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AirMapper Design, Operation, and Maintenance Document

Sue Kimbrough and Rachelle Duvall
Center for Environmental Measurement and Modeling
Office of Research and Development
U.S. Environmental Protection Agency
Research Triangle Park, NC 27711

Stephen Krabbe and Shawn Henderson
Region 7
Environmental Sciences and Technology Division
U.S. Environmental Protection Agency
Kansas City, KS USA 66101

Tim McArthur
Alexander Korff
Parikshit Deshmukh
Jacobs Technology, Inc
Research Triangle Park, NC, USA 27709

Disclaimer

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List of Acronyms

%	percent
°C	degrees Centigrade
µA	microamp
µg/m^3	micrograms per cubic meter
AGC	automatic gain control
CO_2	Carbon Dioxide
CPU	central processing unit
CST	Central Standard Time
dB	decibel
DC	Direct Current
DQI	data quality indicator
DST	daylight savings time
EEPROM	Electronically Erasable Programmable Read-Only Memory
EPA	U.S. Environmental Protection Agency
g	gram
GB	gigabyte
GC	gas chromatograph
GPS	global positioning system
HHMM	hour minute (time format)
HTTP	Hyper Text Transfer Protocol
Hz	hertz
I/O	input/output
ICSP	in circuit serial programming
in	inches
IR	Infrared
KB	kilobyte
KC-TRAQS	Kansas City Transportation and Air Quality Study
KS	Kansas
L/min	liters per minute
LCD	liquid crystal display
LED	light-emitting diode
m/s	Meters per Second
mA	milliamp
mg/m^3	milligrams per cubic meter
MHz	megahertz
mL/min	milliliters per minute
mm	millimeter
MMDDYY	month day year (date format)
mph	Miles per Hour

ms	millisecond
mW	milliwatt
nA	nanoamp
NDIR	non-dispersive infrared
NiMH	nickle-metal hydride
OEM	Original Equipment Manufacturer
OPC	Optical Particle Counter (OPC-N2)
PM	particulate matter
PM_1	particulate matter < 1 micron in diameter
$PM_{2.5}$	particulate matter < 2.5 microns in diameter
PM_{10}	particulate matter < 10 microns in diameter
PWM	pulse-width modulation
QAPP	Quality Assurance Project Plan
RETIGO	Real Time Geospatial Data Viewer
RH	relative humidity
RTC	real-time clock
SCL	Serial Clock
SD	secure digital
sec	second
SMA	SubMiniature version A
SPI	serial peripheral interface
SRAM	Static Random-Access Memory
TFT	thin-film transistor
TTL	transistor-transistor logic
TXCO	temperature compensated crystal oscillator
UART	universal asynchronous receiver-transmitter
USB	universal serial bus
V	volts
VDC	volts direct current
VGA	variable gain amplifier
VID	vendor identification

1. Concept & Implementation

1.1 Introduction

The AirMapper is a portable air sensor designed to be used by researchers and citizen scientists to record air pollutant concentrations. The AirMapper is a small instrument case that can be carried or attached to a bicycle (not an EPA supplied item), and includes rechargeable battery power, global positioning system (GPS), optical particle sensor (PM_1/$PM_{2.5}$/PM_{10}), carbon dioxide (CO_2) sensor, accelerometer, noise sensor, and combined temperature and humidity sensor. A touch screen interface is also included with the AirMapper. Data is automatically recorded on a ~10 second interval to a text file, with a new file generated and stored to a microSD card each time the device is power-cycled. Citizen scientists or researchers can explore the various measurements on the touchscreen interface or download the data after their measurement period and view online using a free data explorer tool, called Real Time Geospatial Data Viewer (RETIGO) (www.epa.gov/retigo). RETIGO allows users to explore data interactively on a map and on multiple graphs. The types of data collected are shown in Table 1 below.

1.2 History and Development

Over the years, the U.S. Environmental Protection Agency (EPA) has been developing new ways for community members to learn about air quality in their neighborhood and participate in research. The original AirMapper plan was developed when EPA's Region 5 Office was working with the Jane Addams Elementary School in Chicago, IL to test new air pollution monitoring technologies designed for research and educational outreach purposes. The AirMapper is a new portable air sensor that EPA researchers developed to allow environmental conditions to be easily mapped by researchers and citizen scientists. In the initial developmental phase, the EPA pilot tested five AirMapper units with the Jane Addams school. The teachers and students designed their own field monitoring studies and took the AirMapper out on walking field trips, reviewed the data on RETIGO or wrote them in a science logbook.

The EPA research team then improved the AirMapper design in the summer of 2016 based on the feedback received and the AirMapper was used for further data collection as part of the KC-TRAQS study in Kansas City, KS.

1.3 AirMapper Environmental Conditions

Specifications for each environmental condition are found in **Error! Reference source not found.** and following subsections of this report. The air monitoring component of the AirMapper includes the measurement of PM and CO_2 in real-time (1-minute data). Other environmental sensors include temperature, humidity, and ambient noise levels. For the mapping component of the system a GPS sensor is needed.

Table 1. AirMapper Measurements

Measurement	Units	Saved to microSD?
PM <10µm	µg/m^3	Yes

Measurement	Units	Saved to microSD?
PM <2.5µm	µg/m^3	Yes
PM <1µm	µg/m^3	Yes
Carbon Dioxide (CO_2)	ppm	Yes
Temperature	°C	Yes
Relative Humidity	%RH	Yes
Noise	dB	Yes
GPS Latitude	Degrees/minutes	Yes
GPS Longitude	Degrees/minutes	Yes
GPS Speed	Mph	Yes
Accelerometer	Gs	Yes

2. AirMapper Components

2.1 Primary Instruments – Air Quality and Meteorological

Each AirMapper has an array of sensors that are used to record environmental conditions near the user and logged to a microSD card. A list of the measurements and instruments can be found in Table 1 and Table 2, respectively.

For additional information about each sensor, please refer to the user's manual in Appendix F. Detailed information about the system's operation related to each instrument can be found in Section 8.

Table 2. AirMapper Sensors, Sample Rate, Sample Interval.

Parameter	Sample Rate	Sample Interval	Instrument
$PM_{2.5}$	1 sec	Continuous	Alphasense OPC-N2 (Essex, United Kingdom)
CO2 Sensor			COZIR gas chromatography (GC)-0015 (Cumbernauld, Scotland)
Relative Humidity			Aosong Electronics Co., Ltd. DHT22 (Guangzhou)
Temperature			
Noise			Maxim Integrated, San Jose, CA
GPS (latitude/longitude)			Chang Hong Information Co., Ltd (Taiwan)

Parameter	Sample Rate	Sample Interval	Instrument
Accelerometer			GlobalTop Technology Inc. (Taiwan)
Clock			Maxim Integrated, San Jose, CA

2.1.1 Alphasense OPC-N2

The Alphasense OPC-N2 is used as a small particle monitor ($PM_{1.0}$, $PM_{2.5}$ and PM_{10}.) for the AirMapper system. The optical sensor uses a laser beam to detect particles from 0.38 to 17 microns in diameter and separates them into 16 bins. The sensor counts each bin and converts to a mass concentration based on internal algorithms. The sensor runs on 5 V and outputs SPI logic. Figure 1 is an image of the optical sensor. Specifications for the Alphasense OPC-N2 can be found in Table 3.

Figure 1. Alphasense OPC-N2

Table 3. Alphasense OPC-N2 Specifications

Specifications
Sampling Interval: 1-10 seconds Total Flow rate (typical): 1.2 L/min Sample Flow rate (typical): 220 mL/min Max particle count rate: 10.000 1/sec Coincidence probability: 0.84% at 106 particles/ L Digital Interface: SPI (Mode 1), USB 2.0 Data Storage: 16 GB micro SD USB VID: Ox04D8 USB PID: OxF3D5 Laser classification: Class 1 Weight: <105 g
Measurement
Measurement range: 0.38 to 17 microns, Spherical equivalent size (based on RI of1.5+i0) Size categorization (standard): 16 bins

Temperature range: -20-50 °C Humidity range: 0 to 95 (non-condensing) % rh (continuous) Detection limits: Minimum: 0.01 µg/m3 Maximum: 1,500 mg/m3
Electrical/Mechanical
Power input: 4.8-5.2 V DC Current Measurement mode: 175 mA Current non-Measurement mode: 95 mA (Laser at minimum power; fan off) Transient power on start-up: <5000 mW for 1 ms

2.1.2 CO_2 Meter Gas Chromatography-0015 CO_2 Sensor

The COZIR gas chromatography (GC)-0015 (Cumbernauld, Scotland) (Figure 2) is a 0-5% CO_2 monitor for ambient CO_2 detection. This monitor uses non-dispersive infrared (NDIR) to measure CO_2. It uses TTL serial output. The specifications for this sensor are included in Table 4 and an image of the sensor is shown in Figure 2.

