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Drone-Based System to Reduce Air Pollution Using Inexpensive Materials

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ABSTRACT

Outside, polluted air contains many particles that are harmful to all organisms. Currently, there are no reliable, efficient, or effective ways to clean outside air pollution. This paper describes an early attempt to create a drone-based pollution vacuum cleaner that uses inspiration from the tornado's Fibonacci spiral shape's ability to create powerful vacuums. By mounting various Fibonacci spirals onto a drone, the aim was to create a vacuum that can collect, and filter simulated polluted air. The reduction in pollution particles was measured with an Air Quality Index (AQI) meter. The engineering process involved:

1. 3D printing and designing Fibonacci-shaped spirals with varying degrees of curvature.
2. Testing various motors and spirals and their efficacy in vacuuming air into the filters.
3. Testing the vacuum effect on the drone's ability to fly

The process compared the effectiveness of the spirals based on their improvement of the AQI in the simulated polluted environment. The wide spiral (Spiral #1) is 1.5cm in width, and 1cm in height with 5729.57 degrees of curvature resulting in the most reduced AQI, from 500 to a healthy breathable number in 15 minutes. In addition, the drone ascended 3 meters while withstanding the vacuuming effect coming from the attached spiral. The project utilizes natural designs such as the Fibonacci spiral shape of a tornado on a smaller scale as a prototype for an improved air filter. For further research, the plan is to make the drones autonomous and test more spirals using different materials.

Introduction and Goal

Daily pollution from cars to barbecues to smoke from fires all contain harmful particulate matter (PM). PM particles are small, harmful particles made of incompletely broken-down fossil fuels, acids, metals, and more. [1] Particulate matter hugely impacts animals, birds, and humans. Breathing in PM particles can result in lung cancers, worsening breathing, and even premature death. Over 42 million people die prematurely from outdoor air pollution every year, and currently, around 2.4 billion people are being affected by this problem.[7]

There are two different types of PM particles $PM_{2.5}$ and PM_{10} [Fig 1]. The numbers correlate to the diameter of the particles on a micron level. Particles larger than 0.1 but smaller than 2.5 microns fall in the category of $PM_{2.5}$. Particles larger than 2.5 but smaller than 10 microns belong to PM_{10}.[7] Though only $PM_{2.5}$ is invisible to the naked eye, both $PM_{2.5}$ and PM_{10} are very dangerous if inhaled. $PM_{2.5}$ particles mainly affect the lungs. When $PM_{2.5}$ particles are in your lungs, they are impossible to remove and can have long-term health effects such as asthma. PM_{10} particles mainly affect the upper half of the respiratory system, meaning the throat, mouth, and nose. When exposed to PM_{10} particles, you can have difficulty breathing, a heart attack, or a stroke. [7 10 12]

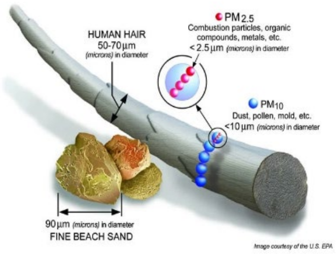


Figure 1. PM2.5 particles

A current solution to this problem is an electrostatic precipitator (ESPs) [Fig 2][16]. ESPs use electric currents to collect the particles in the air. Though they can clean the air at around 95% efficiency, ESPs are known to release high amounts of ground-level ozone. Ground-level ozone is known to cause a large number of health problems. In addition, the ESPs make the particles stickier. [16] Also, ESP's storage of the particles is not the best, the stickier particles are more prone to reentering the air and going into the lungs and staying there. As more particles stick to the plates of the ESPs, their efficiency can drop as low as 60%. Not only are these devices not that efficient, but they also consume a lot of energy. Just in a month, one ESPs uses around 120-131 kilowatts. [16]

