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Ambient Air Quality Monitoring: Impetus, Complexities, Challenges and Solutions

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AMBIENTAIR QUALITYMONITOR INGIMPETUS COMPLEXITIES CHALLENGES AND SOLUTIONS

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Ambient Air Quality Monitoring: Impetus, Complexities, Challenges and Solutions

Rao Tatavarti

Abstract- The poor state of air quality all over the world in general, and across India in particular, is a cause for extreme concern as it is directly and indirectly linked to the deterioration of human health and economies of nations The many complexities and challenges posed by ambient air quality monitoring, prompted the World Health Organization (WHO) to suggest a road map for all nations for the year 2020 -to arrive at a consensus for effective air quality monitoring by all stakeholders – nations and governments, regulatory and controlling bodies, NGOs, scientists and researchers and private citizens.

As we approach the end of 2021, the multifaceted and multidimensional problems related to effective ambient air quality monitoring still remain herculean, and extremely expensive for wider deployment to gather a realistic spatiotemporal information related to ambient air quality, in order to draw up effective plans to curb or mitigate the air pollution.

The complexities for effectively monitoring ambient air quality led to confusing practices in selection of sensors and systems for air quality monitoring, the siting of systems, and the empirical approaches followed by different stakeholders in arriving at averaging times related to expensive systems for measurements, resulted in different definitions of air quality.

Today, the confusion is worse confounded with the advent of new entrants into the field advocating low cost sensors with lesser accuracies for niche applications.

Against this backdrop the present two-part paper highlights the impetus, complexities and challenges posed for ambient air quality monitoring in the first part of the paper. The second part of the paper introduces a novel indigenously developed state of art photonic system for ambient air quality monitoring having higher accuracies with overarching capabilities for diverse applications.

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Prof. Tatavarti has more than 192 peer reviewed scientific and research publications and 8 international and national patents to his credit and is a distinguished member of SITARA, Fellow of Optical Society of India, Fellow of Andhra Pradesh Academy of Sciences. A unique calibration facility designed and developed for the indigenous photonic system ensures that after a onetime calibration the system can be deployed for field usage anywhere in the world under any extreme weather conditions.

AUM was compared with the conventional imported ambient air quality monitoring stations and found to be far superior in characteristics.

The indigenously designed and developed system, called as AUM (Air Unique-quality Monitoring) is extremely economical compared to the conventional standard reference stations, thus making it ideal for large scale deployment to effectively monitoring the hitherto eluded spatio temporal variations of ambient air quality.

I. Impetus

igher levels of air pollution are a pernicious global problem affecting not only the densely populated countries, but also, countries with sparse populations, as well as regions like Arctic and Antarctica where no population exists. That global pollution is associated with atmospheric and oceanic dynamics and the resulting climate change, with a feedback loop is now accepted and understood. Air quality monitoring therefore involves the systematic collection of physical, chemical, biological, and related data pertaining to ambient air quality, pollution sources, meteorological parameters, and other factors that influence, or are influenced by ambient air quality.

Air pollution may result in huge impacts, causing different effects on human health, on the environment (*e.g.*, ecosystem damage) and on the economy of industrialized and developing countries [1, 2]. For these reasons, air quality monitoring is typically required by national and international regulations to systematically and accurately assess the environmental exposure of the general population to multiple environmental contaminants [3].

Recent research published in April 2020 by researchers of Harvard University USA; made a startling suggestion that even an increase of $1\mu g/m^3$ level of PM_{2.5} could lead to a 15% increase in fatality rates due to COVID -19 infections [4]. The Harvard University study amply demonstrates and underlines the urgent necessity and paramount importance of *effective* ambient air quality monitoring, as air quality *or rather the lack of it*, directly affects the nations' health, economy and security.

It is imperative therefore, to protect the air we breathe by taking actions to ensure its best possible

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quality. Measures to ensure good air quality demand accurate and cost effective air quality monitoring.

II. Complexities and Challenges

From a historical perspective, it is imperative to realize that the United States Environmental Protection Agency (US EPA) was one of the first regulatory bodies to worry about air quality and pollution. Starting with the Clean Air Act of 1955 the US EPA has come up with Standards for Measurements (National Ambient Air Quality Measurement Standards – NAAQMS) in 1970 [5, 6], which were followed by the regulatory bodies of other developed and developing countries in Europe (European Union Standards)[7], Australia, Japan [8, 9, 10],World Health Organization, WHO [11, 12] and Asia. India followed suit in 2009 publishing its own standards, by and large culled from the NAAQMS of USEPA and the WHO guidelines [13].

With the advent of new technologies and a better understanding of the Science behind air quality monitoring, US EPA researchers published an important study [14] in the reputed and peer reviewed American Chemical Society Journal in 2013. The study pointed out a number of issues and challenges faced by the existing air quality monitoring methods, the standards practised and concluded that the monitoring methods and practices have seriously jeopardized the quality and sanctity of air quality data.

Subsequently, many scientists and researchers all over the world also concluded that a paradigm shift in air quality monitoring methods and standards is essential by adopting new and emerging technologies. However, neither the regulatory bodies, nor, the industry paid any attention to the growing concerns on the quality of air monitoring systems worldwide.

In 2018, the internationally reputed, peer reviewed Scientific American Journal published startling revelations made by the Centre for Public Integrity in USA, that, for decades the USEPA was complicit in wantonly and systematically under reporting the levels of pollution, taking the general public for a ride. The study pointed out that the hazardous emissions by industries were much larger than reported and documented [15].

This shocked the world's scientific fraternity and all other stakeholders who realized, rather late, that the situations were similar in their respective countries. Consequently, there was a vociferous demand for a paradigm shift in the policies and attitudes of an otherwise complacent and complicit regulatory authorities for air quality / pollution monitoring.

Following the hue and cry, it is now widely accepted worldwide that proper ambient air quality assessment cannot be accomplished, without addressing the following pertinent questions:

1. What are the limitations of current measurements, monitoring techniques and the standards currently being employed across the world?

