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Research Article

Cyber-Physical Systems with Anti-smog Guns for Busy City Areas to Suppress Air Pollution Efficiently

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Abstract— Living in once the world's most polluted city i.e. Kathmandu, it is obvious to question ourselves what adverse effect we could have by just inhalation of the toxic air every day, especially, when inhaling the air for a single day equals the fumes produced by nearly 10 cigarettes. Meanwhile, the long-term plans–planting trees, strict traffic regulations, and awareness–seemed to be implausible for the locals and city hustles. Similarly, instant solutions like Anti-smog vehicles invite more problems like traffic congestion and management efforts, and solutions like air scrubber technology are yet to be implemented that require prior data of polluted areas to place the scrubber efficiently. Therefore, a concept to tackle these issues, a system that automatically implements instant solutions to suppress air pollution for adverse effects, is to be introduced. This paper explores the concept of Technology, IoT, Data Science, and Cloud computing concepts to build a Cyber-Physical System and uses water mist with suitable eco-friendly surfactants to suppress air pollution in busy city areas efficiently. Our proposed solution uses a chain of Nephelometers throughout the city at specific distances that send data to the cloud that is further processed to operate the nearby automatic immobile Anti-smog gun to suppress the particulate matter without any traffic congestion or mass wastage of resources. The collected data collected in the cloud could be further evaluated to place additional Air Scrubber Systems in specific required areas.

Keywords— Cyber-Physical System, Air Pollution Suppression, Transdisciplinary approach, Anti-smog guns, Air Scrubber, Nephelometer, IoT, Cloud computing, etc.

1. Introduction

Air pollution is one of the most pressing issues of the decade, taking nearly 7 million lives each year, around half of which are within urban areas [1]. Therefore, finding solutions for urban areas is more demanding than those areas with comparatively fewer sources of air pollution [2]. For a few decades, lots of work has been done to mitigate air pollution that is, however, unable to reduce the severe effect on the locals, currently suffering from the harsh and toxic air of urban areas. Some of the general solutions include afforestation, planting in city areas, and regulating strict traffic and household policies to reduce carbon emissions [3]. However, all of these solutions require a certain dedication and long-term vision from the public that seems to be less promising when it comes to controlling the effects on health by urban air pollution [4]. Especially in congested city areas with less land to plant trees and a busy lifestyle, the mentioned solutions are never meant to be feasible [5]. Meanwhile, solutions addressing the health effects on the urban population by air pollution are also introduced and implemented as well in some of the top air-polluted cities such as New Delhi, Beijing, Seoul, etc. [6]. The most common technology used these days is anti-smog guns that use pure water or water with some eco-friendly surfactants to dissolve the pollutants in the air to settle it down [7]. Still, it uses mobile anti-smog guns in urban areas, loaded on trucks, that increase traffic congestion and are likely to waste resources with non-dynamic spraying of water without relying on proper data of location with major pollution [8]. Thus, the solution discussed in this paper works with the Cyber-Physical System (CPS) to address these issues and primarily reduce the potential health risks to locals from air pollution in an instant approach rather than a long-term solution.

1.1 Literature Review and Related Works

Air pollution in urban settlements, especially in marketplaces with congested populations and traffic ways is one of the major health concerns. In dense population areas, the instant solution to reduce the impact on the health of the major population requires dedicated attention to mitigate it with regard to dense settlements and busyness [18]. Several studies have explored solutions to mitigate air pollution, including long-term strategies like afforestation, and technological interventions like air purifiers and anti-smog guns for urban

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settlement to reduce the impact of air pollution in dense settlements where solutions like afforestation are hard to implement [13, 18].

1.1.1 Studies and Past Works

Afforestation and urban greening have been introduced very before to reduce air pollution. Trees and green initiatives can absorb air pollution and improve air quality which requires a certain long-term plan. However, as shown in the studies held by Nowak et al. and McPherson et al., in the context of dense and congested settlements, these solutions become too hard to implement [17, 18]. Due to these limitations, the health of the public residing in air polluted areas becomes vulnerable.