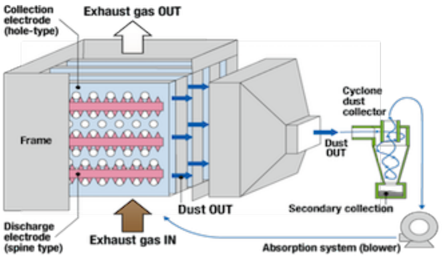


Figure 2. Electrostatic Preceptor

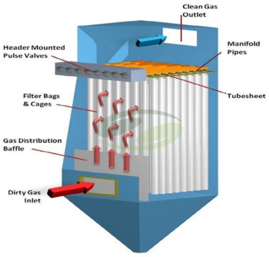


Figure 3. Bag House

Another solution to this problem is the baghouse, Fig 3. Baghouses use a bag filter, which can filter out dust, but not in large amounts. [2] In addition, Baghouses tend to take up a large amount of space and require a lot of maintenance. Baghouses are also prone to catching on fire or causing an explosion. They also usually fail due to chemical erosion, abrasion caused by rubbing against themselves, and more. [2] So, is there an eco-friendly and efficient way to remove most of the wildfire's particle pollutants in the outside air to enable the user to safely spend time outside?

One possible solution was to use a vacuum. Nature is the source of inspiration to create a vacuum powerful enough to suck in moderate amounts of air and not cause disruption. The Fibonacci spiral is the main reason that tornadoes can create such powerful vacuums [Fig. 4]. This shape could be used to make an eco-friendly and efficient way to clean the air [Fig 5].[9] [18]

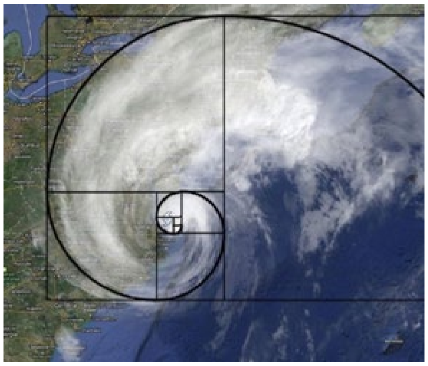


Figure 4. Tornado in a Fibonacci Spiral

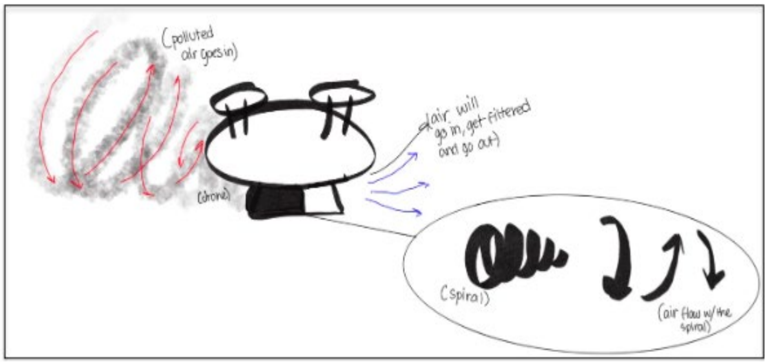


Figure 5. Using Air to Improve the Air

METHODS

Modeling/Printing of Spirals

First, the spirals were 3D modeled and printed. The spirals were modeled using the application called Blender and printed using a 3D printer. Three different sizes of spirals were tested. The dimensions of each spiral are described in Table 1 and the pictures of them in Blender are shown in Fig 6. The spirals were printed twice, the first printed batch was thin and bendable (Group 1). Thickness was increased in the second batch which was sturdier and more rigid (Group 2).

Modeled Spirals Selection

Both groups were tested, Group 1 and Group 2, to see which one would perform more effectively. After running them using a motor of 16,000 RPM, it was determined that Group 1's spirals were fast spinners but did not have enough volume of air. Whereas Group 2's spirals got enough volume but required a stronger motor. The Group 2 spirals were tested again with an RPM of 56,000 with a 9 Volt battery, and the outcome was adequate. Group 2 was used for the rest of the study. The differences between Groups 1 and 2 are listed in Table 2.

