CENTER FOR NON-DESTRUCTIVE EVALUATION

# ANNUAL REPORT

2023 -2024

# TABLE OF CONTENTS



# INTRODUCTION

The Center for Nondestructive Evaluation (CNDE) was established at the Indian Institute of Technology, Madras, in April 2001. The CNDE is Asia's leading academic center for Nondestructive Evaluation (NDE) research and technology translation.

CENTER FOR NON-DESTRUCTIVE EVALUATION

CNDE is uniquely positioned in the field of NDE research due to IIT's innovation ecosystem, which includes the Center for Innovation, Nirman-Pre-incubation support, the Incubation Cell, Research Park, and Industrial Consultancy & Sponsored Research- an administrative framework to take care of finance and legal compliance. CNDE has been focusing its research efforts on the following areas:


*Figure .1 focus areas*

CNDE

# Mission and Vision

## → Mission

Deep-research based non-destructive technologies for improved performance, enhanced safety, and increased life for industrial applications and societal well-being.

## → Vision

To become the world's largest Deep-research and technology translational center in the field of NDE

# SUMMARY OF ACCOMPLISHMENTS (2001-2023)

CNDE has been playing key roles in developing and deploying NDE 4.0 technologies through a collaborative mode. The global stakeholders of the CNDE include the various exchange programs, joint research with international institutions, and collaborations and projects in association with government and national labs and industries worldwide.


*Figure. 2 Global presence of CNDE*

CNDE has developed cutting-edge innovations in quantitative thermography, robotized ultrasonic scanners, annular plate and pipe support inspection, feature-guided waves, robotics for pipelines and railway tracks, immersed structure inspection, and waveguide sensors. CNDE has also pioneered affordable NDE simulation tools. The emphasis on translational research has led CNDE to develop a strong technology entrepreneurship base, with as many as 12 spin-out ventures emerging over the last five years alone.

CNDE is now globally considered as the pre-eminent academic NDE research center in India, ranking together with such globally eminent groups as CNDE Iowa State University USA, Penn. State USA, RCNDE UK, IZFp & BAM, Germany, ZUT Poland, Sungkyunkwan University Korea, and Nanjing University China.Due to the academic excellence, productization of technology, and significant international collaborations as well as wide clientele, the CNDE and its eco-system comprising its startups that includes approximately 1200+ personnel, the global ranking in the field of NDE will be in one of the top 8 in the world. Through this CoE efforts, it is envisaged that CNDE at IITM will be ranked in the top 3 centers in the world.

CNDE is currently considered as one of the leading centers of excellence in this field with NINE faculty from various disciplines joining in this proposed effort. The demographics of the team is illustrated in the Figure 3 below showing the multidisciplinary nature of the proposed team and the combined strong track record in academic, international collaborations, Publications and its impact, Outreach including startups and Research Funding.


*Figure 3: The recent 2015-19 four-year track record of the CNDE CoE Team*

# NDE 4.0 Technologies

Asset Integrity and Process Monitoring technologies have a logical impact on operational costs. Efficiencies realized by effectively managing labor, inventory and other support services directly impact the bottom line by helping to control costs. More timely and precise user intervention can improve productivity, reduce materials use and decrease the cost of doing business.

This has led to the development of NDE 4.0 technologies over the past 10 years, where the CNDE has played a key role in the technology's development, evangelization, and deployment through technology transfer and incubated startup companies. Figure 4 below shows the transitions in the NDE technologies and the relevance of NDE 5.0.

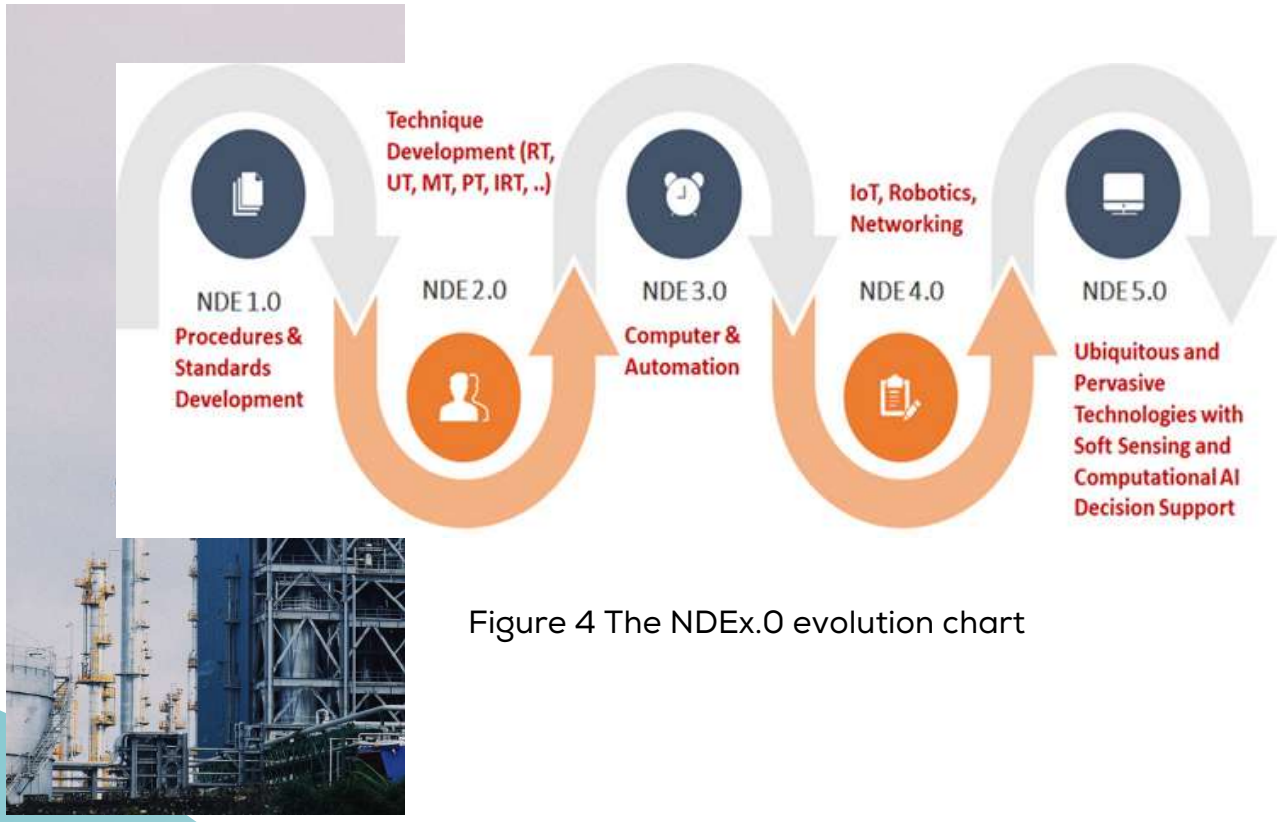



Figure 4 The NDEx.0 evolution chart

A robust approach to integrity and maintenance is key to safely improving reliability, maintaining production, reducing cost and increasing profitability. Equipment failures cost the U.S. refining industry over $4 billion per year alone. In the upstream sector, best-in-class operators deliver up to 30 per cent more value from producing assets, with facility reliability at 95-98 per cent .

One key reason being the reactive culture in operations, with many unplanned breakdowns and maintenance issues being solved only as they come up during the day. This typically results in poor reliability and safety and higher cost of operations. Organizations are challenged with how to maximize the value of assets throughout their lifecycle. In fact, in a recent survey of asset managers worldwide, more than 75% of respondents cited system reliability as the fundamental reason to invest in enterprise asset management.

Asset management, driven by valuable insights from IoT data and data obtained using automated and/or autonomous robotic tools, can have a significant impact. One critical step is to unify processes that manage wide-ranging functions across an organization's multiple sites. When this framework is in place, organizations can optimize production and service systems within each site. As a result, organizations can wield greater control of the complex asset environments necessary for bottom-line results.

Several inspection technologies are employed by these industries to perform periodic assessments, usually during the scheduled shutdowns. Few leave-in-place sensors are also commonly found in some of the better performing operators. However, the poor performance efficiency, frequency forced shutdowns, early retirement of critical assets, increased safety and environmental risks, are found to be common across the board, particularly due to the routine pressures of supply/demand.

The data collected are often reported in textual context with only broad inferences based on experiences and/or standards followed in the industry. This often has led to the adaptation of higher than necessary factors of safety during the decision-making processes. Also, the relationship between the process parameters, the state of the asset, the future demands, the history of the asset utilisation, the geographical and local factors that influence the life of the asset, etc. are not readily available and certainly not available in a quantitative form to make critical decisions.

Hence, the need for improved asset management systems including IIOT has been well documented. According to an A. T. Kearney survey in Industry Week, 558 companies that currently use "computerized maintenance management systems" exhibited an average of:

- 28.3 percent increase in the productivity of maintenance
- 20.1 percent reduction in equipment downtime
- 19.4 percent savings in the cost of materials
- 17.8 percent decrease in inventory maintenance and repair
- 14.5 months of payback time

Some of the status of the Inspection Technologies under the NDE 4.0 paradigm as developed by CNDE eco-system in the recent years are summarized as below:

Under-fluid Robot for Storage Tank Bottom Inspection & Monitoring: Currently, the large tank bottom metal floors are inspected by

(a) emptying and cleaning the tank and using Magnetic or Low Frequency eddy current sensors, leading to a long downtime and expensive operation,

(b) or using robots (emerging approach) which uses conventional ultrasonics or Magnetic techniques, leading to very slow mode of inspection and missing out on critical pitting type defects. This cumbersome process has been replaced with an under-fluid robot that uses an IITM patented HOMC inspection technology for in-service inspection.

IIOT for distributed temperature & moisture sensing to predict onset of corrosion: Currently, the moisture in the insulated reactors leads to condensation on the inside surface that leads to corrosion and hence prone to unplanned outages and expensive interventions. If the onset of condensation can be determined, without intrusive sensors, process interventions are possible that can mitigate this detrimental effect. Currently, there are no validated methods that can be used during the operation of the reactor.

