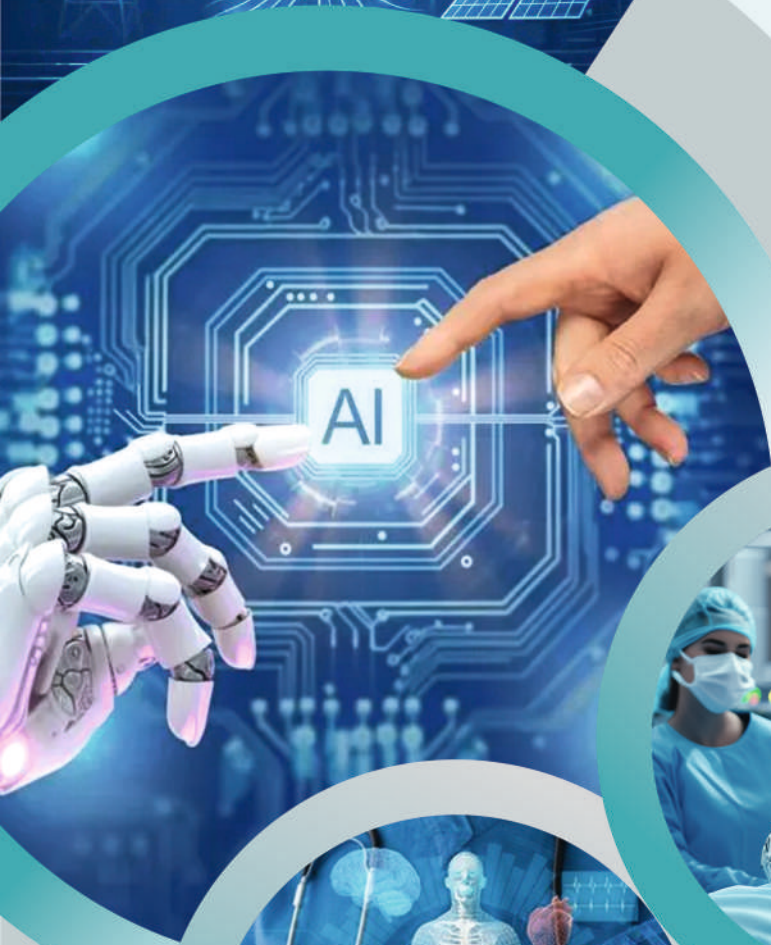




POWER GENXT

Volume : 14



ENGINEERS' WELFARE FORUM

THE WEST BENGAL POWER DEVELOPMENT CORPORATION LIMITED

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on

Application of AI in Healthcare & Power Systems

at

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THE WEST BENGAL POWER DEVELOPMENT CORPORATION LIMITED

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Er. Arindam Ghosal, Er. Soumyajit Dutta, Er. Shubhro Sen
& Er. Dibyendu Ghatak

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Santanu Basu, IAS

প্রধান সচিব

বিদ্যুৎ দপ্তর, পশ্চিমবঙ্গ সরকার

Principal Secretary

Power Department

Government of West Bengal



বিদ্যুৎ উন্নয়ন ভবন

কলকাতা-৭০০ ১০৬

Bidyut Unnayan Bhawan (5th Floor)
3/C, LA-Block, Sector-III, Salt Lake City,

Kolkata-700 106

Telephone : +91 33 23351269

Fax : +91 33 23358378

e-mail : powersecy@wb.gov.in

No. 07-PS (P)/2026.

February 11, 2026

**MESSAGE**

It gives me immense pleasure to learn that Engineers' Welfare Forum of the West Bengal Power Development Corporation Limited (WBPDC) is going to organize its 14th National Seminar on **"Application of AI in Healthcare & Power Systems"** at 10.30 am on 22nd February, 2026 at the WBPDC Corporate Auditorium of *Bidyut Unnayan Bhawan*, 3/C, LA Block, Sector-III, Salt Lake, Kolkata – 700 106 and a Souvenir would be brought out on this auspicious occasion.

I pray for their further prosperity and convey my heartfelt thanks to all of them on this occasion.

Shri Soumen Das
General Secretary
Engineers' Welfare Forum
West Bengal Power Development Corporation Limited
Bidyut Unnayan Bhawan
3/C, LA Block, Sector-III
Salt Lake, Kolkata – 700 106.

(Santanu Basu)

Santanu Basu, IAS
Principal Secretary
Power Department
Government of West Bengal

Dr. P. B. Salim, IAS
Chairman & Managing Director



Date:

Message

It is a matter of great honor and privilege to be associated with the 14th National Seminar on “*Application of AI in Healthcare & Power Systems.*” This gathering reflects the collective vision of academia, industry, and research communities to harness the transformative potential of Artificial Intelligence for the betterment of society.

Healthcare and power systems are two pillars of national development. In healthcare, AI is enabling early diagnosis, personalized treatment, and efficient management of medical resources—bringing hope to millions and redefining patient care. In power systems, AI is driving smart grids, predictive maintenance, and sustainable energy management, ensuring reliability and efficiency in meeting the growing demands of our nation.

This seminar is not just a platform for exchanging knowledge, but also a call to action: to innovate responsibly, to collaborate across disciplines, and to ensure that technology serves humanity with fairness, transparency, and inclusivity.

I extend my heartfelt congratulations to the organizers, participants, and contributors for their dedication to advancing this vital field. May the discussions and deliberations here inspire new ideas, foster meaningful collaborations, and pave the way for impactful solutions that shape a brighter future.

With best wishes for the success of the seminar.

(P. B. Salim)

Soumen Das
General Secretary
Engineers' Welfare Forum, WBPDCCL
Bidyut Unnayan Bhaban,
3/C, Block-LA, Sector-III
Pin – 700 106.

The West Bengal Power Development Corporation Limited
(A Government of West Bengal Enterprise)
CIN: U40104WB1985SGC039154
Bidyut Unnayan Bhaban, Plot No. 3/C, Block-LA, Sector-III, Bidhannagar, Kolkata-700106
Phone: 033 2335 0402, 2339 3291 | Fax: 033 2335 0523 | Email: cmd@wbpdcl.co.in
Website: www.wbpdcl.co.in



www.wbpdclwef.org.in

ENGINEERS' WELFARE FORUM
THE WEST BENGAL POWER DEVELOPMENT CORPN. LTD.

Regn. No.: S/ 1L/ 74829)

Address for Communication: Bidyut Unnayan Bhaban,3/C, Block-LA,
Sector-III, Bidhannagar, Kolkata-98, E-mail: wbpdclwef@gmail.com,
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Message From The Editor

Artificial Intelligence or AI, commonly characterized as the intelligence exhibited by machines and software, including robots and computer programs, is a scientific discipline that explores, develops, and simulates human behaviour and its underlying principles. The term primarily denotes creating systems possessing human-like cognitive processes and attributes, such as reasoning, learning from experiences, generalization, discrimination, and error correction.

AI techniques have proven instrumental in addressing numerous challenges in healthcare and power systems, and their effectiveness is further amplified when combined with traditional mathematical approaches. Examples of these techniques include artificial neural networks (ANNs), fuzzy logic (FL), adaptive-network-based fuzzy inference systems (ANFISs), intelligent techniques and expert systems.

In healthcare, AI is applied in medical imaging for early disease detection, in predictive analytics for diagnosing illnesses and in personalised treatment planning by analysing patient's data, genetics and lifestyle factors. AI powered system also supports hospital management through automated scheduling, virtual assistants and remote patient monitoring, improving efficiency and patient outcomes.

In Power System, AI plays vital role in load forecasting, demand-supply optimization and fault detection in transmission and distribution network. Machine learning algorithms help predict equipment failure, integrate renewable energy sources and enhance grid stability by enabling real time control and self-healing mechanism.

This issue of **POWER GENXT**(Vol-14) has come up with write up and reviews on AI applications in healthcare and power systems identifying key challenges and research gaps based on recent publications.

My heartiest good wishes and congratulations to the Seminar Organising Committee for organising this 14th National Seminar on today's burning topic AI in healthcare and power systems.

(PRASANTA SINHA)

Editor, Power Genxt

&

Chairman, Engineers Welfare Forum, WBPDCI



A Brief Write-up on

The National Engineering Innovation Challenge 2026



Er. Agnimitra Biswas is the Chief Executive Officer of **IDEAS – Institute of Data Engineering, Analytics and Science Foundation**, the Technology Innovation Hub and Technology-Based Incubator of the **Indian Statistical Institute, Kolkata**. He holds a PGDM from **IIM Calcutta** and a B.Tech from **IIT Kharagpur**, and has over **30 years of experience** across industry and academia.

Agnimitra has led technology consulting, practice building, and large-scale digital transformation initiatives with global organisations such as **PricewaterhouseCoopers** and **IBM**. At **ISI Kolkata**, he has played a key role in building the start-up incubation ecosystem, supporting more than **30 early-stage deep-tech startups**. His previous roles include **Dean, School of Business** at **Kaziranga University**, **Project Director** at **IIT Kharagpur**, and **Director of R&D** at **Prophecy Sensorlytics**. He is also a visiting faculty member and advisor to several technology startups.

Er Agnimitra Biswas

CEO, IDEAS Foundation, Indian Statistical Institute

□ THE MOTIVATION: A VISION FOR AN AI-DRIVEN FUTURE:

The National Engineering Innovation Challenge 2026, organized by the Engineers' Welfare Forum of **The West Bengal Power Development Corporation Limited (WBPDCL)** in **Collaboration with: IDEAS-TIH, Indian Statistical Institute (ISI) Kolkata**, was born from a critical realization: while Artificial Intelligence (AI) is the “electricity” of the 21st century, its implementation in core sectors like **Healthcare** and **Power Systems** requires specialized, localized innovation.

As we stand at the intersection of technology and industry, Artificial Intelligence (AI) continues to transform vital sectors like healthcare and power systems, offering unprecedented opportunities for innovation and efficiency. The motivation behind the first **NEIC 2026** was to bridge the gap between academic brilliance and industrial needs. By fostering a deeper understanding of how AI can drive service delivery and sustainability, the seminar aimed to explore the immense potential of AI in addressing critical challenges in these fields.

The National Energy Innovation Challenge (NEIC) 2026 was launched as the flagship student competition of this

seminar. The goal was to provide a professional stage for undergraduate engineers to transition from classroom theory to industrial application, fostering a mindset of “Applied AI” that improves service delivery, ensures worker safety, and enhances grid sustainability. Innovative ideas from faculty led student teams were invited on two themes: Power Systems & Healthcare.

□ NEIC 2026: A RESOUNDING SUCCESS IN INNOVATION

The inaugural edition of NEIC 2026 witnessed an overwhelming response from the engineering student community across the country. The competition successfully emerged as a platform for young innovators to propose proactive, AI-powered solutions to pressing real-world challenges.

- **Total Ideas Submitted:** Over 30 high-quality and innovative ideas were received from leading government and private universities and colleges.
- **Shortlisting Process:** Following a rigorous evaluation by a panel of domain experts, **11 ideas** were shortlisted. The selected teams were invited to submit detailed projects and participate in the final presentation round.
- **Final Presentations:** The final project presentations were held on 30 January 2026, before a distinguished panel of judges from industry and academia, marking the culmination of a three-month-long competitive process.

□ FINAL ROUND - JUDGING PANEL

1. **Asoke Kumar Paul**, Former General Manager, SAIL
2. **Prof. Gautam Saha**, IIT Kharagpur
3. **Prof. Tarun Kanti Bhattacharyya**, IIT Kharagpur

□ THE CHAMPIONS OF NEIC 2026:

Winner (1st Position)	
Idea	Physics-Informed Neural Networks for Detecting Faults in Transmission Line Insulation
Description	This project addressed the “hit-or-miss” nature of traditional infrared inspections by blending AI with thermal physics. Using a Mask R-CNN and a Physics-Informed Neural Network (PINN), the team created a “digital stand-in” for insulators that can pinpoint internal defects with high accuracy.
Institution	Indian Institute of Engineering Science and Technology (IEST), Shibpur
Team Members	Homagni Dutta, Aarush Roy, Soham Mishra and Rupanjan Bhattacharyya
Faculty Guide	Dr. Amalendu Bikash Choudhury

1st Runner Up (2nd Position)	
Idea	Predi Transformer: AI Powered Fault Diagnosis for Power Grids
Description	Aiming to shift transformer maintenance from reactive to predictive, this team developed a framework that ingests multi-sensor data (DGA, thermal profiles, etc.). By using hybrid deep learning and Explainable AI (XAI), the system provides operators with a clear “why” behind every fault warning.
Institution	Indian Institute of Engineering Science and Technology (IIST), Shibpur
Team Members	Sumit Kumar, Suryansh Singh, Varshith Guptha Maddula and Vijay Nitin Deshmukh
Faculty Guide	Dr. Pritam Paral

2nd Runner Up (3rd Position)	
Idea	AI-IoT based Health & Fatigue Monitoring System for Industry Workers
Description	Designed for high-demand industrial environments, this project features a low-cost wearable system that monitors physiological and ambient data. It uses a deep-learning model to infer a personalized “Fatigue Index,” allowing for early intervention before accidents occur
Institution	Techno India University, West Bengal.
Team Members	Arpan Chakraborty, Md. Youhanna Hassan and Soumendu Dinda
Faculty Guide	Sudip Modak

□ OTHER NOTEWORTHY SUBMISSIONS

Several other compelling projects featured among the top contenders, including:

- *AI for Vacuum Circuit Breaker Arc Duration Measurement (Meghnad Saha Institute of Technology)*
- *Development of Sensor for Detection of Microplastics (Meghnad Saha Institute of Technology)*
- *AI-Driven Pipeline for Standardization and Authentication of Ayurvedic Formulations (IIST, Shibpur)*

The diversity, depth, and application-oriented nature of the submissions clearly reflect the strong potential of student-led innovation in applied AI. The organisers extend their sincere appreciation to all participating teams and faculty mentors for their dedication and exemplary pursuit of impactful, real-world solutions.

❑ IDEAS TIH, ISI KOLKATA: AN ENRICHING PARTNERSHIP

IDEAS – Institute of Data Engineering, Analytics and Science Foundation at the Indian Statistical Institute has been an integral partner in the successful conduct of NEIC 2026, which was organised for the first time this year. Established with three core mandates—Technology Development, Skill Development, and Entrepreneurship Development—IDEAS Foundation operates at the forefront of Data Science, Artificial Intelligence, and Machine Learning.

Over the years, IDEAS Foundation has emerged as a vibrant hub for technology innovation and talent development, particularly in eastern India. With a strong emphasis on nurturing next-generation talent in deep-tech domains, NEIC 2026 provided an ideal platform for advancing the Foundation’s mission. Encouraged by the success of this inaugural edition, IDEAS Foundation is pleased to extend its continued support to EWS for future editions and looks forward to jointly working towards establishing NEIC as a premier national-level event for the student community in India.

IDEAS Foundation expresses its sincere gratitude to the organisers and judges, and extends special thanks to its team of data scientists and domain experts—Dr. Sujoy Biswas, Dr. Chandan Biswas, and Mr. Koustab Ghosh—for their enthusiastic support and active participation in making the event a success.

The Foundation also invites industry partners and startups to collaborate in translating innovative research ideas from the laboratory to commercially viable solutions. Being housed within the prestigious Indian Statistical Institute, IDEAS Foundation leverages the rich intellectual capital and research ecosystem of its parent institute to fulfil its role as a responsible and impactful industry–academia partner.

For more information on the wide range of activities and initiatives undertaken by IDEAS Foundation at the Indian Statistical Institute, readers are encouraged to visit www.ideas-tih.org.

❑ LOOKING AHEAD TO NEEDS:

The **National Energy Excellence Drive (NEED) 2026** is a flagship professional initiative hosted by the **Engineers’ Welfare Forum (WBPDC)**, aimed at accelerating the adoption of cutting-edge technologies across India’s core industrial sectors. A key highlight of this initiative is the **14th National Seminar**, scheduled for **February 22, 2026**, which will focus on two contemporary and impactful themes: **Artificial Intelligence in Healthcare** and **Artificial Intelligence in Power Systems**.

Adding to the significance of this year’s seminar, the champion teams from **NEIC 2026** will be invited to present their innovative solutions to a distinguished audience comprising veteran engineers, academic researchers, and student innovators, creating a vibrant platform for the exchange of ideas and knowledge. To recognise excellence and innovation, cash prizes totaling ₹ **50,000** will be awarded to the winning teams.

The seminar will serve as a fitting culmination of this **three-month-long initiative**, envisioned as a strategic bridge between theoretical research and real-world industrial applications, with a strong emphasis on **Applied AI**.

The Breath Detectives

Professor Tarun Kanti Bhattacharyya, *Institute Chair Professor*
Professor and Head E&ECE Department IIT Kharagpur



Prof. Tarun Kanti Bhattacharyya is an Institute Chair Professor at the Indian Institute of Technology Kharagpur and a nationally and internationally respected leader in electronics, nanoelectronics, MEMS, VLSI, and sensor systems, with over 35 years of academic, research, and industrial experience spanning government laboratories, industry R&D, and premier academic institutions.

At IIT Kharagpur, he is currently Professor & Head, Department of Electronics and Electrical Communication Engineering, Professor & Head, Advanced Technology Development Centre, Professor-in-Charge of the High-Performance Device Laboratory, Professor-in-Charge of the Microelectronics and MEMS Laboratory, and National Coordinator of the National MEMS Design Centre. He has been instrumental in establishing and strengthening world-class research infrastructure, including state-of-the-art VLSI and MEMS laboratories and an advanced VLSI test facility developed in collaboration with Keysight Technologies, enabling industry-grade chip, MEMS, and system validation.

His contributions have been recognized through several prestigious honours, including the IBM Faculty Award (2012); the DST–Lockheed Martin India Innovation Growth Programme Gold Medal (2016) for microfluidic drug-delivery technology; INAE and ISSS doctoral thesis awards; and the Gandhian Young Technological Innovation (GYTI) Award for nano-engineered MEMS technologies for space applications. He has also been selected for elite international programs such as the Indo-US Frontiers of Engineering, Indo-Japan Advanced Micro/Nano Manufacturing Initiative, and the Indo-US Centre for Advanced and Futuristic Manufacturing, and is a recipient of the UNIDO (Vienna) Fellowship for international research collaboration.

Breath is the most ordinary human act—and perhaps the most revealing.

Breath is the most effortless act of being alive. It requires no instruments, no needles, no conscious decision. Yet within this simplicity lies a chemical complexity that rivals the most sophisticated biological samples. Every exhalation carries a cloud of volatile organic compounds—VOCs—generated deep within the human body as by-products of metabolism, cellular stress, inflammation, and organ-specific biochemical pathways.

These molecules are not incidental. They are evidence.



Acetone emerges when glucose metabolism shifts, announcing insulin imbalance and diabetic states. Ammonia escapes into breath when kidneys struggle to clear nitrogenous waste or when hepatic detoxification falters. Aldehydes and short-chain hydrocarbons arise from lipid peroxidation, oxidative stress, and malignant cellular activity, particularly within lung tissue. Long before a tumor is visible on a scan or a symptom becomes clinically obvious, these molecules begin to appear—quietly, persistently.

Breath, therefore, is not just air leaving the lungs. It is a biochemical autobiography written in real time. Modern medicine has long relied on invasive sampling—blood draws, biopsies, imaging—each costly, episodic, and often uncomfortable. These methods offer precision, but at the price of intrusion and delay. Breath offers something radically different: a continuous, non-invasive, and patient-friendly diagnostic medium. The scientific foundations proving this potential already exist. What has been missing is a way to listen—clearly, affordably, and at scale.

Listening to breath has traditionally demanded silence of the laboratory and instruments of extreme precision. Gas Chromatography–Mass Spectrometry (GC–MS) has been the undisputed gold standard for VOC analysis, capable of separating and identifying individual molecules with astonishing accuracy. In research settings, GC–MS has linked breath signatures to diabetes, kidney disease, liver dysfunction, and multiple forms of cancer, particularly lung malignancies.

But GC–MS comes with an unspoken assumption: healthcare can afford complexity.

A single GC–MS system costs more than ₹1 crore. It requires controlled environments, expert operators, elaborate sample preparation, and long analysis times. These systems are confined to elite laboratories, disconnected from clinics, community health centers, ambulances, and homes. They are instruments of discovery, not deployment.

As a result, breath diagnostics has remained paradoxical—scientifically validated yet clinically absent. Precision has become a barrier. The very tools capable of hearing breath clearly are too expensive, too slow, and too immobile to serve the populations that need them most.

To make breath diagnostics real, the field does not need a cheaper GC–MS. It needs a different way of thinking altogether.

At **IIT Kharagpur**, this realization triggered a fundamental shift in perspective. Under the leadership of **Prof. T. K. Bhattacharyya**, Chair Professor and Head of the Department of Electronics and Electrical Communication Engineering, a multidisciplinary team began to reimagine breath diagnostics not as a chemistry problem, but as a systems-engineering challenge.