Figure 2. GC-0015 Sensor

The manufacturer's specifications relevant to the AirMapper implementation are listed in Table 4 below.

Table 4. GC-0015 Sensor. Manufacturer's Specifications

Specifications
Measurement range: 5% to 100%

Ultra-low power: 3.3V, 3.5mW Peak current: 33mA Weight: 8 g Serial communications: 9600/8/1/N Analog voltage output proportional to CO2 concentration
CO_2 Measurement
Sensing Method: NDIR with Gold-plated optics Sample Method: Diffusion / Flow with tube adapter Measurement Range: 0-5%, Accuracy: ±70 ppm ± 5% of reading Response Time Filter: 4 secs to 2 mins (user configurable) refreshed 2x/sec.
Electrical/Mechanical
Power Input: 3.3 ±0.1 volt DC < 3.5 mW

2.1.3 Aosong DHT22

The Aosong Electronics Co., Ltd. DHT22 (Guangzhou) (Figure 3) is a low-cost temperature and humidity sensor used to monitor the conditions inside the instrument's enclosure. It runs on 5 V power and outputs at the TTL level logic.

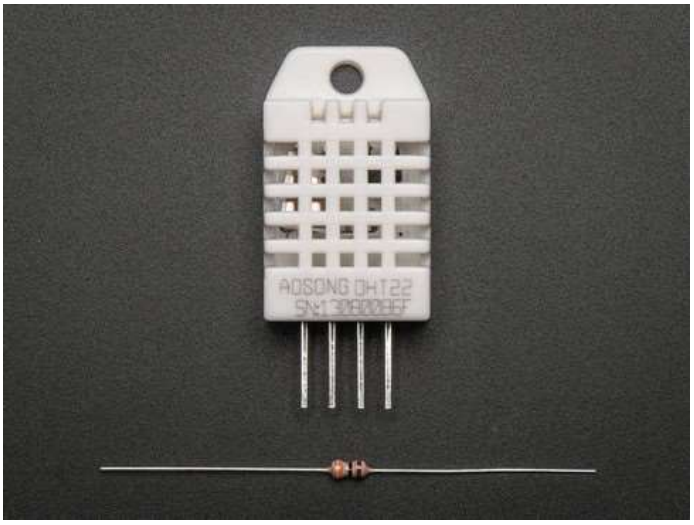

Figure 3. DHT22 Sensor

Table 5. Aosong DHT22 Temperature and Humidity Sensor Specifications

Specifications
Communications: Analog Analog voltage output proportional to humidity and temperature readings
Measurement

Measurement range: 0-100% humidity readings with 2 to 5% accuracy of the reported value -40 to 80 °C temperature readings ±0.5 °C accuracy
Electrical/Mechanical
Power: 3 to 5 V power and input/output (I/O) Peak current: 2.5 mA maximum current use during conversion (while requesting data)

2.1.4 Electret Microphone Amplifier - MAX9814 with Auto Gain Control

The MAX9814 is a microphone amplifier with automatic gain control (AGC) and low noise microphone bias. The device is designed with a low-noise preamplifier, variable gain amplifier (VGA), output amplifier, microphone-bias-voltage generator, and AGC control circuitry. The sensor can operate on a voltage range from 2.7- 5.5 V and has three gain set points. The sensor has a digital output. The sensor can be seen in Figure 4, and sensor specifications can be found in Table 6.

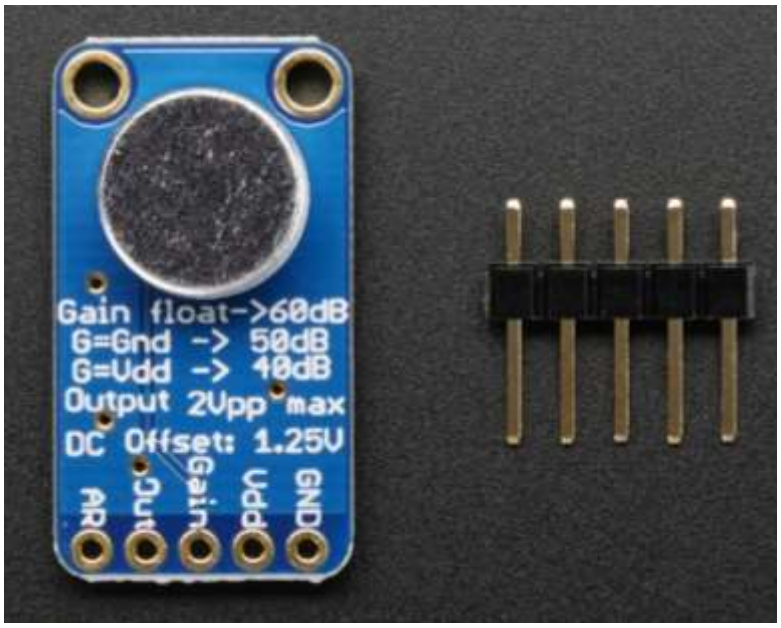

Figure 4. Electret Microphone Amplifier - MAX9814 with Auto Gain Control

Table 6. Electret Microphone Amplifier - MAX9814 with Auto Gain Control

Specifications
Automatic Gain Control (AGC) Three Gain Settings (40dB, 50dB, 60dB) Programmable Attack Time

Programmable Attack and Release Ratio
Measurement
Range: 0-60 dB
Electrical/Mechanical
Operating Voltage: 2.7 to 5.5 V Current Supply: 3.1 mA Peak Current: 6 mA

2.1.5 Ultimate GPS Breakout

Adafruit Ultimate GPS Breakout - 66 channel w/10 Hz s a GPS module designed using the MTK3339 chipset. The GPS module can use up to 22 satellites and 66 channels with the built-in antenna. The GPS module can be seen in Figure 5, and equipment specifications can be found in Table 7.

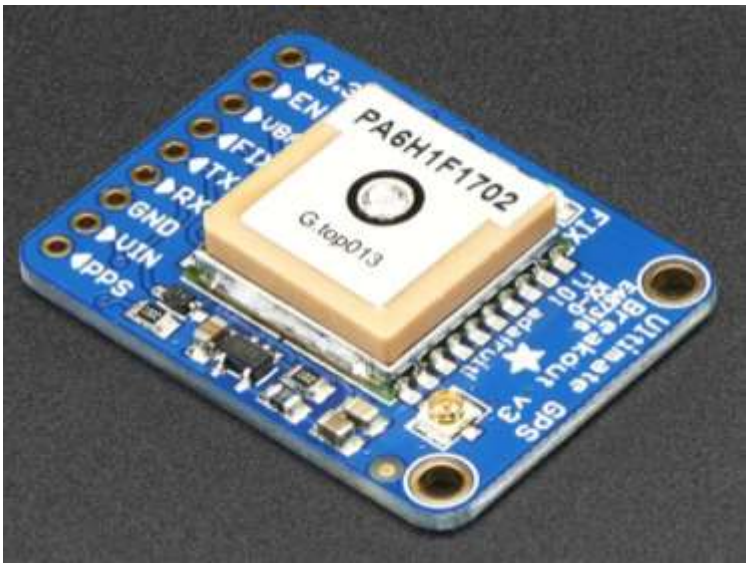

Figure 5. Adafruit Ultimate GPS Breakout

Table 7. Adafruit Ultimate GPS Breakout Specifications

Specifications
Satellites: 22 tracking, 66 searching Patch Antenna Size: 15mm x 15mm x 4mm Update rate: 1 to 10 Hz Output: NMEA 0183, 9600 baud default Up to 210 PRN channels

Jammer detection and reduction Multi-path detection and compensation
Measurement
Position Accuracy: < 3 meters (all GPS technology has about 3m accuracy) Velocity Accuracy: 0.1 meters/s Warm/cold start: 34 seconds Acquisition sensitivity: -145 dBm Tracking sensitivity: -165 dBm Maximum Velocity: 515m/s
Electrical/mechanical
Voltage: 3.0-5.5 V Current: 25 mA (tracking), 20 mA (navigation)

2.1.6 GPS Antenna - External Active Antenna

GPS Antenna - External Active Antenna - 3-5V 28dB 5 Meter SMA connects to the system GPS module to increase connectivity. The external antenna will create an additional 28 dB with an associated power draw of 10 mA. The external antenna can be seen in Figure 6, and equipment specifications can be found in Table 8.