IIOT GUMPS for high temperature pipes (CUI): Hot pipes are insulated to preserve the energy and keep the products at optimal temperatures. The high temperature pipes are more prone to damage mechanisms, but due to the temperature and insulation are often not inspected. Currently the only approach is to wait for a maintenance shutdown where the entire insulation is removed and conventional inspection tools are employed. This is currently an expensive approach.

IIOT CUPS for hidden corrosion evaluation at pipe supports: Pipe supports are very prevalent and prone to corrosion due to the accumulation of rainwater in the crevice region. The inspection of this region is extremely challenging. Currently, the only reliable approach is an IITM Technology called CUPS and has been adopted by many multinational companies worldwide. In this proposal, it is proposed to convert this CUPS technology into an IIOT approach with leave-in-place sensors to make this an autonomous system.

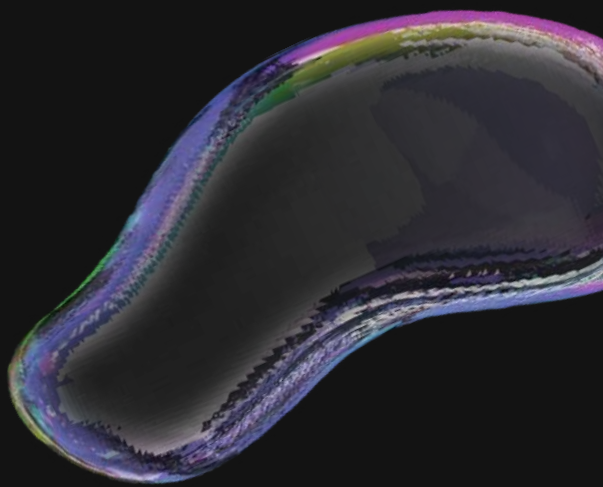
Short Range Laser Profiling Robot for unpiggable pipes: Pipes inside the battery limits are buried or in inaccessible locations and the only approach to inspection is by robots. While there are no current methods to inspect such pipes, it is proposed here to develop a novel small footprint robot that can crawl inside the pipes and evaluate the internals of the pipes using a patent pending laser profiling approach. Under-water Robot for automated assessment of Marine Concrete Assets: The process industry such as refineries maintain marine concrete assets which are prone to damage mechanisms. Current approach is to use human divers. This approach depends on the availability of trained divers, their safety, reduced performance due to fatigue and absence of quantifiable and archivable information. Use of remotely operated underwater robots with information processing dashboards is being proposed here.

Automated Aerial Drone based Inspection, Monitoring and 3D digital-twin reconstruction: The current approach for inspection of elevated assets is by installing scaffolding and human inspectors. Same as divers, this is dangerous and not robust. The use of drones allows rapid inspection methods that can go beyond gathering digital datasets. Multiple sensors including Ultrasonics, infrared, and visual modalities can be used and the data is fused to provide enhanced information. Using photo-gravimetry, 3D data models can be reconstructed for digital-twins of these assets and corrected for any changes in the asset over time.

RESEARCH

# THEMES

CNDE



# NDE 5.0 Technologies

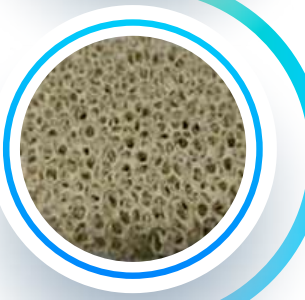
NDE 5.0 will aim to create a knowledge base that leverages the current NDE 4.0 efforts but introduces new themes and concepts

## UBIQUITOUS SENSING

- Fibre Optic/Ultrasonic Waveguides
- Nano-functional Sensors

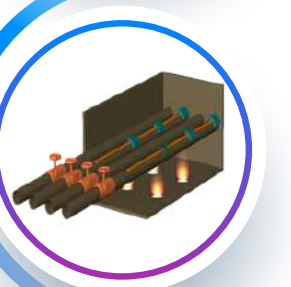
## STRUCTURED MATERIALS FOR IMAGING

- Meta-materials based imaging & sensors
- Patterned surfaces for improved inspection
- Nano-structured coatings



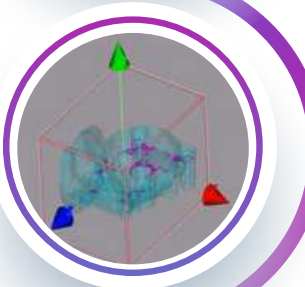
## EDGE INTELLIGENCE & SOFT-SENSING

- AI enabled rapid computations
- Simulated Assisted Decision Process
- Distributed computational Algorithms
- Reduced Order Computations



## WIDE INSPECTION TECHNOLOGIES

- Wide Multi-spectral Imaging (THz, IR, X-ray)
- Multi-modality Fusion Algorithms



## REMOTE AND PERVASIVE INSPECTION

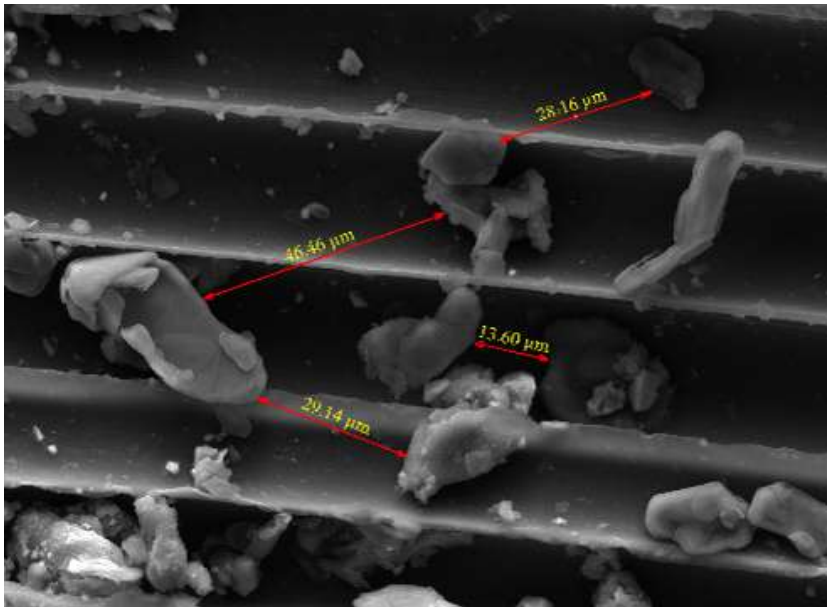
- Autonomous Robots
- Swarm Inspection Robots

# Theme 1: Ubiquitous Sensing

## Continuous Distributed Sensing using Fiber Optic Sensors:

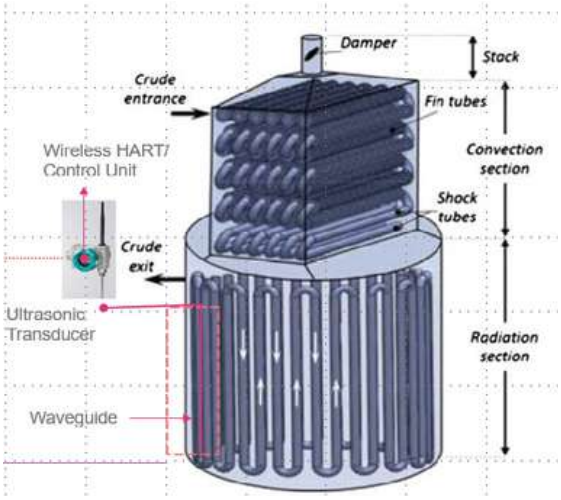
The current state of the art for fiber optic sensing is the use of Fiber Bragg Grating and similar discrete sensing elements for localizing the measurements. These techniques are now well known and applied in practical applications such as for structural health monitoring and process measurements. However, when faced with large volume of monitoring, the discrete approach becomes very limited in scope and increasing the number of discrete sensors becomes the limiting factor. Hence, continuous sensing will be the preferred solution where the sensing element is non-discrete and information anywhere along the length of the fiber can be obtained.

Currently, continuous sensing is feasible using Rayleigh Scattering. This covers large volume, but with low resolution. Hence, it is necessary to explore new paradigms in fiber optic sensing techniques where large volume and higher resolution of measurement becomes feasible. In addition, the current sensors have an upper operational temperature range and increasing this operational temperature ranges will also be desirable.



## Continuous Distributed Sensing using Ultrasonic Waveguide based Sensors

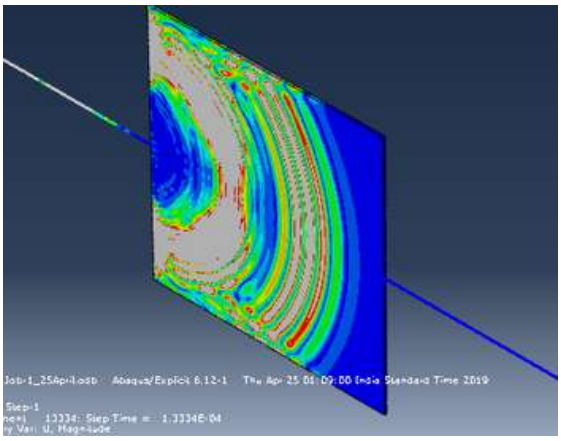
Ultrasonic waveguide sensing technologies are discrete in nature. The key advantage of this technique is the improved robustness as well as the temperature range of operations (-100 C to +1500 C). These sensors can measure process parameters such as ambient temperature, rheology of surrounding fluids, level and flow rate of fluids, etc. simultaneously using multiple guided wave modes. Using discrete sensor located along the length of the waveguide, it is feasible to obtain multiple measurements at different locations along the length of the waveguide.




*A schematic representation of an ultrasonic waveguide inside a high temperature furnace for skin-temperature monitoring.*

The CNDE at IITM is currently considered the leading group in the world in this technology and have an incubated company XYMA Analytics that is carrying this work into the commercial world with applications in high temperature measurements and structural health monitoring. The discrete nature of the measurements is again a limitation in the current technologies. Hence, it is envisaged in this work to explore phonon interaction mechanisms using ultrasonic wave-mixing approach for the isolation of information along the length of the waveguide. The phonon interactions are known to exist for ultrasonic waves, but have been explored to only a lesser extent with applications in the characterisation of materials.

