Design and Integration of an Indoor Plume Experimental Setup

A Major Qualifying Project Report

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in Aerospace Engineering

by

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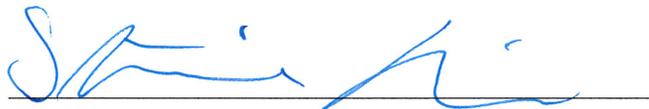
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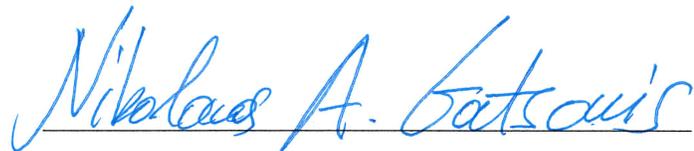
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Abstract

This project involves the design and integration of a carbon dioxide plume generation system, a plume detection system, and a data acquisitions system for indoor plume experiments. The design of these systems is aided by 3d simulations of carbon dioxide plumes from a stationary source and a known release rate. The plume generation system is designed using SolidWorks and consists of a stand with a pressurized tank, a regulator, a solenoid valve, a mass flow controller and a nozzle. The plume detection system is designed with SolidWorks and consists of carbon dioxide sensors and wind speed sensors placed on a horizontal arm that can be repositioned vertically on a stand. The systems are controlled using LabVIEW implemented on a data acquisition computer stand.

Acknowledgements

We would like to thank Professor Gatsonis for providing us with guidance and support throughout this entire project. We would also like to thank Tatiana Egorova a Post Doctoral Fellow in Professor Gatsonis' Lab for her assistance with the simulations performed in the project.

Authorship

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1. Introduction

The estimation of plumes from accidental or intentional releases of harmful gases in the atmosphere can provide an opportunity to prevent or minimize their impacts or identify and track the source of the gas. Research has been conducted at Worcester Polytechnic Institute (WPI) in order to develop algorithms and methods with which to estimate and model gas plumes in the atmosphere. The main objective of this research is to develop and integrate codes onto unmanned aerial systems (UAS's) to execute these algorithms while flying through gas plumes in the atmosphere, then model these plumes in real time so that the center of operations may obtain useful data with which they can formulate a plan to neutralize or lessen the negative effects of the toxic gas [Egorova et al, 2016; Court et al, 2013]. In order to evaluate the effectiveness of this estimation technique, a ground-based demonstration using a ground gas source and an unmanned terrain system (UTS) has been underway (NAG1501, 2015; MAD1501, 2015). The goal of this Major Qualifying Project (MQP) is to design, fabricate, and integrate an experimental setup shown in Figure 1.1 that includes a plume generation system, a plume detection system, and all associated electronics. The system generates a gas plume of a known size, then measures the concentration of gas at different locations in a test area to provide model validation. This plume generation system will be used in ground experiments with a UTS equipped with gas sensors (MAD1601, 2016) as shown in Fig 1.2, which will take concentration measurements throughout the plume and attempt to locate the source of gas.
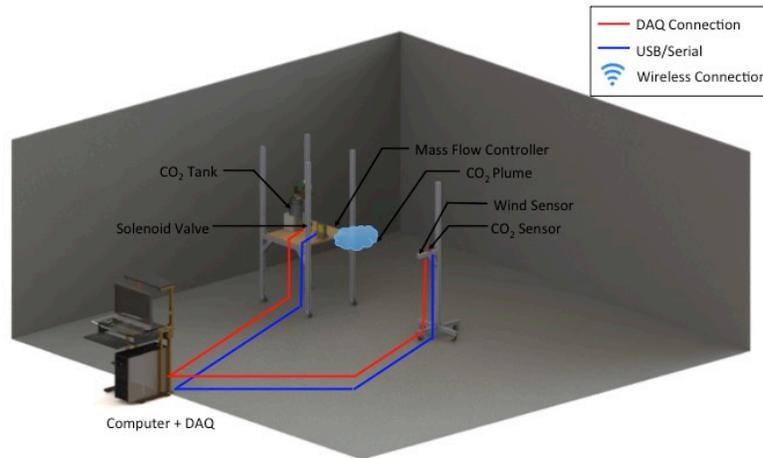
Figure 1.1 Plume Generation System and Stationary Plume Detection Stand.
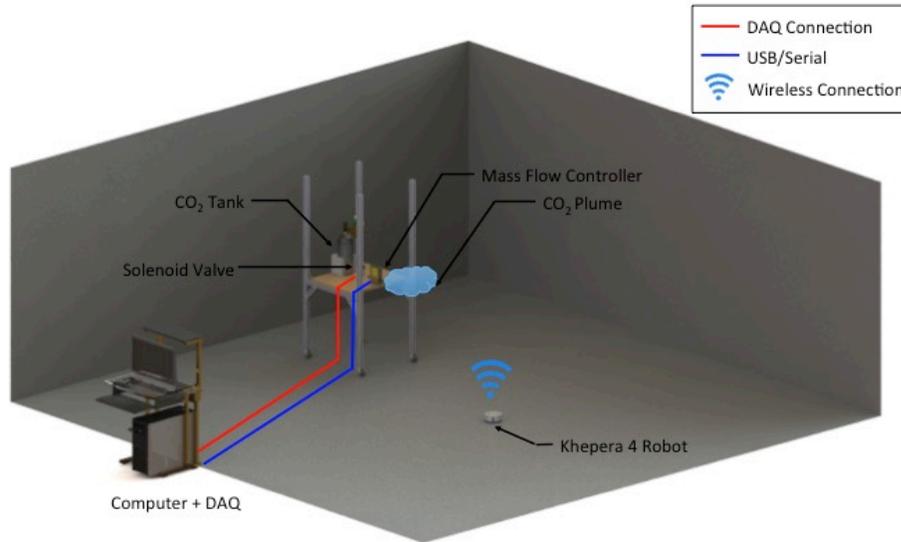
Figure 1.2. Plume Generation System with Mobile Gas-Sensing Robot.

1.1   Background and Literature Review

In NAG1501 (2015) the MQP group designed the prototypes designed the prototypes of a CO_2 plume generation system and a plume detection system. Plume simulations were also performed with different sets of CO_2 mass flow rates into the test area assumed to be under atmospheric conditions, not indoor conditions. Also, NAG1501 generated a list of components for the plume generation and detection system, and developed computer aided design (CAD) models of these systems. This MQP expands considerably on the NAG1501 (2015) by redesigning the plume generation and detection systems, performing simulations under indoor conditions, and proceeding in the realization of the design. This project expands on the literary research of a previous MQP group (NAG1501, 2015) in several areas, specifically the diffusivity of carbon dioxide at room temperature ambient conditions, and wind speed measurement through micro hot wire anemometry.

In order to effectively model and predict the plume dispersion from a gaseous source in indoor or outdoor environments, it is necessary to obtain the coefficient of diffusivity, or diffusion coefficient, D (m^2/s). The diffusion coefficient provides a measure of how a mass of gas diffuses across a unit surface over a unit time in a background gas. The diffusion coefficient

depends, among other factors, on the gas's molar weight and size, temperature, and pressure. This project exclusively studies the diffusion of carbon dioxide gas in indoor air. Several experiments have been conducted to observe the diffusive properties and behaviors of carbon dioxide (CO_2) gas in air. A study conducted by W. J. Massman (2004) analyzes variations in historical data relating to the diffusivity coefficient of CO_2 in air as well as other gases, as different researchers have historically claimed different values for this property. After several methods of regression analysis, Massman determined that out of all the gases researched, carbon dioxide actually had relatively low variability and it was determined that the coefficient of diffusivity for CO_2 in air was $0.1381x10^{-4}$ m^2/s at standard temperature and pressure.

Modeling or estimation of plume dispersion requires also knowledge of the ambient wind conditions. While no plume simulations in windy environments were conducted in this project, further research will require windy simulations as well as instruments to measure local wind velocity. Literature search into different wind-measuring methods and instruments is necessary for subsequent experimentation with the Plume Generation System and Plume Detection System. Our research shows that there are numerous methods of measuring flow velocity that employ either direct or indirect measurement. Methods employing direct measurement include mechanical in which forces and moments applied by the stream affect a mechanical system, and marker tracing in which markers in the flow itself are monitored and traced. Though these systems can be effective, they may not be practical for a particular experiment.

