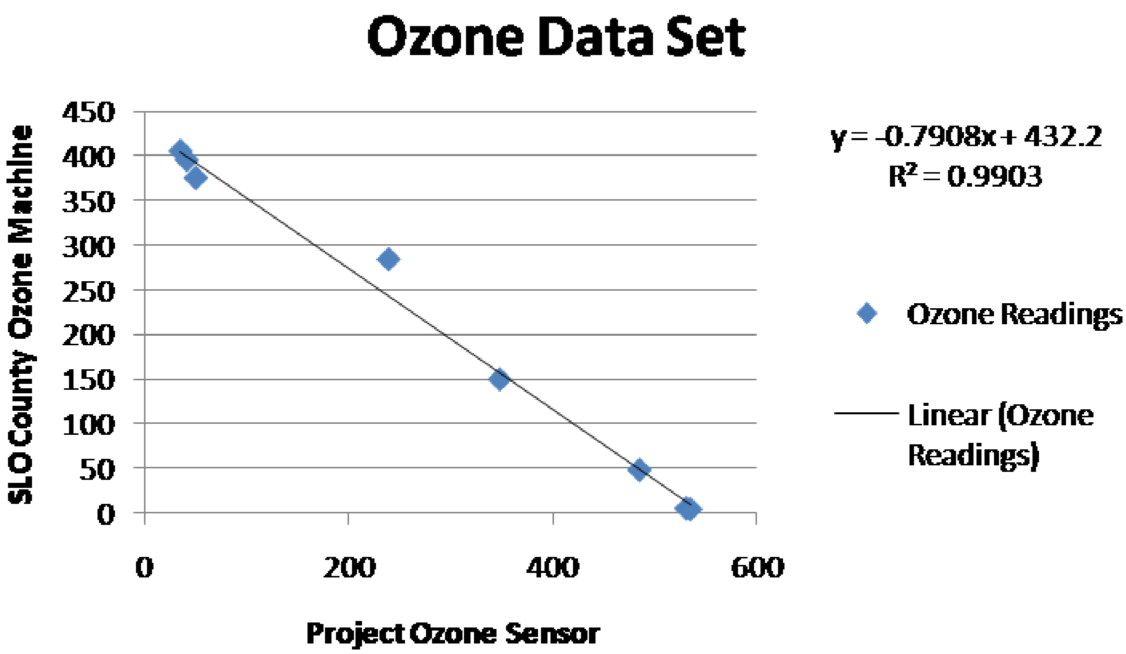


Figure 6.5 - Ozone Data Set

Temperature Sensor

Since the Temperature@lert series 2 router was not completed by the customer, we added a temperature sensor to our system to maintain its current functionality of measuring room temperature. To test this sensor, we placed it in our gas chamber along with the Fluke Airmeter and increased the temperature in the chamber using a hair dryer. We then allowed the temperature to drop and recorded the temperature every 2 minutes. The result was that our sensor was within 5% error of the calibrated sensor and thus it passed our verification test. The temperature sensor was not effected by the enclosure; in addition, no other sensors were effected by the testing.

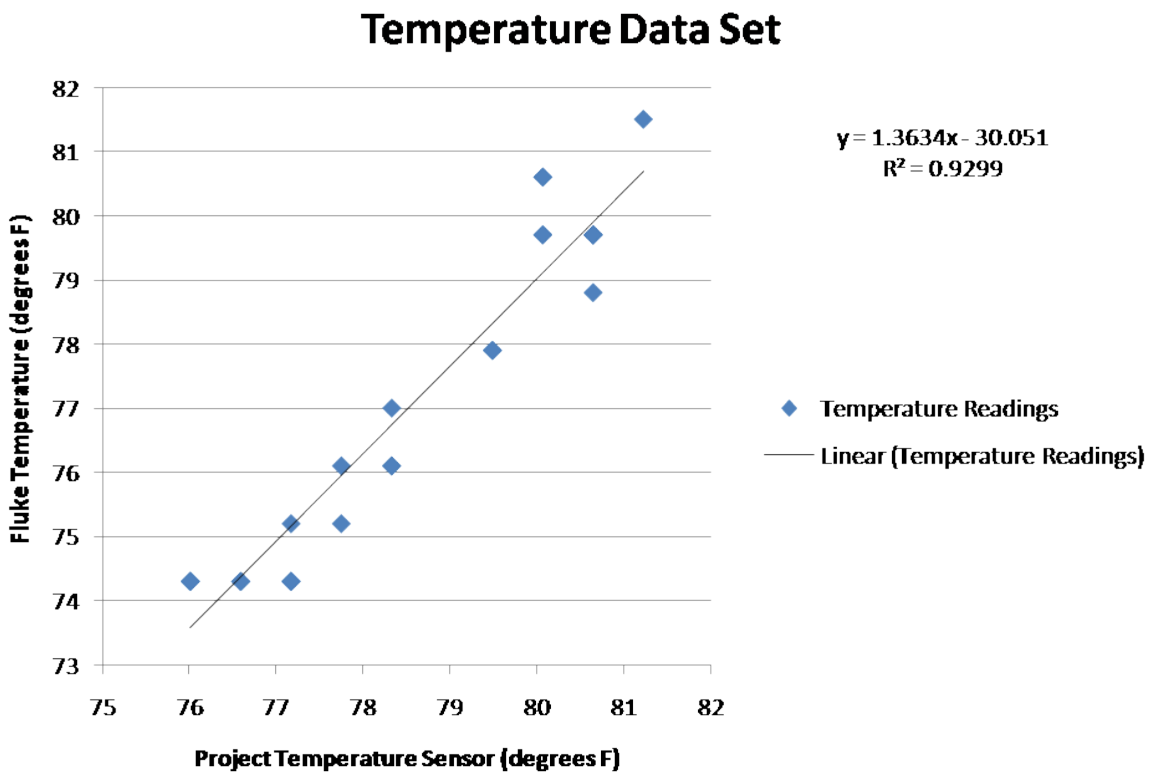


Figure 6.6 - Temperature Data Set

Feedback Testing

It is important to see if the sensors do not effect one another or give double positives, meaning that the sensors are reading the same gas. Thus we must put all four sensors in the same testing area and monitor and record any fluctuations or false readings that occur. If this occurs it is important we adjust our calculations and outputs given to the user as needed.

During the testing of our sensors, only the temperature sensor gave back results that were inappropriate. This was due to the fact that the heat from our sensors caused the temperature to go up by 2 or 3 degrees Fahrenheit. We corrected this by just factoring that into our equation. Considering the fact that the temperature sensor was supposed to be on the Temperature@lert router, this would have prevented this from being a problem and thus we consider this test to be a success.

Enclosure Impedance Testing

When we are done gathering data from the sensors we need to see if it is impacted by the enclosure. The reason for this is that the enclosure can prevent particles from reaching the sensors or it can create a static charge that can throw off the sensors readings. This requires us to perform the same tests with the enclosure surrounding the sensors and comparing the results to the sensors that do not have the enclosure on it. If it was off by less then 5% it passed the test, if not we would have to make adjustments to the readings or get a new enclosure.

Since None of the sensors were impacted by the enclosure, this test was a success.

LCD and Web Page Functionality Testing

We must monitor the functionality of LCD and web page to make sure the users are getting appropriate readings. This simply requires we measure the readings by the sensors and make sure the LCD and web page are both giving the same readings. Then we will make any necessary adjustments to make sure the data is accurate.