In the study by Chen et al., Technological solutions like air purifiers and scrubbers have been found to significantly reduce particulate matter and other pollutants, which were observed in indoor areas [13]. However, to dispense these technological solutions in outdoor environments, the study led by Zhao et al. urges certain strategic placements and determined infrastructures [19].

A recent study done by Kumar et al. shows mobile anti-smog guns have been used to spray water mist in cities like New Delhi and Beijing so that airborne particles settle down which improves AQI [16]. However, the use of mobile anti-smog guns attached to trucks and semi-trucks has led to issues such as traffic congestion and inefficient resource use. In recent studies, the requirement for more urban-feasible and data-driven technology has been highlighted [14].

The study of Gupta et al. shows the integration of IoT and data science in environmental monitoring, especially in the concept of Smart City initiatives, is gaining attention which uses sensor networks to monitor air quality in real-time, providing valuable data that can be further stored to analyze the air quality data for targeted interventions [15]. Further, this data-driven approach seems promising to ensure the efficiency of the resources used in air pollution control measures.

1.1.2 Research Gap

The long-term solution becomes too generic and time-consuming when it comes to a solution to reduce the health impact for the population in the main city area. The instant planning to reduce the health impact on urban settlement, from the observation of past works, seems to be challenging with the current methods and technology used. Thereafter, the introduction of a new technology architecture is required to address the issues of implementing air pollution control to reduce the severe impact on public health. Accordingly, solutions with the integration of real-time data analysis and automated control systems which also take issues like traffic congestion and crowded settlements into account are required.

1.2 Approach for the Solution

The solution is based on two initializing steps, one operational step, and one post step that could be implemented to place the air scrubber system later. The two primary steps include installing a chain of any communicable AQI measuring devices or nephelometers in the most vulnerable urban areas with a specific radius of 70 to 100 meters to collect data the first [9]. In the second step, the data collected are evaluated in the preference of primary locations, where the pollution is majorly accumulated at first and then starts to spread, to place the anti-smog guns efficiently with a radius coverage of 50 to 70 meters at the top of an 8 to 12 meters high building (if available) with good accessibility of water, with eco-friendly surfactants if feasible, and electricity [10]. In the operational step, the incoming data from nephelometers at the server are first analyzed with reference to different aspects including wind speed and weather forecasting for rains to operate specific anti-smog guns rather than just spraying water from nearby anti-smog guns randomly [11]. Further, the stored data could be used to place the air scrubber system efficiently in the central locations for air pollution [12].

1.3 Transdisciplinary Nature of the Solution

The approach introduced in the paper blends Computer science, Engineering, Environmental science, and Urban planning to bring the solution to one of the major concerns about public health. The solution proposed in the approach uses the concepts of Environmental science and Urban planning to build the basics, and algorithms to analyze the data. Similarly, the core system of the approach uses a complete Cyber-Physical System that includes the concepts of IoT, data science, Application Programming Interface (API) and cloud computing which falls under the scope of Computer science, and the complete system’s architecture uses physical knowledge of the Engineering concepts to leverage wind velocity, distance predictions, efficient locations of IoT devices and anti-smog guns in the model to meet the common goal i.e. to mitigate the severe impact of air pollution on main city areas’ dwellers.

2. Proposed Cyber-Physical System

To achieve the automated air pollution suppressing system that uses an anti-smog gun with a concept of IoT, firstly, several communicable and compatible AQI measuring devices (or nephelometers) are installed across the city that reports the three specific data to the server at a duration of 10-20 minutes i.e. data of particulate matters present in the air, its location and the specific time with date. The nephelometers are set up at a radial distance of about 100 meters. There are most often specific areas in the city that primarily produce or accumulate pollutants at a wide range and then those pollutants spread with the wind making a wide coverage of air pollution-affected areas. Therefore, it is important to analyze the data from a complete chain of nephelometers to read the specific area that produces or accumulates the pollutants primarily, and then the direction followed by it to spread as shown in Figure 1. In this way, we could come up with specific areas where anti-smog guns can be fitted initially to make it more economical for a wide coverage to suppress the air pollution throughout the main urban area at first.