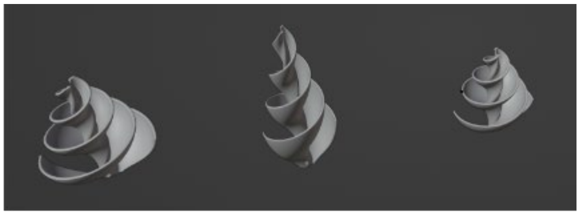


Figure 6. 3D Modeled Fibonacci Spirals

Table 1. Spiral sizes

Spirals	**Spiral 1 Wide**	**Spiral 2 Elongated**	**Spiral 3 Short**
Radius [Farthest Circle]	1 cm	1 cm	1.5 cm
Height [Top to Bottom]	2 cm	2.5 cm	2 cm

Table 2. Compare and Contrast Group 1 and Group 2's Spirals

Characteristics	Group 1	Group 2
Thickness of Fill	50% infill	100% infill
Average Spinning Speed	3RPM	2RPM
Weight	4 grams	7 grams

Attachment of Spirals onto the Motor

The next part was figuring out how to attach the 3D-printed spirals to the motor.
While in the designing process, a hole was added to each spiral, to attach the raft end of the motor directly into the spiral, therefore ensuring stability as well as convenience. But while morphing the original spiral shape, the hole morphed as well, and the motor raft did not fit securely.

This led to two additional ideas to secure the spirals:

- Attachment #1. A 3D printed stick
- Attachment#2. A LEGO piece

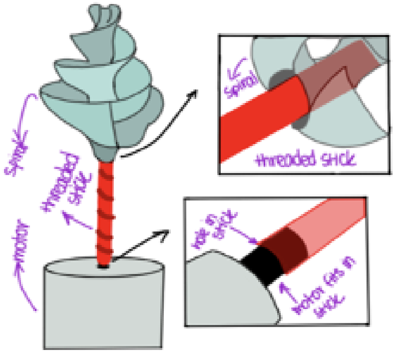


Figure 7. Attachment #1

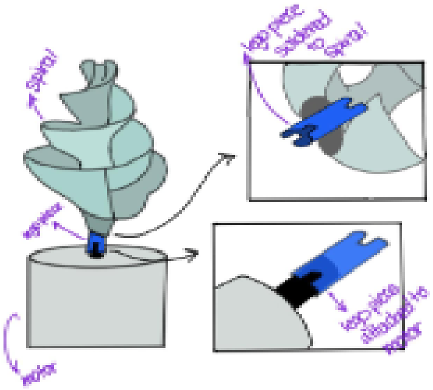


Figure 8. Attachment #2

<u>Attachment #1</u>

A 3D-printed threaded rod with a hole at the bottom for the motor head [Fig 7] was used but it was not able to fit into the motor. Modeling and using different sizes did not work either as the printer was not able to print a precise hole that could fit in the motor. So, hot glue was used to glue both plastic pieces together. However, after spinning the motor a couple of times, the spiral, along with the rod would fly off. This was not able to secure the spirals to the motor.

<u>Attachment #2</u>

The next attempt was to attach the spiral to the motor using a LEGO piece. This LEGO piece had one side inserted into the hole in the spiral and the other side enveloped the motor head [Fig 8]. This attachment resulted in a stable attachment, when used on the Spiral 1 spiral, but for the other two spirals, the LEGO piece had a hard time fitting in the hole at the bottom of the spirals, as they had become a lot smaller. To fix this problem, again hot glue was used to glue the two pieces together and reinforce it with duct tape, to ensure that the spirals would not fly off. This attachment ended up being a very secure and reliable way for attaching the spirals to the motor, and was the attachment used when testing the spirals. Fig 8 shows the planned design, and Fig 9 shows how the spirals look with the LEGO piece attached.

Figure 9. Final Spirals with Lego

Attachment to Drone

The next step was to attach the motor with the spiral to the drone in a way that did not affect the drone's ability to function. After much brainstorming and testing various ways of attachment [Fig.10], it was decided to use paper cups to hold the vacuum. a filter could be attached to the back, where the air could pass through, and easily attach it to the drone.