Both the LCD and Web Page continued to give the same readings that the sensors were giving while the tests were being performed, meaning we maintained the same level functionality throughout the system.

Drop Test

The device may be dropped from a table while being used by our customers which necessitates a drop test for our product. In the process of a drop test we will first drop the enclosure without sensors at a 3 foot height to make sure that it retains the same structure and does not deflect. If it passes this test we will perform the same test with the sensors. Then we will test the sensors to make sure they are within a 5% difference of the non dropped device. This can be done by gathering data from each device every 1 minute for a half hour. If it does not pass this test we may have to suggest another type of material for manufacturing. This test will not cost anything but should be the last test we should do due to potential loss of our product.

After a random drop test our sensors worked exactly as they were supposed to. This means our enclosure managed to protect the sensors.

Regulatory Agency Compliance Testing

Since this product is not designed to monitor, and any current regulations of individual parts have already been covered by the manufacturers, there are no regulations required.

Operating Environment Testing

Environment Testing

To test how the device responds in an environment similar to its intended use, we will place the device in one or multiple team members' home(s). Results from the web page will be monitored to determine correct operation. If the web page gives us back results that are erratic or inappropriate, it fails and we will need to determine the origin of these problems and make corrections to the device. The device will be compared to another while they are in the same testing area to make sure their results are within 5% of one another. If this is the case we can assume this device can be mass produced appropriately otherwise it is a failure. This test will not cost anything and will be performed for a weekend or perhaps longer if we can to make sure it works well in a proper environment.

Our sensors did not show any irregularities while being used in the environment it was designed to work in.

User Testing

By bringing in people outside the team to setup and use the product we can confirm the success of the user interface and the simplicity of our design. It is important to make sure all subjects are given the instructions in the same way while in a relaxed atmosphere to perform the test accurately. Those giving the test must each have a position and the ones interacting with the users will have a script they must stick to. This is to measure the time it takes the average person to understand how to use our device and gather feedback for improvements in the user interface.

Due to limited time, we decided it was more appropriate to test only if those unfamiliar with the webpage could use it. By having our colleagues use the page, it was determined they could easily grasp and use the page. Thus this requirement was fulfilled.

Shipping and Storage Testing

In order to make sure it can be shipped and stored appropriately, the device will remain sealed in a box and shipped to Professor Lupo. After delivery, we will check the shape of enclosure to make sure it was not damaged. If it is undamaged we will test for delays in the sensor reading to make sure the sensors are not having burn time issues. Not passing this test means our client, Temperature@lert, will need to bring this fact to the attention of the customers. The sensor readings of the shipped device will be compared to the one we did not ship to determine whether shipping and storage had an effect on the device. Data will be gathered every 1 minute for a half hour. If the results are off by more than 5% of each other then the device cannot handle shipping. The response to this failure means that we will have to design a way to ship the device to correct this. This test should only take about 3 days to be shipped to Professor Lupo and will be the cost of standard shipping. It should be performed out of town to make the test as accurate as possible.

We decided that it was inappropriate to potentially damage our prototype in this test.

Reliability & Product Life Verification Testing

Reliability Testing

As stated in previous tests we will have more then one device that will be built. The devices will be compared to another while they are in the same testing area to make sure their results are within 5% of one another. If this is the case we can assume this device can be mass produced appropriately otherwise it is a failure.

Unfortunately we had 2 out of 3 routers fail preventing us from performing this test.

Life-Cycle Testing

To test the life cycle a software stress test will be performed. This means that the device will be gathering data at the highest rate the sensors can read. We will attempt to do this test for as long as we can. By doing this we can determine if and when the device or the software might breakdown. We will monitor the data stored to see if there are any irregularities and that the data is properly stored. By finding out when this occurs we can calculate the actual life of the product. If this does not provide adequate data we can use the data provided by the sensor data sheets and find the smallest life cycle of the manufactured hardware we had bought.

This test proved that even under the stress of constant readings our prototype and software continued to perform adequately, making the life of the product to be unobtainable at this time. Our back up plan was to use the shortest life of the products we bought, but they do not list their life on the data sheets.

Maintenance Testing

After a cleaning of the sensors is performed it is important to see if the sensors still remains accurate within 5% percent of the readings we get from the other device it passes. We will gather the data for this test for a half hour while gather data every 1 minute. If it passes this test then no appropriate actions will need to be taken. Otherwise we may need to inform customers that hand cleaning the sensors can affect the readings and that blowing out the particles might be a more appropriate way to clean.

We decided that this test was inappropriate due to the fact that our final project was only a prototype.

Chapter 7 - Project Conclusions

Paul Fake

The project turned out to be a success despite some setbacks early on. The technical details of the project were not particularly challenging, but the group did face challenges with coordination and, occasionally, cooperation. It is very difficult to get six people with six different schedules and technical backgrounds on the same page, and without a clear group
leader it was a challenge to come up with a solid plan of who should do what, and when.

Even though the air quality sensor will likely not be manufactured by the client, the project still functioned as a learning experience. As far as CPE-related knowledge goes, I learned a little bit about how to write HTML and Ruby script, both of which I imagine might be useful to know when applying for jobs. More so, however, I learned about group dynamics. Previous group projects at Cal Poly lasted a few weeks at most, and there was very little time to learn how to really function well as a team. This project, however, lasted the entire school year. Once the simple politeness of unfamiliarity wears off, teamwork starts to require more effort. I, for one, was more likely to step up and take charge at the beginning of the project when I felt the need to make a good impression on the group. This eventually faded, and I developed more of a "tell me what to do and I'll get it done" mentality. In retrospect, this was pretty unfair to the other team members, because it should not have been their job to give me work. So, the biggest lesson I took away from this experience is that in groups without a definite leader (such as an explicit project manager), it is the responsibility of each member to perform a fair share of the leadership duties.

Stephen Beard

There were several challenges that we faced as a group during this project. The first was in actually choosing this project, as our original project ended up being infeasible. This put us several weeks behind, which was difficult to make up for. The project was also of only passing interest to our sponsor, so there wasn't a strict level of accountability. Since the project was a "throw away project," the motivation for it came only from within, which is sometimes difficult to muster when you have so many other things going on.

While the group was multidisciplinary, and we had some level of interaction between our different fields, I feel like the group stayed rather segregated. We probably should have done more to involve everyone in all aspects of the project. I often felt like I was the only one that was thinking of the project as a whole, rather than just one particular aspect that I was working on at the time. This probably came down to a problem of leadership. I am very much a proponent of the shared leadership style, where each member of the group is dedicated and assumes leadership of the group for their area of expertise. Early on I should have recognized that this wasn't working for the group and tried to get everyone on the same level. I now believe that, even with a shared leadership approach, you still need the one strong and clear leader to keep the group focused and progressing.

There were a few technical issues that I dealt with in the project as well. My original plan to create a software RS232 interface proved to be impossible on our embedded Linux router. I thought that the lack of critical timing control would not be an issue for our very short messaging requirements, but this turned out to be incorrect. The process would sometimes get interrupted during transmission, which would cause garbage to be displayed. I considered changing the code to be a kernel module, where I could completely disable interrupts to ensure proper timing, but decided against it because this could cause clock skew. Instead I built a custom SPI driver for the project. This required extra lines and logic to control the chip select and clock lines.