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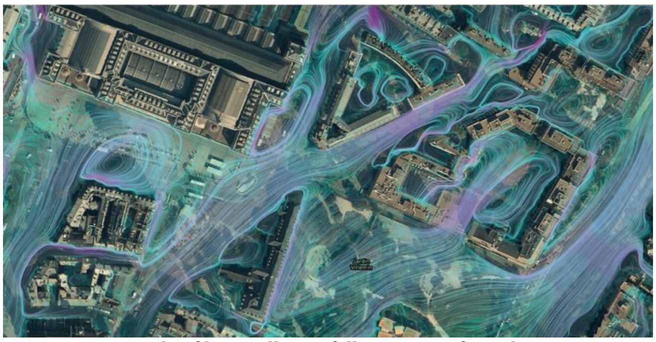

Figure 1. Example of how pollution follows a specific path in a city area. Source: PRACE [22]

The figure shows the predicted path that polluted air generally follows, using a software tool, used for air quality simulation for the industry. As shown, air pollution follows a certain path that is mostly made along with the flow of air and blockages from the infrastructures.

Here, instead of using mobile anti-smog guns that congest the traffic making it almost deniable for the main city area, anti-smog guns are fixed at specific pollution initializer points as per analyzed data: fitted at about 8-12 meters high buildings(if available) to cover optimal area. Generally, anti-smog guns cover a radius of 50-70 meters whereas with the uplift of its specified height, it can touch the ground at a horizontal distance of 100 meters. In the operational step, all the nephelometers' real-time data are analyzed as a whole in the server using specific data science algorithms and processed to resend instructions to the IoT-based anti-smog guns that are capable of rotating automatically as per the instruction sent by the server. The algorithms used in the server to analyze the data use additional data such as wind speed, weather forecast, etc. to smartly determine the anti-smog guns that are needed to be operated. Data security for this type of work is not a primary issue, generally, since the leakage of data does not reveal any sort of confidentiality. Data poaching or unauthorized manipulation, however, could be a serious issue, due to which Security Enhancement in Cloud Computing should be done [20, 21]. This approach saves water when there is a high probability of rain, and learns the wind direction and its speed to determine the efficient anti-smog guns needed to be operated that may be a distance away but can reach the polluted location depending upon the velocity of the wind.

Figure 2. Demonstrative image of CPS/IoT based Anti-smog guns to suppress air pollution

The image demonstrates the visualization for the proposed approach of the solution. The sprayers demonstrated at the top of the buildings figurize the anti-smog guns i.e. supposed to be lifted 8-12 meters above the ground to increase the area coverage of each gun. Similarly, the pentagonal structure symbolizes the operation using IoT and the system's connection to the cloud to make consequential spraying at specific prime locations of air pollution.

The final and supplementary step of the solution includes the additional analysis of the stored data. The data collected for this must be stirred data that should be collected from the nephelometers in two situations: one just before the activity of anti-smog guns, and another after the water-firing of anti-smog guns. From this, specific data analysis is done to collect the locations where anti-smog guns can't reach or seem to be insufficient to suppress air pollution. Further, air scrubber systems are installed at the discerned locations, and if the system could cover the areas where anti-smog guns are already there, anti-smog guns at those locations can be shifted to other prime locations.

3. Dataflow and Visualization Diagrams

The primary data that is needed to initiate the solution, firstly, is our intuitive location of the major polluted area that is used to place the cloud-based communicable nephelometers. The flow and work with the data shown here is only to demonstrate the data flow of the solution, rather than discussing the complete thorough data science algorithm. The data flow of the proposed model can be broken down into two modules one for placing the anti-smog guns (Dataflow Model 1), and another for the operation of the anti-smog guns (Dataflow Model 2). For the first one, data from the nephelometers are collected for processing to locate air pollution-producing or gathering areas, and place anti-smog guns thereby.