The team—Dr. Santanab Majumder, Dr. Avik Sett, Dr. Lisa Sarkar, Dr. Tanmoya Ghosh, doctoral researchers Mayank Kohli and Deblina Kar, and MS student Gairik Karmakar—brought together expertise spanning semiconductor devices, nanoelectronics, sensor physics, circuit design, and artificial intelligence. Their collective objective was not to miniaturize laboratory instruments, but to redesign the diagnostic pipeline itself.

Instead of asking how to identify every molecule, they asked a more fundamental question: *Do we truly need molecular identity, or do we need diagnostic meaning?*

This question reframed breath analysis from molecular enumeration to pattern recognition. It marked the beginning of a concept now central to their work: **active sensing**.

In conventional gas sensors, the device waits. A gas arrives, adsorption occurs, resistance changes, and a steady-state value is recorded. Such passive sensing produces limited information, often plagued by cross-sensitivity, drift, and poor selectivity. Complex biological signals are reduced to a single number.

Active sensing rejects passivity.

In this paradigm, the sensor is electrically interrogated—subjected to controlled biasing schemes, dynamic voltage sweeps, and time-dependent excitation—while interacting with breath-borne VOCs. Each molecule perturbs the electronic system in a distinct manner. Ammonia donates electrons, modifying carrier concentration and transport pathways. Acetone influences surface dipoles, trap states, and interfacial energetics. Formaldehyde alters adsorption kinetics and transient charge exchange.

When these interactions occur under dynamic electrical excitation, they generate rich, multidimensional electrical fingerprints rather than single-point responses. Current–voltage characteristics evolve. Transient responses reveal kinetic processes. Nonlinearities expose deeper interaction mechanisms.

Breath is transformed from a chemical mixture into a structured electrical signal space.

These signals, however, are not amenable to threshold logic or rule-based interpretation. Their richness demands intelligence.

Inside the Laboratory: Where Breath Becomes Signal

Behind the conceptual elegance of active breath sensing lies a laboratory ecosystem where materials, devices, and signals are patiently shaped into meaning. The work unfolds not as a single experiment, but as a sequence of deliberate transformations—chemical, electrical, and computational—each refining the conversation between breath and electronics.

The laboratory journey begins at the level of materials, where the sensing layer is treated not as a passive surface, but as a programmable interface. Reduced graphene oxide, silk fibroin dielectrics, carbon nanotube networks, and functionalized two-dimensional materials are synthesized and modified with an almost biological intent. Functional groups are not merely attached; they are curated. Hydroxyl groups are preserved for ammonia selectivity, amine groups are introduced to modulate humidity response, and defect densities are tuned to balance adsorption strength with reversibility.

In these materials, sensitivity is not accidental—it is engineered.

Microscopy and spectroscopy form the first language through which these materials speak. FESEM and HRTEM images reveal wrinkled graphene sheets, nanoscale porosity, and defect-rich landscapes that later become sites of molecular interaction. Raman spectra trace the evolution of disorder and graphitization. FTIR signatures confirm the survival or removal of specific functional moieties, each peak hinting at how a future breath molecule might bind, donate charge, or retreat.

Yet material characterization is only the prologue.

The heart of the laboratory lies in device fabrication, where sensing materials are embedded into transistor architectures that blur the line between electronics and chemistry. Field-effect transistors are fabricated not simply as switches, but as electrostatic lenses—capable of amplifying, suppressing, or reshaping the interaction between gas molecules and charge carriers. Silk, an ancient biological material, is repurposed as a high-k gate dielectric, its molecular order enabling low-voltage operation while maintaining mechanical flexibility and environmental stability.

Within these devices, the gate electrode becomes more than a control terminal. It becomes an active participant in sensing. By tuning the gate bias, the laboratory team learns to selectively involve electrons or holes in the sensing process, revealing that minority carriers—often ignored in resistive sensors—can dominate sensitivity when properly summoned. This gate-induced carrier modulation transforms ordinary gas sensors into adaptive systems whose response can be reshaped even after fabrication.

The laboratory does not stop at fabrication; it interrogates behavior.

Custom gas-sensing chambers simulate breath conditions with careful control over concentration, humidity, and exposure dynamics. Ammonia, acetone, formaldehyde, and other volatile compounds are introduced not as isolated stimuli, but as evolving environments. Transient current responses are recorded, recovery kinetics are observed, and baseline drift is challenged repeatedly to test resilience. Unlike conventional sensors that fear humidity, these devices are forced to coexist with it—mirroring the complexity of real breath.

Over time, patterns emerge. Response amplitudes increase not monotonically, but selectively under certain gate biases. Recovery accelerates when charge transfer pathways align with electrostatic fields. In some regimes, contact resistance becomes a sensing element itself, subtly altered by molecular adsorption at metal–semiconductor interfaces. These observations do not merely validate device performance; they inform theory.

Parallel to experiments, simulation becomes a silent collaborator. Density functional theory and

TCAD-based models translate laboratory observations into band diagrams, adsorption energies, and carrier redistribution maps. In ammonia sensing, simulations reveal how gate fields deepen adsorption wells or modulate Schottky barriers. In humidity sensing, the concept of pseudo-electron injection emerges—an explanation for dramatic current amplification driven by molecular dipoles and band alignment rather than bulk conduction alone.

The laboratory thus becomes a place where intuition is tested against physics.

Crucially, these activities are not isolated demonstrations. Each experiment feeds into a growing internal knowledge base—a library of electrical fingerprints associated with specific materials, biases, and analytes. These datasets form the training ground for the final layer of the system: machine intelligence. Rather than forcing sensors to be perfectly selective at the material level, the laboratory embraces controlled imperfection, allowing AI algorithms to learn from multidimensional signal spaces.

Here, noise becomes information.

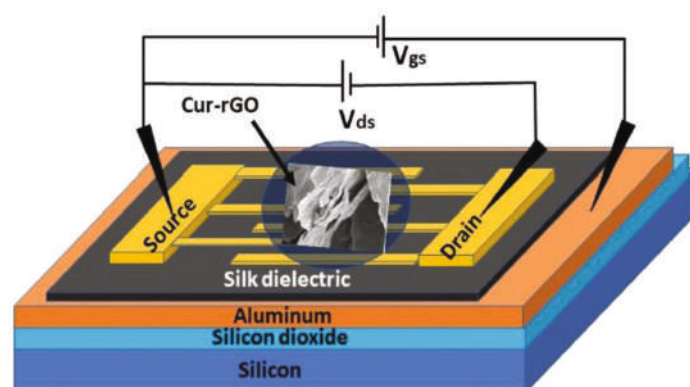
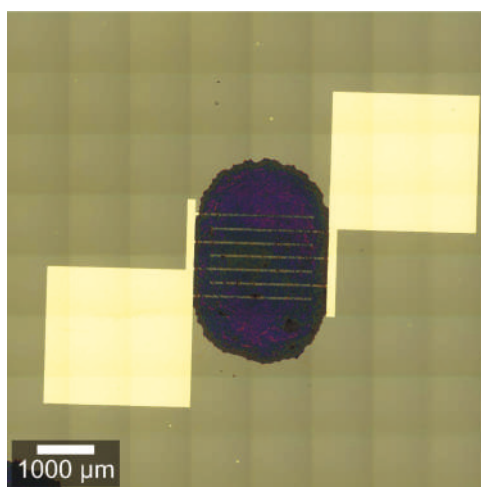
Repeated experiments across devices, batches, and environmental conditions generate variations that would traditionally be considered undesirable. In this framework, they become features. The laboratory trains algorithms not to chase absolute values, but to recognize shapes, trajectories, and correlations—how signals evolve rather than where they settle. This philosophy aligns naturally with breath itself, which is never static.

Over months of iteration, the laboratory effort matures from exploratory experiments into a coherent sensing philosophy. Materials are chosen not only for sensitivity, but for stability. Device geometries are optimized not only for response, but for manufacturability. Measurement protocols are refined to balance rigor with realism. Each decision reflects an awareness that this work must eventually leave the lab.

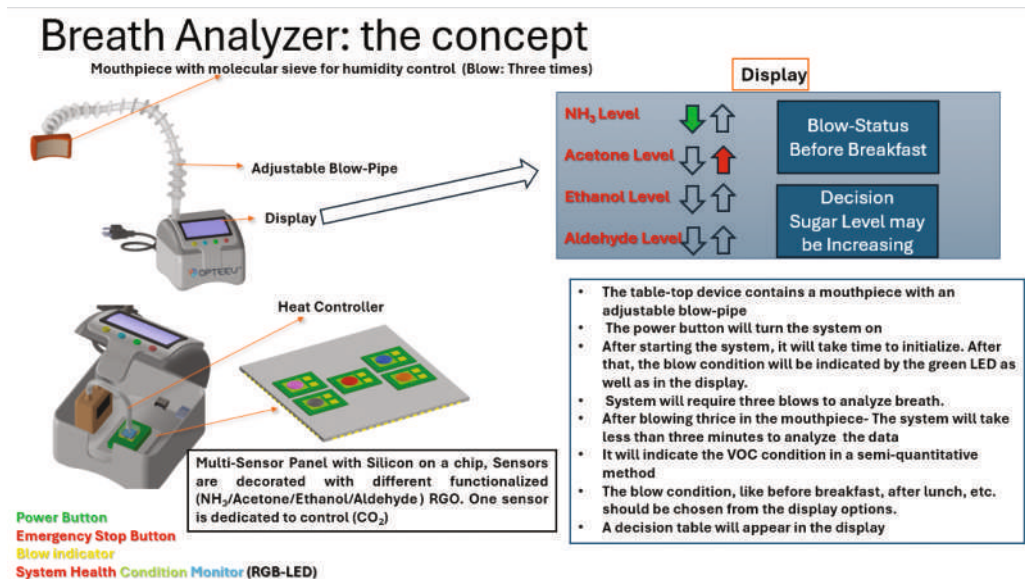
Perhaps the most striking aspect of these laboratory activities is their refusal to remain confined. Flexible substrates are bent, devices are aged over weeks, humidity is varied deliberately, and recovery is tested repeatedly—not to satisfy reviewers, but to anticipate deployment. The lab behaves as a rehearsal space for the real world.

In this environment, the boundary between research and translation begins to dissolve.

What emerges is not just a collection of devices, but a reproducible workflow: from material synthesis to device fabrication, from electrical interrogation to intelligent interpretation. This workflow is the true product of the laboratory—a blueprint for scalable breath diagnostics that does not depend on fragile precision instruments, but on robust physics and adaptable intelligence.



The laboratory, in this sense, is not merely a place of validation. It is where breath is taught how to speak in electrons, and where electronics learn how to listen.



Here, **artificial intelligence and machine learning** form the final sensing layer. Using state-of-the-art feature extraction and classification algorithms, the system learns to recognize disease-specific patterns across populations. Healthy breath occupies one region of signal space. Diabetic breath forms another. Renal dysfunction, liver disease, and pathological states cluster distinctly—even when individual VOC concentrations overlap.

The system no longer asks, “Which molecule is present?” It asks, “Which physiological state does this pattern represent?”

This shift—from molecular identification to disease classification—is profound. It allows robust operation in real-world environments, tolerant to biological variability, sensor drift, and environmental noise. It mirrors how clinicians think: diagnosis emerges from patterns, trajectories, and context rather than isolated measurements.

As the sensing philosophy matured, equal attention was given to system-level realization. The breath analyzer envisioned by the team was not conceived as a laboratory prototype, but as a deployable instrument. Its architecture was intentionally simple: a disposable mouthpiece for hygiene, a filtered breath inlet, an active sensing chamber housing nano-engineered sensor elements, and compact electronics for signal acquisition and processing.

Importantly, the system was designed to be disease-agnostic. Unlike earlier breathalyzer concepts narrowly associated with specific outbreaks or conditions, this platform avoids disease-specific labeling altogether. It is built to evolve.

New disease signatures are introduced through data, not hardware redesign. The same device can be trained for metabolic disorders today, renal dysfunction tomorrow, and oncology screening in the future. This adaptability gives the platform longevity, regulatory flexibility, and broad clinical relevance.

From a cost perspective, the implications are transformative. Built using standard electronics and scalable fabrication methods, the system targets affordability by design. What once required core-scale instrumentation is reduced to a portable, low-power platform suitable for clinics, community health centers, and potentially home use.

As breath-based diagnostics move from concept to reality, a deeper implication begins to emerge. What is being sensed is not merely the presence of volatile compounds, but the **state of the body itself**, encoded in transient, evolving electrical responses. In this sense, active breath sensing becomes more than a diagnostic tool—it becomes a new physiological interface.

Traditional biomarkers are static. A blood glucose value, a creatinine level, a tumor marker—all are snapshots frozen in time. Breath, by contrast, is dynamic. It reflects metabolism in motion, organ stress

in flux, and disease progression as a continuum rather than a threshold. When paired with active sensing, this dynamism is preserved rather than averaged out.

The electrical signatures generated during breath interrogation are time-resolved, bias-dependent, and nonlinear. They contain information about adsorption kinetics, charge transfer rates, surface state occupancy, and desorption dynamics. These parameters are indirectly shaped by biochemical processes occurring within the body—mitochondrial efficiency, oxidative stress, enzymatic bottlenecks, inflammatory cascades.

In effect, the sensor does not merely measure disease. **It resonates with physiology.**

This perspective enables longitudinal monitoring rather than episodic diagnosis. A patient's breath profile can be tracked over days, weeks, or months, revealing trends rather than isolated abnormalities. Subtle deviations from personal baselines—often invisible to population-based thresholds—can signal early disease onset or therapeutic response.

Such capability is especially transformative for chronic conditions like diabetes, kidney disease, and liver dysfunction, where progression is gradual and early intervention is critical. It also holds promise for oncology, where early metabolic shifts often precede anatomical changes by months or years.

The breath analyzer that emerges from this work is therefore not a product in the traditional sense. It is a platform.

Its hardware is general. Its sensing philosophy is universal. Its intelligence layer is adaptive. As datasets expand and algorithms mature, the platform grows in diagnostic capability without changing its physical form.

This stands in contrast to traditional medical devices, which are often rigidly tied to a single indication or biomarker. Here, adaptability is intrinsic.

From a technological standpoint, the platform aligns seamlessly with modern electronics—embedded intelligence, edge computation, secure connectivity, and personalized analytics. From a healthcare perspective, it aligns with the shift toward preventive, decentralized, and patient-centric medicine.

Most importantly, it challenges the assumption that advanced diagnostics must remain centralized and expensive. By leveraging standard electronics, indigenous innovation, and intelligent signal interpretation, the platform lowers barriers to access while preserving scientific rigor.

What began as a question about breath becomes a statement about healthcare itself.

In this vision, hospitals are no longer the sole gatekeepers of diagnosis. Clinics, community centers, and homes become sites of meaningful health insight. Disease is no longer detected only when it is loud, but when it first begins to whisper.

The breath analyzer does not replace clinicians, laboratories, or imaging systems. Instead, it complements them—providing early signals, continuous context, and actionable intelligence where none previously existed.



Breath has always carried the truth of the body. For the first time, technology is prepared to listen—carefully, intelligently, and at scale.

For more information-

https://www.youtube.com/watch?si=Dxnhp_iXUfecWjCN&v=FMjeGCgBelE&feature=youtu.be

Eye as Mirror of Human Health

Professor Santanu Chaudhury

*Professor & Dean, School of Advanced Computing
Ashoka University*



Prof. Santanu Chaudhury did his B.Tech (1984) in Electronics and Electrical Communication Engg and Ph.D (1989) in Computer Science and Engg. from I.I.T, Kharagpur, India. Presently, he is Dean and Professor in the School of Advanced Computing at Ashoka University. He retired from the position of Professor in the department of Electrical Engineering., IIT Delhi on January 31st, 2026.

He had been Director, IIT Jodhpur and Director CSIR-Central Electronics Research Institute. He was also Dean, Undergraduate Studies at IIT Delhi. He held a number of Chair Professor positions at IIT Delhi.

He was awarded INSA medal for young scientists in 1993. He is a fellow of Indian National Academy of Engineers (INAE), The National Academy of Sciences (NASI) and International Association of Pattern Recognition (IAPR). He is also a recipient of Distinguished Alumni Award of IIT Kharagpur..

He has over 350 publications in reputed Journals and conferences and 15 patents with technologies commercialised by global industries. His areas of interests are Computer Vision, Artificial Intelligence, Digital Heritage, AR-VR & Multi-sensory media.

1. Introduction

The human eye is not only a window to the world—it is also a mirror of what’s happening inside the body. Because it contains blood vessels, nerves, and connective tissue that reflect systemic changes, the eye can reveal disease processes long before other organs show symptoms. The retina, optic nerve, and surrounding structures are the only part of the central nervous system visible non-invasively through direct examination. The eye’s microvascular network mirrors the condition of blood vessels elsewhere in the body. Metabolic, vascular, and neurological disorders all leave markers that can be observed during ophthalmic evaluation. Also, measurement and quantitative analysis of eye movements and related ocular signals are useful to understand vision, cognition, neurological function and health.

2. Eye Examination

2.1 Imaging

Retinal imaging is a non-invasive, high-resolution imaging tool that creates detailed, digital, 2D or 3D images of the retina, optic nerve, and blood vessels at the back of the eye. Common types include the following:

- (i) Fundus Photography: Takes a detailed, often wide-field, color picture of the back of the eye.
- (ii) Optical Coherence Tomography (OCT): Uses light waves to create cross-sectional, 3D images of retinal tissue layers, allowing for precise measurements.
- (iii) Fluorescein Angiography (FA): Uses a dye injected into the bloodstream to visualize blood circulation.

2.2 Oculometry

Oculometry is the scientific measurement and quantitative analysis of eye movements and related ocular signals to understand vision, cognition, neurological function, and health. Oculometry focuses on dynamic eye behavior rather than static eye structure. It measures

- (i) Saccades – rapid eye movements between points of fixation
- (ii) Fixations – periods when the eye is relatively still
- (iii) Smooth pursuit – tracking moving objects
- (iv) Micro saccades – tiny involuntary movements during fixation
- (v) Vergence – coordinated movement of both eyes
- (vi) Blink rate and duration
- (vii) Pupil dynamics (often overlapping with pupillometry)

These tools are non-invasive, quick, and painless, yet they offer powerful diagnostic information far beyond what a standard eye test can provide.

2.3 Spectroscopy

Spectroscopy is a technique that examines the interaction between light and matter. It is now one of the innovative methods at the forefront for investigating both ocular and systemic diseases. This method is not new to the scientific community; it has long been used in various other fields such as astronomy and environmental science. The use of spectroscopy in the eye is a recent development. This powerful tool is being harnessed to explore the eye's intricate biological landscape. By decoding distinct spectral signatures of proteins and molecules—much like molecular fingerprints—spectroscopy provides a new frontier in diagnostics. Spectroscopy is enabling the precise identification and quantification of different biomarkers. This has potential applications in ophthalmology, neurology, cardiology, primary care, and more. By revealing the specific molecular changes within the eye, spectroscopy offers a transparent view of the biological processes at play. This clarity is enabling more targeted and personalized medical interventions, enhancing patient outcomes across the board.

Despite its promise, ocular spectroscopy faces several challenges:

- (i) Sensitivity to eye motion and illumination conditions
- (ii) Lack of standardized acquisition and analysis protocols
- (iii) Limited large-scale clinical validation
- (iv) Translational barriers from laboratory systems to clinical devices

Addressing these issues is essential for widespread adoption.

3. Key Health Indicators from Eye

3.1 Retinal Scan can provide input on:

A. Cardiovascular Health: Changes in retinal blood vessels—such as narrowing of arterioles, widening of venules, or unusual “kinks”—are strong indicators of hypertension (high blood pressure), atherosclerosis (cholesterol buildup), and risk for heart attack or stroke.

Metabolic Disorders: Leaking blood vessels or small yellow deposits (exudates) are hallmark early signs of diabetes and diabetic retinopathy, often appearing before a formal diabetes diagnosis.

Neurological Health: Because the retina is an extension of the brain, thinning of its nerve layers can be a precursor to neurodegenerative diseases like Alzheimer's, Parkinson's, and Multiple Sclerosis (MS).

B. Systemic Inflammation & Aging: Recent studies suggest that the complexity of retinal vessel branching can indicate “biological age” and systemic inflammation, potentially predicting a person's overall lifespan.

C. Other Conditions: Scans can reveal signs of kidney disease, certain blood cancers

(leukemia/lymphoma), and even brain tumors through pressure-induced changes in the optic nerve (papilledema).

3.2. Oculometry Measurements can provide input on

A. Neurodevelopmental and Mental Health Indicators

ADHD(Attention Deficit Hyperactivity Disorder): Oculomotor abnormalities, such as increased saccadic intrusions (unwanted eye movements) and poor inhibitory control, are robust markers.

Autism Spectrum Disorder (ASD): Differences in fixation patterns, specifically reduced focus on faces or eyes, are key indicators.