As a whole, this project a was a great learning experience for me in interacting with other disciplines, in group dynamics and leadership, and in embedded systems design.

Joshua Engel

I feel this project was very successful with some issues we had along the way. The designing of the enclosure proved to be more complicated then we initially planned. We had some arguments among the group members of what direction to go which somewhat delayed the process. This led to me learning that concurrent engineering, although a useful tool in preventing costly mistake, it can create problems in a time constraint and sometimes its better to have results that failed rather then a successful first attempt. I feel rapid prototyping may not have been the best way to design this project but given the time it was what we had to work with. Unfortunately, this had plenty of limitations that we could not overcome and some members in our group were not comfortable with some of the designs. Still the final conclusion we had come up with turned out better then expected.

The process taught me lots of things that sometimes as a systems engineer if an argument arises in a group its better to take action rather then decide to move on to another path we can agree on. Conflict is an important part of a team and sometimes compromises must be made for the good of the project and you wont always be able to satisfy every team member. I learned that to feel comfortable not understanding aspects of the project. I was having trouble understanding the programing side and it made me feel uneasy at times but I wont always know the entire aspect of a project and it was important for me to be confronted with that. I feel as a team we came together over time which was why we were able to get results, but that group dynamic did not develop in the first quarter as hoped. I think this was mostly due to the division of work I created at the beginning, we did not have members doing the floating that I suggested which as Stephen mentioned led to some segregation amongst team members. This led to a lack of communication and a lack of trust between the members, which ruined the group dynamic. I think I may have needed to be a more strong leader, however I felt uncomfortable taking on that role at first because Stephen was much better suited for the role with a deeper knowledge of the product. I learned that even if you are not the group leader that it is still important to take a leadership role on the team, which forced

me to make some leadership decisions such as moving away from rapid prototyping. If I had not stepped back at the beginning of the project as it seemed necessary to do at the time, due to my feeling uncomfortable taking a leadership role in a project that I knew nothing about, perhaps I and several other members of the team would not have felt detached from the other group. This was all a learning experience for me and perhaps if we did have more leadership then we would have had quicker and better results, but after it was brought to my attention that I had stepped to far back from a leadership role, I tried to get more involved and I noticed others did the same as well. In the end the project turned out well because it became more of a joint effort.

The final project turned out well and at the expo our feedback was mostly positive, with several people sounding interested in having this in their home. Many felt that the product could be used well in smart homes as we suggested, and some even felt it could be used at construction sites. Judging from the feedback I can say it was a successful project, and I would gladly work with many if not all of my team members again now that we have experienced what it means to be a team.

Diego Flores

Throughout this project I did notice that I did not specifically use the skills taught in my major classes to figure out the issues we came across, but rather relied on logic to solve problems. Although I would have liked to have applied more Materials Engineering aspects to it, I did not feel it necessary throughout the project. However, I know that once I begin a career in whichever industry I choose, I will not always be seen as a Materials engineer, but rather an engineer. Overall we were able to create our home air quality sensor and I believe that the project was a success. As we displayed our project at the expo, I realized how much our project can expand if it were applied to other industrial sectors and what a need there truly is for this product.

In terms of a group dynamic I learned a great deal regarding the importance of a group leader. Honestly it was not until I read some of the other team members conclusions that I realized that in fact we did need one leader. One leader could have helped us make a solid decision when we were in limbo between choices. One leader would have helped us move along faster and been ensured we had our work on time. Unfortunately we did not have one leader throughout the entire project and so we had some difficulties. But as I mentioned before our project was completed and it appeared to be a success (from my point of view) with the people we spoke with at the expo.

Overall I enjoyed working with everyone and learned more about working with different personalities. I do wish I would have spent more time with trying to learn about the sensor array and how it was set up. But I still believe I gained a great deal from this project!

Alvaro Nunez

Cal Poly lived up to its motto of “Learn by Doing” once again. The senior project provided me with an opportunity to work on a yearlong project for the first time. Working with a multi-disciplinary team was very exciting and interesting. Whenever someone during the project got stuck on a task or problem, one of the six team members of the team knew how to perform the task or at least which professor to speak to. I was always confident that the team could solve any problem that we came across. The type of environment provided the team a very real world experience.

Despite the new team experience, our project met some difficulties. Our first issue was a delay in starting our project due to lack of interest from our first customer. After we selected the team’s new project, the team had to cram in a lot of work in the few

remaining weeks of the fall quarter. The team was affected by two main issues throughout the year: people asking too many “what if” questions and we had no clear direction by the customer. Team members spent too much time deciding what to do as opposed to choosing a task and completing it. Fortunately, our team was able to successfully complete the project and presentation on time. More direction from a customer or having a specific leader in the group would have prevented this problem.

With this project experience, I will be more confident in my future jobs. I now have a better understanding of what a good project teams requires and what it needs to prevent any wasted time. I will recommend this senior project class to any student who desires to get the best out of what Cal Poly has to offer. I had a great experience with this team and hope to continue learning from working on team projects.

Miguel Wong

This project presented several challenges that one would not face in a class setting. Amongst them are working with an outside stakeholder or client, working for an extended amount of time with other students, and, of course, technical challenges that may be outside of one’s own field of knowledge.

Our original project involved creating a climate action plan for the San Luis Obispo county. Unfortunately, we could not proceed with this project due to various issues with bureaucratic red tape and problems with finding clients. These issues consumed a large portion of the first quarter and essentially created a time period with zero productivity. We ultimately had to scrap the project and think of a new one, which ended up being developing a home environment sensor for Temperature@lert.

Working with our client Harry at Temperature@lert provided an experience similar to what we’d face in industry. We were presented with an existing system and asked to integrate additional functionality to that system. However, since the client showed little interest in bringing out our project to market, there was little motivation or sense of accountability in designing the system. The project felt like just another educational exercise rather than something that would make a real impact.

Multidisciplinary projects present an opportunity for students to work with people outside of their expertise. The issue we faced for our project was integrating everyone’s skills in a meaningful manner. The project was separated into two groups, one working on hardware/software and the other working on the enclosure for the project. There was little need for interaction between the two. Another issue was a lack of direction and leadership. I believe that a designated leader is not necessary so long as individual members share an interest and take on responsibilities for themselves in the group. This type of group leadership requires motivation from each individual team member, which I felt we were sorely lacking due to knowing that our product would likely not be used by the client at all.

As for technical issues, before this project I had little experience working with microcontrollers. Over the course of the project, I learned about both hardware and software aspects of microcontrollers. The hardware side presented several issues, such as interactions between analog and digital systems. Problems with analog to digital conversion include providing a stable known reference voltage and separation of analog and digital grounds to reduce noise. On the software side of things, I had to become familiar with the MPLAB toolchain for programming the PIC microcontroller and what kinds of limitations and quirks it had.

Overall, the project provided an interesting experience which resembled what it might be like to work in industry. It provided experience working with others, running into problems and overcoming them, and working outside of your own comfort zone. We ran

into a lot of issues, which is not necessarily a bad thing since one learns much more when encountering problems than if everything had gone smoothly.