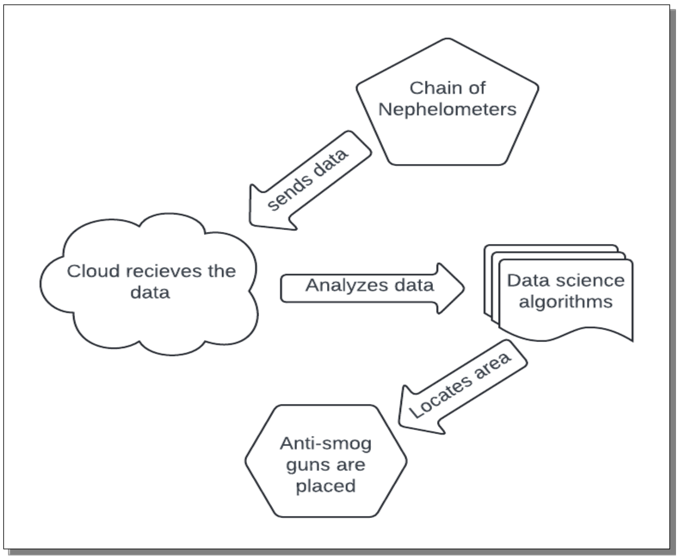

Figure 3. Dataflow visualization for Anti-smog guns placement/Dataflow Module 1

The data flow diagram above visualizes the systematic data collection flow. In the above data flow diagram, the chain of nephelometers or any AQI measuring device collects the primary air pollution data, which is then sent to the cloud periodically. The data is analyzed using a data science algorithm, and then it locates the area for the placement of anti-smog guns.

The second module i.e. the operational dataflow of the proposed system includes continuous monitoring of the

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nephelometers for the data which can be automated to operate anti-smog guns smartly. The process begins with continuous communication and data sharing between the cloud and the chain of nephelometers. The cloud integrates data analysis algorithms that smartly use the weather and wind velocity data from third-party Application Programming Interfaces (API) or official real-time data sources. The data was smartly processed and analyzed to operate the specific anti-smog guns with optimal efficiency based on the three data viz. polluted location (from nephelometers), weather and wind velocity. The cloud, then, sends the instruction to the communicable anti-smog guns installed to operate accordingly.

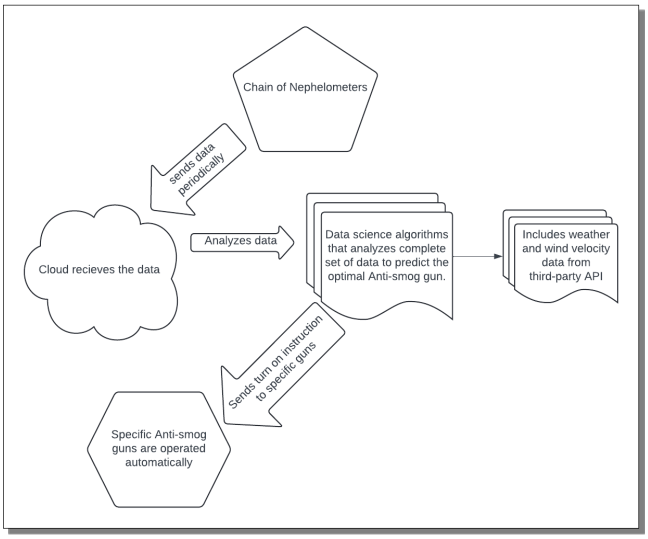

Figure 4. Dataflow visualization for cloud based Anti-smog guns operation/Dataflow Module 2

The figure above shows the data flow during the operation of the proposed system. The data is, firstly, collected from the chain of nephelometers continuously. It is sent periodically to the cloud/server, where it is analyzed using complex algorithms that include data on weather, wind velocity, etc. Then, the analyzed data targets specific anti-smog guns to operate automatically.

The supplementary step of the solution i.e. installing an air scrubber includes further analysis of data. The dataflow for the supplementary step is similar to the Dataflow Module 1 that involves a similar goal to achieve but anti-smog guns instead of air scrubbers.

