AirTack

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March 14th, 2013

Dr. Andrew Rawicz
School of Engineering Science
Simon Fraser University
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Re: ENSC 440 Design Specification for the Real Time Air Monitoring System

Dear Dr. Rawicz:

Attached is a document from AirTack Industries that provides technical guidelines for the design of the AirTack Real Time Air Monitoring System (RTAMS). The monitoring system is a real-time device that will respond to sensed environmental conditions via text message notification, electrical shutoff and ventilation management, thereby protecting families and property from dangerous levels of airborne pollutants and hazardous home conditions.

The design specifications illustrated in this document apply to the proof-of-concept device only. Future iterations containing design improvements are discussed but will not be implemented at this stage of development.

If you have any questions or concerns about our proposal, please feel free to contact us by phone at (604) 710-5476 or e-mail at rra19@sfu.ca.

Sincerely,

*Rouzbeh Roshanravan*

Rouzbeh Roshanravan
President and CEO
AirTack Industries

**Enclosure:** Design Specification for a Real-Time Air Monitoring System

# Design Specification for a

# Real-time Air Monitoring System

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## Executive Summary

At AirTack, we aim to produce a Real-Time Air Monitoring System (RTAMS), capable of detecting hazardous levels of various gases and other environmental factors and respond in one or several ways to protect persons and property. Sensed factors include carbon monoxide gas ($CO_{(g)}$), natural gas (methane), smoke (particulate) levels, humidity ($H_20_{(g)}$) levels and temperature. Once a threshold level of a detected substance is reached, the system will alert the user with an SMS, initiate a ventilation system and/or initiate an electrical circuit break to turn off the suspected source of heightened gas or particulate levels.

This document provides a set of design specifications for the RTAMS, including detailed descriptions for the design and development of our proof-of-concept model and rationale for design choices. The specifications described within this document apply to the proof-of-concept model only. Therefore, design considerations pertaining to functional requirements –A or –B will be addressed, representing phase I or II of proof-of-concept development respectively.

The main system consists of three fundamental components: the sensor module, server module and active module. Additionally, data analysis is completed through USB serial communication between the server module and a PC in CSV format. Data analysis and statistical trending software produces graphical reports for the user to provide a complete picture of environmental conditions where the system is installed. The user will be able to access custom long and short-term statistical trends for each sensor, as well as correlation information in graphical format.

This document shall serve as a set of guidelines for the device design, implementation and testing process. The detailed test plans provided herein will used as a measure of project compliance and progress, as well as for the planning and direction of future tasks and development.

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## Acronyms

**RTAMS** Real-Time Air Monitoring System

**$CO_{(g)}$** Carbon Monoxide gas

**CSA** Canadian Standards Association

**I/O** Input/Output

**GSM** Global System for Mobile Communications

**PC** Personal Computer

**CSV** Comma Separated Values

**LEL** Lower Explosive Limit

**RH** Relative Humidity

**TCP/IP** Transmission Control Protocol/Internet Protocol

**SIM** Subscriber Identity/Identification Module

**IC** Integrated Circuit

**IMSI** International Mobile Subscriber Identity

## Glossary

**GSM** Global System for Mobile Communications, originally Groupe Spécial Mobile. It identifies a standard set by the European Telecommunications Standards Institute (ETSI) to describe protocols for digital cellular networks.

**SD Card** Secure Digital memory card, a non-volatile memory card for use in portable devices.

| | |
|---|---|
| **SIM Card** | Subscriber Identity/Identification Module, an IC that securely stores the IMSI data and associated key to identify and authenticate mobile subscribers on mobile devices. |
| **SMS** | Short Message Service. A text-only messaging service component of communication systems under a standardized protocol. |
| **TCP/IP** | Transmission Control Protocol/Internet Protocol, a set of communication protocols used for the internet and other networks. |
| **Correlation** | Correlation is a statistical measure of how related two variables are. Correlation must always be between -1.00 and +1.00, with -1.00 indicating perfect negative correlation, +1.00 indicating perfect positive correlation and 0.00 indicating no correlation exists at all. Fractional values between these boundaries are acceptable and simply describe varying degrees of positive or negative correlation. |
| **Perfect Positive Correlation** | A perfect positive correlation has a value of +1.00 and indicates that the relationship that appears to exist between the two variables being studied is positive 100% of the time. As one variable increases, the other will always decrease. |
| **Perfect Negative Correlation** | A perfect negative correlation has a value of -1.00 and indicates that the relationship that appears to exist between the two variables being studied is negative 100% of the time. As one variable increases, the other will always decrease. |
| **LEL (Lower Explosive Limit)** | A measure of flammability of gases, LEL is used for natural gas and other hydrocarbons. A 100% LEL indicates certainty that a gas has reached an explosively dangerous level. |

 

# 1. Introduction

The AirTack Real-Time Air Monitoring System (RTAMS) is a sensing and response system that will detect hazardous levels of various gases and other environmental factors and respond in one or several ways to protect persons and property. The modular system monitors carbon monoxide, natural gas, humidity and smoke (particulate) levels in the air and communicates sensed data to a central server through power line communication. Once a threshold level of a detected substance is reached, the system will alert the user with an SMS, initiate a ventilation system and/or initiate an electrical circuit break to turn off the suspected source of heightened gas or particulate levels. Our aim is to create a highly usable system for the home, bringing together the functionality of several existent monitoring systems into a single product with added response and data analysis features to enhance safety and efficacy. In addition, the product will be highly customizable, with options to remove or add additional sensors or add additional rooms to be monitored with limited technical aptitude required of the user. This enhanced flexibility also permits flexibility in the end user application of the RTAMS. This design specification describes the technical details for the design of each component of the RTAMS.

## *1.1 Scope*

This document will describe the hardware and software design blocks for the Real-Time Air Monitoring System (RTAMS) and shall further expand on the rationale behind design decisions. The design specification includes discussion of proof-of-concept system requirements only, which are denoted –A and –B in the functional specification. In addition, a series of test plans for all system modules are provided, which will guide testing and evaluation of prototype device functionality.

## *1.2 Intended Audience*

This document will be used by all members of the AirTack Industries team through the development of the Real-Time Air Monitoring System (RTAMS), and shall serve as a set of guidelines for the device design, implementation and testing process. AirTack's President and CEO, Rouzbeh Roshanravan, will use this design specification as a measure of project compliance and progress, as well as for the planning and direction of future tasks and development. During the integration and implementation process, AirTack engineers shall refer to this document to ensure the prototype performs according to the goal of the product. Additionally, during testing, this document shall serve as an evaluation tool to ensure compliance and acceptable performance.

