TerraRover 2 Augmented to Detect a Suite of Atmospheric Parameters Using Arduino Related Technology

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Abstract:

In this research, a NASA **TerraRover 2** was modified to detect and record data for fine **particulate matter**, carbon dioxide (CO_2), **carbon monoxide (CO)**, ultraviolet light (UV), and sound. All sensors were independently programmed using the **Arduino** programming language and wired onto Arduino Uno Boards. Due to the limited space, the researchers prototyped an elevated, lightweight platform. This platform supported the CO_2, CO, UV, and sound sensors. The researchers used CAD modeling to design and 3D-print new wheels for the TerraRover 2 in an effort to increase the thickness of the wheels for better traction. Multiple trial runs were made with particle size concentrations ranging from 0.3 to 0.5 microns, carbon dioxide (ppm), carbon monoxide (ppm), ultraviolet light (nm), and sound (decibels) at three different sites around our school. All **atmospheric sensors** were remotely mobilized using the TerraRover 2, a robot using 3D-printed components and a controller. Micro SD cards were used to remotely save data for each sensor. The goal of this research was to use the data collected to compare with select atmospheric data (using GLOBE protocols) from several different areas around Crestwood High School. The data we collected and analyzed is significant over time as overall health and wellbeing may be compromised. Knowing levels of select atmospheric gases may help alert school personnel of unsafe outdoor air conditions. Data analysis demonstrated some differences between PM, carbon monoxide, carbon dioxide, ultraviolet light, and sound at various different locations. However, the difference was less than expected. In the future, the use of the TerraRover 2 can expand to different protocols other than air quality, allowing it to be used for various purposes. The microsensors on the TerraRover 2 can be a significant and novel way to monitor potentially toxic air remotely.

Key Words: Particulate Matter (PM), Carbon Monoxide (CO), TerraRover 2, Arduino, Atmospheric Sensors

Research Questions

The following research questions guided our investigation of select atmospheric parameters around a suburban high school campus.

1. How does particulate matter, carbon monoxide, carbon dioxide, ultraviolet light, and sound levels vary in different locations?

2. Are levels of particulate matter, carbon monoxide, carbon dioxide, ultraviolet light, and sound more abundant in areas near heavy traffic?

3. Can a TerraRover 2 be modified to monitor outdoor levels of particulate matter, carbon monoxide, carbon dioxide, ultraviolet light, and sound?

Null Hypotheses:

1. There is no difference in particulate matter, carbon monoxide, carbon dioxide, ultraviolet light, and sound levels at various locations around a high school.

2. Levels of particulate matter, carbon monoxide, carbon dioxide, ultraviolet light, and sound are not abundant in areas near heavy traffic.

3. A TerraRover 2 cannot be modified to monitor particulate matter, carbon monoxide, carbon dioxide, ultraviolet light, and sound levels outdoors.

Introduction and Review of Literature:

Air pollution is emitted from both natural and anthropogenic sources. Human activities, such as the increased burning of fossil fuels, have resulted in the significant rise of polluted air. Poor air quality is commonly linked to the increased risk of cardiovascular and respiratory diseases in humans and "approximately 7 million premature deaths" every year (World Health Organization, 2021). Air pollution not only affects humans but the environment as well. Climate change is an ongoing issue driven by the emissions of heat-trapping gasses. Consequences of global warming include rising temperatures and sea levels. This has resulted in growing risks of drought, heat waves, heavy rainfall, and species loss all over the globe. In this study, student researchers collected data on particulate matter, carbon dioxide, carbon monoxide, ultraviolet radiation, and noise pollution. 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. 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). Carbon dioxide is a greenhouse gas produced by the burning of carbon and organic compounds. Fuel combustion accounts for "almost 95% of the national total CO_2 emissions" reported in industrialized countries (Klaassen, 2005). The increase in carbon dioxide is linked to global warming as the carbon dioxide is trapping too much heat in the atmosphere. In humans, carbon dioxide has even "been found to affect decision-making and exam performance" (Yasuda, 2012). Carbon monoxide is a colorless, odorless gas produced during the incomplete combustion of fossil fuels or biomass. At high concentrations, carbon monoxide can cause impaired vision and coordination, headaches, dizziness, flu-like symptoms, etc. Ultraviolet radiation is a type of non-ionizing radiation emitted by the Sun. Human exposure to UV radiation may result in health effects on the skin - such as some cancers - the eyes, and the immune system. The World Health Organization states that "more than 60,000 skin melanoma-related deaths were estimated to be caused by solar UV radiation in the year 2000" (World Health Organization, 2021). Noise pollution is sound at levels high enough to cause physiological stress and hearing loss. Hearing sounds over 85 dB consistently can have long term effects such as psychological disorders, brain damage, loss of hearing, cardiovascular disease, etc. Animals like birds and amphibians who utilize vocalization for life strategies like mating, avoiding predators, and hunting are negatively impacted by anthropogenic sound.

Research Methods:

The TerraRover 2 was previously outfitted with only surface temperature and relative humidity sensors. The researchers added a $PM_{2.5}$ air quality sensor that measures various particle sizes with a fully wired data logging and collecting system in 2022. To expand the suite of air quality sensors on the TerraRover 2, the researchers added carbon monoxide, carbon dioxide, ultraviolet light, and sound sensors. To eliminate potential error and human contact, the researchers also connected a wireless data logging and collecting system to each sensor through SD card adapters onto each Arduino Uno. Consequently, the researchers could collect data wirelessly.

Each Arduino sensor was independently programmed and wired onto a corresponding Arduino Uno board. The researchers used the Arduino programming language and Arduino IDE to program each sensor. Each sensor was wired onto the designated breadboard and Arduino Uno board through Arduino wires. The researchers attached each SD card adapter onto individual Arduino Uno boards, therefore communicating with the corresponding sensor. The additional sensors were attached onto a platform 0.2 meters above the ground. Three trials were conducted in each of the three locations. Each trial ran for about five minutes and sensors were collecting data every 10 seconds. Over the course of 3 hours, data was being collected and immediately sent to the corresponding SD card attached to each sensor and Arduino Uno. Following this, all data was transferred to a Microsoft Excel and each sensor output of each trial were averaged. The data was analyzed to check if concentrations of PM, carbon monoxide, carbon dioxide, ultraviolet light, and sound levels differed in various locations in student-congested areas surrounding Crestwood High School. The researchers also averaged the barometric pressure, relative humidity, and temperature of the collection date. Atmospheric data was obtained using GLOBE atmospheric protocols.