4. Experimental and Data Observation Methodology

For the observation to project the efficiency of the proposed model, a prototype of the model was developed using the pesticide sprayer and light scattering-based PM sensor that measures PM2.5 and PM10 data for the interval of every one minute. Firstly, the data was observed for the half hour during which water mist was not sprayed. Then, for the next half hour, the water was sprayed periodically, and the data was observed. The data was observed for each minute, therefore the data then was averaged for each half an hour, before and after the mist spray, and for each location.

To measure the AQI using PM2.5 and PM10 concentration data collected from the Nova PM Sensor, the mathematical equations below were used in addition to the standard AQI range for the corresponding breakpoints of PM2.5 and PM10 concentration.

$$AQI_{PM2.5} = \frac{C_{PM2.5} - Clow_{PM2.5}}{Chigh_{PM2.5} - Clow_{PM2.5}} \times (Ihigh - Ilow) + Ilow$$

$$AQI_{PM10} = \frac{C_{PM10} - Clow_{PM10}}{Chigh_{PM10} - Clow_{PM10}} \times (Ihigh - Ilow) + Ilow$$

$$Final\ AQI = \max(AQI_{PM2.5}, AQI_{PM10})$$

Key Terms,

Clow: The lower concentration breakpoint for the pollutant (PM2.5 or PM10) that is less than or equal to the measured concentration.
Chigh: The upper concentration breakpoint for the pollutant (PM2.5 or PM10) that is greater than or equal to the measured concentration.
Ilow: The AQI value corresponding to the Clow concentration breakpoint.
Ihigh: The AQI value corresponding to the Chigh concentration breakpoint.

This is a widely used AQI measuring expression in the availability of PM2.5 and PM10 concentration data. The standard AQI and breakpoints for the concentration of PM2.5 and PM10 used in the observation are tabulated below for each.

Table 1. Standard AQI range for the PM2.5 and PM10 concentrations

PM2.5 (µg/m³)	PM10 (µg/m³)	AQI Range
0.0-12.0	0-54	0-50
12.1-35.4	55-154	51-100
35.5-55.4	155-254	101-150
55.5-150.4	255-354	151-200
150.5-250.4	355-424	201-300
250.5-500.4	425-604	301-500

The table above shows the range of concentration of PM2.5 and PM10 for the corresponding AQI Range. The lower limit and higher limit are the lower and higher concentrations (Clow and Chigh), respectively, of PM2.5 and PM10. Similarly, the lower limit and higher limit of each AQI Range are Ilow and Ihigh values.

5. Results and Discussion

The introduced solution holds the magnificent promise to reduce pollution in outdoor sites, especially on the sites that are regarded as the primary sources of pollution in urban settlements. For observation, AQI at various types of locations was observed using a Nova PM sensor, and data were collected primarily for average change in AQI, before and after spraying a fine mist of water for the duration of half an hour for each in a specified small area for the sake of data observations only. With the prototype model, it was assumed to observe the data with the prediction of accuracy somewhere in the fourth quartile of 100 percent i.e. error was speculated to be less than 25% about all the error factors such

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as environment constraints and miscellaneous. However, the accuracy assumption was the informal predictions without any strong calculations and additional work. The primary data of the observation at various locations is shown in the table below.

Table 1. Observations of change in average AQI at various locations in Kathmandu city area when fine mist is sprayed using AQI measuring device (Nova PM sensor)

S.N.	Location type	Avg. AQI before mist	Avg. AQI after mist	Remarks
1	Residence (Indoor)	25	23	AQI reduced by 2
2	Outdoor park	27	24	AQI reduced by 3
3	Main road area	54	49	AQI reduced by 5
4	Industrial area	71	62	AQI reduced by 9
5	Construction site	78	59	AQI reduced by 19
6	Active warehouse (Indoor)	65	58	AQI reduced by 7

The table shows the averaged data from the hourly observation at each location, collected using a prototype model of the proposed system that was simulated to check the projected efficiency of the proposed system. It includes type of the locations of observations, average AQI data before and after the water mist was sprayed for the duration of half an hour each, and remarks of observed difference in the data.