The CNDE at IITM along with National Metallurgical Laboratory in Jamshedpur has been working in this field over the past 5 years. The use of the phonon interactions for measurements of physical parameters and for health monitoring is a relatively new and unexplored field.



*The FEM simulation of an ultrasonic waveguide transmitter and fiberoptic receiver concept*

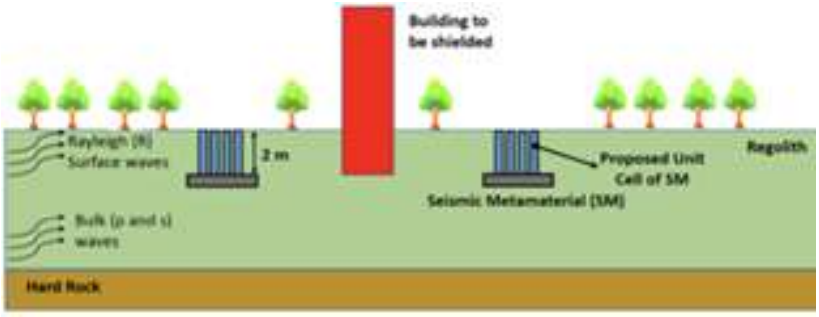
## Hybrid Fiber-Optic & Ultrasonic Waveguide Techniques

The use of hybrid approach where the Ultrasonic Waveguides as a transmitter while employing Fiber-Optic sensing as a receiver unit will be explored and developed in this project. This has never been attempted before, but has several applications such as in an explosive environment where remote transduction is necessary for safe interrogation of the components.

# Theme 2: Structured Materials for Imaging

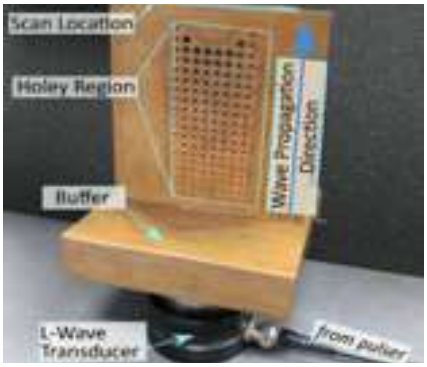
## Metamaterials-based Ultrasonic/Acoustic imaging & sensors

The CNDE group has been a leader in the field of employing meta-crystals and meta-materials for realizing extraordinary properties in imaging, vibration damping and mode filtering. This sub-theme will take a leap forward from these efforts, to achieve next generation sensing and device capabilities. In keeping with the goals of NDE 5.0, this sub-theme will explore technologies that can be integrated and embedded into structural members, such that self-sensing and self-warning capabilities can be in-built into them.




*Seismic Metamaterials for self-mitigation of dangerous surface vibrations*

Topological devices such as material-contrast and step-change lenses will be explored for integration into structural and machine elements, such that using passive excitation consisting of random external vibrations, local defect generation events can be flagged for immediate attention soon after a threshold indication. This process requires studying mechanical filtering mechanisms such that coherent information can be extracted from such random excitations. Once extracted, the signals will trigger an alarm through excitation of electromagnetic indicators for remote logging. The other broad topic that will be studied under this sub-theme, is that of metamaterial-based material sensors for online materials characterization. For example, integration of metamaterial layers into the walls of sensitive locations such as fuel or water tanks will be explored such that the level of toxic/ unwanted contaminants can be self-monitored, triggering an alarm beyond a threshold.

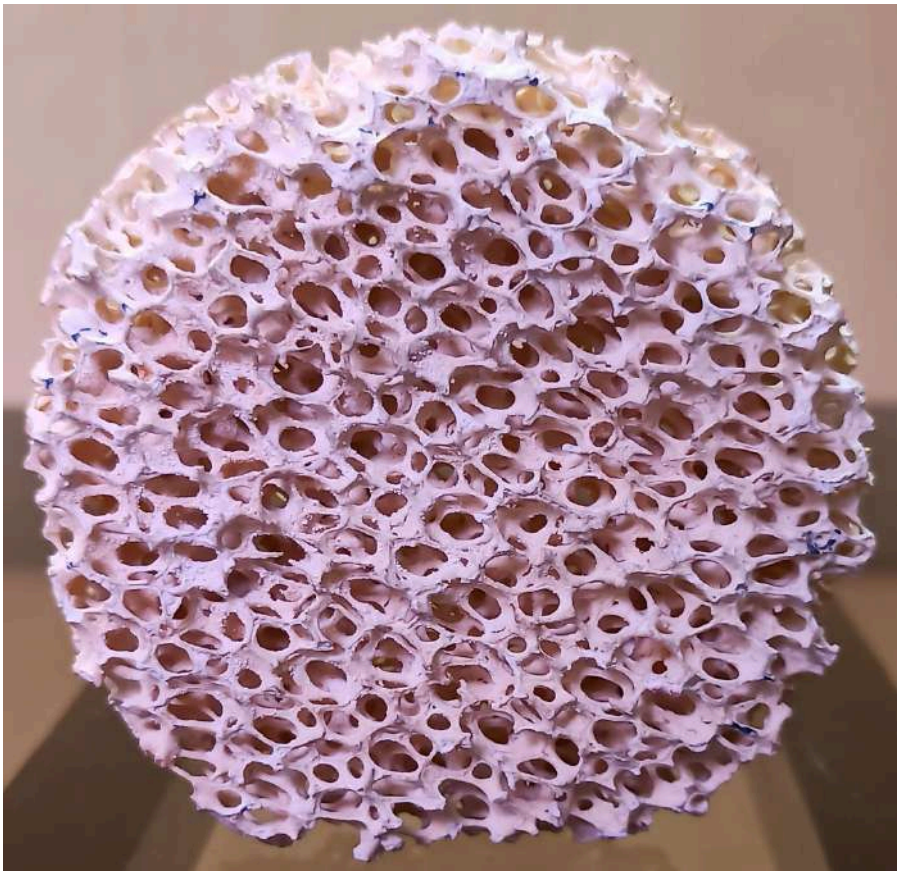



Another example is the incorporation of metamaterial ridges into piping, wiring and cabling to achieve self-sensing and self-warning using passive random excitation, while embedded bandgap layers for blocking vibration and seismic disturbances is the other topic to be studied. These topics also contribute to the overall NDE 5.0 theme of 'ubiquitous and distributed sensing and mitigation'

## Meta-materials-based Electro-Magnetic (EM) imaging & sensors

Conventional microwave and EM NDE employ waveguide-b dielectric and non-metallic composites. Information obtained using microwave sensors are used for determining material properties such as permittivity and permeability, material density, glass transition temperature, level, humidity for real time non-contact process monitoring. Other applications of microwave in the field of NDE are detection of voids, delamination, dislocations and layer thickness measurements in layered dielectric media and non-metallic heterogeneous composites.

The major bottle neck in microwave NDE are the large dimensions and spatial resolution. This can be addressed using EM metamaterial surfaces which can enhance the coupled EM field strength between a sensor and the material under test (MUT). In this proposal, we will explore and develop novel engineered EM metamaterials to enhance the efficiency of the sensors and improve spatial resolution of microwave imaging.



# Theme 3: Edge Intelligence & Soft-Sensing

## AI enabled super-fast computations

Currently, numerical computational methods such as Finite Element, Finite Difference, Finite Volume, Boundary Element, etc. are extensively used for calculations. However, the speed of computation and the resource requirements will necessitate the off-line mode of computation. In this proposed work, a disruptive approach to exploring the translation of these numerical calculations to the edge computing platforms such as GPUs and TPUs will be demonstrated for very sophisticated calculations. This is a relatively new paradigm with very limited literature available.

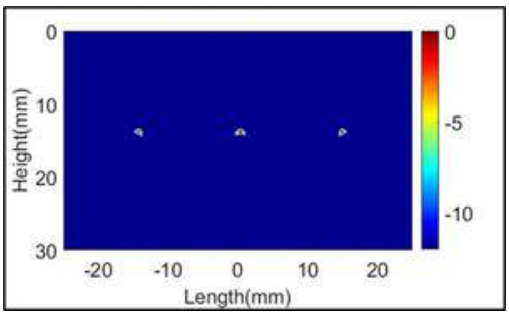
The CNDE group has been developing this approach over the past 2 years and have achieved more than 7 orders of magnitude reduction in computational time and with very small computational resources for classic problems in wave propagation, PAUT, and IR thermal imaging. In this work, the numerical models are used to train a sophisticated AI engine using a range of computational models. The trained AI engine is expected to then provide, computationally efficient, calculations in edge computing platforms. Up until now, about 1000% extrapolation has been demonstrated on 2D and 3D Problem sets. Using this approach, edge problem solving will be explored to enhance the last mile intelligence at the sensor end and provide real-time problem solving capability to the sensors.

This, to the best of our knowledge, has never been attempted.

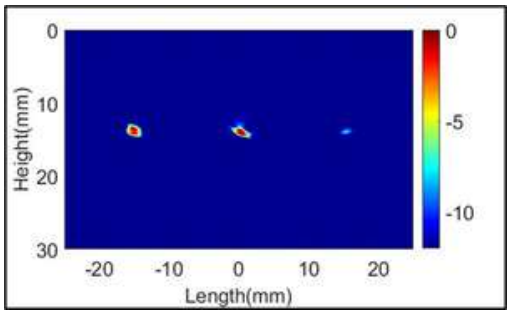
Physics and Data based Soft Sensing Algorithms and Devices

- The technology of soft-sensing using physically based numerical models will be explored in order to enhance the fidelity of the sensor data. Currently, the spatial density of the data points often defines the fidelity of the information. However, using physical based models, it is expected that the edge computed information can enhance the spatial density of measurements. It is also expected that this will also be useful to extrapolate the information to locations where measurements cannot be made due to the hostile environment or limitations in access. Again, very limited literature is currently available in this domain.