Other indirect methods can be employed that take into account relations between flow properties and the flow velocity, where one or several properties of the flow will be observed and the velocity will be inferred or calculated based on the acquired information. The primary categories of indirect methods include the frequency-shift, thermal, and pressure difference. Frequency shift measures the Doppler effect of the flow, thermal measures the heat transfer of the flow, and pressure difference measures the static and total pressures of the flow and the surrounding area (Tavoularis, 2005). Investigation of these methods and their individual advantages yielded that the most practical category to employ in our experiments is the thermal anemometry.

Hot-wire anemometry, the most common form of thermal anemometry, is based on the use of a thin metal wire typically composed of a platinum alloy that is suspended between two prongs and heated to a known level (Tavoularis, 2005). Once the flow contacts the wire, the wire is

cooled and the difference in resistance between the original known level and the measured resistance level provides enough information to calculate the flow velocity acting on the anemometer.

Hot wire anemometry was used in this Plume Generation and Detection experiment due to its lightweight and sensitive nature. Two identical sensors were procured for use in the NAG1601 (2016) and in the MAD1601 (2016) projects.

1.2   Objectives and Approach

The goal of this project is to design, fabricate, and integrate a PGS, a PDS and a Data Acquisition System (DAQ) that can be used in plume experiments. The plumes will be generated in an indoor environment with a 5m X 5m surface area centered about a stationary CO_2 source with a given mass release rate until they reach steady state. The objectives and approach are as follows:

- Perform plume simulations using a code that solves numerically the 3D advection-diffusion equation from a stationary source CO_2 source to guide the design of the PGS and PDS. These simulations will determine the range of mass flow rates for the PGS that produces plumes detectable by sensors of the PDS and eventually the UTS; the plumes must be above ambient levels of about 400 ppm but cannot exceed 50,000 ppm and become toxic to those conducting the experiments.
- Select and purchase the components for the PGS to include a pressurized CO_2 gas tank, a mass flow controller, a solenoid valve, an air pressure regulator, and framing.
- Design the PGS using SolidWorks.
- Select and purchase the components for the PDS to include a CO_2 sensor, a wind sensor, and framing.
- Design the PDS using SolidWorks
- Fabricate frames and stands for both PGS and PDS
- Generate and compile LabVIEW code to power and control the mass flow controller, the solenoid valve of the PGS, and the CO_2 sensors and wind sensor in the PDS. Compile onto one LabVIEW front panel so they can all be controlled and monitored at once through the computer and DAQ box.
- Select and purchase a computer stand to house the computer workstation and DAQ equipment, which is to be stored outside of the experimental setup.

2. Design of the Plume Generation System and the Plume Estimation System

This chapter describes the design and integration of the plume generation and detection hardware, including hardware stand design, instrument and sensor choices, and plume simulations.

2.1   Plume Generation System and Plume Detection System

This experiment requires stands for both the plume generation and the plume detection equipment (Figure 2.1). The Plume Generation System (PGS) consists of the carbon dioxide tank and regulator valve, a solenoid valve, a mass flow controller, and a diffusion nozzle. The Plume Detection System (PDS) consists of the wind sensor and CO_2 sensors. The stands needed to have variable height to test the plume dispersal at multiple z-coordinates. They also needed to be easily moveable so as to estimate the plumes from multiple distances. To achieve this, two frames were designed out of 80-20 T-slot. The platform of the plume generation stand and the sensor beam on the plume estimation stand are secured to the upright beams via several McMaster-Carr T-slot bracers that can be easily loosened and slid along the upright beams for quick change of height. To allow ease of mobility, both stands are fitted with casters, which can be locked when stationary to prevent unwanted movement during the experiment.

Figure 2.1 Plume Generation (Left) and Plume Detection (Right) Stands.

2.2   Plume Simulations from a Stationary CO_2 Source

The plume experiments will be conducted in an indoor environment of about 5m x 5m centered around the CO_2 source as shown in Figure 2.3.
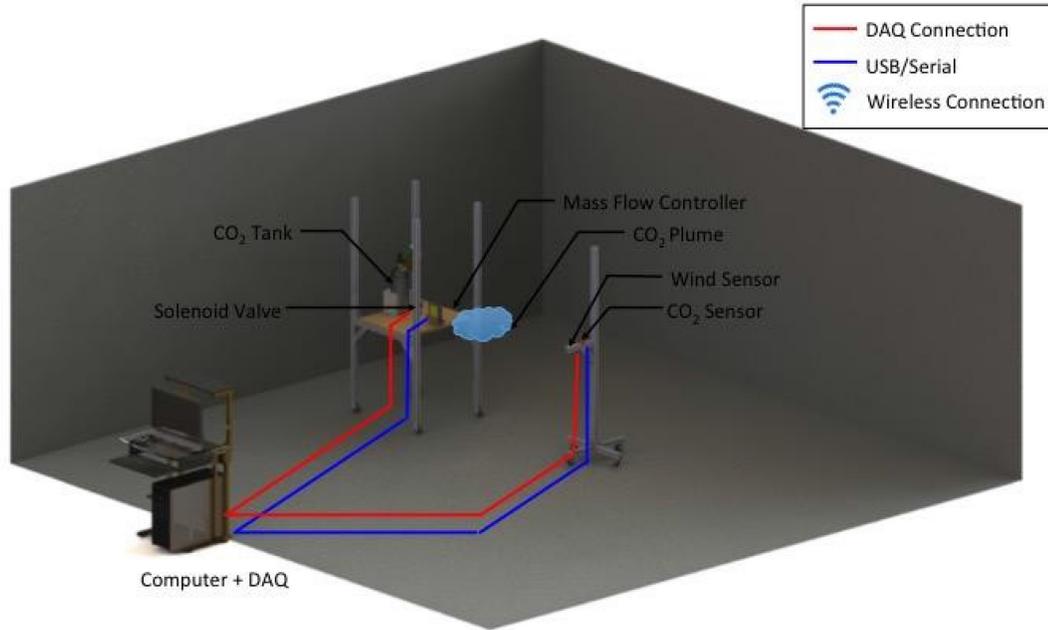
Figure 2.3: Plume Generation and Detection Experiment Setup.

In order to select the volume of the gas source, the flow meter, the release mass flow rate of the CO_2, the nozzle of the PGS as well as the sensors on the PDS, we performed plume simulations from a stationary CO_2 source. The code to perform these simulations is discussed in Egorova et al. (2015) and solves numerically the advection-diffusion equation

$$\frac{\partial c}{\partial t} + u\frac{\partial c}{\partial x} + v\frac{\partial c}{\partial y} + w\frac{\partial c}{\partial z} = D\left(\frac{\partial^2 c}{\partial x^2} + \frac{\partial^2 c}{\partial y^2} + \frac{\partial^2 c}{\partial z}\right)(1)$$

In the above, c is the concentration of the CO2, u, v, and w are the background wind velocities in the x, y, z directions, and D is the diffusivity of CO2 (Arya, 1999).