# 2. Overall System Design

## 2.1 Classification

Keeping with the format introduced in the RTAMS functional specification documentation, the following modified convention will be used to describe functional requirements:

R[n - p] – i Functional requirements

Where **n** is the functional requirement number and **p** is the development phase in which the requirement will be addressed. **p** may be A or B, depending on whether the requirement is attributable to sensing or response functionality. **i** denotes either the proof-of-concept device ( – I) or future developments beyond the scope of the current design ( – II) and this document.

## 2.2 High Level System Design

The gas monitoring system has three distinct types of modules: the sensor module, server module, and active module. Figure 1 shows the inputs and outputs of the system.

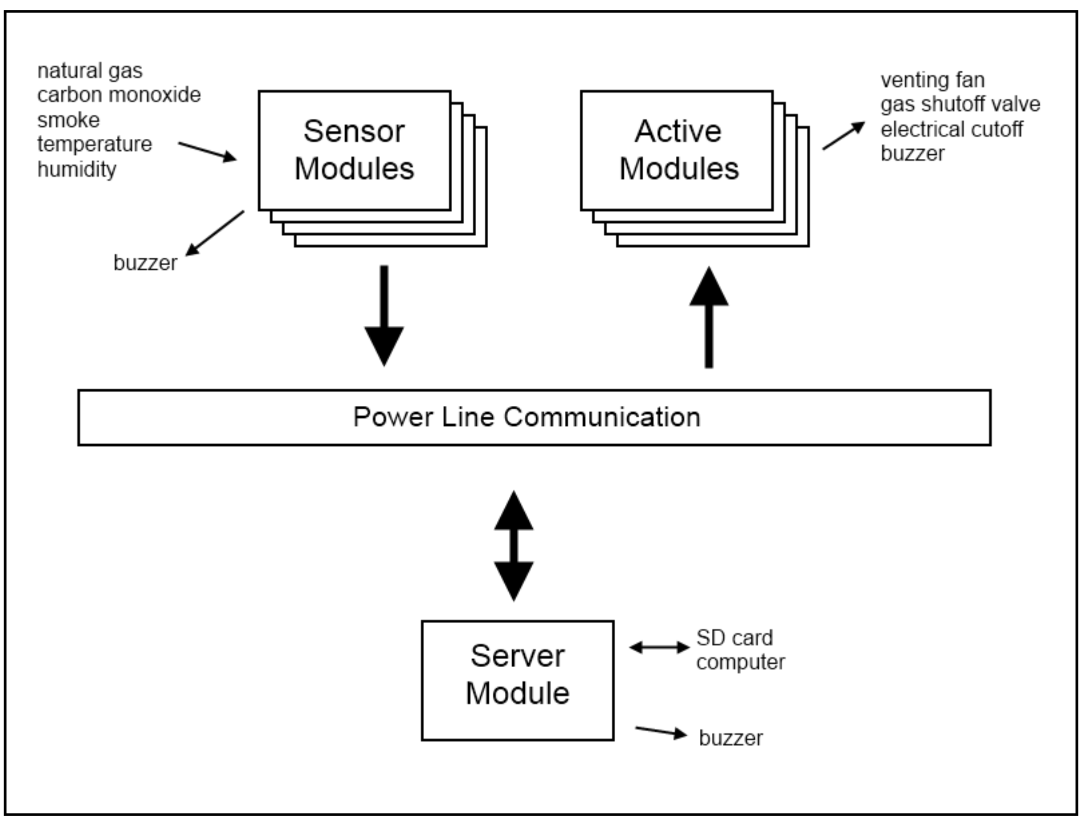


**Figure 1: High Level System Design Diagram**

### 2.2.1 Sensor Module

The sensor module has five sensors connected to it. The role of the sensor module is to read the values from the sensors and raise an alarm and communicates with other modules when a sensor detects a hazard. If an alarm signal is received from another module, the alarm will sound. The sensor module can also send its sensor data value to other modules when requested.

Every sensor module can operate independently without a connection to a server. If only one sensor module is installed, it operates as a normal smoke/natural gas/etc. detector. When more sensor modules are added, the modules are able to setup communication between each other. If one module detects a hazard, it will alert the other modules and will sound an alarm.

### 2.2.2 Server Module

The server module serves several functions and acts as a central node for the network. The module keeps track of all the modules in the network and assigns new modules an address. The server can request data from any sensor module and controls the functions of the active module. Data received from the sensor modules is stored in a SD card. The module also determines which active module to start in an emergency.

A computer can be connected to the server module as required by [R28-A]-I. This will allow the home owner to change settings and the monitor the home remotely [R29-A]-I. The server can also communicate to the home owner via SMS messages. This will alert the home owner of any hazards while the user is away from home.

### 2.2.3 Active Module

The active module is installed in key locations in the house; in the wall connected to a venting fan for example. The role of the active module is to prevent damages to property by preventing a hazardous environment from developing. For example, if a sensor module detects smoke in a room, the active module will turn on a fan to extract the smoke from the room. The active module requires a server module to operate.

## *2.3 Electrical System Design*

**Table 1: Electrical System Design Requirements**

| Requirement Number | Requirement Description |
|---|---|
| **[R6-A] – I** | The power supply should be able to power all the components of the module. |
| **[R7-A] – I** | The module shall be usable with a wall supply of 110V at 60 Hz. |
| **[R8-A] – I** | The module should only require a single plug to the wall. |
| **[R9-A] – I** | A backup battery shall be installed in the module in case of a power outage. |
| **[R10-A] – II** | The modules shall be able to run at 220V at 50Hz in future updates. |

AirTack has attempted to minimize the number of components in the RTAMS by including components that serve more than one purpose. The digital sensor for monitoring humidity also keeps track of the temperature. The initial prototype will be completed on a breadboard to allow for easy modification of the design and testing. The response mechanisms include a fan to assist with ventilation as well as a buzzer alarm to provide audible feedback to users when a hazard exists. The GSM module will also notify a specified user via SMS that one or more sensors have detected an abnormal situation.

### 2.3.1 Environmental Sensors

Table 2 lists the sensors as well as the purpose they will be used for:

**Table 2 Sensor Functionality**

| Sensor | What it detects: |
|---|---|
| **MQ7** | $CO_{(g)}/CO_{2(g)}$ |
| **MQ4** | Methane |
| **COM-09689** | Smoke Particulate |
| **RHTO3** | Temperature/Humidity |

The MQ7, MQ4 and the B008MSQO0W are analog sensors which mean that they will be connected to the analog pins on the Arduino microcontroller while the RHTO3 will be connected to the digital pin. The pin layout is shown in table 3 which can be cross referenced with Figure 2 to see where they will actually map to.

