Use of a TerraRover 2 to Collect Fine Particulate Matter Using Arduino Related Technology

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Abstract:

In this research a NASA TerraRover 2 was modified to sense and record fine particulate matter along with its normal measurement of surface temperature. A micro $PM_{2.5}$ air quality sensor was independently programmed using the programming language of Arduino and the Arduino Leonardo Board. Multiple trial runs were made with the concentrations of particle size ranging from 1.0 microns to 10.0 microns (0.3 microns, 0.5 microns, 1.0 microns, 2.5 microns, 5.0 microns, 10.0 microns) in the Crestwood High School Teacher Parking Lot, Student Parking Lot, along Beech Daly Road, Band Practice Field, and the Student Practice Soccer Field. The $PM_{2.5}$ Air Quality Sensor was mobilized using the TerraRover 2, a robot using 3D printed components and a controller, to collect measurements of different sized particles around the designated area. The goal of this research was to use the data collected by the $PM_{2.5}$ air quality sensor to compare data from several different areas around Crestwood High School. Ground level PM concentrations are critical to collect and analyze because inhaling such fine particles, especially over a long period of time may cause respiratory health issues. Knowing the levels of particulate matter, may help alert school personnel know when it is safe for outdoor athletic activities. An analysis of the data showed some difference between PM and different locations around the school. However, the difference was less than expected. In the future, other air quality sensors can be added to the TerraRover 2, allowing a suite of air quality data to be collected.

Key Words: Particulate Matter (PM), Particles, PM2.5 Air Quality Sensor, Micrometers, TerraRover 2

Research Questions:

The following research questions guided our investigation of particulate matter around a suburban high school campus.

1. How do particulate matter levels vary in different locations?
2. Are particles with a size less than 2.5 microns more abundant in areas near heavy traffic?
3. Can a TerraRover 2 be modified to monitor outdoor levels of particulate matter?

Null Hypothesis:

1. There is no difference in particulate matter levels at various locations around a high school.
2. Particulate matter with a size less than 2.5 microns do not increase in places near running cars.
3. A TerraRover 2 cannot be modified to monitor Particulate Matter levels outdoors.

Introduction and Review of Literature:

Particulate matter (PM) refers to a complex combination of tiny, lightweight solid and liquid droplets that can be suspended in air for extended periods of time. The types analyzed in our research are Particles > 0.3 microns; fine particles with diameters greater than 0.3 microns, Particles > 0.5 microns; fine particles with diameters greater than 0.5 microns, Particles > 1.0 microns; fine particles with diameters greater than 1.0 microns, Particles > 2.5 microns; fine particles with diameters greater than 2.5 microns, particles > 5.0 microns; fine particles with diameters greater than 5.0 microns, particles > 10.0 microns; fine particles with diameters greater than 10.0 microns. Most particulate matter found in the air can be filtered mechanically by our nose and upper respiratory passageways. However, particles lower than 2.5 microns are a bigger threat than particles greater in size because the fine particles can travel farther into the body's bronchitis. Fine particles that reach the alveoli can permanently damage gas exchange. The finer particulate matter is, the harder the human eye can see. Examples of particulate matter that may have been present in the researcher's areas consist of dust, tobacco smoke, ash, car exhaust, suspended tiny droplets, ultrafine particles from

airplanes, and possibly particulates originating from a Ford Factory. Numerous health studies have found a clear correlation between “epidemiological and experimental findings" that clearly indicate the role of particulate matter in the development and progression of respiratory diseases (Schwarze 2006). There has also been a significant association between particulate matter concentration and mortality stemming from cardiovascular disease as well (Panyacosit 2000). Dearborn Heights’ weather is heavily affected by the prevailing south westerlies winds. Wind speeds and wind directions in the location Dearborn Heights, MI are associated with the varying air pressure which also impacts particulate matter concentrations. Unfortunately, to be able to find accurate particulate matter measurements, expensive professional equipment is necessary. Currently, only universities, laboratories, state, and federal agencies are able to afford such expensive equipment, not the general public. However, if citizen scientists and schools could have access to particulate matter sensors that constantly provide data about particulate matter levels, it would be easy to provide alerts to individuals sensitive to poor air quality. In our area, Crestwood High School is a very active school. Band practice, soccer practice, track practice along Beech Daly, student’s cars entering the parking lot, student’s cars leaving the parking lot, teacher’s cars entering the parking lot, and teacher’s cars entering the parking lot simultaneously happen all day. Having particulate matter measurements from the Crestwood High School area can give the school the information of the health concerns of the activity.