Several plume simulations were conducted for a stationary CO_2 source in an indoor environment. The domain in all simulations is discretized with a grid as shown in Figure 2.4. The

domain of our test area is (X, Y, Z) = (5, 5, 2)m with the number of volumes measured of (100,100,40). This means that there are 20 samples taken every meter in all three dimensions, with every sample volume having dimensions (dX, dY,dZ) = (.05, .05, .05)m.
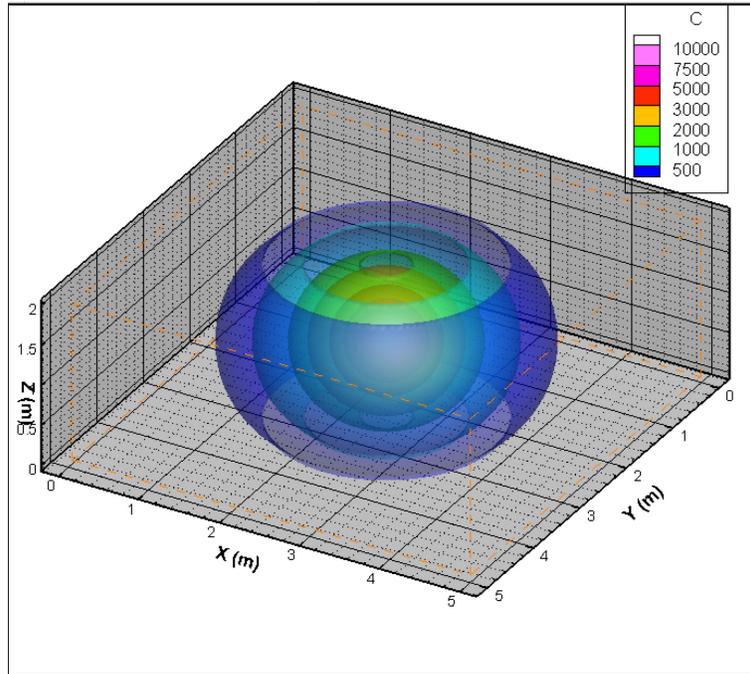
Figure 2.4 Plume Generated in Gridded Test Area.

The CO_2 source is placed in the center of the computational domain at X = 2.5m, Y = 2.5m, and Z = 1m, with a fixed mass flow rate. The simulation requires as inputs the position of the source, the release rate of CO_2 (kg/s), the domain size, boundary conditions, and time-step for the numerical integration. The input parameters are shown in Table 1. All simulations were run for up to 180 seconds. The goal of these runs was to determine the range of mass flow rates that produce a plume detected by our sensors, without becoming toxic to those conducting the experiment. The code outputs the concentration at each grid point at any time. The simulation data is imported into Tecplot and several plots are generated.

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Table 1: Plume Simulation parameters.

Simulation	Mass Flow Rate (mg/s)	Release Time (s)	Time Step (s)
1	100	180	0.05
2	250	180	0.05
3	500	180	0.05
4	750	180	0.05

2.3   Simulation Results and Discussion

Simulation 1

Figure 2.5 shows the CO_2 concentration at t = 180s on an (X,Y,Z=1m) plane for Simulation 1. The greatest concentration of 12600 ppm is at the location of the source, while the lowest concentration is marked in blue.
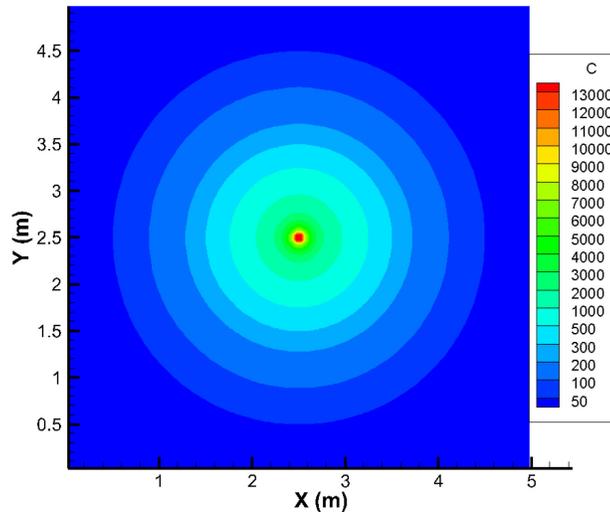
Figure 2.5 CO2 concentration at t = 180s for Run 1.

Figure 2.6 shows the concentration of CO_2 in ppm at t = 180s along the X axis through Y = 2.5 m on the (X, Y, Z = 1 m) plane. The maximum is close to 13,000 ppm which exceeds the toxic levels, but for an area of a few centimeters around the source.
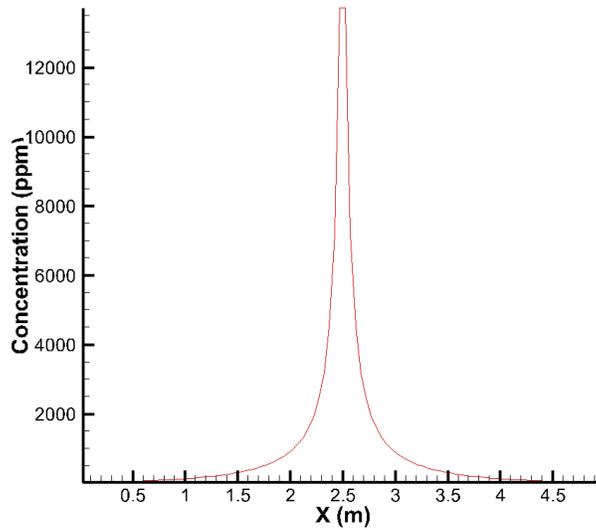
Figure 2.6 CO$_2$ concentration at t = 180s for Run 1.

Figure 2.7 shows the CO$_2$ concentration in ppm, as a function of time from t = 0 s to the end of the simulation at t = 180s. The concentration is plotted at various radial distances from the source on the (X,Y,Z = 1 m) plane. Since the gas is diffusing evenly in every direction, given there is no wind, these graphs represent the concentration of CO$_2$ at the specified distance away from the source in any direction. The concertation levels for this flow rate are very low for the PDS experiments.
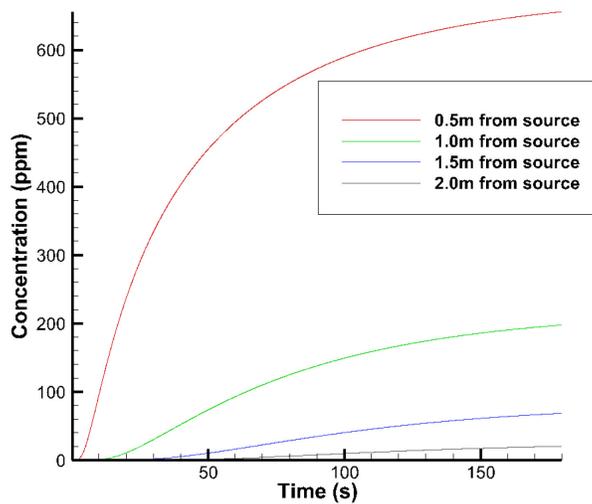
Figure 2.7 CO$_2$ concentration at t = 180s for Run 1.

Simulation 2

Figure 2.8 shows the CO_2 concentration at t = 180s on an (X,Y,Z=1m) for Simulation 2. The greatest concentration of 32,000ppm is at the location of the source, while the lowest concentration is marked in blue.
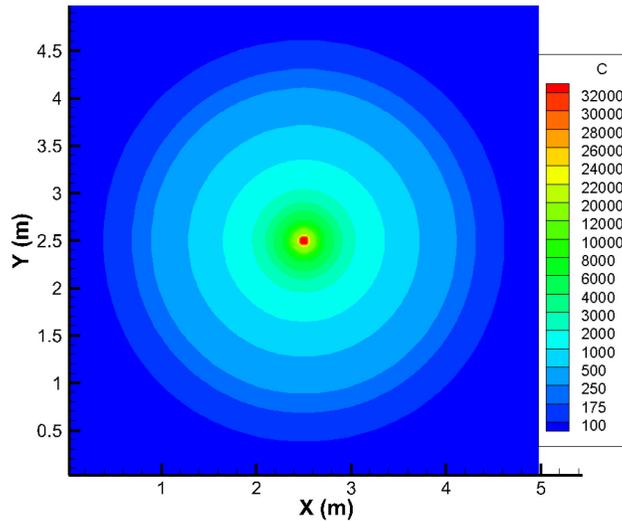
Figure 2.8 CO_2 concentration at t = 180s for Run 2.