Schizophrenia: Eye-tracking tasks can reveal disruptions in smooth pursuit and visual attention.

Depression/Mood Disorders: Oculometry helps identify attention biases, such as difficulty disengaging from negative stimuli.

B. Neurological and Neurodegenerative Conditions

Alzheimer’s Disease & Dementia: Retinal neurodegeneration (measured via OCT) and altered pupillary dynamics (pupillary light reflex) can indicate early cognitive decline.

Parkinson’s Disease: Reduced blink rates and abnormalities in saccadic eye movements can be early markers.

Fatigue and Drowsiness: Pupil size reduction, increased blink duration, and slower saccades are used for real-time monitoring of fatigue.

C. Physiological and Behavioral Indicators

Cognitive Load: Pupillary dilation (increase in pupil diameter) is a direct measure of cognitive effort and mental workload.

Situational Awareness: Analysis of gaze fixation helps determine how a person perceives their environment.

3.3 Direct Eye and Vision Health Indicators

Refractive Errors: Measurement of refractive error (myopia, hyperopia, astigmatism).

Glaucoma: Thinning of the retinal nerve fiber layer (measured by OCT) and functional vision loss.

Dry Eye Syndrome: Blink rate, stability of the tear film, and lid, position can indicate severe dryness, sometimes linked to autoimmune diseases like rheumatoid arthritis.

Nutritional Status: Severe nutritional deficiencies can manifest in retinal diseases.

3.4 Systemic Conditions Detectable through the Eye Examination include

A. Autoimmune / Inflammatory diseases

B. Infectious Diseases

C. Hematologic Diseases

D. Nutritional Deficiency

E. Thyroid Disorder

Recent advances show that the eye is emerging as a non-invasive biomarker platform.

4 Oculome and Oculomics

Eye is the only place in the human body that allows direct and unobstructed visualization of both neural tissue and vasculature. Visual access to the retina and its complex circulatory system provides unparalleled opportunity to assess the integrity of the structure and to detect and quantify an array of proteins and molecules circulating in the blood. The spectrum of changes in the eye, ranging from microscopic alterations to visible clinical signs, constitutes what is known as the “**Oculome**”.

Oculome is central to the concept of identification of ocular biomarkers. These are objective parameters can help forecast, evaluate, or diagnose diseases and guide treatment decisions. The study of these biomarkers, along with other eye-related changes and their connection to systemic health, falls under the emerging field of “**Oculomics**”. This discipline exploits data from eye exams, imaging, and diagnostic tests to identify and monitor systemic diseases, assess disease risk, and evaluate treatment responses.

4.1 Impact of Oculomics

Oculomics leverages the eye’s unique diagnostic potential to extend routine eye exams beyond vision care into powerful tools for systemic health assessment. By enabling opportunistic detection, eye exams can reveal early signs of underlying diseases, supporting timely intervention and contributing to public health prevention strategies.

The widespread accessibility of eye care clinics, including in community and rural settings, enhances the reach of early detection across diverse populations. Oculomics also offers cost-effective diagnostics, providing affordable alternatives to expensive imaging modalities such as MRI and CT, while reducing long-term healthcare costs through earlier intervention.

Central to oculomics is interdisciplinary collaboration, where ocular findings prompt referrals and coordinated care across medical specialties, improving patient outcomes. Among emerging technologies, spectroscopy stands out as a leading approach for detecting ocular and systemic biomarkers.

Looking ahead, advances in imaging, AI, and ocular biomarker research position oculomics as a key weapon against major chronic diseases—including cardiovascular, neurodegenerative, metabolic conditions, and cancer. With continued innovation, including noninvasive spectroscopic platforms, the eye is poised to become a critical gateway for early detection, personalized care, and improved health outcomes.

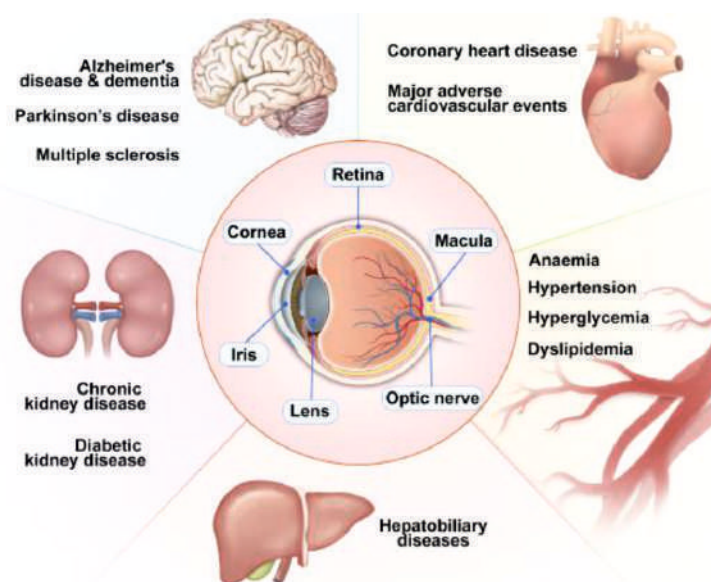


Fig.1 Schematic figure illustrating the eye as a window to systemic health
(from reference [1])

As an emerging field, oculomics offers a non-invasive, simple and rapid approach for the early screening, grading, monitoring, and risk stratifying a range of diseases. Oculomics can help address health disparities and optimize resource allocation. The accessibility of eye care facilities and AI-based

oculomics software could simplify disease detection and potentially timely intervention can reduce disease burden minimizing healthcare costs.

5 AI and Oculomics

The integration of artificial intelligence (AI) into oculomics has significantly advanced the field, enabling more accurate, efficient, and scalable analysis of ocular biomarkers for systemic disease detection and prediction. Below is an analysis of AI's impact in oculomics:

A. Enhanced Diagnostic Accuracy

- (i) **Improved Disease Detection:** AI models, particularly deep learning (DL) algorithms, have demonstrated high accuracy in detecting systemic diseases such as cardiovascular disease (CVD), diabetes, chronic kidney disease (CKD), and neurodegenerative disorders like Alzheimer's disease (AD). For example: AI models can predict coronary artery calcium (CAC) scores and myocardial infarction risk from retinal images with accuracy comparable to traditional clinical tests. AI-based retinal imaging has shown promise in detecting early signs of dementia, Parkinson's disease, and multiple sclerosis.
- (ii) **Non-Invasive Biomarker Prediction:** AI enables the prediction of systemic biomarkers (e.g., blood pressure, cholesterol, hemoglobin levels) from retinal images, offering a non-invasive alternative to traditional tests.

Some details are presented here.

A study developed an AI model to predict cardiovascular magnetic resonance (MR) metrics, such as left ventricular end-diastolic volume and left ventricular mass, using prognostic biomarkers and demographic data (Diaz-Pinto et al., 2022). The model was able to predict the risk of myocardial infarction with a high AUC of 0.8, indicating retinal imaging's potential as a more accessible alternative to magnetic resonance imaging (MRI).

Based on hypertension-related changes in retinal vessels, such as narrowing arterioles and arteriovenous nicking, AI models have demonstrated varying performance in the prediction of blood pressure. For the prediction of systolic blood pressure (SBP) and diastolic blood pressure (DBP), model performances were found acceptable but varying across subgroup populations.

Oculomics has shown potential in predicting various hematological indicators such as anemia classification, hemoglobin levels, red and white blood cell (WBC) counts, platelet count, and hematocrit. There are also efforts to predict high cholesterol levels using retinal or iris images, which could serve as indicators of heart diseases and stroke risk. This approach holds promise for non-invasive lipid testing.

Retinal imaging holds potential as an inexpensive, radiation-free screening tool for discriminating CAC status in patients at risk of CVD. A DL system was developed for predicting CAC (Coronary artery calcium), utilizing a large dataset comprised of 216,152 subjects from South Korea, Singapore, and the UK. This DL system outperformed all alternative single clinical parameter models demonstrating comparable performance to CT scan-measured CAC in CVD risk stratification.

The retina has some similarities with the brain in vascular anatomy, blood barriers, neuroanatomy and pathophysiology. These similarities enable ocular images to serve as a promising proxy for certain brain functions and for the identification of several neurological conditions. For instance, early detection of age-related white matter changes (e.g., white matter hyperintensity [WMH]) via retinal images. Retinal images could be useful for population screening, allowing for early intervention for cognitive decline (Zee et al. It was reported that DL models primarily focused on the macula and retinal vasculature to detect WMH, indicating these regions may be critical for predicting white matter changes.

B. Enhanced Efficiency

AI has replaced manual and semi-automated methods for analyzing retinal images, significantly reducing the time and expertise required for diagnosis. Also, AI-powered tools can process large datasets, making ophthalmology accessible to diverse populations and healthcare settings, including resource-limited areas.

C. Integration of Multimodal Data

AI facilitates the integration of multimodal data, such as retinal imaging, clinical metadata, and omics data (genomics, proteomics, metabolomics), providing a comprehensive understanding of systemic health. Foundation models like RETFound and large language models (LLMs) are being developed to analyze multimodal data, enabling generalizable disease detection and personalized medicine. RETFound, a foundation model pretrained on 1.6 million retinal images. Unlike traditional supervised learning approaches that rely on extensive labeled data, RETFound achieved performance comparable to fully supervised models when fine-tuned with minimal labeled data. This capability has been demonstrated in predicting systemic conditions such as heart failure.

D. Cost-Effectiveness

AI-driven ophthalmology reduces reliance on expensive and invasive diagnostic tests, such as CT scans and blood tests, by providing non-invasive alternatives. Portable and smartphone-based imaging devices powered by AI can lower costs and improve accessibility, especially in underserved areas.

E. Challenges

Data Bias: AI models may underperform when applied to populations different from the training datasets, highlighting the need for diverse and representative data.

Explainability: The “black-box” nature of AI models can hinder trust and adoption among clinicians and patients. Explainable AI (XAI) techniques will be useful for addressing this issue.

Regulatory and Ethical Concerns: AI algorithms require robust validation, regulatory approval, and ethical frameworks to ensure safety, privacy, and accountability in clinical practice.

F. Future Directions

Advanced AI Models: Reasoning-based models and LLMs are being explored to improve transparency, interpretability, and clinical adoption.

Real-World Validation: Prospective studies and pragmatic trials are needed to validate AI models in diverse clinical settings and populations.

Integration with Healthcare Systems: AI-powered ophthalmology tools can be integrated into electronic medical records (EMRs) and clinical workflows to enhance decision-making, disease monitoring, and personalized care.

AI has revolutionized ophthalmology by enabling non-invasive, accurate, and scalable analysis of ocular biomarkers for systemic health. While challenges remain, such as data bias, explainability, and regulatory hurdles, the future of AI in ophthalmology is promising, with potential to transform healthcare through early disease detection, personalized medicine, and improved health outcomes.

6. Conclusions

The eye is a biological dashboard that reflects the state of the heart, brain, kidneys, immune system, and beyond. Systemic diseases often leave visible signatures in ocular tissues. Integrating eye screening into general health programs allows detection of conditions like diabetes or hypertension earlier and more affordably. With AI and imaging, the “eye as a mirror of health” is becoming a reality in predictive medicine.

Ophthalmology is being recognised by clinicians as a valuable tool for decision support, disease monitoring, and optimizing clinical workflows, particularly in the management of systemic diseases, by leveraging non-invasive ocular imaging.

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Artificial Intelligence in Healthcare : an Outlook

Professor Soumyo Mukherji



Prof. Soumyo Mukherji did his B.Tech. in Instrumentation Engineering, Indian Institute of Technology (Kharagpur), MS in Mechanical Engineering, Colorado State University (Fort Collins, USA) and Ph.D. in Biomedical Engineering, University of North Carolina (Chapel Hill, USA). After his PhD he joined IIT Bombay in 1997, where he moved through the ranks to occupy an Institute Chair position and then the Madhuri Sinha Chair Professor of Biomedical Engineering in the Department of Biosciences and Bioengineering. He proceeded on lien as the Director of the BITS Pilani Hyderabad Campus (2024-2025). He was the Head of the Centre for Research in Nanotechnology and Sciences at IIT Bombay from 2010-2013 and the Dean of Student Affairs of IIT Bombay from 2015-2019. He is a Fellow of the Indian National Academy of Engineers (INAE) and National Academy of Sciences India (NASI).

His research interests are in sensors and instruments for widescale deployment in resource constrained locales for medical and environmental applications, mobile health, security etc.

He has guided / is guiding more than 30 doctoral students and 60 Masters students and has more than 200 journal and conference publications to his credit.

For decades in the past, since, human beings started space explorations, when confronted with a problem of medium difficulty level, the saying use to be, “You don’t have to be a rocket scientist or a neurosurgeon to solve this problem.” It was indeed a matter of great precision for scientists to aim rockets and precise points in space. It was probably a more difficult problem for a surgeon to operate on a part of the brain, or excise a pathologically affected part of it, without affecting the functionality of adjacent parts which might be millimetres or even hundreds of microns apart. Initially it was also assumed that, when a sensory organ loses function, the part of the brain associated with that, generally becomes morbid and non-functioning as well. However, it was subsequently observed and shown that new neural connections form, which use this portion of the brain to increase the acuity of perception of other sensory organs (*the plastic brain*).

At the same time, while discovering the structure of DNA and delving into the information that is contained in these complex polymeric structures it was postulated that, the human genome consists of approximately 3.1 billion base pairs, which translates to about 875 megabytes of data. This is equivalent to around 106 volumes of the Encyclopaedia Britannica. Further, about one gram of DNA can potentially hold up to 455 exabytes of data. (For context, this amount of data is equivalent to all the information currently stored globally, showcasing DNA’s remarkable efficiency in data storage).

As we all may know, DNA does not function independently. Rather, DNA is a blueprint for various proteins which are the primary functional units of the body. These proteins can interact between each other in a complementary, supplementary or antagonistic sense. Thus, to really understand the human body functionality and pathophysiology, one needs to delve deep into other “omics” areas (like

proteomics, metabolomics, etc.). All this is complicated by the body interacting with external agents (like bacteria, viruses, chemicals, etc).

For aeons of human existence, without knowing these specific details, medical practitioners (Ayurveds, Shamans, Healers and the likes) studied the human pathology in a phenomenological way and frequently found solutions to cure them (and frequently did not). The knowledge was carefully curated and passed down either through family generations or via the guru-shishya Parampara. It embodied thousands of years of observational and empirical studies. It is only recently that the western methods of question driven or hypothesis driven research have made their way into the study of medicine and healing. However, for this as well, most of the inspirations have been taken from the knowledge of yore, proving or disproving their efficacy, or using modern day synthetic chemistry, tweaking molecules to enhance potency / modify functionality. So in one view, this can be called “empirical” as well, as opposed to “rational” as western practitioners would like us to accept.

All of these go to illustrate that not only the brain is a tremendously complex organ / system, and we have not even scratched the surface as regards it’s functioning. It can be further surmised that the cells of the body are storehouses of tremendous amounts of information, the outcome of which interacts in ways which are yet to be fully understood from the rationalist point of view.

In the present era, over the last two decades, “*Artificial Intelligence (AI)*” has captured popular imagination. It is being seen as the panacea to all complex problems, including that of human health. The submission in this lecture is the thesis that AI is neither artificial nor intelligence. It is definitely true that, given a large set of data, which human beings have difficulty in comprehending or making sense of, AI can quickly parse through the data and probably find trends and commonalities, at a speed which far exceeds that of human beings, without fear of drudgery and exhaustion.

But just like a child, who is being taught various concepts, AI also needs to be trained to ask the right questions and make proper inferences, which are contextual. In that sense, intelligence, which we would normally define to be the ability to flexibly adopt based on past experiences, and create new contextual solutions, still eludes the world of machines. In the narrow world of LLM-s, probably, given a range of areas to discuss, the present tools do, to a large extent, fulfil the requirements as laid out by Alan Turing. In addition, a software can be trained to not only write snippets of new / adapted code, but also find solutions in a limited domain (*the massive lay-offs of software developers, who were so high in demand a decade back, is testimony to that*).

In the healthcare domain: blood parameters, images, clinical symptoms, verbal and very importantly non-verbal cues, give rise to a probabilistic diagnostics and treatment methodology to a health care practitioner. However, very experienced health care service providers also frequently rely on specialists in other domains, whose lifelong experience may help the patient. Unless all these specialities are codified, according to standardized norms and observations arising from diagnostic modalities, it will be indeed difficult to treat human disease from a systemic point of view, as opposed to reduction of a particular clinical symptom. A case in point today is sudden cardiac death. Anecdotally many more younger people are succumbing to it today than earlier. A specific cause has not yet been established. Whether it is a sedentary lifestyle and work pattern, mental stress, environmental pollution, unhealthy food habits, endocrine disruptor chemicals in normal food, *etc.* or a weighted sum of all of these and beyond, complicated by heredity and genetic factors, is still a matter being actively discussed. In the face of it, given the exact parameters fully, AI can give probabilistic estimates, but not a full diagnostic, treatment and prognostic parameters. *In short, AI might help us parse a large amount of*

data, but the inferences are still a matter of training, and only as human service providers develop inferences, AI can be taught to draw the same, without significant amount of synthesis.

No discussion regarding AI can be complete without, at least a cursory, look at the power and water consumption required. The following points may be noted (*some data might not exactly match up, but the general trend needs to be observed*):

- Globally, data centers consumed approximately 460 TWh in 2022, representing about 2% of total worldwide electricity consumption. According to the International Energy Agency, data centers are projected to consume between 650-1,050 TWh by 2026, with these facilities accounting for roughly 1.5% of global electricity consumption in 2024.
- In 2023, U.S. data centers consumed approximately 176 terawatt-hours (TWh) of electricity, equivalent to powering about 16 million homes for a year.
- According to Goldman Sachs, global power demand from data centers is expected to increase by 50% by 2027 and could surge by 165% by 2030 compared to 2023 levels.
- AI workloads currently account for about 14% of total data center power usage, but this is projected to rise to 27% by 2027, with overall power demand reaching 84 gigawatts (GW).
- AI-powered virtual assistants such as ChatGPT use more energy than traditional search engines. According to the International Energy Agency (IEA), a single ChatGPT request requires ten times more electricity than a Google search. The average ChatGPT query costs approximately 0.36 cents (USD).
- The requirement of electrical power has gone up significantly.
- Today, data centers account for 1% to 2% of overall global energy demand, (similar to airline industry). That figure is likely explode hitting ~21% by 2030.
- Carbon Heavy ... a Million tokens (\$1 compute time, i.e. Car driven 10 miles).
- A GenAI driven image creation is equivalent to fully charging a smartphone.
- The total water (cooling) consumption of AI data centres have crossed the amount of Bottled water consumption in the world.

The human brain is a tremendously energy efficient data parsing and inference generating centre. In comparison, the power and water requirements of in-silico tools are extremely high. Even with the use of Agentic AI or Edge AI, the world might face an energy crisis, which will thwart the progress of AI in medical practice.

Use of Artificial Intelligence to Detect Cardiac Status by Interpreting Stethoscope Sound

Professor Goutam Saha, PhD

*Professor, Department of Electronics & Electrical Communication Engineering
Professor-in-Charge, Audio & Biosignal Processing Laboratory
Indian Institute of Technology Kharagpur*



Prof. Goutam Saha, BTech., PhD from IIT, Kharagpur had a short Management Training at XLRI, Jamshedpur. During 1990-1994, he worked with Tata Steel. He joined the faculty of Electronics and Electrical Communication Engineering at IIT Kharagpur in 2002. In 2006, he served the University of Southern California, USA as a 'Visiting Professor' for one semester. His research interest includes investigation into healthcare technology developments and audio based applications. His work on heart sound analysis was declared a winner in DST-Lockheed Martin India Innovation Growth Program while his work on lung sound analysis became an editorial article in the leading journal 'Respirology'. Besides journal & conference publications, he has been granted several patents and copyrights technology developments. He is co-author of two popular engineering text books published by McGraw-Hill, India. He has served many administrative positions at IIT Kharagpur and coordinated national level initiatives. Currently, he is serving as the Professor-in-Charge of Audio and Biosignal Processing Laboratory at the Department of Electronics & ECE, IIT Kharagpur.

I. Introduction:

According to the World Health Organization, cardiovascular disease (CVD) is the foremost cause of morbidity and mortality. An estimated 17.9 million deaths per year, representing 31% of global deaths, is attributed to CVD. Among these, more than 75% cases are reported from low and middle-income countries [1]. The underserved communities suffer more due to poor healthcare infrastructure, high cost of diagnostic tests, and a shortage of trained physicians and health workers.

Cardiac auscultation, a method to understand heart health by listening to its sound using stethoscope, is a non-invasive, low-cost, easy-to-use tool for cardiac disease screening. However, its use is dependent on the experience and skills of the practitioner and that varies with time. Further, the range of sound a human can comprehend in terms of frequency and intensity, is limited. In this regard, computer-aided disease detection systems can provide objective appreciation of underlying disease by artificial intelligence(AI) aided analysis of the heart sound signal or phonocardiogram (PCG). Over the years, this field has advanced from handcrafted feature-based approaches to end-to-end deep learning(DL)-based classification approaches.