Research Methods:

The data was collected using a TerraRover 2 with a $PM_{2.5}$ air quality sensor, surface temperature sensor, and 2 Arduino Leonardos. The TerraRover 2 was previously outfitted with only a surface temperature sensor connected to a singular Arduino Leonardo with a GPS and Data Logger Shield. To expand the amount of data that can be pulled from the TerraRover 2, student researchers added a new particulate matter sensor with an additional Arduino Leonardo. After coding and connecting the particulate matter sensor with the Arduino, they attached the sensor and Arduino to the TerraRover 2 at 0.3 meters above the ground. Three trials were

conducted in each of the five locations for the most accurate results. Each trial ran for about 3 minutes and the sensor was collecting data every 10 seconds. Over the course of 3 hours, data was being collected and immediately sent to a laptop using USB connection. Following this, the data was inputted into a Google Spreadsheet and every variable of each trial was averaged. The data was analyzed to check if PM concentration levels differed in various locations. The researcher also averaged the wind speed, humidity, and temperature of the collection date. This information was obtained from Crestwood High School's WeatherBug weather station, a high-quality instrument that sends all of its measurements directly to the GLOBE database.

Results:

The high school where this research was conducted lies within a heavily populated suburban neighborhood and is bounded by a road to the east with fairly heavy traffic throughout the day.

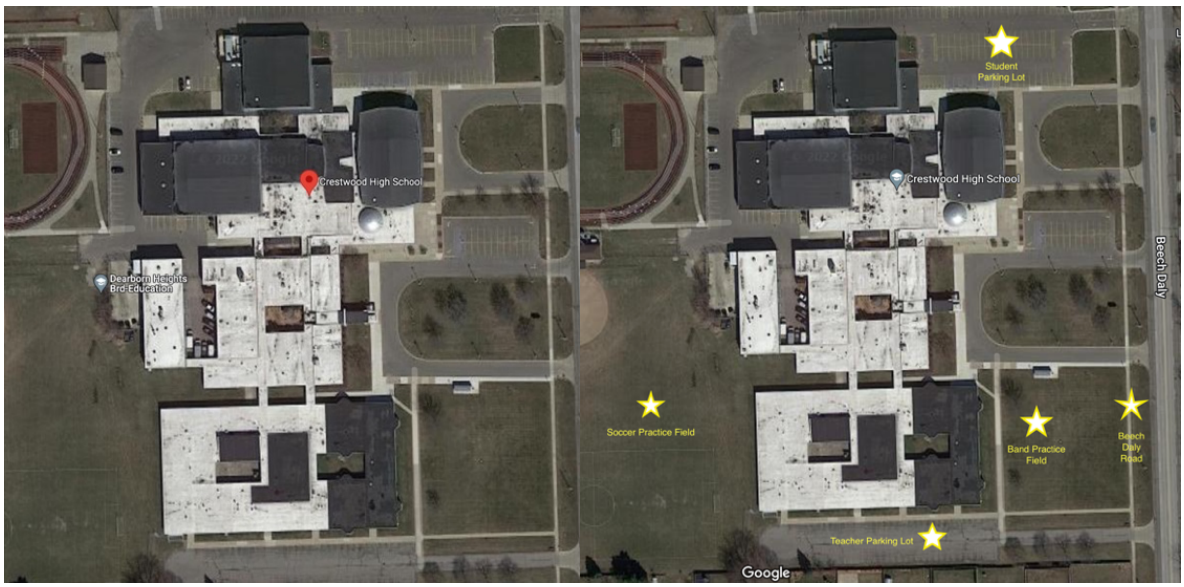


Figure 1. Research Site. Image on the left is an overview of Crestwood High School's location within Dearborn Heights, Michigan, USA. Latitude 42.19, Longitude -83.17, elevation 216.3 meters. Image on the right shows each of the five (5) sites were PM (particulate matter) data was collected.