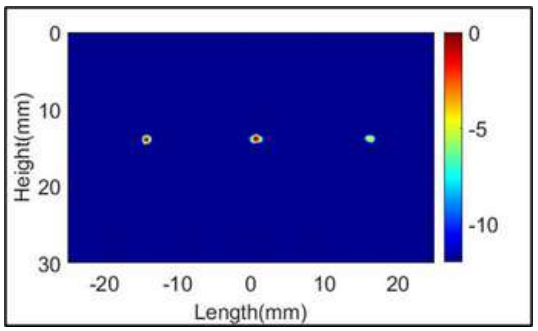
Phased Array Ultrasonic Images using FMC/TFM Approach of 3 SDHs




FEM numerical method ( 3800 minutes)




CNDE's DPAI method (12 minutes)




Experiment Result

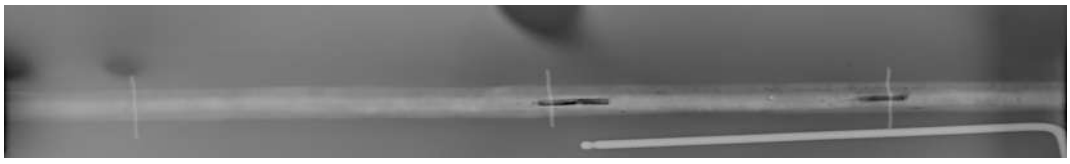
# Theme 4: Wide Inspection Technologies

## Wide Multi-spectral Imaging (Ultrasound, THz, IR, X-ray)

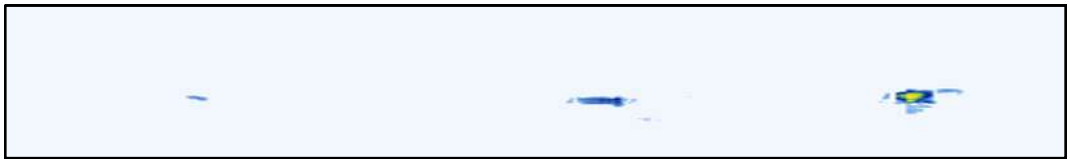
Generating the image of an object in 2D and 3D using acoustic/elastic/electromagnetic waves has emerged as an invaluable aid for non-destructive evaluation of the object. Highly resolved images result only when spatial and temporal information are rich on multiple scales. Spectral and spatial resolution in imaging are constrained by bandwidth and field of view on the one hand, and illumination and collection efficiencies on the other. At every wavelength employed, sub-wavelength features are desirable but difficult to obtain through conventional imaging modalities. Obtaining well-resolved images is currently not feasible in all the spectral domains and time-consuming wherever it has been recently demonstrated.

The plan at CNDE would be to develop generic computational imaging tools in conjunction with metamaterial components and machine learning algorithms to address the challenges.

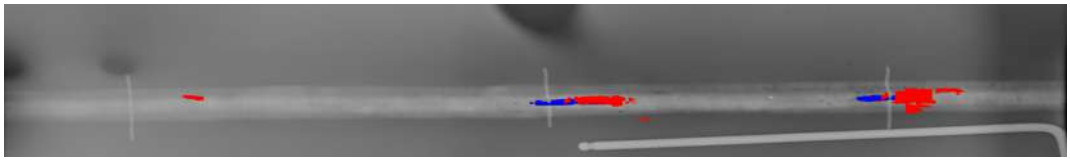
Multi-Modal Data Fusion (Digital RT and PAUT) for Weld Inspection



RT Image



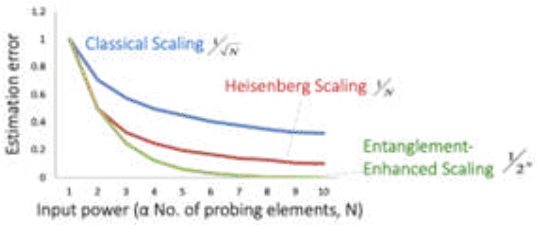
PAUT-Scan with Probe on one side of the Weld (270º)



Fused RT&UT Image

# Quantum Phononics

The concept of imaging at depths with high resolution has been of much interest to scientists for decades. However even today, most technique available for very high resolution imaging are restricted to ultrathin materials or surfaces. Moreover typically being based on electromagnetic waves, such methods also often carry the risk of ionizing radiation when the depth of penetration has to be increased. The Phonon spectrum offers rich opportunities for imaging and communications at depths, but suffers from the challenge of poor resolution and noise.




*Plot showing the improvement in estimation performance vs. Signal strength using quantum sensing technologies*

Although the use of metamaterials in recent years has allowed breaking down resolution limits (with CNDE itself contributing the best reported values in the ultrasonic domain at 1/72 of the operating wavelength), ultimately the only way to reach subnanometer resolutions is to reach the supra-hypersonic frequency range. However at these frequencies, we are hobbled by shot noise in the source, besides material noise inside the medium being interrogated. Here is where quantum technologies offer enormous promise, where single or 'antibunched' Phonon excitations are expected to overcome the shot-noise, while entanglement offers the tantalizing prospect of noise-cancelled imaging.

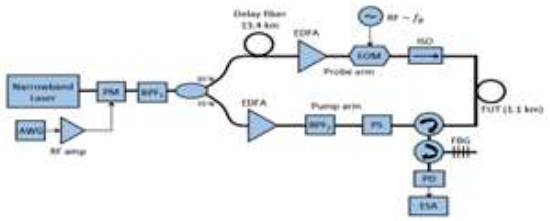
Quantum Phononics may finally enable us to image at subnanometer resolutions at micrometer depths. On the other hand, with their natural ability to harness waste heat and vibration, Quantum Phononic networks could be elegantly integrated into existing structures and devices. With Phononic Quantum computing and logic devices, pervasive integration of ultrahigh precision sensing is a tantalizing possibility. The investigations will involve the development of sources for single and entangled phonons, as well as phononic logic and computing devices.

# Theme 5: Remote Large Area Inspection

## Intelligent Infrastructure (civil and industrial)

CNDE is a world leader in developing health monitoring solutions for both civil and industrial structures. This sub-theme will massively build upon CNDE efforts in embedded waveguided approaches for achieving intelligent and self-sensing building materials. Sleeved rebar structures already used extensively in concrete structures will be the primary vehicle of these studies.

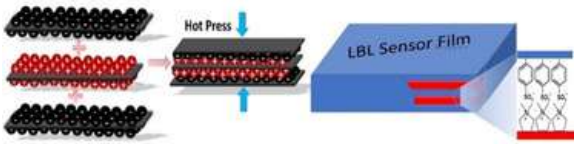
By introducing de-sleeved regions at periodic target locations, and making using of the rebars as acoustic waveguides, this project will study the possibility of online monitoring of the health of concrete and composites. In applications ranging from bridge piles, building pillars, composite pipes and aircraft wing assemblies, this sub-theme will study the introduction of such 'de-sleeve sensors' for periodic internal imaging of the structures. The investigations will involve the embedment and study of single, periodically and randomly multiple sleeve-de-sleeve waveguides into structural members.



*Schematic diagram of external modulation-based Brillouin Optical Correlation Domain Analysis scheme*

## Nano-structured coatings

The use of nano-structured multi-layered coating is proposed here using CNT and Graphene hybrid nanostructures with magnetic and conducting nano-particle decorations. The different layers of the coatings will be used to provide directional property measurements such as strain. The CNDE at IITM has previously reported on developing these hybrid structures using CNTs that connect Graphene sheets to provide unprecedented strain measurement gage factors exceeding 115. This work was the first-ever report that exceeded a gauge factor of 100. The CNDE group has now explored these high-strain measurements into wearables, including gloves, fabric, etc. In this proposal, it is envisaged that this work will be extended in developing sensor coatings that will provide a complete stress state on the surface using directional strain sensing using the decorated nano-structured materials to be developed.

