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A Review of Existing Method, Research and Emerging Technologies in Particulate Matter Evaluation Field

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ABSTRACT

Health effects and quality of life can be adversely affected by air pollution. Particulate Matters (PM) are one of the noxious substances caused by atmospheric pollution. Generally, in air quality index (AQI) calculation, most atmospheric monitoring devices does not evaluate particulate matter 0.1 micron, also known as ultrafine particles (UFP), due to the difficulty in evaluating particles of such small size, resulting in inaccurate air quality index calculations. Most of the current detection and evaluation techniques, such as Gravimetric, Optical, Microbalance have reliability issues and limitations to be implement in monitoring field. In addition to being expensive, existing methods to detect PM are not geared toward air quality monitoring especially UFPs evaluation. The purpose of this article is to review existing method and summarize recent technological advancements in particulate matter detection methods. In addition, this paper explores latest progress and development in evaluating particulate matter. In this review, the researcher will gain insight into the advancement and challenges of particulate matter detection technologies.

Keywords:
Particulate matter; evaluation method; ultrafine particle; measurement; air quality; air pollution; air pollution source; health risk

1. Introduction

The World Health Organisation (WHO) defines "air pollution" as the intrusion of different substances, whether they are chemical, physical, or biological, into our indoor and outdoor environments that change the pristine aspects of the atmosphere [1]. Surprisingly, 99% of the world's population is exposed to air that is teeming with contaminants above the WHO's recommended limits. To put it another way, almost everyone on Earth is breathing air that is far from the clean, fresh atmosphere we deserve. These contaminants are most likely to be present in low- and middle-income nations. Air pollutants can have either a natural, anthropogenic, or a combination of origins, depending on their sources or the origin of their precursors [2]. Our home planet is bustling with

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human activity, including colossal industrial machinery, enormous power plants, blazing combustion engines, and fleets of cars. Although impressive in their own right, these great forces of growth also carry a heavy burden: they are the main sources of the release of dangerous compounds into our atmosphere. In fact, these enormous activities dominate as the primary causes of air pollution due to their enormous magnitude. Among them, the ubiquitous presence of cars bears the heaviest blame, accounting for an astounding 80% of global air pollution [3]. Our actions have an undeniable impact on the air we breathe, from looming smokestacks to rumbling motors, and this calls for our immediate attention. According to estimates from the Global Burden of Disease [4,5], outdoor air pollution contributed to 4,506,193 premature deaths in 2019. Based on data analysis, air pollution is the third-highest risk factor for deaths by number in 2019.

A broad shadow is cast over many parts of our life by air pollution, which comes from a variety of sources including transportation, industry, commerce, housing, institutions, dwellings, and vegetation zones [6]. Its wide-ranging effects affect not only our own well-being but also plant health, weather dynamics, agricultural output, structural integrity, and material durability. Among the many pollutants that contaminate our air, a few that the Clean Air Act of 1971 designated as "criterion pollutants" stand out for their potential to impair both the environment and public health, surpassing the effects of other primary and secondary pollutants [6]. These culprits include tropospheric ozone (O_3), lead (Pb), carbon monoxide (CO), nitrogen dioxide (NO_2), sulphur dioxide (SO_2), and particulate matter (PM). The negative effects of these pollutants on human health and the environment have been thoroughly investigated and documented by conscientious researchers since they are imbued with such weight [7-9]. They encourage us to tackle the pressing need for cleaner air and healthier habitats by shedding light on the depressing realities we must contend with.

Table 1
Source of noxious pollutants and health risk it possesses [10-13]

Pollutants	Source	Risk
Nitrogen dioxide (NO_2)	Transportation, power plants, off-road vehicles, industrial emissions, utility boilers, and nitrogen fertiliser oxidation.	Exacerbates respiratory problems, leading to coughing, wheezing, and breathing challenges. It aggravates airway irritation, raising the risk of asthma attacks, heart issues, poor birth weight, and early mortality.
Sulfur dioxide (SO_2)	Automobile emissions, industrial processes including metal smelting, and the burning of coal and oil.	Shortness of breath, chest tightness, and wheezing. Particularly for persons with asthma, increase respiratory symptoms and decrease respiratory functioning.
Carbon monoxide (CO)	Automobiles, biomass burning, industrial fossil fuel combustion, gas stoves, and cigarette smoke are examples of incomplete combustion products.	Headaches, exhaustion, nausea, dizziness, confusion, and irritability are some of the symptoms of carbon monoxide overdose. Long-term CO exposure can result in nausea, unconsciousness, brain damage, irregular heartbeat, respiratory problems, muscular weakness, miscarriage, and even death.
Lead (Pb)	Industrial emissions from metal smelters, incinerators, refineries, power plants, and recycling operations, as well as the use of leaded petrol and lead-based paints.	lead poisoning, cancer growth, high blood pressure, and neurodegeneration.
Ozone (O_3)	Created in the atmosphere when sunlight causes an interaction between nitrogen oxides (NOx) and volatile organic compounds (VOCs).	Increased chance of dying too soon. respiratory infections, pulmonary inflammation, asthma attacks, wheezing, coughing, and chronic obstructive pulmonary disease (COPD) are some of the things that can make breathing difficult.