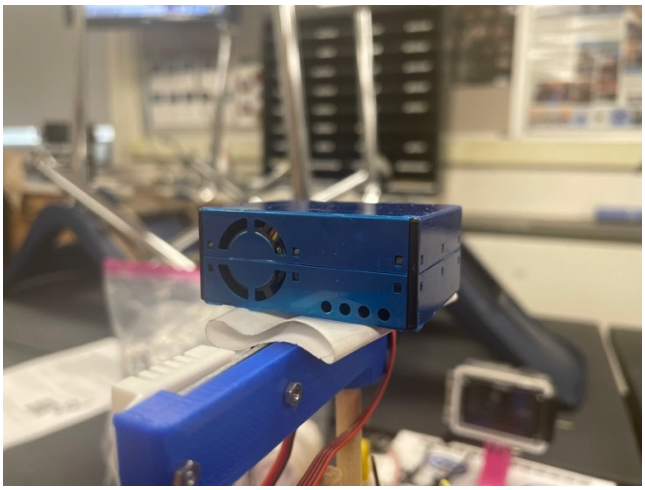


Figure 2. PM2.5 Air Quality Sensor. Image above displays the Particulate Matter Sensor the researchers used to collect PM data. The sensor was placed on the top of the TerraRover, secured by industrial tape. The PM2.5 Air Quality Sensor was programmed by the researchers using the Arduino IDE and Arduino programming language. The researchers used Arduino Serial, which gave fast communication between the PM2.5 Air Quality Sensor and the Arduino Leonardo Board.

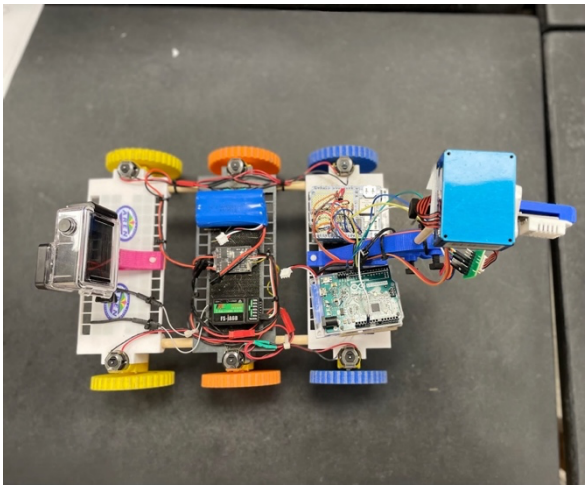
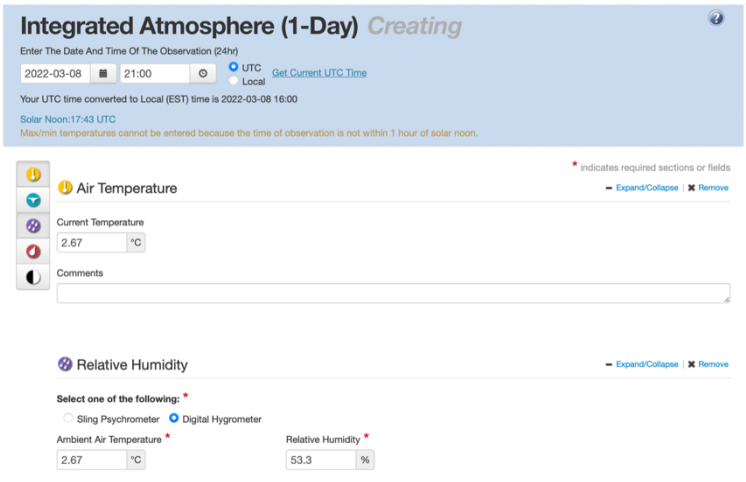


Figure 3. TerraRover 2. Image above includes the mobilization aspect of the research, the TerraRover 2. The TerraRover 2 was provided by NASA GLOBE AREN Project from Mr. David Bydlowski and Mr. Andy Henry. The TerraRover 2 gave insight to the researchers about how much mobilization is important in terms of particulate matter. The TerraRover 2's use can be extended to be used in areas where human contact is impermissible because of irritation and/or lethal consequences. The TerraRover 2 is necessary in areas where human health is at risk such as places where acid spills, chemical spills, and nuclear waste are present.

Figure 4. TerraRover 2's Use at Crestwood High School. Images above greatly shows TerraRover 2 at Crestwood. Throughout the research, the TerraRover 2 was being driven to efficiently collect data for particulate matter and GPS all around the researchers' sites.