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 and Figure 2. 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 three (3) sites where particulate matter, carbon monoxide, carbon dioxide, ultraviolet light, and sound data were collected.

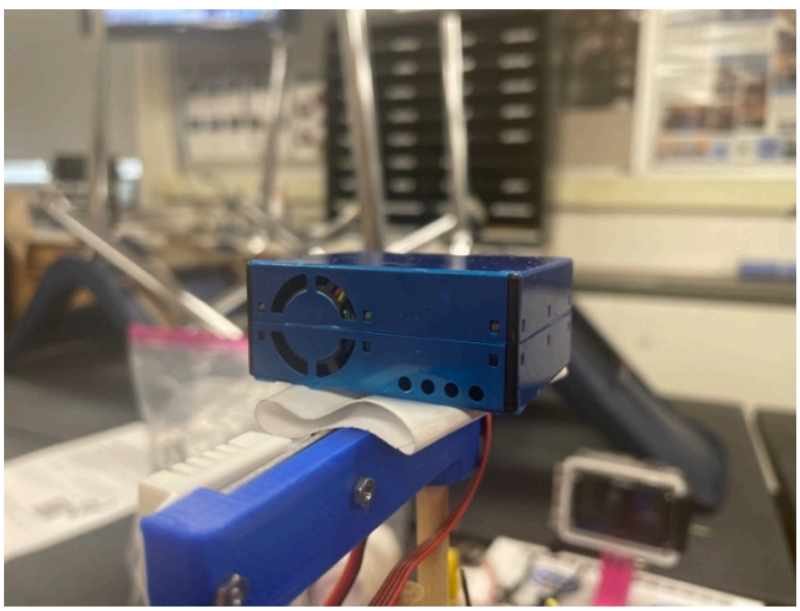


Figure 3. PM2.5 Air Quality Sensor. Image above displays the Particulate Matter Sensor the researchers used to collect PM data. The sensor was placed on the top of the TerraRover 2, secured by industrial tape. The PM2.5 Air Quality Sensor was programmed by the researchers using the Arduino IDE and Arduino programming language. The researchers used SD cards to

achieve a wireless data logging and collecting system, which gave fast communication between the PM2.5 Air Quality Sensor and the Arduino Uno Board.

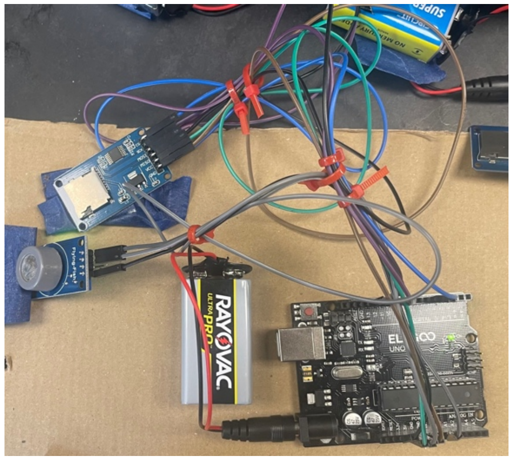


Figure 4. MG-7 Carbon Monoxide Sensor. Image above displays the MQ-7 Carbon Monoxide Sensor the researchers used to collect CO data. The sensor was placed on a platform connected onto the TerraRover 2, secured by industrial zip-ties. The carbon monoxide sensor was programmed by the researchers using the Arduino IDE and Arduino programming language. The researchers used SD cards to achieve a wireless data logging and collecting system, which gave fast communication between the carbon monoxide sensor and the Arduino Uno Board.

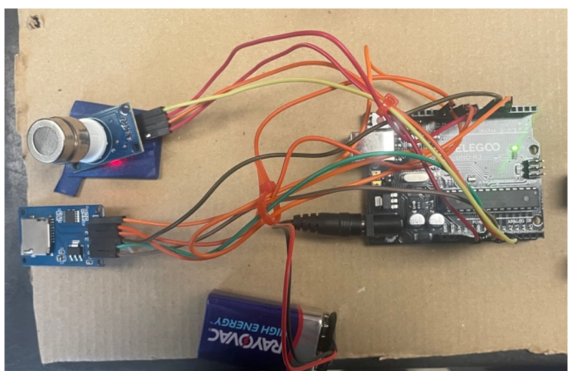


Figure 5. MG-811 Carbon Dioxide Sensor. Image above displays the MQ-811 Carbon Dioxide Sensor the researchers used to collect CO_2 data. The sensor was placed on a platform connected onto the TerraRover 2, secured by industrial zip-ties. The carbon dioxide sensor was programmed by the researchers using the Arduino IDE and Arduino programming language. The researchers used SD cards to achieve a wireless data logging and collecting system, which gave fast communication between the carbon dioxide sensor and the Arduino Uno Board.

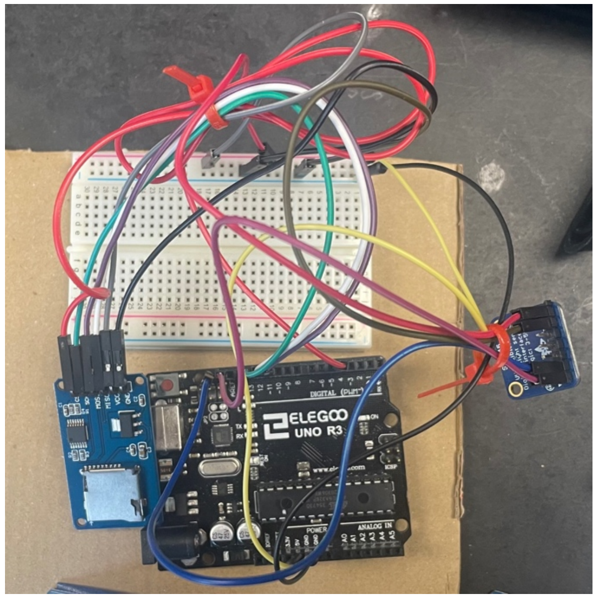


Figure 6. Ultraviolet Light Sensor. Image above displays the Ultraviolet Light Sensor the researchers used to collect UV data. The sensor was placed on a platform connected onto the TerraRover 2, secured by industrial zip-ties. The ultraviolet sensor was programmed by the researchers using the Arduino IDE and Arduino programming language. The researchers used SD cards to achieve a wireless data logging and collecting system, which gave fast communication between the ultraviolet sensor and the Arduino Uno Board.