Particulate matter (PM)	Construction, unpaved roads, field fires or smokestacks, petrol engine combustion, industrial activities, power generators, tobacco smoke and rubbish burning are all environmental hazards.	Can shorten the lives of people who already have heart or lung conditions, cause heart attacks, aggravate asthma, decrease lung function, and appear as a painful range of respiratory symptoms, such as chronic coughing, breathing trouble, and irritability of our delicate airways.

Organization and government agencies associate with the environmental field, introduced an indicator called Air Quality Index (AQI), means to measure " condition or state of each relative to the requirements of one or more biotic species and/or to any human need or purpose" as stated by Schraufnagel *et al.,* [14] which in easy word, AQI tells public the condition of the current air quality whether it good or bad or in another way forecast how the quality of the air will be. Each nation establishes its own air quality standards to safeguard its residents' health, and as a result, they play a significant role in national risk management and environmental policy. A complex balancing act between health concerns, technological viability, economic considerations, and a variety of political and social variables shapes the criteria for air quality regulations, which vary among nations. The selection of these standards is based, among other things, on the degree of development and air quality control know-how of a country. The route to cleaner, healthier air is guided by a complex tapestry where research, politics, and societal forces interact [15]. Table 2 shows the comparison of the air quality standards imposed by different regions.

Table 2
Air quality standards guideline comparison [16-20]

Air pollutant	Averaging time	Malaysia department of environment (DOE)	United States environmental protection agency (U.S. EPA)	World health organization (WHO)
		Not to be exceeded		
NO_2	1 Hour	280 µg/m^3	100 ppb	200 µg/m^3
	24 Hours	70 µg/m^3	-	25 µg/m^3
	1 Year	-	53 ppb	10 µg/m^3
SO_2	1 Hour	250 µg/m^3	75 ppb	-
	3 Hours	-	0.5 ppm	-
	24 Hours	80 µg/m^3	-	40 µg/m^3
CO	1 Hour	30 mg/m^3	35 ppm	30 mg/m^3
	8 Hours	10 mg/m^3	9 ppm	10 mg/m^3
	24 Hours	-	-	4 mg/m^3
Pb	3 Months	1.5 µg/m^3	0.15 µg/m^3	0.15 µg/m^3
	1 Year	-	-	0.5 µg/m^3
O_3	1 Hour	180 µg/m^3	-	-
	8 Hours	100 µg/m^3	0.070 ppm	100 µg/m^3
PM_{10}	24 Hours	100 µg/m^3	150 µg/m^3	45 µg/m^3
	1 Year	40 µg/m^3	-	15 µg/m^3
$PM_{2.5}$	24 Hours	35 µg/m^3	35 µg/m^3	15 µg/m^3
	1 Year	15 µg/m^3	12 µg/m^3	5 µg/m^3

2. Particulate Matter (PM) Size

Due to its size, PM are difficult to observe using naked eye. Even though the particles are too tiny to see, when concentrations are high, the air becomes opaque resulting in haze that blurs the spread of sunlight [21]. PM also are categorized in terms of coarse, fine, and ultrafine. The American Lung

Association [21] describes the various sizes of airborne particles. While microscopic particles have a diameter of 2.5 microns or less, coarse particles range in size from 2.5 to 10 microns. Then there are the illusive ultrafine particles, which are imperceptibly small (less than 0.1 micron), but have a significant influence. These particles, which range in size from the bigger to the smallest, provide an intricate and varied picture of the world of airborne matter. Normally, human natural body defense mechanisms will expel some coarse particles out of the respiratory system through cough or sneeze, but smaller particles manage to pass through [21]. The United Nations Environment Programme (UNEP) [22] also states that with every breath taken, tiny particles are sucked in that can harm lungs, hearts, and brains, cause a lot of other health problems or complications. Figure 1 shows the size comparison of the PM and human hair size to provide insight about the PM size and Figure 2 shows the PM size and how deep it can travel into human pulmonary system according to their respective size categories. It shown that ultrafine can travel deep into the respiratory tract due to its tiny size.

