UC DAVIS
AIR QUALITY RESEARCH CENTER

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Conference Sessions & Descriptions

Opening Panel: Where we are and where we're going with small air quality sensors

Moderated by: Pratima Singh, CSTEP

This panel will discuss the current uses and perspectives of small low-cost air quality sensors within India. Panelists will consider questions surrounding the future use and applications of these sensors, with the goal of creating a common vision. Additionally, they will review the benefits and possible hurdles that will be encountered by integrating them into sensor networks throughout India and surrounding countries.

Panelists:

- Dr. Zoe Chafe, C40 Cities
- Mr. Vasu Kilaru, US EPA
- Mrs. Bhavreen Khandhari, Warrior Moms

Session 1A: Data Modeling & Analytics

Moderated by: Dr. Saumya Singh, UC Berkeley

Calibrating Networks of Low Cost Air Quality Sensors

Presented by: Dr. Priyanka deSouza, University of Colorado, Denver

Ambient fine particulate matter (PM2.5) pollution is a major health risk. Networks of low-cost sensors (LCS) are increasingly being used to understand local air pollution variation. However, measurements from LCS have uncertainties which can act as a potential barrier for effective decision-making. LCS data thus need to be calibrated to obtain better quality PM2.5 estimates. In order to develop correction factors, LCS are typically co-located with reference monitors. A calibration equation is then developed that relates the raw output of the LCS as closely as possible to measurements from the reference monitor. This calibration algorithm is then typically transferred to measurements from monitors in the network. Calibration algorithms tend to be evaluated based on their performance at co-location sites. It is often implicitly assumed that the conditions at the relatively sparse co-location sites are representative of the LCS network, overall. Little work has been done to explicitly evaluate the sensitivity of the LCS network hotspot detection, and spatial and temporal PM2.5 trends to the correction method applied. This presentation provides a first look at how transferable different calibration methods are using a dense network of Love My Air LCS monitors in Denver. It offers a series of transferability metrics that can be applied to other networks and offers some suggestions for which calibration method would be most useful for different end goals.

Open Data Management System for Air Quality

Presented by: Mr. Sean Khan, UNEP

Scientific understanding is an essential ingredient for the design of successful policy interventions, but knowledge and data relevant for effective policies is often inadequate or absent in many areas of the world where it is needed. Air quality data analytics and information systems with observational and modelling components are key elements for adaptive and mitigation measures to reduce the negative impacts of air pollution. The open Data Management System (oDMS) was developed by Sailbri Cooper Inc, a subsidiary of Sailhero Environmental Technologies, and hosted by UNEP on the UN Cloud to strengthen data sharing, access to historical data and quality assurance.

Development of the oDMS addresses large-scale monitoring and offers a platform to any entity wanting to share and manage their air networks and collaborate with other data providers in the same locality. In timer, it will support a unified mechanism for data exchange. The oDMS adopts Browser/Server (B/S) layered structure development & design by using multi-layer structure. Modules are coupled and interconnected through Web services. In addition, the separated front-end and back-end designs guarantee strong scalability. The hierarchical structure of system is divided into application layer, service layer, data layer, transmission layer, and acquisition layer.

For the real-time monitoring module, the real-time monitoring data and status of each site can be displayed by selecting the area and monitoring parameters. Monitoring sites can be ranked ascending or descending based on user preference.

This session will demonstrate how the platform can empower local governments and citizens alike to collate data across the monitoring landscape and work towards a collaborative environment to make evidence-based decisions. It will also highlight some of the management features for physical monitoring and seek feedback from participants on how to improve the utility of the service UNEP is providing.

Accurate and Scalable Gaussian Processes for Fine-grained Air Quality Inference

Presented by: Mr. Zeel Patel, IIT Gandhinagar

Air pollution is a global problem and severely impacts human health. Fine-grained air quality (AQ) monitoring is important in mitigating air pollution. However, existing AQ station deployments are sparse. Conventional interpolation techniques fail to learn the complex AQ phenomena. Physics-based models require domain knowledge and pollution source data for AQ modeling. In this work, we propose a Gaussian processes based approach for estimating AQ. The important features of our approach are: a) a non-stationary (NS) kernel to allow input depended smoothness of fit; b) a Hamming distance based kernel for categorical features; and c) a locally periodic kernel to capture temporal periodicity. We leverage batchwise training to scale our approach to a large amount of data. Our approach outperforms the conventional baselines and a state-of-the-art neural attention-based approach.