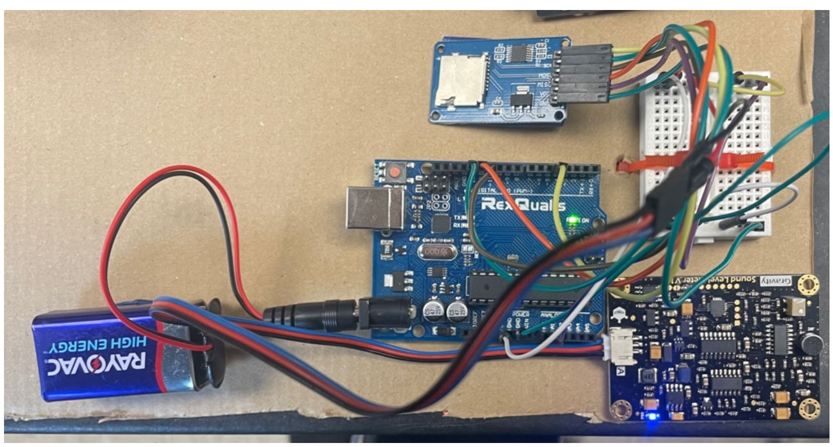


Figure 7. Sound Sensor. Image above displays the Sound Sensor the researchers used to collect sound (dBA) data. The sensor was placed on a platform connected onto the TerraRover 2, secured by industrial zip-ties. The sound sensor was programmed by the researchers using the Arduino IDE and Arduino programming language. The researchers used SD cards to achieve a wireless data logging and collecting system, which gave fast communication between the sound sensor and the Arduino Uno Board.

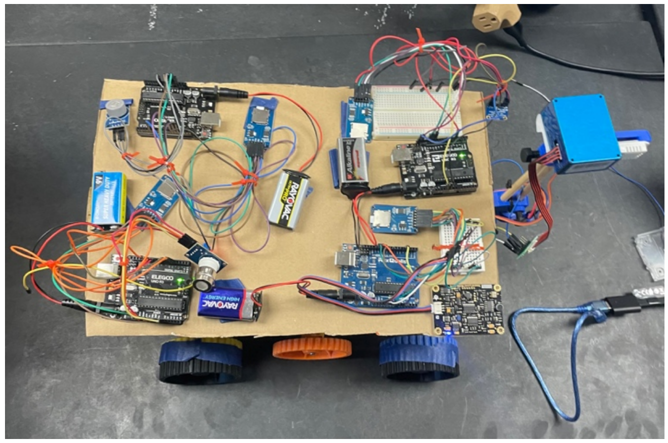


Figure 8. TerraRover 2. Image above includes the mobilization aspect of the research, the TerraRover 2. The TerraRover 2 was provided by NASA GLOBE AREN Project from Mr. David Bydlowski and Mr. Andy Henry. The TerraRover 2 gave insight to the researchers about how much mobilization is important in terms of particulate matter, carbon monoxide, carbon dioxide, ultraviolet light, and sound. 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.

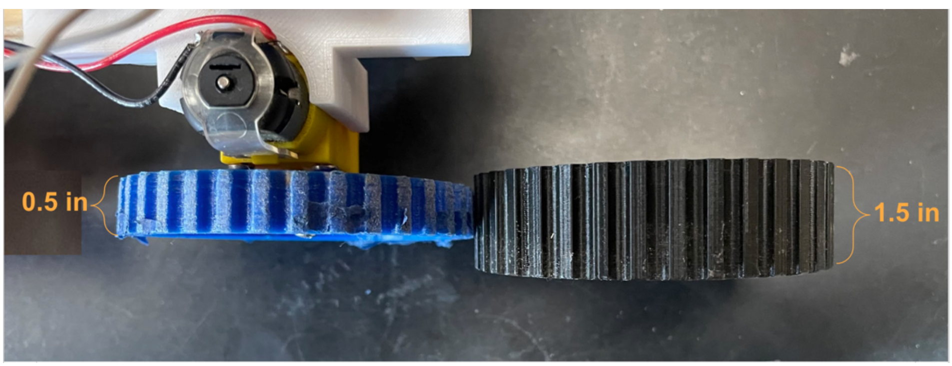


Figure 9. 3D-printed TerraRover 2 Wheels. Image above includes the different dimensions of the wheels used during data collection. The researchers independently used computer-aided design (CAD) to model new wheels for the TerraRover 2 with an increase to 1.5 inches. The researchers were aided by Mr. Andy Henry during the modeling process and 3D-print the design at Wayne RESA.

Figure 10 and Figure 11. 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, carbon monoxide, carbon dioxide, ultraviolet light, sound and GPS all around the researchers' sites.