In this technical note, we present a few studies conducted in the Audio and Biosignal Processing Laboratory of Indian Institute of Technology Kharagpur where AI based approach has been used for disease detection from digitally acquired stethoscope sound.

II. Methodology: General architecture

The general framework of classification/prediction paradigm of underlying diseases using different kinds of biomedical signals studied in our laboratory is represented in a block diagram as given below which is followed by explanation.

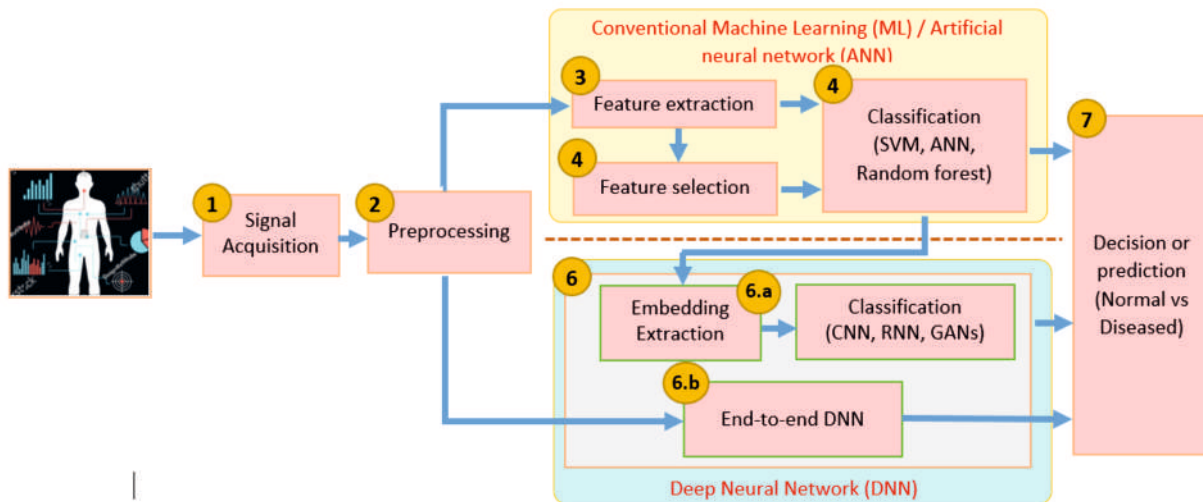


Fig.1: General framework for AI aided classification of biomedical signals

- 1. Signal Acquisition:** It captures raw biomedical signals non-invasively from the human body such as, Phonocardiogram (PCG), Lung sounds (LS), Electro-encephalogram (ECG), etc. These signals at this stage are low in amplitude and contaminated by noise. In the hardware of the data acquisition system (DAS) contains signal conditioning circuit which amplify the signal and filter out the unwanted noise in analog domain and followed by analog-to-digital (ADC) conversion. The signal is then stored in digital form in various file formats like .wav, .flac, .csv, .hsa, etc.
- 2. Preprocessing:** In preprocessing we improve the signal quality before analysis by applying digital filters to remove power-line interference, motion artifacts, baseline wandering, etc. We perform signal normalization and segmentation/windowing as well. The output in this stage is clean and standardized signals.
- 3. Feature extraction:** In conventional machine learning (ML) and shallow neural network like artificial neural network (ANN) we extract meaning features from the signals which are domain-knowledge-driven. Features such as time, frequency, time-frequency domain and non-linear features are extracted.
- 4. Feature selection:** Out of all the features we select informative features to reduce dimensionality, improve classification accuracy, and to avoid over fitting. The techniques such as principle component analysis (PCA), linear discriminant analysis (LDA), etc. are some of the popular feature selection techniques we use.
- 5. Classification (ML/ANN):** Conventional ML and ANNs are most desired classification methodology applied till today for explainable models. Methods such as SVM, KNN, ANN, Random forest, logistic regression, etc. are some the preferred algorithms in this area of research. These methods are generally driven by hand-crafted features and produce output as class probabilities or labels.
- 6. Deep learning (DNN):** Deep learning is the presently most sought-after classification/prediction learning method. It contains more than two hidden layers of neural network so that it will capture all

the intricacies of the data behaviour which is to be modelled to classify the classes which we want to. Lot of architectures are proposed over the time in recent decades for different applications such as, convolutional neural networks (CNN), recurrent neural networks (RNNs), transformers, autoencoders, generative adversarial networks (GANs), etc. These models excel at automatic feature learning from complex non-linear data and are widely used in tasks such as computer vision, natural language processing, and pattern recognition in biomedical AI.

- a. **Embedding extraction:** Embedding are fixed length automatically learned features that replace hand-crafted features. These features are extracted both from shallow ANNs and DNNs from the output of the last hidden layer. These are then fed to DNNs for classification.
- b. **End-to-end DNN:** In end-to-end neural networks, feature learning and classification are jointly optimized, enabling the model to directly map raw or preprocessed signals to diagnostic outputs without explicit feature engineering. This approach enhances modeling capability for complex and nonlinear biomedical data while reducing reliance on domain-specific handcrafted features.

7. **Decision / Prediction:** The output of this block is a decision whether the test sample is belongs to normal class or diseased class and based on score how much severity also we can predict which is useful for clinical decision support, monitoring systems, and research analysis.

III. Case Studies with Results

The Audio and Biosignal Processing Laboratory, IIT Kharagpur focuses on advancing biomedical signal analysis and audio / speech processing aided by artificial intelligence based decision making. Key research includes heart and lung sound diagnostics, EEG-based cognitive studies, voice-based biometrics etc. with development of patented, AI-driven diagnostic tools. In this section, we present studies in two domain done on application of AI to interpret stethoscope sound.

A. Valvular Disease Detection

Heart is pump that sends oxygenated blood to whole body and deoxygenated blood to lungs. It also received deoxygenated blood from whole body and oxygenated blood from lungs. Four chambers of the heart participate in the process where two pairs of valves open and close in unison for proper flow of valve. During this process, they generate lub-dub sound which appears as 1st and 2nd heart sound in PCG signal. Fig. 2 shows heart chambers and valves.

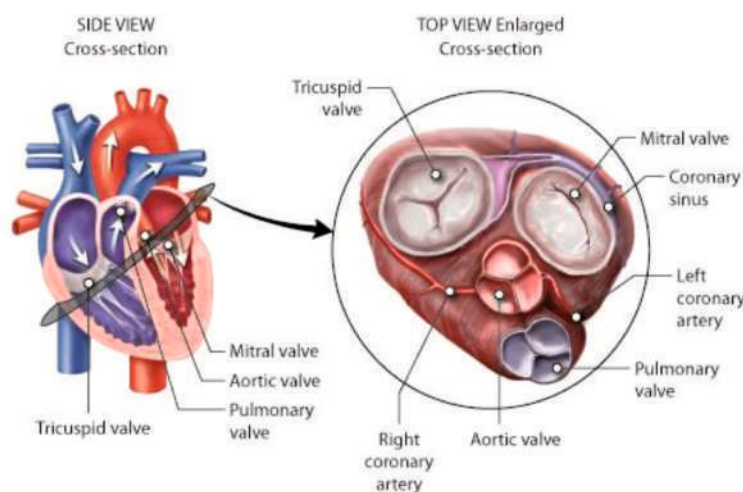


Fig.2: Valves of the heart from anterior and cross-section [2]

In an abnormal PCG, besides first (S1) and second (S2) heart sounds, there are other sounds like murmur in the intermediate spaces called systole and diastole, which may correspond to different pathological conditions as per location, shape, duration and other associated features. Fig. 3 gives an illustration such abnormal heart sounds with ECG signal as reference.

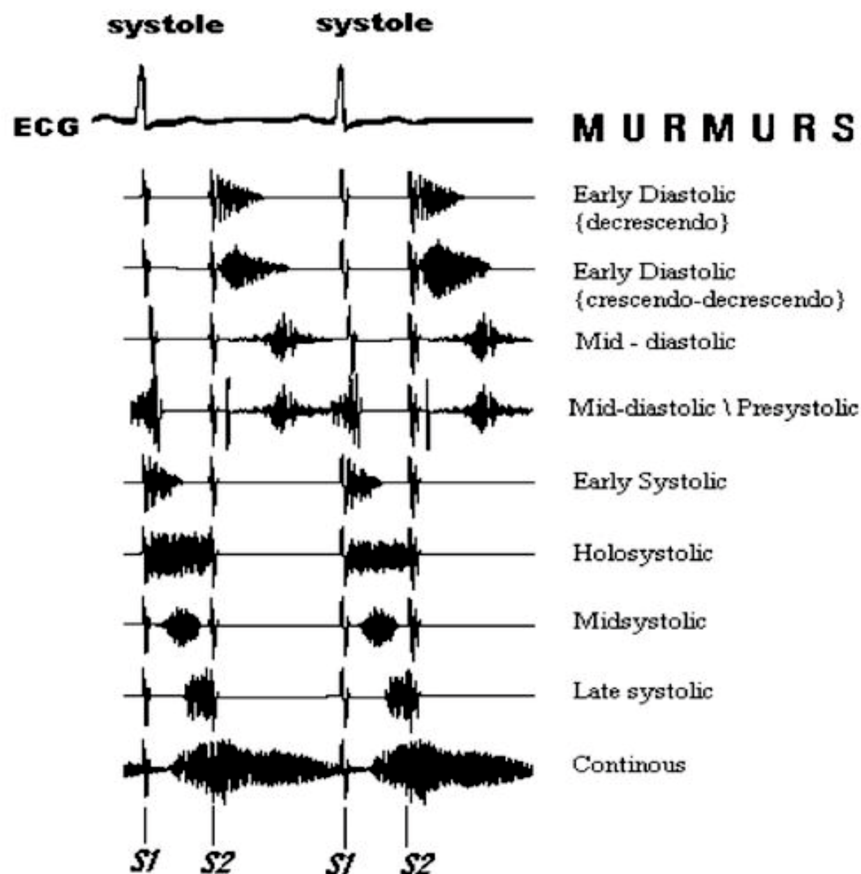


Fig.3: Various types of heart sound murmur [3]

In [3], S Ari, et al. proposed an algorithm for automatic identification of the timings of systolic (S1) and diastolic (S2) heart sounds from PCG signals without relying on auxiliary signals such as ECG to segment the heart sound signal in different phases. This approach reduces data acquisition hardware and simplifies the process. The researchers achieved an overall segmentation accuracy stands at 95.5 – 97.5 % for correctly identifying S1 and S2 boundaries. They proposed another algorithmic method in [4] based on to automatically detect heart valve disorder at two noise scenarios. The algorithm achieved an accuracy of 96.7% for 15dB signal-to-noise (SNR) and 93.33% accuracy at 5 dB SNR. Empirical mode decomposition (EMD) used to derive intrinsic mode functions (IMFs), from which statistical and spectral features were computed and fed into Artificial Neural Network(ANN), Support Vector Machine(SVM), and k-nearest neighbourhood (k-NN) to classify PCG signals between normal and abnormal signals. This work reported best accuracy of 96.2% using ANN model [5]. Furthermore, in [6] they introduces an optimized ANN framework for classifying abnormal heart sounds by combining singular value decomposition (SVD) and QR factorization with column pivoting (QRcp) to reduce input features and prune unnecessary hidden nodes, thereby addressing overparameterization and improving efficiency. Finally [7] the same group comes with another process using linear minimum mean square error (LMS) based least squares SVM (LS-SVM) classifier for PCG classification between normal and valvular diseases with improved model convergence and robustness against noise making it suitable for automatic HS analysis and computer-aided diagnosis.

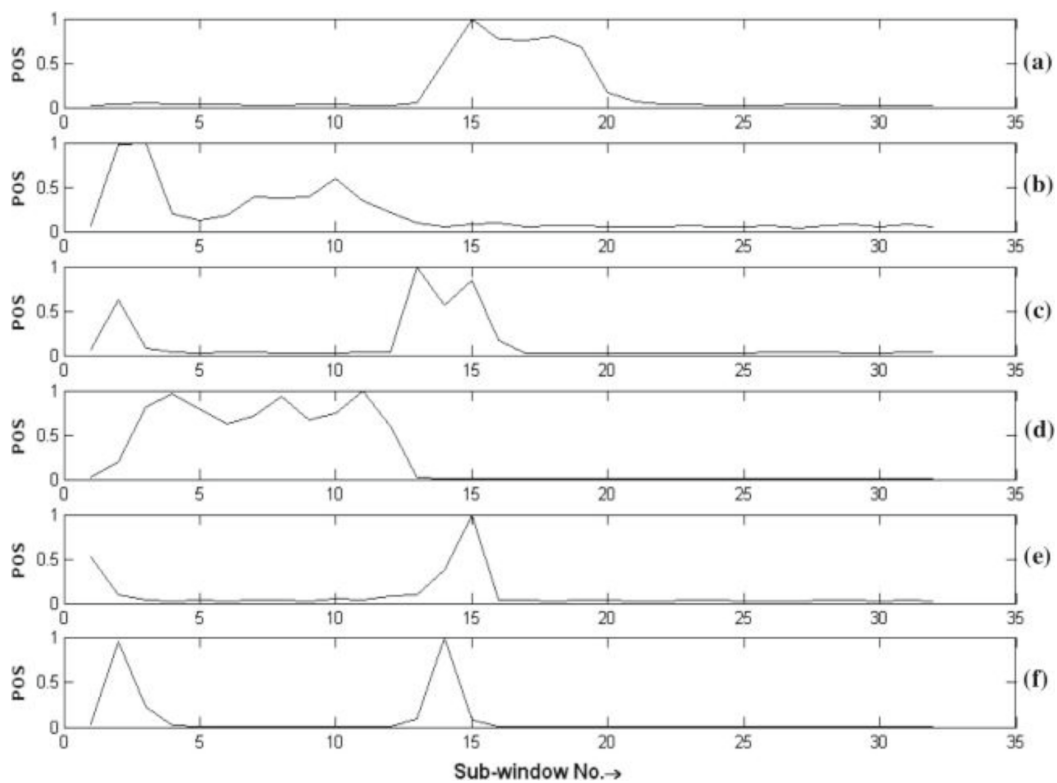


Fig. 4. Wavelet based feature vector for: (a) aortic insufficiency, (b) aortic stenosis, (c) atrial septal defect, (d) mitral regurgitation, (e) mitral stenosis, and (f) normal heart sound signal. [7]

This work achieved more than 90% accuracy for classifying normal and 5 commonly occurring valvular disorders on 64 recordings. Typical feature vector used in the study is illustrated in Fig. 7.

In a more recent work, Maity A, et al. [8] proposes a transfer-learning-based framework for classifying heart valve diseases using PCG signals. Such framework is useful to use deep learning models for low volume of data. By leveraging pre-trained deep learning models and adapting them to PCG classification through fine-tuning, the team extracted rich high-level features that improved classification performance over traditional feature engineering approaches. Evaluated on relatively noisy, multiple source database PhysioNet/CinC 2016 Challenge dataset of normal and multiple pathological heart sounds, the transfer-learned model achieved overall classification accuracy exceeding 92% while accuracy went past 99% for cleaner Yaseen GitHub database.

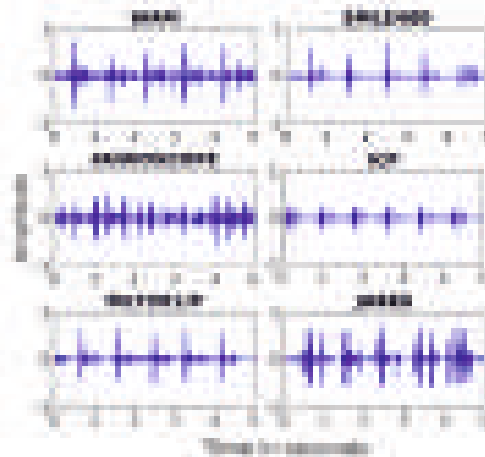


Fig. 5: Fig. Normal PCG signals collected using a different stethoscope [9]

Collection of heart sound from different stethoscopes poses challenge if the AI model is tested on heart sound from a source on which it is not trained. Fig. 5 illustrates how normal PCG signal looks like when collected from stethoscopes of different makes. In their next work[9], Maity et al. proposed a framework that combines domain-invariant preprocessing with transfer learning to improve the robustness of PCG signal classification across different recording conditions, devices, and patient populations. By standardizing signal characteristics and adapting learned representations from one domain to another, the method significantly reduces performance degradation typically seen in cross-domain scenarios. Evaluated on multi-site PCG datasets, the proposed approach achieved cross-domain classification accuracies above 91–95%, with the best transfer-learned model reporting 95.3% accuracy when tested on an unseen domain.

B. Coronary Artery Disease Detection

Coronary arteries, depicted in Fig.6, supply blood to heart muscles that performs the pumping action. In coronary artery disease (CAD), the main blood vessels faces reduced blood flow due to formation of plaque making the arteries narrow. The gold standard for CAD diagnosis is expensive, invasive procedure. This is beyond reach of many and is typically recommend when patients experiencing symptoms. There is a need of non-invasive, affordable screening device for CAD detection.

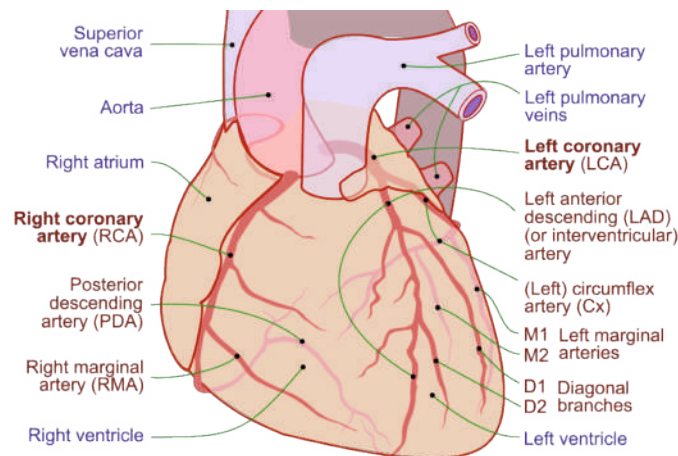


Fig. 6: Coronary arteries [10]

Samanta P, et al. in [11] proposed a multi-channel PCG-based classification system to distinguish coronary artery disease (CAD) patients from healthy subjects using features extracted from synchronized heart sound recordings taken from multiple auscultation points. The ANN based model achieved more than 80% accuracy for a study on 33 CAD and 33 normal subjects using leave one out for cross validation.



Fig. 7: CAD data acquisition using 4 stethoscopes [11]

Pathak A, et al. in their first study [12] used imaginary part of cross power spectral density (ICPSD) to capture the spectrum of HSs. Subband based spectral features obtained from ICPSD are classified in a machine learning framework. On 40 CAD and 40 normal subjects, using 5-fold cross validation, an accuracy of 75% was obtained. They also performed noise study which with above 65% accuracies for 3 different kind of noises at 0 dB SNR. Next in [13], they used synchrosqueezing transform (SST) to extract advanced time–frequency features from phonocardiogram (PCG) signals, enhancing the representation of subtle heart sound components associated with CAD. The extracted SST-based features were classified using machine learning models (e.g., SVM, Random Forest), achieving classification accuracies above 92–95% on test datasets. Specifically, the best performing model reached an overall accuracy of 95.2%, with sensitivity 94.8% and specificity 95.6%. They also showed in [14] that a hybrid machine learning framework combining transfer learning (pre-trained models on related tasks) with multiple kernel learning (MKL) can give more than 90% accuracy in CAD detection.

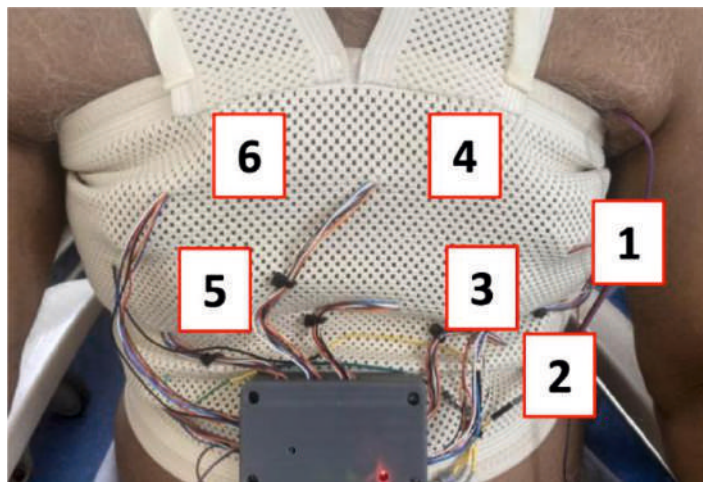


Fig. 8: CAD data acquisition by 6 channels from front and 1 channel from back [15]

Fynn M, et al. work [15] introduced a wearable vest based system equipped with an array of multi-channel PCG sensors designed for practical and accurate pre-screening of coronary artery disease in real-world environments. The proposed wearable system is convenient to use and demonstrated robust performance across varied ambient noise during recording process. Using extracted features from the multi-channel signals and machine learning classification, the system achieved more than 80% classification accuracies in distinguishing CAD subjects from healthy controls. These results suggest that the wearable vest provides a practical yet precise platform for non-invasive CAD pre-screening outside clinical environments.