- 2. Do the methods of measurements involving synthetic chemicals, themselves result in pollution of air, water and soil?
- 3. As the objectives determine the degree of accuracy, sensitivity, method of monitoring and the sampling mechanism in situ or in-vivo sampling, what are the stated assumptions and objectives of the air quality monitoring?
- 4. What is the area for which measurements are representative and reliable?
- 5. What is the proper mix and location of fixed stations, moveable stations, airborne stations, and what is the role of modelling in achieving the objectives?
- 6. What level or degree of errors are acceptable?
- 7. What is the importance of exposure monitoring as related to the pollutants that are air oriented or to those that occur in other media including the food chain?
- 8. What related collocated meteorological data must be collected with air quality data?
- 9. What is the importance of sample averaging times to the design of monitoring stations and the inferences on air pollution?
- 10. What are the effects of physical and chemical transformations at the sampling locations and network design for example, for monitoring ozone or sulphates?
- 11. What quality assurance programs are necessary to assure that data are representative and legally and scientifically defensible?
- 12. What measures need to be taken for including public participation to ensure non-obfuscation and integrity of data?

Based on the knowledge and insights gained over many decades, the world over, air quality monitoring is now expected to involve a rigorous, systematic and complex approach based on the stated objectives and therefore, should necessarily adopt newer knowledge and innovative technologies after due scientific and technical diligence[16].

III. MEASUREMENT OF AIR QUALITY WITH LOW COST SENSORS

Of late, low-cost air pollution sensors are attracting more and more attention. They offer air pollution monitoring at a lower cost than conventional methods, in theory making air pollution monitoring possible in many more locations. However, at the current stage of development, measurements with lowsensors (Electro-Chemical Sensors, Photo cost Ionization Detectors Optical Particle Counters, Optical Detectors) are often of lower and more questionable data quality than the results from official monitoring stations carried out by pollution monitoring bodies in accordance with international standards and methods [17]. If the quality of the measurements can be improved, low cost solid state sensors could become a

game changer in monitoring air pollution, traffic management, personal exposure and health citizen pollution assessment, science and air assessment in developing countries. But unfortunately there are many intrinsic constraints and limitations associated with the existing low cost solid state sensors. Studies have demonstrated that the signals from sensors not only depend on the air pollutant of interest, but also on a combination of several effects, such as other interfering compounds, temperature, humidity, pressure and signal drift (instability of signal). At high concentrations the signal from the air pollutant can be strong, but at ambient air levels the signal is weaker in comparison to the interfering effects and therefore the utility of the low cost solid state sensors would be

severely limited for any real world application unless there is a paradigm improvement in the structure and sensing mechanisms of the sensors *per se*.

IV. Status in India

Interestingly in India, notwithstanding the knowledge regarding the limitations of measurements at fixed locations, and the paradigm shift suggested in the approaches to ambient air quality monitoring methods worldwide, CPCB India and the State Pollution Control Boards, are still refusing to see the woods for the trees by pigheadedly insisting on the questionable measurement methods and standards for the instrumentation -in spite of their two revised guidelines in 2013 and 2018 [18, 19].

Table 1: National Ambient Air Quality Monitoring: Existing Standards, Guidelines, Methods, and their Drawbacks

			Concentrati	ion in Ambient Air			
S. No.	Pollutant	Time Weighted Average	Industrial, , Residential, Rural and Other Areas	Ecologically Sensitive Area(<i>Notified</i> <i>by Central</i> <i>Government</i>)	Methods of Measurement	Drawbacks	
(1)	(2)	(3)	(4)	(5)	(6)	(7)	
1	Sulphur	Annual*	50	20	Improved West and	Interference of oxides of nitrogen and ozone are well documented	
	Dioxide (SO ₂), µg/m ³	24 hours**	80	80	Geake Method	concentrations of interfering oxidants should be less than that of SO_2 , i.e., up to about 2 ppm.	
					Ultraviolet Fluorescence	This technique is very sensitive but other gaseous components are known to interfere. Quenching (e.g. by O_2 or H_2O) of the excited species can lead to an underestimation of the SO_2 concentration. Positive interference occurs by molecules which absorb radiation and fluoresce in the same region than SO_2 (e.g. NO and HC) [3]. In exhaust gases, nitric oxide (NO) is usually the main positive interferences, while oxygen is the most important quenching species if water vapor is removed by a Nafion dryer. Filters and selective traps are often used to remove interfering gases. Scrubbers for H_2S gases are needed if it is present in high concentrations. Correction for temperature and pressure is made and calibration is made against some primary standard (guidelines).	
2	Nitrogen Dioxide (NO ₂), µg/m³	Annual* 24 hours**	40 80	30 80	Modified Jacob & Hochheiser (NaAsO ₂)	This method involves the use of Sodium Arsenite, Nitric oxide (NO), Carbon Dioxide (CO_2) and Sulphur Dioxide (SO_2) interfere in the testing.	
					Chemiluminescence	Requires elaborate instrumentation and use of various chemicals. Interference from other pollutants like non NO_x reactive nitrogen species like HNO_3 and ambient O_3 can pose interferences. [<u>Ref</u> : EJ Dunlea et al, <i>AtmosChemPhys.</i> , 7, 569-604, 2007 and ibid 2691-2704].	
3	Particular Matter PM ₁₀ µg/m ³	Annual* 24 hours**	60 100	60 100	Gravimetric	Manual intervention is required and may lead to personal errors.	
					ТОЕМ	Mechanical noise and dramatic temperature fluctuations can interfere with the operation of a TEOM device [1,2]. In addition, water droplets cannot be distinguished from particle mass, so the device must adjust the incoming air temperature to cause water droplets to evaporate, [3] or contain a dryer or humidity sensor to adjust the readings [4]. Under ideal conditions, TEOM is just as accurate as the standard reference method, but its sensitivity presents complications for use for environmental monitoring in urban areas.	
						Her. [1] (WIKIPEDIA, "Tapered element oscillating microbalance". Queensland Department of Environment and Heritage Protection. 2017-03-27. Retrieved 2017-06-28.	