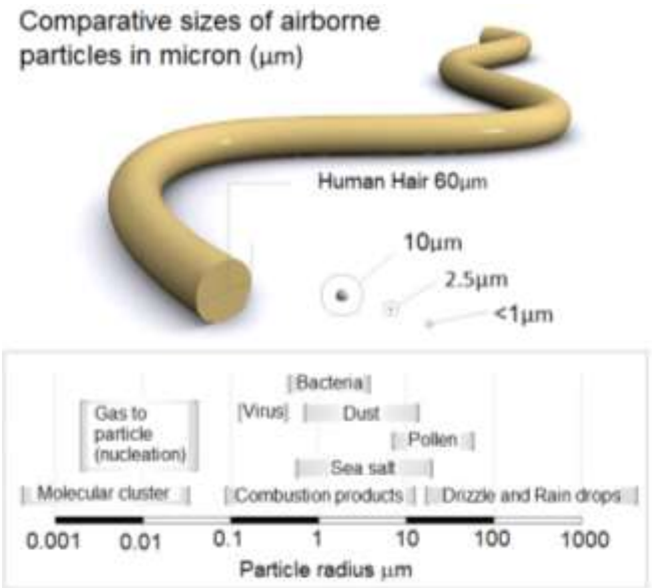

Fig. 1. Size comparison of PM relative to human hair and particle radius [23].

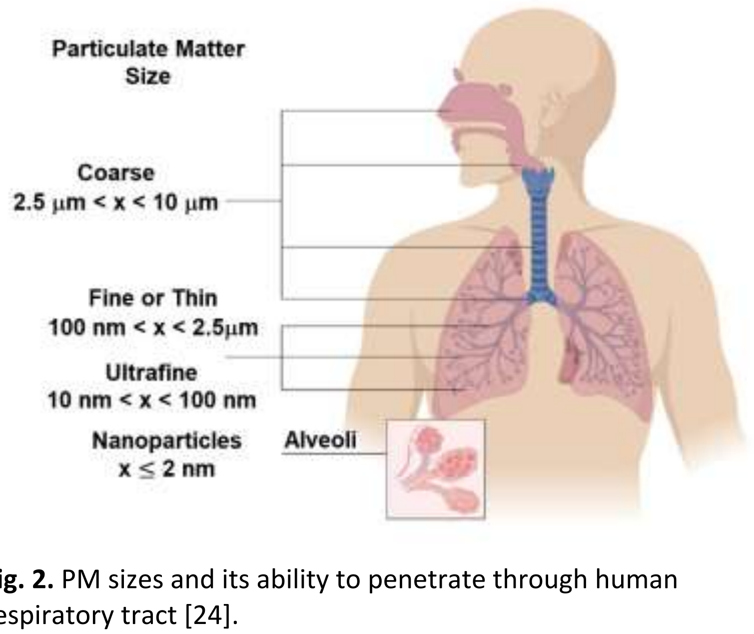

Fig. 2. PM sizes and its ability to penetrate through human respiratory tract [24].

3. Existing Method in Detection of Particulate Matters (PM)

Evaluation of PM and UFPs has been the subject of the review articles. Kirsova and Guzan [25] in their work, state that among the four types of particulate matter measurements, there are the particle mass measurement that generally used to estimate impact of PM on the people's health, particle number, the particle surface area measurement and particle size distribution measurements. When assessing the impact of PM on the climate, particle quantity and size distribution data are preferred [25]. As the UFP mass is negligible, suitable method is by measuring the particle quantity [26]. In the review by Amaral *et al.,,* [27], the particulate matter evaluation method is classified into two categories, based on particle concentration and size distribution. The subcategories for concentration methods are gravimetric method, microbalance and optical method via light scattering, extinction, and absorption. Particle size distribution method consists of five categories, via microscopical, impaction technique, diffusion method, charging and complete systems.

Table 3
Existing method of PM evaluation

Method	Description
Gravimetric technique	Gravimetric technique relies on the calculation of particle mass weight difference between samples taken before and after a sampling interval [25,27]. According to Nussbaumer *et al.,* [28] the particle sampling period usually 15 minute or more, results usually fast processes of the particles not worth considering. Cascade Impactor instrument is example of method that utilize gravimetric principle.
Optical technique	Evaluation of a particle using an optical medium often falls under the headings of scattering, absorption, and the sum of these three, known as extinction. According to Kiresova and Guzan [25], optical methods assess particles based on how they interact with light. The fundamental components of the optical measurement technique are the light beam intensity and scattering angle. Examples of methods that use optical approach include the photometer, Optical Particle Counter (OPC), Condensation Particle Counter (CPC), Opacity Metre, Spotmeter, Aethalometer, Photoacoustic Soot Sensor (PASS), and Laser Induced Incandescence (LII).
Microbalance technique	According to Giechaskiel *et al.,* [29], oscillatory microbalance elements that have particles aggregated across their surface employ a change in resonance frequency to determine the PM. Instruments that use the microbalance approach include the Tapered Element Oscillation Microbalance (TEOM) and the Quartz Crystal Microbalance (QCM).
Impaction technique	Amaral *et al.,* [27] state that impactors are equipment with numerous impact stages that measure the size distribution in a mass using the gravimetric principle. Some of the equipment also has multiple orifices. Widely used instruments are Berner Low Pressure Impactor (BLPI), Low Pressure Cascade Impactors (Andersen Impactor) and Dekati Low Pressure Impactor (DLPI) [28].
Spectrometer	Giechaskiel *et al.,* [29] describe that spectrometers consist of particle loader, classification column and series of detectors. Commonly used instruments are Fast Mobility Particle Sizer (FMPS), Differential Mobility Spectrometers (DMS) [30,31] Scanning Mobility Particle Sizer (SMPS) [27].
Diffusion	Nanoparticle Surface Area Monitors (NSAM) are instrument used to detect UFP or particles sizes below 0.1 µm [25]. This is due to the particles that are not subject to severe gravitational or inertial forces. As a result, their behaviour is poorly captured by aerodynamic diameter, a commonly used measurement in conventional equipment [32]. Another instrument used to detect 0.1 µm is Electrical Diffusion Battery (EDB).