Figure 6. GPS Antenna - External Active Antenna - 3-5V 28dB 5 Meter SMA

Table 8. GPS Antenna - External Active Antenna - 3-5V 28dB 5 Meter SMA

Specifications
Operating Frequency: T1 1575.42±1.023 MHz Output Impedance: 50 ohms Polarization: R.H.C.P. Bandwidth: 10 MHz min. @S11<=-10 dB Gain at 10° elevation: -1 dBic Typ. Axial Ratio: 3.0 dB Typ.

Measurement
Gain: 28 dB
Electrical/mechanical
Voltage: 2.3~5.5V Current 2.5V : 6.6mA Typical 3V : 8.6mA Typical 4V : 12.6mA Typical 5V : 16.6mA Typical

2.1.7 ADXL326 - 5V ready triple-axis accelerometer (+-16g analog out)

ADXL326 - 5V ready triple-axis accelerometer is an accelerometer with 3 analog outputs correlating to each axis (X,Y,Z) that is used by the AirMapper to record motion. The accelerometer was designed to interface with a 5V microcontroller and has low power draw. The external accelerometer can be seen in Figure 7, and equipment specifications can be found in Table 9.

Figure 7. ADXL326

Table 9. ADXL326 - 5V Ready Triple-Axis Accelerometer

Specifications
3-axis sensing Small, low profile package 4 mm × 4 mm × 1.45 mm LFCSP Minimum full-scale range: ±3 g
Measurement
X Axes Range: 0.5 Hz to 1600 Hz Y Axes Range: 0.5 Hz to 1600 Hz

Specifications
Z Axes Range: 0.5 Hz to 550 Hz
Electrical/mechanical
Voltage 1.8 to 3.6 V Current: 350 µA (typical)

2.1.8 ChronoDot - Ultra-Precise Real Time Clock

The AirMapper uses an Ardunio micrcrontroller that requires a real time clock (RTC) to hold time when not connected to an external server. The AirMapper uses the ChronoDot RTC as the internal RTC. The ChronoDot RTC is based on the DS3231 temperature compensated RTC (TCXO) and includes a CR1632 battery, with an estimated 8-year lifespan. The RTC can be seen in Figure 8, and equipment specifications can be found in Table 10.

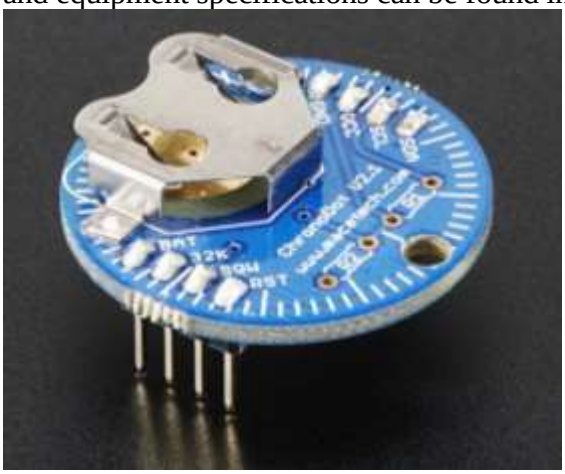

Figure 8. ChronoDot - Ultra-Precise Real Time Clock

Table 10. ChronoDot Specifications

Specifications
Length: 30.4mm/1.2in diameter Height: 14.1mm/0.55in Weight: 4 g Board/chip:I2C 7-bit address 0x68
Measurement
Drift: <1 minute per year
Electrical/mechanical
Voltage:2.3 to 5.5 V Current: 200µA (active), 840nA (timekeeping)

2.2 AirMapper Operational Components

2.2.1 LCD Display

The AirMapper was designed with to use a 3.5" TFT 320x480 - HXD8357D touchscreen display. The HXD8357D is a resistive touchscreen that can be operated in 8-bit or SPI modes. The touchscreen screen can be seen in Figure 9, and equipment specifications can be found in Table 11.

Figure 9. HXD8357D Display.

Table 11. 3.5" TFT 320x480 - HXD8357D touchscreen Specifications

Specifications
3.5" diagonal LCD TFT display 320x480 resolution 18-bit (262,000) color capable 8 bit digital interface, or SPI mode with 4 or 5 SPI data/control lines (4 pins minimum) Weight: Weight: 52g
Measurement
N/A
Electrical/mechanical
Voltage: 3.3-5 V

2.2.2 Arduino Uno

Arduino Uno is a microcontroller board based on the ATmega328P with 14 digital input/output pins, six analog inputs, a 16 MHz quartz crystal, a USB connection, a power jack, an ICSP header and a reset button. The Arduino Uno can be seen in Figure 10, and equipment specifications can be found in Table 12.

Figure 10. Arduino Uno

Table 12. Arduino Uno Specifications

Specifications
Digital I/O Pins: 14 (of which 6 provide PWM output) PWM Digital I/O Pins: 6 Analog Input Pins: 6 Flash Memory: 32 KB (ATmega328P) of which 0.5 KB used by bootloader SRAM: 2 KB (ATmega328P) EEPROM: 1 KB (ATmega328P) Clock Speed:16 MHz
Electrical/mechanical
Input Voltage: 7-12 V Operating Voltage: 5 V DC Current per I/O Pin: 20 mA DC Current for 3.3V Pin: 50 mA

2.2.3 Arduino Mega 2560 R3

The Arduino Mega 2560 is a microcontroller board based on the ATmega2560 with 54 digital input/output pins, 16 analog inputs, 4 UARTs (serial ports), a 16 MHz crystal oscillator, a USB connection, a power jack, an ICSP header, and a reset button. The Arduino Mega can be seen in Figure 11, and equipment specifications can be found in Table 13.

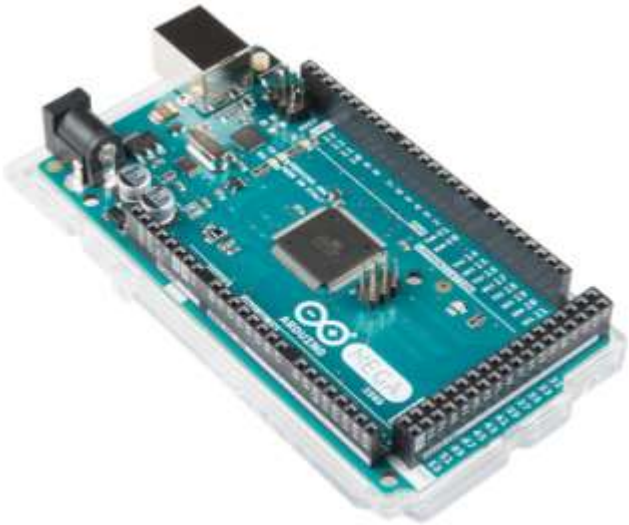

Figure 11. Arduino Mega 2560.

Table 13. Arduino Mega 2560 Specifications

Specifications
Digital I/O Pins: 54 (of which 15 provide PWM output) Analog Input Pins: 16 Flash Memory: 256 KB of which 8 KB used by bootloader SRAM: 8 KB EEPROM: 4 KB Clock Speed: 16 MHz LED BUILTIN: 13
Electrical/mechanical
Operating Voltage: 5V Input Voltage (recommended): 7-12V DC Current per I/O Pin: 20 mA DC Current for 3.3V Pin: 50 mA

2.2.4 Custom Printed Circuit Board

Due to limited space and a desire to keep the overall package small, many components of the AirMapper were placed atop the Mega in a stacked configuration. There are 2 stacked "shields" connected to the Mega. The first shield "Mega1" includes the GPS breakout and ChronoDot RTC. The second shield "Mega2" includes the Noise meter, DHT22, and CO_2 sensor onboard.

The "Uno1" shield includes the power input, regulators and distribution for the entire system, as well as the connector to the OPC.

These shields were made using custom printed circuit boards and the board layouts are shown in Figures 12-14 below.