Figure 2.9 shows the concentration of CO_2 in ppm at t = 180s along the X axis through Y = 2.5 m on the (X, Y, Z = 1m) plane. The maximum is close to 34,000 ppm which exceed the toxic levels, but for an area of a few centimeters around the source.
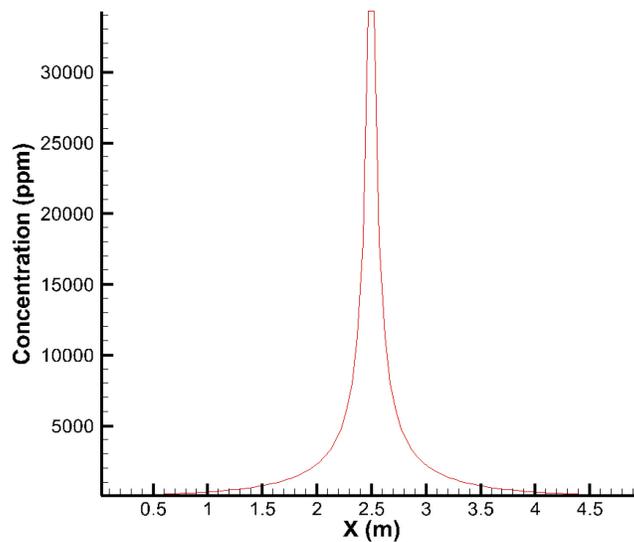
Figure 2.9 CO_2 concentration at t = 180s for Run 2.

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Figure 2.10 shows the CO_2 concentration in ppm, as a function of time from t = 0 s to the end of the simulation at t = 180s. The concentration is plotted at various radial distances from the source on the (X,Y,Z = 1 m) plane. Since the gas is diffusing evenly in every direction, given there is no wind, these graphs represent the concentration of CO_2 at the specified distance away from the source in any direction.
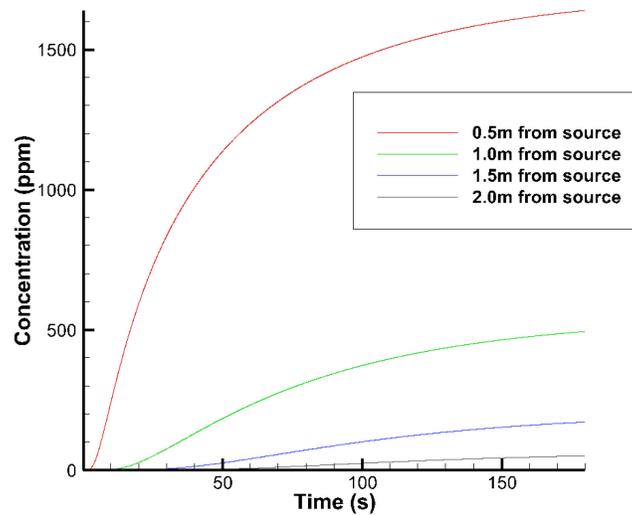
Figure 2.10 CO_2 concentration at t = 180s for Run 2.

Simulation 2 produced a CO_2 plume with a mass flow rate of 250 mg/s from the source. Compared with Simulation 1, Simulation 2 produced a plume profile that can be more accurately measured by our COZIR Ambient 5k CO_2 gas sensors. At 0.5 m away from the source the concentration of CO_2 is around 1600 ppm, and at 1.0 m distance the concentration is approximately 500 ppm. However, at 1.5 m and 2.0 m away from the source, the concentration is less than 200 ppm, which is a more difficult range for our sensors to accurately measure. Increasing the mass flow rate once again will likely yield a more ideal plume profile for the experiment.

Simulation 3

Figure 2.11 shows the CO_2 concentration at t = 180s on an (X,Y,Z=1m) for Simulation 3. The greatest concentration of 65,000ppm is at the location of the source, while the lowest concentration is marked in blue.
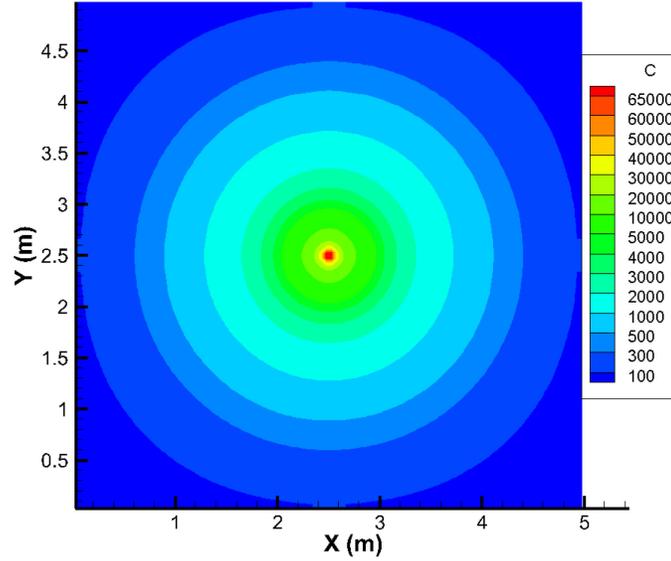
Figure 2.11 CO_2 concentration at t = 180s for Run 3.

Figure 2.12 shows the concentration of CO_2 in ppm at t = 180s along the X axis through Y = 2.5 m on the (X, Y, Z = 1m) plane. The maximum is close to 65,000 ppm which exceed the toxic levels, but for an area of a few centimeters around the source.
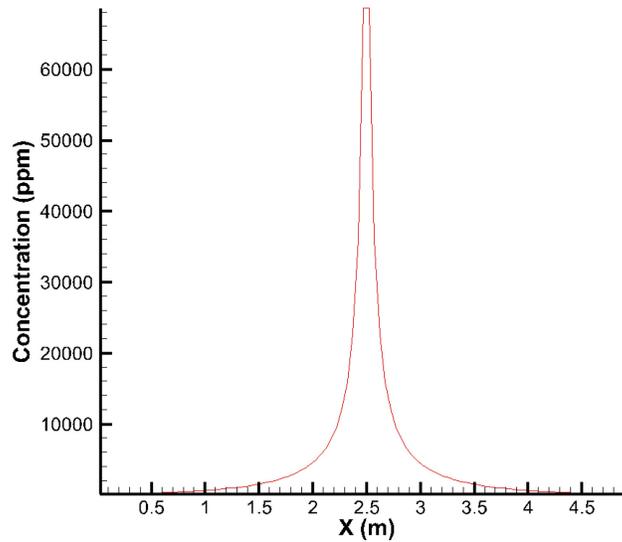
Figure 2.12 CO_2 concentration at t = 180s for Run 3.

Figure 2.13 shows the CO_2 concentration in ppm, as a function of time from $t = 0$ s to the end of the simulation at $t = 180$s. The concentration is plotted at various radial distances from the source on the (X,Y,Z = 1 m) plane. Since the gas is diffusing evenly in every direction, given there is no wind, these graphs represent the concentration of CO_2 at the specified distance away from the source in any direction.
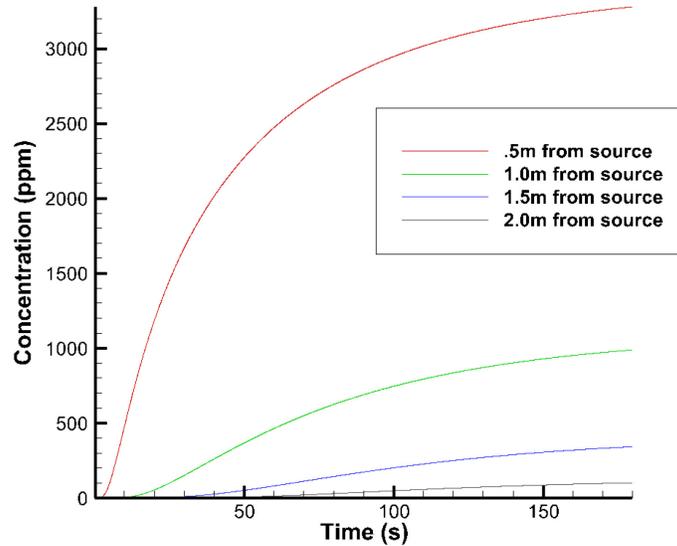
Figure 2.13 CO_2 concentration at t = 180s for Run 3.

Simulation 3 produced a CO_2 plume with a mass flow rate of 500 mg/s from the source. The plume profile generated seems like an ideal profile for our CO_2 sensors. At 0.5m from the source the concentration is 3300ppm, at 1.0m from the source the concentration is 1000ppm, at 1.5m from the source the concentration is 400ppm, and at 2.0m from the source, the concentration is 100ppm. This plume profile represents an ideal set of concentrations to measure with the PDS.

