Ambient Air Quality Monitoring - I: *Impetus, Complexities, Challenges and Solutions*

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Impetus

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

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:

i) *What are the limitations of current measurements, monitoring techniques and the standards currently being employed across the world?*
ii) *Do the methods of measurements involving synthetic chemicals, themselves result in pollution of air, water and soil?*
iii) *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?*
iv) *What is the area for which measurements are representative and reliable?*
v) *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?*
vi) *What level or degree of errors are acceptable?*
vii) *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?*
viii) *What related collocated meteorological data must be collected with air quality data?*
ix) *What is the importance of sample averaging times to the design of monitoring stations and the inferences on air pollution?*
x) *What are the effects of physical and chemical transformations at the sampling locations and network design for example, for monitoring ozone or sulphates?*
xi) *What quality assurance programs are necessary to assure that data are representative and legally and scientifically defensible?*
xii) *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].

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 low-cost sensors (Electro-Chemical Sensors, Photo 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 assessment, citizen science and air pollution 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*.

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].

Against this backdrop a group of researchers from academia and industry undertook an 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]:

i) The air quality monitoring instrumentation presently being used are characterized by high costs, and a high level of maintenance.
ii) The air quality monitoring stations provide representative data only for a very restricted area in space. This is a disadvantage because measurements at adequate spatial scales are essential for monitoring air pollution in heterogeneous environments such as those naturally found in the atmosphere [21].
iii) To a large extent the air monitoring stations were sited at locations where sources of pollution were far away.
iv) 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.
v) The problems associated with in-vivo sampling vis-à-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.
vi) 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.
vii) The non-uniform standards practised by various equipment suppliers across the stations, make Intercomparisons of degrees of pollution very difficult across the different stations.
viii) 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.
ix) All the stations were not monitoring all the required parameters responsible for computing the air quality index of a location.
x) In bigger cities like New Delhi where more monitoring stations are located, the spatio-temporal variations in air quality are markedly significant.
xi) 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.
xii) 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.
xiii) Air quality effects of the major industrial accidents (like in Visakhapatnam, Andhra Pradesh on 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.
xiv) The effects of multiphase chemistry, need to be considered in pollution monitoring using passive sampling techniques [22].
xv) 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.

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-the-art 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.

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Ambient Air Quality Monitoring – II: *Indigenous Photonic System AUM*

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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 sensitivity and accuracies by adopting COTS (commercially-off-the-shelf) technologies, thus making them significantly cheaper for wider deployment.

Against this backdrop, 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.

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:

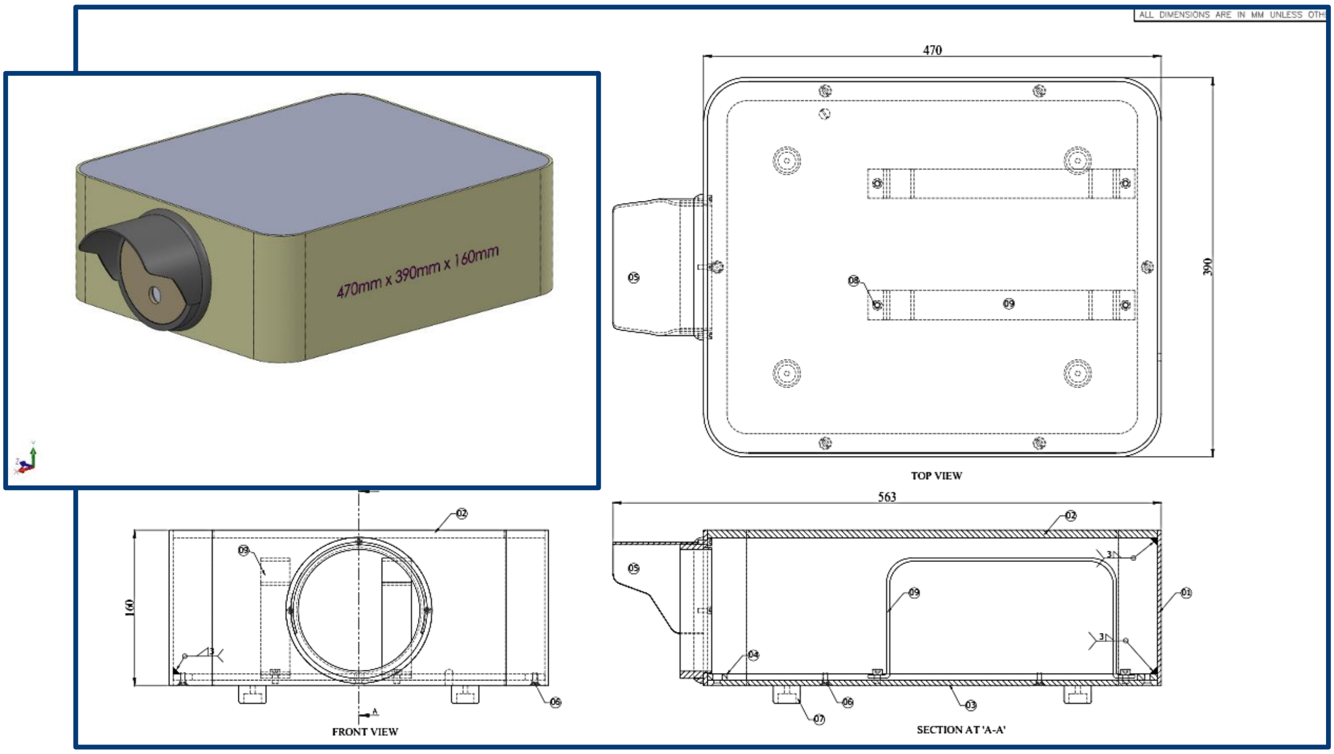
- Photonic System Source – Laser (<10 *milliwatt*, Wavelength 250-850*nm*, <2*mm* circular diameter beam, TEM_{00} Irradiance).
- Photonic System Detector: Position Sensing Photo Detector (low SNR, 20mm × 20mm, Si-Duo Lateral Position Sensing Diode, with submicron (0.01μm)/ nanometre (10*nm)* resolution.
- 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 $(563mm\ X\ 390mm\ X\ 160mm)$

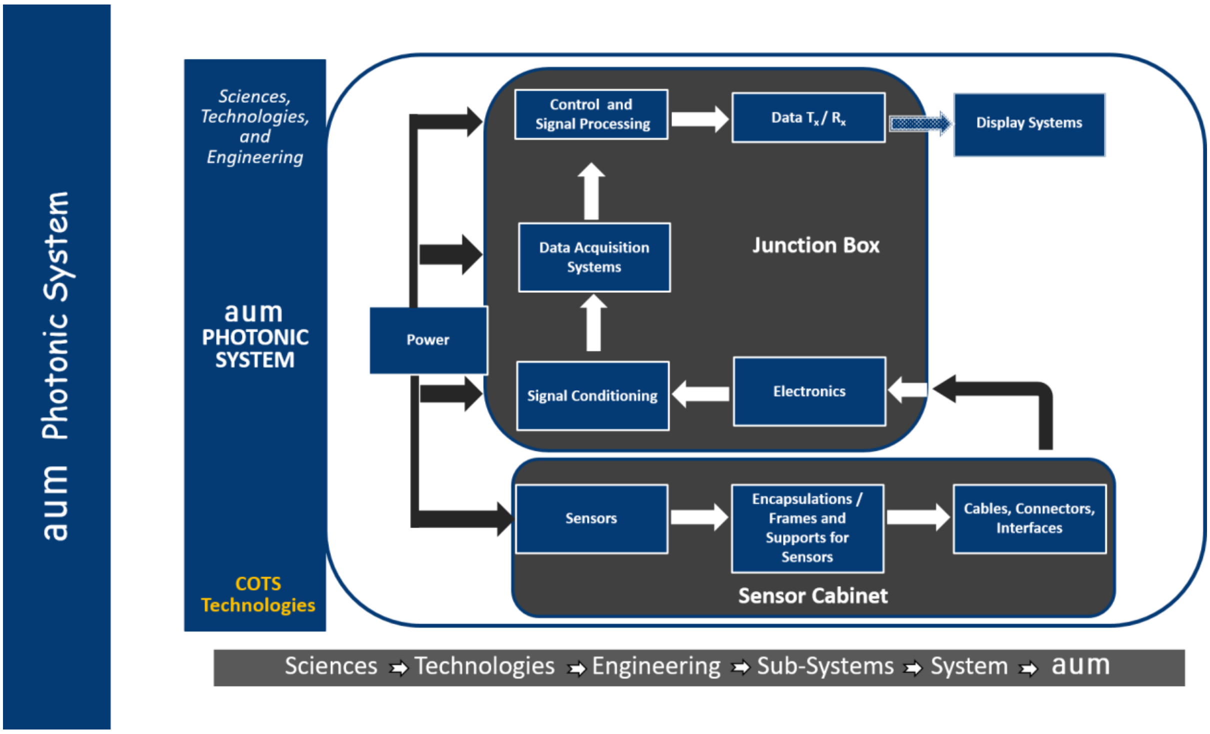
For the ruggedized configuration, additional optical coatings and appendages for AUM photonic system to be supplied to take care of operations during extreme weather conditions (temperatures ranging from +70^{0}C to -25^{0}C, relative humidity ranging from 0 to 100%, and wind loads up to 250kmph).