						 [2] Gilliam, Joseph H.; Hall, Eric S. (2016-07-13). "Reference and Equivalent Methods Used to Measure National Ambient Air Quality Standards (NAAQS) Criteria Air Pollutants – Volume I". U.S. Environmental Protection Agency. pp. 10, 24, 32. Retrieved 2017-06-28. [3]"Machine-Mounted Continuous Respirable Dust Monitor". NIOSH Technology News. U.S. National Institute for Occupational Safety and Health. July 1997. Retrieved 2017-06-28. [4] Ray, Alison E.; Vaughn, David L. (2009-09-01). "Standard Operating Procedure for the Continuous Measurement of Particulate Matter" (PDF). U.S. Environmental Protection Agency. pp. 1–1, 3-1–3-2, 6-1–6-2. Retrieved 2017-06-28.)
					Beta Attenuation	The measurement of both sizes of particles is not simultaneous (guidelines) To discriminate between particle of different sizes (e. g., between PM_{10} and $PM_{2.5}$), some preliminary separation could be accomplished, for example, by
						specially designed inertial particle size separators like cyclones or impactors. Drawbacks: (from Thermo- Fischer website, https://www.thermofisher.com/in/en/home/industrial/environmental/environme ntal-learning-center/air-quality-analysis-information/beta-attenuation- technology-particulate-matter- measurement.html#:~:text=From%20the%20above%20description%20of,rad ioactive%20source%20also%20limits%20acceptance.) The primary drawback is that it is a non-continuous monitoring technology. Typically, only 4 PM readings per hour can be collected. The technology is also fairly expensive limiting its market acceptance. Its radioactive source also limits acceptance.
4	Particulate Matter PM ₂₅ µg/m ³	Annual* 24 hours**	40 60	40 60	Gravimetric/ TOEM/ Beta- Attenuation	See above
5	Ozone(O ₃) µg/m ³	8 hours** 1 hour**	100 180	100 180	UV Photometric	Require chemical reagents which themselves are pollutants
					Chemiluminescence	Presence of water vapor causes errors.
					Chemical Method	If done manually, there is always a scope for personal errors. Need chemicals
6	Lead (Pb) μg/m ³	Annual* 24 hours**	0.50 1.0	0.50 1.0	AAS / ICP method after sampling on EPM 2000 or equivalent filter paper	Use of argon gas is required to generate plasma. Both maintenance and purchase costs are high. Permissible limits have recently been reduced worldwide, which fall below the detection limits of the ICP AAS. ICP-MS is the preferred instrument now but it is too expensive [<u>Ref:</u> M. Harrington <i>et al</i> , Environmental Science: Processes and Impacts
					ED-XRF using Teflon	16(2) December 2013, DOI: 10.1039/c3em00486d] Expensive instrumentation.
7	Carbon Monoxide (CO) mg/ m³	8 hours** 1 hour**	02 04	02 04	filter Non Dispersive Infra- Red (NDIR) Spectroscopy	LEAD standards are used. Can be affected by humidity and temperature. Accuracy declines at high concentrations of CO <u>Ref</u> : Trieu-Vuong Dinh <i>et al</i> , sensors and actuators B: Chemical, Vol 243, May 2017, 684-689. Standard CO gas needs to be stocked up (Guidelines). Any leak in the gas cylinders can have hazardous consequences.
8	Ammonia (NH ₃) μg/m ³	Annual* 24 hours**	100 400	100 400	Chemiluminescence Indophenol blue method	Requires bubbling of the air through sulphuric acid prior to the analysis. Involves the use of chemical reagents like phenol Need of expensive catalytic molybdenum converters (Guidelines) Operated at high temperatures 950-1000° C, (Guidelines) Filters are used to remove particulate matter. Any gases adsorbed on the particulate matter may be removed during the process Converter efficiency may be gradually lost and correctionsareto be applied during the calculations. The instrument needs to be operated in an environmentally controlled AC room (where temperature and humidity are controlled).

In short, temperature, pressure, humidity, flow and vibration controls are required to be stringently set up at continuous ambient air quality monitoring stations, for effective functioning of the various equipment at a station. The role of interference caused by additives during the tests and the role of scrubbers employed during testing is still ambiguous. In summary, the existing methods of measurements practiced for ambient air quality monitoring are far from sacrosanct and are not problem free, having significant biases, limitations and drawbacks which remain to be addressed.

Against this backdropa group of researchers from academia and industry undertookan elaborate and exhaustive research, during the first half of 2020 to study the status of current ambient air quality monitoring across India. Utilizing data from 233 Continuous Ambient Air Quality Monitoring Stations (CAAQMS) in India, during a period of 180 days from January 1, 2020 to June 30, 2020, highlighted the following issues and limitations which have serious implications to the validity, efficacy and sanctity of air quality/pollution monitoring [20]:

- 1. The air quality monitoring instrumentation presently being used are characterized by high costs, and a high level of maintenance.
- 2. The air quality monitoring stations provide representative data only for a very restricted area in space. This is а disadvantage because measurements at adequate spatial scales are monitorina air pollution essential for in heterogeneous environments such as those naturally found in the atmosphere [21].
- 3. To a large extent the air monitoring stations were sited at locations where sources of pollution were far away.
- 4. All air quality monitoring stations use a suction mechanism to pump air from a higher elevation and route the air through conduits to different sensors located below in an environmentally controlled container, making the measurements in vivo but not in situ.
- The problems associated with in-vivo sampling visà-vis the preferred in situ sampling are well documented in scientific and technical literature. Most of the standards of in vivo sampling and measurements pertaining to various standalone sensors for pollutant monitoring have significant limitations.
- 6. The air samples for monitoring are taken from a location well above the height at which the general public live and breathe. The complex natural diffusion processes affecting the fluid flow patterns and the atmospheric stratification effects in the vertical direction raise serious questions regarding the validity of air quality monitoring at elevations well

above the domain of human existence and relating the same data to health effects of the population. The role and degree of plausible contamination of the sampled air being routed through conduits before reaching the particular sensors for measurement are well studied and documented in scientific literature, pointing out uncertainties and undocumented errors associated with in vivo sampling techniques of the current air monitoring stations.

- 7. The non-uniform standards practised by various equipment suppliers across the stations, make Inter comparisons of degrees of pollution very difficult across the different stations.
- 8. Out of all the CAAQMS, during the study period of six-months, more than 90% of the stations reported missing data (*perhaps, due to non-functional sensors*) for periods longer than three to five days continuously.
- 9. All the stations were not monitoring all the required parameters responsible for computing the air quality index of a location.
- 10. In bigger cities like New Delhi where more monitoring stations are located, the spatio-temporal variations in air quality are markedly significant.
- 11. It would therefore be very difficult to determine the spatio-temporal variations in air quality, given the sparse sampling and the fixed nature of the CAAQMS locations across India.
- 12. Effects of strong and powerful natural events, like Cyclone *Amphan* crossing over land near Kolkata, West Bengal on the East Coast of India (May 21, 2020); and Cyclone *Nisarg* crossing over land near Konkan Coast, Maharashtra on the West Coast of India (June 3, 2020), were not even recorded by the CAAQMS located in the respective regions.
- 13. Air quality effects of the major industrial accidents (like in Visakhapatnam, Andhra Pradeshon May 7, 2020 when Styrene Gas leaked with its effects spreading to large spatial extent of a 10 km radius) were not even recorded by the Visakhapatnam CAAQMS station.
- 14. The effects of multiphase chemistry, need to be considered in pollution monitoring using passive sampling techniques [22].
- 15. Most of the stations indicated that all the monitored parameters were either in the *Good* or in *Satisfactory* category of the CPCB India Standards, while factual ground observations, indicated poor air quality.