Appendix A - References

[1] Lawrence Berkeley National Laboratory. "Impacts of Building Dampness on Indoor Air Quality." *Indoor Air Quality Scientific Findings Resource Bank*. Lawrence Berkeley National Laboratory Environment Department, Spring 2010. Web. 9 June 2010. <http://www.iaqscience.lbl.gov/dampness-impacts.html>.
This source supports the claim that high humidity can exacerbate allergies

[2] U.S. Environmental Protection Agency. "An Introduction to Indoor Air Quality (IAQ)." *U.S. Environmental Protection Agency*. EPA, 23 Apr. 2010. Web. 9 June 2010. <http://www.epa.gov/iaq/ia-intro.html>.
This website summarizes the sources and health risks of air pollution

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Appendix B - Decision Analysis

	Cost		Multidetection		Resolution		Ease of Integration		Total
Product Name	actual	score	actual	score	actual	score	actual	score	SCORE
Compact Optical Dust Sensor (Sharp)	$11.38	4	2	4	unknown	3	pulse width output	3	14
DSM501A (dust senor module)	**$5.50**	**5**	**1**	**3**	**Particle Size: 1 microns or over**	**5**	pulse width output	**3**	**16**
inShinyei PS-2 (Pollen Sensor)	$1,300	3	3+	5	Particle Size: 15 microns or over	4	pulse width output	3	15
Humidity and Temperature Sensor	$29.00	3	2	4	Accuracy: 0.03 %RH and 0.01oC	5	variable resistivity	5	17
Relative Humidity & Temperature Sensor	**$9.90**	**5**	**2**	**4**	**Accuracy: 0.03 %RH and 0.01oC**	**5**	**variable resistivity**	**5**	**19**
Humidity Sensor	$9.90	5	1	3	Accuracy: 3 %RH)	4	variable resistivity	5	17
Ozone (O3) Sensor	**$12.90**	**4**	**1**	**3**	**10ppb to 2ppm.**	**5**	**variable resistivity**	**5**	**17**