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.

AUM- Photonic System - Sensor Structures, Modules, Mechanisms



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 -10*kHz*, while for the wireless version the sampling frequency is ~150-200*Hz.*

AUM - Calibrations Procedure and Protocol

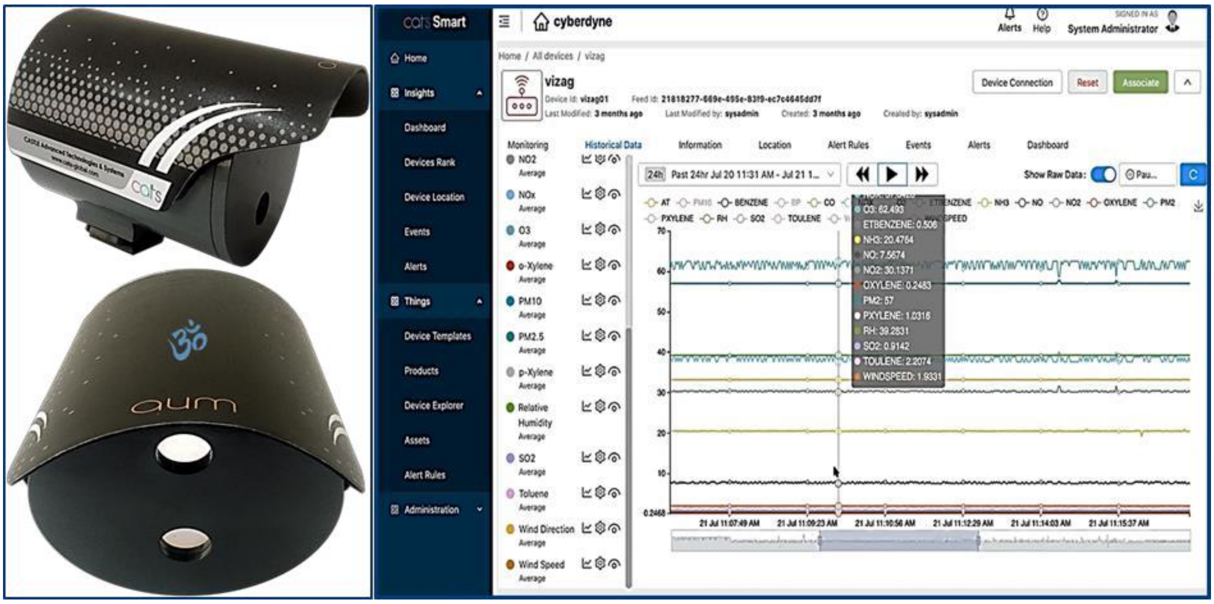
Specially designed and developed, portable, light weight Calibration Setup/Facility enables easy calibrations with standard gases, mixtures, at varying ambient environmental conditions of air temperature, air pressure, and relative humidity). The AUM's laser beam would be focussed into the environmentally 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.

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 EffecTech, UK an ISO 17025 2000 International Standard Accredited Laboratory), and also compared in the field with the imported systems from Environment SA, France and EcoTech, 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 -10*kHz*, while for the wireless version the sampling frequency is ~150-200*Hz.*

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.

AUM - Spatial Profile Monitoring Capabilities

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.