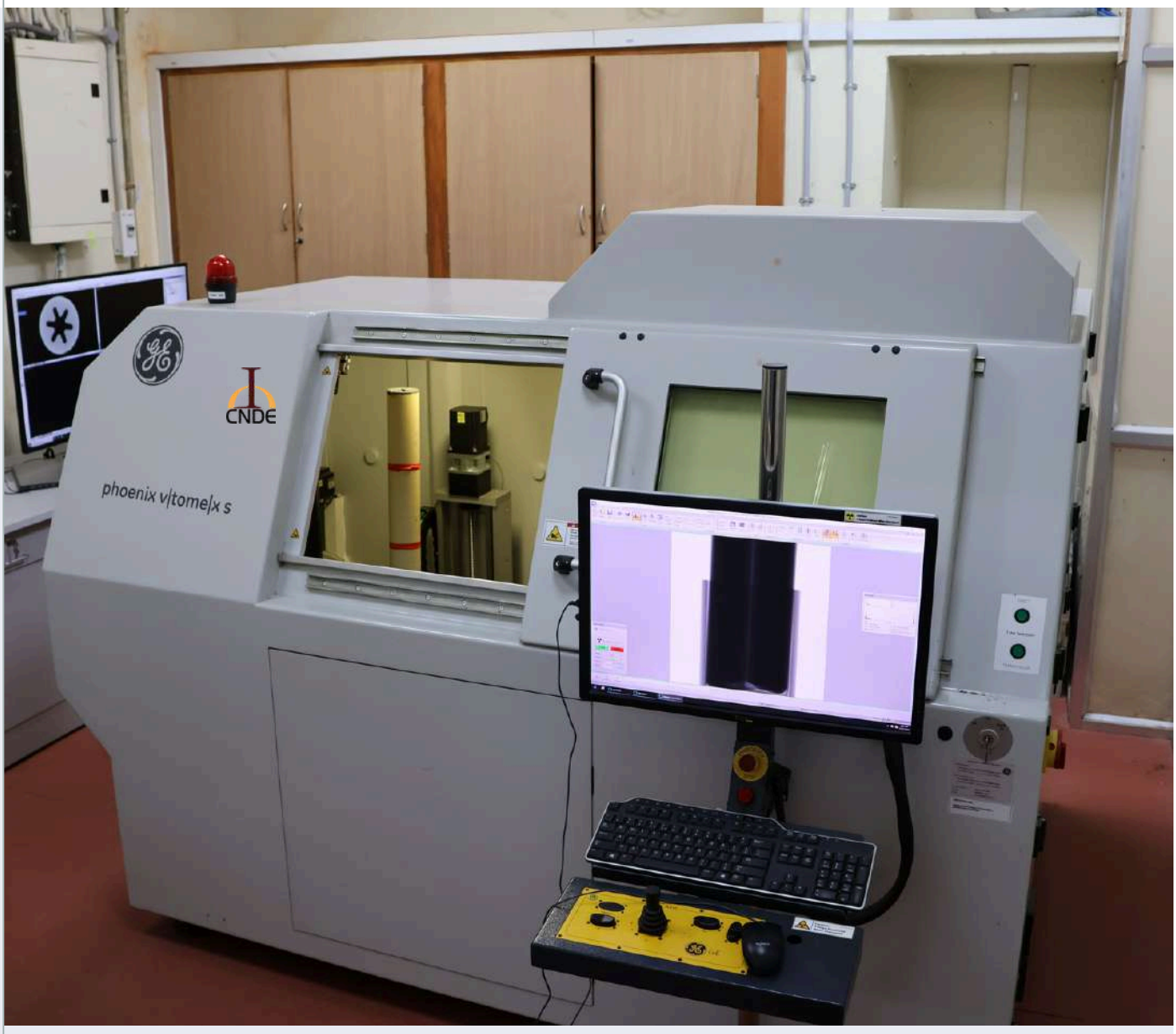



*Schematic of layer by layer polymer nanocomposite.*

# KEY
## Infrastructure 2023-2024

# Experimental Facilities at CNDE

The Centre for Non-destructive Evaluation (CNDE) at IITM addresses the critical research, development, and training needs of a wide range of national and multinational industries and organizations. Industries involved in infrastructure, aerospace, energy, transportation, medical and archeology, will significantly benefit from the proposed activities. The Centre for Nondestructive Evaluation (CNDE) will focus on the research and development of new theories and techniques for use in quantitative NDE as well as the dissemination of knowledge in the field of NDE.




Micro and Nano Computer Tomography

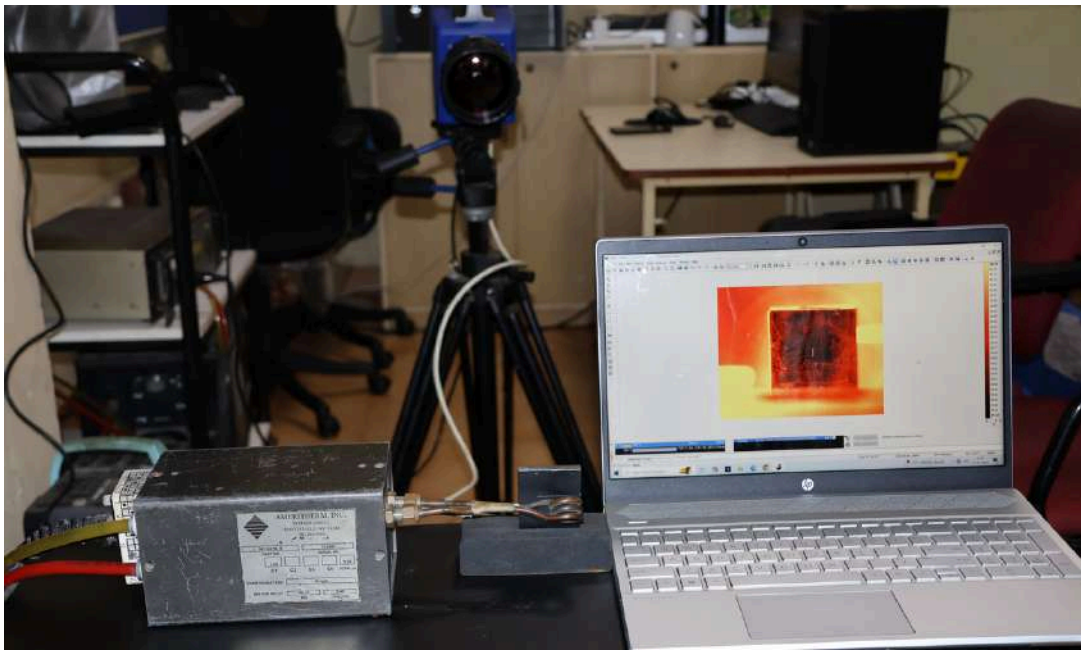
# key instruments

CNDE capabilities included modeling and experimental aspects of NDE. There are several faculty from various departments who are involved. The CNDE has a core facility located in a 4400 sq. ft. area that includes 15 labs, 1 classroom and 1 conference room and a reception. The key instruments includes

- FLIR and CEDIP IR Cameras
- Ameritherm Induction Heating Source.
- LTI Electronic Shearography System,
- Ultrasonic C-scan systems,
- High frequency (200 MHz.) Pulse Receiver systems,
- RITEC SNAP and RPR 4000 systems
- Panametrics 5052 PR high amplitude (10MHz, 900V) pulser/receiver systems,
- High Temperature Ultrasonic Measurement System
- Air Coupled Guided Wave Measurement Systems
- Elastic Moduli Evaluation System
- Ultrasonic Guided Wave Experimental System
- Laser Ultrasound System
- IR Imaging System
- Micro-scale IR Imaging Bench
- GSSI Ground Penetrating Radar System at 2.6 GHz.
- 20 GHz. Agilent Network Network Analyser with workbench up to 12 GHz.
- AE 4 channel system
- 230 kva digital x-ray systems with Flat Panels from VIDISCO and RadIcon
- MPI and LPI facilities
- HP Workstation Clusters for modeling and several PC based Data Acquisition System

# key instruments

## Induction thermography

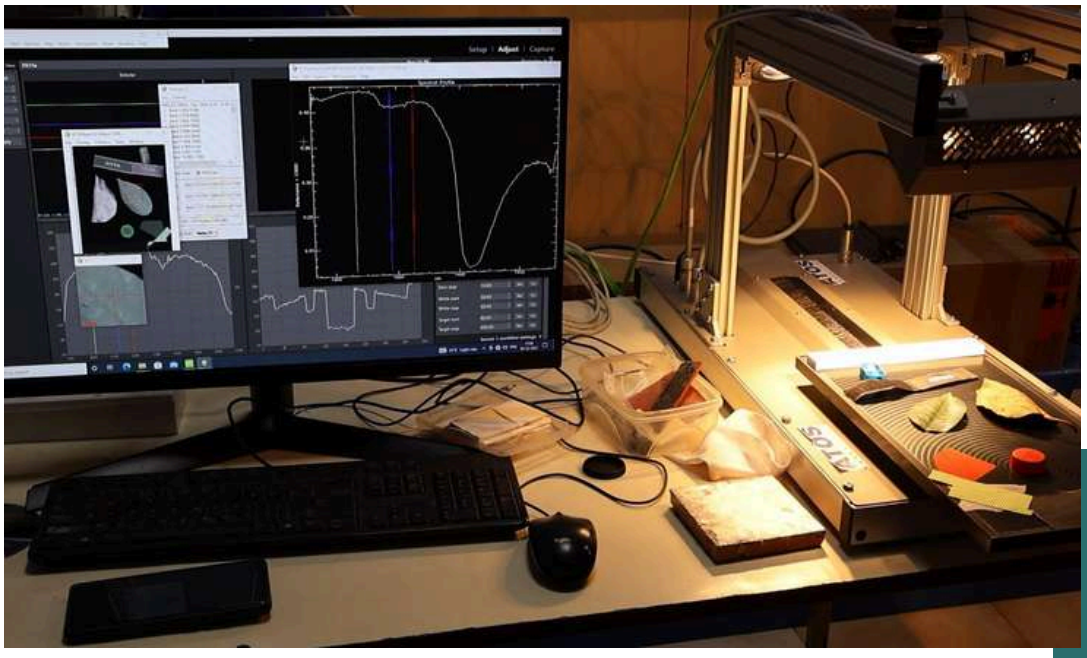


## Phased array UT

# key instruments

Ultrasonic C-scan systems,

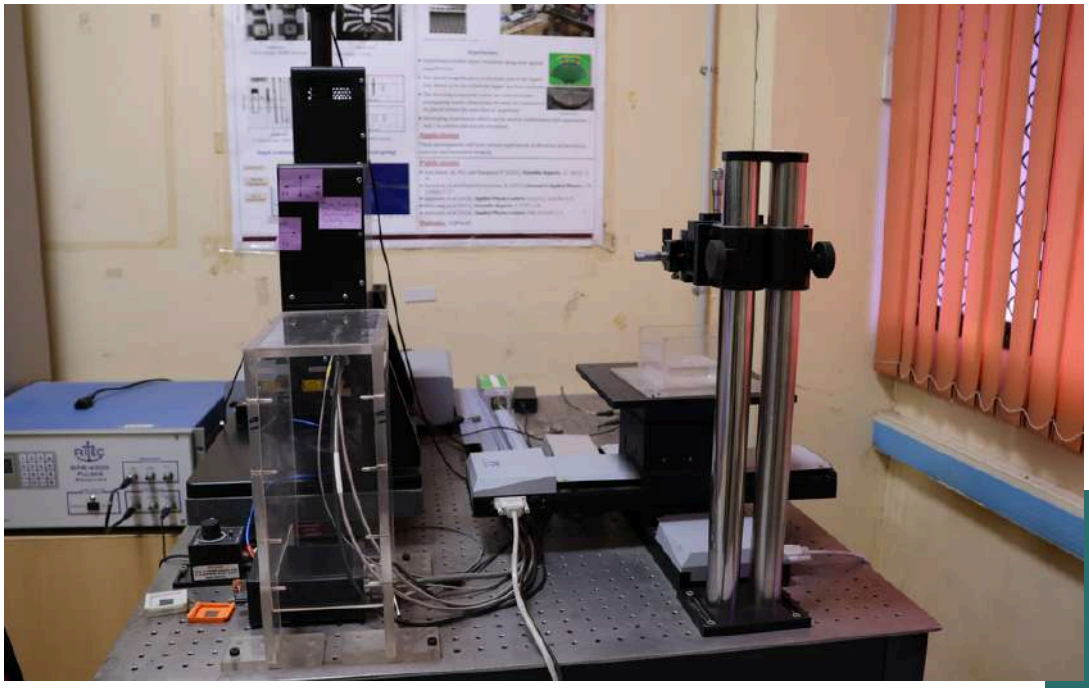

Hyper spectral imaging



# key instruments

## Staggered EMAT pipeline Scanning

## Acoustic Microscopy and Micro-focal Laser.



key instruments

## Pulsed IR Thermography

The ancillary facilities within the IITM campus that are associated with the CNDE include