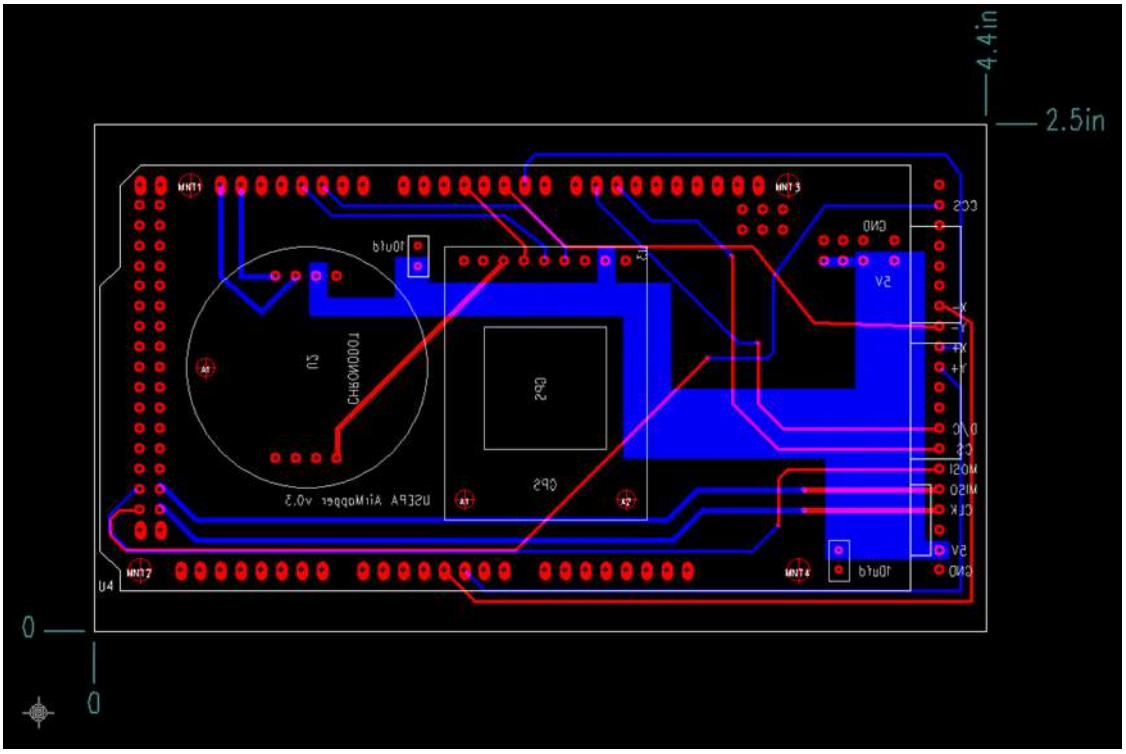

Figure 12. Mega1 Layout

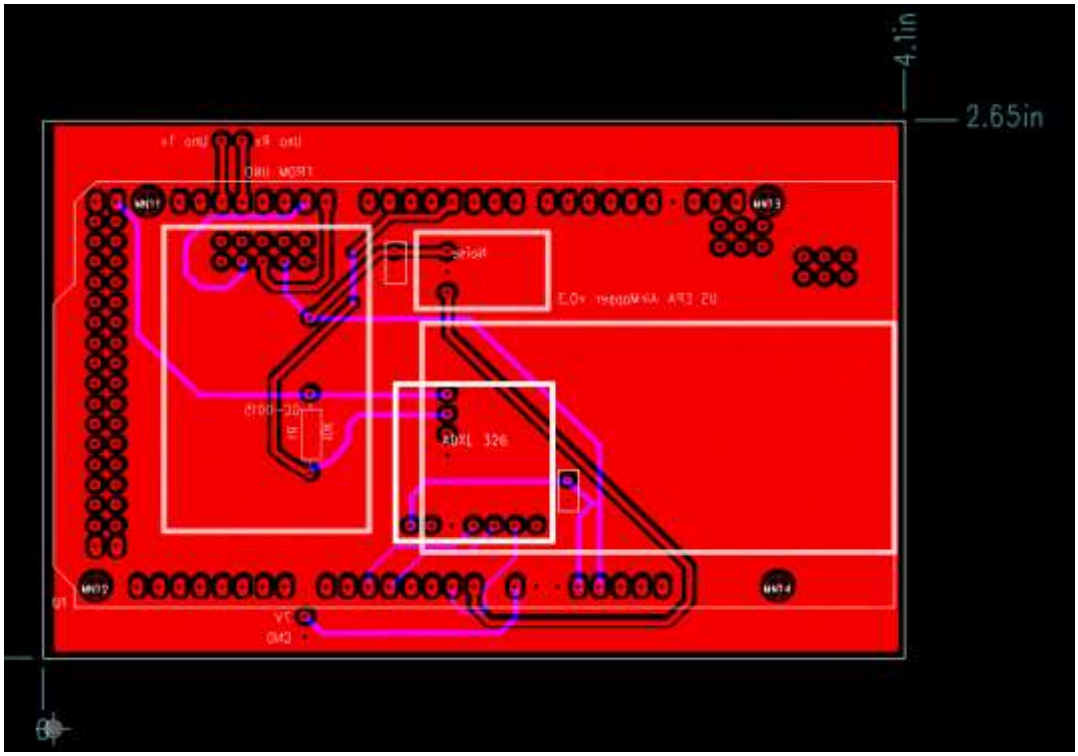

Figure 13. Mega2 Layout

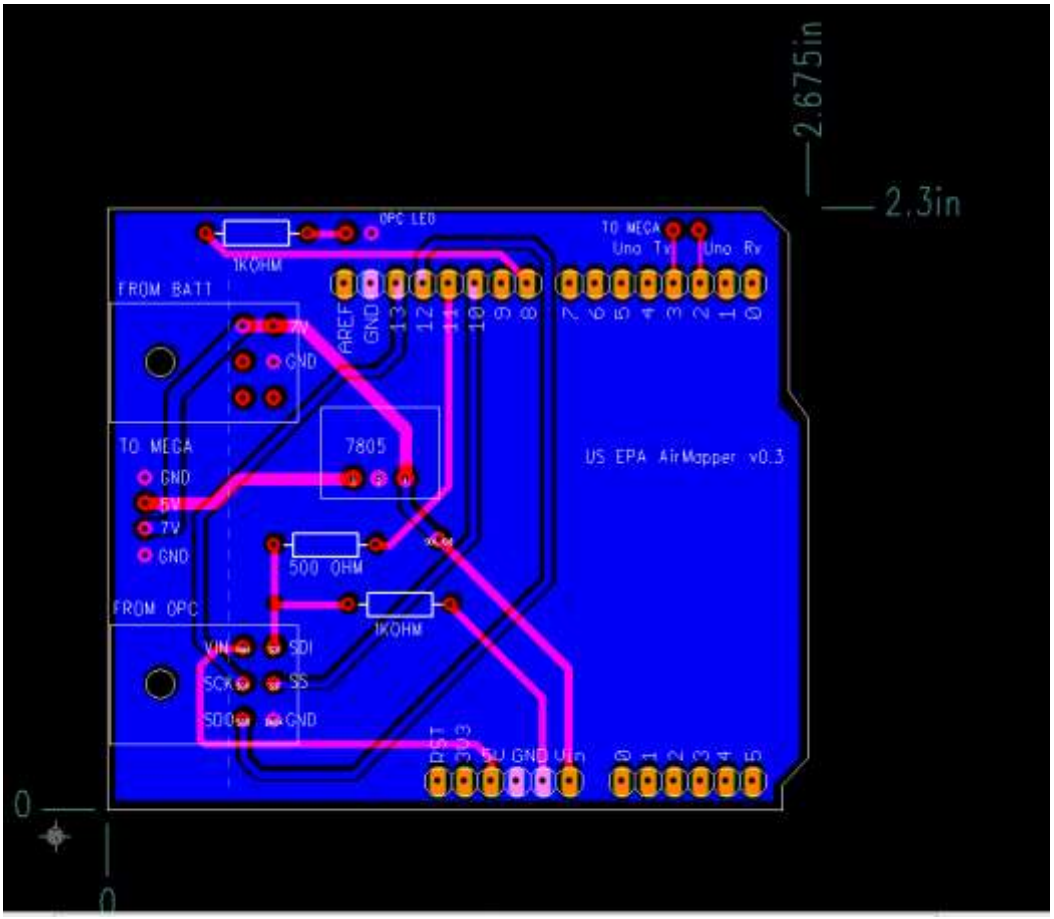

Figure 14. Uno1 Layout

2.2.5 microSD Card

The microSD card should be 4 GB or smaller due to limitations of the software libraries (Figure 15).