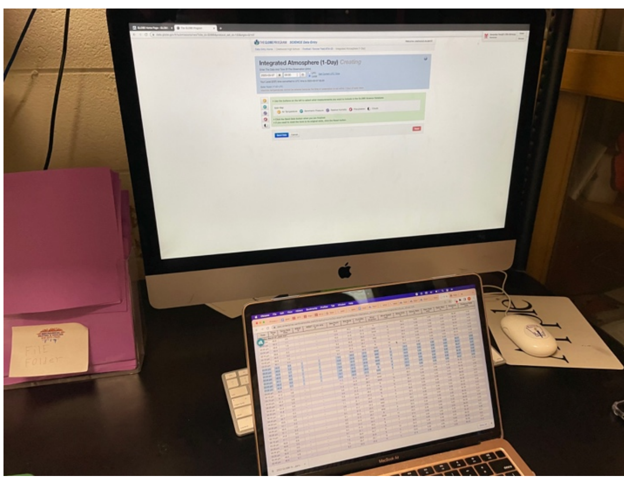
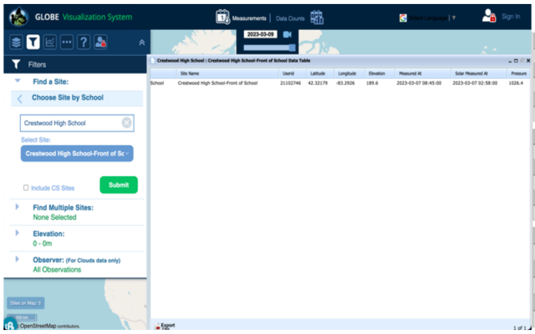
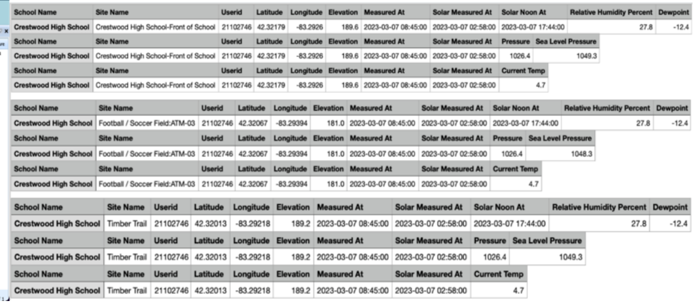



Figure 12 and Figure 13. Data Entry. To impute their data, the researchers used the GLOBE website's "SCIENCE Data Entry" area. The researchers logged the air temperature, relative humidity, and pressure of the day they collected data. The researchers plan on using this data to later monitor the correlation of weather changes with all atmospheric concentrations sensed. Figure (right) show the researcher, Hala Komaiha, inputting the collected data into the GLOBE website.





School Name	Site Name	Userid	Latitude	Longitude	Elevation	Measured At	Solar Measured At	Solar Noon At	Relative Humidity Percent	Dewpoint
Crestwood High School	Crestwood High School-Front of School	21102746	42.32179	-83.2926	189.6	2023-03-07 08:45:00	2023-03-07 02:58:00	2023-03-07 17:44:00	27.8	-12.4

School Name	Site Name	Userid	Latitude	Longitude	Elevation	Measured At	Solar Measured At	Pressure	Sea Level Pressure
Crestwood High School	Crestwood High School-Front of School	21102746	42.32179	-83.2926	189.6	2023-03-07 08:45:00	2023-03-07 02:58:00	1026.4	1049.3

School Name	Site Name	Userid	Latitude	Longitude	Elevation	Measured At	Solar Measured At	Current Temp
Crestwood High School	Crestwood High School-Front of School	21102746	42.32179	-83.2926	189.6	2023-03-07 08:45:00	2023-03-07 02:58:00	4.7

School Name	Site Name	Userid	Latitude	Longitude	Elevation	Measured At	Solar Measured At	Solar Noon At	Relative Humidity Percent	Dewpoint
Crestwood High School	Football / Soccer Field:ATM-03	21102746	42.32067	-83.29394	181.0	2023-03-07 08:45:00	2023-03-07 02:58:00	2023-03-07 17:44:00	27.8	-12.4

School Name	Site Name	Userid	Latitude	Longitude	Elevation	Measured At	Solar Measured At	Pressure	Sea Level Pressure
Crestwood High School	Football / Soccer Field:ATM-03	21102746	42.32067	-83.29394	181.0	2023-03-07 08:45:00	2023-03-07 02:58:00	1026.4	1048.3

School Name	Site Name	Userid	Latitude	Longitude	Elevation	Measured At	Solar Measured At	Current Temp
Crestwood High School	Football / Soccer Field:ATM-03	21102746	42.32067	-83.29394	181.0	2023-03-07 08:45:00	2023-03-07 02:58:00	4.7

School Name	Site Name	Userid	Latitude	Longitude	Elevation	Measured At	Solar Measured At	Solar Noon At	Relative Humidity Percent	Dewpoint
Crestwood High School	Timber Trail	21102746	42.32013	-83.29218	189.2	2023-03-07 08:45:00	2023-03-07 02:58:00	2023-03-07 17:44:00	27.8	-12.4

School Name	Site Name	Userid	Latitude	Longitude	Elevation	Measured At	Solar Measured At	Pressure	Sea Level Pressure
Crestwood High School	Timber Trail	21102746	42.32013	-83.29218	189.2	2023-03-07 08:45:00	2023-03-07 02:58:00	1026.4	1049.3

School Name	Site Name	Userid	Latitude	Longitude	Elevation	Measured At	Solar Measured At	Current Temp
Crestwood High School	Timber Trail	21102746	42.32013	-83.29218	189.2	2023-03-07 08:45:00	2023-03-07 02:58:00	4.7

Figure 14 and Figure 15. GLOBE Visualization Page. The image above shows the researchers' data points using the GLOBE Visualization Page.

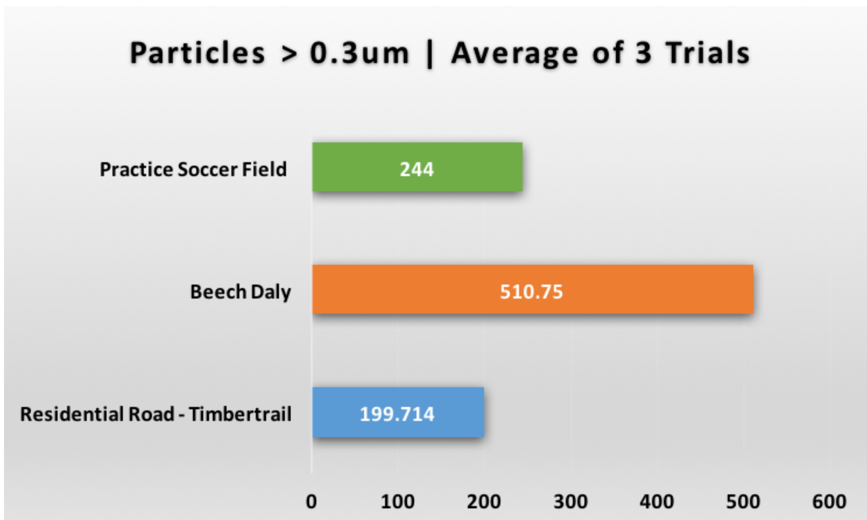


Figure 16. Comparison of Particles > 0.3 microns Over the Average of 3 Trials in Different Research Sites. The bar graph above shows the averages of the different amounts of particulate matter at the different research sites the researchers collected data from over 3 trials. As you can see, the Beech Daly site had most 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. Also, as the TerraRover 2 was moving along a sidewalk during the trials of Beech Daly, showing the connections between the pedosphere and atmosphere, different debris and particulates being picked up by the particulate matter sensor may have caused the drastic amount. 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 re-model of the site and be able to ensure the safety of their children and students.