- The Micro-electronics Laboratory with capability to fabricate, characterize and test MEMS
- Computer Aided Engineering Laboratory with several workstations, and softwares including ANSYS, NASTRAN, DYRAD, PRO-E, IDEAS, AUTOCAD, ADAMS, MEMSCAP, etc.
- Magnetics Research Laboratory with expertise in the area of magnetostrictive and magnetoresistive sensors.
- Microwave Characterization Laboratory with expertise and facilities for developing microwave NDE techniques and sensors.
- Applied Optics Laboratory with several lasers including Q switched Nd-YAG
- X-ray Diffraction Laboratory for stress measurements
- Electron Microscope Laboratory for SEM and TEM studies
- Composites Technology Centre with extensive fabrication capabilities

# Students and Researchers

# CURRENT PROJECT

Kaushik V N

Research Scholar

## Arista: The future of railway track inspection

Guide: Prof.Krishnan Balasubramanian

As rail operation standards advance to meet societal needs. The incredible demands lead to increase rail track damage, due to the large forces from powerful locomotives with traction control systems, increasing frequency more high-speed passenger vehicles, and larger loading forces from increased freight limits. Maintaining railway tracks is essential for safety and efficiency, but traditional inspection methods are often workforce-intensive and prone to human error. These methods can overlook critical flaws, leading to potential safety hazards and costly maintenance issues.
We provide an innovative railway track inspection method using autonomous mobile robots equipped with multi-sensor technology. This approach allows for predictive maintenance, improved inspection accuracy, increased operational efficiency, and data-driven maintenance, all without disrupting traffic or maintenance activities.

The autonomous mobile robot features an ultrasonic flaw detection system for inspecting internal rail fractures. It also has a laser profiler sensor to detect track buckling and an AI-powered vision-based inspection system for visual track inspections. By leveraging big data from multiple sensors and storing it on a dedicated cloud platform, helps in precisely detect structural flaws in the tracks. This predictive capability enables timely maintenance, minimizing accident risks and extending the lifespan of railway tracks. The robot works during periods when the track segment is free of trains, ensuring smooth operations without causing blockages. Its redundant system design boost's reliability, making it a state-of-the-art solution for modern railway maintenance.


Autonomous mobile robot for track inspection


Loheshwaran Chandran

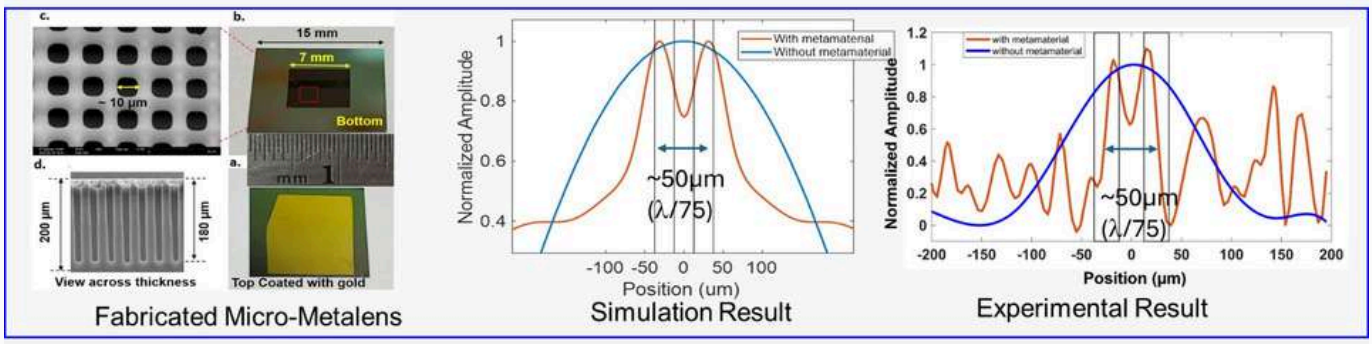
Research Scholar


# Super resolution imaging using metamaterials and array transducer

Guide: Prof.Prabhu Rajagopal

Structured channel metalens (SCM) have excellent application in super resolution imaging. Several demonstrations have shown deep subwavelength imaging in both optics and acoustics using slits or sources as imaging targets and only in a through transmission configuration. However, in the context of Non-destructive Evaluation (NDE), imagining defects inside the sample close to the surface is of much interest. Also, in applications where access to both sides of the material is limited or impossible, such as in structural testing scenarios, pulse-echo becomes a more practical choice than through transmission technique. Hence, the extension of metamaterial concepts from research to productization has gained more attention recently.

This work presents a novel methodology to image defects inside samples using a narrow band conventional phased array probes to capture the amplified evanescent fields transmitted through the subwavelength features of SCM in both pulse-echo and through transmission modes. Simulations are performed to optimize the structured channel metalens. In finite element models, ultrasonic waves are assumed to impinge on the side drill holes (defects) in a normal incidence both in pulse-echo and through transmission configuration. A line-scan image at the receiver location is generated based on the captured waves according to the pitch of the conventional phased array probes past the metalens. The simulations are validated with experiments conducted in a similar fashion.




Micro metamaterial based super resolution imaging

Gokula Vishnu Kirti Damodaran

Project Staff

# Shobot " Human assistive robot for shop floor environment"

Guide: Prof.Prabhu Rajagopal

An AI-integrated, multipurpose collaborative robot designed to operate fluidly within human-centric environments. Our core focus lies in providing intelligence to the robot to perceive its surroundings, engage in natural communication with users, and perform tasks autonomously.

We primarily work on two verticals:
1. Robotic Arms – Shobot's robotic arms are built to handle and manipulate, in a human collaborative dynamic environment
2. Autonomous Mobile Robots (AMR) – Our AMRs are designed for independent navigation, moving safely within shared spaces and effectively executing various tasks.
Developed usecases include AI integrated Shopfloor Assistive robot (Shobot) Shopping assistive robot for a retail environment.

Pictures of the Shobot in the arena while picking the carton box from the shelf

Srijan Tiwari
Research Scholar

# NDE- All in One Platform (Enhancing NDE with Digital Ecosystems: Bridging Gaps in Procurement, Training, and Asset Management )

**Guide: Prof.Krishnan Balasubramanian**

Operational challenges, such as manual inspection processes, fragmented job search platforms, record-keeping errors, and inadequate traceability, impede the industry's growth. Our platform digitizes these processes, ensuring compliance with industry standards such as ISO 17025 and enhancing inspection quality.

Aligned with Industry 4.0 and NDE 4.0 principles, our platform integrates automation, AI, and data analytics into NDE processes, fostering innovation and improving resource allocation. By offering global reach and specialized features, the platform supports career growth and addresses regional gaps in emerging markets.

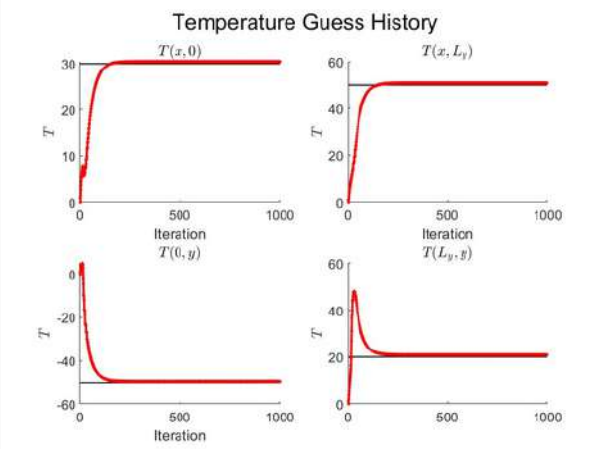

TIQ World Platform

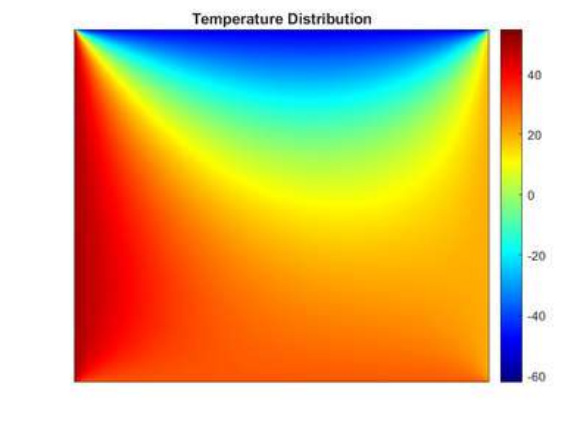
Abhijeet Balaji
Project Staff

# NDE 5.0 - Industrial Assets and Process Management

Guide: Prof.Krishnan Balasubramanian

Thermal methods of non-destructive evaluation are extremely valuable tools in fault diagnosis and crack detection. They lend themselves extremely well to passive monitoring and control. However, in many cases, it is difficult to fully map the thermal field. Furthermore, infrared thermography cannot access all parts of compact and complex assemblies. The objective of my research is to investigate the application of inverse heat transfer methods in non-destructive evaluation. In other words, it is an attempt to estimate the temperature field using measurements at few points/areas.




Example of inverse heat transfer method: estimating boundary temperature values with point measurements from a two-dimensional domain.