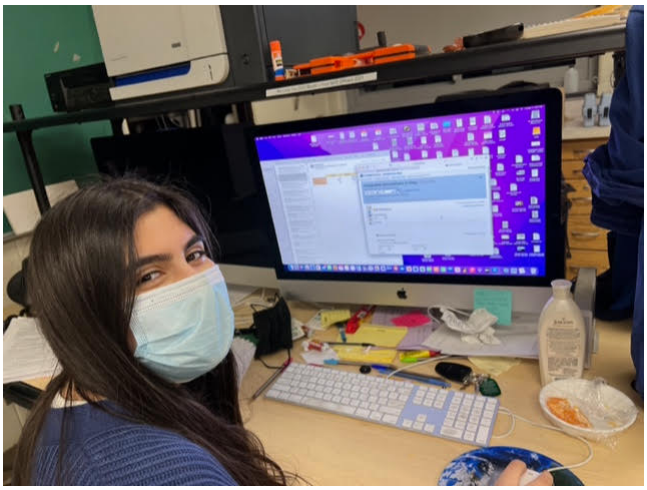


Figure 5. Data Entry. To impute their data, the researchers used the GLOBE website's "SCIENCE Data Entry" area. The researchers logged the air temperature, wind speeds, and humidity of the day they collected data. The researchers plan on using this data to later monitor the correlation of weather changes with particulate matter (PM). Figure (right) show the researcher, Hala Komaiha, inputting the collected data into the GLOBE website.

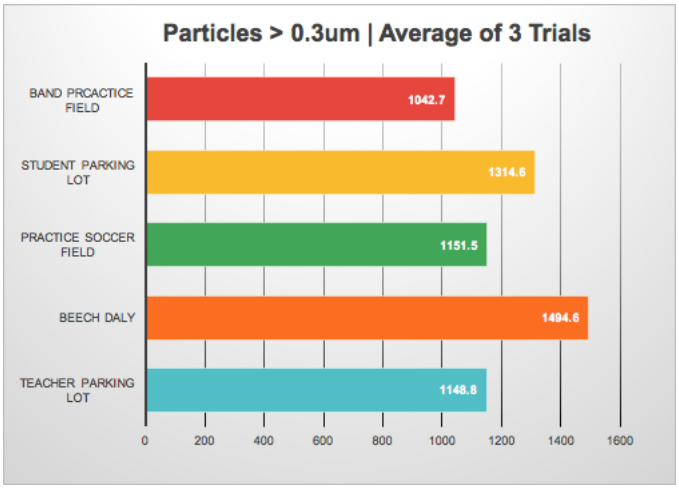


Figure 6. Comparison of Particles > 0.3 microns Over the Average of 3 Trials in Different Research Sites. The bar graph above shows the averages of the different amounts of particulate matter at the different research sites the researchers collected data from over 3 trials. As you can see, the Beech Daly site had the most of the fine particles. The Beech Daly site is near a busy road, Beech Daly Road, and has consistent contact with vehicle exhausts and other factors around the concepts of wind direction and wind speed. This site is also always used by the students of Crestwood High School frequently. Giving more information of this matter, can alarm the Crestwood School Board and city politicians for a re-model of the site and be able to ensure the safety of their children and students

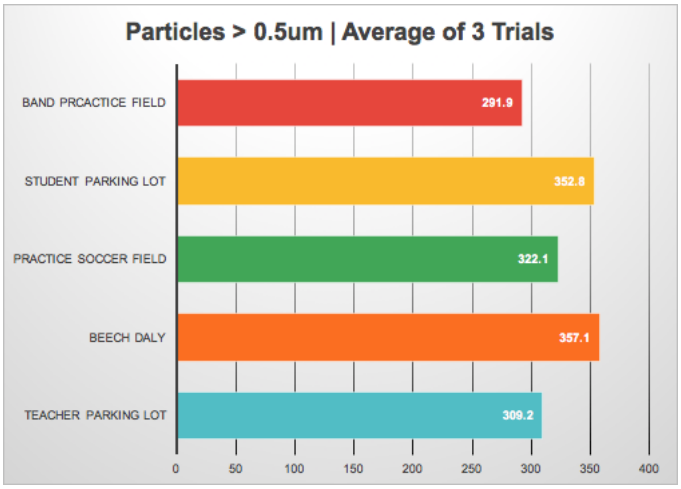


Figure 6. Comparison of Particles > 0.5 microns Over the Average of 3 Trials in Different Research Sites. The bar graph above shows the averages of the different amounts of particulate matter at the different research sites the researchers collected data from over 3 trials. Similarly, from **Figure 5**, the Beech Daly site had the most of the particles, but you can see a drastic change from the Student Parking Lot site. The Student Parking Lot also has contact with student vehicles, buses, and opponent's buses for sports events.