Table 3 Sensor Pin Layout

| Sensor | Pin |
|---|---|
| **MQ7** | Analog In 0 |
| **MQ4** | Analog In 1 |
| **COM-09689** | Analog In 2 |
| **RHTO3** | PWM 7 |


Figure 2: Arduino Mega Pin Layout

### 2.3.2 Speaker / Fan response

The speaker and fan will be connected to digital pins 2 and 3 respectively. They will act in an on/off manner and will not have amplitude/speed adjustment. Refer to Figure 2 to see where they will fit in physically on the board.

### 2.3.3 GSM Module

The GSM Module that is used in the proof-of-concept RTAMS is a cellular shield with a SM5100B cellular module. This module is used to send or receive text messages, and adds SMS, GSM/GPRS, and TCP/IP functionalities to Arduino. It requires two additional parts: a SIM card and an antenna. A GSM SIM card from Rogers was used in conjunction with a Quad-band Cellular Duck Antenna SMA, a standard cellular antenna. The SM5100B cellular module is mounted on top of an Arduino.

Figure 3: Quad-band Cellular Duck Antenna

Figure 4: SM5100B Cellular Module

The GSM module code includes mechanisms to monitor the status of the device and methods to send a text message, receive a text message, choose which messages are supposed to be sent to the user depending on which sensors are triggered and finally, a method to analyze the message received. If the keyword sent to the Action module is "status," the status of the sensor is sent to the user. To implement these methods, the SerialGSM library designed for Arduino microcontrollers, is utilized.

## *2.4 Communication Design*

Each of the modules is able to communicate between each other via power-line communication. This communication enables that any hazard detected by one module to be broadcast to the other modules, thereby alerting the occupants of the building of a hazard. This mode of operation is designed to satisfy [R21-A]-I and [R22-A]-I. The system is designed to be modular in accordance to [R26-A]-I.

The communication is done via the power-line modem PLM-1 made by Ariane Controls. Power-line communication was chosen as the method of communication because it provides a direct connection compared to wireless or IR communication. Power-line communication is also not limited by a wireless range; it is able to communicate anywhere in the building as long as there is a mains outlet nearby. An advantage over other smoke alarm systems is that it reduces the installation cost of adding a dedicated communication system by using existing power-lines present in the wall which satisfies [R1-A]-I.

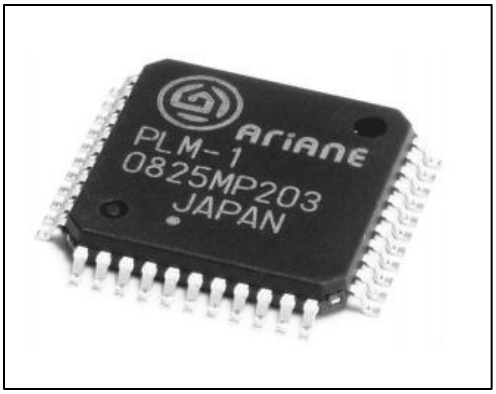


Figure 5: PLM-1 power-line modem from Ariane Controls

The PLM-1 modem by Ariane Controls was chosen because of it has the ability to communicate over several different mediums such has AC power-lines or twisted pair which satisfies [R20-B]-I. This means that the communication is not dependent on the mains frequency and it allows the modems to communicate during a blackout. Another advantage of the PLM-1 is that it is protocol neutral; addressing and networking are handled by the controller rather than the modem. The PLM-1 also provides collision detection and error checking which creates a robust network.

### 2.4.1 Power-line Functional Description and Utilization

The modem uses a narrowband frequency-shift keying modulation to encode binary data to be sent over the power-line. [1] Frequency is shifted between two discrete values to represent logic values. An electronic filter is used to filter out all other frequencies. The filter reduces the noise seen by the modem which in turn reduces the number of errors encountered.

Since the Mamba shield for Arduino uses the PLM-1 modem, it was decided to use the shield rather than designing a new circuit. The shield provides an analog filter, line isolation, and amplifying circuit in one package. The Mamba shield also includes a C library to be quickly implemented in the software.

### 2.4.2 Communication Protocol

The communication network is based on packet switching. Each packet is exactly 16 bytes long to simplify processing. Each packet contains the destination and source address, a command code, and data up to 13 bytes of data. **Error! Reference source not found.** shows the content of the packet.

Table 4: Data Packet Content

| |
|---|
| Destination Address |
| Source Address |
| Command Code |
| Data Byte 0 |
| ⋮ |
| Data Byte 12 |

#### *2.4.2.1 Device Address*

Each device in the network is assigned a one byte network address. The destination address takes up the first byte in the packet; the source address takes up the second byte.

Certain addresses are reserved for the server, initialization, and broadcasts. The server module is set at address 0x01 on initialization. Other modules will initialize to address 0x00, and then request an address from the server if available. Address 0xFF is assigned to be the broadcast address. Any packets sent to the broadcast address will be received by all other modules on the network. With this address assignment, the network is able to host up to 254 modules including the server module. **Error! Reference source not found.** shows the address table.

Table 5: Module Addressing

| Address | Module Type |
|---|---|
| **0x00** | reserved |
| **0x01** | Server |
| **0x02**<br>⋮<br>**0xFE** | Sensor/Active |
| **0xFF** | broadcast |

#### *2.4.2.2 Command Code*

The command code is one byte long and is the third byte in the packet. **Error! Reference source not found.** describes the parameters in the code.

Table 6: Command Code Parameters

| B7 | B6 | B5 | B4 | B3 | B2 | B1 | B0 |
|---|---|---|---|---|---|---|---|
| ALM1 | ALM0 | MOD1 | MOD0 | 0 | OPR1 | OPR0 | ACK/ $\overline{REQ}$ |

<u>ALM</u> [2 bits]

This raises or lowers the alarm signal. It also determines whether to increase or decrease the alarm signal count or reset the counter.

Table 7: Alarm Parameters and Functions

| ALM1 | ALM0 | Function |
|---|---|---|
| 0 | 0 | No alarm |
| 0 | 1 | Alarm count decrease |
| 1 | 0 | Alarm count reset |
| 1 | 1 | Alarm count increase |

MOD [2 bits]

The MOD parameters describe what type of module sent the packet.

Table 8: Packet Source Module Determination

| MOD1 | MOD0 | Function |
|---|---|---|
| **0** | 0 | Server |
| **0** | 1 | Sensor |
| **1** | 0 | Active |
| **1** | 1 | reserved |

OPR [3 bits]

The operation bits determine what functions needs to be performed.