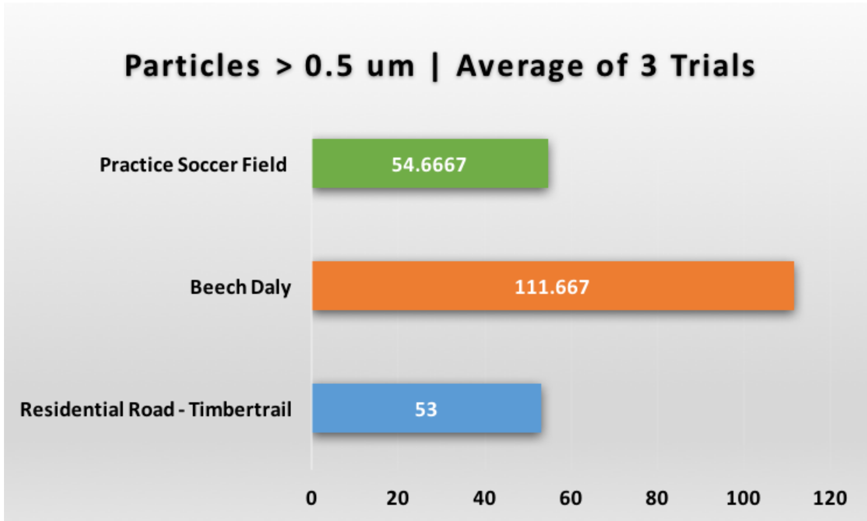


Figure 17. Comparison of Particles > 0.5 microns Over the Average of 3 Trials in Different Research Sites. The bar graph above shows the averages of the different amounts of particulate matter at the different research sites the researchers collected data from over 3 trials. Similarly, from Figure 11, the Beech Daly site had the most of the particles, and the Practice Soccer Field continued to be very similar the Residential Road.

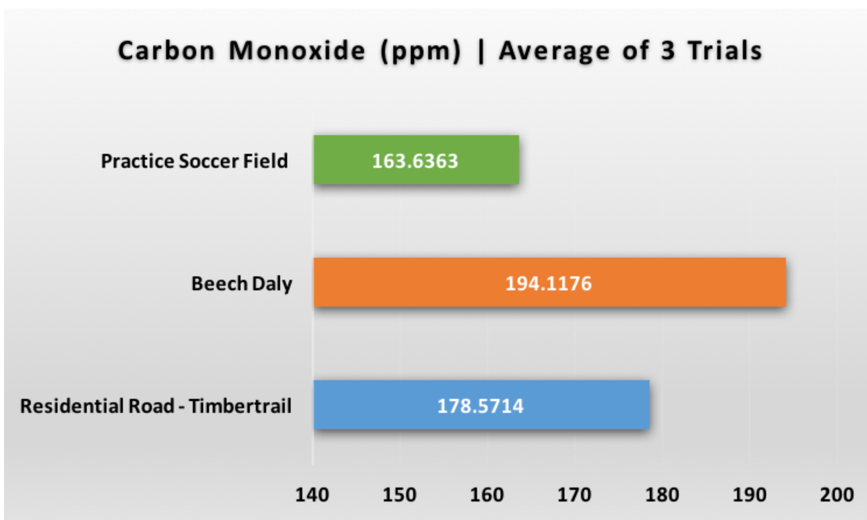


Figure 18. Comparison of Carbon Monoxide Concentrations Over the Average of 3 Trials in Different Research Sites. The bar graph above shows the averages of the different amounts of carbon monoxide at the different research sites the researchers collected data from over 3 trials. As you can see, the Beech Daly site had the largest amount of carbon monoxide part per million. This may have been the results of constant travel through passing cars and their excessive emissions.

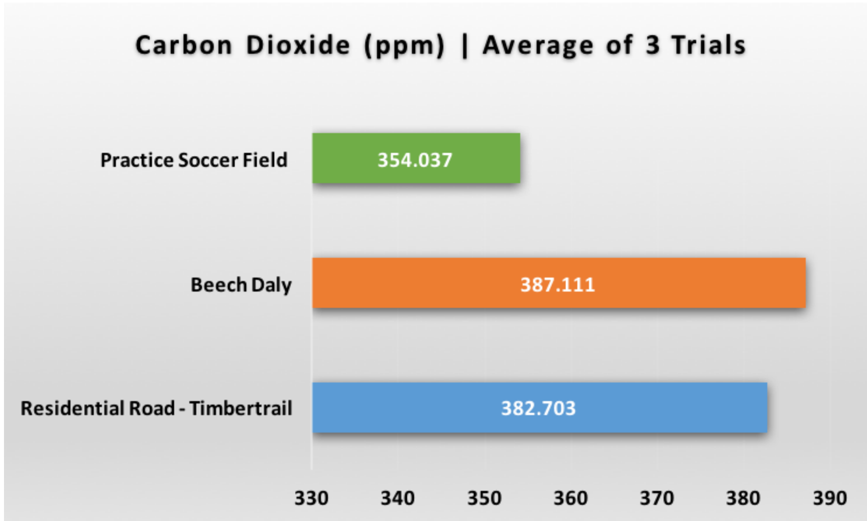


Figure 19. Comparison of Carbon Dioxide Concentrations Over the Average of 3 Trials in Different Research Sites. The bar graph above shows the averages of the different amounts of carbon dioxide at the different research sites the researchers collected data from over 3 trials. Similarly, to Figure 13, the Beech Daly site had the most concentration of carbon dioxide. Although, Residential Road – Timber Trail had a similar amount of carbon dioxide concentration. This may be a result of the close contact the residential road has with the Beech Daly site.