Simulation 4

Figure 2.14 shows the CO_2 concentration at t = 180s on an (X,Y,Z=1m) for Simulation 4. The greatest concentration of 100,000ppm is at the location of the source, while the lowest concentration is marked in blue.
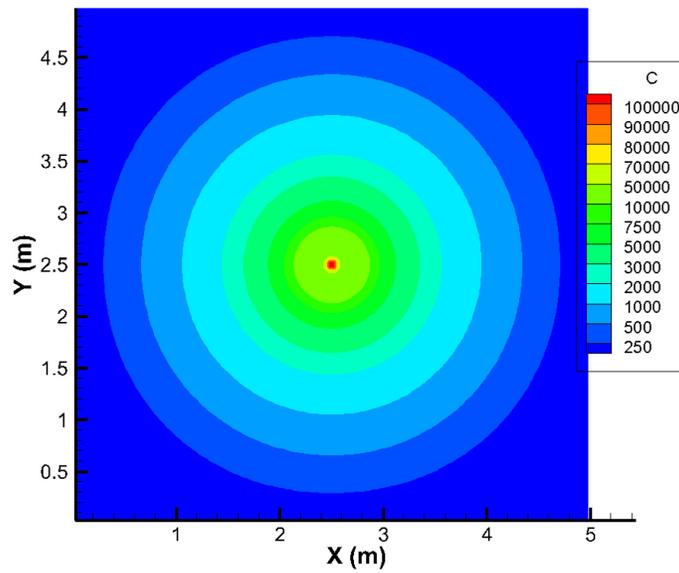
Figure 2.14 CO_2 concentration at t = 180s for Run 4.

Figure 2.15 shows the concentration of CO_2 in ppm at t = 180s along the X axis through Y = 2.5 m on the (X, Y, Z = 1m) plane. The maximum is close to 100,000 ppm which exceed the toxic levels, but for an area of a few centimeters around the source.
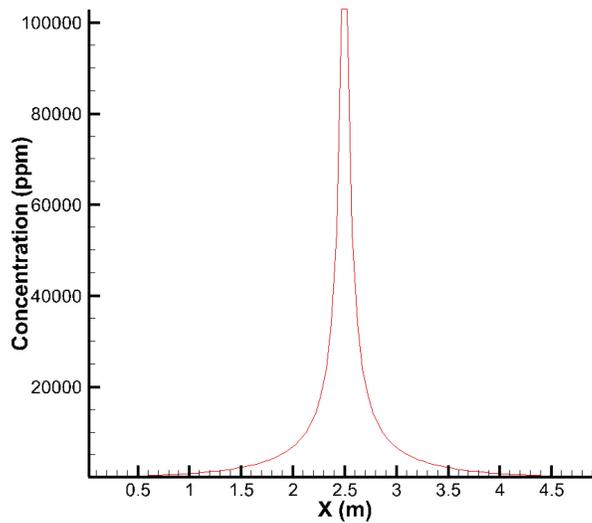
Figure 2.15 CO_2 concentration at t = 180s for Run 4.

Figure 2.16 shows the CO_2 concentration in ppm, as a function of time from t = 0 s to the end of the simulation at t = 180s. The concentration is plotted at various radial distances from the source on the (X,Y,Z = 1 m) plane. Since the gas is diffusing evenly in every direction, given there is no wind, these graphs represent the concentration of CO_2 at the specified distance away from the source in any direction.
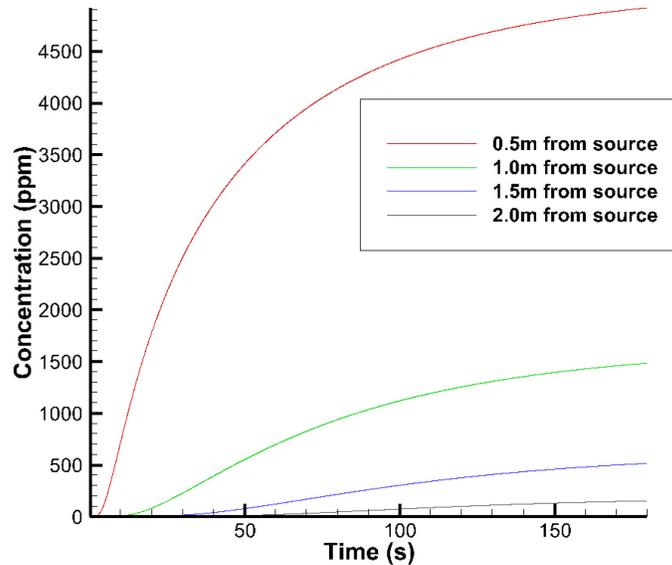
Figure 2.16 CO_2 concentration at t = 180s for Run 4.

Simulation 4 produces a CO_2 plume with a mass flow rate of 750mg/s from the source. This flow rate generates a plume within acceptable concentrations at each location.

Summary

The simulations show that the ideal mass flow rate releases of CO_2 into a test area of 5m x 5m with no wind include 500 mg/s and 750 mg/s. Both mass flow rates create plumes profiles measureable with available CO_2 sensors of the PDS. These plume profiles show that the CO_2 concentrations even at a distance of 2 m from the source are above background atmospheric conditions.

Also, these simulations show that the concentration of CO_2 at 2.0 m away from the source is always substantially smaller than from 0.5 m away. If CO_2 sensors take measurements more than 2.0 m away from the source, they will likely yield concentration data that is close to, or at environmental conditions.

2.4 Components of the PGS and PDS

For this experiment to be fully realized, a variety of sensors and instruments were selected to carry releasing carbon dioxide at a specific mass flow rate, measuring carbon dioxide concentration, and measuring wind speed.

Sierra SmartTrak C100L Mass Flow Controller

The Sierra SmartTrak C100L mass flow (Figure 2.17) controller was chosen for it's full-scale range (10sccm – 50,000 sccm for nitrogen at room temperature conditions) as well as its high-pressure capacity and ease of digital communication. A 15 pin, 24 VDC power supply was required, and the mass flow controller communicated digitally through the PC with a 100 – RS232 cable National Instruments provided a LabVIEW program for this device which was incorporated into the main program the experimental setup.

Figure 2.17 Sierra SmartTrak C100L Mass Flow Controller.

COZIR Carbon Dioxide Sensors

The carbon dioxide sensors used in the PDS (Fig. 2.18) were selected by a previous MQP group (NAG1501) for their light weight and accuracy (5000 ppm +/- 50 ppm). A LabVIEW code was also provided via the National Instruments website which was incorporated into the main LabVIEW execution file for this experimental setup.

Figure 2.18 Cozir Carbon Dioxide Sensor.

Modern Device Wind Sensor Rev.P

In order to accurately measure the plume as it is released, a wind sensor is necessary to gauge any wind that might affect plume dispersal. Micro hot wire anemometers were explored for their high sensitivity, as well as their small size and mass, so that they could be used on the concurrent MAD1601 (2016) MQP without adding significant mass to the Khepera 4 robot's payload. The Wind Sensor Rev. P (Figure 2.19) from modern devices met all of the necessary criteria with the addition of having the exceptionally low cost of $20.00. The sensor was tested with the provided Arduino code before ultimately being programmed in LabVIEW using an NI DAQ box. This wind sensor requires a 12V external power supply.
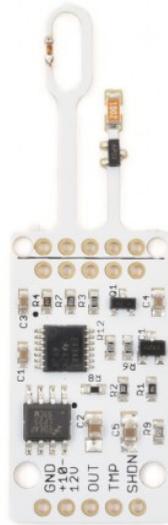
Figure 2.19 Modern Devices Wind Sensor Rev.P.

National Instruments USB-6009 DAQ

A National Instruments DAQ box was purchased for data acquisition and communication for the wind sensor and solenoid valve. The NI DAQ options offered the best solution for integration of the sensors with LabVIEW as they are designed to work with the software. The NI USB-6009 DAQ (Figure 20) was also selected because of the 8 analog inputs (we required 5) and it's support of the Linux version of LabVIEW.

Figure 2.20 NI USB-6009 DAQ.

