Womanium Global Quantum + AI Project

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1. Problem Statement and Background

Problem: Aggravating trends of urban air pollution and its effects in various aspects

Background: Air pollution has emerged as a huge global issue most especially in the expanding urban centers of the world. The complexity of the issue stems from various interrelated sources, including:

1. **Vehicular Emissions:** Motor vehicles are the main source of urban air pollution. They emit gases such as nitrogen oxide (NO), carbon monoxide (CO), and also tiny particles in the air (Particulate Matter or PM2.5). These pollutants not only affect the poor perceptibility of the air, but also the formation of smog and ground-level ozone that raise the risks of exclusive respiratory and cardiovascular diseases.
2. **Industrial Pollution:** Industrial regions of large cities especially in less developed countries emit wide ranging pollutants including SO2, VOCs, and heavy metals. These pollutants are released during manufacturing processes of products, energy generation and waste management processes that degrade the air quality resulting in adverse impacts on human health.
3. **Construction and Urbanization:** Construction activities result in pollution of air with dust and particulate matter. All these activities release coarse and fine particles that can easily penetrate the lung tissues and the bloodstream with disastrous health effects.
4. **Domestic Contributions:** Domestic wood, charcoal and dung are normally burned to cook food and boil water, and coal is used for heating and boiling water; these activities are confirmed to have led to air pollution especially in the low income elicited regions of many urban areas in many developing countries.

Importance to Our Team:

Scaling methods to reduce urban air pollution is one of the primary concerns of our team because its severity leads to the degradation of the health of people as well as the environment hence employing advanced technologies for such noble causes is fulfilling. The implications of unchecked urban air pollution are vast:

1. **Public Health:** Long-term exposure to atmospheric pollution leads to various diseases like asthma, COPD, cardiovascular diseases and lung cancer. The socially marginalized section, comprising children & the elderly, suffer the most and those with chronic diseases, wherein morbidity and mortality rates rise, thereby increasing healthcare costs and deteriorating the population’s quality of life.
2. **Environmental Degradation:** Air pollution is one of the causes of environmental problems, mainly the climatic problems. Some of the pollutants causing the globe’s temperature to rise include black carbon while some, like sulphur dioxide, lead to the production of acid rain which degrades

ecosystems and affects the general diversity. Moreover, air pollution also influences the quality of soil and water, in turn, the productivity of plants and availability of food.

3. **Economic Impact:** Taking into consideration the previous findings this paper concludes that there are huge economic costs associated with air pollution. These are; the direct costs relating to resources used in treatment of the diseases and loss of productivity owing to sickness and the indirect costs which include diminished worker performance and pressure on other health care facilities. Besides, the reduction in traders' competitiveness due to air pollution affects tourism and impacts property prices, which has a ripple effect on the entire economy.

Interest in Solving the Problem: Our interest in solving urban air pollution stems from the potential to apply cutting-edge technologies to a critical and tangible problem. Through the use of AI, we aim to do the following:

1. **Enhanced Monitoring:** Develop advanced sensor networks and data analytics tools for real-time, high-accuracy air quality monitoring. This will enable the identification of pollution hotspots and improve our understanding of temporal and spatial variations.
2. **Predictive Modeling:** Utilize machine learning algorithms to forecast pollution levels based on factors such as weather conditions, traffic patterns, and industrial activities. This predictive capability can inform proactive measures and policy decisions.
3. **Mitigation Strategies:** Design and implement AI-driven solutions to reduce pollution, such as optimizing traffic flow, improving industrial processes, and promoting cleaner energy sources.
4. **Public Awareness:** Create platforms and applications to educate the public on air quality issues and provide actionable advice on minimizing exposure.

By addressing urban air pollution, we aim to contribute to healthier and more sustainable cities while advancing our expertise in AI, reinforcing our commitment to technological innovation and societal impact.

2. Literature Review

A new approach to target complex and noisy scenarios, such as turbulent flows, consists of learning a post-processing correction operator on low accuracy solutions that are forced by a high-accuracy solution. [1] Using this, it is possible to obtain the dynamics of the underlying system directly and engage minimal training data, even if whatever statistics associated with it vastly differ from convergence. It resolves the difficulties associated with random systems; most activities are computationally intense to mimic accurately in the long run. As a result, the corrections can be made in post-processing while maintaining the climate models' original form, as the framework is non-invasive. It uses probabilistic neural networks to identify and estimate probability risks and early occurrences of extreme climatic conditions in weather patterns, even with small instances of data. The performance of the given framework is shown on quasi-geostrophic flow cases that demonstrated ability to predict statistics over much longer time intervals than those used in training and improve the risk evaluation of climate modeling.