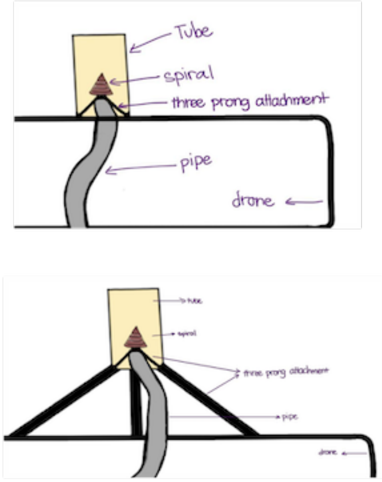


Figure 10. Initial Test Designs

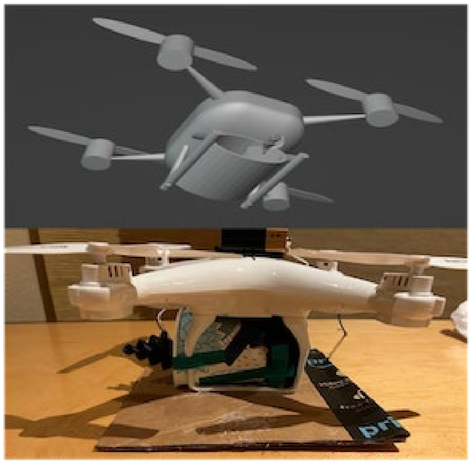


Figure 11. Final Design and Implementation

On the base of the drone, a rectangular cardboard was attached to provide more stability and support to the drone as well as the cup with the vacuum [Fig.11].

Suction Test

Before attaching the spirals to the drone, a suction test was used to test how strong each of the spirals was when it came to being able to vacuum air. A piece of paper on a pole and two stacks of books were used, each spiral was run and the angle at which the piece of paper lifted relative to where it was placed was recorded. The setup is displayed in Fig 12 and each of the spiral tests is shown in Fig 13-15. During the test, each spiral was run for 5 minutes from the same starting point, and on the paper, the angle the paper was at when it was maximum displaced was recorded.

Through this data, it was clear which spiral had the best suction. Later this data was compared to the cleaning efficiency of the spirals too.

Figure 12. Set Up

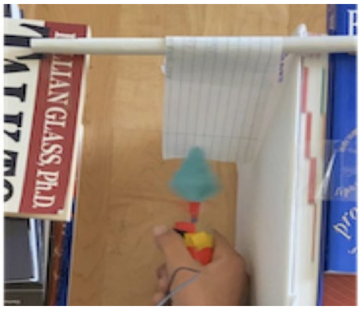


Figure 13. Spiral 1(Wide) Spiral Suction Test

Figure 14. Spiral 2(Elongated) Spiral Suction Test

Figure 15. Spiral 3(Short) Spiral Suction Test

Simulated Test

The last step was to see how well the spirals work when it comes to actually cleaning the air. To test this quality, a simulated polluted environment was created in a cardboard box [Fig.16].

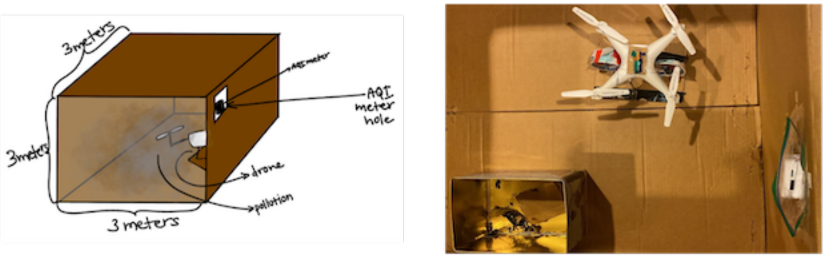


Figure 16. Simulated Polluted Environment

The spirals were now tested. An environment of 500 AQI was created in the box at the beginning and the drone with the spiral running (not flying the drone) inside the box and timed. To measure the AQI within the box, an AQI meter was used. In addition, due to the long periods of time, a phone was used to record the meter and later the video was scanned to read the AQI meter at certain time points. The last test was a flight test to see if the vacuum was interfering with the drone's ability to fly, and during this test, it was measured that the drone was able to fly 3 meters in the air. At first, the drone was not able to fly, due to the heavy battery, motor, and camera that was attached. To lighten the weight that it was carrying, the camera was removed, and the drone ended up flying. In addition to doing the tests for the 3 spirals, two control tests were performed to receive a baseline of how well the box was holding the polluted air, as well as how a regular fan would compare to the spirals.