Figure 15. microSD card with adapter

2.3 Power System

2.3.1 Battery

The AirMapper uses a Venom 8.4V 5000mAh 7-Cell NiMH Battery Flat with Universal Plug for the power supply. This is a high current capacity battery pack that fits inside the footprint of the AirMapper enclosure. The battery pack can be seen in Figure 16.

Figure 16. NiMH Battery

2.3.2 Multi-Current Smart Charger

The battery pack is charged (while the unit is in the OFF position) by a Powerizer Smart Charger. This charger features fast charging, charge indicators, short circuit protection and UL listing. A custom molded plug was made to fit the AirMapper so that it can only be plugged in in the correct orientation. An image of the battery charger can be seen in Figure 17.

Figure 17. Battery Charger

2.3.3 Noctua A-Series Cooling Fan

Noctua A-Series Cooling Fan A Noctua A-Series Cooling Fan (NF-A4x10 FLX) is used to circulate air flow in the AirMapper unit. An image of the fan can be seen in Figure 18.

Figure 18. Cooling Fan

3. Instrument Blocks

3.1 Overview

The Arduino Mega 2560 microcontroller (Figure 11), based on the ATmega2560, is the main processor for the AirMapper module. The module is capable of polling the instruments, receiving and formatting the returned string, monitoring the enclosure temperatures, controlling the ventilation fan and formatting the data. The Arduino Mega 2560 provides a compact, low-power, and flexible platform for data processing and wireless communication. The Mega 2560 was chosen over the other Arduino microcontrollers primarily because of the 4 UARTS (hardware serial ports) that are used to communicate with the air monitoring instruments.

In addition to the Mega, the OPC-N2 instrument is designed to operate on a separate SPI bus. To accomplish this, the AirMapper design has a separate Arduino Uno (Figure 10) which extracts data from the OPC-N2 and relays the data to the Arduino Mega 2560.

3.2 Arduino Code

Please see Appendix B for the sensor pod's code.

4. Physical Design

4.1 Original

The first iteration of the AirMapper was developed at the EPA-RTP. Multiple iterations have been developed over the years, but the internal components stay mostly the same with minor wiring, positioning, and mounting changes to accommodate different case designs.

4.2 Internal Components

The internal operating units are the same for each AirMapper variant. The Arduino shields stack, Figures 19-21, to save space and reduce redundant wiring. Some sensors and switches still need to be wired individually from the stacked boards.

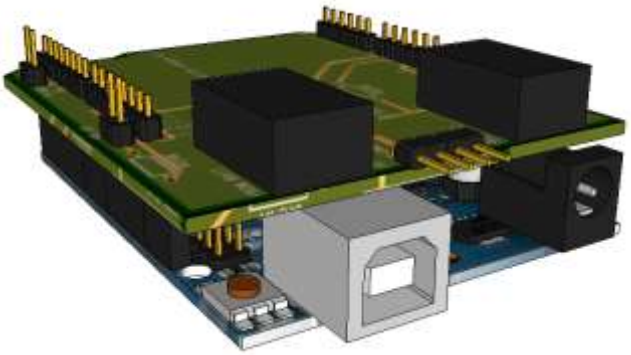

Figure 19. Uno w/ Shield Attached

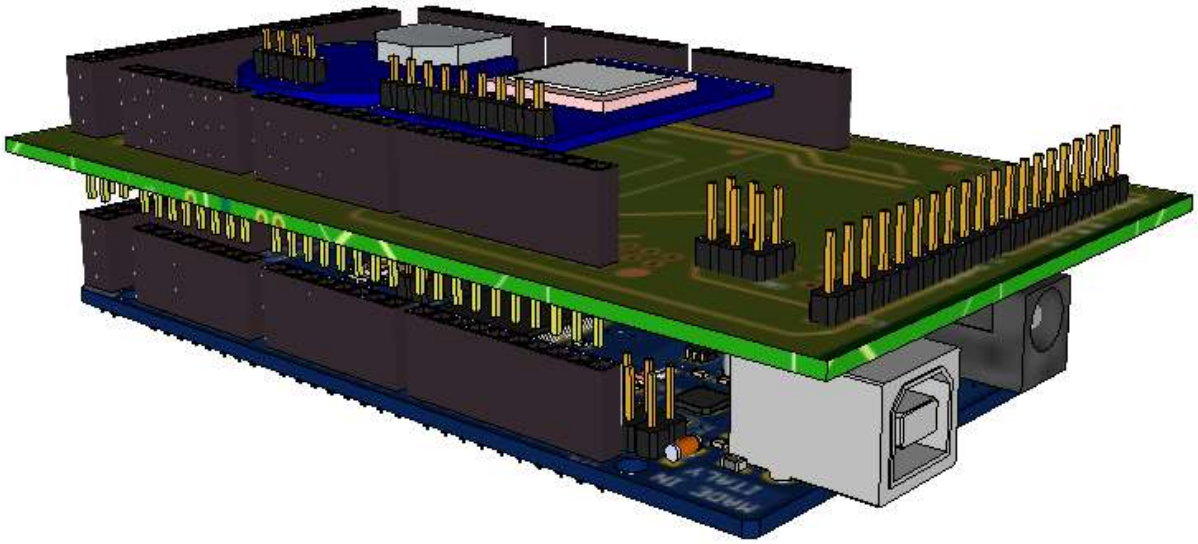

Figure 20. Mega w/ Mega1 Shield Attached

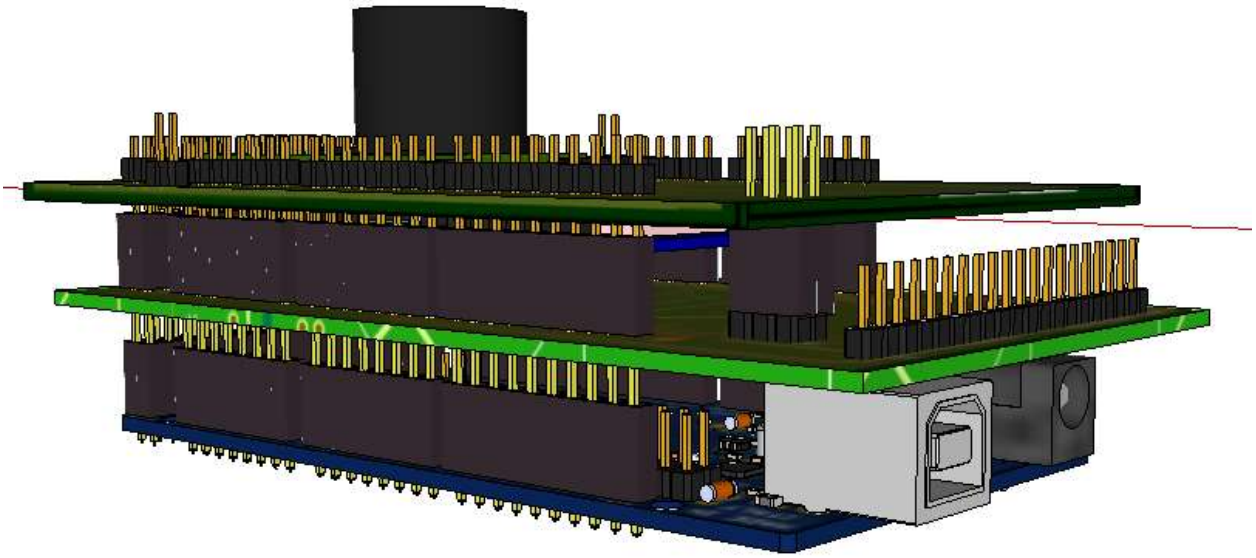

Figure 21. Fully assembled Mega

4.3 External Components

4.3.1 Internal Case

Custom metal cases were fabricated in -house to create a strong backbone for the AirMapper system. Holes and mounting plates were machined to meet system component footprints. The digital file for the internal case is included in the Appendix A. A digital sketch of the internal case is included in Figure 22.

