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Research Article

Application of Drones in Pollution Mitigation through Artificial Rainfall

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ABSTRACT
Air pollution is a critical global challenge, with urban areas experiencing hazardous levels of particulate matter and harmful gases. Artificial rainfall via cloud seeding offers a potential solution by inducing precipitation to cleanse the atmosphere. Traditional methods rely on manned aircraft to disperse agents like silver iodide or sodium chloride into clouds, stimulating rain. While effective, this approach is costly, labor-intensive, and lacks precision, making it impractical for frequent or small-scale operations, especially in budget-constrained regions.
Drones present a transformative alternative for cloud seeding. Compared to aircraft, drones are cost-effective, scalable, and highly adaptable. Coordinated drone swarms can target specific urban areas, enhancing the accuracy and efficiency of agent dispersion. Their autonomous capabilities reduce the need for extensive personnel or infrastructure. By leveraging drone technology, artificial rainfall becomes a more practical, flexible, and environmentally friendly method to address air pollution

1. Introduction

Air pollution is a severe environmental and public health crisis, especially in urban areas where industrial activities, vehicle emissions, and construction dust contribute to high levels of airborne pollutants. Elevated levels of pollutants such as particulate matter (PM2.5 and PM10), nitrogen oxides (NOx), and sulphur dioxide (SO2) significantly degrade air quality, leading to adverse health effects, reduced visibility, and even increased mortality rates [1-3]. Traditional pollution control measures, such as vehicle emissions regulations and air purifiers, are insufficient to counteract the rapid rate of pollution accumulation, particularly during periods of high atmospheric stability, which can trap pollutants close to the ground.

In recent years, artificial rainfall via cloud seeding has shown promise as an effective method to cleanse the atmosphere by washing away pollutants. However, conventional cloud seeding methods primarily rely on manned aircraft to disperse seeding agents, which is both costly and logistically challenging, limiting its scalability for regular or widespread use [4-6]. The reliance on aircraft also restricts the precision and responsiveness of cloud seeding, especially in targeting specific urban areas with concentrated pollution.

This project addresses the need for a cost-effective, precise, and scalable solution to mitigate urban air pollution through artificial rainfall by deploying a swarm of autonomous drones for targeted cloud seeding. By leveraging drones, the goal is to improve the feasibility, flexibility, and efficiency of cloud seeding, enabling more frequent and localised operations that could make artificial rainfall a viable method for reducing pollution levels in high-density areas.

1.1 Health & Environmental Effects of Air Pollution

- Health Effects

Irritation of the eyes, nose, and throat Wheezing, coughing, chest tightness, and breathing difficulties Worsening of existing lung and heart problems, such as asthma Increased risk of heart attack.

- Acid Rain

Damages trees, ecosystems, buildings, and water bodies, making habitats unfit for some wildlife.

- Wildlife Impact

Air toxics cause birth defects, diseases, and biomagnification in aquatic food chains.

2. Cloud Seeding - Overview

Researchers have been testing the effects of cloud seeding since the 1940s. In 1946, a chemist at New York's General Electric Laboratory made an encouraging discovery that sparked the experiments. In 1946, Mr. Vincent Schaefer successfully recreated a snowfall and rainfall in a controlled laboratory setting. Success in transforming dry ice particles (frozen carbon dioxide) into extremely cold water droplets was the result of a string of experiments that followed the original results. The trials for rainfall enhancement were initiated by these trials, which were conducted several years later. In an effort to reduce the destructive power of cyclones, the United States launched a program in the 1960s called "Stormfury" due to the widespread scientific support for cloud seeding [7-8]. Prior to realizing the approach was useless, they believed it was worthwhile to test it on several Atlantic hurricanes. Reason being, there isn't enough water in hurricanes for the chemicals to bond and have that great of an effect. In the world's driest places, like the United Arab Emirates, Saudi Arabia, Jordan, Morocco, Libya, and Syria, cloud seeding has become a popular way to increase rainfall thanks to scientific study and technological advancements. In 2009, the Chinese government conducted One of the most noticeable cloud-seeding operations. It was launched over the capital city of Beijing [9-10]. The Indonesian government also used cloud seeding to extinguish jungle fires that were sending thick smoke to the capital Jakarta. It was not easy to control the fire, so they sprinkled salt over the clouds by using Indonesian military aircraft.