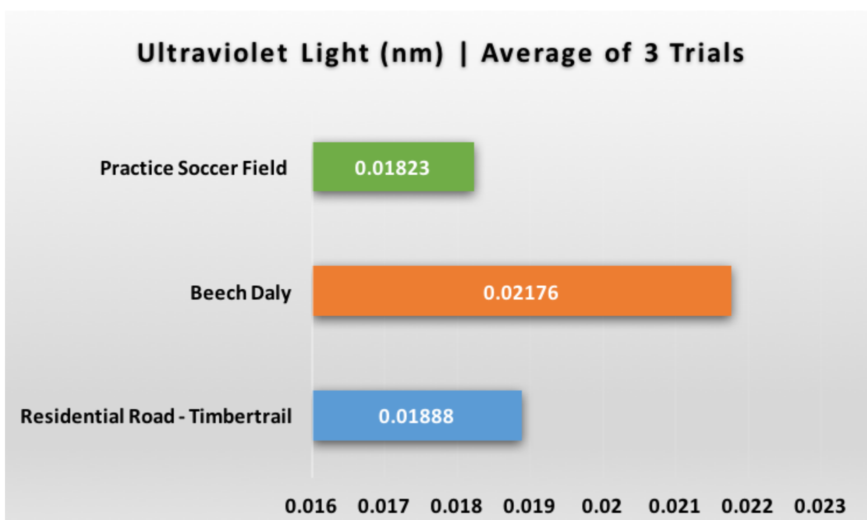


Figure 20. Comparison of Ultraviolet Light Over the Average of 3 Trials in Different Research Sites. The bar graph above shows the averages of the different amounts of ultraviolet light at the different research sites the researchers collected data from over 3 trials. All 3 sites had similar amounts. Although, the Practice Soccer Field and Residential Road – Timber Trail may have similar averages because of the shade both sites carry. The Practice Soccer Field has shade from the school, and the Residential Road – Timber Trail has shade from the neighborhood trees.

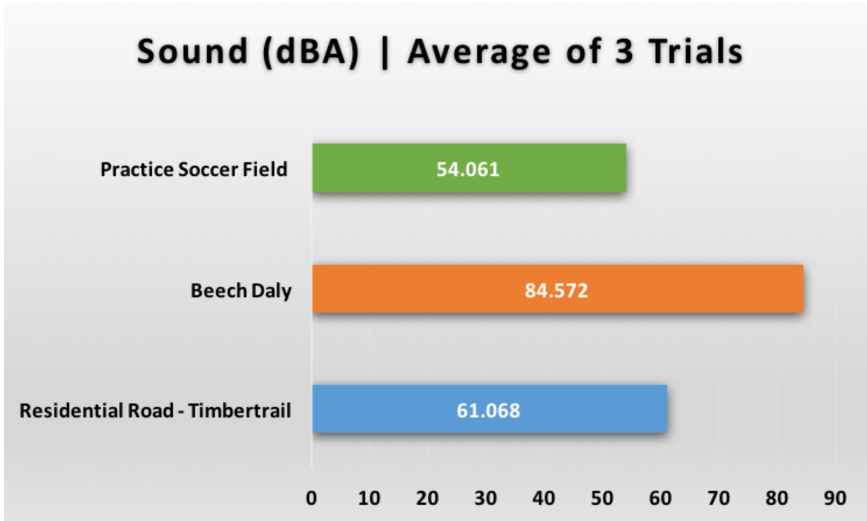


Figure 21. Comparison of Sound Values Over the Average of 3 Trials in Different Research Sites. The bar graph above shows the averages of the different amounts of sound levels at different research sites the researchers collected data from over 3 trials. The Beech Daly site had the highest level as vehicles were passing by. This may also aid the sound value of the Residential Road – Timber Trail as the site is neighboring the Beech Daly site.

All of the programmed sensors worked well when collecting data remotely with the TerraRover 2. The results show higher levels of each parameter were found at the Beech Daly site. The other sites show some variation between each parameter.

Discussion:

PM, CO, CO_2, UV, and sound levels varied slightly between each of the 3 research sites. While most of the data did not differ as much between each sensed parameter, the data taken near the Beech Daly site had higher levels of particulate matter > 0.3-um, particulate matter > 0.5-um, carbon monoxide, carbon dioxide, ultraviolet light, and sound. This location is directly near a major road making car exhaust and low vegetation the most probable cause for the shift in concentrations of particulate matter, carbon monoxide, and carbon dioxide. At the Residential Road – Timber Trail site, levels carried the second-highest concentrations. The levels of particulate matter, ultraviolet light, and sound may have been affected by the close houses and abundant vegetation at elevated levels. The trees overhead and nearby shrubs may have collected airborne particles, provided shade, and blocked sound from human activity. At the Practice Soccer Field site, the levels were generally the least. The levels of PM, CO, CO_2, UV, and sound may have been affected by the open space and high amounts of vegetation at low levels.

Possible sources of error include the limited data collected and accuracy of each sensor. To verify the sensors' results, the researchers could compare data with a professional grade sensor. Unfortunately, this is outside the researchers' budget. In the future, the researchers can verify the data points by visiting an outside lab. GLOBE research previously written by Nazih Baydoun, Hassan Berry, and Nour Kochaiche at Crestwood High School used a PocketLab Air Particulate Matter sensor at higher altitudes. Similarly, the researchers hope to advance their robot to collect data at a human's breathing level to accurately measure how much of the various atmospheric gases humans take in. As the research develops, the researchers are going to monitor the differences of particulate matter, carbon monoxide, carbon dioxide, ultraviolet light, and sound levels compared to weather conditions including pressure, relative humidity, and temperature. The researchers had to reject their first null hypothesis as there was great differences of particulate matter, carbon monoxide, carbon dioxide, ultraviolet light, and sound levels in different locations. The researchers rejected their second null hypothesis, as there were greater levels of particulate matter, carbon monoxide, carbon dioxide, ultraviolet light, and sound levels near heavy traffic. The researchers also rejected their third null hypothesis, as the TerraRover 2's was successfully able to drive while collecting particulate matter, carbon monoxide, carbon dioxide, ultraviolet light, and sound data outdoors.