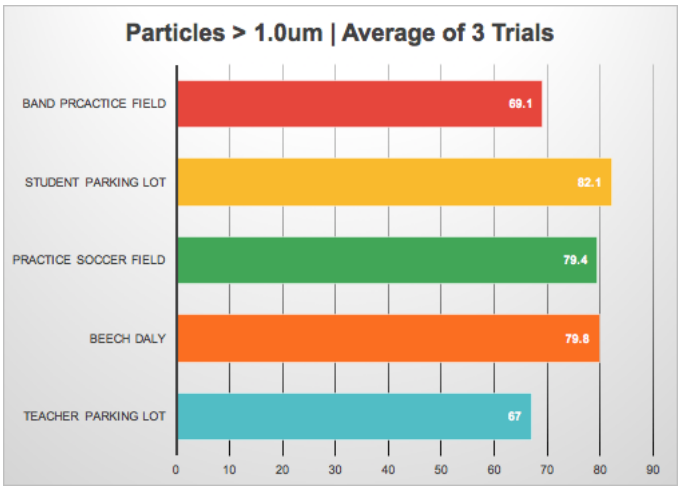


Figure 7. Comparison of Particles > 1.0 microns Over the Average of 3 Trials in Different Research Sites. The bar graph above shows the averages of the different amounts of particulate matter at the different research sites the researchers collected data from over 3 trials. This bar graph finally shows the variability of the particulate matter in the Student Parking Lot. As you can reference from **Figure 5** and **Figure 6**, the Student Parking Lot was steadily showing results for the different sizes of particles. **Figure 7** now shows a larger criteria of particle size.

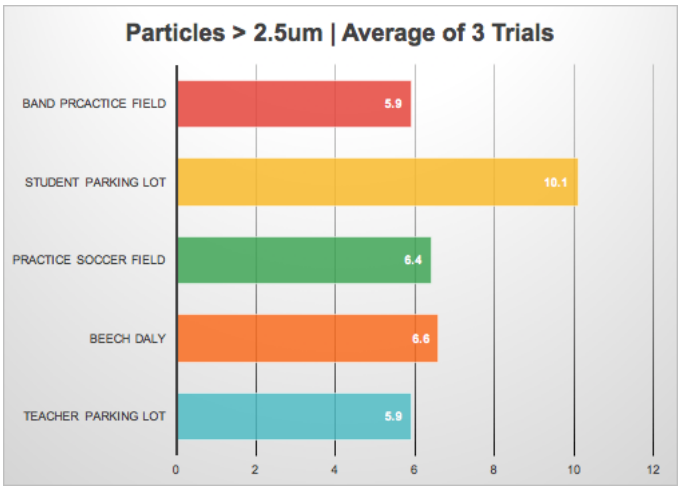


Figure 8. Comparison of Particles > 2.5 microns Over the Average of 3 Trials in Different Research Sites. The bar graph above shows the averages of the different amounts of particulate matter at the different research sites the researchers collected data from over 3 trials. Similarly to **Figure 7**, **Figure 8** greatly shows how to improve the particulate matter in the Student Parking Lot site.

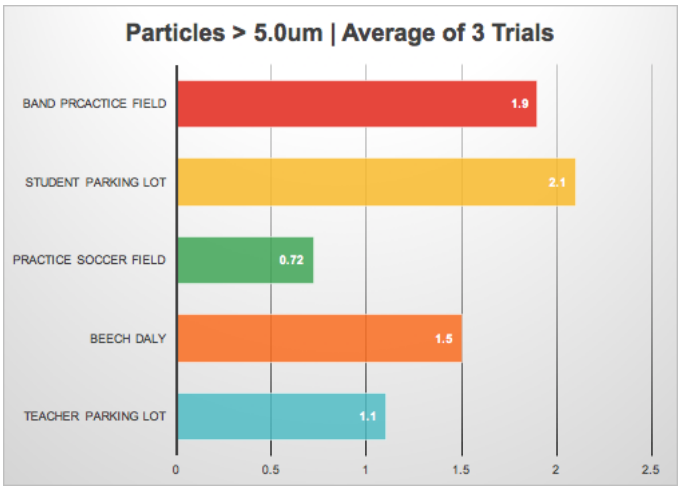


Figure 9. Comparison of Particles > 5.0 microns Over the Average of 3 Trials in Different Research Sites. The bar graph above shows the averages of the different amounts of particulate matter at the different research sites the researchers collected data from over 3 trials. Surprisingly, the Band Practice Field site showed a great value for this criteria. This may be because of the grassy and flat terrain of the field and that may have higher the chances of particles in the air while driving the TerraRover 2.