Table 9: Operation Bit Functions

| OPR2 | OPR1 | OPR0 | Function |
|---|---|---|---|
| 0 | 0 | 0 | No operation |
| 0 | 0 | 1 | Ping |
| 0 | 1 | 0 | Address request |
| 0 | 1 | 1 | Data request |
| 1 | 0 | 0 | Active control |

ACK/ $\overline{\text{REQ}}$ [1 bit]

Determines if the packet is a request or acknowledge signal. Alarm signals do not require an acknowledge signal.

#### *2.4.2.3 Data Format*

The rest of the packet is reserved for data values. The data values and the order depend on the operation bits in the control code and the ACK/ $\overline{\text{REQ}}$ bit.

No Operation

The module receiving this packet is not required to respond. It is also the operation that is send during an alarm signal.

Ping

This operation is to test the connection between two modules. One module sends the packet with a request bit and no data. The receiving module returns a packet with the acknowledge bit with no data.

Address Request

The initial setup of the sensor and active modules will request the server to assign the module with an address. During setup, a two byte key is generated. A request packet is sent to the server with the key as the data. The server will send back an acknowledge packet with same key followed the by the new address as the data. If the returned key matches the generated key, then the address is assigned to the module. If there is no response from the server, the module will assign itself an address which is not in use.

Data Request

The server will send a request packet to one of the modules with no data. The sensor module will then return an acknowledge packet with the sensor values. See **Error! Reference source not found.** for the order of the sensor values.

Table 10: Request Data Order

| | |
|---|---|
| **Byte 0-1** | Smoke |
| **Byte 2-3** | Natural gas |
| **Byte 4-5** | Carbon Monoxide |
| **Byte 6-7** | Temperature |
| **Byte 8-9** | Humidity |

Active Control

The server will send a request packet to an active module. The data is a byte value where each bit turns on or off one device connected to the active module. An acknowledge packet is returned with no data.

## 2.5 Software Design and Data Analysis

The main stand-alone software component of this device is for data analysis. The central server of the device is connected to a PC through serial and data is transferred from the central server's SD card to the computer for analysis. Three types of graphs are available- short term data trends, long term data trends and correlation value bar graphs. The RTAMS was designed to be as user friendly as possible, so the statistical data and trending information provided by the system's software is meant to be as simple, readable and easily understandable as possible. Short and long-term data trending and correlation coefficient bar graphs provide enough information about the current behavior of measured environmental factors in the home without getting into advanced statistics, which may overwhelm a non-technical user.

Data analysis is performed with scripts written in and for **R** [2], an open source statistical computing application. R was chosen for its usability and status as open-source software, which will allow AirTack to produce further developments to its software in the future, using pre-existing solutions to enhance its solutions. To further simplify the application for the user, should they ever have to work directly with the program and not just view its output, **R-Deducer** [3], an open source GUI for R has been implemented. Once the device is connected to the computer, the user can simply double click an icon on their desktop to begin the data analysis process. At this time, a bash script will execute, R will be opened and will start executing the data analysis scripts. Once the data analysis is complete, the script will output a PDF document with all relevant/selected graphs.

### 2.5.1 Graphing: Short and Long-Term Data Trends

Short term data trends are available in a variety of time periods. Samples are taken from the sensors at a rate of once every five seconds, so this is the maximum resolution for a trending graph. The user may provide input to the script to set the time period during which to produce the graph. The real-time component of the software will also allow for consistently updated graphs with new data from the system's central server (delivered by serial). Updates are made after a set time period. If the PDF is already open, a new version is created with updated data. Long-term data trend graphs are updated in the same way.

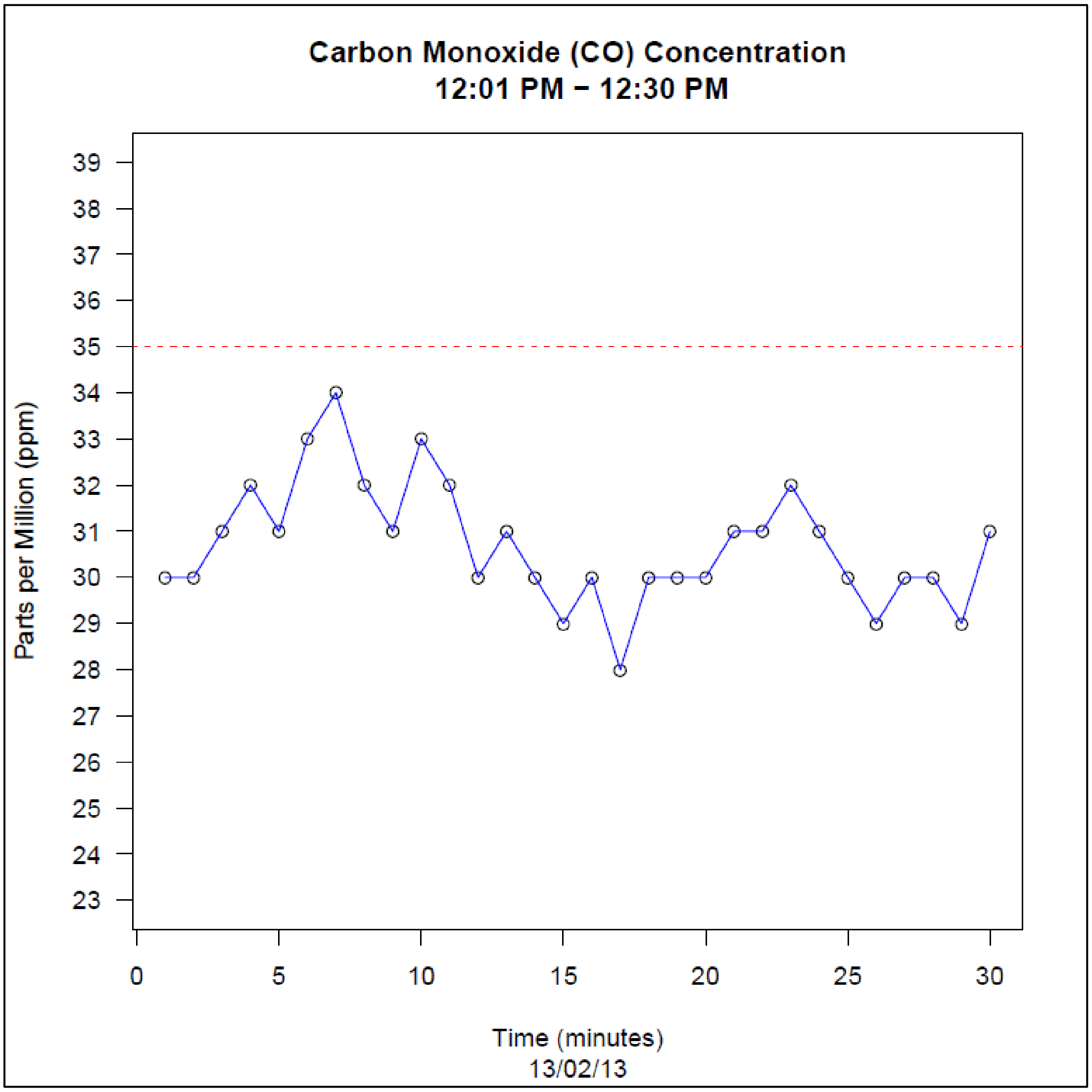


Figure 6: Short-Term Data Trend Graph – $CO_{(g)}$ Concentration over a half hour period.