Session 1B: Choosing & evaluating a Sensor; co-location & calibration

Moderated by: Karthik Ganesan, CEEW

High-resolution spatial mapping of PM2.5 over Bengaluru, combining low-cost sensor data and statistical modeling

Presented by: Dr. Sreekanth Vakacherla, CSTEP

We established a 50+ node Purpleair sensor network in the city of Bengaluru. We calibrated the Purpleair data and subsequently build monthly land-use regression models. These models predicted PM2.5 at a 50 m spatial resolution. Here we present data and results from these exercises.

Use of low-cost sensors to strengthen Air Quality Management

Presented by: Ms. Meenakshi Kushwaha

For countries like India, where many sizable cities lack reference-grade monitors, no single technology can provide comprehensive monitoring. Instead, a bouquet of technologies, including LCS can constitute cost-effective and sustainable solutions. I will present practical considerations for LCS selection and use as documented in our recent publication titled "Integrated Use of Low-Cost Sensors to Strengthen Air Quality Management in Indian Cities" (Vital Strategies, 2021). One of the main goals of the compendium is to support state pollution control boards and city governments in their efforts to develop bid documents to procure the comprehensive set of services needed for LCS campaign planning, development, deployment, analysis, integration with complementary air quality data, and results communication and management. I will cover 1) using LCS to address issues specific for NCAP cities 2) possible LCS applications 3) understanding limitations of current LCS 4) developing tender/ call for proposals for LCS network projects, and 5) key considerations for LCS selection. As a practical case study, I will also present results from our ongoing multi-season performance evaluation of eight different low cost PM2.5 sensors, most of which are assembled and available in India.

A field sampling campaign to identify the fundamental issues with low-cost particle sensors

Presented by: Mr. Vasudev Malyan, Indian Institute of Technology Bombay

Low-cost sensors are gathering interest of researchers and monitoring agencies around the world due to their compact size and economic feasibility. This allows a spatiotemporally dense network of monitors to collect air quality data, however, the data recorded by LCS is often of low-quality as it has calibration dependencies and biases that must be corrected. A 15 day field sampling campaign was conducted at five sites with different sources of PM emission to understand the fundamental issues associated with low-cost sensors. PurpleAir PA-II and Alphasense OPC-N2 LCS were collocated with reference-grade (BAM) and research-grade (DustTrak and OPC) instruments at the sampling locations for their inter-comparison and LCS calibration. Both LCS and DustTrak are in good agreement with BAM at locations where the contributing sources produce more PM2.5 particles as compared to

PM1 and PM10, however, the performance decreases as the contribution of PM1 and PM10 particles increases. ML models were used to calibrate LCS with BAM. Random Forest has the best performance with a R2 of 0.98 and 0.97 for PA-II and OPC-N2 sensor respectively. The number concentration recorded by LCS is in disagreement with the particle counter especially for particles > 1 µm. The particle count for PM2.5 and PM10 particles recorded by LCS is predominantly zero which indicates that they appear to assume some underlying size distribution that is used in the apportionment of PM1, PM2.5, and PM10 mass. It is one of the fundamental problems with LCS measurements as any error in the number measurement is increased 3-fold in the conversion to mass. Sometimes, the LCS may be in good agreement with reference instruments because the sampled particles have similar properties such as shape, particle size distribution, porosity, and complex refractive indices, to the calibration particles. This study highlights the fundamental issues in low-cost sensor measurements and a direction in their development.

Session 2A: Data Assimilation, Sharing & Harmonization

Moderated by: Tanushree Ganguly, CEEW

Air Sensor Data Standards: A critical need for Interoperability

Presented by: Mr. Vasu Kilaru, US EPA

With the growing variety of sensor makes and models, data and metadata standards are needed in order to assimilate data from a various sources. Furthermore, through the use of metadata, data quality indicators (e.g precision, bias, RMSE, min/max detection levels, calibration date,...etc.) can be embedded with the sensor data. This provides users with much more relevant information to allow for better interpretation and assimilation of data from various sources into a more coherent picture of air quality.

Turning real-time air quality monitoring data into actionable insights using smart data visualization & analytic

Presented by: Mr. Ayyan Karmakar, Oizom

Real-time air quality monitoring using IoT devices reduces the need for human labour, allows real-time monitoring, and increases the spatial range of monitoring. Many different communication protocols have been created over the years, allowing the IoT devices and platforms to send each other data in new, interconnected ways like GSM, LoRa, WiFi, Sigfox, NB-IoT, Sigfox, Modbus etc.