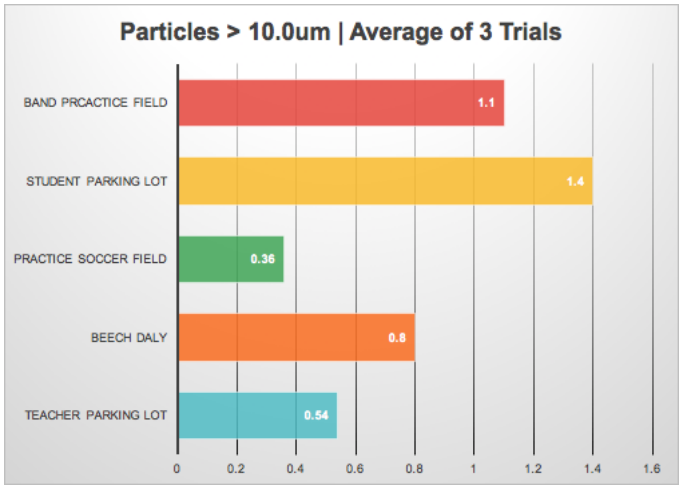


Figure 10. Comparison of Particles > 10.0 microns Over the Average of 3 Trials in Different Research Sites. The bar graph above shows the averages of the different amounts of particulate matter at the different research sites the researchers collected data from over 3 trials. Similarly, to **Figure 8**, both the Band Practice Field and Student Parking Lot shows higher concentrations of the larger particles. Similarly to the reasons said in **Figure 5,** the Student Parking Lot was expected to show the high concentrations. Referring to **Figure 8**, the Band Practice Field persistently shows the high concentration of larger particle sizes.

Discussion:

PM concentration levels slightly vary in different locations. While most of the data did not differ much, the data taken near Beech Daly Road had higher levels of Particulate Matter greater than 0.3 microns (ultrafine particles). This location is directly near a major road meaning that car exhaust is the most probable cause for this shift in data. Possible sources of error include weather changes between location switches, the time of day that the data was collected, accuracy of the Particulate Matter sensor, the instability of the Particulate Matter Sensor while driving, and altitude of Particulate Matter Sensor. Globe research previously written by Nazih Baydoun, Hassan Berry, and Nour Kochaiche at Crestwood High School using a PurpleAir device at higher altitudes whereas the high school researchers hope to advance their robot to collect data at a human's breathing level to accurately measure how much particulate matter humans breathe. The previous research also included data on the topic of wind speed, relative humidity, and temperature all impacted the particulate matter of the area. As the research develops, the researchers are going to monitor the differences of particulate matter levels compared to weather conditions including wind speed, relative humidity, and temperature. The researchers had to accept their first null hypothesis as there was little difference in Particulate Matter levels in different locations. The researchers rejected their second null hypothesis, as there were more particles with a size less than 2.5um at Beech Daly Road than every other area in which data was collected. The researchers also rejected their third null hypothesis, as the TerraRover 2's was successfully able to drive while collecting Particulate Matter data outdoors.

Conclusion:

The Clean Air Act was a legislation that was passed in 1970 with the intention to control and regulate air pollution in the United States of America and hopefully give a ripple effect to other countries to improve their air pollution. 52 years have passed since then, are there discrete changes in air pollution? With the help of scrubbers, catalytic converters, the cancellation of leaded gasoline, nitrogen oxides (NOx) and sulfuric oxides (SO_x) and other criteria pollutants have declined. But what about particulate matter? What about the