3. Integration of the Plume Generation System, the Plume Detection System and the Data Acquisition System

This chapter describes the steps taken to integrate the components of the plume generation system (PGS) and plume detection system (PDS) components, the Computer Stand and DAQ Equipment. The chapter presents the writing and compilation of the LabVIEW code that controls and powers all the instruments of the PGS and PDSs.

3.1 Integration of the PGS and the PDS

The PGS and PDS are both integrated by mounting their respective instruments as well as accompanying USB, serial, and power cables, onto 80/20 T-slot structures fabricated for each system.

The plume generation system is mounted onto a four-legged frame and table which holds all instruments. Due to the use of the T-slot beams in constructing the legs and frame, the entire system is fully articulated, with the table resting parallel to the ground at a maximum height of 1m off the ground. The pressurized CO_2 tank, regulator, solenoid valve, mass flow controller, and nozzle are all connected via flexible plastic tubing, and fastened to the table with screws and velcro strips. The tank and regulator are controlled by hand, while the solenoid valve is connected to a USB 6009 DAQ I/O, which is connected to the LINUX system. The mass flow controller is connected via a serial cable directly to the LINUX system.

The Plume Detection System consists of a T-Slot stand, which holds the CO_2 sensor and wind sensor on its arm, which is also fully articulated. The CO_2 sensor is connected directly to the LINUX system via a USB connection. The wind sensor is connected to the USB 6009 DAQ box through its I/O ports. The USB 6009 DAQ box is connected to the LINUX station via a USB connection which allows for remote control of all instruments. The mass flow controller and CO_2 sensor is connected directly to the LINUX computer via USB connection. The DAQ and LINUX computer are mounted on a Two-Post Economy Open Frame Rack, shown below in Figure 3.1.

Figure 3.1 Two-Post Economy Open Frame Rack (Left) and Frame (Right).

3.2 Programming Sensors and Instruments for Experiment Integration Using LabVIEW

To perform data acquisition and control the components, LabVIEW was chosen to program the experiment, as it has the capability to not only to run each sensor and component, but also offers a clean user-interface called a "front panel" with controls and outputs and write results directly to a spreadsheet in real time. The front panels correspond to a "block diagram" that runs through the commands behind the scenes to allow an uncluttered user interface. LabVIEW programs, or "VI's" were provided for the mass flow controller and the CO_2 sensors (Figures 3.2, 3.3, 3.6, and 3.7), but needed to be written for the wind sensor and the solenoid valve.

3.3 PGS LabVIEW Implementation

Code for the mass flow controller with data acquisition via USB or BUS connection was provided by National Instruments for our specific instrument (Figures 3.2 and 3.3).
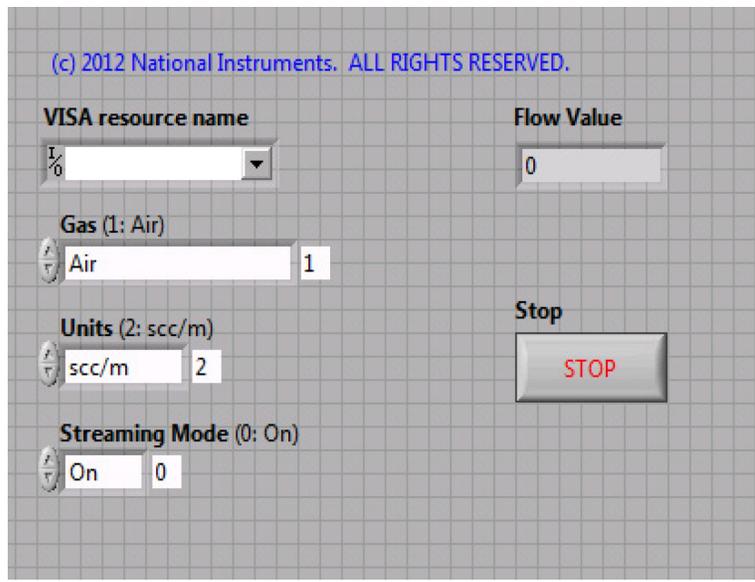
Figure 3.2 Sierra SmartTrak Mass Flow Controller Front Panel © 2012 National Instruments.
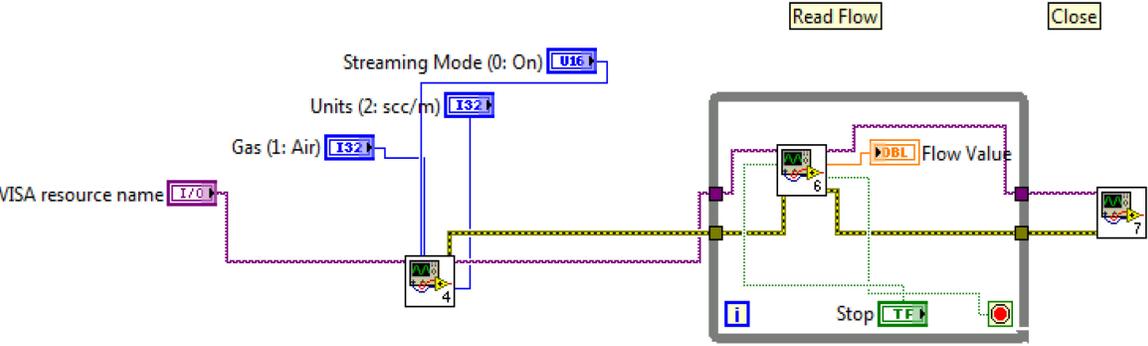
Figure 3.3 Sierra SmartTrak Mass Flow Controller Block Diagram © 2012 National Instruments.

However, the code for the solenoid valve needed to be written. As the DAQ chosen for running the experiment was not powerful enough to power the solenoid valve, a simple code to power a 120 VAC relay was written in LabVIEW to cycle the valve on command, via a button press on the VI's front panel (Figure 3.5).
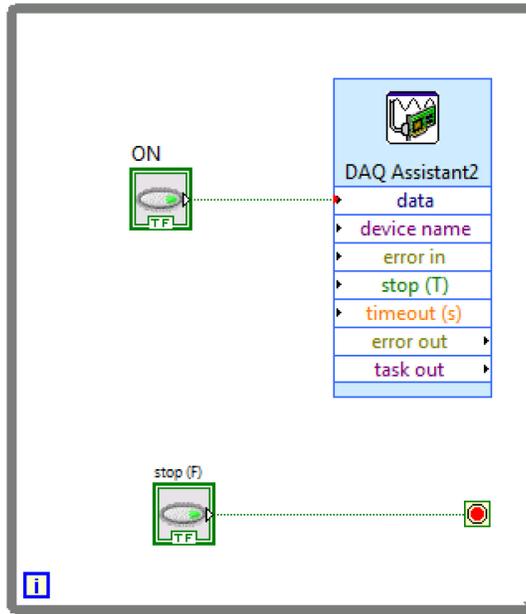
Figure 3.5: LabVIEW Program for Relay/Solenoid Valve.