The exhaustive study [20] covering the entire geographical region of India over a statistically long period, thus raised disturbing and disconcerting questions on the *validity*, *efficacy and sanctity* of the current monitoring stations, in spite of their *apparently satisfactory* standards and certifications endorsed by concerned authorities.

The study has also showcased that air quality monitoring resulted in less than appropriate and adequate data, has not been cost effective, and in certain instances has resulted in implementation of costly programs which provided questionable benefits.

With the current air quality measurements getting embroiled in many serious issues and challenges, and threatening to jeopardize the primary objective of the Clean Air Initiatives of the Central Government of India as well as of the many States of India, a strong wakeup call to all the slumbering stakeholders and authorities would therefore be timely and necessary.

Hence it would be apt to summarize that given the limitations in measurements, coupled with the complexities of tropical atmospheric and oceanic dynamics associated with the Indian sub-continent, the current air quality monitoring methods, mechanisms and management needs a thorough overhaul.

V. Accurate, Cost Effective Solutions

It is high time that the concerned stakeholders realize that the solution to the air quality monitoring imbroglio lies in looking at newer and better sensors and technologies. The ability to assess ambient air quality depends heavily on the availability and applicability of appropriate sensors. Until recently, most pollutant sensors capable of providing quantitative information were of the type, where the air to be monitored should be brought to the sensor. Such sensors are restricted to measurement of a parameter at a single point in space, or, when mounted on a mobile platform, at sequential points as a function of time, but cannot be labelled as in-situ sensors.

Moreover, because of the difficulty of relating a point in space remote from the sensor to sensor data, great care must be taken in selecting the site for the sensor, and in drawing meaningful inferences thereafter.

Maximum use of new concepts and methodologies as they become available, therefore is essential. Such concepts as integrated monitoring systems, new optimization techniques and state-of-theart measurement devices, such as those employing remote sensing techniques, are becoming operational in the sense of being available for testing and application.

Needless to say that ignoring to use them to their fullest capabilities will result in a loss of the opportunity to develop rational environmental assessment tools [21]. As new devices become available, they should be incorporated into operational monitoring systems. There is no doubt of the ever increasing importance of remote sensing for air quality monitoring programs. These techniques can not only replace contact monitors but also will augment and improve monitoring methodology. As newer techniques and hardware become more available and enhance our ability to monitor our environment, we will be faced with the question of, what is the most cost-effective combination of fixed, mobile contact and remote sensors for a specific monitoring problem? Hence new systems and technologies capable of spatio-temporal monitoring with high sampling frequencies, capable of large spatial areas of coverage would be advantageous and cost effective.

Another area where advances are yet to come is in the development of monitoring methods for assessing exposure-dose relationships. In the past, environmental monitoring has been carried out in response to an already existing hazardous condition. Future monitoring systems must be able to detect potential problems and monitor the appropriate parameters before they reach crisis proportions.

Some possibilities which might be explored are the use of biological exposure indicators as trend monitors to predict changes, and the development of personal exposure meters, such as biochemical measurements which integrate the total exposure of an individual to a pollutant or class of pollutants. When we achieve accurate, valid and broadly applied exposure monitoring, we then shall have made a major step toward achieving the ability to truly and rationally evaluate the management of our air resources.

In summary, air quality management requires an understanding of the type of air pollutants being emitted by various sources from on road vehicles, large industrial facilities, power plants and smaller sources such as residential heating and asphalt paving. The development of emissions inventories is critical for the states to implement accurate and effective air pollution control strategies [23].

These challenges can therefore only be met by portable, light weight sensors and systems which are capable of *accurately* monitoring all pollutants in-situ from remote location, in real time. Sensors with capabilities for simultaneous spatio-temporal monitoring, with high sampling rates would certainly be a boon in our crusade for accurate and cost effective ambient air quality monitoring.

VI. Ambient Air Quality Monitoring-II: Indigenous Photonic System AUM

a) Indigenous Photonic System for Real Time, Remote Air Quality Monitoring - AUM

With the current systems and technologies used for air quality monitoring *having serious constraints, in addition to being prohibitively expensive for wider deployment* - the impetus for an indigenous development of a system for real time remote monitoring of all air quality parameters becomes crucial for India not only in achieving self-reliance in high end technologies, but also in aiding the nation's health and economy.

Against this backdrop Prof. Rao Tatavarti of Gayatri Vidya Parishad, designed and developed a novel innovative photonic system capable of real time remote monitoring of various air parameters simultaneously, to arrive at the in-situ air quality at a particular location or as a spatial profile with high sensitivitv and accuracies by adopting COTS (commercially-off-the-shelf) technologies, thus making them significantly cheaper for wider deployment.

An indigenous photonic system, for real time remote monitoring of all air quality parameters was designed and developed, with the sponsorship by DST, Govt. of India under the Clean Air Research Initiative, and M/S CATS Ecosystems Pvt Ltd, Nashik which is the technology transfer partner for commercialization. The indigenous development is christened as AUM (Air Unique-quality Monitoring) system.

b) AUM - System for Real Time, Remote, In-Situ Monitoring of Air Quality

AUM photonic system has a modular design with interchangeable components and modules from any other system. The photonic system AUM comprises of the following subsystems:

- Photonic System Source Laser (<10 milliwatt, Wavelength 250-850nm, <2mm circular diameter beam, TEM₀₀ Irradiance).
- Photonic System Detector: Position Sensing Photo Detector (low SNR, 20mm × 20mm, Si-Duo Lateral Position Sensing Diode, with submicron (0.01μm)/ nanometre (10nm) resolution.
- Optical Filter (transmission at a narrow pass bandwidth ±10nm, centred as per selected source)
- Optoelectronic Amplifier
- Signal Conditioning Unit
- Signal Processing Unit
- Multilayer PCBs- (for protection from EMI/EMC, appropriate power electronics, signal conditioning and signal processing)
- Mechanical Encapsulation Cabinet (for housing the photonic system and providing protection from the vagaries of weather, environment and rain).
- Junction Box (for housing the integrated electronics, communications interfaces, multilayer PCBs).
- Power Source (rechargeable DC power source, 19V, 7.1 amps).
- Wired Communication Unit (for multichannel lossless transmission of signal data to connected server)
- Wireless Communication Unit (for multichannel lossless transmission of signal data to remote server, real time).