After monitoring the air quality data, its visualization and analysis become essential to comprehend the entire scenario. Data can be presented in various forms depending upon the user’s requirements such as creating public awareness, statistical analysis, performing studies etc. Analytics helps identify the problem's root cause and suggest possible actions. The primary purpose is to break down the complex environmental data to make it comprehensible for the consumer.

A data visualization software enables the user to get a bird’s eye view of the air quality monitoring network and also allows to compare parametric data for different equipment over different time periods. The software also represents the air quality data in the form of the National AQI of the respective countries. This presentation highlights a complete flow of data acquisition, the modes of sharing the data to the end-users and visualization software with essential features like smart notifications, automated reports, historical data analytics and many more. This presentation will also focus on few case studies highlighting real world applications of actions insights from real-time air quality data.

Selection of sensors for hyperlocal air quality assessment

Presented by: Mr. Parthaa Bosu

Environmental Defense Fund is working to pilot its hyperlocal monitoring work in India. We will combine emission inventory, dispersion modelling and air quality sensors to understand the localised sources of pollution in a designated study area. The sensors will be used to strengthen the emission inventory. EDF and its technical partners conducted a rigorous collocation study exercise to select the sensors.

A detailed list of specifications was drawn and circulated widely amongst commercial sensor vendors in India, who sent details of their product(s). Based on a thorough literature search, the study of the parameters and discussions with each vendor, five potentials were invited to be a part of the colocation study. They were renamed (for anonymity) as S1, S2, etc. One sensor from each brand was tested blind for two months in a location with similar to actual study area, to match weather conditions.

All sensors (S1 to S5) were placed on an open area, along with a manual sampler. The location was following two CAAQMS stations. Data was collected for a continuous period of 2 weeks for PM 2.5, NO_2, and RH. Both daily and hourly averages were considered to narrow down the choice of sensors. Along with sensors, a manual monitor (reference grade) was set up to check the accuracy of sensors with corresponding monitoring techniques. Descriptive analysis and visualisation of the data for each pollutant parameter were performed. Parameters like r^2, RMSE, fac2 and % within Range were calculated for each brand, following which a final selection was made. The performance-based method helped select sensors from a wide range of commercially available ones, especially in India's absence of established testing methods and standards.

Session 2B: Network Design & Operations

Moderated by Ms. Devaja Shah, Google

Designing a low-cost monitoring network to map urban-rural gradients in India's air quality

Presented by: Dr. Saumya Singh

The use of low-cost air quality monitoring to understand the spatial heterogeneity in pollution levels in Indian cities is becoming increasingly popular in India. However, these monitors are primarily located in institutional areas and urban centres. Air quality monitoring continues to remain sparse in rural India. Therefore, the SAMOSA (Sensor-based Air Measurement Observatory for South Asia) collaborative has designed a monitoring strategy which serves two purposes - 1) Plugs critical data gaps around air quality in Rural India 2) Maps the urban-rural gradient in India's air quality. It is important to note here that while There have been many studies related to calibrating and optimising the sensors, there is limited information and guidance on how networks should be designed to serve varying study objectives.

Under SAMOSA, we have deployed over 70 low-cost sensors in Central and Eastern Uttar Pradesh covering both urban and rural areas in these regions. We use a stratified cluster sampling scheme to characterize how PM2.5 varies regionally and as a function of settlement size and proximity to pollution sources. Each cluster is anchored around a major city consists of a stratified sample of cities, towns, and villages within a ~50-150 km radius of the anchor city. Within each settlement, we use land-use classification using satellite imagery to identify suitable sites for the deployment of sensors. In our study, we describe how these clusters and the settlements within the cluster were selected. We also describe how data from these deployed sensors can be used to understand the urban-rural gradient and regional extent of pollution in the Indo-Gangetic plain.

Low Power Wireless Sensor Network Design for Nationwide Air Quality Monitoring

Presented by: Mr. Ronak Sutaria, Respirer Living Sciences Pvt. Ltd.

India is deploying sensor-based air quality monitoring networks at an unprecedented pace. Tens of thousands of sensor-based air quality monitoring devices are slated to come online in the coming one to two years. Air Quality Monitoring Networks at the city and nationwide-scale do not work as isolated monitoring devices but are always part of a large-scale wireless sensor network solution.

Building, deploying and most importantly maintaining a nationwide air quality sensor network requires careful design, planning and execution. Several competing standards, technologies and frameworks are available to meet different use-cases and requirements. Cellular data transmission technologies like Narrow Band IoT (NBIoT), Low Power Wide Area Networks (LoRaWAN) to IPv6 over Low-Power Wireless Personal Area Networks (6LoWPAN) and Application Protocols such as MQTT, HTTP or TCP need to be taken at the Design stage.