3.4   PDS LabVIEW Implementation

The code for the carbon dioxide sensors was provided by Cozir and read data collected by the sensors in real time (Figures 3.6 and 3.7).
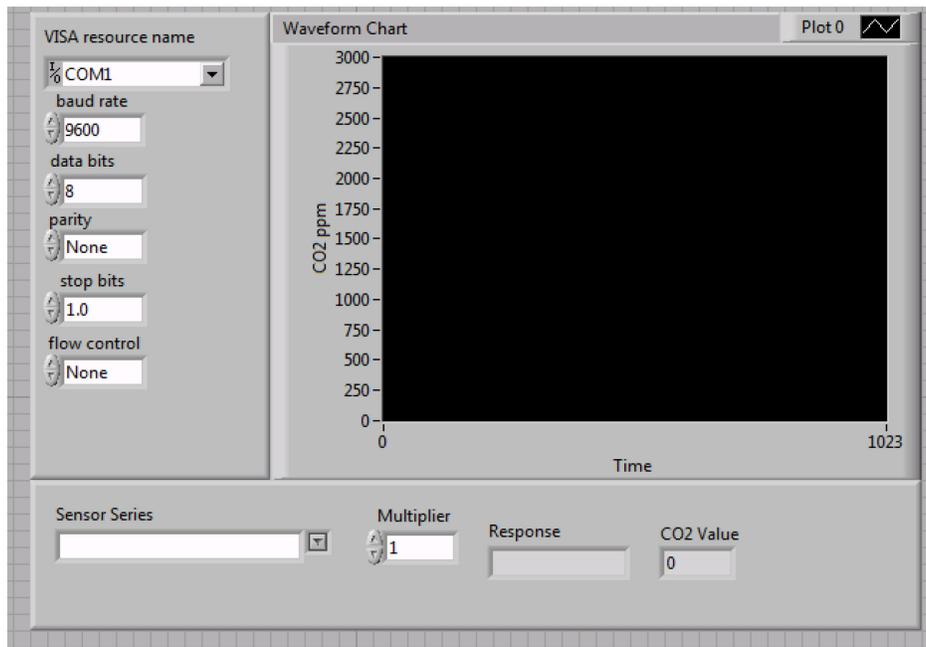
Figure 3.6: LabVIEW Front Panel for Cozir CO$_2$ Sensors © Cozir 2015.
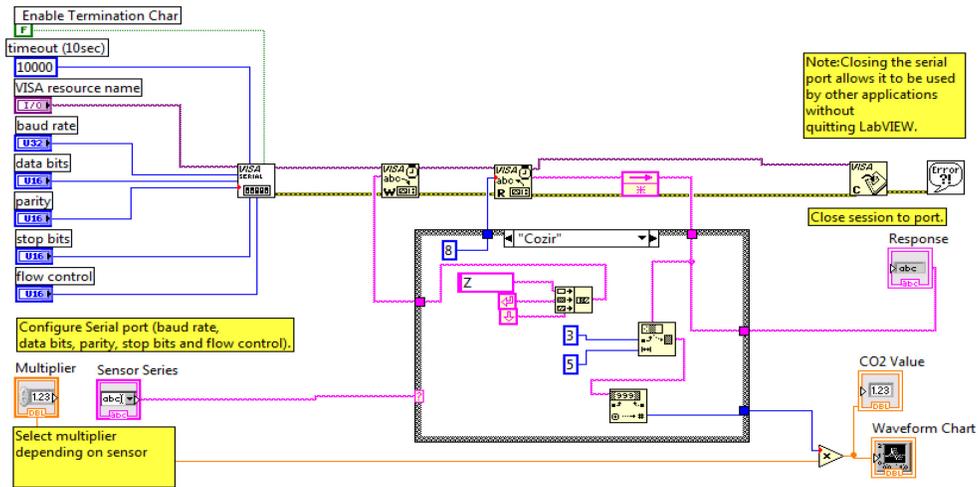
Figure 3.7: LabVIEW Block Diagram for Cozir CO₂ Sensors © Cozir 2015.

To develop code for the wind sensor, we first analyzed and tested the provided Arduino code for the Wind Sensor as shown in Figure 3.2.

```
/* A demo sketch for the Modern Device Rev P Wind Sensor
 * Requires a Wind Sensor Rev P from Modern Device
 * http://moderndevice.com/product/wind-sensor-rev-p/
 *
 * The Rev P requires at least at least an 8 volt supply. The easiest way to power it
 * if you are using an Arduino is to use a 9 volt or higher supply on the external power jack
 * and power the sensor from Vin.
 *
 * Hardware hookup
 * Sensor      Arduino Pin
 * Ground      Ground
 * +10-12V     Vin
 * Out         A0
 * TMP         A2
 *
 * Paul Badger 2014
 * code in the public domain
 */

const int OutPin  = A0;    // wind sensor analog pin  hooked up to Wind P sensor "OUT" pin
const int TempPin = A2;    // temp sesnsor analog pin hooked up to Wind P sensor "TMP" pin


void loop() {

    // read wind
    int windADunits = analogRead(OutPin);
    // Serial.print("RW ");    // print raw A/D for debug
    // Serial.print(windADunits);
    // Serial.print("\t");


    // wind formula derived from a wind tunnel data, annemometer and some fancy Excel regressions
    // this scalin doesn't have any temperature correction in it yet
    float windMPH =   pow((((float)windADunits - 264.0) / 85.6814), 3.36814);
    Serial.print(windMPH);
    Serial.print(" MPH\t");




    // temp routine and print raw and temp C
    int tempRawAD = analogRead(TempPin);
    // Serial.print("RT ");     // print raw A/D for debug
    // Serial.print(tempRawAD);
    // Serial.print("\t");

    // convert to volts then use formula from datatsheet
    // Vout = ( TempC * .0195 ) + .400
    // tempC = (Vout - V0c) / TC   see the MCP9701 datasheet for V0c and TC

    float tempC = (((((float)tempRawAD * 5.0) / 1024.0) - 0.400) / .0195;
    Serial.print(tempC);
    Serial.println(" C");
    delay(750);
}
```

Figure 3.2 Arduino Program for Wind Sensor Rev. P.

This program was tested with the Arduino before translating the code into LabVIEW's visual programming. The code was set to output temperature and wind speed as numeric integers in an indicator text box as shown Figure 3.3 and Figure 3.4.
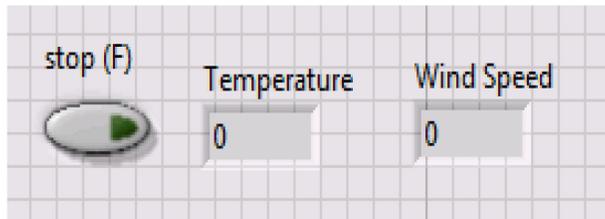
Figure 3.3 Wind Sensor Front Panel.
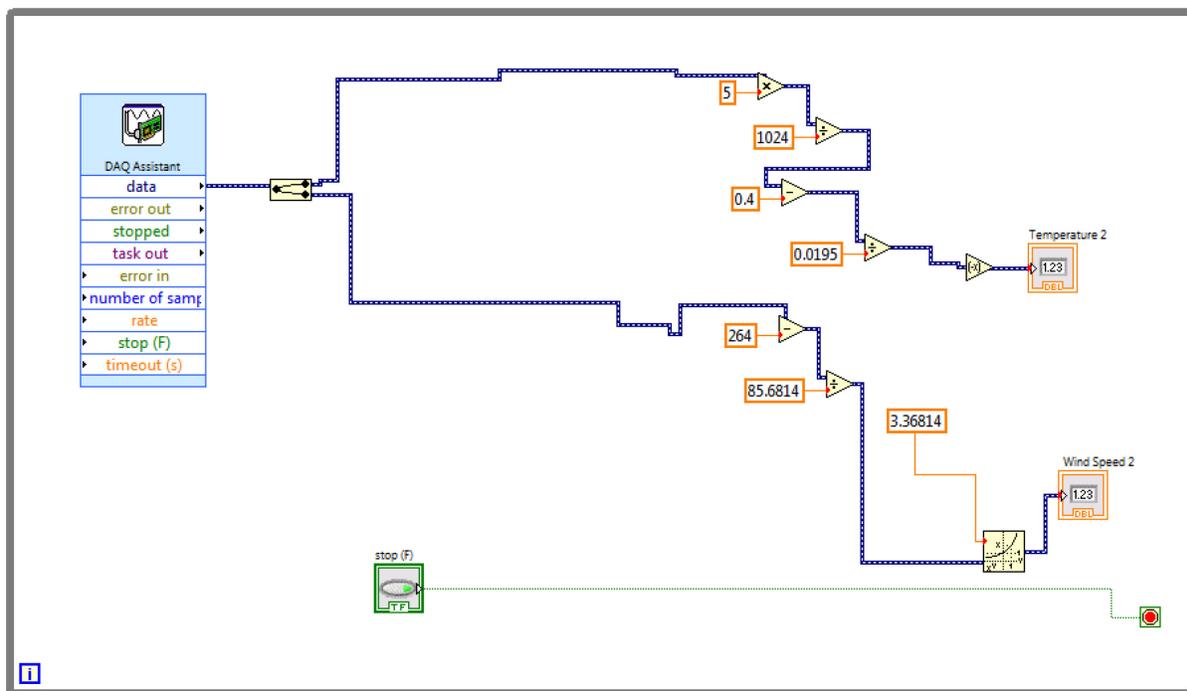
Figure 3.4 Wind Sensor Block Diagram.