The uniqueness and novelty of AUM (patent pending), lies in an innovative application of the

principles of laser back scattering, statistical mechanics, optoelectronics, artificial intelligence, machine/deep learning, and Internet of Things - resulting in a unique system capable of identification, classification and quantification of various pollutants *simultaneously* (of accuracies of less than one ppb) and meteorological parameters, with very high precision, sensitivity and accuracy.

AUM is a unique photonic system capable of non-intrusive monitoring in real time of all the air quality parameters of interest at one go, with very high sampling frequencies. AUM has the additional unique capability of enabling spatial profile sampling information in addition to temporal sampling. The system has embedded intelligent algorithms and software operating on a user selectable remote server with data encryption, which ensures data security as well as free flow of desired information to authorized users as per specific requirements.

AUM system comes in two configurations – *standard* and *ruggedized*. Each configuration has again two options for data communication – *wired* or *wireless*. The physical characteristics of each configuration are designed differently enabling them to withstand either normal environmental loads (*standard configuration*), or extreme environmental loads (*ruggedized configuration*).



AUM – Standard System for Field Deployment (120mm X 180mm)



AUM – Integrated Ruggedized System for Field Deployment (563mm X 390mm X 160mm)

For the ruggedized configuration, additional optical coatings and appendages for AUM photonic system to be supplied to take care of operations during extreme weather conditions (temperatures ranging from $+70^{\circ}$ C to -25° C, relative humidity ranging from 0 to 100%, and wind loads up to 250kmph).

Each of these configurations have two options for data communications – a *wired* option or a *wireless* option enabling different sampling frequencies of data from system as per user requirements. All other technical details of the system are the same in both configurations. The accuracy and resolutions of the outputs are also the same for both the configurations and the data communication options.

AUM is integrated with proprietary software that can be deployed on local or cloud server. The software is developed on Apache Cassandra platform so that it can handle terra bytes of data. AUM equipment is robust and can functions day and night in harsh environment conditions. AUM is Wi-Fi enabled and can seamlessly connect to any Wi-Fi network protocols. The equipment is also supported with battery backup for 4 hours so as to provide uninterrupted operations even during power failure.

AUM comes packed in an unbreakable, watertight, airtight, dustproof, chemical resistant and corrosion-proof hard case. The external case is made of ultra-high-impact structural copolymer that makes it extremely strong and durable. The external case lid has a neoprene O-ring to ensure water proof and dust proof environment during transportation, and easy to open, double-throw latches that seal perfectly. It has a built-in automatic pressure equalization valve for changes in altitude or temperature. The case uses stainless steel hardware and has padlock protectors to provide added strength and extra security against cutting and theft. It can be carried by three comfortable rubbers over the moulded haul handles, a retractable handle and built-in wheels.

c) AUM - Photonic System - Sensor Structures, Modules, Mechanisms



d) AUM - Sampling Protocol

AUM System has two configurations, defined by the data communication protocols (Wired and Wireless) from system to the server. AUM has an active sampling, real time remote detection capability. The sampling frequency for the wired version is 1 - 10kHz, while for the wireless version the sampling frequency is ~150-200Hz.

e) AUM - Calibrations Procedure and Protocol

Specially designed and developed, portable, light weight Calibration Setup/Facility enables easy calibrations with standard gases, mixtures, at varying ambient environmental conditions of air temperature, air pressure, and relative humidity). The AUM's laser beam would be focussed into the environmentally controllable air chamber and calibrations completed for different standard gases under widely varying ambient air temperatures, pressures, humidity enabling effective calibrations of all pollutants. The standard gases are to obtained from ISO 17025 certified sources. The temperature/humidity/ flow sensors to be used are to meet International Standard specifications with higher accuracies and sensitivities. Once AUM photonic system is calibrated, then routine or periodic calibration is not required.

f) AUM - Laboratory and Field Evaluations

AUM was successfully evaluated during laboratory trials in a sub-sonic wind tunnel, in the laboratory with gold standards (in collaboration with Effect Tech, UK an ISO 17025 2000 International Standard Accredited Laboratory), and also compared in the field with the imported systems from Environment SA, France and Eco Tech, Australia operated by Karnataka State Pollution Control Board's Central Environmental Laboratory with ISO 17025-2005 & NABL Accreditation; under the aegis of the Central Pollution Control Board of India.

AUM was demonstrated to be very highly sensitive and accurate and capable of simultaneous

detection and quantification of all air quality parameters and offers a number of merits over any of the currently available conventional systems, having the following features and characteristics:

- Portable, compact, low powered and economical.
- *Plug and play* system, requires no setting up time and no additional civil infrastructure for housing.
- Provides information on all gases, and meteorological parameters simultaneously.
- Non-intrusive, remote, in-situ, real time monitoring system with very high sensitivities and accuracies.
- Single system capable of monitoring in both spatial and temporal domains, with high sampling rates.

- Data from sensors seamlessly streamed to a cloud server, from where encrypted real time dash board information is pushed to authorized users.
- System can work continuously, even under extreme weather and climatic conditions
- Embedded intelligent monitoring algorithms to identify and alert impending system failures to enable preventive maintenance.
- Spatial sampling as per user requirements, dictated by unhindered line of sight conditions in the field.



Side and Front Views (top and bottom Left) of AUM System (180 X 220mm), and typical Real Time Dashboard Information (Right)

AUM System has two configurations, defined by the data communication protocols (wired and wireless) from system to the server. AUM has an active sampling, real time remote detection capability. The sampling frequency for the wired version is 1 - 10kHz, while for the wireless version the sampling frequency is 150-200Hz.

AUM photonic system has built in intelligent monitoring system which is capable of performing real time diagnostics. The photonic system has an *optical filter* which is embedded in the system and is part of the hardware.