2.1 Indian History of cloud seeding

National Physical Laboratory (NPL) conducted experiments on seeding during the period of 1957-1966 in India using ground-based generators. IITM conducted experiments on cloud seeding during the period of 1973-1974 and 1979-86, resulting in a 24% increase in rainfall. The Tamil Nadu government conducted experiments on cloud seeding during the period of 1983-87 and 1993-94. Karnataka state initiated cloud seeding by using modern equipment like radars and aircraft in 2003. Maharashtra state also started to conduct experiments on cloud seeding. Andhra Pradesh state also conducted operations on cloud seeding during 2003-2009. It is considered the longest and biggest cloud seeding program in South East Asia [11-12]. In 1952 Dr. Banerji experimented on cloud seeding using catalysts such as salt and silver iodide in hydrogen-filled balloons. In 1953 Council for Scientific and Industrial Research (CSIR) recommended a committee called Rain and Cloud Physics Research (RCPR) to undertake extensive studies on making rain on cloud physics. From 1957 to 1966 RCPR conducted experiments on rainmaking in North India using salt as a catalyst. In their experiments, they found a 20% increase in the rainfall amount. During the period 1973, 1975-1977 similar experiments were conducted by IITM in the Tamil Nadu state. Cloud seeding experiments were also conducted in the monsoon season in 1973 in Mumbai. The experiment conducted by IITM in Maharashtra state at the Baramati area during the time of 1973-74, 1976, and 1979-86 indicates that there was an increase of 24% rainfall by Murty, and Ramachandra 2012. Rainmaking stimulation on warm clouds was done in the monsoon season at Jaipur, Agra, and Delhi using aircraft. Results revealed that the orographic cloud in the summer season in South India at Munnar increased the precipitation amount. The increase in precipitation amount is 18.6 - 58.5 percent.

2.2 Cloud Generation

Vaporized water vapor, produced as surface temperatures rise, is what gives rise to clouds. The vapor is heated at lower levels and cooled at higher ones due to differences in elevation. There are various sorts of particles in the air, and when they collide with vapour, they form new particles. Condensation of nuclei is the chemical process by which vapour forms around air particles. The end product of this process is larger water droplets, yet they are so light that they continue to fly and form the familiar clouds, thanks to this process. Relative humidity is a critical atmospheric condition that must be satisfied for this process to proceed.

In order for clouds to form, the relative humidity must be high, ranging from 60% to 100%. The relative humidity can be expressed as the product of the partial pressure of vapour and the total pressure of vapour. To put this in context, the partial pressure is the concentration of water molecules in a given medium, while the total pressure indicates the capacity of that medium [13-14].

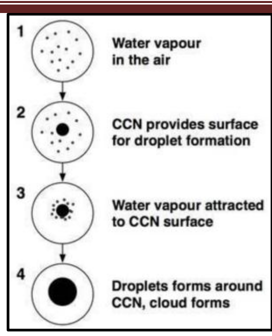

Figure 1. Formation of water drop on CCN

Thus, relative density is high when molar concentration is little and low when molar concentration is big in relation to the capacity of the medium. Clouds are more likely to form when there are a lot of droplets, to put it simply.

2.3 Benefits of Cloud Seeding

Many of the problems that countries have experienced in the past can be better handled with the help of cloud seeding. The primary advantage of cloud seeding is that it can bring much-needed rain to regions who are desperately in need of it, since it is often the sole method for doing so [15]. Because more condensation needs to fall to the earth, cloud seeding tries to increase precipitation. Conditions that are favorable for rain but the clouds aren't powerful enough to bring it down have a beneficial effect on parts of our planet that suffer from chronic shortages. The use of this method aids farmers in increasing yields while also improving crop quality. It paves the way for recharging of groundwater habitats. We can lessen the likelihood of global starvation when we are successful in disseminating this technology. When precipitation is scarce, people turn to silver iodine to make it rain. Precipitation plays a crucial role in maintaining soil moisture and plant growth.