IV. Conclusion

The studies presented in this report show that the digital data acquisition, advanced signal processing and machine learning algorithms can lead to a paradigm of AI aided stethoscope sound interpretation. Such an inexpensive, easy-to-use, non-invasive, point-of-care tool for screening can make healthcare affordable and available among the masses. In this report, the emphasis was on monitoring cardiac health through stethoscope sound. Our laboratory has used the single channel and multi-channel stethoscope system for acquisition and interpretation of lung sound towards lung disease detection. There are multiple granted patents on these works. Such AI framework has been used for appreciation of other biomedical signals too, depicting immense potential of AI in healthcare domain.

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AI in Medical Imaging and Diagnostics: The DRISTi Platform for Automated Detection of Diabetic Retinopathy

Mr. Subhadeep Pal, Mr. Piyusha Priyadarshi, Mr. Girish Somvanshi, Mr. Pradeep Walia

Affiliation: Artificial Learning Systems India Pvt. Ltd.,

1665/A, 14th Main Rd, Sector 7, HSR Layout, Bengaluru, Karnataka 560102



Mr. Subhadeep Pal is a Software Lead at Artificial Learning Systems India Pvt. Ltd. (Artelus), with extensive experience in architecting and delivering scalable software platforms across multiple domains. He has led cross-functional teams in the design, development, and deployment of complex technology solutions, including regulated healthcare systems such as DRISTi, an AI-enabled platform for Diabetic Retinopathy screening. His experience spans real-world implementations, system integration, and end-to-end project execution. His professional interests lie in building robust, maintainable, and scalable software systems, with a strong emphasis on practical deployment and long-term sustainability.



Mr. Piyusha Priyadarshi is an AI Engineer representing Artelus.ai, working on ophthalmic and multimodal healthcare AI systems focused on clinically reliable and explainable solutions. The work includes AI-driven retinal image analysis for early disease detection and structured grading, along with designing reasoning frameworks that support safe, context-aware patient engagement. Collaboration with clinical and engineering teams ensures alignment of AI systems with real-world healthcare standards. Previously, experience includes roles at Vudio.ai, Deccan AI (associated with Scale AI), and TELUS AI (supporting systems developed by Google), along with earlier experience in quantitative analytics and risk modeling.



Mr. Girish Somvanshi is a healthcare leader driven by a singular belief - that access to early diagnosis should not depend on geography, income, or infrastructure. With over 21 years of experience across pharmaceuticals, nutraceuticals, medical devices, and AI-led health innovation, he has dedicated his career to translating science and technology into scalable solutions that strengthen public health systems.

With deep expertise in P&L management, commercialization, policy engagement, and health systems strategy, Girish connects innovation with clinical realities and large-scale implementation. At Artelus, he has contributed in building and deploying AI-enabled retinal diagnostics and screening platforms in private practitioners as well as for detecting preventable blindness at the community level. His work ensures that advanced medical technologies reach the last mile, advancing responsible AI adoption and driving sustainable, system-level impact that improves lives - not just metrics.



Mr. Pradeep Walia is a visionary entrepreneur and one of the founders of Artelus (Artificial Learning Systems India Pvt. Ltd.), a technology company focused on using artificial intelligence to advance accessible healthcare diagnostics. Born in Calcutta, he later returned to Kolkata with a mission to help bring quality healthcare to the masses. With over two decades of experience in the IT industry and academic grounding from Carnegie Mellon University, he has steered Artelus toward creating AI-enabled screening and diagnostic solutions for conditions such as Diabetic Retinopathy and other retinal pathologies, prioritizing tools that can operate in varied, including resource-limited, healthcare settings. Under his leadership, Artelus has pursued innovations aimed at bringing early disease detection tools to underserved populations, reflecting a strong commitment to democratizing healthcare through cutting-edge AI and deep learning technologies.

Abstract

Diabetic Retinopathy (DR) is a leading cause of preventable vision impairment among adults with diabetes. Large-scale screening and early detection are critical to reducing disease progression; however, manual evaluation of retinal images is resource-intensive and constrained by the availability of trained specialists. Artificial Intelligence (AI)-enabled medical imaging systems have emerged as a practical solution to address these challenges. This paper presents **DRISTi**, an AI-enabled medical imaging platform developed by **Artelus** for automated detection and grading of Diabetic Retinopathy from retinal fundus images. DRISTi is designed as an end-to-end system integrating image acquisition, quality assessment, AI-based inference, and structured clinical reporting. The paper describes the clinical context, system methodology, and deployment considerations, demonstrating how AI-driven platforms can support scalable and consistent DR screening programs.

Keywords

Artificial Intelligence, Medical Imaging, Diabetic Retinopathy, Fundus Imaging, Automated Screening, Clinical Decision Support

1. Introduction

Medical imaging plays a central role in modern clinical diagnosis, enabling non-invasive visualization of internal anatomical structures. In recent years, Artificial Intelligence (AI) techniques, particularly deep learning-based image analysis, have shown significant promise in assisting clinicians by automating pattern recognition tasks across various imaging modalities, including radiology, pathology, and ophthalmology.

Ophthalmology is especially well suited for AI-assisted diagnostics due to the availability of standardized imaging techniques and well-defined disease grading criteria. Retinal fundus imaging involves capturing photographs of the interior surface of the eye, including the retina and blood vessels, and is routinely used for screening diabetic patients for Diabetic Retinopathy (DR).

DR is a progressive microvascular complication of diabetes and one of the leading causes of vision loss among working-age adults. The disease progresses through identifiable stages, and early detection followed by timely intervention can significantly reduce the risk of blindness. However, population-scale screening programs face challenges related to high image volumes, variability in image quality, and limited access to ophthalmology specialists.

AI-enabled screening systems can help address these challenges by acting as clinical decision support tools, automating initial image analysis and prioritizing cases for expert review. In this context, this paper presents **DRISTi**, a medical imaging platform developed by **Artelus** to support automated detection and grading of Diabetic Retinopathy in adult patients.

2. Problem Definition

The effective screening of Diabetic Retinopathy requires the evaluation of large numbers of retinal images with consistent accuracy and timeliness. In practical clinical settings, several challenges arise:

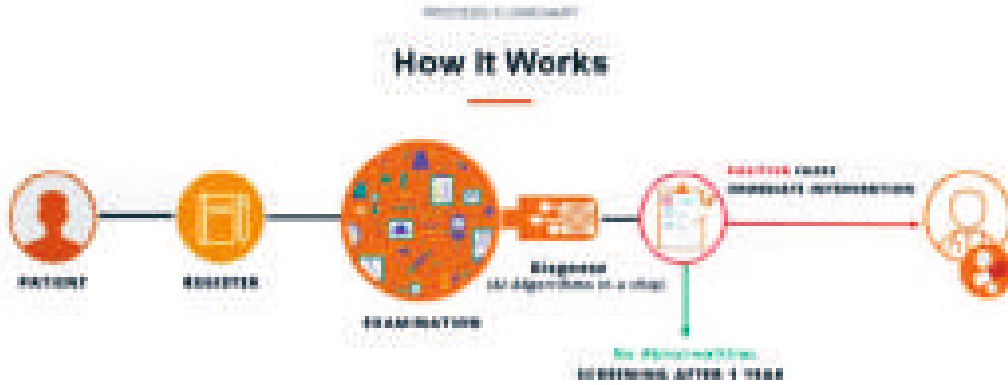
- High screening volumes that make manual image review time-consuming and costly
- Variability in image quality due to differences in camera hardware and operator expertise
- Uneven availability of trained ophthalmologists, particularly in primary and secondary care settings
- Need for standardized and interpretable reporting to support clinical workflows

These challenges motivate the need for an automated, scalable, and reliable imaging-based screening approach. From a system perspective, the problem can be formulated as the automated assessment of retinal fundus images to determine image gradability and classify disease severity, while integrating seamlessly into existing clinical workflows.

3. Methodology and System Design

DRISTi is conceived as an end-to-end AI-enabled medical imaging platform rather than a standalone software application. The platform architecture emphasizes modularity, scalability, and controlled integration of AI-based analysis into clinical workflows.

3.1 Platform Overview



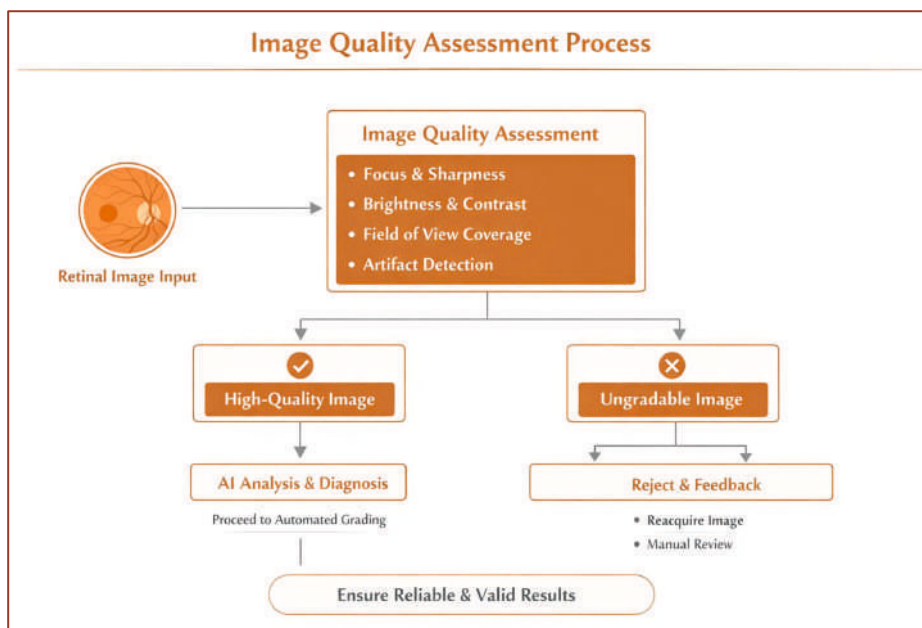
At a high level, the DRISTi platform comprises the following functional components:

- **Image Acquisition Interface:** Accepts retinal fundus images exported from compatible fundus cameras
- **Workflow and Application Layer:** Manages image ingestion, metadata handling, user interaction, and process orchestration
- **AI Inference Service:** Performs automated analysis and grading of Diabetic Retinopathy
- **Reporting Module:** Generates structured clinical reports for review and downstream use

The platform supports deployment in both centralized (cloud-based) and localized (edge-based) configurations, enabling operation across varied infrastructure environments.

3.2 Image Ingestion and Quality Assessment

DRISTi is designed to be camera-agnostic and supports commonly used image formats such as JPG and DICOM. Upon ingestion, images undergo automated checks to assess suitability for analysis, including validation of basic image properties and detection of poor-quality or ungradable images.



Images identified as suboptimal or ungradable are excluded from AI inference to prevent unreliable outputs. Such images are explicitly flagged by the system, and structured feedback is generated to indicate the reason for rejection. This enables corrective actions such as image reacquisition or referral for manual clinical review. By enforcing quality-aware gating, the platform ensures that downstream AI outputs are derived only from diagnostically valid inputs, supporting safety, robustness, and clinician trust in real-world screening workflows.

Images deemed unsuitable for automated analysis are flagged appropriately to ensure that unreliable results are not generated.

3.3 AI-Based Analysis and Grading

The core analytical capability of DRISTi is based on a deep learning–driven inference pipeline trained to detect features associated with Diabetic Retinopathy and assign clinically meaningful severity grades.

The AI-based analysis component supports clinical screening by identifying disease-relevant patterns in retinal images and assigning standardized grading outputs. Images that pass quality assessment are processed to detect visual indicators associated with diabetic retinopathy and related abnormalities. To support clinical interpretability, the system generates localization cues and heatmaps that highlight image regions contributing to the grading outcome, enabling clinicians to visually verify areas of interest during review.

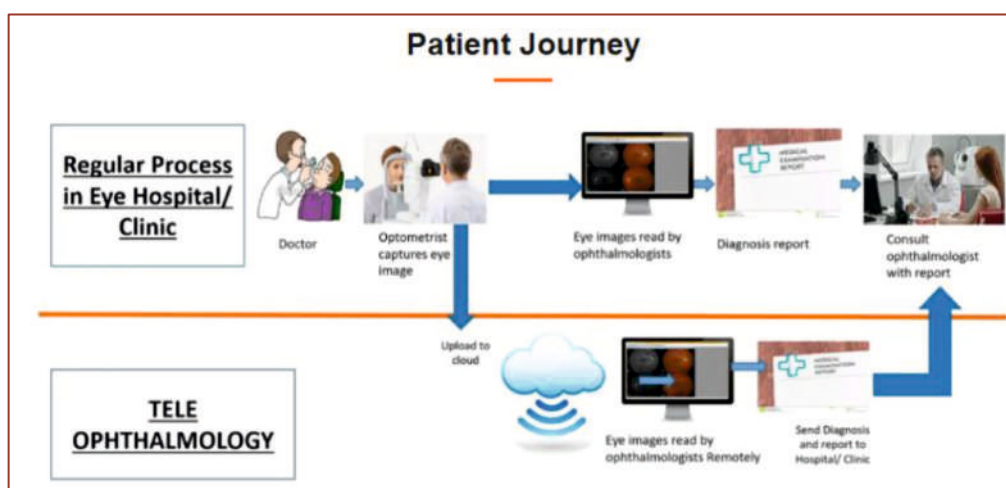
Grading follows clinically recognized diabetic retinopathy categories, ranging from DR0 (no retinopathy) to DR4 (advanced retinopathy). Images assessed as DR0 are classified as normal and scheduled for routine follow-up, while higher grades are progressively prioritized based on severity. Cases flagged with advanced grades are marked for timely clinical attention and referral.

This combination of grading, localization, and visual explanation allows the system to function as an assistive screening and clinical decision-support tool, improving consistency and scalability while maintaining transparency and clinician oversight.

The AI component is implemented as a dedicated service, enabling controlled interaction with the application layer and supporting independent updates and validation. DRISTi is intended to function as a clinical decision support system, with AI-generated outputs designed to assist, rather than replace, clinician judgment.

3.4 Workflow Automation and Reporting

The DRISTi platform automates the screening workflow from image ingestion to report generation. For each analyzed image set, the system produces a structured report summarizing findings, image quality status, and screening outcomes.



This automated workflow helps reduce manual effort while maintaining consistency and traceability of results.

Note: The platform is developed following established software quality and data protection practices applicable to AI-enabled medical systems.

4. System Validation and Observations

The DRISTi platform has been evaluated through structured validation activities focusing on system robustness, processing consistency, and operational suitability.

Validation activities focused on assessing system robustness, operational consistency, and suitability for deployment in screening workflows. The platform demonstrated stable processing behaviour across defined operating conditions and consistent handling of images with variable quality. Automated identification of ungradable images reduced the likelihood of unreliable outputs and supported appropriate follow-up actions. The structured reporting mechanism enabled uniform presentation of screening results, contributing to repeatability and traceability across deployments.



Observed outcomes include:

- Stable processing performance under defined operating conditions
- Consistent handling of variable image quality
- Uniform report structure across different deployment scenarios

Clinical performance metrics and detailed validation results are established as part of controlled evaluation processes.

5. Discussion

The DRISTi platform illustrates how AI-enabled medical imaging systems can support scalable screening programs for Diabetic Retinopathy. By adopting a platform-based design, DRISTi enables flexible deployment, integration with diverse imaging devices, and adaptability to evolving clinical needs.

From a broader perspective, the use of AI in ophthalmic screening highlights the potential of such technologies to extend specialist expertise to settings where access is limited, while maintaining consistency and standardization. Ongoing validation and monitoring remain essential to ensure sustained performance in real-world use.

6. Conclusion

This paper presented **DRISTI**, an AI-enabled medical imaging platform developed by **Artelus** for the automated detection and grading of Diabetic Retinopathy in adults. By integrating image acquisition, AI-based analysis, and structured reporting within a unified system, DRISTI demonstrates the practical application of AI in medical imaging diagnostics. Such platforms have the potential to enhance early detection efforts, improve screening efficiency, and support clinicians in delivering timely and informed patient care.

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Artificial Intelligence in Digital Health and Medicine

Er. Gautam Kr. Das

(B-Tech, Mechanical Engineering), 44 years, Design & Engineering experience in TPP, NPP, Solar Plants, LNG-CNG Plants etc.

Er. Nehali Das

(B-Tech, Mechanical Engineering), 11 years, Design & Engineering experience in TPP, Steel Plants, Solar Plants, Refineries etc.



Er. Gautam Kr Das, Mechanical Engineering Graduate (B-Tech.) from IIT Kharagpur in the year 1982. Forty three years' Design & Detail Engineering experience in – Mechanical Static & Rotary Systems, Oil Exploration services, Piping Systems, Fire & Safety Systems etc. in the PROJECTS of SOLAR PLANTS, BIO-GAS PLANTS, LNG PLANTS, REFINERIES, OIL&GAS, NUCLEAR POWER PLANTS, THERMAL POWER PLANTS, STEEL PLANTS, OFFSHORE DRILLING & OFFSHORE PLATFORMS, ALUMINA PLANTS, PETROCHEMICALS, PLANT & NON-PLANT BUILDINGS, COLONIES, RESIDENTIAL BUILDINGS, ETC. Worked with EIL, BBUNL, FOSTER WHEELER (UK), DCPL, TCS.



Er. Nehali Das, Mechanical Engineering Graduate (B-Tech.) from Camellia Institute of Technology and Management (CITM) in the year 2015. Eleven years' Design & Detail Engineering experience in – Mechanical Static & Rotary Systems, Piping Systems, Fire & Safety Systems etc. in the PROJECTS of SOLAR PLANTS, THERMAL POWER PLANTS, STEEL PLANTS, etc. Worked for Pre-investment Studies, Feasibility Studies, Site Selection & Site Survey.

A comprehensive digital health strategy, strengthened by the effective use of artificial intelligence (AI), has the potential to improve treatment protocols, enhance patient satisfaction, increase productivity, and increase clinician satisfaction. The aim of this discussion paper is to investigate and introduce the role of artificial intelligence in the medical field and explore its applications, benefits, and limitations.

Artificial intelligence is a rapidly growing field of science, technology, and engineering that seeks to simulate human intelligence. AI systems aim to replicate cognitive capabilities such as understanding, learning, reasoning, logic, problem-solving, and decision-making, and to embed these capabilities into machines, software, and computer applications. AI has been widely implemented across scientific, engineering, and medical domains, where it has demonstrated significant potential to enhance efficiency and accuracy.

Applications of AI in Medicine

AI is used across multiple areas of the medical field, including accurate disease diagnosis, drug discovery, medical data analysis, patient care, healthcare system optimization, electronic health

records, clinical trials, and diagnostic imaging analysis. Since the advent of computers, there has been a continuous effort to augment or replace human expertise with computational systems. Central to these efforts is the simulation of human intelligence, now collectively referred to as artificial intelligence.

Human intelligence encompasses a wide range of abilities, including language comprehension, logical reasoning, learning from experience, memory, pattern recognition, problem-solving, planning, and communication. AI research aims to develop systems capable of thinking and acting in ways similar to humans. Over time, AI has evolved into several branches, enabling the development of intelligent software systems.

Artificial Neural Networks, Machine Learning, and Deep Learning

One of the most influential AI technologies is the Artificial Neural Network (ANN), which mimics the structure and function of the human brain. The human brain consists of billions of interconnected neurons that enable reasoning and decision-making. Similarly, ANNs are composed of interconnected artificial neurons organized into layers, trained through weight adjustments and activation functions.

The development of ANN architectures led to the emergence of machine learning (ML) and deep learning (DL). These technologies allow systems to recognize patterns in data and classify new data with increasing accuracy. Over the past five decades, AI applications in medicine have advanced rapidly, driven by improvements in algorithms, computing power, and data storage capacity. AI has become integral to disease diagnosis, personalized treatment, medical data analysis, and healthcare delivery. As a result, trust in AI technologies has increased among healthcare professionals, administrators, and patients.

AI-Based Medical Diagnosis

AI-based medical diagnosis involves identifying the underlying cause of a disease by applying AI algorithms to medical history, clinical assessments, patient-reported symptoms, laboratory results, and diagnostic imaging such as X-rays, CT scans, and MRI. The primary objective is to determine the most effective treatment plan. AI significantly improves diagnostic speed and accuracy by processing large and complex datasets.