Thacker Setu Rameshbhai

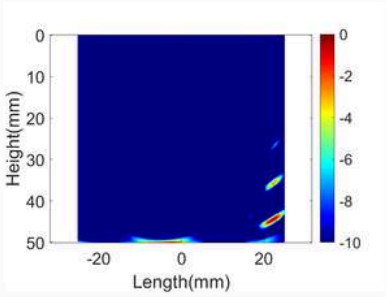
Research Scholar

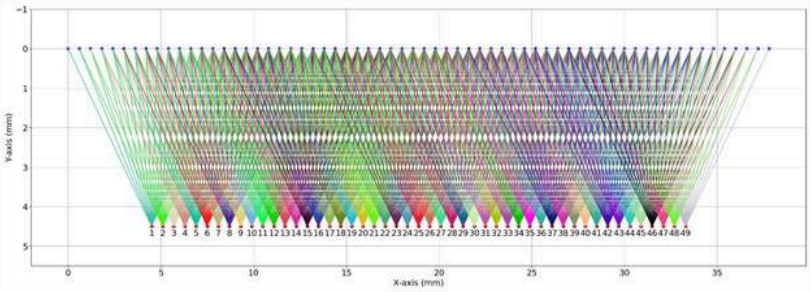
# Eccentric Virtual Array Source Aperture (EVASA) Ultrasound Imaging Technique Using Phased Array Excitation

Guide: Prof.Krishnan Balasubramanian

The EVASA method employs a custom algorithm where array elements transmit ultrasound waves with pre-calculated delay laws, achieving beamforming focused at eccentric virtual sources located beneath the transducer. These virtual sources will focus at particular depth and angle and send a high amplitude wave into material. Once the desired set of eccentric virtual sources is formed within the material, the synthetic algorithms of FMC/TFM can be used to image the regions of the material. The parameters for these virtual sources, including the number, aperture position, and locations within the material, are based on the propagation angle and focal depth, extending up to the near-field distance. Comparative evaluation with FMC/TFM, using metrics such as SNR, API, defect size, and image processing time, shows significant improvements. EVASA is implemented using standard PAUT probes and instruments, requiring only customization in focal laws and reconstruction algorithms.

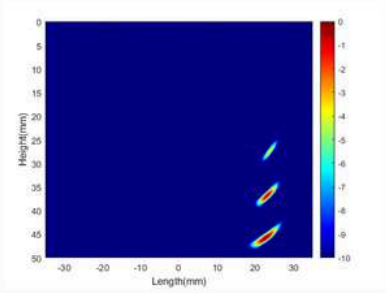
VASA

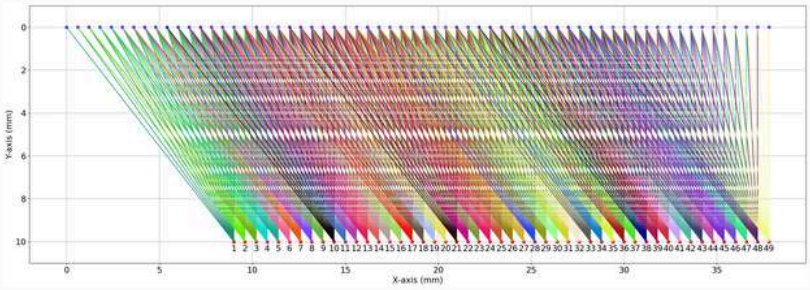



Excitation pattern for VASA of set of element in phased array probe

EVASA



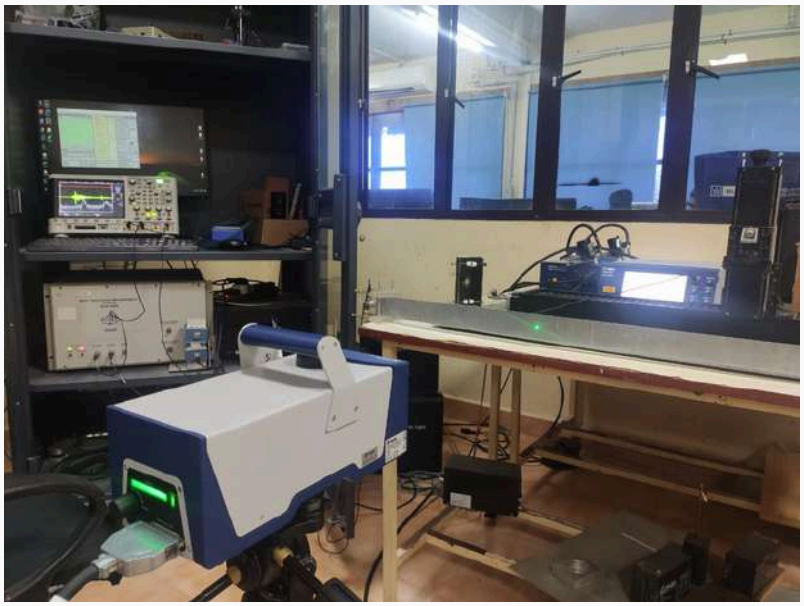

Excitation pattern for EVASA of set of element in phased array probe

Krishnadas V K
Research Scholar

# Nonlinear ultrasonics in guided media and usage of metamaterials

**Guide :Prof.Krishnan Balasubramanian**

During the PhD period, presence of second harmonic guided waves is explored and their significance is studied. Also the studies regarding the usage of metamaterial for harmonic suppression was done as an internal collaboration project. Presently, I'm exploring and having my hands on some new techniques such as PAUT, Thermography, Terahertz imaging as there are these equipments in the lab and taking the opportunity to get familiar with them. I'm also supporting new scholars or staffs who are working in ultrasonics when they are facing issues and solving together.



Experimental setup for nonlinear ultrasonic guided wave propagation on plate.


Sachit Sekhar Patra

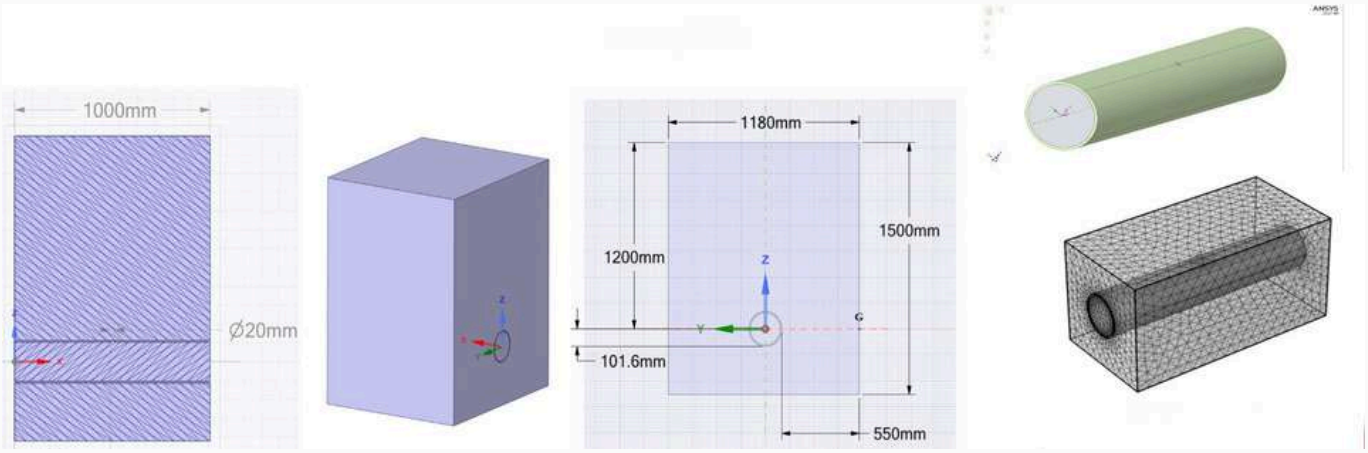
Project Staff


# *Aero acoustic simulation for buried gas pipelines.*

**Guide:** Prof. Balaji Srinivasan

Advanced aero-acoustic simulations within a soil medium to evaluate sound pressure levels at various sensing points. This involves systematically varying key dimensional parameters to understand their influence on acoustic behavior. The simulations utilize a comprehensive suite of ANSYS modules, including Fluent for fluid flow analysis, Structural for mechanical response, Harmonic Acoustics for acoustic wave propagation, Harmonic Response for frequency-domain analysis, and the Coupled Field Transient module for integrated multi-physics simulations.

The results from these analyses, captured in the time domain, are seamlessly integrated into a Distributed Acoustic Sensing (DAS) system. This integration enhances the system's capability to detect gas pipeline leakages at an early stage, thereby significantly improving the safety and reliability of pipeline operations. Sponsored by GAIL, this project emphasizes cutting-edge techniques in pipeline monitoring and highlights the critical role of simulation-driven approaches in addressing complex engineering challenges.




Acoustic simulations of gas pipeline leakage buried under soil.

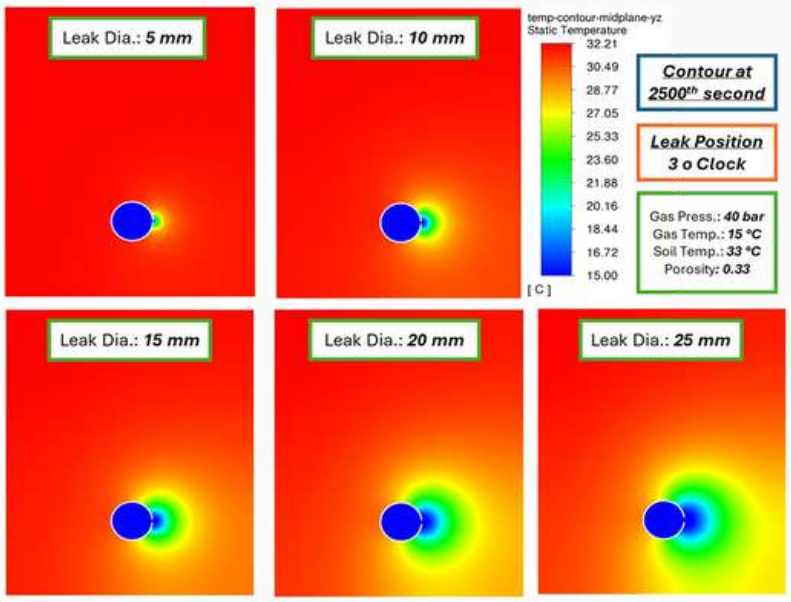

Arsath Abbas

Project Staff


# Development of fibre optic based intrusion and leak detection for gas pipelines

Guide: Prof. Balaji Srinivasan

GAIL Project - To ensure the safety of GAIL natural gas pipelines running more than 15000 kms, a leakage and intrusion monitoring system based on Distributed Acoustics Sensing DAS and Distributed Temperature Sensing DTS using optic fibre cable has been developed. The lab scale DAS and DTS equipment is being built and experiments have been conducted.