Figure 5 shows a typical data trend from the device's $CO_{(g)}$ sensor. An individual graph is created for each sensor and included in the PDF report package. As described in *Section 5: Safety Concerns* of this report, humans start experiencing adverse effects from prolonged exposure to $CO_{(g)}$ when levels go above 35 ppm (0.0035%). The red threshold line on the above graph indicates this division between acceptable and harmful levels of $CO_{(g)}$. Should any data point cross this line, the system has been designed to respond in one or more user-defined ways. Response mechanisms and thresholds for each environmental factor are available in Table 12 in *Section 5: Safety Concerns*.

### 2.5.2 Graphing: Correlation

Based on the sensor data, a correlation coefficient is calculated by the software module between each environmental factor. Bar graphs of these correlation coefficients are then produced, allowing the user to monitor the positive or negative relationship between sensed data. Correlation is a statistical measure of how related two variables are. Correlation must always be between -1.00 and +1.00, with -1.00 indicating perfect negative correlation, +1.00 indicating perfect positive correlation and 0.00 indicating no correlation exists at all. Fractional values between these boundaries are acceptable and simply describe varying degrees of positive or negative correlation. Perfect positive correlation indicates that as one variable increases in the positive direction, the other will always increase in the positive direction as well. Conversely, perfect negative correlation indicates that as one variable increases in the negative direction, the other will always increase in the negative direction as well. While correlation is not causation, in the context of this monitoring system, it is useful to consider the relationships between certain environmental factors. A highly positive correlation between $CO_{(g)}$ and smoke (particulate) levels, for example, may indicate a fire hazard before smoke levels alone would.

The software makes use of a built in correlation calculation function which computes the Kendall rank correlation coefficient, also referred to as Kendall's tau (**τ**) coefficient to measure the association between two sensor's data. The Kendall **τ** coefficient is defined as follows:

$$\boldsymbol{\tau} = \frac{(number\ of\ concordant\ pairs) - (number\ of\ disordant\ pairs)}{\frac{1}{2}n(n-1)}$$

**Figure 7: Calculation of the Kendall tau coefficient**

Where **n** is the total number of pairs available for comparison (number of paired samples).

Figure 7 illustrates an example bar graph of calculated Kendall correlation coefficients (**τ**) for each sensor pair. This particular graph shows the association between particulate data and data from the four other sensors based on data gathered over a 24 hour timeframe with periodic sampling. An individual graph is created for each sensor and included in the PDF report package.

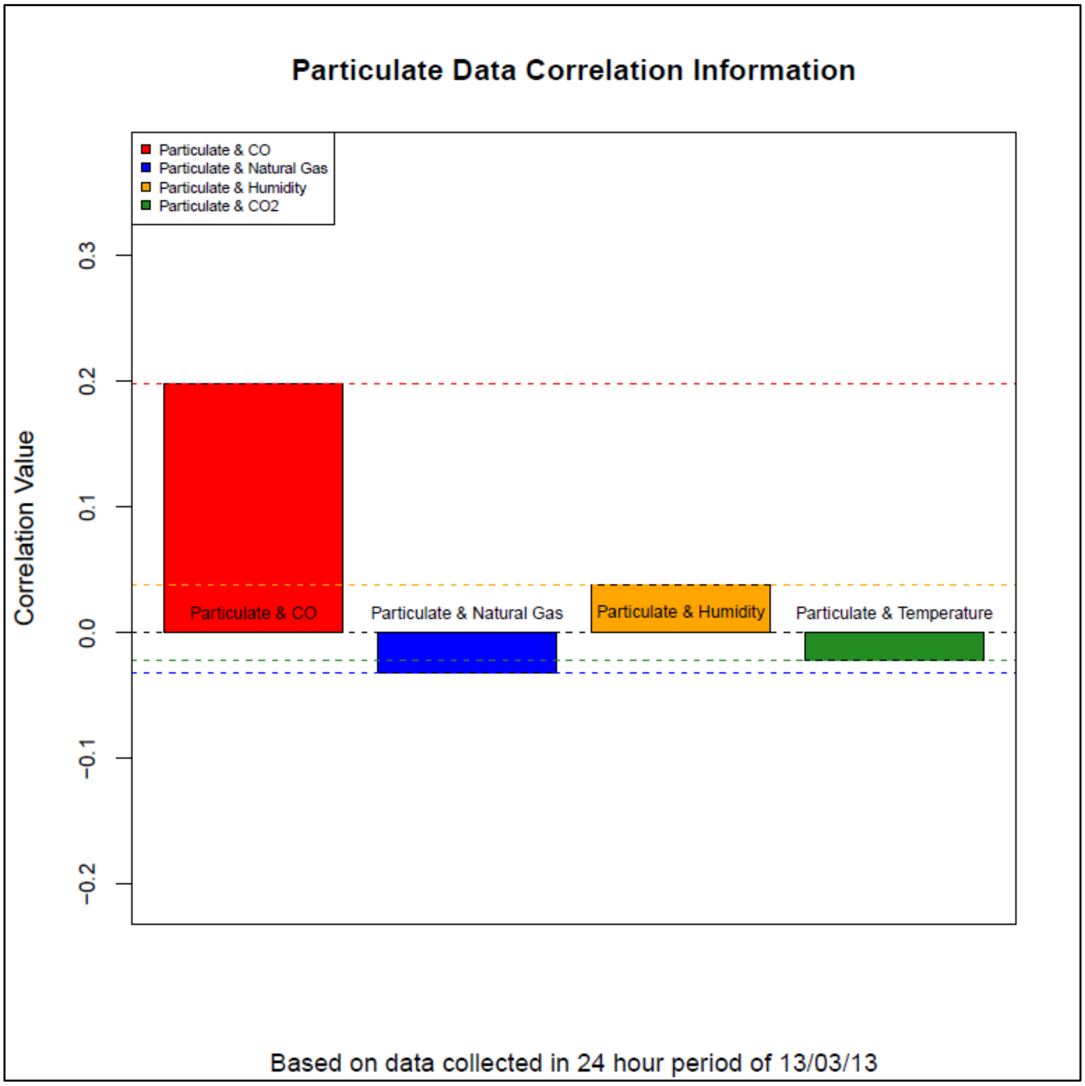


Figure 8: Kendall 'tau' rank correlation coefficients between sensors, organized in a bar graph