In traditional diagnostic processes, clinicians collect extensive patient data, including family history, clinical observations, imaging studies, vital signs, and laboratory results. Decision-making relies heavily on human knowledge and experience, which can be prone to error. AI systems can analyze large datasets using ML and DL algorithms, reducing diagnostic errors and supporting early disease detection, particularly in chronic conditions. Integrating multiple data sources provides a comprehensive view of patient health, improving outcomes while reducing costs.

AI-based diagnostic systems are widely used in detecting diseases such as:

Cancerous diseases: lung, breast, brain, gastric, colon, and skin cancers

Non-cancerous diseases: cardiology, ophthalmology, dentistry, diabetes, psychiatric, and neurological conditions

AI in Robotic Surgery and Patient Care

Robotic surgery represents another major AI-driven advancement in healthcare. Surgeons use robotic systems to perform minimally invasive procedures through small incisions using cameras and robotic arms controlled via computer systems. These technologies enhance surgical precision and patient recovery. AI-powered robots are also used in patient care, particularly for individuals with disabilities who require assistance.

AI in Drug Discovery

Drug discovery is traditionally a lengthy, expensive, and complex process involving multiple stages: initial research, drug discovery, preclinical testing, clinical trials, and post-market review. AI offers a transformative approach by processing vast datasets related to genetics, proteins, molecular interactions, and clinical trials.

Pharmaceutical companies worldwide have invested heavily in AI-driven drug discovery systems to accelerate development, reduce costs, and improve success rates. Machine learning and deep learning models can analyze genomic and molecular data, simulate drug interactions, and reduce reliance on animal testing. These innovations enable faster and more effective drug development and foster collaboration across the pharmaceutical industry.

AI in Medical Records and Hospital Management Systems

Healthcare systems generate massive amounts of data, including patient demographics, medical histories, diagnoses, imaging, laboratory results, treatments, and outcomes. This data is managed through Hospital Management Systems (HMS), which support daily hospital operations across departments.

Managing these systems presents challenges related to data volume, security, privacy, and usability. Advances in computing power, storage, and communication have enabled the development of more robust, efficient, and cost-effective HMS. Integrating AI into these systems introduces intelligent functionalities that support clinicians, administrators, and patients.

AI-based medical record systems improve time management, service accessibility, patient monitoring, and cost control. Knowledge-based systems, incorporating rule-based reasoning and logical inference, can enhance decision-making in healthcare management. AI models such as fuzzy logic, neural networks, and genetic algorithms can be applied to predict disease patterns, assess community health risks, and analyze healthcare costs.

AI in Medical Imaging

Medical imaging has been a cornerstone of diagnosis since the introduction of X-rays in 1896. Imaging technologies have evolved to include CT, MRI, ultrasound, PET, and nuclear medicine. AI has introduced new possibilities in image analysis, enabling faster and more accurate detection of abnormalities.

Deep learning models can analyze large volumes of medical images, supporting tasks such as image segmentation, object detection, and tumor identification. AI algorithms have demonstrated high accuracy in detecting early signs of diseases such as breast, lung, and brain cancer. Additionally, AI-driven imaging analysis supports personalized treatment planning, improving treatment effectiveness and reducing side effects.

AI, Telemedicine, and Chatbots

AI integration has significantly enhanced telemedicine, particularly during the COVID-19 pandemic. AI algorithms approved by the FDA have demonstrated high sensitivity and specificity in diagnosing conditions such as stroke, intracranial hemorrhage, pulmonary embolism, breast cancer, tuberculosis, and ophthalmologic diseases, enabling earlier intervention.

AI-powered Chatbots have gained prominence in telemedicine for patient screening, triage, appointment scheduling, and health education. During the COVID-19 pandemic, Chatbots effectively classified patients based on symptoms, reducing strain on healthcare hotlines. Studies have shown high

accuracy rates, with some Chatbots achieving over 90% correct responses. While Chatbots such as ChatGPT show promise in providing medical information, limitations in consistency and depth highlight the necessity of clinician oversight.

Conclusion and Limitations

The convergence of AI and telemedicine represents a transformative force in healthcare. AI enhances diagnostic accuracy, supports remote monitoring, improves efficiency, and promotes patient-centered care. However, challenges related to accuracy, ethical considerations, and regulatory oversight require careful supervision by healthcare professionals.

Limitations of this study include the rapidly evolving nature of AI and telemedicine technologies, which may outpace the scope of current analysis. Ethical implications and variability across populations and healthcare settings warrant further research. Future studies should explore long-term outcomes of AI-driven interventions and their impact on healthcare delivery models.

AI Applications in Coal-Fired Power Plants: A Case Study

Dr. M R Shaiju
AGM NTPC Ltd

Dr. Neethu Sathyan M
Assistant Professor, CAPE

Er. Ram Sewak Jaiswal
DGM – NTPC Ltd



Dr. M R SHAIJU, AGM, HOD (Business Excellence), NTPC Vindhyachal (4660MW Coal power plant), NTPC Ltd, completed his B.Tech (Mechanical Engineering) from Calicut University, M.Tech (Thermal Engineering) Kerala University and Diploma in Management – IGNOU, PhD (Performance analysis and diagnosis of industrial gas turbine system using AI) NIT Calicut.

His Key research interests' Industrial application of AI, Gas turbine, BESS. His other relevant information you'd like to include Bureau of Energy Efficiency (BEE) Certified Energy Auditor, Director of Factories and Boiler Certified Boiler Operation Engineer (BOE), IPMA Level D certification.



Dr. Neethu Sathyan M, completed her Bachelor of Engineering in Computer Science and Engineering in May 2005 from Sri Subramanya College of Engineering and Technology Palani, Tamilnadu. PG Diploma in Embedded System Design August 2006 from CDAC Thriuvananthapuram, Kerala

M.Tech from College of Engineering Karunagappally Kollam, Kerala, in Computer Science and Engineering with specialization in Digital Image Processing, completed Doctor of Philosophy in Computer Science and Engineering. Presently working as an Assistant Professor of the Computer Science department concluded her research on industrial Thermal Image Processing using cutting-edge machine learning methods, namely deep learning models. Enthusiastic about working on a data science project to learn more about this emerging field.



Er. Ram sewak Jayswal has completed B-Tech in Electrical and electronics engineering in 2007 and joined NTPC. He has More than 18 years work experience in Thermal power plant Operation, Energy efficiency and Commercial related activities. He is currently posted at Vindhyachal super thermal power station.

Abstract

Artificial Intelligence (AI) is emerging as a transformative enabler for enhancing reliability, efficiency, and safety in coal-based power plants. This paper presents an integrated framework for AI adoption across administrative functions, operational systems, and advanced optimisation tasks, culminating in a detailed case study on AI-based operation and maintenance assessment of a boiler Induced Draft (ID) fan. The proposed methodology spans the application of large language models for workflow automation, AI-enabled video analytics for safety compliance, predictive analytics for maintenance planning, and machine learning driven process optimisation.

A dedicated AI model was developed for the ID fan using historical sensor data—including pressures, temperatures, power consumption, and operating hours—to predict total flue gas flow and assess performance degradation. The model generates dynamic characteristic curves under varying operating conditions and accurately reflects deterioration patterns due to fouling, blade erosion, leakage, and mechanical wear. Comparative evaluation of multiple algorithms demonstrates that XGBoost provides the highest predictive accuracy for deployment. The AI-generated characteristic curves further support predictive maintenance by forecasting future performance and identifying deviations that indicate potential faults. The results highlight AI's ability to enhance draft management, improve reliability, and enable informed maintenance planning. The study establishes a practical roadmap for integrating AI-based diagnostics and optimisation tools into conventional power plant operations, contributing to safer, smarter, and more efficient energy generation.

Keywords — Artificial Intelligence, Predictive Maintenance, ID Fan, Characteristic Curve, Coal-Fired Power Plant, XGBoost, Draft Control Calcutta

1. Introduction

Artificial Intelligence (AI) has become central to the modernization of coal-fired power plants, delivering measurable gains in efficiency, reliability, safety, and workforce productivity under tightening environmental and market constraints. Recent deployments show that AI can be embedded into control-room decision support, predictive maintenance programs, and enterprise functions to yield rapid, bankable outcomes [1–5]. AI models learn complex nonlinear relationships among process variables to continuously optimize heat rate and emissions while respecting operating limits. Field results reported at the Martin Lake Power Plant (USA) demonstrate neural-network-based heat-rate optimization with sustained efficiency improvement and substantial cost and CO₂ reductions, followed by fleet-scale replication [1]. Similar benefits have been documented at the Suratgarh Super Thermal Power Station (India), where explainable AI and large language models (LLMs) enhanced unit-level efficiency and balance-of-plant reliability with strong ROI [2].

Beyond efficiency optimization, machine learning (ML) applied to streaming sensor data improves availability by providing pre-warning of degradation and actionable diagnostics, as evidenced in U.S. Department of Energy/EPRI programs that enabled earlier detection of actionable events and proactive interventions [3]. Complementary academic studies further validate the technical feasibility of AI-assisted plant-wide optimization under environmental constraints—reporting high predictive fidelity and quantifiable reductions in emissions alongside thermal-efficiency gains [4]. At the enterprise level, AI extends its impact to inventory, HR, safety, and knowledge workflows. LLMs streamline documentation and knowledge retrieval, while AI-enabled video analytics reinforce PPE compliance and reduce unsafe acts—together forming a data-driven ecosystem that complements operations and maintenance to improve reliability, availability, and cost-effectiveness [2, 5]. Building on this context, the paper outlines a structured methodology for AI integration across administrative, operational, analytical, and advanced domains, and presents a detailed case study on AI-based operation and maintenance assessment of a boiler Induced Draft (ID) fan—covering model development, characteristic-curve generation across operating hours, and predictive maintenance use cases [1–5].

2. Methodology for the Implementation of AI in the Power Plant

The implementation of Artificial Intelligence (AI) in a coal fired power plant must follow a structured, phased methodology that aligns with operational priorities, digital readiness, and long term modernization goals. Given the diverse functions within a power station—from boiler and turbine operations to maintenance, safety, and administrative workflows—AI adoption is most effective when

executed through a tiered framework that progressively builds capability and value across the organization.

The first stage focuses on enterprise productivity enhancement, where Large Language Models (LLMs) are integrated to support day to day office work. Tools such as Microsoft 365 Copilot streamline drafting, reporting, document processing, note sheet preparation, e mail management, and knowledge retrieval. This reduces administrative workload, enhances documentation quality, and enables faster decision making across departments. The second stage targets AI enabled safety and monitoring using existing plant infrastructure. Through computer vision based analytics, the plant strengthens compliance in areas such as PPE adherence, wagon tippler operations, coal yard surveillance, fire/smoke detection, and switchyard safety. These applications continuously monitor high risk areas and reduce unsafe acts, thereby improving workforce protection and operational discipline.

The third stage utilizes historical and real time process data for predictive analytics and operational insights. AI models analyze historian data, maintenance records, and operational logs to identify degradation patterns, fault precursors, and optimization opportunities. This enables predictive maintenance, early detection of equipment abnormalities, improved performance of HT equipment, optimized soot blowing, and enhanced reliability of combustion systems. The final stage advances into collaborative AI development with academia (IITs/NITs) to address complex optimization and diagnostic challenges. Applications include intelligent attemperation control, valve tuning, radiographic (RT) film interpretation, and virtual instrumentation for control room assistance. These initiatives bring cutting edge research into the plant environment and support continuous performance improvement. Together, these four stages create a holistic AI integration pathway—covering administrative efficiency, operational safety, predictive maintenance, and advanced optimization—enabling power plants to evolve into intelligent, data driven, and future ready energy systems.

3. AI-Based Operation and Maintenance Assessment of Boiler ID Fan — Case Study

The Induced Draft (ID) Fan is a vital component of a thermal power plant's air gas circuit, responsible for extracting flue gases from the boiler furnace and maintaining the negative pressure essential for stable combustion. By sustaining the required draft level, the ID fan enables smooth entry of fresh air into the furnace while preventing any reverse flow of hot gases into the boiler or plant area. Handling large volumes of hot, particulate laden flue gases generated during coal firing, the ID fan continuously draws the gases through the boiler's heat exchange surfaces—such as the economizer, air preheater, and electrostatic precipitator (ESP). This regulated gas movement ensures efficient heat recovery, optimal fuel utilization, and consistent boiler performance.

The fan also plays a key role in achieving proper flue gas discharge velocity through the chimney, supporting effective atmospheric dispersion and adherence to emission compliance norms. In coordination with Forced Draft (FD) and Primary Air (PA) fans, it maintains balanced draft conditions across the boiler under varying load demands. Additionally, the ID fan enables efficient operation of pollution control systems, including ESPs, bag filters, and flue gas desulfurization units. Overall, the ID fan ensures efficient combustion, stable draft, enhanced heat transfer, effective pollution control, and safe discharge of flue gases—making it indispensable to reliable and environmentally compliant plant operation.

3.1 ID Fan Characteristic Curve

A typical ID fan characteristic curve, developed by the manufacturer, shows how the fan performs under various operating conditions by relating flow rate, static pressure, efficiency, power consumption, and speed lines. It plots flow rate on the X axis and static pressure on the Y axis, illustrating the pressure the fan can generate at different flue gas flows. The curve also includes efficiency, indicating the Best Efficiency Point (BEP), along with power consumption, which helps determine motor rating and operating cost. For variable speed fans, multiple constant RPM lines are shown, and the system resistance curve intersects the fan curve to determine the actual operating point. This complete characteristic curve is essential for fan selection, stable draft control, ensuring energy efficient operation, preventing surge, monitoring performance health, coordinating with FD/PA fans, and troubleshooting any performance deviations.

3.2 Model Generation

Developing an intelligent model for a boiler's Induced Draft (ID) fan involves analysing how various operating parameters collectively influence flue gas movement and overall fan performance. The goal is to build a predictive system capable of estimating total flue gas flow, identifying performance deterioration, and supporting optimisation of fan operation within power plant environments.

The model is built using historical operational data collected from plant sensors. Key inputs include discharge pressure, power consumption, inlet and outlet temperatures, inlet pressure, and cumulative operating hours. Each of these parameters affects airflow dynamics, system loading, and the mechanical condition of the fan. Using statistical techniques and machine learning algorithms—such as regression models, random forests, or neural networks—the model learns the complex relationships between these inputs and the resulting total flue gas flow. After training, the system can forecast fan behaviour under different load conditions, enabling operators to adjust VIGV positions, optimise draft levels, and plan maintenance activities based on data driven insights. Figure 1 shows the flow chart of the AI model developed.

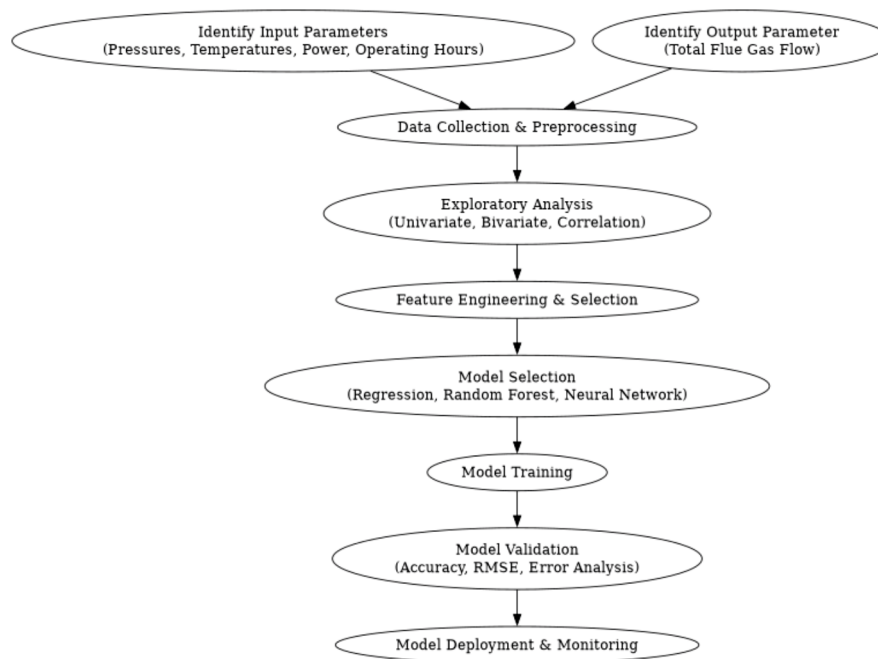


Figure 1 Flow Chart of AI Model Development

3.3 Data Preparation and Analysis

3.3.1 Data Preprocessing. Data preprocessing forms the foundation of developing a robust AI-based ID fan model. In this stage, raw sensor data—including pressures, temperatures, power consumption, operating hours, and total flue-gas flow—is systematically cleaned and standardized to ensure analytical reliability. Missing values are addressed through interpolation or statistical imputation, while outliers are detected and treated to prevent distortion of model patterns. Numerical features are scaled or normalized to maintain a consistent range, which is essential for stable gradient-based learning in neural networks. Time stamps are synchronized, corrupted or inconsistent records are removed, and categorical fields (if present) are properly encoded. Effective preprocessing minimizes noise, enhances data quality, and significantly improves both the accuracy and convergence behaviour of the final predictive model.

3.3.2 Univariate Analysis. Univariate analysis involves examining each variable independently to understand its statistical distribution, variability, and operational characteristics. For the ID fan dataset, parameters such as discharge pressure, inlet temperature, and motor current are evaluated using histograms, box plots, descriptive statistics, and temporal trend visualization. This step highlights potential issues such as sensor drift, abnormal spikes, cyclic behaviour, or logging inconsistencies. It also clarifies the typical operating ranges of each parameter under normal plant conditions. These insights guide decisions regarding feature scaling, transformation, and parameter selection, ensuring that the neural network learns from clean and meaningful signals.

3.3.3 Bivariate Analysis — Heat Map. Bivariate analysis focuses on understanding relationships between pairs of variables, with the correlation heat map serving as a key diagnostic tool. The heat map visually quantifies the strength and direction of associations—positive, negative, or weak—between parameters. Applied to the ID fan dataset, it reveals interactions such as the relationship between inlet pressure and motor power consumption or between power consumption and discharge pressure. These insights inform feature selection by identifying variables that meaningfully influence the target output while also detecting multicollinearity, which can degrade neural-network performance if left unaddressed. By isolating critical and non-redundant features, the heat-map analysis ensures that only informative variables are input to the model, ultimately improving predictive accuracy and computational efficiency.

3.4 Model Training and Validation

The accompanying schematic visually represents the modelling framework. The arrows on the left depict the input variables feeding into the ID fan, while the arrow on the right represents the predicted output—total flue gas flow—which the model aims to accurately estimate and optimize. Figure 2 shows the input-output information diagram.

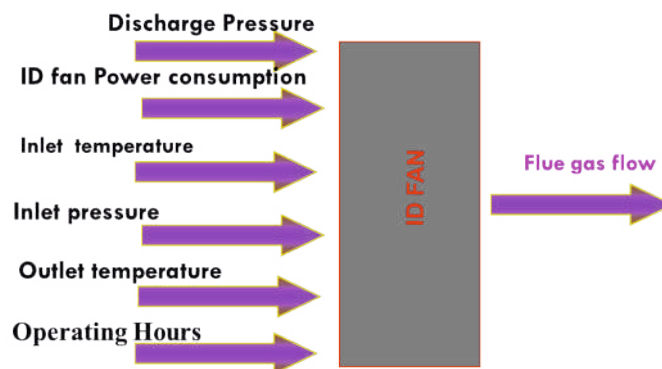


Figure 2 Input Output Information Diagram

Model Performance Metrics Comparison

Table 1 Model Performance Comparison

Model	Dataset	RMSE	MAE	R2	Adjusted R2	MAPE
Random Forest Estimator	Training	0.479	0.226	0.999	0.999	0.002
	Testing	0.772	0.404	0.999	0.999	0.003
Random Forest Tuned	Training	0.66	0.387	0.999	0.999	0.003
	Testing	0.766	0.436	0.999	0.999	0.004
XGBoost (XGB)	Training	0.626	0.355	0.999	0.999	0.003
	Testing	0.754	0.418	0.999	0.999	0.003
XGBoost Tuned	Training	0.696	0.405	0.999	0.999	0.003
	Testing	0.766	0.437	0.999	0.999	0.004

Analysis and Interpretation

The performance evaluation of the four machine-learning models shows consistently high predictive capability, with all models achieving R^2 and Adjusted R^2 values of 0.999, indicating that they collectively explain 99.9% of the variance in total flue-gas flow. This demonstrates excellent model fit and strong generalization across operating conditions. Among the models tested, the Random Forest Estimator displayed the largest discrepancy between training and testing performance, with RMSE increasing from 0.479 to 0.772, suggesting overfitting. Hyperparameter tuning significantly improved its behaviour, reducing the performance gap to only 16%, although some residual variance remained. In contrast, both XGBoost variants maintained stable performance across training and testing phases, showing better consistency.