3.1 Existing Work in PM Detection in Year 2021.

Most of the researchers had come up with their ideas in their respective works to tackle their objective and come up with better solutions in particle measurement field for deeper understanding of the PM. Table 3 shows the author and their works based on PM evaluation respectively.

Table 4
Emerging research in PM evaluation field in year 2021

Year	Author	Research
2021	Beauchemin *et al.,* [33]	Researchers used a unique technology called the Nano MOUDI II Deposit Impactor, along with a Teflon Filter, in their effort to comprehend the elemental composition of ultrafine particles (UFP) obtained from the accumulated street sweepings in the dynamic City of Toronto, Canada. They were able to examine the existence of metals within these tiny particles at the microscopic level thanks to this creative combination. They methodically separated the airborne particles into thirteen distinct size fractions, ranging from a tiny 10 nanometers to a considerable 10 micrometres, by aerosolizing dust samples collected from diverse road types, including highways, arterials, and local roads. Aimed to reveal the mysteries of the urban dustscape through this elaborate procedure, as well as to shed light on the complex connection between our streets and the elemental world that silently penetrates our urban environments.
2021	Bertke *et al.,* [34]	Imagine a cutting-edge tool called a single-chip differential mobility particle sizer (DMPS) that makes use of complex micro-fluidic channels (FCs) and resonant micro cantilevers. This brilliant invention sets out on a heroic mission: to keep watch on the enigmatic world of airborne nanoparticles (NPs). It carefully monitors the concentrations of PM_1 and $PM_{2.5}$, those minute airborne particles, between 0.7 and 50 g/m^3, with accuracy and precision. By revealing the mysteries of the tiny world, this ground-breaking technology gives us crucial new understandings about the makeup and concentration of the airborne particles that surround us.
2021	Fujitani *et al.,* [35]	In order to solve the riddles of particulate matter (PM), the study adventure started with precise measurements. The complicated character of PM dynamics was shown by size-resolved offline measurements in conjunction with real-time live measurements capturing fast changes. A fascinating procedure known as source apportionment took place in order to identify the sources of these particles. PM mass concentrations were cleverly attributed to 13 different emission sources using a combination of the positive matrix factorization technique, organic aerosol data from a twin-site research, and the analytical capability of an aerosol mass spectrometer. The amazing soot aerosol mass spectrometer (SP-AMS) was used to reveal the chemistry of $PM_{1.0}$ particles, revealing their chemical composition in unparalleled detail. Five consecutive workweeks were dedicated to this scientific investigation, during which two FRM and two NanoMOUDI samplers worked side by side at each site to capture a vast amount of data. Gold foil was used for samples that needed size resolution, while polytetrafluoroethylene (PTFE) and quartz fibre filters were the ideal team for the delicate task of capturing $PM_{2.5}$. These methods and resources opened the door to a deeper comprehension of PM and the complex interweaving of its structure and behaviour.
2021	Jakubiak *et al.,* [36]	Researchers conducted an intriguing lab experiment to see if the tried-and-true technology used in smoke detectors that contain radioactive sources might be used to calculate the numerical concentration of ultrafine particles. The sensor output showed a linear response, faithfully reflecting changes in diesel soot concentration within a range of up to 8.3 x 10^5 particles per cubic centimetre, according to their findings, which led to a stunning discovery. Additionally, this sensor demonstrated a remarkable capacity to quickly identify rapid changes in aerosol concentration. Empirical equations were used to fully realise the sensor's capabilities, rigorously accounting for the impact of air velocity, temperature, relative humidity, and