The water sprayer used during the observation of data, however, was not the actual anti-smog gun that is discussed. The sprayer used was a typical pesticide spray that sprays a mist of water of diameter around 50 to 100 microns, as specified by the manufacturer. By contrast, actual anti-smog gun spray can reach up to as fine as 10 to 30 microns in diameter which can mitigate air-suspended particulate matter more efficiently. Therefore, the data observed should be considered as bare minimums, and also might contain some errors as observations were done in the determined space with specific environments, and not the actual main city area. The Nova PM sensor used for the observation is shown below.

Figure 5. Image of Nova PM sensor used in the observation.

The figure above shows one of the AQI measuring devices i.e. Nova PM Sensor, which was used during the observation. It is based on the Laser Scattering principle. It measures suspended matters in the air to show the PM data in the display connected to it. It has a nozzle, just above the "Nova PM Sensor" in the figure, from where the air is allowed to pass, and the hidden interior follows the principle to measure the data using laser beam.

The observation shows a significant reduction in the AQI after the application of fine water mist at primary locations such as industrial and construction areas. The above data shows that water mist is more efficient in environments with air-suspended particulate matter. Industrial areas, Active warehouses and Construction sites, for example, seem to have most of the dust and carbon emissions that get suspended in air where the AQI got reduced by the most points i.e. by 9, 7 and 19, consecutively using the water mist. Similarly, in the less vulnerable locations like inside residences and outdoor parks where there are fewer air-suspended matters, a reduction in AQI was not significantly observed i.e. reduction in AQI by 2 and 3 respectively. Thus, using the grouped anti-smog guns can be conclusive as an efficient way to suppress air pollution in dense urban settlements with air-suspended particulate matter if bolstered with effective data-driven technology.

6. Conclusion and Future Scope

As observed, the difference in the AQI data before and after spraying the water mist is appealing. The observations of the solution hold a demanding urge for the implementation to suppress air pollution for the general public health hustling in the main city area, vulnerable to air pollution. The AQI reduction in the outdoor city areas, as observed, with higher concentration of particulate matters was significant to mitigate health effects due to air pollution. Specifically, it was observed that when AQI was higher i.e. mostly in outdoor areas, the water mist reduced the AQI with more points comparatively, denoting that the solution has good potential to reduce the air pollution in the outdoor city area as well.

Air pollution is one of the major global problems and city dwellers are the most vulnerable to air pollution where huge traffic and industrial sites, with a handful of areas to plant trees, make it non-negotiable. The solution introduced uses an efficient way to address the issues of mitigating air pollution to reduce its impact on public health. Economic factor, however, is one likely obstacle, that is to be addressed by the collaboration of government or municipal bodies since it is the solution for public health rather than any business ideals. If placed efficiently, the economic factor can also be resolved making the solution bearable for the main cities area. Further, this solution also has the potential to reduce the main city areas' temperatures and speed up work as well, which is beyond the scope of this paper.

The observation done, however, does not include the complete data science algorithms, weather factors, wind velocity, etc., which is left for the further continuation of the study and falls under the future scope. The complete CPS to implement the idea may be similar but might have some

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different issues that were not considered in the scope of the study. Moreover, it might take significant efforts to build a complete system with such integrations, which directs the topic of future study motivated by the compelling result of observations in this study. Consequently, This study handover a proposed model to be implemented for the mitigation of health impacts from air pollution in the city areas efficiently.

Conflict of Interest
The author reports no conflict of interest.

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Shivam Kumar Sah is a high school student of the 2024 graduating class at St. Xavier's College, Maitighar, with a STEM focus. Currently, he works as an Embedded systems and Research intern at BOTS Industries Pvt. Ltd. Primarily, he is interested in Computer science and engineering with a specific focus on IoT, data science and generic software development. He leverages his studies and interests in practical life to approach societal solutions. In the past, he had developed a model of a simulation game for space tourism, and computer-vision based AI to detect the obstacles and its distance estimation for assistance in the locomotion of blind people independently, continuing the promise of innovation to serve back to the community with his learnings.

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