XGBoost emerged as the best-performing model, achieving the lowest RMSE (0.754), lowest MAE (0.418), and lowest MAPE (0.003), confirming its superior accuracy and minimal prediction error. The very low MAPE values (<0.5%) show that all models possess strong practical utility, with XGBoost offering the most reliable real-world performance. Hyperparameter tuning yielded mixed results: while it improved Random Forest generalization, it provided marginal benefit for XGBoost, suggesting its default configuration was already near-optimal. Overall, untuned XGBoost offers the best balance of predictive accuracy, robustness, and computational efficiency, and is therefore recommended for deployment.

3.5 Characteristic Curve Development Across Operating Hours

An AI based model for an Induced Draft (ID) fan enables dynamic generation of characteristic curves under varying operating conditions, especially as the fan continues to accumulate operating hours. Unlike a static manufacturer provided curve, the AI model learns the real behaviour of the fan from historical data—pressures, temperatures, power consumption, and cumulative running hours—and predicts how performance will evolve over time. As the fan ages, factors such as fouling, erosion, blade wear, bearing degradation, and reduced mechanical efficiency gradually reduce the achievable pressure and flow. The AI model captures these degradation patterns and generates updated characteristic curves that reflect the expected performance at different time intervals, such as after 500 hours, 1000 hours, or any chosen period.

By forecasting the future condition of the fan, the model helps plant engineers identify when performance is likely to fall below acceptable limits, enabling timely planning of overhauling or major maintenance activities well in advance. This prevents emergencies, avoids forced outages, and ensures optimal draft management. Additionally, any deviation between the predicted performance curve and

the real time operating data serves as an early warning. A significant mismatch indicates abnormalities such as leakage, damper malfunction, sensor defects, or abnormal resistance build up in the flue gas path. Thus, the AI model acts as both a predictive planner and an intelligent fault detection tool. Figure 3 shows the comparison characteristic curve of ID Fan and different cases.

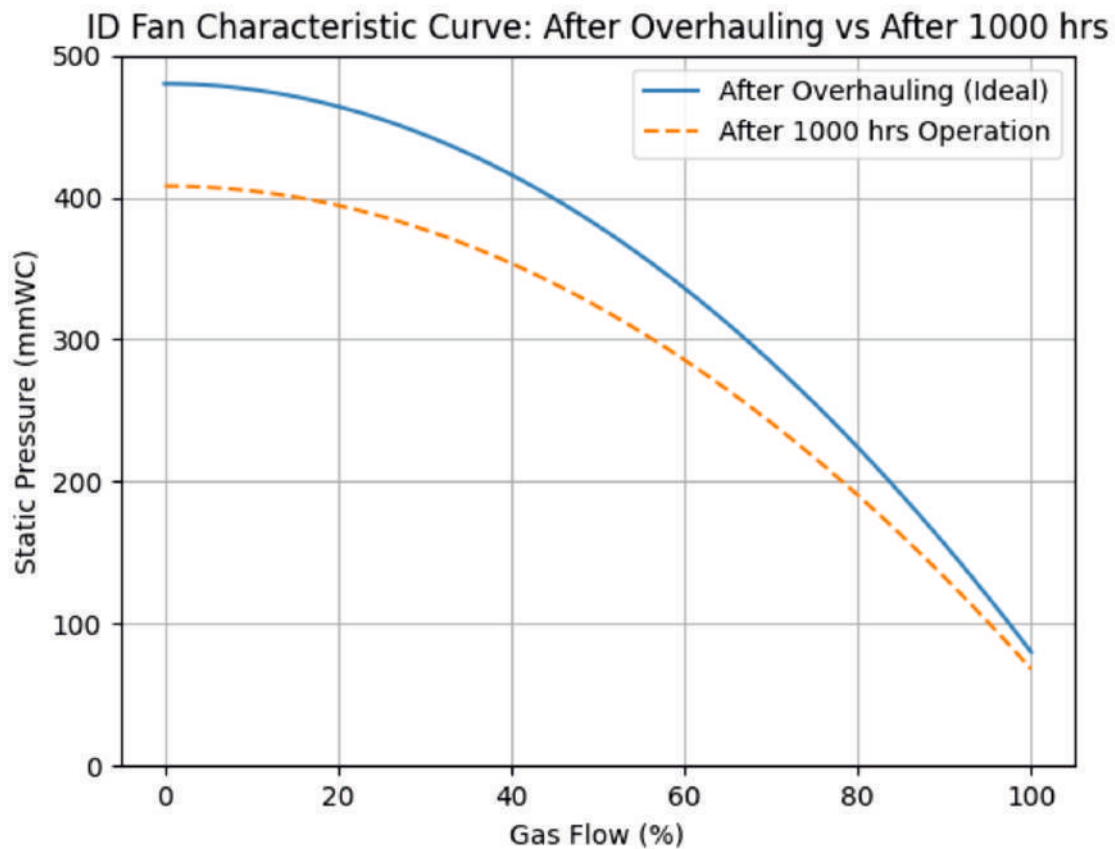


Figure 3 ID Fan Characteristic Curve

The deterioration of ID fan performance over time is primarily caused by mechanical wear, fouling, and gradual loss of aerodynamic efficiency. As the fan operates continuously, dust, ash, and fine particulate matter accumulate on the fan blades, altering their shape and increasing surface roughness. This fouling disrupts smooth airflow, reducing the fan’s ability to generate the required static pressure and decreasing overall volumetric flow. Erosion is another significant factor—high velocity fly ash particles strike the blades repeatedly, thinning the metal and changing blade profiles. Even small changes in blade geometry can reduce lift, leading to a noticeable drop in fan output.

Bearing degradation and misalignment also play a role. Over thousands of operating hours, lubrication deteriorates, resulting in increased friction, vibration, and mechanical losses. As the motor and shaft assembly experience higher resistance, the fan demands more power to maintain the same performance. Additionally, leakage across seals and wear in inlet guide vane mechanisms can reduce effective airflow control, causing inefficient operation. Temperature variations and thermal cycling further weaken material strength, contributing to performance drift. Collectively, these factors prevent the fan from achieving its original full flow capacity, leading to the observed difference between post overhauling performance and performance after extended operation.

4. Conclusion

This paper demonstrated a practical, phased pathway for implementing AI in coal based power plants—spanning enterprise productivity, safety analytics, predictive maintenance, and advanced optimisation—and showed how these tiers combine to deliver measurable operational value. By grounding the methodology in existing plant infrastructure and data sources, we outlined a low friction adoption route that builds digital capability while de-risking deployment.

The case study on the boiler Induced Draft (ID) fan illustrated the end to end workflow: defining inputs and outputs, rigorous preprocessing, exploratory analytics, feature selection, and supervised learning to predict total flue gas flow across operating conditions and hours. Results showed that gradient boosting (XGBoost) provided the most reliable generalisation among the tested models, enabling accurate, dynamic generation of characteristic curves rather than reliance on a single static manufacturer curve. These AI derived curves capture degradation drivers—fouling, erosion, leakage, and mechanical wear—supporting proactive overhaul planning before performance falls below limits.

Operationally, the framework converts model predictions into actionable maintenance and draft control decisions; deviations between predicted and measured performance serve as early warning indicators of faults across the gas path, dampers, and sensors. Strategically, the approach scales beyond a single asset to a plant wide data ecosystem that improves reliability, availability, and cost effectiveness while supporting compliance objectives.

Future work will integrate physics informed features, domain adaptation across units, and closed loop set point optimisation, alongside MLOps for monitoring, retraining, and governance. Overall, the study provides a replicable blueprint to embed AI into conventional plant operations, unlocking safer, smarter, and more efficient energy generation.

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- [5] Industry case studies on enterprise AI in coal power plants (2025). The power sector is undergoing a rapid digital transformation driven by increasing system complexity, higher reliability expectations, and the integration of renewable energy sources. Substations, being critical nodes of the power system, play a decisive role in maintaining grid stability and operational continuity. Among all substation equipment, circuit breakers are particularly critical, as their failure to operate correctly during fault conditions can lead to widespread outages or even large-scale blackouts.

Applications of AI in Power System Operations – POWERGRID

Er. Ravi Sushant Chaudhary

DGM

Power Grid Corporation of India Limited



Er. Ravi Sushant Chaudhary is a professional associated with the Power Grid Corporation of India Limited (POWERGRID), a Maharatna Central Public Sector Enterprise under the Ministry of Power, Government of India.

He has served as a Manager/Chief Manager in the Asset Management (AM) department at POWERGRID in Gurgaon. He is an ISO 55001 certified auditor, specialized in asset management.

In April 2025, Ravi Sushant Chaudhary, along with senior officials, represented POWERGRID to receive the prestigious GAISA award at the 5th Global Artificial Intelligence Summit & Awards 2025 held at Bharat Mandapam.

He was recognized for his efforts in the "Best Use of AI in Energy Sector" category, specifically for contributing to AI implementation within the Asset Management department. He is also recognized for his research and work profile in the field of electrical engineering.

1. Executive Summary:

POWERGRID has progressively embedded Artificial Intelligence (AI), Machine Learning (ML), and Data analytics across the asset lifecycle to enhance reliability, reduce maintenance effort, and optimize costs. This outlines the current landscape centralized operations (NTAMC), reliability-centered maintenance, AI-based defect detection in lines (PG-AMRIT), automated interpretation of advanced test results, substation and HVDC inspection robots, satellite-based vegetation risk analytics, dynamic line loading, digital twins, connected-worker tools, and IoT-enabled condition monitoring along with outcomes and a practical roadmap ahead.

2. Why AI for Power System Maintenance in POWERGRID:

- Massive, diverse, and fast-growing operational data from substations, lines and control centers requires automated analytics to convert to information and decisions.
- Predictive and prescriptive maintenance reduces outages, improves restoration time and extends equipment life.
- Digital substations, IoT sensors, CNPN/Wi-Fi, edge/cloud computing and drones/robots create a data fabric that AI can leverage.

3. POWERGRID's AI/ML Applications brief:

Centralized Operations (NTAMC)

Remote operation & monitoring of all substations from a centralized location enabling faster restoration through online diagnostics and safe, secure operations with minimal human intervention.



Reliability Centered Maintenance (RCM)

Real-time health indexing, risk-impact mapping, individualized maintenance plans and inventory optimization across transformers, reactors and transmission lines; man-hours reduced and planned outages lowered.

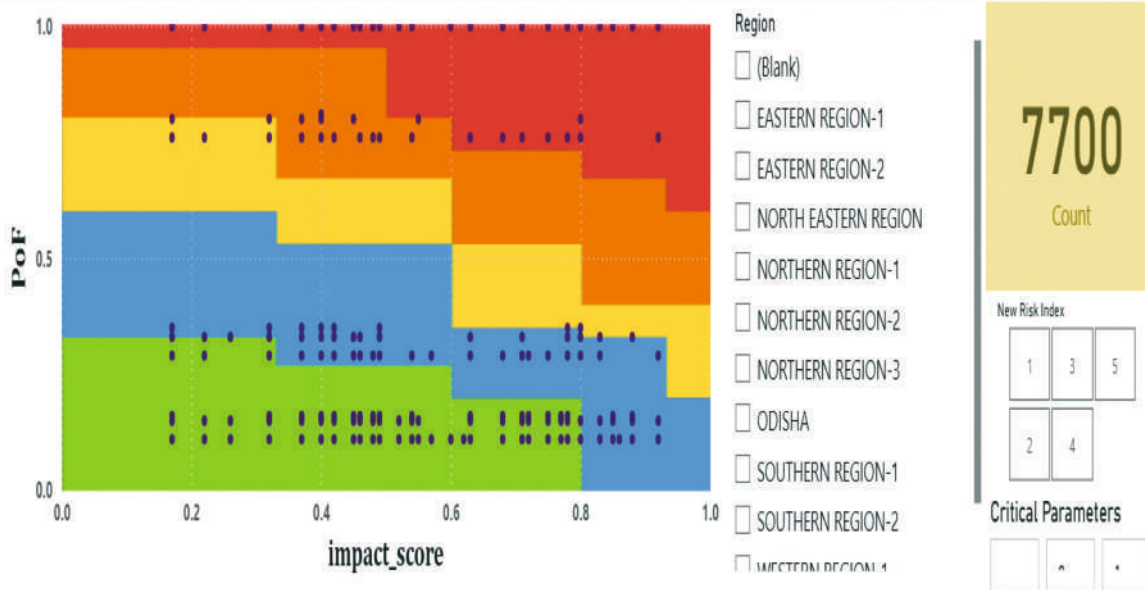
Reliability Centered Maintenance (RCM) in POWERGRID is a comprehensive, data-driven framework designed to optimize maintenance interventions across critical transmission assets such as Transformers, Reactors, and Transmission Lines. It integrates health, risk, impact, and ageing models to create an intelligent, asset-specific maintenance approach.

RCM uses real-time health indexing, which combines sensor data, design parameters, operational history, and test results to determine the condition of each asset. This helps in rationalizing maintenance actions, reducing unnecessary outages, and prioritizing interventions for high-risk equipment. It is supported by systems like PALMS, UDAAN, and NTAMC, ensuring a unified digital ecosystem for asset health monitoring.

A key component of POWERGRID's RCM strategy is the development of advanced analytical models—Health Model, Failure Model, Impact Model, and Ageing Model. These models evaluate the probability of failure and the consequences of failure, enabling risk-based maintenance decisions rather than time-based schedules. This transition has resulted in measurable operational improvements across the organization.

As per POWERGRID's performance outcomes, the implementation of RCM has reduced planned maintenance outages for Transformers and Reactors from 13,353 hours in FY 2022–23 to 10,817 hours in FY 2024–25. Gross maintenance hours per equipment also dropped from 3.6 hours to 2.7 hours in the

same period, reflecting a 20% reduction in workforce effort. Moreover, the failure rate of major assets such as Transformers and Reactors has dropped from above 1% (in 2018) to below 0.6% (in 2024).



RCM also contributes significantly to inventory optimization. Through risk-based severity indexing and the identification of critical equipment, POWERGRID has been able to refine inventory norms. As a result, annual inventory purchase budgets have reduced from an average of Rs. 450 crore (FY19–21) to around Rs. 275 crore (FY22–24), amounting to nearly 37% savings. The RCM continues to evolve with integration of predictive analytics, AI-driven interpretation of advanced tests (like SFRA and DCRM), IoT sensor data, and digital worker tools. POWERGRID plans to extend RCM to Circuit Breakers by March 2026, further strengthening reliability & resilience across the transmission network.

PG-AMRIT – AI-based Line Defect Identification

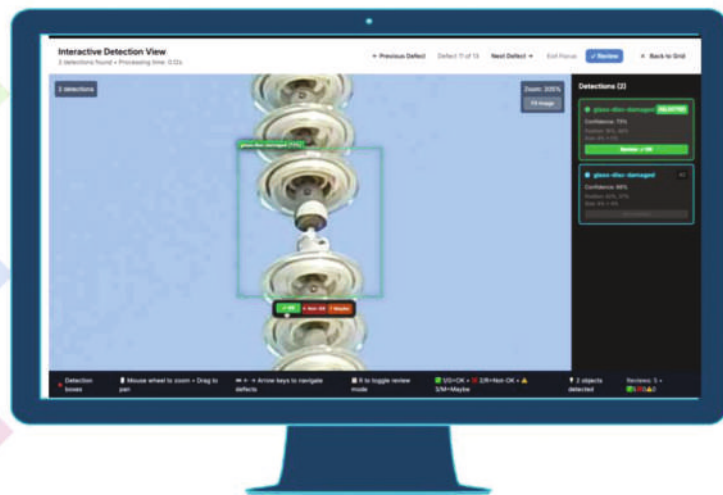
CNN-based image processing flags >30–40 defect types with high throughput and operational accuracy; geospatial tagging accelerates rectification planning. PG-AMRIT (POWERGRID Asset Management through Artificial Intelligence in Transmission) is an enterprise-scale AI/ML platform designed to automate defect identification in transmission line components using advanced image analytics. It represents one of POWERGRID’s flagship digital initiatives for improving reliability, maintenance efficiency, and inspection accuracy.

The system uses Convolutional Neural Networks (CNNs) trained on thousands of field images to automatically classify more than 30–40 types of defects, including damaged or broken insulator discs, loose/missing tower bolts, rusted structural members, hotspot indicators, conductor issues, bent/chipped hardware fittings, bird-nest obstructions, and corrosion-related deterioration. PG-AMRIT processes images at extremely high speed — up to 400 photographs per minute enabling end-to-end automation of transmission line patrolling analytics. The model currently operates with an accuracy exceeding 70%, significantly reducing manual review workload for POWERGRID’s field teams and improving turnaround time for defect reporting. The platform is fully integrated with geospatial tagging, allowing detected defect to be mapped automatically to its exact tower location. This feature accelerates planning of rectification activities, supports better maintenance scheduling, and ensures standardized severity classification across regions.

30+ Defect Types: Both Drone & Ground Patrolling
Identifies tower bolt missing, bird guard missing, damaged insulators, reversed grading rings, bird nests, bent tower parts, hanging members, missing joint plates, etc.

High-Speed Processing:
Processes 400 photographs per minute
Upto 90% accuracy reducing analysis time

GPS-Based Identification:
Automatically identifies tower numbers and transmission line names from GPS tagged photographs, generating comprehensive defect reports including SAP notification.



PG-AMRIT has been formally implemented across POWERGRID and forms a core component of the digital asset management ecosystem that also includes PG-DARPAN (patrolling supervision), PALMS (health indexing), RCM (risk-based maintenance), and NTAMC (centralized operations). Together, these systems enable a unified, data-driven maintenance strategy.

Future enhancements planned for PG-AMRIT include few-shot learning to detect new defect classes with minimal additional data, integration with drone-captured imagery for higher-resolution inspections, automated work-order generation integrated with SAP/CMMS, prioritization based on risk and environmental exposure, and continuous model retraining using field-validated data. These planned improvements will further accelerate defect closure and improve grid reliability.

Automated Analysis of SFRA/DCRM

Clustering/ensemble techniques convert subjective waveform interpretation into objective, repeatable diagnostics for transformers/reactors and circuit breakers. AI plays a pivotal role in transforming the evaluation of **DCRM (Dynamic Contact Resistance Measurement)** for Circuit Breakers and **SFRA (Sweep Frequency Response Analysis)** for Transformers/Reactors—from a traditionally subjective, expertise-dependent task into a fast, objective, and data-driven diagnostic system. POWERGRID has developed AI-enabled algorithms based on **Big Data Analytics, Clustering Models, and Ensemble Learning**, enabling scientific interpretation of signatures that previously relied heavily on human judgment.

1. AI Converts Subjective Signatures into Objective Diagnostics

Manual interpretation of DCRM and SFRA curves often varies across experts and regions. POWERGRID's AI models analyse thousands of historical waveforms to identify patterns, anomalies, and mechanical deviations with high consistency. These models automatically flag

2. Pattern Recognition Using Machine Learning

AI models cluster frequency-domain and resistance-time signatures into healthy vs. abnormal pattern groups. Such clustering enables:

- Early identification of progressive deterioration trends
- Detection of subtle deviations invisible to human reviewers
- Comparison with “standard” reference curves stored in POWERGRID’s diagnostic libraries
- The shift to machine-learning-based pattern detection improves both fault predictability and intervention planning.

3. Acceleration of Analysis and Reduction in Human Workload

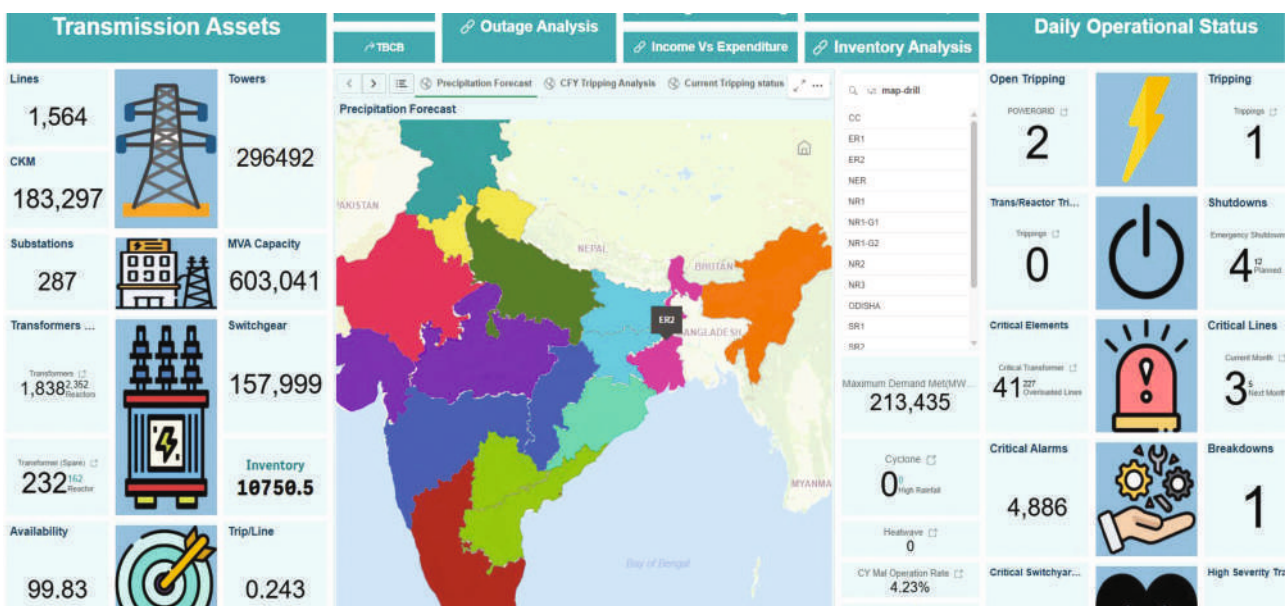
AI reduces analysis time from hours of manual visual comparison to **near-real-time automated interpretation**, enabling field engineers to focus on action rather than analysis. This capability is essential because the volume of test data continues to rise with increasing fleet size and the adoption of digital inspections.