		pressure on its output. With this novel information, it is clear that the ionisation sensor has enormous potential as a tool for calculating our exposure to ultrafine particles and deciphering the complex interaction between these tiny aerosols and our environment.
2021	Kazys *et al.,* [37]	A ground-breaking study is taking place in the field of scientific innovation, introducing a cutting-edge ultrasonic measurement equipment created to allow accurate monitoring of airborne dust changes in powder classification systems. This unique approach was tested with unwavering accuracy using a pilot-scale classifier designed specifically to separate and collect ultrafine particles (UFP) originated from fly ashes produced by coal combustion. You want to know how it functions. The extraordinary phenomenon of ultrasonic wave attenuation is the key to the monitoring process. Particles interact with the ultrasonic waves as they move around suspended in the classifier's airflow and leave behind their distinct signature. With insights that could fundamentally alter our knowledge of the categorization processes for powders, this cutting-edge instrument holds the potential to open up new vistas in dust concentration monitoring.

4. Emerging Method in PM Evaluation Field Discussion

As there is advancement in the field of PM measurement field, the latest technology might provide a more fitting method to detect PM which can be utilized in real-time air monitoring. Table 4 shows the latest research that had been carried out in PM evaluation field.

Table 5
Latest research in PM evaluation field

Year	Author	Research
2023	Lee *et al.,* [38]	A stunning standalone analyzer that combines cutting-edge nanoparticle analysis, effective density assessment, and a dash of environmental awareness emerges from the domain of scientific imagination. This state-of-the-art invention combines three types of sensors: mass concentration, humidity, and temperature. But this wonder is more than that. Real-time calibration of the mass concentration sensor is now possible thanks to a ground-breaking calibration technique. This clever method combines the information obtained from each sensor and analyzer with a mass concentration calibration technique that is based on deep learning. The performance of the analyzer was compared to that of a beta attenuation mass monitor in order to assess the accuracy of this calibration. The results proved the analyzer's accuracy and established new benchmarks for scientific success, leaving no space for doubt.
2023	Ranpara *et al.,* [39]	A fascinating investigation into the complex world of fine and ultrafine TiO_2 particles seeks to ascertain the various concentrations of these particles in terms of mass, number, and surface area. The research progressed with the aid of a variety of cutting-edge tools and measures, such as the DustTrak DRX, personal DataRAMs (PDR), GRIMM, and diffusion charger (DC). Each field study tool (DRX, PDR, GRIMM, and DC) was deployed with exacting accuracy in controlled chamber testing, carefully evaluating a variety of variables. The analysis took into account the gravimetric mass concentrations of both fine and ultrafine TiO_2 particles to ensure precision. Analysis of variance (ANOVA) was expertly used to decipher the complex web of data, revealing the subtleties of intra-device, inter-instrument (between various instrument kinds), and inter-instrument (within instrument) components. The study sought to push the boundaries of science by revealing the mysteries buried inside the particles through this multidimensional exploration.

2022	Jeon *et al.,* [40]	A cost-efficient and user-friendly measurement tool created to identify and quantify airborne particles with electrostatic properties smaller than 100 nm emerges as a spectacular scientific accomplishment. This clever contraption exhibits an intriguing pattern by making use of the condensation nucleation technique. The likelihood of successfully counting particles improves sharply with particle size, reaching an astounding 100% count probability for particles 50 nm or larger. This ground-breaking tool outperforms optical methods by providing ease of use, low cost, and on-site real-time monitoring. Its streamlined design makes maintenance simple, enabling hassle-free investigation of particle dynamics.
2022	Pachkwade *et al.,* [41]	A fascinating inquiry centred on the Micro-Electro-Mechanical Systems (MEMS) resonant sensor is taking place in the world of technological marvels. Researchers are interested in this sensor because of its low power consumption, consistent dependability, and tantalising promise of lower pricing. The achievement of providing direct mass weighing, which offers up intriguing possibilities for particle identification and concentration measurement, is where it truly shines. This work revolutionises our understanding of particle dynamics as it explores the possibilities of the MEMS resonant sensor and delves into a world where accuracy meets efficiency.
2022	Phairuang *et al.,* [42]	The $PM_{0.1}$ cascade air sampler, or nano-sampler, is a unique technology that was developed to catch the elusive $PM_{0.1}$ particles. This extraordinary device has a number of potent parts, including four impactor stages ($PM_{10,\ 2.5,\ 1.0}$, and $_{0.5}$), 55 mm-diameter quartz fibre filters (QFF), an inertial filter (IF) stage made for particles between $PM_{0.5}$ and $PM_{0.1}$, and a reliable backup filter placed after the IF stage. This complex system operated in perfect harmony to capture the ultrafine particles that frequently evade the reach of traditional sampling procedures. The nano-sampler was a ray of hope, illuminating the mysterious world of $PM_{0.1}$ particles with unparalleled accuracy.