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September 25, 2016

TO WHO SO EVER IT MAY CONCERN

A Novel and Innovative Photonics System, capable of remotely monitoring Air Flow, Temperature and Humidity simultaneously in real time, at different spatial locations inside a Network Data Centre was designed and developed by Prof. Rao Tatavarti based on his R&D at Visakhapatnam, India. The Photonic System is called as *AUM - IAQ* $_{DC}$ and is being launched into the market by M/S CATS ECOSYSTEMS PVT. LTD, NASHIK, INDIA.

As it was learnt that the single photonic system (*AUM - IAQ* $_{DC}$) is capable of accurately monitoring spatial (*i.e., pertaining to different spatial locations*) data pertaining to air flow, temperature and humidity, inside the data centre from a remote location; a Proof of Concept Trials were planned at our NETMAGIC Data Centre located in the Bombay Stock Exchange Building in Mumbai on May 25, 2016.

The Proof of Concept Trials involved demonstration of the photonic system to monitor in real time the air flow, temperature and humidity parameters at different spatially separated locations inside the NETMAGIC Data Centre simultaneously. During the trials air parameter data were also monitored separately by different standardly used thermal sensors (as part of the existing Building Management System at NETMAGIC Data Centre) and additionally Industry Standard KESTREL (USA Make) Systems located at various locations inside the Data Centre. The purpose of these standard sensors was to validate and compare the data from the Photonics System.

This is to state that M/S CATS ECOSYSTEMS PVT. LTD had successfully demonstrated the remote monitoring of Air Flow (m/s), Air Temperature (° C) and Relative Humidity (%) parameters in real time, simultaneously at different spatial locations inside the NETMAGIC Data Centre, BSE, Mumbai using their Single Photonic System called as *AUM - IAQ* $_{DC}$.

The successful demonstration and completion of Proof of Concept Trials at NETMAGIC DATA CENTRE, BSE, Mumbai was witnessed and monitored by the technical team of NETMAGIC, which had also validated the results displayed live by *AUM-IAQ* $_{DC}$ system, with Industry Standard Sensor as part of the existing Building Management System and additionally with Industry Standard KESTREL System (Make USA).

This is to confirm that results of the photonic system AUM- IAQ $_{DC}$ were in sync with independent observations made by standard sensors.

We therefore realized, that the current industry challenges for monitoring monitor real time air flow (CFM) at any location (in horizontal or vertical directions, measured in CFM of air flow) can be successfully answered by this Remote Monitoring Photonic System, *AUM- IAQ* $_{DC}$. The POC trails also demonstrated the unique capability of the system in obtaining the three-dimensional information related to air flow, temperature and humidity from a single system (across the length and height of an aisle, along with information at different angles).

We understand from Dr. Tatavarti, that the data obtained from each of the *AUM – IAQ* $_{DC}$ Photonic System can be integrated and networked (smart systems with data residing on a dedicated server in house as well as connected to a cloud for easy accessibility across the world) to enable CFD simulations, even for complex and challenging Data Centre geometries for futuristic diagnostic purposes.

The *AUM- IAQ* $_{DC}$ Photonic System demonstrated during POC and is being proposed now for our Data Centres would also facilitate a more scientific, economical and effective way for controlling the air flow as desired by different customers. The efforts made by Dr. Tatavarti in inventing this state of art technology are highly commendable. We wish him and M/S CATS ECOSYSTEMS PVT LTD. all the best for their future endeavours.

Sharad Sanghi
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NATIONAL INSTITUTE OF WIND ENERGY
(नवीन और नवीकरणीय ऊर्जा मंत्रालय, भारत सरकार
Ministry of New and Renewable Energy, Government of India)

नीवे NIWE
ISO 9001:2008

डॉ. एस. गोमतिनायगम
महानिदेशक
Dr. S. GOMATHINAYAGAM
Director General

LETTER OF APPRECIATION

This is to express NIWE's deep appreciation to Prof. Rao Tatavarti, the Principal Investigator of the R&D project, wherein an indigenous photonic system for was designed and developed for real time remote monitoring of wind and other related air parameters simultaneously at different heights. The prototype system was tested and evaluated in laboratory experiments as well as experiments conducted at the NIWE field Sites located in Kayathar and Chennai and found to be working well in comparison to the commercially available Mast Anemometers, SODAR and a LIDAR.

A Peer Technical Review Committee - consisting of members from NIWE, CEERI-CSIR Chennai CSIR-SERC - after pertinent technical reviews has already placed on record, their deep appreciation for the excellent and pioneering work done by Prof Rao Tatavarti in proving new photonic technologies and system, for real time remote monitoring of wind and other air parameters.