### 2.5.3 Real-time Updating Mechanism

The data used for analysis is provided through the PC's serial connection in CSV format. Sample data is taken by each sensor in the system every five seconds, so this is the maximum data resolution for any graph computed. The rate of graph updates can be easily set by the user, and delays between updates are achieved via a sleep system call. The speed of the update constitutes a real-time mechanism, with graphed data timestamps being highly accurate. If the PDF output file is already open when an update is to occur, a new –numbered version will be created.

# 3. Test Plan

Testing begins with examining the compliance of each part of the system through individual testing. These parts include sensors, the GSM module, the fan (ventilation system), the SD module, and the Mamba shield which provides the main communication link between the system parts. After each individual part is fully tested and is confirmed that each part is functional Airtack will test the device in action under extreme conditions.

## *3.1 Unit Testing*

To verify that each part is working properly Airtack will test each individual part as follows:

### 3.1.1 GSM Module:

1. Monitor the Arduino from the serial port after inserting the SIM card.
2. If the status of the device is set to active, then both the SIM Card and the antenna are functional.
3. Program the Arduino to send a simple SMS text message to a phone number.
4. Send an SMS text message to the SIM Card and monitor the status through the serial port.

### 3.1.2 Fan:

1. Airtack make a simple circuit with the fan.
2. Airtack will provide an input to the fan and will monitor the results.
3. If the fan starts to spin upon receiving the input, the fan is functional.

## *3.2 Sensor Testing*

Our system has five different sensors. Each sensor will be tested and monitored separately to ensure that each sensor is functional. The purpose of this testing is only and only to prove that each sensor works properly and calibration of the sensor is not performed by the following measures.

Testing of all each sensor will take place in an enclosed transparent plastic box.

### 3.2.1 $CO_{(g)}$ Sensor:

1. A simple circuit is created on a bread board.
2. Sensor is placed on the circuit.
3. The output is monitored through serial port on our computer.
4. Sensor is placed under the transparent box.
5. An option to test the sensor at this point is to spray some $CO_{(g)}$ from a Carbon Monoxide Test Kit.
6. If the sensor's output showed the changes, then the sensor is functional.

Calibration of the device involves repeating the above steps. Different known concentrations of Carbon Monoxide should produce different responses, which can be monitored from the computer through USB to serial. The response of the RTAMS must satisfy the requirements stipulated in the functional specification documentation, particularly CSA Standards. [4] [5] [6]

### 3.2.2 Natural Gas Sensor:

1. A simple circuit is created on a bread board.
2. Sensor is placed on the circuit.
3. The output is monitored through serial port on our computer.
4. Sensor and calibrated natural as monitor is placed under the glass box.
5. A small amount of methane of known concentration is sprayed near the sensor.
6. If the sensor's output showed the changes, then the sensor is functional.

Calibration of the device involves repeating the above steps. Different known concentrations of Natural Gas should produce different responses, which can be monitored from the computer through USB to serial. The response of the RTAMS must satisfy the requirements stipulated in the functional specification documentation, particularly CSA Standards. [4] [5] [7]

### 3.2.3 Smoke Sensor:

1. A simple circuit is created on a bread board.
2. Sensor is placed on the circuit.
3. The output is monitored through serial port on our computer.
4. Sensor is placed under the glass box.
5. Airtack will use a fog machine.
6. Airtack will turn on the fog machine and monitor the results through the serial port.
7. Airtack should see an increase in the data produced by our sensor.
8. Once the glass box and the fog machine are removed the monitored level should go back up to its initial value.

Calibration of the smoke sensor device was done at the time of production. Information can be found on the device data sheet. [8]

### 3.2.4 Humidity Sensor:

1. A simple circuit is created on a bread board.
2. Sensor is placed on the circuit.
3. The output is monitored through serial port on our computer.
4. Sensor is placed under the glass box.
5. Airtack will use a small portable air humidifier.
6. The air humidifier is placed under the glass box along with the sensor.
7. Airtack will turn on the air humidifier and monitor the results through the serial port.
8. Airtack should see an increase in the data produced by our sensor.
9. Once the glass box and the humidifier are removed the monitored level should go back up to its initial value.

#### 3.2.5 Temperature Sensor:

1. A simple circuit is created on a bread board.
2. Sensor is placed on the circuit.
3. The output is monitored through serial port on our computer.
4. Sensor is placed under the glass box.
5. Airtack will use an air can.
6. A small amount of air will be directly sprayed on the sensor.
7. Since the air coming out of the can has a lower temperature a change(decrease) in data should be observed on the monitored data coming from the sensor.
8. Once the can is not sprayed anymore the monitored level should go back up to its initial value.

## 3.3 Communication Testing

Communication testing will begin once unit testing and sensor testing has been completed. Several different setup scenarios will be analyzed.

#### 3.3.1 Two sensor modules:

1. Two sensor modules will be installed in separate rooms
2. Wait for both modules to complete initialization
3. One of the sensors will be stimulated with smoke from a fog machine
4. If the alarm sound on both modules, then Airtack know that the communication has been set up properly

#### 3.3.2 Two sensor modules and a server:

1. A server module is installed
2. Wait for the server to complete initialization
3. Install the two server modules
4. Wait for both sensor modules to complete initialization
5. A computer is connected to the server
6. The data is read from the server
7. If the data from the sensor modules is correct, the server communication functions are working.

#### 3.3.3 Sensor, Server, and Active:

1. The server module is installed and wait for initialization
2. The sensor module is installed and wait for initialization
3. The active module is installed and wait for initialization
4. Configure the server to turn on a fan when smoke is detected
5. Stimulate the sensor module with smoke from a fog machine
6. If the fan connected to the active module turns on, the server module is correct configured to control the active module.

### 3.4 Software/Data Analysis Testing and Corner Cases

The main stand-alone software component of this device is for data analysis. The central server of the device is connected to a PC through serial and data is transferred from the central server's SD card to the computer for analysis. Three types of graphs are available- short term data trends, long term data trends and correlation value bar graphs. Data analysis is performed with scripts written in and for **R**, an open source statistical computing application. Software testing has been ongoing throughout its development to ensure predictable and accurate behavior even before integration with system hardware. During the integration process, further tests will be executed as per below.