Power requirements for Network Design are particularly important as supply of uninterrupted power cannot be guaranteed across the country. Energy harvesting solutions for wireless sensor networks include technologies such as Photovoltaic harvester, Piezoelectric harvester, Thermal harvester, Flow harvester and Wind harvester. While Solar panel based photovoltaic cells are the most common, their limitations during off-peak months requires backup strategies.

Finally, for long-term network maintenance - a strong Machine Learning based preventive network maintenance solution would involve sending predictive alerts based on battery consumption patterns, sensor-fault detection (via current consumption patterns of the air quality sensors) and other electronic component failures. A robust predictive analytics system for preventive maintenance can provide huge benefits for fewer maintenance overhead and better uptime of the entire air quality network.

Journey of Sensor Based Air Quality Monitoring in India

Presented by: Prof. S.N. Tripathi

Air Pollution is a major global environmental challenge impacting human health. Recognising its adverse effects India launched National Clean Air Program-NCAP- in 2019 with an aim to reduce PM2.5 by 20-30% by 2024. In first phase of NCAP 133 cities have been selected where monitoring network needs to be expanded. Existing monitoring techniques (BAM+ Gas analysers) though accurate are cost prohibitive. Therefore hybrid monitoring combining BAM and sensors is the way forward to meet monitoring needs in India. I will discuss sensors (PM and gas) in lab and on the fly calibrations and real time applications of sensor based data. I will also present some results from existing sensors network from several cities of the country from diverse environments.

Session 3: Performance Targets & Sensor Calibration; regulation; sharing data

Moderated by Ms. Namita Gupta, Airveda

Sensing urban air quality and hyperlocal air pollution: Experiences from Pittsburgh and Doha

Presented by: Dr. R. Subramanian, QEERI

Sensors are used for air quality monitoring in a variety of contexts, including citizen awareness, environmental assessments, and research. The use of a particular sensor for a particular application depends on sensor performance, the pollution being monitored, environmental conditions, and appropriate performance targets. Applications in two cities are discussed: (1) supplementing a regulatory network in Pittsburgh, PA for citizen awareness and to identify point source impacts; (2) monitoring hyperlocal air pollution at football stadiums in Qatar. Sensor corrections improve the utility of low-cost sensors in every case. While transparent linear corrections may be adequate for sensing particulate matter mass (PM2.5/PM10), more complex machine learning algorithms are usually required for nitrogen dioxide (NO_2) and ozone (O_3). Some sensors are demonstrably better than others for particular use cases. Best practices for sensor calibration and data sharing, especially in the context of monitoring the largest environmental health risk, are also discussed.

A machine learning-based calibration of low-cost particulate matter sensors with on-field and long-term evaluation: Case Study of India

Presented by: Mr. Adeel Khan, Council on Energy Environment and Water (CEEW)

Low-cost sensors for real-time ambient air quality monitoring have gained momentum in recent years. Given the scale and severity of air pollution in India, the development of this affordable technology provides the prospect to plug existing information gaps relating to air pollution in Indian cities. However, the reliability of sensor data is an important prerequisite, necessitating calibration and rigorous performance evaluation in comparison to reference-grade monitor. This study presents our approach for calibrating sensor measurements and evaluating its performance on the field. Prior to field deployment, 52 Purple air sensors were colocated for a four-week period with the regulatory grade monitor at IIT campus Delhi, India, as part of a NASA Citizen Science initiative. Additionally, two sensors were also colocated for long term analysis and evaluation. Two different machine learning models, i.e., multi-linear regression (linear model) and Random Forest (non-linear model) were used to calibrate the sensors. Both the models showed satisfactory performance across different performance indices. The R^2 value for the linear and non-linear models were about 0.83 and 0.91, respectively. Further, after calibration, the error was reduced by up to ~25%. The developed calibration is further evaluated on the on-field deployed sensors by mapping them with the nearest regulatory monitor and also on long-term colocated sensors. Overall, data from purple air sensors showed strong agreement with regulatory monitors. This reinforced that a robustly evaluated low-cost sensor network can be an integral component for air quality monitoring in Indian cities.