Conclusion:

In order to limit and regulate air pollution in the United States of America and, ideally, have a positive rippling effect on other countries' air quality, the Clean Air Act was passed into law in 1970. Since then, 52 years have gone. Has air pollution changed noticeably? Scrubbers, catalytic converters, the elimination of leaded gasoline, and other technologies have helped to reduce nitrogen oxides (NOx), sulfuric oxides (SOx), and other criteria air pollutants. But what about particulate matter, carbon monoxide, and carbon dioxide? What about the constant contact with ultraviolet light? Or the rise of noise pollution as a consequence of urbanization? And most importantly, how does the atmosphere in these conditions impact the other Earth spheres, such as the biosphere and pedosphere? Research in the area of atmospheric pollutants, their interactions with different Earth spheres, and their concentrations has become of upmost importance in both developing and developed countries. The Beech Daly research site held the highest concentration of PM, CO, CO_2, UV, and sound. This may have been due to the presence of car exhaust and low vegetation. The Residential Road – Timber Trail research site held the second-highest concentration of PM, CO, CO_2, UV, and sound. This may have been the presence of trees and houses acting as covers and shade for airborne particulate matter, carbon monoxide, carbon dioxide, ultraviolet light, and sound. The Practice Soccer Field research site held the lowest concentration of PM, CO, CO_2, UV, and sound. This may have been the presence of open space and vegetation assisting the particulate matter, carbon monoxide, carbon dioxide, ultraviolet light, and sound. This interaction of vegetation with concentrations sensed shows a great example of two of Earth's spheres interacting to result a large impact. This impact is the increase and large concentration of air pollutants being contact with humans. Throughout the data, there lies a higher concentration of the parameters collected in the Beech Daly and Residential Road –

Timber Trail. As previously stated, both sites have similar geographic characteristics with low vegetation and cement. This shared characteristic was amplified with the contrasting result of the carbon dioxide concentrations. Unlike Beech Daly and Residential Road – Timber Trail, the research site of the Practice Soccer Field has a high vegetation, which may explain the carbon dioxide concentrations being lowest at the Practice Soccer Field. This correlation of high vegetation and lower concentrations of atmospheric parameters, such as carbon dioxide, is seen through the graphical difference of the Practice Soccer Field and, both, the Beech Daly Road and Residential Road – Timber Trail research sites. As a consequence of the world opening back up after the die down of COVID-19, human activities increased once again. Correspondingly, the concentrations of various air pollutants also rose. This growth may cause upper respiratory complications with ultra-fine particles, carbon monoxide poisoning, and carbon dioxide poisoning resulting in a possible increase of mortality due to the negative health effects on the human heart and lungs. By measuring local levels of particulate matter, carbon monoxide, carbon dioxide, ultraviolet light, and sound, students involved in school outdoor activities can be warned on days that they might be exposed to high levels. Teaching staff and coaches can make informed decisions about whether or not to allow outdoor play, labs, etc. Lungs damaged by inhaling fine particulate matter, carbon monoxide, or carbon dioxide can lead to increased pulmonary and heart issues if COVID-19 or other respiratory diseases are contracted. In the future, the researchers would like to compare concentrations of particulate matter, carbon monoxide, carbon dioxide, ultraviolet, and sound on warmer weather days to see if weather has a positive correlation. 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 the sensors. The drive will also be much smoother and faster because of the improved mechanism of the wheels. Another advancement that the researchers would like to include is multiple air quality sensors that would simultaneously run to display other pollutants in the air such as Nitrogen Oxides, Sulfuric Oxides, Lead, Ozone, and other criteria air pollutants. The GLOBE program might want to consider adding a particulate matter and ultraviolet light protocol. Working with our project mentor and former AP Environmental Science teacher, Mrs. Diana Johns, provided us with the knowledge of the TerraRover 2 and its wide scope of abilities. Mrs. Johns introduced both researchers on the dangers and possible solutions of air and noise pollution. Most importantly, Mrs. Johns introduced both researchers to the GLOBE program in early 2021.

Limitations:

While the researchers were able to successfully collect their data through a wireless data logging and collecting system while simultaneously driving the TerraRover 2, a major limitation was time constraints. All four newly added sensor had to be compatible with a specific Arduino model, Arduino Uno, because of memory storage. The researchers also had to program and connect the $PM_{2.5}$, carbon monoxide, carbon dioxide, ultraviolet light, and sound sensor to each corresponding Arduino Uno and SD data logging module 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 long period of time while analyzing the data to check the weather's role in the different concentrations collected.

Another limitation of this study was how accurate the different sensors are. With the use of more professional sensors, the collected data would be more precise than the current sensors attached to the TerraRover2. A high-quality version of the multiple sensors could also be used to validate the data values given by the current sensors that is currently in use.

Citations/Bibliography:

World Health Organization. (2021). Air pollution. In *Compendium of WHO and other UN guidance on health and environment* (pp. 9–32). World Health Organization. http://www.jstor.org/stable/resrep35857.8

Schwarze PE;Ovrevik J;Låg M;Refsnes M;Nafstad P;Hetland RB;Dybing E; (n.d.). *Particulate matter properties and health effects: Consistency of epidemiological and toxicological studies*. Human & experimental toxicology. Retrieved March 9, 2023, from https://pubmed.ncbi.nlm.nih.gov/17165623/

Klaassen, G., Berglund, C., & Wagner, F. (2005). Carbon dioxide. In *The GAINS Model for Greenhouse Gases — Version 1.0: Carbon Dioxide (CO_2)* (pp. 19–22). International Institute for Applied Systems Analysis (IIASA). http://www.jstor.org/stable/resrep15745.5