#### 3.4.1 CSV Input Testing

This test must ensure CSV data input has the expected number of variables. CSV data should be input into the software in the following format:

*second, minute, hour, day, month, year, sensor_address, data1, data2, data3, data4, data5*

The software shall first check that CSV data is received from serial. If this is successful, it should check the number of parameters (columns) in the CSV input and compare it to the expected number of parameters.

**<u>Failure Conditions:</u>** CSV data not received, **OR** CSV data received **AND** (number of parameters) != (expected number of parameters). Software will throw an error to indicate data not received or an error to indicate missing data due to a missing sensor not connected to the system hardware.

**<u>Success Conditions:</u>** CSV data is received **AND** (number of parameters) = (expected number of parameters). Software will initiate normal data analysis procedures.

#### 3.4.2 PDF Output Generation

If an output PDF already exists and is still open when a new report is generated as part of the real-time update, the software should create a new report by the same name with an appended number following the previous filename. This will address the error R throws when a file meant to be edited is still open.

**<u>Failure Condition:</u>** An error is still thrown by R: *Error in pdf("DataAnalysis.pdf") : cannot open file ' DataAnalysis.pdf'*.

**<u>Success Condition:</u>** A new PDF is successfully created with an appended number.

### 3.4.3 Matching Sensor Samples for Analysis

For correlation calculations and computation of bar graphs to illustrate correlation coefficients, data from two sensors at a time must be paired and analyzed together. This process requires both sets of data to be the same size. A corner case has been programmed into the code to check if each individual data vector for analysis has an identical number of samples so pairing will be successful. If there is a problem with pairing data, an error will be thrown and hardware operation/communication modules should be checked for correct operation.

**Failure Condition:** An error is thrown by R:

*Error in cor(exampletest, datamatrix$data5, use = "all.obs", method = "kendall") :*

*incompatible dimensions*

**Success Condition:** All data vectors of interest are of identical lengths. Software will initiate normal data analysis procedures.

### 3.4.4 Dangerous Environmental Factor Levels Indication

Action alerts for dangerous levels are sent by the system's central server when it has determined that levels of an environmental factor have gone outside of acceptable ranges. It is not crucial that the data analysis software output, which just generates trending and correlation information also alert the user to problems, however this feature has been included to enhance the quality of information the outputted graphs provide. This corner case ensures that when a sample in the graph's range has stepped outside of acceptable threshold levels, a red warning message will be included on the graph.

## 3.5 System Testing

### 3.5.1 Normal Case 1: No Sensors Activated

**User Input:** User plugs in the fan, sensors, and the server to the outlet.

**Conditions:** There are no significant substances in the air to trigger any of the sensors.

**Expected Observations:** Each individual part is connected to the server. None of the sensors are triggered. The data monitored from all sensors shows a moderate normal status. The fan is off. No text message is sent.

### 3.5.2 Normal Case 1: No Sensors Activated

**User Input:** User plugs in the fan, sensors, and the server to the outlet. One sensor is activated.

**Conditions:** One of smoke, $CO_{(g)}$ or natural gas, temperature, humidity levels are higher than the normal level.

**Expected Observations:** Each individual part is connected to the server. Data monitored shows which sensor is triggered. For any sensor activated a text message is sent to specified number indicating the level of the gas, level of danger, and the buzzer is triggered. If either of $CO_{(g)}$ or natural gas sensors are activated the fan will also start to run. Once the level of substance detected drops to normal level a text is sent again to inform user that everything is back to normal, the buzzer and fan will stop as well.

### 3.5.3 Extreme Case2: All Sensors Activated at Once

**User Input:** User plugs in the fan, sensors, and the server to the outlet. All sensors are activated simultaneously.

**Conditions:** All devices are communicating with the main server. All of the smoke, $CO_{(g)}$, natural gas, temperature, and humidity levels are higher than the normal level.

**Expected Observations:** Each individual part is connected to the server. Data monitored shows that all of the sensors are triggered. For all sensors a text message is sent to specified number indicating each level of the gases, level of danger, and the buzzer is triggered. Since, smoke sensor is also activated, the fan will NOT start. The buzzer will be triggered. Once the level of substance detected drops to normal level a text is sent again to inform user that everything is back to normal, the buzzer will stop as well.

# 4. Safety Considerations

The main purpose of the RTAMS is to protect the safety and physical well-being of people and their property. As a result, compliance with required standards and the alignment of system behaviour to achieve these requirements is of paramount importance. Threshold levels for system response have been chosen to satisfy standard compliance requirements in Table 11, along with the requirement that the RTAMS respond to hazardous levels within five seconds.

Table 11: Standard Compliance Requirements

| Requirement Number | Requirement Description |
|---|---|
| **[R15-B] – I** | The system shall conform to C22.2 NO. 208-03 standards. [4] |
| **[R16-B] – I** | The module shall conform to CAN/CSA-C22.2 NO. 60079-29-1:12 standards. [7] |
| **[R17-B] – I** | The module shall conform to CAN/CSA-6.19-01 standards. [5] |

Table 12 illustrates the threshold levels and associated actions the RTAMS will perform in response. Citations next to threshold levels indicate references consulted in the decision to use that level. Supporting data for these design and calibration decisions can be found in the safety subsections that follow the table.

Table 12: RTAMS Threshold Levels and Responses

| Environmental Factor | Threshold Level | Action |
|---|---|---|
| **Carbon Monoxide** | 35 ppm [9] | Send SMS message immediately when first data sample crosses threshold. If levels remain above 35 ppm for ten minutes, send another text message and initiate ventilation system. If levels reach 100 ppm, sound buzzer, send SMS, ensure ventilation system is ON. Update user with additional SMS every 10 minutes while levels are above 35 ppm. |
| **Natural Gas** | 10% LEL, or 5000 ppm [10] | Send SMS message immediately when first data sample crosses threshold. Also sound buzzer and initiate ventilation system. If levels remain high for five minutes, send SMS to FortisBC. |
| **Smoke (particulate)** | 65 ug/m$^3$ | Send SMS message to user when levels cross first threshold and initiate ventilation system. If levels cross second threshold, sound the buzzer and send SMS message to 911 indicating a possible fire. |
| **Humidity ($H_20_{(g)}$)** | 30-50% RH | Send SMS to user to indicate humidity levels are too high or too low in reference to desired levels. |

| | | |
|---|---|---|
| **Temperature** | Below 19 °C (66 °F)<br>Above 22 °C (72 °F) | Send SMS to user to indicate temperature getting too high or too low once first data sample crosses either threshold. Provide a follow-up status SMS if still out of acceptable range 10 minutes later. Repeat status SMS every 10 minutes until temperature returns to acceptable range. |

### 4.1.1 Dangerous Levels of Carbon Monoxide

Table 13 denotes the health effects of increasing $CO_{(g)}$ concentrations in the air. The decision to design the RTAMS to initiate action when a level of 35 ppm is reached is based on the data in the table below.