AUM operates on principle of backscatter of light and there are no moving components inside the system. Faults occur only if one of the components malfunctions. The only component which requires replacement is the laser source, in the AUM Photonic System. The embedded intelligent alert monitoring system would flag a degrading laser source well in advance so that replacement of the same can be planned at least a week in advance. The replacement can be accomplished by a technician/engineer having basic tools within a span of one hour. Replacement of components is easy and simple. The information related to malfunctioning will be alerted and an alarm raised by the intelligent alert monitoring system so that appropriate action can be taken to ensure smooth functioning.

AUM is integrated with proprietary software that can be deployed on local server or laptop. The software is developed on Apache Cassandra platform so that it can handle terra bytes of data. AUM equipment is robust and can functions day and night in harsh environment conditions. AUM is Wi-Fi enabled and can seamlessly connect to any Wi-Fi network protocols. The equipment can also be supported with battery backup for durations specified by user, so as to provide uninterrupted operations even during power failure.

g) AUM - Spatial Profile Monitoring Capabilities

The genesis for AUM technologies lies in the earlier development of photonic system taraNi(Technology for Air-data Reckoning for Aerial Navigational Information) for effectively monitoring molecular air data products from on-board a fast moving aircraft, supported by Aeronautical Defence Agency (ADA), Ministry of Defence, Government of India. The spatial profiling technology subsystem is an add on feature to the ruggedized version of AUM and facilitates sampling of air quality parameters at varying ranges from system (from less than 10m distance to more than 1 km distance) at sampling intervals of every 1 *minute*. The AUM photonic system version with spatial profiling capabilities is being commercialized under the brand name SAMIRA – Seeing Air in Motion Instrumentation for Remote Sensing Applications - an indigenous system capable of monitoring all air quality parameters and environmental parameters at different ranges (distances) from the system simultaneously. The system was extensively tested in wind tunnels, laboratories and in the field and compared to some of the commercially available systems. Real time, remote monitoring of the spatial profiles of environmental parameters were successfully demonstrated at Kayathar, Tamil Nadu in association with National Institute of Wind Energy (NIWE), Ministry of New and Renewable Energy, Government of India at the Nippon Group (Japan)'s Net Magic Data Centre at Bombay Stock Exchange, Mumbai. Please see Certificates and Testimonials attached from NIWE, Government of India and Net Magic, India.



AUM: Universal Calibration Facility - Indigenous Design and Development



A specially designed and developed AUM universal calibration facility, ensures that after a onetime calibration the AUM photonic system can be deployed anywhere in the world capable of monitoring pertinent gases and environmental parameters.

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CHARACTERISTICS	AUM - PHOTONIC SYSTEM	CONVENTIONAL MONITORING SYSTEMS #EcoTech. Australia: #Environment SA. France: #Thermo-Fischer. USA. etc.)
ACCURACY AND SENSITIVITY	 Temporal response of system is <10ms. Spatial resolution of detector is < 100mm. Higher orders of accuracy and sensitivity, capable of monitoring different gases even at very small concentration levels (< 1ppb) and meteorological parameters at <0.1 SI units respectively. Detectability range for all parameters is large (3 to 4 orders of magnitude). Photonic system generally has about three to four orders of magnitude higher sensitivity compared to most conventional systems. 	 Changes in environment such as temperature, pressure, humidity, air turbulence, and airborne particles affect sensors. Temporal responses are therefore slow. Lower temporal responses. Lower sensitivity. Different detectability ranges as per individual sensors (lower detectability ranges). Cross sensitivity is a common problem, especially at low concentrations of gases Species interferences, leaks and contaminations are known problems.
SENSING AREA COVERAGE	 AUM system can cover from 10mm to 1Km in range, and unit can be rotated 360°. Data of air can be collected vertically as well as horizontally at distance of every 10mm to 5km as per requirements. The laser beam travels to the targeted area / source of pollutants. With few nos. of installation complete city can be monitored for pollutants and weather conditions. Hence monitoring emission from giant chimney, duct, stack is done with utmost ease. The only limiting factor with respect to area of coverage, is clear line of sight. One single unit from its fixed location can cover a huge area in all 360° directions. 	 The polluted air is sucked/pumped in using high energy consuming suction fans. The air has to pass in to the proximity of sensors. Hence area of coverage is the biggest limiting factor. The fixed station (sensor) must be located near the source of gases, which becomes a severe limiting factor. Pollutants, Gasses, Temperature, humidity, Air pressure etc. are measured from fixed location only.
CALIBRATIONS	 No routine calibration required. Calibrations performed with primary gases / gas mixtures of ISO 17025, ISO 17034 international standards. 	 Routine calibration required, gases and chemical are required to be stored for monthly (periodic) calibration exercise. Refilling for some pollutants monitoring is periodically required. Reagents used for calibrations can themselves be pollutants/contaminants.
TEMPERATURE	1. System can operate in extreme external environments as well as indoors.	 The system is required to be maintained in controlled environments of temperature and humidity and protected from the vagaries of external weather and dust. Hence environmentally controlled containers are mandatory.
HAZARDS	 Safe laser having minimal battery power requirements is used. If uninterrupted source of electric power is available, then no battery is required. The system is rugged and can be placed anywhere. The system is designed using CFD (Fluid Simulations and Thermal Analysis) to appropriately dissipate the heat. 	 Minimum of 10kVa of UPS and battery bank is required. Gases like hydrogen, carbon radio isotope (C₁₄) etc. are used by analyzers. Banks of different types of gas cylinders are required to conduct routine calibration. Hence Fire and Safety protocols are mandatory requirements. The complete system has to be installed in a highly protected shelter (container). The area needs to be 100% leak proof, environmentally controlled.
EASE OF USE	 No human intervention. No special training required to operate and maintain. 	 The systems require human intervention. Special training for all different types of analyzer are required. Hence most of the system sold are operated and maintained by respective vendor.
DELIVERY AND INSTALLATION	 Immediate delivery of system Installation is mere plug and play. No learning curve required. 	 Delivery takes minimum of 90 days Installation is required to be done near the source due to limiting sensing distance. Installation, testing and deploying takes at least 15 days. Users require detailed training on protocols and practices.
USEFUL LIFE	 With miniscule maintenance, and no moving parts, the useful life shall be more than that of any conventional system. 	1. With consistent maintenance, the system has useful life of 10 years.
MOBILE	 Photonic system can be used as a handheld unit, fitted on any moving vehicle or on a fixed a platform (tripod). The unit is very light in weight. Speed of vehicle is not a constraint. The system can be used to monitor outdoor air as well as indoor air. 	 Pollution station is fixed in one place. Weather monitoring can be integrated with mobile. Mobile unit has to be located on truck as Fixed unit. Individual analyzers are available as handheld, but cumulatively the same have to be integrated and fixed in one place.
SIZE	1. City air quality and weather monitoring system size is compact, of the order of 180mm*220mm.	1. The bulky systems are housed in containers, as big as big 40 feet $ imes$ 20 feet.
MAINTENANCE	 Only change of laser diode required. A single laser source is designed to operate for 10,000 hours. The unit can also have a self-cleaning mechanism. Inventory required is of laser sources only and based on usage, replacement may be required once in a vear. 	 Routine maintenance and cleaning required. Filters need periodic changing. Calibration gases are required to be refilled. Batteries are required to be replaced every 3-5 years based on make and warranty clause.