Appendix C - Final Drawings

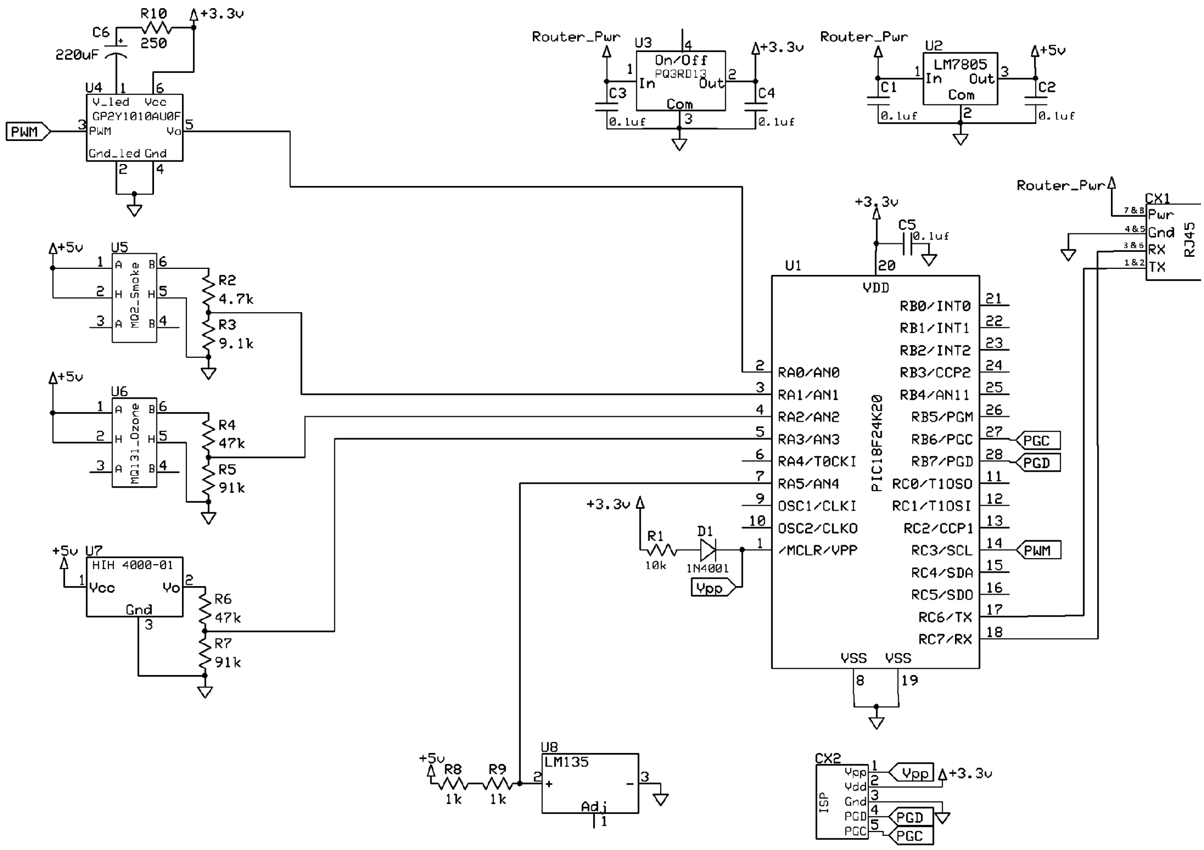


Figure C1 - Sensor Array Circuit Schematic

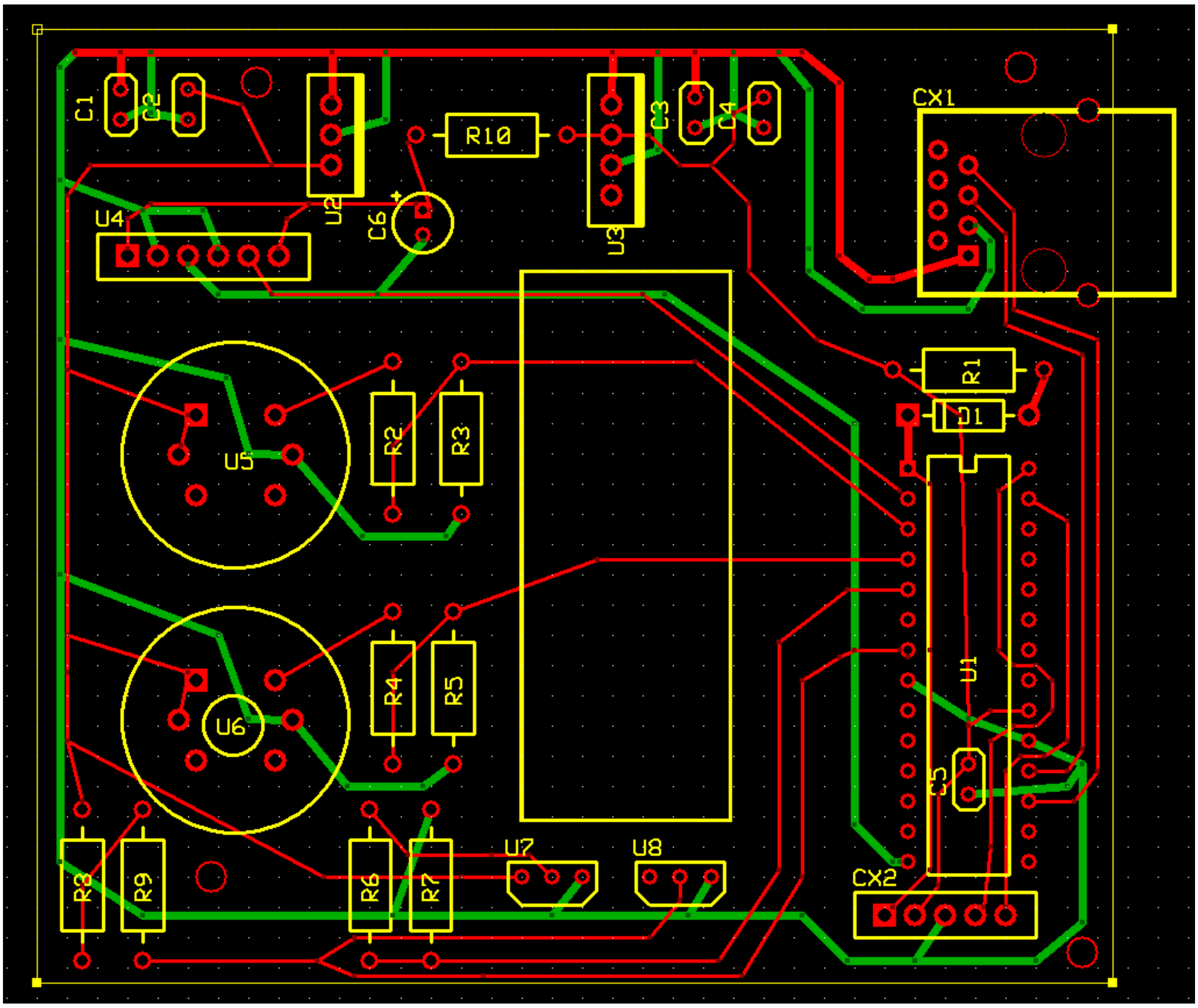


Figure C2 - Sensor Array Layout

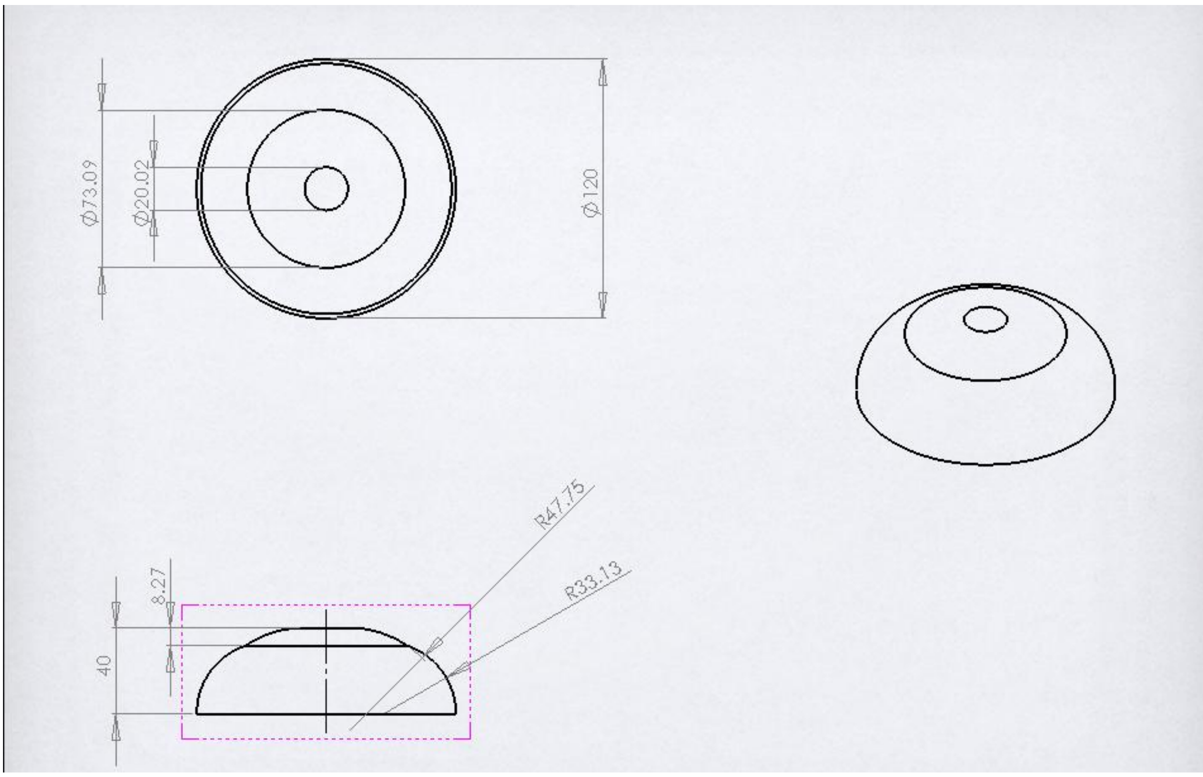


Figure C3 - Aluminum Mesh Dimensions

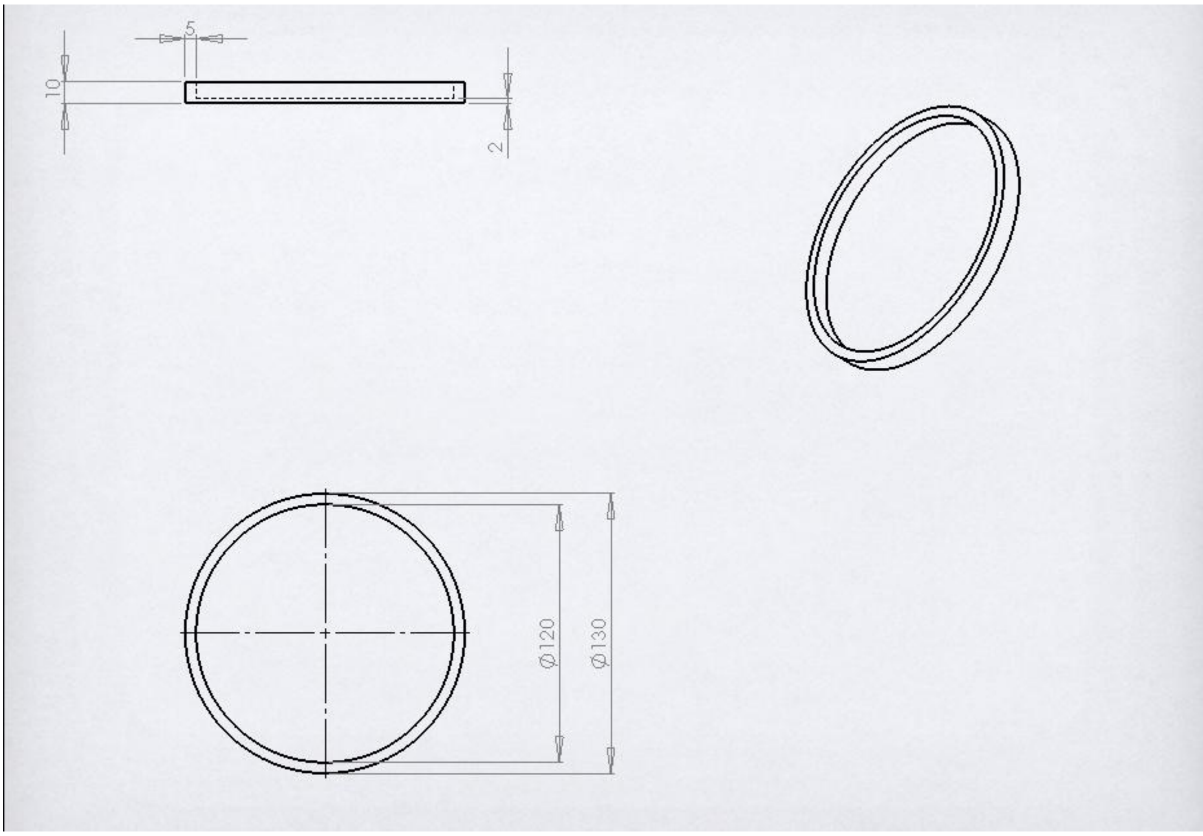


Figure C4 - Polyethylene Base Dimensions