3.5   LabVIEW Main Program Integration

With the individual programs written for each component of the experiment, we integrated the programs as subprograms to a larger main program. This was accomplished by integrating the individual programs into a single LabVIEW program as "Sub VI's", which allows the programs to run individually while being controlled from a single front panel (Figs. 3.5 and 3.6)
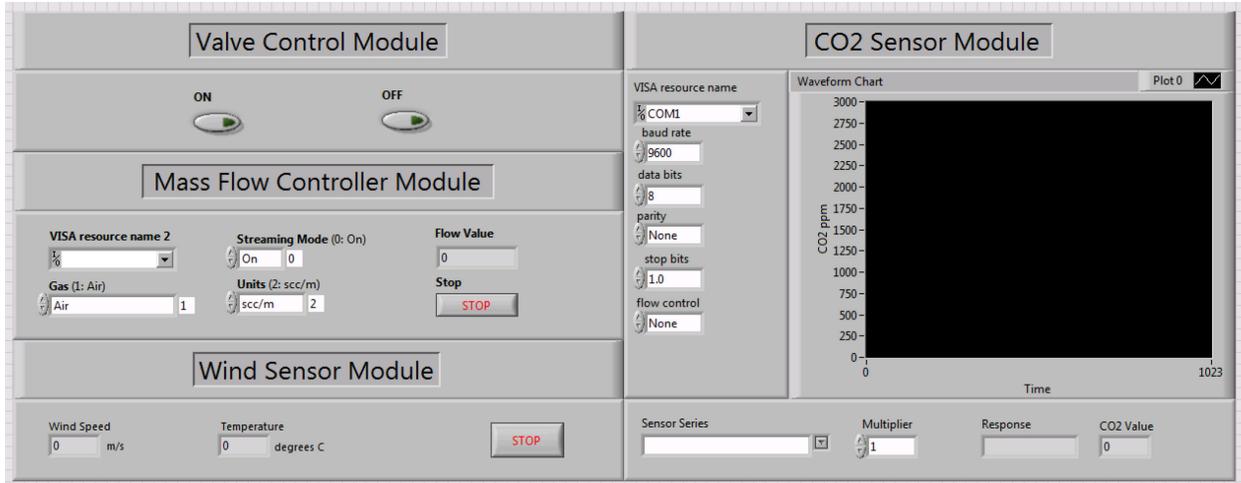
Figure 3.5 Main Program Front Panel.
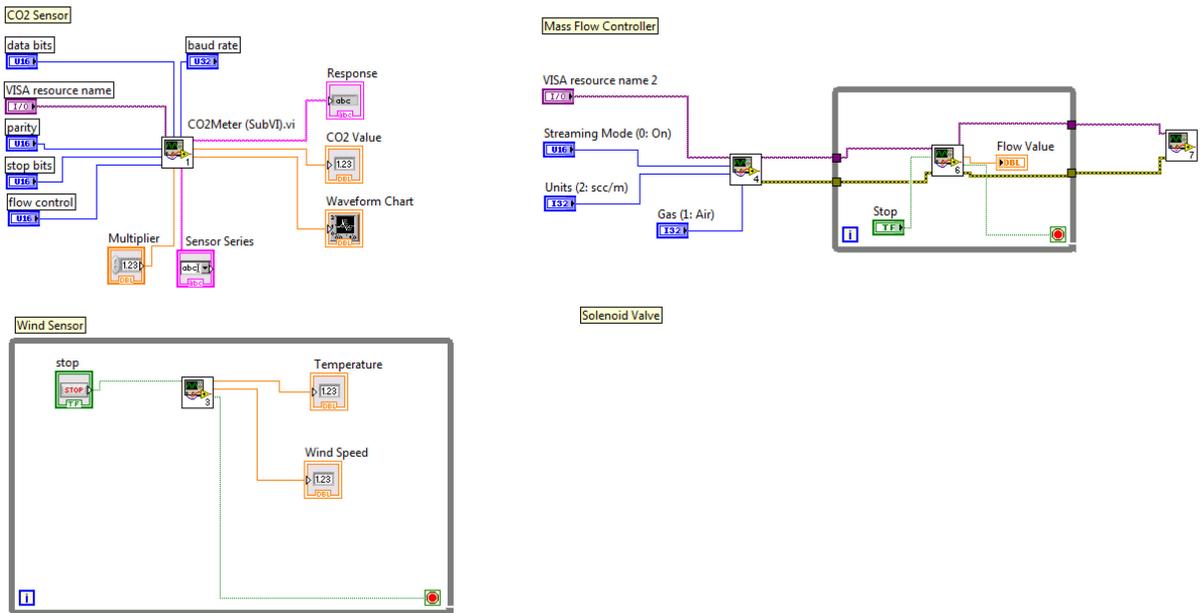
Figure 3.6 Main Program Block Diagram.

4 Summary, Conclusions, Recommendation

The goal of this project is to design, fabricate, and integrate a Plume Detection System (PDS), a Plume Generation System (PDS) and a Data Acquisition System (DAQ) that can be used in plume experiments. The plumes will be generated in an indoor environment with a 5 m X 5m surface area centered around a stationary CO_2 source with a given mass release rate.

4.1 Conclusions

Plume Profile Simulations

Plume simulations were performed using a code that solves numerically the 3D advection-diffusion equation from a stationary CO_2 source to guide the design of the PGS and PDS. These simulations were performed for domains of 5 m x 5 m x 2 m and determined the range of mass flow rates for the PGS that produce plumes detectable by sensors of the PDS and eventually the UTS. Analysis of different mass flow rates and their resulting plume profiles have determined that ideal profiles can be generated with a mass flow rate of 500 mg/s or 750 mg/s. The resulting plumes are ambient levels of above 400 ppm but cannot cause the room CO_2 level to exceed 50,000ppm and become toxic those conducting the experiments.

PGS Components

The PGS components are listed in chapter 2.4, and include a 5 lb pressurized CO_2 gas tank, an air pressure regulator, an Omega SV3300 solenoid valve, a Sierra SmartTrak C100L Mass Flow Controller with power supply, and a 3D printed gas diffusing nozzle. All components will be mounted on the frame and supports composed of 80/20 T-slot beams.

Design of PGS in SolidWorks

The PGS was designed in SolidWorks, complete with all necessary components and 80/20 T-slot framing, with a 3D model, 2D drawings, and bill of materials. The 3D design can be see in Figure 2.1 (Left).

PDS Components

The PDS components are listed in section 2.4, and consist of one COZIR Ambient 5k CO_2 GC-0012 Sensor and one Modern Device Wind Sensor Rev.P, and are mounted onto a stand and tower composed of 80/20 T-Slot beams.

Design of PDS in SolidWorks

The PDS was designed in SolidWorks, complete with all necessary components and 80/20 T-Slot framing, with a 3D model, 2D drawings, and bill of materials. The 3D model of the PDS can be seen in Figure 2.1 (Right).

LabVIEW Code

LabVIEW code was written to control and power the Omega SV3300 solenoid valve, Sierra SmartTrak C100L Mass Flow Controller, COZIR Ambient 5k CO_2 GC-0012 Sensor, and Modern Device Wind Sensor Rev.P. Script was written for each component individually, then all scripts were compiled onto one LabVIEW front panel so they can all be controlled and monitored at once through the computer and DAQ box. The front panel is shown in Figure 3.5, and the block diagram is shown in Figure 3.6.

4.2   Recommendations

Recommended research for future groups includes the following:

- Design of the PGS nozzle to achieve a very low-Mach number flow at its exit.
- Purchase remaining components needed for the PGS, PDS or the DAQ (power supply and relay for solenoid valve, tubing, etc.).
- Perform experiments using the PGS, PDS and DAQ in indoor environments.
- Design, testing, and integration of a wind-generation system that simulates ambient wind profiles. Potential designs may include a set of box fans that can be controlled through the DAQ system in this experiment that can generate a known wind velocity.
- Design of a mobile gas-dispersing source in place of a stationary one to recreate the effects of an intruder.

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