The technologies developed in record time with very little funding, have far reaching implications for the national efforts in development of innovative indigenous technologies in an important discipline pertaining to renewable energy, and also in our endeavour to leap frog in development of indigenous technologies and systems for transforming India from being a predominantly importing country to an exporting country. The new technology has far superior characteristics compared to any of the existing technologies worldwide. Keeping in view the Nation's thrust and focus on indigenisation and innovation, it is recommended that the innovative efforts of Prof. Rao Tatavarti which resulted in a major scientific breakthrough in new indigenous technology, needs to be substantially supported for further testing and evaluation in order to result in productionization of innovative systems.

Wishing Lab to Land to happen soon, with improved safety and all weather operational enclosures the product is likely to be all set to be the outcome of financial and technical support of NIWE and dedicated innovation of Prof. Rao Tatavarti as his (IPR) patentable product, for wind industry's applications.

This letter of appreciation stands testimony to his hard work and timely completion leading towards commercialisation with cost effectiveness.

29/9/2016

राष्ट्रीय पवन ऊर्जा संस्थान NATIONAL INSTITUTE OF WIND ENERGY

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AUM: Technical Data and Specifications#

Electrical Power Supply	230*V*, 50*Hz* AC, 15 *amp Electrical Socket*
Current Consumption	135 *watts*
System Detection Range	< 10*m* to >1*km;* Configurable as per user requirements
Accuracy	<1ppb gas concentrations, 0.1 SI units of temperature, wind, pressure
Response Time	<10*ns*
Sampling Frequency	1-10*kHz* (wired), 150*Hz*-200*Hz* (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* × 390*mm* × 160*mm* [(L×W×H) – Ruggedized Version] Cylinder / 180*mm* × 220*mm* [(ø × L) – Standard Version]
Weight	<10.0*Kg*
Protection Class / Deployment	IP65 / IP67 / IP69 / Field Deployable Even in Harsh Environments

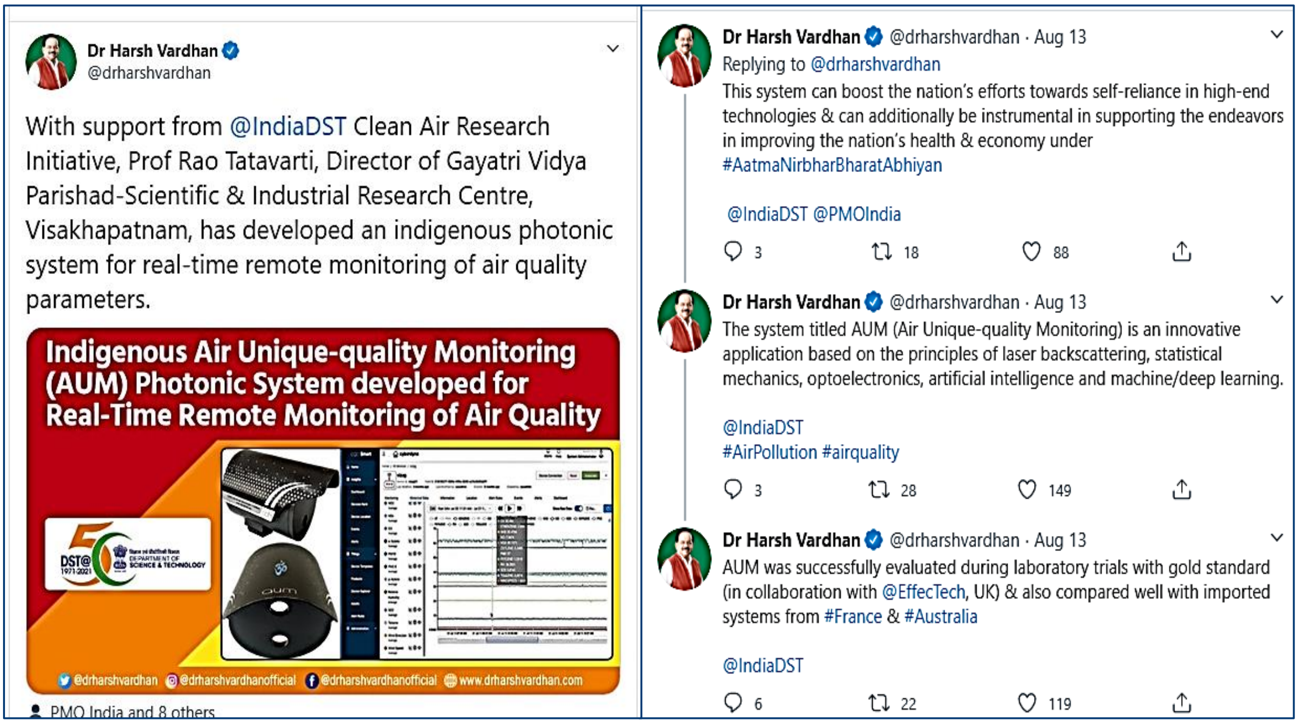
AUM - Measurement of Pollution Parameters, Accuracies, Detection Ranges, Resolutions