4. Integration With RCM & Health Indexing

AI-interpreted DCRM/SFRA outputs automatically feed into systems such as **RCM, PALMS, and NTAMC**, strengthening:

- Health index scoring
- Probability-of-failure modelling
- Risk-impact assessments
- Predictive maintenance schedules POWERGRID’s digital ecosystem thereby becomes more predictive, reducing failure probability and improving long-term asset reliability.

UDAAN: UDAAN – Integrated Performance Dashboard: Consolidates data from SAP, NTAMC, PALMS, I2P, and inspection systems to present a unified real-time operational view, strengthening situational awareness and executive decision-making.



VALVE HALL ROBOT INSPECTION:

The Valve Hall Inspection Robot is an innovative, low-cost IoT-enabled solution developed to safely inspect energized HVDC valve halls where human entry is restricted. Equipped with a FLIR thermal camera, Wi-Fi-based remote control, and a motorized RC platform, the robot enables operators to detect water leakages, identify hotspots, and verify post-maintenance connections in real time without entering the high-risk environment. Field trials at Kolar HVDC confirmed smooth navigation, reliable thermal imaging, and effective detection of cooling system anomalies, significantly improving safety, early defect identification, and overall asset reliability.

Artificial Intelligence Based Circuit Breaker Monitoring in Digital and Conventional Substations

Er. Subh Karan Choradia

Senior Manager Electrical

Er. Rahul Ranjan

Manager Electrical

Er. Atish Anand

Manager Electrical

Damodar Valley Corporation (DVC))



Er. Subh Karan Choradia, holds a BE(Electrical) from Engineering College, Kota and MBA (Financial Management) from IGNOU.

Joined the modern temple of India i.e. Damodar Valley Corporation (DVC) in the year 2003. Brings over 23 years of experience in Grid Operation Maintenance in Transmission, Transmission System Construction, Distribution, Secretariat Department, STA of Member-Secretary etc.

Currently working as Substation In-Charge at Howrah Substation, DVC as well as looking after the work of GOMD-I Division as Divisional Engineer.

Like to Play Table Tennis and also is a philatelist.



Er. Rahul Ranjan, holds a Bachelor of Engineering in Electrical & Electronics from BIT Mesra and an MBA in Financial Management from IGNOU.

Currently working at TSC-III, CTPS, DVC. Brings over 14 years of experience in the grid operation and maintenance, as well as transmission system construction and project execution.

Has successfully contributed to the implementation of the DVC-GE collaborative project for the renovation and modernization of a 220 kV substation.

Has actively engaged in technical knowledge sharing and has presented papers at national-level conferences organized by CIGRE India and CBIP.



Er. Atish Anand, holds a BTech (Electrical & Electronics) from Birla Institute of Technology, Mesra, Ranchi.

Joined Damodar Valley Corporation (DVC) in the year 2013. Since then, have worked in Thermal Power Plant, Power Equipment Testing & Commissioning Division & Transmission Department.

Introduction

The power sector is undergoing a rapid digital transformation driven by increasing system complexity, higher reliability expectations, and the integration of renewable energy sources. Substations, being critical nodes of the power system, play a decisive role in maintaining grid stability and operational continuity. Among all substation equipment, circuit breakers are particularly critical, as their failure to operate correctly during fault conditions can lead to widespread outages or even large-scale blackouts.

Traditionally, the health assessment of circuit breakers has relied on periodic, time-based maintenance practices. While effective to an extent, such approaches are increasingly viewed as inefficient, costly, and disruptive due to the outages required for testing.

In recent years, the convergence of digital substations, smart sensing technologies, and artificial intelligence (AI) has opened new possibilities for continuous and condition-based monitoring of circuit breakers. This evolution is most evident in IEC 61850-based digital substations, where large volumes of high-resolution, time-synchronized data are readily available. However, the fundamental concepts of AI-based monitoring are equally applicable through suitable adaptation to conventional substations as well.

Evolution from Conventional to Digital Substations

Conventional substations are characterized by hardwired analog and binary signals, electromechanical or numerical relays, and largely manual inspection processes. In such environments, circuit breaker condition monitoring typically involves offline tests such as contact resistance measurement, timing tests, and mechanical inspections conducted during scheduled shutdowns. Although these methods provide valuable snapshots of equipment condition, they fail to capture gradual degradation or sudden anomalies occurring between maintenance intervals.

Digital substations, on the other hand, replace extensive copper wiring with fiber-optic communication and standardized data models as defined by IEC 61850. Primary equipment interfaces are handled by process interface devices such as merging units, switchgear interface units, and non-electrical interface units. These devices publish sampled values, GOOSE messages, and reports over the substation network, ensuring precise time alignment of electrical and non-electrical data. This architecture inherently supports advanced monitoring and analytics, making it an ideal foundation for AI-based condition assessment of circuit.

Data Foundation for AI-Based Monitoring

Artificial intelligence systems rely fundamentally on the availability, quality, and diversity of data. In the context of circuit breaker monitoring, relevant data includes electrical parameters such as phase currents and voltages during switching operations, breaker operating times, and total interrupted fault current. In addition, binary status information from auxiliary contacts provides precise indications of breaker open and close events. For certain breaker technologies, non-electrical parameters such as gas pressure, hydraulic pressure, or temperature further enrich the monitoring dataset.

In digital substations, these signals are available in the form of time-synchronized sampled values and event messages, enabling a detailed reconstruction of each switching operation. In conventional substations, similar information can be obtained through retrofitted sensors, portable monitoring devices, or intelligent electronic devices (IEDs) interfaced with existing equipment. While the data acquisition methods differ, the underlying monitoring objectives remain the same: to detect deviations from normal operating behaviour and identify early signs of degradation.

Role of Artificial Intelligence Techniques

Artificial intelligence offers a powerful set of tools to analyse complex, multi-dimensional datasets that are difficult to interpret using traditional rule-based methods alone.

A particularly promising concept in AI-based circuit breaker monitoring is the use of a “digital twin.” A digital twin represents a virtual model of the breaker that captures its expected behaviour under various

operating conditions. By continuously comparing live data against the digital twin, AI algorithms can detect subtle deviations that may indicate wear, mechanical misalignment, or insulation degradation. This approach allows maintenance actions to be planned proactively.

Integration within Substation Architectures

The deployment of AI-based monitoring functions depends strongly on the substation architecture. In distributed digital substations, AI applications may be embedded within protection IEDs or process interface devices, performing local analytics at the edge. Alternatively, centralized architectures leverage substation servers or utility data centres to host more computationally intensive AI models. Each approach presents trade-offs between latency, cybersecurity, scalability, and maintenance.

Applicability to Conventional Substations

While digital substations offer a natural environment for AI-based monitoring, the majority of substations worldwide remain conventional. Importantly, the transition to AI-driven condition monitoring does not require a complete overhaul of existing infrastructure. Wireless sensors, portable diagnostic tools, and mobile devices can be used to collect relevant data during inspections and switching operations. When combined with centralized analytics platforms, these data sources can support AI-based assessment even in legacy installations.

The gradual introduction of smart sensing and mobile supervision technologies enables utilities to adopt condition-based maintenance strategies incrementally. This hybrid approach reduces capital expenditure while still delivering many of the benefits associated with digital substations, such as improved reliability, enhanced safety, and optimized maintenance scheduling.

Benefits and Future Outlook

This paper presents application of artificial intelligence to circuit breaker monitoring offers multiple benefits. Continuous condition assessment reduces the likelihood of unexpected failures and minimizes the need for intrusive testing outages. Early fault detection supports optimized maintenance planning, extending equipment life and lowering lifecycle costs. From a safety perspective, reduced human intervention in high-voltage environments significantly lowers operational risk.

Looking ahead, advancements in edge computing, sensor technology, and communication networks are expected to further enhance AI-based monitoring capabilities. As substations evolve toward higher levels of automation and autonomy, AI will play an increasingly central role in ensuring reliable, resilient, and efficient power system operation.

Conclusion

Artificial intelligence-based circuit breaker monitoring represents a significant advancement in substation asset management. By leveraging the rich data environment of IEC 61850 digital substations and by extending similar concepts to conventional substations through smart sensing, utilities can move from reactive, time-based maintenance toward predictive and condition-based strategies. This transition not only improves system reliability and safety but also supports the broader digital transformation in the power sector.

Rising death in polluted air, Green Energy transition: Can AI be a game changer?

Er. J. Chakraborty

*A working professional on Renewable Energy Systems
Member, IE(I), WBSC*

Er. S. Karmakar

*A senior design engineer of Grid Connected Solar PV Systems,
Serving for a RE MNC in UAE.*



Er. Joy Chakraborty has been graduated in Electrical Engineering from the IEST, Sibpur. He has studied Renewable Energy at IIT, Roorkee and has done MBA in Marketing.

He has been associated with different Renewable Energy programmes like Solar PV (Home Lighting System, Street Lighting System, Rooftop Solar Power Plant), Wind, Biomass and Small Hydro since 1995.

He was associated with preparation of the first State Level Human Development Report for West Bengal and the first State Action Plan on Climate Change and policy framing on Energy Efficiency for household appliances through Indo-US Energy Efficiency programmes. He has publications on Globalisation, Climate Change.

He has got Life Time Achievements Award, 2025 for his contribution towards Renewable Energy propagation in West Bengal by the Solar Quarterly Magazine. He has also received Energy Engineer of the Year 2025 award by the India's first B-School: IISWBM.

Presently, he is working with Rooftop Solar Division of WBREDA as a Divisional Engineer.



Er. S. Karmakar is a senior design engineer of Grid Connected Solar PV Systems, serving for a RE MNC in UAE

Introduction:

Since the Rio De Janeiro Earth Summit in 1992, it is the common understanding of the international community that “Climate change is the worst threat for the very existence of the human civilization, even more dangerous than militancy”. The World Air Quality Report 2023 and also the Lancet report (2025) indicates that air pollution is a massive killer in India, linked to over **1.7 million deaths in 2022** (a 38% jump since 2010) and accounting for a significant portion of premature deaths, with figures suggesting **one in four global air pollution deaths linked to India**. This crisis stems from fossil fuels, affecting health through PM2.5, causing heart disease, stroke, lung issues, and costing billions in GDP.

So, on one hand to clean our poisonous air and also to mitigate climate vulnerabilities, the Indian Government has introduced target based capacity addition from RE sources, energy efficiency measures, green mobility mission, Renewable Consumption Obligation (RCO) etc. These exercises are aimed to limit the global temperature rise within 1.5 degree Celsius by 2100.

In 2015, India had fixed up the target to add 175 GW of Renewable Energy [RE] in its grid by 2022. Later, it was upgraded to 500 GW by 2030 and 1800 GW by 2047. **The recent report of the Ministry of New & Renewable Energy (MNRE) says that 135.85 GW of Solar Power has been installed in India till 28.02.2026. The installed capacity for Wind Energy is 54 GW. All together, the Non-Fossil Fuel (including hydro/nuclear) capacity in India is now over 266.8 GW.**

The transition at a glance:

Installed capacity from different sources in India as on 30.11.25

Name of the energy source	Percentage in terms its contribution to total installed capacity in India
Coal	43% to 45%
Large Hydro	10.08%
RE Except Large Hydro	39.6% to 39.7%

Energy generation from different sources in India as on 30.11.25

Financial Year	Generation from fossil fuel sources in BU	Generation from RE sources in BU
2023-24	1326.6	370.32
2024-25	1824	403.64

Lowest available tariff from RE sources

Energy source	Tariff in Rs. / kwh
Solar	2.15
Wind	2.91
RE + BESS	3.32

(Source: the Central Electricity Authority)

India's next industrial shift – electrons over molecules:

- For over a century, at factories, kiln, molecules power tracks: oil, coal, gas are burnt for heat and motion. That age is now giving way to one where competitiveness is increasingly written in electrons: clean and reliable electricity. Nations that move the faster on molecules to electrons not only cut emissions but also win supply chains, capital and jobs.
- In 2024, close to half of China's industrial energy came as electricity. India is closure to one quarter. The gap directly effects export competitiveness and resilience to fuel price shops.
- Large-scale conversion to electricity also brings a major efficiency dividend. Electric motor convert over 90% of input energy into useful work, while IC engines typically convert less than 35%. This means, each percentage point increase in electrons displaces more fuel molecules than raw energy numbers suggest.

Country	Green electrons (%)	Grey electrons (%)	Total electrons (%)	Molecules (%)
China	18	29	47	53
U.S.	12	20	32	68
India	07	20	27	73
World Average	12	18	30	70

Green power at choke point triggers search for a way out:

- The Central Government has stepped in to resolve, the green power surplus production and insufficient transmission network, following sweeping production cuts at solar & wind farms. It hinders India's ambitious green energy targets.
- This move comes after vast production cuts ordered in Rajasthan & Gujarat, which are India's green power engines. This curtailment, equivalent to 18% of average monthly solar generation like 13 terawatt hours, resulted in a compensation payout of Rs.575-690 Crores to the developers.

Challenges in clean energy propagation in India:

- Enhancing Grid Capacity to accommodate increased RE capacity
- Strengthening land neutral solution for RE propagation like Agri-PV, Floating Solar, Canal Top
- Shifting from direct burning of fossil fuels to grid quality electricity supply, through fossil fuel and clean energy sources: industrial shift – electrons over molecules.
- Making clean energy as Round The Clock (RTC) power source through clubbing with Battery Energy Storage Systems.(BESS)
- Navigating the geo-politics in regard to volatile tariff scenario
- Re-modeling our infrastructure to accommodate enhanced EV penetration
- Other than enhancing the RE installed capacity (GW) , it is the need of the hour to enhance RE generation (Terawatt Hour).

To mitigate said challenges, AI is emerging not just as a tool but also as a transformative force reshaping the Energy Infrastructure. The advancements in AI technology is making it more effective, accessible, and economically sustainable.

The Artificial Intelligence (AI) industry has reached a crossroads. For years, companies poured money into infrastructure such as data centres, chips and underlying models. Now, the big question is not about AI working, but whether it can be profitable. The solution lies in concrete AI applications, and not just having more training or larger GPU clusters.

Policymakers should not hurry into strict regulations. The application layer needs room to experiment, fail and improve until it finds product-market fit. Still, rules about competition, especially reviews of acquisitions that prevent big companies from buying and shutting down potential rivals, are important. The Internet was not monetised by selling bandwidth. It was monetised by building applications that made bandwidth valuable. AI will follow the same trajectory. AI Infrastructure will shape innovation. India has an opportunity to opt for good infrastructure enabled by DPI (Digital Public Infrastructure), partnerships and trust based governance.

The question is no longer, whether India will adopt AI. The real question is the weather AI in India will remain the privilege of a few – or become a shared capability that powers inclusive growth, resilient governess and digital sovereignty. That choice will be made not in code, but in infrastructure including power sector.

AI enables rapid data processing and predictive analysis and provides opportunities for a variety of options, including crisis response, conflict prevention and conflict resolution. Here human kind must develop a set of checks and balances to prevent AI from running away with the bit in its mouth for a very sensitive domain of technology like power sector.

Scientists, policy makers and other must come together to understand the implications of runaway AI technologies and decide how to keep them under control and in a manner that they benefit, rather than become a threat to human kind.

The Human Brain and Artificial Intelligence (AI) are two different species of intelligence. It is not that one is better than another. Rather both are reciprocal in nature. One has expertise in ability and evaluation; other is enabling in large data handling, data forecasting and repetitive jobs.

In many occasion, people think that intelligence means ability to do large calculations or to memorise a vast range of data. But actually, intelligence is leniency and ability to retrieve and reuse acquired information and knowledge for a new creation. Only the human brain has the capability to become smarter than smart phone. A conducive environment, which enables people to think and ask question freely can be the enabler.

Large Language Models are energy hungry and so are data centres. So , AI can be an effective tool for a game changer in Indian Power Sector , if it can be driven by the political will of the government , backed by public spirited bureaucracy , technocracy and inclusive democratic environment.



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ADMINISTRATIVE OFFICE:

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SITE OFFICES

KTPS:	Kolaghat Thermal Power Station, P.O.: Mecheda, Purba Medinipur.
BKTPP:	Bakreswar Thermal Power Project, P.O.: Bk.T.P.P, Birbhum.
SgTPP:	Sagardighi Thermal Power Project, P.O.: Monigram, Murshidabad.
BTPS:	Bandel Thermal Power Station, P.O.: Tribeni, Hooghly.
STPS:	Santaldih Thermal Power Station, P.O.: Santaldih, Purulia.
IISCO:	Steel Authority of India Ltd., P.O.: ISP, Burnpur, Burdwan.
CPL:	Crescent Power Limited, CESC P.O. - Madanpur, Asansol, Burdwan.
IOCL:	Indian Oil Corporation Limited, Haldia Refinery, Purba Medinipur.
DVC:	Damodar Valley Corporation, MTPS, RTPS, DSTPS, KTPS



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- ◆ AMC FOR ELECTRICAL MAINTENANCE OF ESP AND TOTAL DRY ASH SYSTEM.
- ◆ ANNUAL CONTRACT FOR AMMONIA DOSING SYSTEM AND CHLORINATION PLANT.
- ◆ OVERHAULING OF BOILER PRESSURE AND NON PRESSURE PARTS, UP TO 500 MW.
- ◆ OVERHAULING AND MAINTENANCE OF ESP & OTHER ALLIED WORK.
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- ◆ OVERHAULING MAINTENANCE AND RECTIFICATION WITH OIL FILTRATION OF TRANSFORMER.
- ◆ ERECTION & COMMISSIONING OF COAL HANDLING PLANT (CHP).
- ◆ ERECTION & COMMISSIONING OF AMMONIA FLUE GAS CONDITIONING SYSTEM (AFGC).
- ◆ ERECTION & COMMISSIONING OF DRY FLY ASH HANDLING SYSTEM.
- ◆ ERECTION & COMMISSIONING OF HIGH PRESSURE & LOW PRESSURE PIPELINE.
- ◆ FABRICATION, ERECTION & COMMISSIONING OF STRUCTURAL AND IBR PIPING JOB.
- ◆ RATE CONTRACT FOR SERVICING & IBR INSPECTION OF WASTE HEAT BOILERS.

REGISTRATION DETAILS

IBR LICENSE NO.	: WB/REPAIR-FINAL/2024/150 DTD-08.06.24 [Govt. of W.B., Directorate of Boilers]
ELECTRICAL LICENSE NO.	: CL01/2024/00973
FIRM REGN. NO.	: L78984
PAN NO.	: AAJFT3026G
TAN NO.	: CALT06838G
E.P.F.CODE NO.	: WB / CAL / 0033668.
ESIC CODE No.	: 74000260470001001,
PROFESSION TAX NO.	:192002162296 / 191000266271
GST REGN. NO.	:19AAJFT3026G1Z5
POLLUTION REGN. NO.	: 4880-hl-co-0/15/0214 Dated - 06.11.2015
NSIC NO.	: NSIC/GP/KOL/2015/0013512 Dated - 25.07.2023
UDYAM REGN. NO.	: UDYAM-WB-12-0003564

CONTACT DETAILS

PHONE NO.:	03228-231 651,
FAX NO.:	03228 -231 366,
MOBILE NO:	9434749017 / 9434054982 / 9434743707 / 9434743757/ 9434418242
E. MAIL IDS:	techno.14@rediffmail.com / prasanta.dinda@technoengineering.co.in / pritam.dey@technoengineering.co.in
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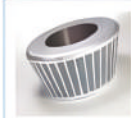
Grinding Media



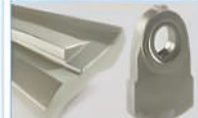
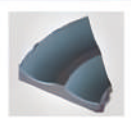
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Gangaramchak & Gangaramchak-Bhadulia Coal Mine



Tara (East & West) Coal Mine



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