**Table 13: Health Effects of Carbon Monoxide Concentrations [9]**

| Concentration | Symptoms |
|---|---|
| **35 ppm (0.0035%)** | Headache and dizziness within six to eight hours of constant exposure |
| **100 ppm (0.01%)** | Slight headache in two to three hours |
| **200 ppm (0.02%)** | Slight headache within two to three hours; loss of judgment |
| **400 ppm (0.04%)** | Frontal headache within one to two hours |
| **800 ppm (0.08%)** | Dizziness, nausea, and convulsions within 45 min; insensible within 2 hours |
| **1,600 ppm (0.16%)** | Headache, tachycardia, dizziness, and nausea within 20 min; death in less than 2 hours |
| **3,200 ppm (0.32%)** | Headache, dizziness and nausea in five to ten minutes. Death within 30 minutes. |
| **6,400 ppm (0.64%)** | Headache and dizziness in one to two minutes. Convulsions, respiratory arrest, and death in less than 20 minutes. |
| **12,800 ppm (1.28%)** | Unconsciousness after 2–3 breaths. Death in less than three minutes. |

### 4.1.2 Dangerous Levels of Natural Gas (Methane)

Danger to persons and property from concentration reaching explosive levels occurs before health effects of breathing or being exposed to methane and so LEL levels are used to determine acceptable threshold for the RTAMS. [11]

Methane levels are measured in LEL% (Lower Explosive Limit). At 100%, gas is explosively dangerous. A strong smell of gas is noticeable at a mere 0.5 to 1% LEL. There are two grades of leaks, Grade 1 indicating an existing hazard to persons or property, and Grade 2 meaning non-hazardous levels at the time of detection, but justifies repair. The RTAMS will respond according to the requirements for a Grade 2 leak in a confined space, which is 10% of the lower explosive limit (LEL). The LEL for methane is

5% by volume, or about 50000 ppm (assuming ideal gas). The RTAMS will initiate action responses when 0.5% by volume is reached, or 5000 ppm. [10]

#### 4.1.3 Dangerous Levels of Smoke (Particulate)

Particulates are classified into two categories: respirable or nonrespirable. Respirable particles are less than 5 microns in diameter and are known to settle in the lower lung, where they cause tissue damage. Nonrespirable particles enter the upper respiratory system only, where they cause irritation. [12] Acceptable levels of respirable and nonrespirable particles are measured in micrograms of particulates per cubic meter of air ($\mu m/m^3$) and acceptable levels are 65 $\mu m/m^3$ and 150 $\mu m/m^3$ in a 24 hour period, respectively. [12] The RTAMS threshold level for particulates is 65 $\mu m/m^3$, ensuring a complete picture of particulate levels in the air is responded to.

#### 4.1.4 Humidity and Temperature Levels for Comfort

While not presenting immediate danger of the same order as $CO_{(g)}$, natural gas or particulate, humidity and temperature are still monitored by the RTAMS and there are typically acceptable levels for human comfort.

Acceptable humidity levels (20-50% RH) and acceptable temperature levels (Below 19 °C (66 °F) and above 22 °C (72 °F)) for the RTAMS were chosen based on recommendations from the Illinois Department of Public Health.

#### 4.1.5 Device Use

As with any consumer electrical system, care must be taken to ensure safe use of the device. Typical safety procedures followed when using electronic equipment should be followed, including avoidance of water during use/installation and restricting the usage indoors. The modules are not intended to have the hardware modified by the end user; the end user simply has to plug in the modules into the wall in accordance to [R25-B]-II. This will limit the user from exposure to the mains electricity.

Despite the user not being meant to access hardware, current in the device itself is very low and does not pose a risk to human safety. The final RTAMS will be encased to protect electronic components from damage, but also the user from any potential danger from their exposure.

# 5. Sustainability

The AirTack team has made sustainability a priority in the development, implementation and eventual manufacturing of the RTAMS. The design is highly robust, modular and customizable which has implications down the line in the decision of whether or not to replace an air monitoring system or simply upgrade it with new components. Sensors can be added and taken away from the system by the end user with minimal hassle. New rooms can be added to the monitoring system simply by connection additional sensor modules to the communication system in the new room. Communication is done through existing power-lines, so construction and renovation is unnecessary. No new infrastructure is required. Construction and renovation typically result in a great deal of air pollution and material waste, so mitigating the need for this (also labour intensive) process is significant in terms of ensuring sustainability. Powering of the microcontrollers and sensors could have been done with battery power instead of powerline, but batteries have significant environmental impacts due to the nature of their production and disposal. The decision to use electrical power was based upon usability and sustainability, given that power in Vancouver is supplied through hydroelectricity.

Other considerations made include the choice of microcontrollers used in the RTAMS. The Arduino is manufactured in Italy, which has stricter manufacturing/labour laws than China where many other electronic components are made. This was a deliberate choice based on knowledge about sustainability and safety with regard to manufacturing practices in China. Arduinos are also re-usable for a multitude of engineering projects and several of them AirTack obtained for this project were recycled from previous Engineering Capstone groups through the ESSEF Fund and Parts Bank. Following the completion of the RTAMS, re-usable parts will be returned to the ESSEF Parts Bank for future use, contributing to the long-term sustainability of the capstone course at SFU. There are no parts of the proof-of-concept design that are not re-usable, so the RTAMS is a waste-free project. In fact, some of the sensors even do double-duty: the digital sensor for monitoring humidity also keeps track of temperature, for example.

Future iterations of the product beyond proof-of-concept will involve the manufacturing of PCB’s to minimize the use of discrete components, reducing waste and creating a more efficient system. The location AirTack will choose to manufacture PCB boards for the RTAMS will also depend heavily upon the sustainability of their business practices.

# 6. Conclusion

The design solutions discussed in this document will help AirTack Industries ensure the fulfillment of the –A and –B requirements outlined in the Functional Specification for the Real-Time Air Monitoring System (RTAMS). This document will serve as a set of guidelines for compliance with design requirements and functional specifications, providing clear goals and procedures to reach them. The development of the proof-of-concept RTAMS is well underway, and the AirTack team is on track for final product completion on April 1st, 2013 and presentation on April 22nd, 2013.

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