fine particles found in our air? The rising importance of research in the area of particulate matter and its concentrations lead to negative health effects on the population as a whole. Developing and Developed countries. After analyzing the data collected during this research, it was evident that the location of Beech Daly Road had the most concentration of particles > 0.3 microns with an average value of all 3 trials of 1494.6 particles and particles > 0.5 microns with an average value of all 3 trials of 357.13 particles. This may be due to the constant contact with cars and its exhaust settling fine particles on the cement. Furthermore, our data expressed that the location of the Student Parking Lot had the most concentration of Particles > 1.0 microns with an average value of all 3 trials of 82.1 particles, particles > 2.5 microns with an average value of all 3 trials of 10.1 particles, particles > 5.0 microns with an average value of all 3 trial of 2.133 particles, and particles > 10.0 microns with an average value of all 3 trial of 1.4 particles. This may be due to the fact that the student parking lot is a main way for all students, buses, and track-related sport teams. In other words, the student parking lot at Crestwood High School is in constant use. Although we have gotten this data, these numbers may have been skewed because the $PM_{2.5}$ Air Quality Sensor is at an elevation and was in constant movement as it drives over dips and cracks on all surfaces. The results of this investigation points to how particulate matter is varied by the conditions of the area being tested. The other locations still impact our research. The Teacher Parking Lot had the averages of all 3 trials of 1148.8 particles > 0.3 microns, 309.15 particles > 0.5um, 67 particles > 1.0um, 5.8787 particles > 2.5 microns, 1.0303 particles > 5.0 microns, 0.54 particles > 10.0 microns. These values can be supported by the Teacher Parking Lot, although only being used primarily in the morning and afternoon, there are a lot of sediments, especially by the drain which is in a deposited area where wind can carefully slide through. The practice soccer field had averages of all of 3 trials of 1151 particles > 0.3 microns, 322 particles > 0.5 microns, 79 particles > 1.0 microns, 6.36 particles > 2.5 microns, 0.7272 particles > 5.0 microns, 0.3636 particles > 10.0 microns. This data may be due to the fact that the field is covered with grass and much more vegetation compared to the other areas included. The band practice field had averages of all of 3 trials of 1042 particles

> 0.3 microns, 291 particles > 0.5 microns, 69 particles > 1.0 microns, 5.93 particles > 2.5 microns, 1.9393 particles > 5.0 microns, 1.0909 particles > 10.0 microns. This may be due to the fact that the band practice field has a grassy vegetation, and on that day the school building blocked some wind coming from the southwest. Due to the global pandemic affecting nations worldwide, studying particulate matter in populous areas is now more important than ever. Because of COVID-19's effects on the upper respiratory system, ultra-fine or fine particles such as particle sizes less than 2.5 microns will be even more detrimental to human health, possibly increasing mortality due to their numerous negative health effects on the human heart and lungs. By measuring local particulate matter of all sizes, students involved in school outdoor activities can be warned on days that they might be exposed to high levels of particulates within the air. Teaching staff and coaches can make informed decisions about whether or not to allow outdoor play, labs, settings in general. Lungs damaged by inhaling fine particulate matter can lead to increased pulmonary and heart issues if COVID is contracted. In the future, the researchers plan on adding a radio module connected to an Arduino Mega because of the larger storage found. This will allow the researchers to be wirelessly connected and drive the robot along the sensors of particulate matter and surface temperature. This will pave the way for the robot to collect data and drive alone into locations that can be dangerous to humans. The researchers also hope to build a new robot using metal and other tough materials. With this new build, there will be a more intact platform for both the sensors and anticipated Arduino Mega. The drive will also be much smoother and faster because of the improve mechanism of the wheels. Additionally, adding a data shield to the Arduino Mega wouldn't require someone to consistently be checking and saving the collected data, the data would instead automatically be saved to a SD card that can be opened at any moment of time. The final advancement that the researchers would include is adding multiple air quality sensors that would simultaneously run to display other pollutants in the air such as Nitrogen Oxides, Sulfuric Oxides, Lead, and other criteria air pollutants.

Limitations:

While the researchers successfully were able to collect their data while driving the TerraRover 2, a major limitation was time constraints. The particulate matter sensor had to be compatible with the Arduino and many sensors did not meet that criteria. The researchers also had to program and connect $PM_{2.5}$ air quality sensor to the Arduino Leonardo leaving little time to spare. With the short time span, the data collected was only a day's worth. In the future, the researchers would like to collect this data over a longer period of time while analyzing the data to check weather's role in particulate matter levels.

Limitations in the data collection was how accurate the Particulate Matter sensor is. With the use of a professional particulate matter sensor, the collected data would be more precise than the current sensor attached to the TerraRover 2. A higher quality particulate matter sensor could also be used to validate the data values given by the current $PM_{2.5}$ sensor that is currently in use.

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Acknowledgement:

Working with Mr. David Bydlowski and Mr. Andy Henry of the NASA AREN program was very educational and inspiring for the researchers. He worked with and advised them on how to improve their methods approaching the Arduino Leonardo setup for the $PM_{2.5}$ Air Quality Sensor, and provided instruments when the researchers needed them most. While working with both mentors, the researchers truly understood the importance and impact of their research and how they approached the research in a technological lens, as studying particulate matter and air quality in general is as significant as it has ever been due to the recent COVID-19 pandemic, and the rising use of fossil fuels.