5. Research Gap

PM measurement now faces significant obstacles, with costly equipment and a lack of a standardised approach impeding advancement. Current methods frequently ignore important particle size-related aspects, particularly when it comes to ultrafine particles, which results in erroneous exposure evaluations. Furthermore, some techniques, especially those using inexpensive sensors, have limited precision [43]. Although portable monitors and lab-grade equipment have been developed, there are still challenges due to their high costs and restrictions on assessing just particle size distribution. In many methodologies, real-time measurement and large detection systems show to be major limitations. Additionally, techniques like gravimetric sampling have lengthy lag times between sample collection and reporting, making it unable to record abrupt changes in PM, and routine filter weighing further stalls outcomes [44]. Techniques like CPC, which struggle with precise sample measurement, and NSAM, which is extremely sensitive to environmental influences, provide complications. The majority of techniques also fall short in measuring ultrafine particles (UFPs) and in detecting finer particles.

Only a few equipment has the ability to measure lower sizes, and most only have the ability to detect PM_{10} and $PM_{2.5}$. For many techniques, the criterion of less than 0.1 micron is still mostly unreachable. While instruments with heating elements can evaporate semi-volatile species, altering measurement findings, wind turbulence and airflow have a significant negative impact on measurement accuracy [45]. These difficulties underscore the urgent need for more advancements in PM measurement techniques in order to increase accuracy, enable real-time monitoring, and provide greater insights into the state of the air. In order to overcome these challenges and deliver more accurate, timely, and comprehensive data on our atmospheric conditions, the search for enhanced tools and refined approaches holds considerable promise.

6. Conclusions

This paper provides insight into particulate matter as one of the main components of air pollution substances, its sources and how it can impact human well-being. There is many research paper that had describe how PM can negatively affect the human respiratory and cardiovascular system when exposed to it whether short-term or long-term, how to deep it can penetrate human body based on it sizes, causing disease such as asthma, cancer, cardiovascular disease and increase mortality rate. These virulent substances had led to the importance in air monitoring to measure the particles that come in when different sizes come from different sources.

Moreover, research papers on the health effect caused by UFPs had described it are more dangerous than bigger particles which lead for development of device, method or technique that is suitable for UFPs evaluation. Past research based on the years 2015 to 2023 in the particles measurement also are documented in this paper to provide insight about the current growth or new method currently implemented in the PM evaluation field. Method that are implement some which is a combination from difference method, calibration for better data accuracy, adjustment or modification of existing method and new method to achieve better PM measurement with the aim to tackle nowadays air pollution and deeper understanding in the PM characteristics and the limitation that it possesses for future guidance.

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References
[1] Mackenzie, Jillian, and Jeff Turrentine. *Air Pollution Facts, Causes and the Effects of Pollutants in the Air NRDC. NRDC*. 2021.
[2] European Environment Agency. 2025. "Air Pollution Sources." *European Environment Agency*.
[3] Manisalidis, Ioannis, Elisavet Stavropoulou, Agathangelos Stavropoulos, and Eugenia Bezirtzoglou. "Environmental and health impacts of air pollution: a review." *Frontiers in public health* 8 (2020): 14. https://doi.org/10.3389/fpubh.2020.00014
[4] L Murray, Christopher, Aleksandr Y Aravkin, Peng Zheng, Khaled Khatab, Abbafati Cristiana, Afshin Ashkan, and S. Lim Stephen. "Global burden of 87 risk factors in 204 countries and territories, 1990–2019: a systematic analysis for the Global Burden of Disease Study 2019." *The Lancet* 396, no. 10258 (2020): 17-23.
[5] Roser, Max, and Hannah Ritchie. 2025. "Outdoor Air Pollution." *Our World in Data*.
[6] Saxena, Pallavi, and Saurabh Sonwani. *Criteria air pollutants and their impact on environmental health*. Vol. 1, no. 1. Singapore: Springer Singapore, 2019. https://doi.org/10.1007/978-981-13-9992-3_1
[7] He, Yi, Wanyanhan Jiang, Xi Gao, Chengwei Lin, Jia Li, and Lian Yang. "Short-term effects and economic burden of air pollutants on acute lower respiratory tract infections in children in Southwest China: a time-series study." *Environmental Health* 22, no. 1 (2023): 6. https://doi.org/10.1186/s12940-023-00962-3
[8] Luo, Huihuan, Qingli Zhang, Yue Niu, Haidong Kan, and Renjie Chen. "Fine particulate matter and cardiorespiratory health in China: a systematic review and meta-analysis of epidemiological studies." *Journal of Environmental Sciences* 123 (2023): 306-316. https://doi.org/10.1016/j.jes.2022.04.026
[9] Lyu, Lizhi, Yu Xu, Hongbo Wang, Xin Guo, Yanjun Gao, Shumin Duan, Furong Deng, Xinbiao Guo, and Yun Wang. "Changes in heart rate variability of healthy subjects shortly exposed to printing shop particles and the effect of air purifier intervention." *Environmental Pollution* 315 (2022): 120418. https://doi.org/10.1016/j.envpol.2022.120418