Results

Suction Test Results

After performing the suction test on each of the spirals as in Fig10- Fig13, the lines measuring the angle of displacement were drawn. The result is shown in Fig.17. Regarding the regular fan and the spirals, there is a clear difference when it comes to the suction test, in that all the spirals were able to pull the paper to a greater angle than the fan. The Spiral 1 spiral showed the best displacement.

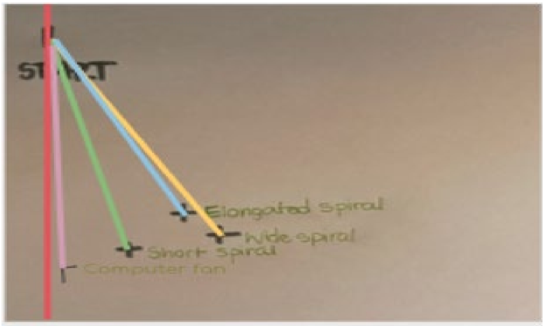


Figure 17. Suction Test Results

Simulated Test Results

The next test performed was the cleaning test in a simulated environment. During the 20 minutes when the test was performed, the timestamp and the AQI reading at that time were recorded periodically.
The outcomes of both the spiral tests and the controls are listed in Table 3.

Table 3. AQI meter readings with different spirals, no spiral, and computer fan

Time	Spiral #1 AQI	Spiral #2 AQI	Spiral #3 AQI	No Spirals AQI	Computer Fan AQI
0:00	500	500	500	500	500
3:30	236	317	320	500	490
5:00	175	325		480	480
7:30	172	282	342	476	460
10:00	177	253	347	480	467
12:30	163	230	333	477	450
15:00		259			

However, the spirals were not able to bring the AQI down to a healthy number within 20 minutes. To get an estimate of when AQI would be at a healthy level, the data points that were collected were graphed and the line of best fit was drawn, Fig [18-22].