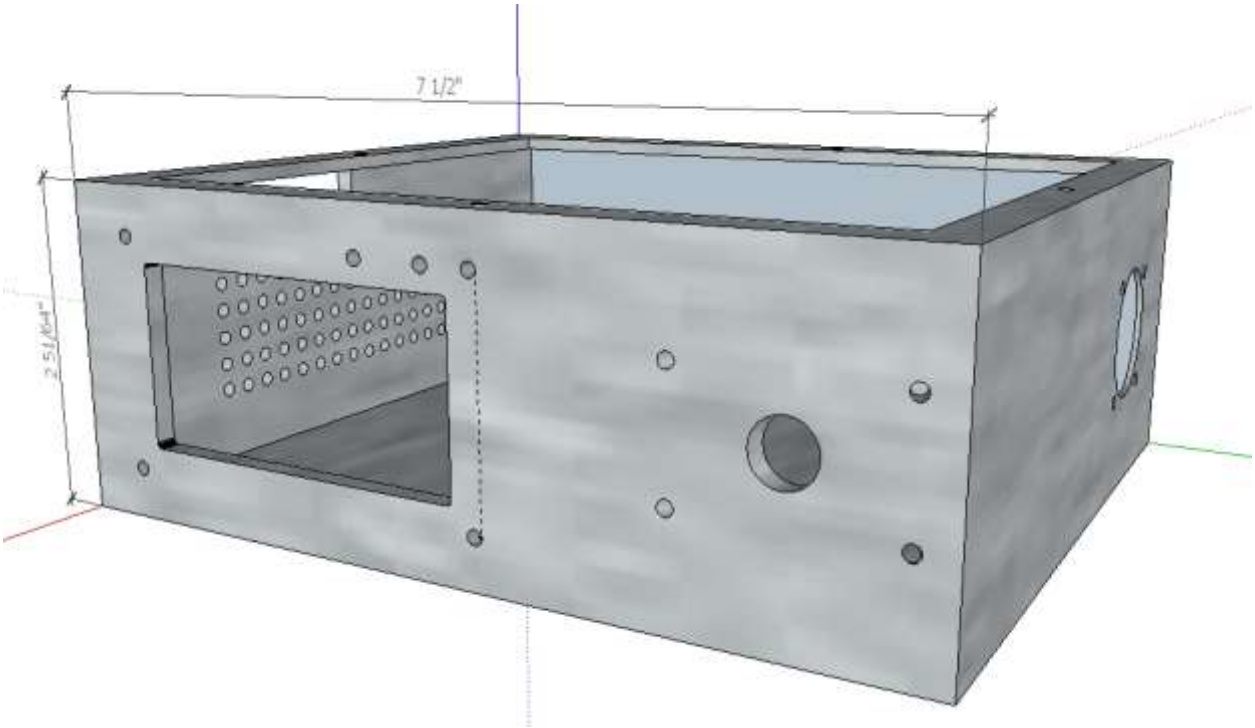

Figure 22. Internal Case

4.3.2 External Case

A Roswheel bicycle case is used as the external case for the AirMapper system. The Roswheel bag needed some modifications to fit the components and allow for access points. An image of the external case can be found in Figure 23.

Figure 23. Roswheel Bike Bag

4.3.3 Other Miscellaneous Components

Sensor covers were 3D printed to protect the external sensors from mechanical interferences. Examples of the covers can be found in Figure 24.

Figure 24. Exterior Sensor Guards

4.4 Variation 1

4.4.1 Internal Component Layout/Design

The main component layout is unchanged from the original with the exception of the battery. The battery was removed from the internal case and affixed to the outside with a metal plate covering it. The internal enclosure was changed to plastic from the original metal. A fuse was added to the power system to help with compliance.

4.5 Variation 2 Internal Component Layout/Design

The component layout in the 3D printed case variant is very much the same as the original variant with the addition of the fuse as in the first variant. The temperature and humidity sensor were replaced with an AM2302, which is the same sensor, but with a manufacturer's case and wiring. The location of the microphone was moved to the front of the case near the screen and the GPS antenna was moved to the top of the case.

4.5.1 External 3-D Printed Case

The 3-D printed case of this variant was printed with PLA material. It was designed to minimize the catching of the device and straps on the user's clothing or bags/backpacks.

5. Data Quality Indicator Goals

Table 14 lists the data quality indicators (DQIs) applied to the measurements collected from the AirMapper. These checks are not performed by the Arduino but are performed by the end-user after data collection. Additional or modified DQIs may be needed depending on the instrument selection or site conditions. These DQIs were determined based upon instrument documentation and additional communication with the manufacturer.

Table 14. Data Quality Indicators

Parameter	Analysis Method	Measurement	Criteria
$PM_{2.5}$	Alphasense OPC-N2	1. Average PM concentration	1. Post-data collection processing and quality assurance
CO_2	COZIR GC-0015	1. CO_2 concentration	1. CO_2>400 ppm, CO_2<1000 ppm
RH, Temp, and BP	Asong DHT22	1. Temp 2. RH	1. Temp >-20 °C 2. RH>=0%, RH<=100%
Noise	Electret Microphone Amplifier - MAX9814	Noise in decibels	1. Ability to show "louder vs. quieter".

Parameter	Analysis Method	Measurement	Criteria
GPS	Ultimate GPS Breakout - 66 channel w/10 Hz updates	Latitude and longitude	1. Within 3 meters
Accelerometer	ADXL326 - 5V ready triple-axis accelerometer		1. Post-data collection processing and quality assurance

6. Calibrations

Some sensors in the AirMapper need calibration.

The Alphasense OPC does its own simulated two-point calibration upon startup by turning its fan off and turning the laser emitter on to simulate no PM then simulating the maximum amount of PM that can be sensed by turning off the laser emitter and turning the fan on.

The CO_2 sensor has on-board calibration procedures, which used a software approach to calibrate to ambient air at 405ppm. This can be done by going into the settings menu and selecting “cali” button.

The temperature/humidity sensor (DHT) cannot be calibrated.

The microphone could theoretically be calibrated by measuring the voltage produced at several known ambient noise levels and creating a correction factor that is hard coded for each unit; however, this approach proved to be ineffective and all volume data should be considered inaccurate.

7. Troubleshooting

The AirMapper is a complex system involving many parts and custom code to decipher and deliver information from components not specifically designed to work together.

7.1 Required tools

Before attempting to diagnose and fix any issue with an AirMapper, you must have the following tools available:

Means of grounding – In order to prevent damage to the system. Your body must be grounded at all times when accessing system components (see Section 7.1.1).

General tools – A set of small-medium screwdrivers (Phillips and flathead). pliers, cutters (light gauge).

Multi-meter – A general purpose multi-meter is sufficient. The meter should be capable of reading DC voltages up to 20V and resistances up to 10K. An audible tone for connectivity is recommended.

7.1.1 Grounding (Recommended)

Before accessing system components, the operator must ground their body to the system ground to prevent damage to the system.

Figure 25. Wrist Strap Grounding System

A wrist strap like the one shown in Figure 25. Wrist Strap Grounding System allows the operator to physically connect their wrist to the grounding rod of the bench. Simply place the wrist strap (conductive side down to your skin) on your wrist and tighten appropriately. Next, connect the supplied cable from the wrist strap to clamp. Finally, clamp the wrist strap to a secure ground. Inside the sensor pod, all earth grounds are connected with green wiring or bare copper. Find one ground near your working area (within reach) and connect the clamp.

7.2 Failure Scenarios

Table 15 below lists the most common failure scenarios and directs you to specific sections to learn more about possible causes and their resolutions. Please note these sections do not list all possible causes. The purpose of this information is to assist a qualified technician in diagnosing potential failure points.

Also note that the majority of code-related issues are outside of the scope of this troubleshooting section. It is assumed that the station was working upon installation and no major changes have been made to the code since that time.

For all troubleshooting issues, the first step if possible is to check the serial monitor output for any statement relevant to your problem. The serial monitor may provide information to help you identify the problem more quickly.

Table 15. Common Issues

Instrument	Issue	Section
Entire System	Instruments not on. Powered down.	7.2.1
	Instrument on. Sensor data displaying, but not logging to SD card	7.2.2
Alphasense OPC-N2	Instrument running, but data is not posting.	7.2.3
	Readings are inaccurate.	7.2.4
CO_2 Sensor	No data from sensor.	7.2.5
	Readings are inaccurate.	7.2.6
Temperature/Humidity Sensor.	No data from sensor.	7.2.7
	Readings are inaccurate.	7.2.8
Noise	No data from sensor.	7.2.9
	Readings are inaccurate.	7.2.10
GPS	No data from sensor.	7.2.11
	Readings are inaccurate.	7.2.12

7.2.1 AirMapper Not Operating. Powered down.

Observation: The entire system appears offline; no instruments are audible.