Session 4: Real World Sensor Applications

Moderated by: Dr. Pratima Singh, CSTEP

Application of low-cost sensors for monitoring indoor particulate matter (PM) in cohort studies: Learnings from rural Tamil Nadu, India

Presented by: Dr Naveen Puttaswamy

Household air pollution (HAP) continues to affect health of millions of people in India. In addition, HAP sources contribute significantly to ambient fine particulate matter (PM2.5) levels driving the ambient air pollution in India. Exposure assessment to HAP is limited to short-term measurements (i.e., 24-h or 48-h) of PM2.5 in most cohort studies. Affordable or low-cost sensing technologies (i.e., LCS) offer a unique platform to assess long-term exposures to PM2.5 that would provide reliable estimates of exposure metrics in exposure – response analyses in health-effect studies. Our group is applying LCS technologies in monitoring exposures to HAP in multiple cohorts spread across urban and rural parts of India. We present our experience in using LCS for personal, indoor, and ambient PM monitoring, and strategies adopted for collocation and calibration of LCS both in ambient and indoor environments.

Building Healthy Cities: Addressing air pollution using Low Cost Sensors data and community empowerment

Presented by: Dr. Damodar Bachani, John Snow India Private Limited, New Delhi

The USAID-funded Building Healthy Cities Project (BHC) conducted a study in Indore, India from January 2021 to February 2022 on how to use low cost sensors (LCS) to improve air quality (AQ) in local communities. 20 LCS were installed in residential, industrial, commercial and traffic-congested areas. One sensor is co-located near the MP Pollution Control Board’s AQ measurement station for validation. The project identified and trained a cohort of local community members as Clean Air Guides (CAG) to collate data, educate citizens on source and mitigation measures, and advocate for interventions with local officials.

The LCS collected hourly and daily PM2.5 data. Each CAG analyzed this data for seasonal variations and polluting events, then shared the findings with community members. BHC collated the data from all the sensors to look at cross-city trends. The CAGs also collected qualitative data on acceptability of LCS data, and community knowledge, attitudes, and practices relating to air quality.

The PM2.5 levels from LCS and reference site met or exceeded the U.S. EPA’s performance targets for air sensors. The study found AQ is lowest at industrial and traffic congestion sites. The data also shows better AQ during the day than in the evening and at night. The main sources of pollution are biofuels, mosquito repellent coils, open waste burning, traffic congestion, construction site dust, bus engines emissions at bus stands, old and poorly maintained vehicle emissions, industrial emissions, and large generators in factories during power failure.

CAGs cited the LCS data in discussions with the city Government about potential interventions. As a result, the city banned open waste burning and biofuels in food streets, made dust-reducing curtains compulsory at construction sites, and began a campaign to encourage drivers to switch off engines at red lights. The data was also useful in educating communities and reducing pollution from local sources.

Air quality sensor data towards Clean Air Action Planning in Manila, Philippines

Presented by: Ms. Everlyn Gayle Tamayo, Clean Air Asia

Air pollution remains as the environmental health risk with the highest global burden especially in densely populated cities in developing countries. The City of Manila has the highest number of respiratory-related mortality in the National Capital Region in 2019, with $3.7 million worth of government health insurance claims due to respiratory and cerebrovascular morbidity cases. The Asia Blue Skies Program is a partnership of Manila City Government, 3M, and Clean Air Asia which aims to deliver science-based air quality solutions for a healthier and more livable Manila City.

Air quality monitoring is an integral part of air quality management, informing actions and guiding policies towards air pollution reduction. The project's air monitoring network of non-reference sensors were locally calibrated with the national government's reference monitoring station for more than 17 months, the longest collocation experiment of a commercially sold sensor so far in the country. The process has tracked the performance through time of the sensor, and the corrected data has effectively increased the coverage of air quality information used in the program.

From 2020 to 2022, pollution data has been collected in various locations in the city which include roadsides, open park spaces, school and hospital zones. The data provided insight to spatial and temporal pollution trends across the city during pandemic restriction and seasonal changes. More importantly, the collected air pollution data helped more active communication of air quality to the public and was used in conjunction with the development of an emissions inventory and modeling of emission reductions measures in the city. Overall, the use of the air sensor network led to better understanding of the air quality situation in Manila and provided guidance in developing and implementing air quality solutions as part of the clean air action planning process under the program.

Closing Panel: How to Use Sensor Data to Drive Action

Moderated by: Ms. Shweta Narayan, Health Care Without Harm

The final panel of the day will be a broad discussion of how to use data from small low-cost air quality sensors to enact improvements within communities. Panelists will discuss what was learned throughout the day and how the different sectors can work together to create a consensus on air quality monitoring policies in India that can improve air quality on a local level.

Panelists:

- Mr. Avijit Michael, Jhatkaa
- Mr. Chetan Bhattacharji, NDTV
- Dr. Sarita Ahlawat, IIT Delhi
- Ms. Farah Kazi, Independent Researcher