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CHARACTERISTICS	AUM - PHOTONIC SYSTEM	CONVENTIONAL MONITORING SYSTEMS #EcoTech, Australia; #Environment SA, France; #Thermo-Fischer, USA, etc.)
DATA	 The photonic system collects data at high sampling frequencies. Hence there is all possibility to provide data per millisecond, if required. Huge data provides very accurate aggregation on per minute basis and makes real time data worthwhile. 	 These systems collect only parametric driven source data per 10 seconds. Old installed systems collect data on hourly basis.
IT ENABLED	 Big Data ready with Cloud computing. Internet of Things (IoT) and Array of Things (AoT) solutions can be devised based on available data. GPS in built. Preventive, Prescriptive and Geo Spatial Analytic is possible. Browser based and personal mobile app available. 	 Most of the available system is based on thin client. Systems are not ready for larger data platforms that can enable solutions using loT or AoT. No GPS information, fixed bulky station. Absence of Big Data, geo-spatial analytics is very difficult. Mobile apps are generally not provided by system integrator but by respective Govt. Department ie. pollution control board,
REPORTING	 The data is centralized for all environmental effects due to weather & pollution. Integrated reporting of all parameters of environment can open new pathways for predicting and preventing the future hazards. 	 Environmental Data is all decentralized. There is no integrated medium till date. Hence reporting is limited.
FINANCIALS		
COST	 Photonic system Improves on total life cycle costs. In comparison to conferences of sensors with complex integration, the cost of photonic system is less than 30% to its conventional near to equivalent counterpart. The maintenance cost is also very negligible. 	 The conferences of sensors as complete system are highly Capital intensive. Operating and maintain costs per year are more than 30% of CAPEX.
	 User are open to select the pollutants from a library that they wish to monitor. Some of the selected gases can be deselected and other set of gases can be selected. 	 Such mechanism is not possible. Once an analyzer is purchased, the user is fixed with the single or dual type of
CUSTOMISE TO PAY PER USE ONLY	 This works on similar basis of DTH system. One can select TV broadcasting channel and pay for the usage. Photonic system is also available on rental basis. 	pollutants for life.3. Hence huge amount of capital is blocked as multiple systems for independent pollutants are required to be installed.4. Hence financing options are limited.
OVERALL BENEFITS	 Low CAPEX and Low OPEX. With number of systems installed across the city, Individual are provided with interactive pattern for the kind of exposure they have with environment. This can lead to break through in early prognosis and diagnosis of health issues related esp. with PM 23. and below. 	 Based on sampling indicators from one or two locations and determining the air quality of a city, is prone with errors. High capital and high operating overheads.
APPLICATIONS		
CONTINUOUS EMISSION MONITORING SYSTEMS (CEMS)	 CO, H/C's, H₂S, NO_x, O₃, SO_x and other oxidants. Can identify organic particulates. Volatile Organic Compounds (VOC) - such as formaldehyde, benzene, methylene chloride and per chloro ethylene 	 CO, H/C's, H₂S, NO₂, O₃, SO₂ and other oxidants. Cannot distinguish organic particulates. Volatile Organic Compounds (VOC) - such as formaldehyde, benzene, methylene chloride and per chloro ethylene.
CONTINUOUS OPACITY MONITORING SYSTEMS (COMS)	1. Total Suspended Particles (TSP). Any particles less than 1 μ m in diameter 2. Lead Particulates/Particulate Material (PM _{2.5} /PM ₁₀) and also classifies between lead, metal, gas etc.	 TSP, Lead Particulates / Particulate Material (PM_{5.8} / PM₁₀). Classification of composition of PM at the level of single equipment is not possible.
CONTINUOUS	1. Can monitor the source from far away distance, only clear line of sight is required.	 Independent analyzers used for monitoring.
PARAMETRIC MONITORING SYSTEMS (CPMS)	 2. Measures a surrogate pollutant like carbon monoxide (CO), Methane, Hydrocarbons etc. or any stationary combustion source. 3. Temperature, humidity, air pressure etc. at different heights can be measured. 4. Smoke, fire etc. Can differentiate between smoke and steam. 	2. Respective analyzers / Sensors are required to be located near the source. This is most limiting factor during the course of emergencies like leakage, fire etc. 3. Measures a surrogate pollutant like Carbon Monoxide (CO) Methane, Hydrocarbons or any stationary combustion source. 4. Smoke, fire etc. Does not differentiate smoke and steam.

h) AUM: Technical Data and Specifications[#]

Electrical Power Supply	230 V, 50 Hz AC, 15 amp Electrical Socket
Current Consumption	135 watts
System Detection Range	< 10m to $> 1km$; Configurable as per user requirements
Accuracy	<1 <i>ppb</i> for gases, <0.1 SI units for temperature, wind, pressure
Response Time	<10 <i>ns</i>
Sampling Frequency	1-10kHz (wired), 150Hz-200Hz (wireless)
Cable Types	22, 24 AWG
Real Time Data Recording	On Designated Computer Server, Encrypted
Data / Information Display	Real Time Display on PC/Smart Phone Through Internet, Encrypted
Operational Range of Temperature	-25 °C to +70 °C (Ruggedized), 0°C to +55°C (Standard)
Operational Range of Humidity	0 to 100%
System Shape / Dimensions	Cuboid/563 $mm \times 390mm \times 160mm$ [(L×W×H) – Ruggedized Version] Cylinder / 180 $mm \times 220mm$ [($\emptyset \times L$) – Standard Version]
Weight	<10.0Kg
Protection Class / Deployment	IP65 / IP67 / IP69 / Field Deployable Even in Harsh Environments

i) AUM- Measurement of Pollution Parameters, Accuracies, Detection Ranges, Resolutions