Check system voltage. There should be 8.4 V at the battery.

Warning: There is a dangerous amount of current at the battery. Be very cautious.

Table 16. Troubleshoot Checklist

~8.4V Voltage at Battery?	Instruments On?	Possible Cause	Next Steps/Solution
No	No	Dead battery or misconfigured/mis-wired power system.	Check configuration. Replace battery. Charge battery

7.2.2 AirMapper Operating. No data being logged to microSD card.

Observation: I hear instruments running but nothing is logging.

Table 17. MicroSD Troubleshooting

Is Data Logging to microSD card?	Instruments Logging	Possible Cause	Next Steps/Solution
No	No	Bad SD connection	Check seating. Replace Screen if not fixed.
		Faulty SD card	Replace SD card
		Floating ground in system.	Check all wiring.

7.2.3 Alphasense OPC-N2. Data is not LOGGING.

Observation: The sensor is not logging to microSD card.

Test1: Is data displaying to the screen?

Test2: Check Uno serial output from USB monitor. Is OPC outputting data?

Table 18. Alphasense OPC-N2 Troubleshooting

Test 1	Test 2	Possible Cause	Next Steps/Solution
Yes	Yes	See 7.2.2	See 7.2.2
No	Yes	Uno to Mega connection issue	Check serial connection between
No	No	Bad connection	Check wire and connector
		Bad sensor	Replace OPC
		Bad Uno/Code	Replace Uno

7.2.4 Alphasense OPC-N2. Data is inaccurate.

Observation: The data appears incorrect.

Step 1: Calibrate *There is no calibration, just restarting so it does its own test

Step 2: Check connections or replace the sensor.

7.2.5 CO_2 Sensor. Data is not LOGGING.

Observation: The sensor is not logging to microSD card.

Test1: Check Mega serial output from USB monitor. Is the sensor outputting data?

Table 19. CO2 Sensor Troubleshooting

Test 1	Possible Cause	Next steps/Solution
Yes	See 7.2.2	See 7.2.2
No	Bad connection	Check soldering
	Bad sensor	Replace sensor
	Bad Mega	Replace Mega

7.2.6 CO_2 Sensor. Readings are inaccurate.

Observation: The data appears incorrect.

Step 1: Calibrate.

Step 2: Check connections.

7.2.7 Temperature/Humidity Sensor. Data is not LOGGING

Observation: The sensor is not logging to microSD card.

Test1: Check Mega serial output from USB monitor. Is the sensor outputting data?

Table 20. Temperature/Humidity Sensor Troubleshooting

Test 1	Possible Cause	Next steps/Solution
Yes	See 7.2.2	See 7.2.2
No	Bad connection	Check wiring and soldering
	Bad sensor	Replace sensor
	Bad Mega	Replace Mega

7.2.8 Temperature/Humidity Sensor. Readings are inaccurate.

Observation: The data appears incorrect.

Step 1: Calibrate.

7.2.9 Noise Sensor. Data is not LOGGING

Observation: The sensor is not logging to microSD card.

Test1: Check Mega serial output from USB monitor. Is the sensor outputting data?

Table 21. Noise Sensor Troubleshooting

Test 1	Possible Cause	Next steps/Solution
Yes	See 7.2.2	See 7.2.2
No	Bad connection	Check wire and soldering
	Bad sensor	Replace sensor
	Bad Mega	Replace Mega

7.2.10 Noise. Readings are inaccurate.

Observation: The data appears incorrect.

Step 1: Calibrate.

7.2.11 GPS Sensor. Data is not LOGGING

Observation: The sensor is not logging to microSD card.

Test1: Check Mega serial output from USB monitor. Is the sensor outputting data?

Test2: Check the fix LED on the GPS breakout board (off, solid on, blinking).

Table 22. GPS Sensor Troubleshooting

Test 1	Test 2	Possible Cause	Next Steps/Solution
No	Off	GPS power issue	Check for power. Check connections and wiring
No	Blinking	No GPS location fix	Move to better service (outside). Wait up to ten minutes. Check antenna wiring.
No	On	Communication issue between sensor and CPU	Check stacked board connections. Replace sensor or replace Mega.
Yes	On	See 7.2.2	See 7.2.2

7.2.12 GPS Sensor. Readings are inaccurate.

Observation: The data appears incorrect.

Step 1: Purchase a more accurate sensor.

8. Operations

8.1 Getting Started

The AirMapper is powered by an 8.4V 5000 mAh rechargeable NiMH battery pack. The unit is capable of running 3+ hours under normal data collection conditions when fully charged. To operate the unit, simply slide the switch on top of the unit to the ON position. The switch is circled in Figure 26.

Figure 26. Power Switch Location

8.1.1 Collecting Data

The AirMapper will automatically collect data once the unit is powered on and the SD card is inserted.

The SD card is shown in Figure 27. The holder is located inside the front pocket of the unit, behind the screen. The top side of the SD card holder has a raised outline of an SD card on its face. The SD card should be inserted with the top face up (writing up). When correctly inserted, the SD card should click securely into place.

If the SD card is not inserted on startup, the Home screen will notify you of the error. If you see this error, the unit is not saving data to SD.

Figure 27. microSD Card Holder

The touchscreen navigation has no effect on the SD card data collection. The user is free to navigate through the different screens, and all data are collected regardless of the screen the user is currently viewing.

Variations of the AirMapper have the SD card connected directly to the back of the LCD screen.

8.1.2 Menu Navigation

To navigate through the AirMapper's electronic menu pages, simply press the button for the desired screen. The "home" button located on most screens will return you to the home screen. From here, you can browse to other screens. The home screen is shown in Figure 28. **The touchscreen does not operate on an interrupt. This means that when the unit is processing some more demanding functions, the user's touch may not be immediately sensed. In order to navigate easily, keep the button depressed until the unit responds. This may take up to a second.**

Figure 28. Home Screen

8.1.3 Charging the Battery

As stated earlier in this section, the unit can run 3+ hours on a fully charged battery. It is advised to fully charge the battery before operating the unit. The unit comes with a TENERGY universal smart charger and the user is advised to use the charger provided with the unit rather than a substitute to ensure safe recharge conditions. This charger will charge the battery in approximately 4 hours @ 1.0 amp. Always charge the battery at 1.0 amp when possible. Quicker charging is available with the 2.0 amp selection on the battery charger but should not be used frequently as it can reduce overall battery life.

Charging the battery should always be performed by an adult. It is not necessary to oversee charging but is advised when possible. Always plug the connector into the unit before plugging the cord into the wall outlet and ensure the unit is not positioned near highly flammable materials (e.g. paper).

To charge the battery, plug the pin connector into the unit. The connector is keyed such that it is only possible to plug it in correctly. The connector should slide in easily when positioned correctly. When plugging the connector in, spin the connector until it slides into the adapter on the unit. From this point, screw the connector in until it is tight. Next, ensure that the switch on the TENERGY smart charger is in the “1.0A” position (1.0 amp) and then plug the transformer into any standard (120V AC) wall outlet. This is your normal residential house outlet. The charger pin connector and the adapter on the unit are pictured below (Figures 29 and 30).

Figure 29. Charger Connecter Plugged into Unit Adapter	**Figure 30. Charging Unit.**

Once the smart charger is plugged into the wall, the LED in the top left corner should be lit solid red. If the battery has been over-drained the charger LED may initially blink red, but it should become solid red after a few minutes (< 10 minutes). When the battery has fully charged, the LED will turn solid green. If the LED blinks green, the charger has not recognized a connected battery. Attempt to reconnect the adapter, if the problem persists there may be an issue with the AirMapper, the charger, or some other component associated with the AirMapper.

The charger includes a temperature sensor that is connected to the internal thermocouple to prevent overheating during charging. If overheating is detected, the charging system automatically turns off the charger. An overheating recharge unit should not be used again until the cause of the failure has been determined.