2.4 Disadvantages of Cloud Seeding

There are a number of potential drawbacks to cloud seeding that could impact its use and effectiveness, as is the case with any newly found approach. Keep in mind that chemical seeding of clouds is a real thing. As a result, potentially dangerous compounds might be released into the atmosphere. Even while cloud seeding is designed to protect plants from pests, the chemicals used in the process can harm the ecosystem. The effects of silver iodine on ecosystems have not been the subject of any rigorous research. In cases of "iodism," a form of iodine poisoning, symptoms such as a runny nose, headache, skin rash, anemia, and diarrhoea are possible side effects of using silver iodine. Animals, humans, and fish are all severely affected by it. The long-term effects of cloud seeding on ecosystems are still mostly unknown, but that might change as new studies come out.

3. Literature Review

Drone-based cloud seeding is an innovative approach that leverages unmanned aerial vehicles (UAVs) to induce artificial rainfall, offering a potential solution for air pollution mitigation and environmental management. Traditionally reliant on manned aircraft, cloud seeding involves dispersing particles like silver iodide into clouds to stimulate precipitation. Using drones for this process enhances cost-efficiency, precision, and scalability, making it a viable alternative to traditional methods and applicable in both urban and rural settings.

3.1 Recent Developments

- Efficiency and Flexibility

Studies have shown that drones equipped with precision instruments can measure atmospheric parameters, such as temperature, humidity, and particulate matter concentrations, in real time. For instance, the CLOUDLAB project demonstrated the use of multirotor drones for targeted seeding experiments, enabling precise cloud microphysical adjustments and seeding plume monitoring.

- Instrumentation

Some drones, like the Meteodrone MM-670, integrate advanced payloads such as Portable Optical Particle Spectrometers (POPS) for aerosol measurement and onboard heating systems for operations in supercooled cloud environments. These features allow for higher operational reliability and accuracy in challenging weather conditions.

- Cost-Effectiveness

Compared to manned aircraft, drones require significantly lower fuel and maintenance expenses. Their smaller operational footprint makes them ideal for localized applications, especially in urban areas where air pollution is a pressing concern.

3.2 Advantages of Drone-Based Cloud Seeding

Drones bring several advantages over traditional aircraft, including lower operational costs, greater flexibility, and enhanced safety. Unlike manned flights, drones eliminate risks to human operators, reduce fuel consumption (with many drones operating electrically), and require less maintenance. Additionally, drones can target specific cloud formations with high precision, ensuring efficient dispersal of seeding agents. These capabilities make drones ideal for localised applications, such as urban air pollution control, and large-scale projects in rural areas to support agriculture.

In urban environments, drones could be deployed to reduce air pollution by inducing rain that clears particulate matter, providing a temporary improvement in air quality. Rural regions prone to drought could also benefit from drone-based cloud seeding to enhance rainfall, supporting soil moisture levels and reducing dust, which can affect crop health. The flexibility and scalability of drones make them highly adaptable, allowing for rapid deployment in response to pollution crises and environmental emergencies.

3.3 Cost-Effectiveness and Efficiency

Drone-based cloud seeding is also significantly more cost-effective compared to conventional methods. Traditional cloud-seeding aircraft are costly due to high fuel needs, complex maintenance, and crew requirements. In contrast, drones require less operational investment and can be deployed in larger fleets, improving the geographic reach and efficiency of cloud-seeding operations. This economic advantage enhances the feasibility of implementing cloud seeding in pollution-heavy regions, making it a practical tool for pollution control even in resource-limited areas.

3.4 Technical and Regulatory Challenges

While promising, drone-based cloud seeding faces technical challenges such as limited battery life and flight range, restricting high-altitude and extended operations. Accurate seeding also depends on atmospheric data collection, requiring drones to be equipped with advanced sensors for real-time information on cloud conditions. Additionally, regulatory constraints restrict high-altitude drone operations in many countries.

3.5 Ethical and Social Considerations

Ethical questions surrounding drone-based cloud seeding involve potential impacts on neighbouring areas, as induced rainfall in one region could inadvertently reduce precipitation in others. Transparency and community engagement will be essential to address public concerns and build trust in cloud-seeding projects. Furthermore, public health benefits, while promising, require long-term studies to assess the safety of seeding agents on human health.