The proposed approach of applying ML to atmospheric science involves the Pareto optimal method of rating the performance of a model. [2] In order to present the complex approach of attributing the value of ML, the authors used a hierarchy of models ranging from semi-empirical ones to deep learning. They categorize this added value into four areas: functional representation, feature assimilation, spatial connectivity, and temporal connectivity. The paper illustrates these concepts through three applications: cloud cover parameterization, shortwave radiative transfer, and tropical precipitation modeling. In the end, through the usage of Pareto-optimal hierarchies, the authors seek to increase the reliability of the presented atmospheric process models based on ML, as well as eliminate the noise created by frequent innovations that do not contribute to the development of the field.

The multi-resolution Coherent Spatio-Temporal Scale Separation (mrCOSTS) algorithm is devised for the diagnosis of complex multi-scale data required in climate science, neurology, and turbulence. [3] The previous approaches essentially use supervised learning, which is insufficient to analyze the multiple scale dynamics that are involved, at least in conditions where the processes are non-stationary and temporal and spatial scales may constantly change. It is a new unsupervised method called MrCOSTS, based on Dynamic Mode Decomposition, and allows decomposing patterns simply and with no need of large parameter-learning on multi-scale data. The algorithm is benchmarked on various difficult data sets, such as sea surface temperature anomalies and neural signals, to show its ability to expose obscure patterns and improve comprehension in a variety of fields of science. This advancement is solving one of the important problems in high-dimensional and multi-scale analysis.

Uncertainty Quantification (UQ) in modeling complex systems is postulated by the fact that all models have errors in them and proceeds to demonstrate how UQ provides quantification of uncertainties originating from several aspects. [4] Shannon's entropy and relative entropy describe how uncertainty is measured to determine the differences between probability distributions. They compare the manner in which the uncertainty spreads in linear and nonlinear dynamic systems, and this points to the effect of the nonlinearity of the models. Last of all, the paper presents data assimilation as another method of lowering the uncertainty, by using the model outputs and observations in the best manner possible; this forms the cornerstone of many practical applications of state estimation.

Probabilistic deep learning techniques for improving air quality effectively enunciate how incorporating the two kinds of uncertainties, aleatoric and epistemic, plays a crucial role in decision-making. [5] The authors reviewed many experiments about the comparisons of probabilistic models such as Bayesian neural networks, deep ensembles, and Monte Carlo dropout and proved that Bayesian methods are able to present better uncertainty estimates regardless of some implementation issues. The study also stressed the impacts of adversarial training and the explorative use of temporal and spatial correlation of OD air quality data. All in all, the study suggests the usefulness of the chosen probabilistic models in real-life air quality prediction and their application for policy-making purposes.

The axiomatic approach to quantum logic and its application in quantifying uncertainty within cognitive info-communication highlights the relationship between classical and quantum logic, emphasizing that quantum logic structure, represented by an atomistic ortho-modular lattice, allows for broader applications beyond quantum physics. [6] To quantify similarity in signals, the author offers training signals' algorithms to measurement and makes use of mathematical models espoused by Hilbert spaces. In addition, the paper sheds light on quotas, relating logical operations to quantum mechanics, and showing how the resulting knowledge can improve human-machine dialogue and estimate uncertainty.

A group of the world's largest cities, known as C40 Cities, is working towards mitigating climate change and promoting environmentally friendly urban activities with reduced greenhouse gas emissions, together with associated risks emanating from such actions. [7] Therefore, learning from these cities can offer helpful information about effective climate action and sustainable urban development.

Here are two examples of cities from the C40 network where AI has helped combat air pollution.

i. London:

An Ultra Low Emission Zone (ULEZ) is a designated area in cities where tight standards regarding emissions from vehicles are used to ensure clean air as well. Vehicles that do not fall within these limits are subject to a fee for every day they would like to drive there. This ULEZ aims at curbing pollution by promoting the use of less polluting cars like electric and hybrid ones and enhancing public transport as well as other eco-friendly ways of traveling around.

AI has played a significant role in supporting the implementation and effectiveness of the Ultra Low Emission Zone (ULEZ) in London. [8] Some of the methods are as follows:

1. Air Quality Monitoring
2. Traffic Flow Analysis

3. Emission Source Identification
4. Temporal and Spatial Analysis
5. Impact Assessment

Practical Implementation:

- Data Collected:
    - Air Quality Sensors: Data from over 100 air quality monitoring stations across London measured levels of nitrogen dioxide (NO_2) and particulate matter (PM).
    - Traffic Data: Information from traffic cameras and GPS systems tracked vehicle counts, types, and speeds in and around the ULEZ.
- AI Analysis:
    - Machine Learning Models: AI algorithms were trained on historical air quality and traffic data to develop predictive models. These models analyzed the relationship between vehicle emissions and air quality levels.
    - Impact Assessment: The models predicted that the introduction of ULEZ would lead to a significant reduction in NO_2 levels, particularly in areas with heavy traffic. The AI simulations showed potential reductions of up to 30% in NO_2 levels within the ULEZ zone.
    - Real-Time Monitoring: After ULEZ was implemented, real-time data from sensors was continuously analyzed. AI systems monitored air quality, allowing for immediate adjustments to traffic management strategies if pollution levels spiked.
- Results:
    - The analysis confirmed that NO_2 levels dropped significantly within the ULEZ, with many areas seeing reductions of more than 20% compared to pre-ULEZ data.
    - City officials were able to use these insights to communicate the benefits of ULEZ to the public and encourage continued compliance.

ii. Stockholm:

Stockholm utilized various technical strategies as well as strategies aimed at tackling air pollution using AI: [9]

- Deployment of IoT sensors:
    - PM2.5, PM10, NO_2, and ozone air quality sensors have been installed throughout Stockholm's neighborhoods to collect current data on these pollutants. The sensors produce high-resolution information that can be analyzed to aid in making decisions immediately.