S. No.	Parameter	Accuracy	Detection Range	Accuracy (% Full Scale)	Resolution
1.	NH_3	1 ppb [~$\mu g/m^3$]	0 to 10^3 ppm	0.1%	0.5ppb
2.	CO	<1 ppm [~mg/m^3]	0 to 10^3 ppm	0.1%	0.5ppb
3.	NO	1 ppb [~$\mu g/m^3$]	0 to 10^3 ppm	0.1%	0.5ppb
4.	CO_2	1 ppb [~$\mu g/m^3$]	0 to 10^3 ppm	0.1%	0.5ppb
5.	NO_2	1 ppb [~$\mu g/m^3$]	0 to 10^3 ppm	0.1%	0.5ppb
6.	O_3	1 ppb [~$\mu g/m^3$]	0 to 10^3 ppm	0.1%	0.5ppb
7.	SO_2	<1 ppb [~$\mu g/m^3$]	0 to 10^3 ppm	0.1%	0.5ppb
8.	NO_x (NO_2+NO)	1 ppb [~$\mu g/m^3$]	0 to 10^3 ppm	0.1%	0.5ppb
9.	Benzene [C_6H_6]	<1 ppb [~$\mu g/m^3$]	0 to 10^3 ppm	0.1%	0.5ppb
10.	Toluene($C_6H_5CH_3$)	<1 ppb [~$\mu g/m^3$]	0 to 10^3 ppm	0.01%	0.5ppb
11.	*o* – Xylene [$C_6H_4(CH_3)_2$]	<1 ppb [~$\mu g/m^3$]	0 to 10^3 ppm	0.1%	0.5ppb
12.	*p* – Xylene [$C_6H_4(CH_3)_2$]	<1 ppb [~$\mu g/m^3$]	0 to 10^3 ppm	0.1%	0.5ppb
13.	*Et* – Benzene [$C_6H_5CH_2CH_3$]	<1 ppb [~$\mu g/m^3$]	0 to 10^3 ppm	0.1%	0.5ppb
14.	$PM_{2.5}$	1 ppb [~$\mu g/m^3$]	0 to 10^3 ppm	0.1%	0.5ppb
15.	PM_{10}	1 ppb [~$\mu g/m^3$]	0 to 10^3 ppm	0.1%	0.5ppb
16.	Wind Speed	<0.01m/s	0 to 75m/s	0.01%	0.005m/s
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°C
19.	Relative Humidity	<0.1%	0 to 100%	0.01%	0.005%
20.	Air Pressure	<1kPa	0 to $10^5 kPa$	0.01%	0.5kPa
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.*

AUM – Certification and Appreciation from Minister 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*. (*See attached testimonials from DST, Ministry of Science & Technology, Government of India and the Honourable Cabinet Minister Dr. Harsh Vardhan*). [24].


Dr Harsh Vardhan
@drharshvardhan

With support from @IndiaDST Clean Air Research Initiative, Prof Rao Tatavarti, Director of Gayatri Vidya Parishad-Scientific & Industrial Research Centre, Visakhapatnam, has developed an indigenous photonic system for real-time remote monitoring of air quality parameters.

PMO India and 8 others

Dr Harsh Vardhan @drharshvardhan · Aug 13
Replying to @drharshvardhan
This system can boost the nation's efforts towards self-reliance in high-end technologies & can additionally be instrumental in supporting the endeavors in improving the nation's health & economy under #AatmaNirbharBharatAbhiyan

@IndiaDST @PMOIndia
3 18 88

Dr Harsh Vardhan @drharshvardhan · Aug 13
The system titled AUM (Air Unique-quality Monitoring) is an innovative application based on the principles of laser backscattering, statistical mechanics, optoelectronics, artificial intelligence and machine/deep learning.