3.6 Future Research and Industry Implications

Advances in drone technology, including autonomy and AI-driven precision, suggest that drone-based cloud seeding could become more refined, supporting broader applications in pollution control and agricultural assistance. Investment from UAV manufacturers and environmental agencies is expected to increase as the environmental and economic benefits of drones for cloud seeding become clearer. Long-term studies on the environmental and atmospheric impacts of cloud seeding will be critical to establishing sustainable practices and realising the potential of drones for environmental management.

3.7 Challenges and Limitations

Despite their promise, drone-based cloud seeding faces challenges such as regulatory restrictions, limited payload capacity, and relatively short flight durations. However, ongoing research focuses on addressing these issues through innovations like swarm robotics, extended battery life, and adaptive algorithms for autonomous mission planning.

3.8 Conclusion

Drone-based cloud seeding presents a cost-effective, scalable, and precise solution to air pollution, potentially contributing to significant improvements in air quality and public health. While technical, regulatory, and ethical challenges remain, advancements in UAV technology, regulatory development, and public engagement can help maximise the benefits of cloud seeding with drones. With continued investment in research and infrastructure, drone-based cloud seeding could become a valuable tool for pollution control and sustainable environmental management.

4. Proposed Solution & Methodology

The term “drone” usually refers to any unpiloted aircraft. These craft, also known as "Unmanned Aerial Vehicles" (UAVs), are capable of a wide range of tasks, from military operations to package delivery. Drones are available in a variety of sizes, ranging from the size of a plane to the size of your hand. An unmanned aircraft is referred to as a drone. Drones go by more names than just that: unmanned aircraft systems or unmanned aerial vehicles (UAVs). One definition of a drone is an unmanned aerial vehicle (UAV) that flies with the help of onboard sensors, a global positioning system

(GPS), and software-controlled flight plans stored in its embedded systems. The military had the most common association with UAVs. They were first employed for information collection, anti-aircraft target practice, and, more contentiously, as armament platforms. These days, drones have many civilian uses, such as SAR, surveillance, traffic and weather monitoring, firefighting, videography, farming, and delivery services.

4.1 Material Selection

Selection of appropriate materials to ensure their structural integrity, performance, and durability is crucial in designing drones. Material selection is paramount in engineering as it directly influences a product's performance, durability, and functionality. The right materials ensure structural integrity, resistance to environmental factors, and adherence to specific design requirements. Choosing materials with suitable mechanical, thermal, and chemical properties is crucial for optimising a product's efficiency and longevity. Inadequate material selection can lead to mechanical failure, increased maintenance costs, and compromised safety. In summary, meticulous material selection is indispensable for achieving the desired balance of performance, reliability, and longevity in engineering and product design.

4.2 Commonly Used Materials

Several materials are commonly used in the construction of drones, each with its own advantages and limitations:

- Carbon Fibre

Carbon fibre composites are lightweight, strong, and rigid, making them ideal for drone frames. They exhibit excellent resistance to bending and torsion forces, offering stability and durability. However, carbon fibre is relatively expensive compared to other materials.

- Aluminium and Magnesium Alloys

These alloys strike a balance between strength and weight, providing durability while remaining relatively lightweight. They are often used in drone frames and structural components.

- Plastics and Polymers

Certain plastics and polymers, such as ABS (Acrylonitrile Butadiene Styrene) and polypropylene, are popular for drone bodies and enclosures. They are lightweight, cost-effective, and provide good resistance to impacts. However, they may lack the strength and rigidity of other materials.

- Composites

Various composite materials, such as fibreglass and Kevlar, combine different elements to achieve desired properties. Composites offer a balance of strength, weight, and cost-effectiveness, making them suitable for drone components like propellers and landing gear.

4.3 Process of Selection

Choosing the right materials for drones involves a systematic process:

- Requirements Analysis

Determine the specific requirements of the drone, considering factors like payload capacity, flight duration, operational conditions, and regulatory constraints.

- Material Research

Conduct a comprehensive evaluation of available materials, considering their properties, costs, and suitability for the drone's intended purpose.

- Material Testing

Perform structural and performance tests on selected materials to ensure they meet the necessary criteria, such as strength, weight, and durability.