- Machine Learning Algorithms:
  - Predictive Analytics: Machine learning models were developed that predict pollution levels from past data, climate and traffic patterns. Regression analysis and time series forecasting were some of the techniques used to identify trends with trends in pollution.

- Anomaly Detection:
  - AI algorithms that look for unusual spikes in pollution levels enable authorities to respond quickly when such events occur, like traffic accidents or construction work going on.

- Traffic Management Systems:
  - Smart Traffic Signals: Traffic lights are controlled by AI algorithms to optimize traffic flow in real time. Reducing stop-and-go traffic would help reduce emissions from cars.

- Adaptive Traffic Control:
  - AI systems adjust signal timing dynamically to avoid congestion, which improves travel times and decreases vehicle emissions in general.

- Data Collection:
  - Air Quality Monitoring Stations: Air quality monitoring stations were also established to supplement the sensor networks.

- Application of remote sensing technologies:
  - Stockholm Municipality has used satellite-based methods to obtain information on pollution levels near the city boundaries.

Going beyond these conventional techniques, Stockholm has turned to modern tools such as big data analytics in their models. They work with unstructured data (like sound) as contrasted with structured data (like log files), where strong interconnectedness among diverse variables exists. In this sense, we can point out some artificial intelligence applications that could be useful in reducing air pollution for Stockholm, among others.

Advantages & Disadvantages of using AI for tackling Air Pollution:

Advantages:

1. AI models can analyze vast amounts of data to predict air quality trends and pollution levels with high accuracy. This helps in anticipating pollution events and implementing preventive measures.

2. AI systems can process data from sensors and IoT devices in real time to monitor air quality and vehicle emissions continuously. This enables an immediate response to changing pollution levels.
3. AI can optimize the allocation of resources and interventions by identifying the most effective measures for reducing emissions. This leads to more efficient use of public and environmental resources.

Disadvantages:

1. The extensive data collection required for AI systems raises concerns about privacy and data security. There is a risk of sensitive information being misused or leaked.
2. Developing, deploying, and maintaining AI systems can be costly. This includes expenses related to hardware, software, and ongoing operational support.

3. Analysis

https://github.com/KESHAN2112/Quantum-AI-for-Climate

Recommendations:

Air pollution is primarily caused by major pollutants like carbon monoxide (CO), particulate matter (PM2.5 and PM10), sulphur dioxide (SO_2), nitrogen oxides (NO_x), volatile organic compounds (VOCs), ammonia (NH_3), and ozone (O_3). Out of all these pollutants, particulate matter, especially PM2.5, as pointed out in the discussion, is the most harmful pollutant because it can penetrate deep into the lungs and bloodstream, causing many health problems. Smog and acid rain are caused by NO_x and SO_2, while CO reduces oxygen delivery to body organs, hence leading to adverse health effects. Additionally, VOCs as well as ozone contribute to the formation of ground-level ozone, which is a vital constituent of smog.

All the pollutants have been examined in our study, and it was evident that PM2.5 and PM10 were the major contributors to degrading air quality. The impacts of others were also shown.

As far as mitigation strategies are concerned, the following points should be incorporated efficiently:

1. The impact of PM2.5 and PM10 can be reduced using a combination of policy frameworks and personal as well as community efforts, such as reduced vehicle usage, efficient energy utilization, avoiding burning of wood and trash, advocacy for stricter emission standards, encouraging usage of public

transport, etc. AI usage can be leveraged in monitoring the pollutants, as was done in our analysis.

2. AI could optimize combustion systems on vehicles and other industrial sites to reduce emissions of NOx. Additionally, AI models can forecast periods with high NOx emissions in advance, thereby facilitating traffic rerouting or power plant adjustment.
3. AI algorithms can improve the efficiency of scrubbers in power plants by predicting and adjusting operational parameters to maximize SO2 capture. AI can also help in identifying and targeting areas with high SO2 levels for stricter regulations.
4. AI models can forecast ground-level ozone formation by analyzing weather patterns and precursor emissions, helping to implement timely measures to reduce ozone levels, such as regulating industrial activities during peak periods.
5. Lastly, industrial and urban planning must be done, ensuring that dust control measures are taken. Also, clean industry practices should be followed by the industries.

Literature Review

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