[10] Usmani, Raja Sher Afgun, Anum Saeed, Akibu Mahmoud Abdullahi, Thulasyammal Ramiah Pillai, Noor Zaman Jhanjhi, and Ibrahim Abaker Targio Hashem. "Air pollution and its health impacts in Malaysia: a review." *Air Quality, Atmosphere & Health* 13 (2020): 1093-1118. https://doi.org/10.1007/s11869-020-00867-x
[11] Meersens. 2025. "Nitrogen Dioxide (NO_2) Sources and Health Impacts." *Meersens*.
[12] U.S. Environmental Protection Agency (EPA). "Carbon Monoxide's Impact on Indoor Air Quality." *U.S. Environmental Protection Agency*.
[13] "Carbon Monoxide Poisoning: Health Effects (AEN-166) - Department of Agricultural and Biosystems Engineering." https://www.abe.iastate.edu/extension-and-outreach/carbon-monoxide-poisoning-health-effects-aen-166/ (accessed Dec. 16, 2022).
[14] Schraufnagel, Dean E., John R. Balmes, Clayton T. Cowl, Sara De Matteis, Soon-Hee Jung, Kevin Mortimer, Rogelio Perez-Padilla et al. "Air pollution and noncommunicable diseases: a review by the forum of international respiratory societies' environmental committee, part 2: air pollution and organ systems." *Chest* 155, no. 2 (2019): 417-426. https://doi.org/10.1016/j.chest.2018.10.041
[15] IQAir. 2016. "Why Are the WHO Air Quality Guidelines Used When Different Countries Have Different Ambient Air Quality Requirements?" *IQAir*.
[16] Jabatan Alam Sekitar (Department of Environment, Malaysia). "Standard Kualiti Udara." *Jabatan Alam Sekitar*.
[17] U.S. Environmental Protection Agency (EPA). "NAAQS Table." *U.S. Environmental Protection Agency*.
[18] U.S. Environmental Protection Agency (EPA). "National Ambient Air Quality Standards (NAAQS) for Lead (Pb)." *U.S. Environmental Protection Agency*.
[19] C40 Knowledge Hub. "WHO Air Quality Guidelines." *C40 Knowledge Hub*.
[20] World Health Organization (WHO). "WHO Global Air Quality Guidelines." *World Health Organization*.
[21] American Lung Association. "Particle Pollution." *American Lung Association*.
[22] United Nations Environment Programme (UNEP). "Air Pollution: A Silent Killer." *United Nations Environment Programme*.
[23] Queensland Government. "Particles." *Queensland Government*, Department of Environment and Science.
[24] Sanità di Toppi, Luigi, Lorenzo Sanità di Toppi, and Erika Bellini. "Novel coronavirus: how atmospheric particulate affects our environment and health." *Challenges* 11, no. 1 (2020): 6. https://doi.org/10.3390/challe11010006
[25] Kirešová, Simona, and Milan Guzan. "Measurement of particulate matter: Principles and options of measurement at present." *Acta Electrotech. Et Inform* 22 (2022): 8-18. https://doi.org/10.2478/aei-2022-0007
[26] Kwon, Hyouk-Soo, Min Hyung Ryu, and Christopher Carlsten. "Ultrafine particles: unique physicochemical properties relevant to health and disease." *Experimental & molecular medicine* 52, no. 3 (2020): 318-328. https://doi.org/10.1038/s12276-020-0405-1
[27] Amaral, Simone Simões, João Andrade de Carvalho Jr, Maria Angélica Martins Costa, and Cleverson Pinheiro. "An overview of particulate matter measurement instruments." *Atmosphere* 6, no. 9 (2015): 1327-1345. https://doi.org/10.3390/atmos6091327
[28] Nussbaumer, Thomas, Claudia Czasch, Norbert Klippel, Linda Johansson, and Claes Tullin. "Particulate emissions from biomass combustion in IEA countries." *Survey on Measurements and Emission Factors, International Energy Agency (IEA) Bioenergy Task* 32 (2008).
[29] Giechaskiel, Barouch, Matti Maricq, Leonidas Ntziachristos, Christos Dardiotis, Xiaoliang Wang, Harald Axmann, Alexander Bergmann, and Wolfgang Schindler. "Review of motor vehicle particulate emissions sampling and measurement: From smoke and filter mass to particle number." *Journal of Aerosol Science* 67 (2014): 48-86. https://doi.org/10.1016/j.jaerosci.2013.09.003
[30] Hosseini, S., Qi Li, D. Cocker, D. Weise, A. Miller, M. Shrivastava, J. W. Miller, S. Mahalingam, M. Princevac, and H. Jung. "Particle size distributions from laboratory-scale biomass fires using fast response instruments." *Atmospheric Chemistry and Physics* 10, no. 16 (2010): 8065-8076. https://doi.org/10.5194/acp-10-8065-2010
[31] Hossain, AMM Maruf, Seungho Park, Jae-Seok Kim, and Kihong Park. "Volatility and mixing states of ultrafine particles from biomass burning." *Journal of Hazardous materials* 205 (2012): 189-197. https://doi.org/10.1016/j.jhazmat.2011.12.061
[32] Vincent, James H. *Aerosol sampling: science, standards, instrumentation and applications*. John Wiley & Sons, 2007. https://doi.org/10.1002/9780470060230
[33] Beauchemin, Suzanne, Christine Levesque, Clare LS Wiseman, and Pat E. Rasmussen. "Quantification and characterization of metals in ultrafine road dust particles." *Atmosphere* 12, no. 12 (2021): 1564. https://doi.org/10.3390/atmos12121564
[34] Bertke, Maik, Ina Kirsch, Erik Uhde, and Erwin Peiner. "Ultrafine aerosol particle sizer based on piezoresistive microcantilever resonators with integrated air-flow channel." *Sensors* 21, no. 11 (2021): 3731. https://doi.org/10.3390/s21113731