S. No.	Parameter	Accuracy	Detection Range	Accuracy (% Full Scale)	Resolution
1.	NH ₃	1 ppb [$_{\sim}\mu g/m^3$]	0 to 10 ³ <i>ppm</i>	0.1%	0.5 <i>ppb</i>
2.	СО	$<1 \ ppm \ [_mmode mg/m^3]$	0 to 10 ³ <i>ppm</i>	0.1%	0.5 <i>ppb</i>
3.	NO	1 ppb [$_{\sim}\mu g/m^3$]	0 to 10 ³ <i>ppm</i>	0.1%	0.5 <i>ppb</i>
4.	CO ₂	1 ppb [$_{\sim}\mu g/m^3$]	0 to 10 ³ ppm	0.1%	0.5 <i>ppb</i>
5.	NO ₂	1 ppb [$_{\sim}\mu g/m^3$]	0 to 10 ³ ppm	0.1%	0.5 <i>ppb</i>
6.	O ₃	1 ppb [$_{\sim}\mu g/m^3$]	0 to 10 ³ <i>ppm</i>	0.1%	0.5 <i>ppb</i>
7.	SO ₂	<1 ppb [$_{\sim}\mu g/m^3$]	0 to 10 ³ <i>ppm</i>	0.1%	0.5 <i>ppb</i>
8.	$NO_x (NO_2 + NO)$	1 ppb [$_{\sim}\mu g/m^3$]	0 to 10 ³ ppm	0.1%	0.5 <i>ppb</i>
9.	Benzene [C ₆ H ₆]	$<1 \ ppb \ [_{\sim}\mu g/m^3]$	0 to 10 ³ ppm	0.1%	0.5 <i>ppb</i>
10.	$Toluene(C_6H_5CH_3)$	<1 ppb [$_{\sim}\mu g/m^3$]	0 to 10 ³ <i>ppm</i>	0.01%	0.5 <i>ppb</i>
11.	$o - Xylene [C_6H_4(CH_3)_2]$	<1 ppb [$_{\sim}\mu g/m^3$]	0 to 10 ³ <i>ppm</i>	0.1%	0.5 <i>ppb</i>
12.	$p-Xylene [C_6H_4(CH_3)_2]$	$<1 \ ppb \ [_{\sim}\mu g/m^3]$	0 to 10 ³ ppm	0.1%	0.5 <i>ppb</i>
13.	$Et - Benzene [C_6H_5CH_2CH_3]$	$<1 \ ppb \ [_\mu g/m^3]$	0 to 10 ³ <i>ppm</i>	0.1%	0.5 <i>ppb</i>
14.	PM _{2.5}	1 ppb [$_{\sim}\mu g/m^3$]	0 to 10 ³ ppm	0.1%	0.5 <i>ppb</i>
15.	PM ₁₀	1 ppb [$_{\sim}\mu g/m^3$]	0 to 10 ³ ppm	0.1%	0.5 <i>ppb</i>
16.	Wind Speed	<0.01 <i>m/s</i>	0 to 75 <i>m/s</i>	0.01%	0.005 <i>m/s</i>
17.	Wind Direction	<1°	0° to 360°	0.01%	0.05°
18.	Air Temperature	<0.1°C	-25°C to 70°C	0.01%	0.05° <i>C</i>
19.	Relative Humidity	<0.1%	0 to 100%	0.01%	0.005%
20.	Air Pressure	<1kPa	0 to 10⁵ <i>kPa</i>	0.01%	0.5k <i>Pa</i>
21.	Solar Radiation	$< 1W/m^{2}$	0 to $10^5 W/m^2$	0.01%	$0.5W/m^2$

* specifications subject to change without notice.

j) AUM – Certification and Appreciation from Department of Science & Technology, Ministry of Science and Technology, Govt. of India

After critical and detailed reviews by DST, Dr Harsh Vardhan, the Honourable Minister for Science & Technology, Health and Family Welfare, Government of India, tweeted that the indigenously developed photonic system *AUM*, having better qualities, in comparison to any known international systems, is highly economical *and therefore*, rests on the verge of providing a big boost to the nation's efforts towards self- reliance in high-end technologies, and also can additionally be instrumental in supporting the endeavours in improving the nation's health and economy under #AtmaNirbharBharatAbhiyan. [24, 25, 26].

- k) Diverse Applications of AUM
- Continuous Ambient Air Quality Monitoring System
- Continuous Emission Monitoring System
- Portable Emission Monitoring System
- Continuous Opacity Monitoring System
- Continuous Parametric Monitoring System



I) Way Forward

CATS Eco Systems Pvt. Ltd., Nashik is the technology transfer partner for commercialization of AUM. It is sincerely hoped, that the Ministry of Environment, Forests and Climate Change (CAQM,) and and other central state governmental organizations)in India and other stakeholders around the world would therefore facilitate the due recognition and acceptance of 'AUM' at the earliest, in sync with their established policies of proactively supporting innovative developments for commercialization, as it would certainly be instrumental in supporting the world wide efforts for monitoring and controlling air pollution.

VII. Summary and Conclusions



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The indigenously designed and developed photonic system AUM, was successfully tested and evaluated with gold standards and also with some of the continuous ambient air quality monitoring stations of CPCB. The indigenous system was demonstrated to be having many advantages compared to the existing technologies and systems. The system is capable of monitoring all gases (with accuracy of _1 ppb) and the environmental parameters both in spatial and temporal domains simultaneously at high sampling frequencies. The system can be deployed easily as it is light weight and portable. The system is operable in all weather conditions, and being an indigenous development is also highly economical and can certainly boost the nation's efforts towards self-reliance in high end technologies.

In conclusion, AUM is an innovative, unique, and disruptive technology with the following characteristics, unmatched by other known and established systems.

- Highly Sensitive and Accurate
- Portable, Compact, Low powered and Economical.
- Plug and Play System, no setting up time, no additional civil infrastructure for housing.
- Information on all gases, and meteorological parameters.
- Non-intrusive, remote, in-situ, real time monitoring system. accuracies.
- Single System capable of monitoring in both spatial / temporal domains.
- High sampling rates.
- Data from sensors seamlessly streamed to a cloud server

- Encrypted real time dash board information to authorized users.
- Works continuously, even under extreme weather conditions.
- Intelligent monitoring algorithms to identify and alert failures.
- Spatial Sampling as per user requirements.
 - Unique calibration facility enabling AUM to be deployed anywhere in the world.

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