Badges:

I Make An Impact:

The researchers hope to receive the "I Make An Impact" badge as their research can make not only a huge local difference, but also a global difference. In the future, TerraRover 2s all over the metropolitan area can be outfitted with multiple air quality sensors including Particulate Matter, Nitric Oxide, Sulfuric Oxide, Heavy Metals, and Carbon Monoxide Sensors. We can then map our region's air quality results, giving a vast scale of air quality all around the Detroit Metropolitan Area. Using these mobilized rovers will also allow for air quality tests in locations that aren't viable for humans. Places with toxic fumes can use the rovers to inform humans if the problem can be solved with contact. Particulate matter research can not only improve our conditions of living, but also protect all living organisms all over the globe.

I Am A Stem Professional:

The researchers hope to receive the “I Am A Stem Professional” badge for their collaboration with Mr. Andy Henry and Mr. David Bydlowski of the NASA AREN program. They were both there to guide the researchers on occurring problems with the Arduino Leonardo’s connection to a Particulate Matter Sensor and they provided the technology necessary for the TerraRover 2’s main functions, which helped the research as a whole tremendously. They also helped the researchers fully understand the difference that this research can make and how significant it is in the midst of current global issues.

I Am A Data Scientist:

The researchers hope to receive the “I Am A Data Scientist” badge for their data collection, inferences/analysis of the data, and organization of the data. The researchers collected, transferred, organized, averaged, and then analyzed their data using Google Sheets. From there, the researchers created multiple bar graphs of the three trials of every location that data was collected at. The data collected shows the volume of impact towards the research of particulate matter as the data connects to real-life public areas (Crestwood High School) and the particulate matter found in that area. As the world continues to open back up from the recent COVID-19 pandemic, particulate matter (PM) concentration levels are accordingly going to increase. This is unfortunate because the levels had recently decreased during the height of this pandemic due to a global quarantine. The biggest limitations of our research were time constraints and not being able to check the validity of our Particulate Matter Sensor.

I Am An Engineer:

The researchers hope to receive the “I Am An Engineer” badge because in the beginning of the research, the researchers approached a problem involving the memory storage (SRAM) on the already included Arduino Leonardo on the TerraRover 2 thats main purpose was for a surface temperature sensor, GPS, and Data Logger Shield. The researchers had to think of a solution to this storage problem as the PM2.5 Air Quality Sensor would use a great amount of the already small SRAM capacity. The researchers had a solution for using only one arduino with all of the necessary sensors, Arduino Mega, which has almost double the SRAM size of the Arduino Leonardo, the current Arduino. Until they realized the GPS and Data Logger Shield would not work with the it because the Arduino Mega didn’t support the Data Logger Shield because of the ports availability. After constant emailing with Mr. David Bydlowski and Mr. Andy Henry about the subject, the researchers came to the decision of using another Adruino Leonardo just for the new addition, the Particulate Matter Sensor (PM2.5 Air Quality Sensor). With time being a factor, the researchers hastily purchased both the PM2.5 Air Quality Sensor and Arduino Leonardo. Once arrived, the researchers walked into another problem, how can the Arduino Leonardo and PM2.5 Air Quality Sensor cooperate with each other? The researchers searched for different ways to connect the PM2.5 Air Quality Sensor and Arduino Leonardo electrically and programmatically. In aspect of the electric wires, researchers started to use the Serial ports for the Arduino Leonardo because of the easy and fast communication to the Arduino board and PM2.5 Air Quality Sensor. Additionally, the Serial ports made displaying the data from the PM2.5 Air Quality Sensor more efficiently as instead of the data being displayed in an SD card, the data was displayed on the Serial Monitor found in the Arduino IDE. The researchers learned that different Arduino boards have different Serial ports. For example, the Arduino UNO has the Serial port of 2 and 3. The researchers used this knowledge and logic to actually hypothesize the Serial ports for the Arduino Leonardo which were 10 and 11. This observation gave more insight to the structure of an Arduino boards to the researchers. In terms of programming, the researchers already had experience with Arduino programming and operating with the Arduino IDE. The researchers used the Arduino Library of “Software Serial,” which gives the ability of

using the Serial ports with the Arduino Leonardo. The researchers also experimented with *if, print,* and *loop* statements to collect and print out the particulate matter data to the Serial Monitor. After all of the wiring, programming, and mounting of the PM2.5 Air Quality Sensor, the researchers end result was acquiring more knowledge on Arduino, wireworks, and programming. This fascination and desire soon shifted to the topic of particulate matter research.