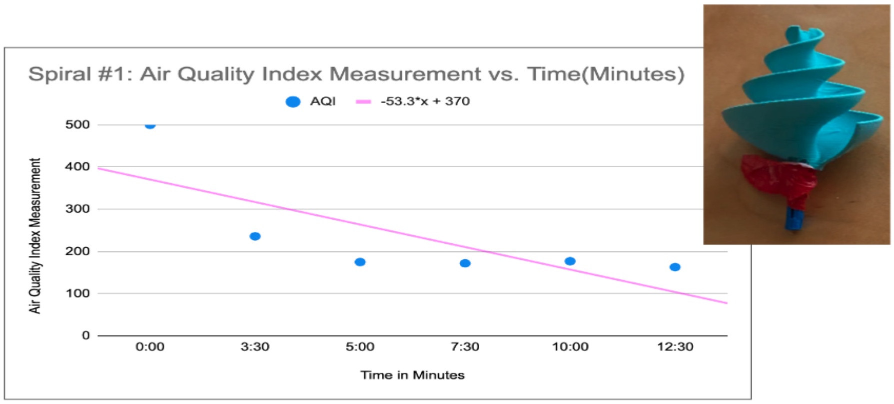


Figure 18. Spiral 1(Wide) Spiral Filter Test

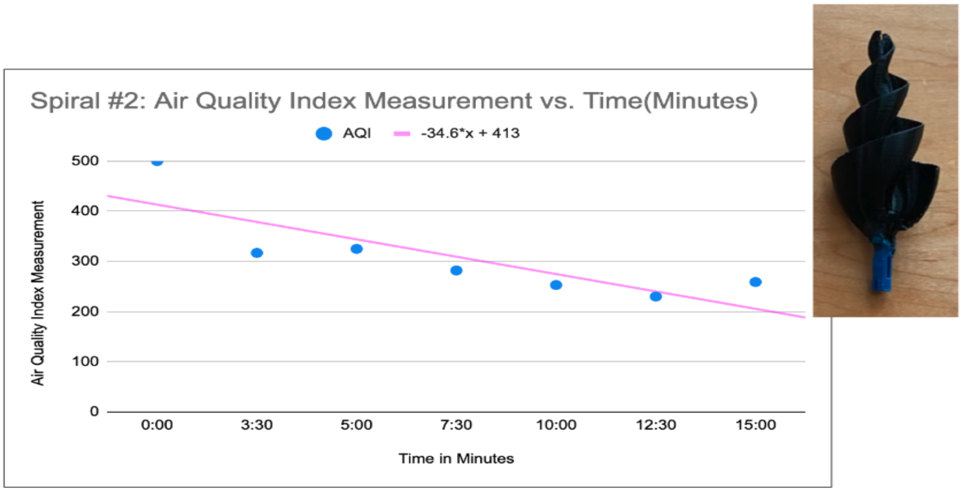


Figure 19. Spiral 2(Elongated) Spiral Filter Test

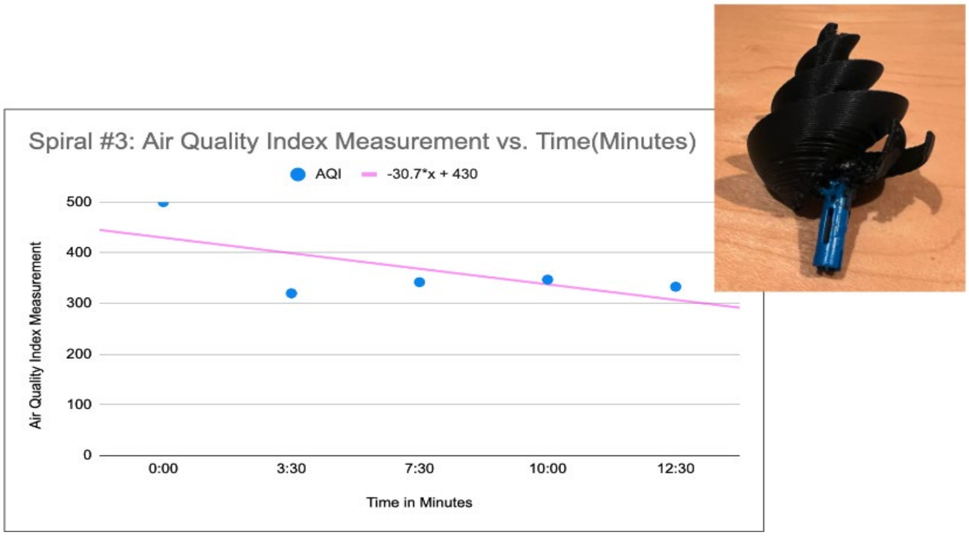


Figure 20. Spiral 3(Short) Spiral Filter Test

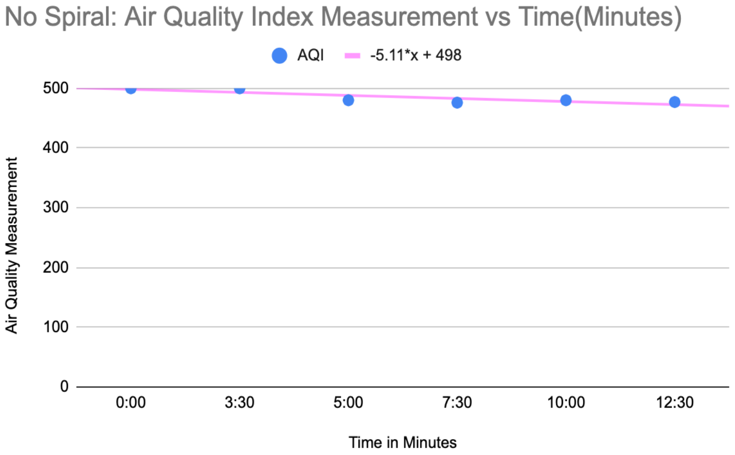


Figure 21. No Spiral Baseline Test

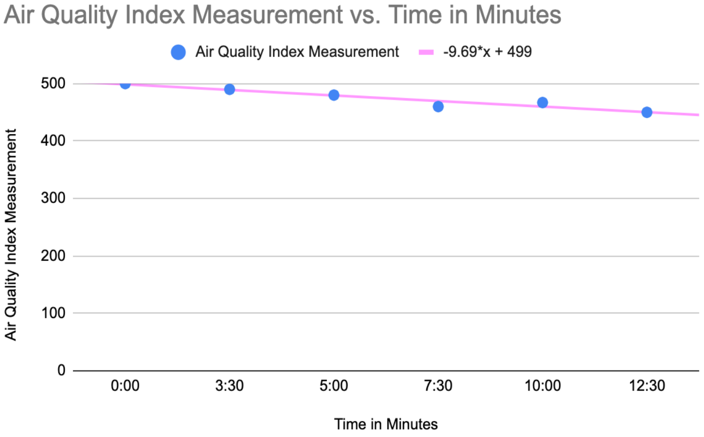


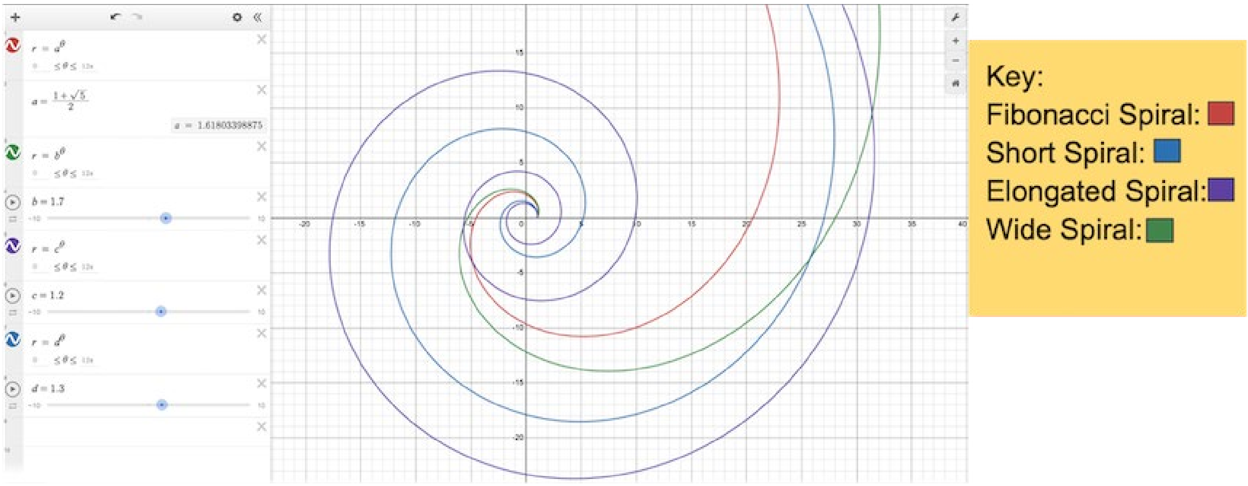
Figure 22. Computer Fan Filtering Test Result

Through these charts, it was determined that the steepest slope was the most efficient. The spirals surpassed the regular fan in terms of efficiency. In 20 minutes, the regular fan did not reduce the air quality as much as the spirals.

Despite the computer fan performing worse in the cleaning test and suction test, when it came to the flight test, the computer fan was better. The drone with the computer fan could fly much higher, considering that it used a smaller motor, which required a much smaller battery, making the overall drone lighter in weight.

The No Spiral baseline test confirmed that the fans were bringing down the AQI through cleaning instead of the box leaking out pollution. In terms of statistical analysis, we can deduce that each of the spirals was able to bring down the AQI by at least 100 in the first 3 minutes. After around 3 minutes, the rate of filtering, measured through change in AQI, became constant in all spirals. There was a possibility of the mask being saturated, but that testing was out of the scope of this research. When each of the spirals was compared to doing nothing to remove pollution, the spirals each performed better in terms of efficiency, as doing nothing took around 3 hours to get the AQI to drop around 100 and extrapolating that data would give us over 15 hours for the AQI to reach a healthy amount. On the other hand, the spirals each would have brought the AQI down in around 6 hours. Also, in comparison to the regular computer fan, which would take around 10 hours to bring down the AQI and had a very low rating during the suction test, the spirals performed much better.