Yasuda, T., Yonemura, S., & Tani, A. (2012). Comparison of the Characteristics of Small Commercial NDIR CO2 Sensor Models and Development of a Portable CO2 Measurement Device. *Sensors*, *12*(3), 3641–3655. https://doi.org/10.3390/s120303641

World Health Organization. (2021). Radiation. In *Compendium of WHO and other UN guidance on health and environment* (pp. 81–93). World Health Organization. http://www.jstor.org/stable/resrep35857.12

Acknowledgements:

Working with Mr. David Bydlowski and Mr. Andy Henry of the NASA AREN program was very educational and inspiring for the researchers. They worked with and advised them on how to improve the CAD models for the new TerraRover 2 wheels and the different methods to approach connection of a data logging and collecting SD card module. The researchers also worked with their former AP Environmental Science teacher, GLOBE Advisor, and Science Club Advisor – Mrs. Diana Johns. Inside and outside the classroom, Mrs. Johns has informed both researchers about the dangers of air pollution and its effects on other Earth spheres. Through working with all their mentors, the researchers were able to truly understand the importance and impact of their research. Studying the relationships between the different Earth

spheres through collecting data on air quality in general is as significant as ever as a result of the COVID-19 pandemic and the rising use of fossil fuels.

I Make An Impact:

The researchers hope to receive the "I Make An Impact" badge as the implementation of this research can make both a local and global difference. TerraRover 2s outfitted with numerous types of air quality sensors can be used around the Detroit metropolitan area. This will allow us to map our region's air quality results. Locally, these results could be used to notify building personnel if air quality results are outside of the range that is safe for humans. The use of TerraRover 2s will also allow us to gather air quality data in places otherwise not viable for humans. On a smaller scale, firefighters could use a TerraRover 2 to gather carbon monoxide/dioxide data to get an idea of what is going on inside a burning building. On a larger scale, we could use the TerraRover 2 to gather air quality data of numerous locations in our solar system like Mars. This would allow us to compare air quality on Earth, an overpopulated planet, to air quality with somewhere that has never been inhabited, to our current knowledge.

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. Both collaborators were there to guide students on any arising issues of the connection between the Arduinos and sensors. This also includes attempting to get the sensors to save data wirelessly which was ultimately solved through the use of an SD card. Mr. Andy Henry and Mr. David Bydlowski also provided the technology needed for the TerraRover 2's main functions. The student researchers ran into issues with the robot not being able to drive effectively over rough terrain. In response, the collaborators allowed the researchers to 3D print replacement wheels that were thicker in order for the robot to overcome any obstacles on its route.

I Am A Data Scientist:

The researchers hope to receive the "I Am A Data Scientist" badge for their collection, interpretation, and organization of data. The researchers coded and wired the TerraRover 2 to continuously save data as they drove the TerraRover 2 around. 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, carbon monoxide, carbon dioxide, ultraviolet light, and sound levels found in that area. Due to global quarantine, air pollution rates had dramatically decreased during the COVID-19 pandemic. Ultrafine particle concentrations are said to have dropped as much as 50%! As the world continues to fully open back up, vehicle and industrial air pollution emissions are unfortunately increasing rapidly once again. Our limitations were time constraints and validity of all sensors.

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 the problem of limited space on the TerraRover 2 for the anticipated four new sensors. This problem lead the researchers to brainstorm and produce prototypes of different additions to increase capacity. During the brainstorm, a possible design was to expand the TerraRover 2 on the sides. This would be achieved as the researchers would attach the platform to the base of the TerraRover 2 with diagonal skewers. The prototype was made with a 15-in. x 11-in. sturdy cardboard platform; to eliminate the movement of the Arduino sensors. Although, the researchers realized this method may not work because the platform would be covering the main power source and the radio signal with the controller. Also, the height of the Arduino sensors would be too short to log and collect accurate data points. The next prototype consisted of a similar model that is already being in use for the particulate matter sensor with a fitted 3D-printed design and skewers to create a tower-like structure. Although, this concept was not tried because with the contrasting size of each Arduino sensor and the balance of each Arduino sensor, inaccurate results may be present. The final prototype that the researchers ended up using was an elevated platform being supported with a vertical structure onto the middle of the base of the TerraRover 2, away from the radio signal and main power source. This design also solved the problem with the elevation of each sensor as each sensor is at a height sufficient for accurate outputs. This design also solved the problem with the imbalance of each sensor as each sensor was securely attached onto the flat platform with industrial adhesive. During the process of independently programming with the Arduino IDE and Arduino programming language and wiring each sensor onto its corresponding Arduino, the researchers had an issue with the Arduino library of the carbon monoxide sensor. This library consisted with all of the programming that the carbon monoxide should “already” know, which would make the process of programming the carbon monoxide smoothly. But, the library primarily being in use with similar projects was terminated because of the newer versions of the Arduino Unos. The researchers tackled this problem by modifying and creating a new and updated open-source library for all carbon monoxide sensors. This library did not only help the programming issue for the researchers, but also future Arduino project with the carbon monoxide for anybody with internet access. Expanding from the researchers’ prior research with the TerraRover 2, the researchers wanted to make the process of data collecting and logging through a wireless system. While speaking to Mr. David Bydlowski and Mr. Andy Henry, the researchers resulted with the attachment of SD cards onto each Arduino Uno and ultimately each Arduino sensor. This efficiently increased the experience of data collecting for the researchers. During the wiring process of the different Arduino sensors, the researchers found out that the SD card data logging and collecting module and the particulate matter both needed 5V power from the Arduino Uno. The researchers solved this minor issue with attaching a 9V battery through the SCP port attached onto the Arduino Uno. With the experience of the TerraRover 2 that the researchers hold, the researchers wanted to change the thickness of the TerraRover 2 wheels because of the different terrains the TerraRover 2 would be going through to collect data. The new wheels would potentially give the TerraRover 2 a smoother ride, giving more accurate results of each sensor. The researchers independently learned and used CAD modeling software to model a fitted TerraRover 2 wheel with a 1-inch increase. This would result with a 0.5-in to a 1.5-in. Mr. Andy Henry at Wayne RESA helped the researchers with the ability of using Wayne RESA’s 3D-printers to print 4 new 1.5-in wheels.