8.2 Screen Descriptions

8.2.1 PM Screen

Figure 31. PM Screen

The PM screen displays PM size distribution data (Figure 31). Counts are graphed for 16 differently sized bins, nominally labeled on the X-axis. The actual bin sizes vary in range. It must be stated that these bin counts are only estimates and the true size distribution of the aerosol being measured cannot be verified. Counts up to 40 are graphed on-screen. The screen automatically updates periodically. If a particular bin has more than 40 counts, a small red cap is placed over the bar, indicating the actual value is off-scale. Return to the Home Screen via the Home button.

The PM Screen is resource-intensive. While on this screen, the touchscreen response may be slower than usual.

The PM inlet is circled in Figure 32. It is important that at no time is this inlet blocked by clothing or other material that might restrict airflow into the AirMapper.

Figure 32. PM Inlet

8.2.2 CO_2 Screen

The CO_2 screen displays (Figure 33) the current CO_2 value in ppm. The "meter" dynamically updates as the value is periodically refreshed by the software. Longer bars and more intense colors indicate higher, less healthy ranges of ambient CO_2 levels. During initial previews with students, it is possible to show how the AirMapper responds to CO_2 reading by breathing into the PM inlet. This is obviously discouraged during scientific data collection.

Figure 33. CO_2 Screen

8.2.3 All Data Screen

The All Data screen displays (Figure 34) all data on one easy to view screen. It is recommended to use this screen if using the AirMapper on a bicycle or when in motion.

Figure 34. All Data Screen

8.2.4 GPS Screen

The GPS screen displays current GPS data, including fix status, longitude, latitude, and speed in mph (Figure 35). The GPS fix is also indicated on all screens by the blue marker located next to the current time and date. The GPS may not be able to get a fix indoors or in bad weather. Some functions require a GPS fix. These will be discussed in the Settings screen section (8.3). The screen refreshes periodically. If no location is defined after 5 minutes, the user may move to an outdoor location to improve satellite signal capture.

Figure 35. GPS Screen

8.2.5 Temp/RH Screen

The Temp/RH screen displays the current temperature and RH from the DHT22 sensor (Figure 36). The screen refreshes periodically. Note the temperature and humidity values will update more rapidly when on the Temp/RH screen. This visual feature does NOT change the true interval that data are collected to the SD card.

The temperature sensor provides only a general estimate of the current condition and some variation in what the AirMapper reports and other temperature sensors you may encounter might be evident due to the sensor location within the device. EPA hopes to improve upon the temperature sensor accuracy in any future version of the AirMapper.

Figure 36. Temperature/RH Screen

8.2.6 Noise Screen

The Noise screen provides a general estimate of noise level in dB. A “meter” automatically updates as the value is refreshed by the software. Longer bars and more intense colors indicate higher, noise levels (Figure 37).

Figure 37. Noise Screen

8.3 Settings

8.3.1 Password Screen

When “Set.” is first pressed from the Home screen, the user will be presented with the screen shown in Figure 38. A password is required to access the Settings page. The level 1 password for all user-configurable settings is determined by the software code and the end-user. Input the password using the number pad. As each value is entered, the numbers will be reported in the bottom right corner. If an incorrect password number is entered, the user will be returned to the Home screen. Once the correct password is entered, the user will access the Settings.

Figure 38. Settings (Password Screen)

8.3.2 Settings Screen

Figure 39. Settings (Settings) Screen

The user-configurable settings can be input from this screen (Figure 39). “set TZ” is used to change the time zone (Figure 40). The unit defaults to CST. The screen display automatically adjusts to daylight savings time (DST) based on the current date. If not using the unit in central time, the timezone can be adjusted by using the touchscreen to select your timezone (Figures 40-42). **It is necessary to obtain a GPS fix to use this function. If the unit does not currently have a fix, an error will be displayed, and the function will not be available.** “Time” is used to change the current time. Time is automatically set using GPS input five minutes after the unit is turned on. If the unit does not have a fix at this time, the procedure fails and a message is displayed. Even so, the time is usually accurate due to the RTC’s onboard battery. The time should rarely need to be set manually. If a manual setting is required the user **MUST** input the time in standard time, not DST, using the number pad to input the time in HHMM 24hr format (Figure 41). “Date” is used to change the current date. The date should be correct due to the real time clock onboard battery. If a manual setting is required, use the number pad to input the date in MMDDYY format (Figure 42). A local cell phone time stamp is a very accurate means of establishing local time.

“Set RTC” is used to set the time to the current GPS information. This can be used if the automatic adjustment five minutes after startup failed but you have since acquired a fix. Simply press the button and the function runs. “DST on/off” is used to manually set Daylight Savings Time on or off for the display time. If DST is on, this button will appear as “DST off”. If DST is off, this button will appear as “DST on”.

Figure 40. Input Time Zone

Figure 41. Input Time

Figure 42. Input Date

8.4 Home Screen

The Home screen is used as a base for navigation to other screens (Figure 43). The blue GPS marker next to the time and date indicate a GPS fix has been acquired. If this does not appear on the screen, there is no GPS fix. The LED in the bottom left corner of the front pocket indicates whether or not the OPC-N2 sensor is communicating properly. If this LED is flashing, communication with the OPC has not yet been established. If the LED is solid (red), the OPC communication is functioning properly. The time and date in the upper-right hand corner displays the date and current time (automatically adjusted for DST using the date).

Figure 43. Home Screen

8.5 Uploading Data

To access the data, simply press in on the SD card inside the SD card holder and release. This will release the SD card. The unit comes with a USB/micro SD card converter. Once the SD card is removed, slide the micro-SD card out of the adapter and slide it into the USB adapter. The micro-SD card should be inserted writing side facing the writing on the USB adapter. This USB adapter can be plugged into your PC to access the files and upload to RETIGO. Visit the RETIGO upload page to upload your data. For help using RETIGO, see the tutorial.

9. Maintenance

9.1 Overview

There is no recommended preventative maintenance for this system. Replace components as needed.

9.2 Accessing the System

Before accessing system components, the operator must ground their body to the system ground to prevent damage to the system. See Section 7.1.1 and Figure 25 for details.

Appendix A. Drawings and Schematics

Appendix A includes all drawings and schematics for existing systems. All schematics and drawings in Appendix A will be either (.pdf) or (.html) and will be readily accessible to any user with Adobe and web-browsing capabilities.

Appendix A is provided in separate files.

Appendix B. Code

Appendix B is provided in separate files.

Appendix C. Parts List

Appendix C is provided in separate files.

- Parts List

Appendix D. Circuit Board Designs

Appendix D is provided in a separate file. See “read me” file.

- Circuit Board Design Files

Appendix E. Photos

Appendix E is provided in a separate file.

- Appendix D - Photos.pdf

Appendix F. User Manuals

Appendix F is provided as web links.

File Name	Manual
http://www.alphasense.com/index.php/air/ Please contact the manufacturer for the manual.	Alphasense OPC-N2 Operating Manual Alphasense Ltd
https://www.co2meter.com/products/cozir-wr-5-percent-co2-sensor Please contact the manufacturer for the manual.	GSS Sensor User's Manual www.co2meters.com GC-0015
https://datasheets.maximintegrated.com/en/ds/MAX9814.pdf Please contact the manufacturer for the manual.	Electret Microphone Amplifier - MAX9814
https://cdn-learn.adafruit.com/downloads/pdf/dht.pdf Please contact the manufacturer for the manual.	Asong DHT22 Relative Humidity, Temperature Sensor
https://cdn-learn.adafruit.com/downloads/pdf/adafruit-ultimate-gps.pdf?timestamp=1585659813 Please contact the manufacturer for the manual.	GPS board (V3)
https://cdn-shop.adafruit.com/datasheets/GPS-01.pdf Please contact the manufacturer for the manual.	GPS Active Antenna
https://www.analog.com/media/en/technical-documentation/data-sheets/ADXL326.pdf Please contact the manufacturer for the manual.	2.1.7 ADXL326 - 5V ready triple-axis accelerometer
https://datasheets.maximintegrated.com/en/ds/DS3231-DS3231S.pdf Please contact the manufacturer for the manual.	ChronoDot Real-Time Clock
https://cdn-shop.adafruit.com/datasheets/HX8357-D_DS_April2012.pdf	3.5" TFT 320x480 - LCD Touchscreen Display
https://store.arduino.cc/usa/arduino-uno-rev3 Please contact the manufacturer for the manual.	Ardunio Uno
https://store.arduino.cc/usa/mega-2560-r3 Please contact the manufacturer for the manual.	Arduino Mega 2560 R3