@IndiaDST
#AirPollution #airquality
3 28 149

Dr Harsh Vardhan @drharshvardhan · Aug 13
AUM was successfully evaluated during laboratory trials with gold standard (in collaboration with @EffecTech, UK) & also compared well with imported systems from #France & #Australia

@IndiaDST
6 22 119

AUM – TV Coverage by DD Science, Ministry of Information and Broadcasting, Govt. of India

A special TV program was broadcast by *Doordarshan*, India regarding AUM, the Indigenous Photonic System [25].

AUM – Certification and Appreciation from Dept. of Science and Technology, Govt. of India

विज्ञान एवं प्रौद्योगिकी विभाग

MENU

Home >> Indigenous Air Unique-quality Monitoring (AUM) Photonic System developed for Real-Time Remote Monitoring of Air Quality

Indigenous Air Unique-quality Monitoring (AUM) Photonic System developed for Real-Time Remote Monitoring of Air Quality

World Health Organisation (WHO)'s reports show that the worsening state of poor air quality is responsible for more than 7.5 million fatalities worldwide annually. This highlights the necessity for accurate, yet cost-effective monitoring of air quality parameters as monitoring is critical to solution. The current systems and technologies used for air quality monitoring are prohibitively expensive for wider deployment. This underlines the need for development of systems for real-time remote monitoring of relevant air quality parameters.

With the support from Department of Science and Technology's Clean Air Research Initiative, Prof. Rao Tatavarti, Director of Gayatri Vidya Parishad-Scientific and Industrial Research Centre (GVP-SIRC) & GVP College of Engineering, Visakhapatnam, has developed an indigenous photonic system for real-time remote monitoring of air quality parameters. Prof Tatavarti was supported by Prof. P. Arulmozhivarman from the School of Electrical Engineering, VIT University, Vellore, and other team members. The system titled AUM (Air Unique-quality Monitoring) had CATS Eco-Systems, Nashik as the technology transfer partner for commercialization.

The AUM system (patent pending) is an innovative application of the principles of laser backscattering, statistical mechanics, optoelectronics, artificial intelligence, machine/deep learning, and Internet of Things. It can identify, classify, and quantify various pollutants simultaneously (of orders of less than one part per billion) and meteorological parameters, with very high precision, sensitivity and accuracy.

AUM was successfully evaluated during laboratory trials with gold standards (in collaboration with EffecTech, UK), and also compared in the field with imported systems from France, and Australia and operated by Karnataka State Pollution Control Board under the aegis of the Central Pollution Control Board of India.

It has been found to be 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. It is portable, compact, low powered and economical, works on plug and play system, requires no setting uptime, and no additional civil infrastructure for housing. It provides information on all gases and meteorological parameters simultaneously. It is a non-intrusive remote, real-time monitoring system with very high sensitivities and accuracies and is capable of monitoring in both spatial and temporal domains, with very high sampling frequencies. Also, the data from spatially separated sensors can be seamlessly streamed to a cloud server, from where digestible real-time encrypted information on dashboard is made available to user at any part of the world.

This system can boost the nation's efforts towards self-reliance in high-end technologies can additionally be instrumental in supporting the endeavors in improving the nation's health and economy under the *Atma Nirbhar Bharat Abhiyan*.

AUM- Summary

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.

Way Forward

It is sincerely hoped, that the Ministry of Environment, Forests and Climate Change (CPCB and other governmental organizations) of India would therefore facilitate the due recognition and acceptance of 'AUM' at the earliest, in sync with their established policies of proactively supporting indigenous developments for commercialization, a sit would certainly be instrumental in supporting the nation's efforts under *Atma Nirbhar Bharat Abhiyan*.

References

1. https://twitter.com/drharshvardhan/status/1293748811647442944
2. https://www.youtube.com/watch?v=fznSi775xW4
3. https://dst.gov.in/indigenous-air-unique-quality-monitoring-aum-photonic-system-developed-real-time-remote-monitoring.

Acknowledgements

Many of my students, interns, colleagues and mentors have immensely contributed at various stages of the design and development of AUM, and other related systems and technologies.

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