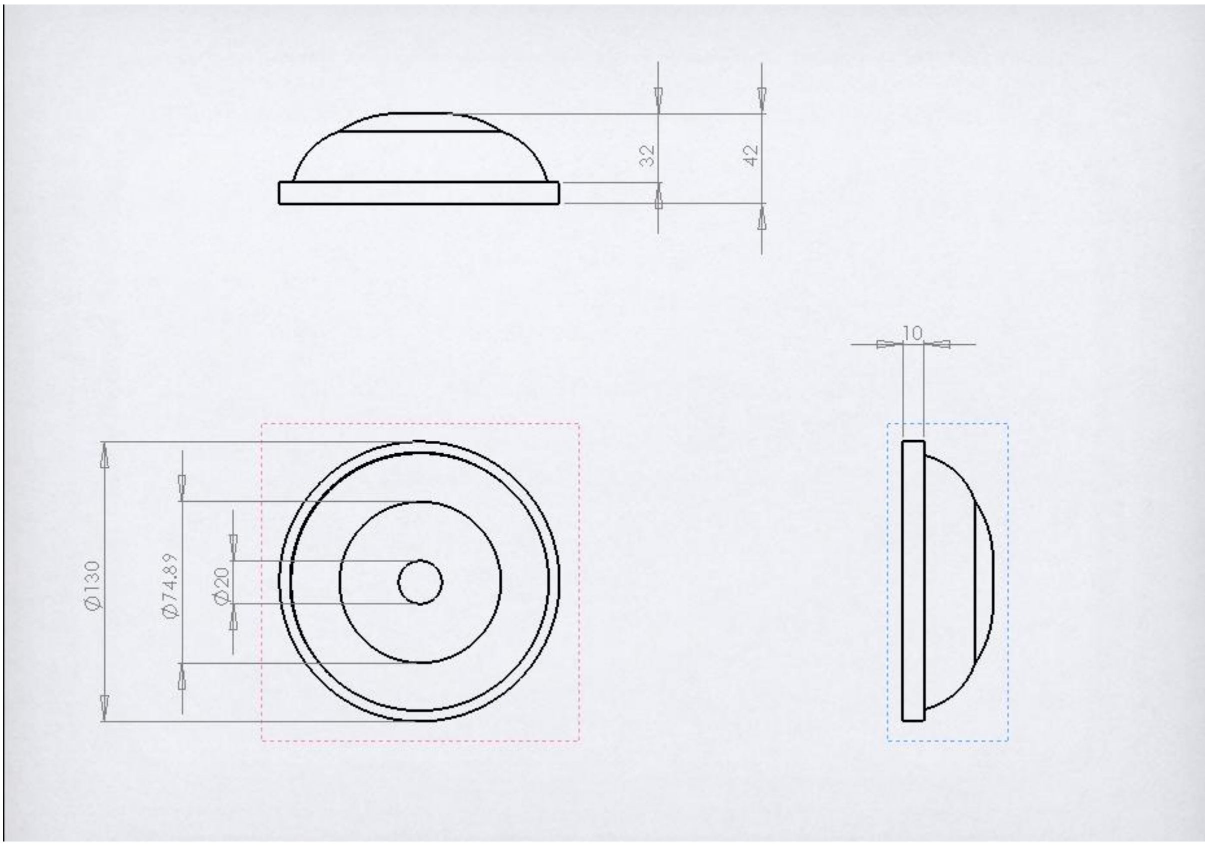


Figure C5 - Assembled Enclosure Dimensions

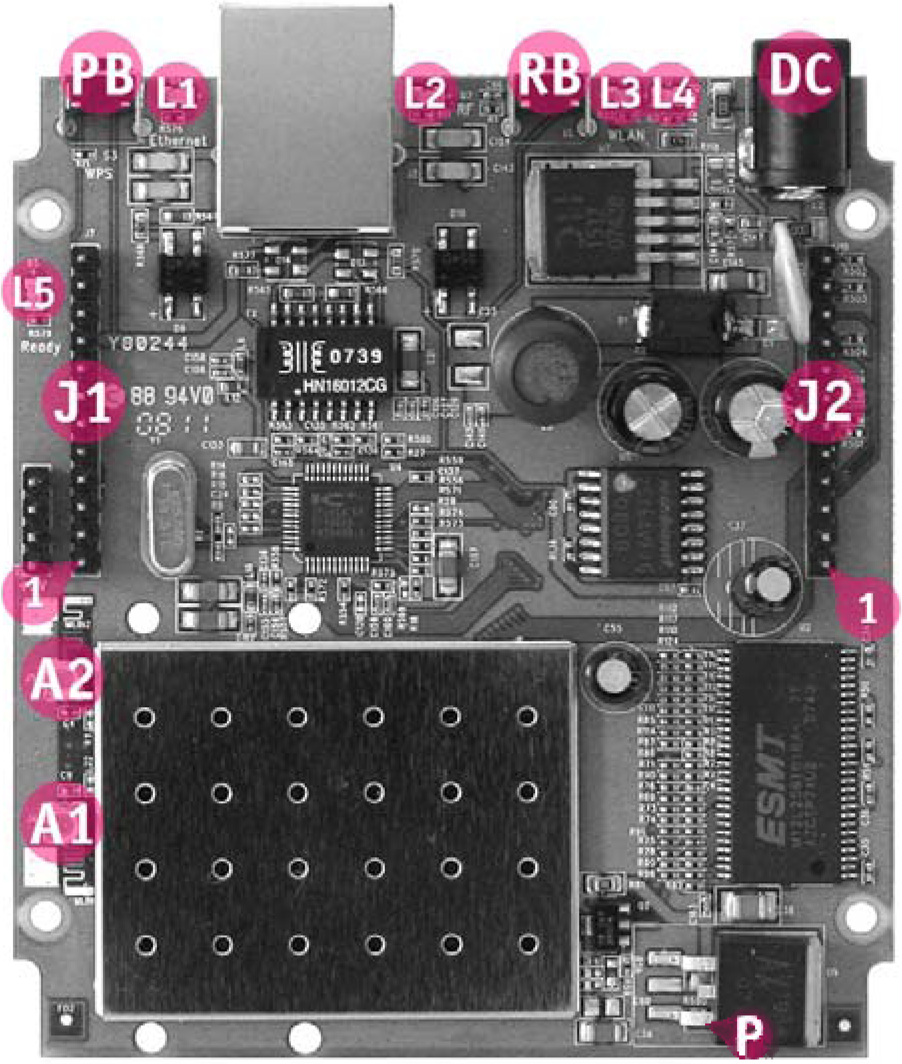


Figure C6 - Router with added 5V lead

Pin 'P' is a small wire soldered onto the router's power regulator to supply a 5v source to the LCD, as no 5v line is available on the router board by default.