[35] Fujitani, Yuji, Katsuyuki Takahashi, Katsumi Saitoh, Akihiro Fushimi, Shuichi Hasegawa, Yoshinori Kondo, Kiyoshi Tanabe, Akinori Takami, and Shinji Kobayashi. "Contribution of industrial and traffic emissions to ultrafine, fine, coarse particles in the vicinity of industrial areas in Japan." *Environmental Advances* 5 (2021): 100101. https://doi.org/10.1016/j.envadv.2021.100101
[36] Jakubiak, Szymon, and Przemysław Oberbek. "Determination of the concentration of ultrafine aerosol using an ionization sensor." *Nanomaterials* 11, no. 6 (2021): 1625. https://doi.org/10.3390/nano11061625
[37] Kazys, Rymantas, Reimondas Sliteris, Liudas Mazeika, Liesbet Van den Abeele, Peter Nielsen, and Ruben Snellings. "Ultrasonic monitoring of variations in dust concentration in a powder classifier." *Powder Technology* 381 (2021): 392-400. https://doi.org/10.1016/j.powtec.2020.11.072
[38] Lee, Seung-Soo, Woo-Young Song, and Yong-Jun Kim. "Intelligent PM 2.5 mass concentration analyzer using deep learning algorithm and improved density measurement chip for high-accuracy airborne particle sensor network." *Journal of Aerosol Science* 167 (2023): 106097. https://doi.org/10.1016/j.jaerosci.2022.106097
[39] Ranpara, Anand, Ryan F. LeBouf, Timothy R. Nurkiewicz, Jinghai Yi, Jared L. Cumpston, and Aleksandr B. Stefaniak. "Multi-instrument assessment of fine and ultrafine titanium dioxide aerosols." *Journal of Toxicology and Environmental Health, Part A* 86, no. 1 (2023): 1-22. https://doi.org/10.1080/15287394.2022.2150730
[40] Jeon, Jae-Wan, Seong-Jae Yoo, and Yong-Jun Kim. "An integrated electrical condensation particle counter for compact and low-cost ultrafine particle measurement system." *Journal of Aerosol Science* 163 (2022): 105996. https://doi.org/10.1016/j.jaerosci.2022.105996
[41] Pachkawade, Vinayak, and Zion Tse. "MEMS sensor for detection and measurement of ultra-fine particles." *Engineering Research Express* 4, no. 2 (2022): 022002. https://doi.org/10.1088/2631-8695/ac743a
[42] Phairuang, Worradorn, Muanfun Inerb, Mitsuhiko Hata, and Masami Furuuchi. "Characteristics of trace elements bound to ambient nanoparticles (PM0. 1) and a health risk assessment in southern Thailand." *Journal of Hazardous Materials* 425 (2022): 127986. https://doi.org/10.1016/j.jhazmat.2021.127986
[43] Mohd Noor, Ahmad Faizal, Siti Norazlina Mohd Noor. "Sustainable Urban Development: A Case Study in Malaysia." Journal of Sustainable Engineering and Technology 2, no. 3 (2023): 30-40.
[44] Mohd Noor, Siti Norazlina, Ahmad Faizal Mohd Noor. "Innovative Waste Management Strategies for Urban Areas." Journal of Sustainable Engineering and Technology 2, no. 1 (2023): 5-15.
[45] Chew, Wai Hoong, Mah Kai Xuan. "Peripheral Arterial Disease in Diabetes Mellitus and Physiotherapy Management." Journal of Health and Quality of Life 4, no. 1 (2024): 18-24. https://doi.org/10.37934/jhqol.4.1.1824