The research also compared the shape of the spirals concerning the Fibonacci spiral shape and whether it had any effect on their performance. With further research, it was determined that the Fibonacci spiral can be represented mathematically through the logarithmic equation of a spiral, $r = a^9$, where a is the golden ratio and theta angle of rotation. An attempt was made to find the closest logarithmic spiral equation for each of the Fibonacci spirals used and graphed them all on the same graph, Fig. 23. This proved that the theory was true, in that the spiral that performed the best out of the three, the Spiral 1 spiral, was the closest to the Fibonacci spiral when it comes to shape.



$r = a^\theta$

$a = \frac{1+\sqrt{5}}{2}$

$a = 1.61803398875$

$r = b^\theta$

$b = 1.7$

$r = c^\theta$

$c = 1.2$

$r = d^\theta$

$d = 1.3$

Figure 23. Fibonacci Spiral

Discussion

Through these results it is evident how using Fibonacci spirals can effectively clean the air and with further work on the drone in terms of design and technology, the cleaning efficiency can only get better. When this experiment was started, it was not clear if the idea of using the Fibonacci spiral as an efficient vacuum would work, or if drones could be used to filter air. Through this paper, it is evident that the Fibonacci spirals attached to drones with easy-to-use filters could prove to be a possible way to collect and filter air in an eco-friendly efficient way.

The experiment faced many issues and they led to many iterations to get to a better solution. The first was that the 3D-printed spirals were too thin and fragile, and testing them didn't give the expected results, so the spirals were reprinted. Printing a sturdier spiral led them to be a lot heavier, meaning that the small DC motor, with an RPM of 16000, was not strong enough to run the spiral. A new motor that has an RPM of 56000 was used and this larger motor needed a bigger battery. Different batteries ranging from 3-volts to 9-volts were tested and it was determined that the motor needed the 9-volt battery to run the best. After the installation of the new equipment, it was determined that the drone was too heavy and could not fly. All the unnecessary parts, like the factory installed camera, were removed to make the drone lighter, allowing liftoff in a controlled manner.

Next, the spiral was glued onto a LEGO piece, which was then connected to the motor. During the 20-minute testing period, the AQI meter would time out and turn off, resulting in missing some of the data because the AQI meter would have to be readjusted to show the correct reading. To solve this problem, the line of best fit was used, and that helped in getting the data's trend. In addition, the AQI would improve during the test but soon reached a constant rate after around three minutes. There are two possible explanations for this, either the spiral is not good enough, or the filter is getting quickly overloaded. To solve the spiral issue, different spiral shapes were used. Mathematical models were used to get the best spiral shape. Even when using the actual Fibonacci spiral, the 3D printer inserted errors in the shape, so using the mathematical model helped determine how far the printer was off and accommodate the results accordingly. In addition, a better filter could be used that will not overload as quickly.

Each spiral was tested twice, and during each test, the results did not change significantly, showing that it is possible to create an eco-friendly pollution control system that does not use harmful chemicals or pollute the environment in another way.

There are many opportunities for further research. The air cleaning process could be improved using smart technology i.e. integration of code, algorithms, and sensors. The spirals used for air collection could be improved by further 3D modeling and mathematical models. In addition, a better attachment to connect the filter and the motor to the drone will allow for better cleaning results. Finding a smaller motor and a lighter battery can allow the drone to fly higher. In terms of technological advancements, drones can be made autonomous by using sensors such that they can detect boundaries set by the users and obstacles in their path. To make this technology more efficient, multiple autonomous drones could be used. The filter used in this experiment was an N95 mask, but in the future, testing done on various materials can be performed to see if more eco-friendly filters can be used.

Conclusions

In conclusion, we can utilize the physics of naturally occurring forces and natural designs in a controlled state, to help us solve tough engineering problems. This project shows the potential for targeted air filtration in scenarios such as wildfires and daily pollution. The results address the research question that drones can rid the air of harmful particles in an eco-friendly and efficient way. Regarding the application of the prototype, in the future, this can be used to help reduce the amount of pollution coming from planes, through having drones following it as it flies. In its current state, the prototype could be used in the backyard to locally clean the air.

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