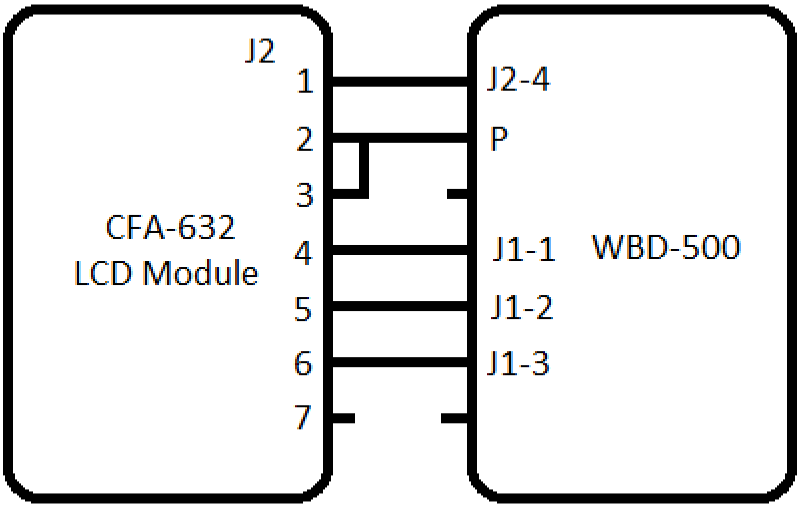


Figure C7 - Router to LCD Wiring Diagram

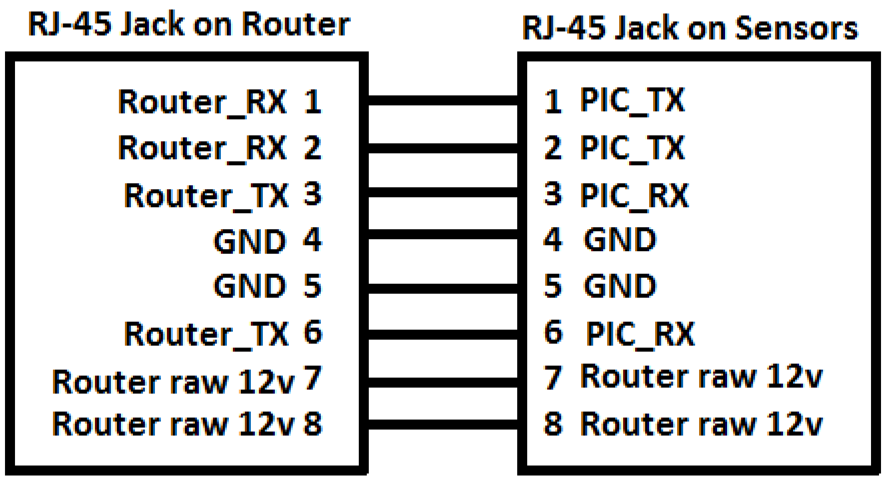


Figure C8 - Router to Sensor Array Wiring Diagram

Appendix D - List of Vendors

Suppliers

- www.robotshop.us
- www.seeedstudio.com
- www.futurlec.com
- www.mouser.com
- www.microchipdirect.com
- www.crystalfontz.com
- Home Depot

Appendix E - Data Sheets

PIC18F24K20 Microcontroller:

http://ww1.microchip.com/downloads/en/DeviceDoc/41303G.pdf

MQ2 Smoke Sensor:
http://www.robotshop.com/content/PDF/datasheet-elb126e4p.pdf

MQ131 Ozone Sensor:
http://www.winsensor.com/english/products/sms/jsq.asp?filename=MQ131.pdf

GP2Y1010AU0F Dust Sensor:
http://sharp-world.com/products/device/lineup/data/pdf/datasheet/gp2y1010au_e.pdf

HIH-4000 Humidity Sensor:
http://sensing.honeywell.com/index.cfm?ci_id=140301&la_id=1&pr_id=145588

CFA632 LCD screen:
http://www.crystalfontz.com/products/632/datasheets/2026/CFA632_Data_Sheet_v2.1.pdf

LM7805 5V Linear Voltage Regulator:
http://www.fairchildsemi.com/ds/LM/LM7805.pdf

PQ3RD13 3.3V Linear Voltage Regulator:
http://sharp-world.com/products/device/lineup/data/pdf/datasheet/pq05rd11_e.pdf

Appendix F - Detailed Supporting Analysis

F1. Resistor Divider Scaling Errors

Given resistors 9.1kΩ and 4.7 kΩ with $\pm$5% tolerances, the worst case voltage scaling occurs when one resistor has a +5% deviation and the other has -5% deviation.

$$9.1k\Omega * 1.05 = 9.555k\Omega$$
$$4.7k\Omega * 0.95 = 4.465k\Omega$$

Then the scaled resistance is:

$$\frac{9.555}{9.555 + 4.465} * 5V = 3.4076V$$

Which has a nominal deviation of :

$$\frac{3.4076 - 3.3}{3.3} * 100 = 3.26\%$$

Similarly,

$$9.1k\Omega * 0.95 = 8.645k\Omega$$
$$4.7k\Omega * 1.05 = 4.935k\Omega$$

Then the scaled resistance is:

$$\frac{8.645}{8.645 + 4.935} * 5V = 3.183V$$

Which has a nominal deviation of :

$$\frac{3.183-3.3}{3.3}*100=-3.55\%$$

F2. ADC C_{HOLD} Charging Time

The greatest input impedance from the sensors to the microcontroller ADC comes from the humidity sensor, whose circuitry is shown below:

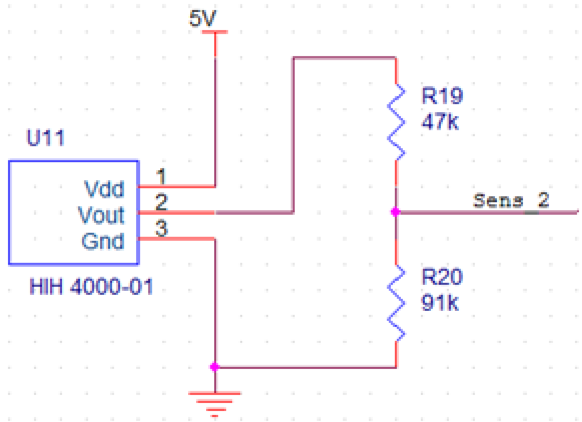


Figure F2.1 - Humidity sensor circuitry

Sens_2 leads to the ADC, so looking into the circuit the ADC sees two branches. One leads to the 91kΩ resistor and ground, and the other branch leads to 47 kΩ and the V_{out} of the humidity sensor. Assuming that the V_{out} pin is a relatively low impedance path to ground, which is typical of output ports in general, then the ADC sees the 47 kΩ and 91 kΩ resistors in parallel for an effective resistance of R_S = 30.99 kΩ. Then from equation 19-1 of the PIC18F24K20 datasheet, the minimum time necessary to charge C_{HOLD} is T_{ACQ}:

$$T_{acq}=T_{amp}+T_c+T_{coff}$$
$$=5\mu s+T_c+(Temperature-25^{\circ}C)*\frac{0.05\mu s}{^{\circ}C}$$

where

$$T_c=-C_{hold}(R_{ic}+R_{ss}+R_s)ln(\frac{1}{2047})$$

with C_{HOLD}= 13.5pF, R_{IC} = 1 kΩ, and R_{SS} = 600Ω, as determined from figure 19-5 from the PIC18F24K20 datasheet. Thus, T_C = 3.19μs. Then assuming operation at room temperature
25°C, the acquisition time is:

$$T_c=5\mu s+3.19\mu s+0\mu s=8.19\mu s$$

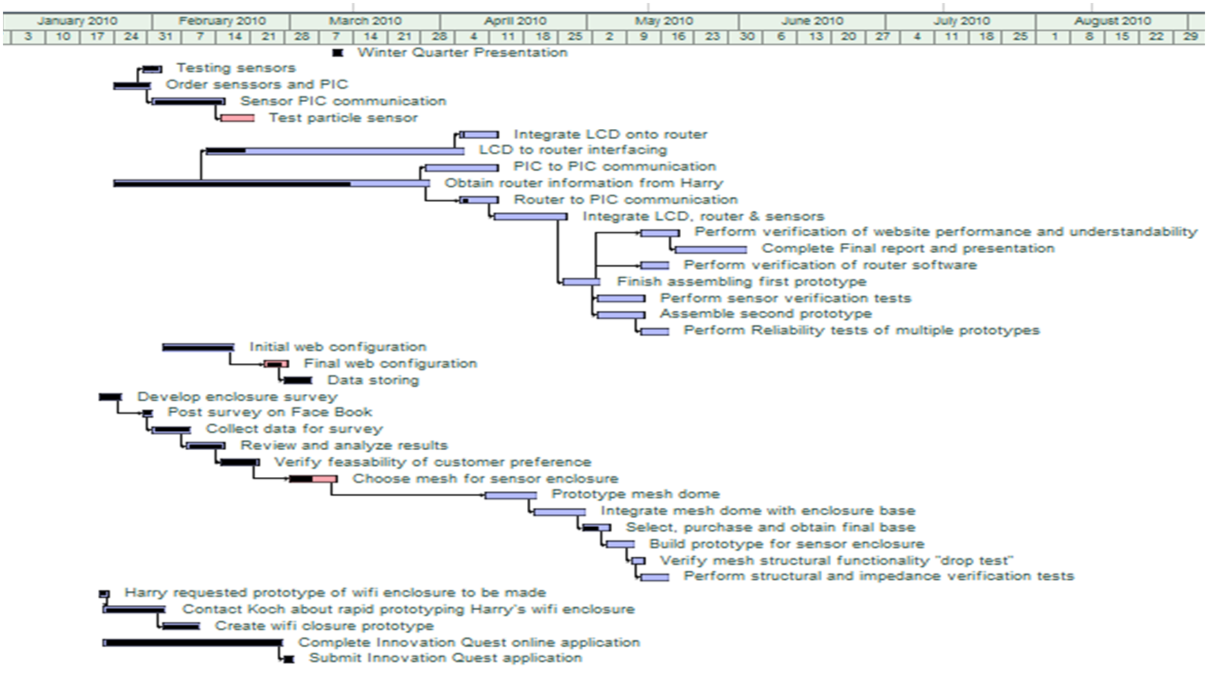
This minimum acquisition time is a valid value that can be programmed into the microcontroller as a multiple of T_{AD}, which is a time unit used in ADC conversion described in section 19 of the PIC18F24K20 datasheet.

F3. Sensor Array Power Draw

Power consumption from datasheets
humidity sensor: 200uA
mq2 smoke sensor: 160mA
mq131 ozone sensor: 130mA
dust sensor: 70mA
pic mcu: 10mA

total: 200uA + 160mA + 130mA + 70mA + 10mA = 370mA
Rounding up and considering line losses and resistor consumption ~ 400mA

Appendix G - Gantt Chart



Appendix H - Statistics Tests

Analysis perform with Minitab
A paired T-Test is used when the actual population average is unknown.
Paired T-Test and CI: Project Temperature Sensor, Fluke Temperature Sensor

```
Paired T for temp - temp ours

              N    Mean   StDev  SE Mean
temp         30  77.120   2.565    0.468
temp ours    30  78.603   1.814    0.331
Difference   30  -1.483   0.946    0.173
```

95% CI for mean difference: (-1.836, -1.130)
T-Test of mean difference = 0 (vs not = 0): T-Value = -8.58 P-Value = 0.000

Correlations: Temperature Sensor, Fluke Temperature Sensor

Pearson correlation of temp ours and temp = 0.964
P-Value = 0.000

Paired T-Test and CI: Project Humidity Sensor, Fluke Humidity Sensor

Paired T for Humidity - Humidity ours

	N	Mean	StDev	SE Mean
Humidity	30	29.94	6.42	1.17
Humidity ours	30	28.42	4.02	0.73
Difference	30	1.516	2.466	0.450

95% CI for mean difference: (0.595, 2.437)
T-Test of mean difference = 0 (vs not = 0): T-Value = 3.37 P-Value = 0.002

Correlations: Project Humidity Sensor, Fluke Humidity Sensor

Pearson correlation of ADC and Hum Act = 0.998
P-Value = 0.000

Paired T-Test and CI: SLOAPCD, Project Ozone Sensor

Paired T for oznone atcual - ozone ours

	N	Mean	StDev	SE Mean
oznone atcual	9	237.3	186.6	62.2
ozone ours	9	255.4	223.9	74.6
Difference	9	-18	410	137

95% CI for mean difference: (-333, 297)
T-Test of mean difference = 0 (vs not = 0): T-Value = -0.13 P-Value = 0.897

Correlations: Project Ozone Sensor, SLOAPCD

Pearson correlation of ozone ours and oznone atcual = -0.991
P-Value = 0.000

Paired T-Test and CI: Project Smoke Sensor, Fluke CO Sensor

Paired T for proj smoke - fluke CO

	N	Mean	StDev	SE Mean
proj smoke	15	720.7	177.2	45.8
fluke CO	15	24.9	18.8	4.8
Difference	15	695.9	162.5	42.0

95% CI for mean difference: (605.9, 785.8)

```
T-Test of mean difference = 0 (vs not = 0): T-Value = 16.59  P-Value =
0.000
```

Correlations: Project Smoke Sensor, Fluke CO Sensor

```
Pearson correlation of proj smoke and fluke CO = 0.805
P-Value = 0.000
```

Appendix H - Testing Data

Testing Data

Fluke Temperature Sensor	Project Temperature Sensor	Fluke Humidity Sensor	Project Humidity Sensor (ADC)	Project Ozone Sensor	SLOAPCD	Project Smoke Sensor	Fluke CO Sensor
81.5	81.233	7.5	211	239	284	280	0
80.6	80.073	7.9	214	348	149.8	750	20
80.6	80.073	8.4	218	485	48.4	540	6
79.7	80.073	14.3	254	531	5.5	600	10
79.7	80.653	18.5	279	50	375	536	5
79.7	80.073	26.3	331	535	4.6	630	12
79.7	80.653	45.4	454	41	395	685	15
79.7	80.653	57.4	499	35	405	760	20
79.7	80.653	66.6	541			867	38
79.7	80.653	74.5	585			855	68
79.7	80.653					919	40
78.8	80.653					909	38
77.9	79.493					870	47
77.9	79.493					832	20
77	78.332					778	34
76.1	78.332						
76.1	78.332						
75.2	77.752						
76.1	77.752						
75.2	77.172						
74.3	77.172						
74.3	77.172						
74.3	77.172						
74.3	76.012						
74.3	76.012						
74.3	76.592						
74.3	76.592						
74.3	76.592						
74.3	76.012						
74.3	76.012						