- Cost Analysis

Evaluate the cost implications of each material option, considering factors such as procurement, manufacturing, and maintenance costs.

- Material Selection

Based on the analysis and testing, choose the materials that best fulfil the requirements and offer the most optimal balance of performance, durability, weight, and cost.

4.4 Frame Design

Material Selection: The selection of appropriate materials to ensure their structural integrity, performance, and durability is crucial in designing drones. The main factors that are considered in the process are Weight, Strength, Durability, Electrical Conductivity & Cost. Choosing the right materials for drones involves a systematic process:

- Requirements Analysis

Determine the specific requirements, considering factors like payload capacity, flight duration, operational conditions, and regulatory constraints.

- Material Research

Conduct a comprehensive evaluation of available materials, considering their properties and suitability for the drone's intended purpose.

- Cost Analysis

Evaluate the cost implications of each material option, considering factors such as procurement, manufacturing, and maintenance costs.

- Material Selection

Based on the analysis and testing, the materials that best fulfil the requirements and offer the most optimal balance of performance, durability, weight, and cost to be chosen.

Several materials are available which have their advantages and disadvantages, and comparing them with one another leads to the best material for the task. These include Aluminium & its alloys, Carbon Fibre, Plastics & Polymers, and Composites etc. Aluminium alloys are easy to use but can get quite heavy when compared with other possibilities. Plastics are a feasible option for smaller parts with the help of 3D-printing technology, but not practical for the whole frame. Composites can be useful but fabricating them comes with its challenges along with the cost. Carbon Fibre tubes and sheets are a highly efficient choice considering how lightweight it is, with the only disadvantage being the cost. To make a drone that's durable enough for future applications and further development, Carbon Fibre along with PLA, ABS & TPU 3D-printing is selected. While Carbon Fibre provides high strength and reliability, 3D printing provides flexibility in design. It allows the team to design the drone with almost complete freedom and develop creative designs and solutions. PLA material is highly rigid and easy to print, so it's utilised in almost all the places where required. ABS has a higher melting temperature, so it's specifically used at motor mounts so it can handle motors as they get heated up in continuous flights. TPU is a very flexible material and is specifically used at the landing part so it can act as a shock absorber.

4.4 Drone Layout

The frame is a unique design deviating from standard X and prioritises weight efficiency. Motors have been placed at the corners of a 370x370mm square maintaining a 4 cm gap between adjacent propellers and more than enough space in the middle to place components. Two plates are spaced 20 mm apart with the arms sandwiched between them with the help of 3D-printed mounts. The arms have a diameter of 12mm for both strength and vibration resistance. These mounts also play a role in maintaining the 4° banking angle accurately. This design facilitates strategic component placement: the bottom plate houses components like the buzzer and PDB while the upper plate accommodates the Flight Controller, Safety Switch, Telemetry and Receiver. The GPS is placed at a completely different height to ensure minimum interference from any other component. The upper plate has a cutout in the middle and is left open on the sides for easy access to PDB, in case of any part change or any other situation. The payload dropping mechanism is ingeniously engineered; incorporating 3D printed PLA parts for durability and rigidity in the 1.8-litre capacity bay. Safety measures include a lightweight propeller shield to mitigate risks of any hand getting too nearby.

4.5 Conclusion, Limitations & Future Scope

In this project, we successfully designed a drone tailored for cloud seeding operations aimed at mitigating air pollution through artificial rainfall.

Despite the project's achievements, it did not include the development of a physical prototype, limiting the validation of our design to simulated environments. While the simulations indicate a high potential for efficiency and precision, real-world testing is essential to validate these findings comprehensively. Additionally, practical challenges such as operational integration, maintenance, and scalability of drone swarms remain untested.

Looking ahead, this project lays the groundwork for creating and testing a physical prototype, allowing for validation in field conditions. Further advancements could include the development of coordinated swarm operations, enabling multiple drones to work in sync for improved cloud seeding efficiency. These steps would deepen our understanding of the practical implications and enhance the scalability of drone-based cloud seeding for pollution mitigation. The promising results from this study highlight the potential for drones to provide a cost-effective, adaptable, and environmentally friendly solution to combat air pollution.

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