Temperature Contour (side section view) at 2500th second for 3 O Clock leak position for various leak sizes in high pressure pipe

Vinay Mudapaka

Research Scholar

# Design and development of the high temperature EMAT sensors for monitoring continuous casting process of steel

Guide: Prof.Krishnan Balasubramanian

The continuous casting process is a critical step in steel manufacturing, where real-time monitoring is essential to ensure product quality and process efficiency. However, the extreme temperatures and harsh environmental conditions pose significant challenges for conventional sensing technologies. This project focuses on the design and development of high-temperature Electromagnetic Acoustic Transducer (EMAT) sensors, tailored for monitoring the continuous casting process of steel. By leveraging the principles of non-contact ultrasonic wave generation and detection, the proposed EMAT sensors are engineered to operate reliably in elevated temperature environments. The research emphasizes sensor material selection, optimization of transduction efficiency, and thermal resilience to address the unique challenges posed by steel casting. Successful implementation of these sensors will enable enhanced process control, defect detection, and improved operational safety, paving the way for advancements in high-temperature industrial sensing applications.


High temperature EMAT sensors

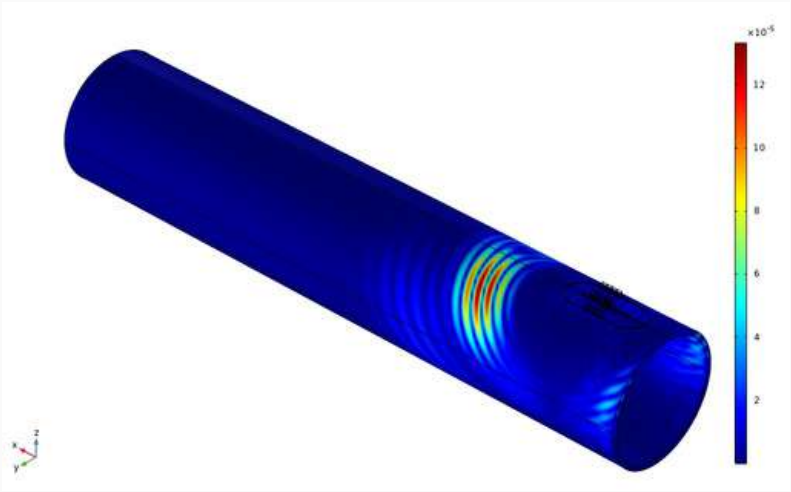
Pranaydeep Garewal

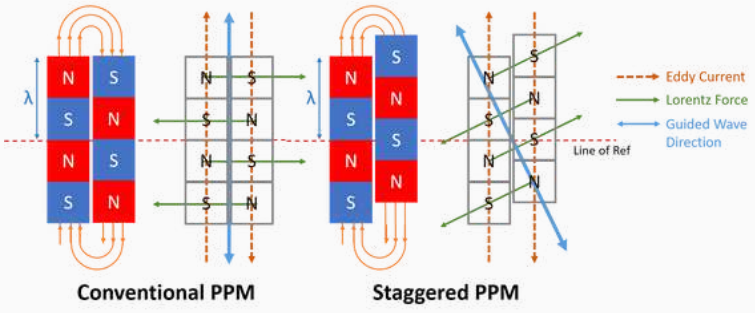
Research Scholar

# Pipe Inspection using Ultrasonic Guided Waves with Staggered EMAT

Guide: Prof.Krishnan Balasubramanian

Large pipelines are utilized for a variety of applications in practically every industry. The pipe beneath the saddle support is the most vulnerable to corrosion, and since these pipes are working in severe environments, corrosion may occur that can result into wall thinning of pipe. The research focuses on the design and optimization of Staggered Electromagnetic Acoustic Transducers (EMATs) and the application of guided wave cut off property to determine the remnant thickness in order to analyze these corroded pipes under saddle support system.






Wave propagation with Staggered EMAT

Kaushal Jagannath Bachhav

Research Scholar

## Guided Wave Phased Array Imaging for Defect Detection

**Guide: Prof.Krishnan Balasubramanian**

My project focuses on defect detection in thin plates using guided wave-phased array imaging. I worked on an algorithm based on the Full Matrix Capture-Total Focusing Method (FMC-TFM) for ultrasonic guided wave signal processing and the Virtual Array Source Aperture (VASA) methodology to enhance defect detection accuracy. The project involved the selection of optimum parameters such as mode and frequency, conducting sensitivity and resolution analysis, and validating results on a steel plate for effective defect visualization and characterization.

Akhil B S

Research Scholar

## Non Collinear bulk wave mixing

**Guide: Prof.Krishnan Balasubramanian**

Nonlinear ultrasonics has emerged as a sensitive tool for evaluating subtle material changes and detecting early-stage damages in engineered structures. Building on our earlier work, where the quality of thin adhesive bonds was assessed by correlating bond quality to the third harmonic generation of the fundamental shear horizontal (SH) mode—excited using a custom-designed magnetostrictive transducer—this study is planned to extend the methodology to thick adhesive bonds. A nonlinear, non-collinear wave mixing approach is developed to enable localized inspection of thick blocks. This study explores the sensitivity of nonlinear wave interactions to detect localized defects and assess bond integrity. The research involves the design and fabrication of a specialized experimental rig capable of generating and detecting interacting wave modes in bonded structures. A complementary numerical model is also under development to simulate nonlinear wave interactions. The numerical modelling results of wave mixing on aluminium and mild steel samples for various mix frequencies align well with the experimental observations. The findings from the validated numerical model highlight the potential of wave mixing as an effective and localized method for assessing material nonlinearity.

Kartik Ramesh

Research Scholar

# In-situ High Temperature Phased Array Ultrasonic Testing for Characterisation of Solid/Liquid Interface during Continuous Casting of Steel

**Guide:** Prof.Krishnan Balasubramanian

In this research work, phased array ultrasonic testing method is used for detecting the location of solid-liquid interface when steel is being casted in continuous casting process. The knowledge of solid-liquid interface during continuous casting process can help in controlling the production rate and process parameters. The phased array ultrasonic imaging uses Full Matrix Capture algorithm to acquire the ultrasonic A-scan data from the steel when it is solidifying from very high temperature and just came out of caster. Total Focusing Method uses this elementary A-scan data and plot a two-dimensional image in distance domain where location of solid-liquid interface can be seen. The phased array ultrasonic probe is protected from direct contact with high temperature steel surface. The Alumina (A1203) and Silicon dioxide (SiO2) plates are used as a wear cap between probe and solidifying steel slab. A circulating cooling water mechanism is also used to provide proper cooling to the probe assembly. FEA simulations and experiments are performed to get the optimum thickness of wear cap plates to have maximum time of contact of probe assembly with solidifying steel. Effect of thickness of wear cap plates on ultrasound and its effects on accurate location of solid-liquid interface are also studied.

Rahul Kumar Pandit

Research Scholar

# Development of a Noise-Based Passive Structural Health Monitoring System for Composite Structure

Guide: Prof.Prabhu Rajagopal

In this project, we developed a passive, noise-based Structural Health Monitoring (SHM) technique for composite materials. The focus was on creating a reliable, power-efficient method suitable for use in harsh environments where access to power is restricted. Using a Piezoelectric Transducer (PZT) sensor, we captured the diffused wave field within the composite structure, allowing us to monitor its integrity without active excitation.

A key innovation in this project was the application of cross-correlation and a discrete wavelet transform de-noising technique. This approach enhances SHM accuracy by filtering out unwanted noise, thereby improving the clarity of B-Scan imaging for regions of interest. The method was validated through experiments involving an external noise source—compressed air, manually sprayed onto the sample. We then applied a cross-correlation analysis on out-of-plane displacement data collected from two locations on a Glass Fiber Reinforced Polymer (GFRP) sample. This analysis allowed us to retrieve the Green's function, demonstrating a strong correlation and confirming the method's validity through comparison with active wave propagation. While the results were promising, challenges remain in achieving consistent wave field distribution and frequency stability across the composite. This project marks a significant step toward creating passive SHM systems for composite structures, offering a feasible solution for environments where continuous monitoring is critical but power sources are limited.

Sreehari K C

Project Staff

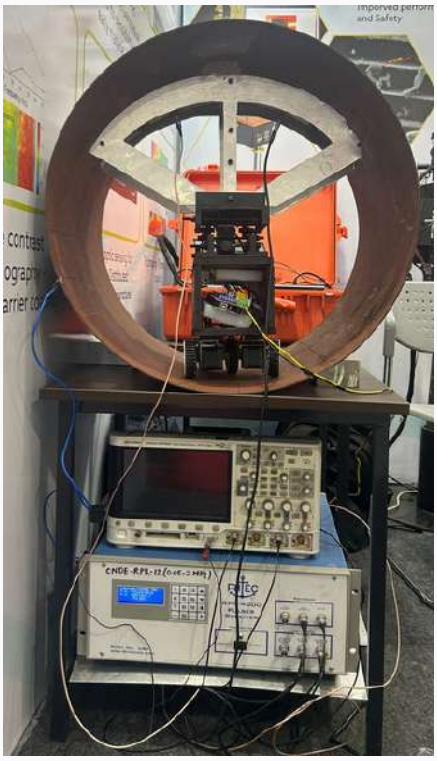
# Super-Resolution Ultrasonic Imaging Using Structured Channel Metamaterial Lenses

**Guide:** Prof.Prabhu Rajagopal

This project focuses on leveraging acoustic metamaterials, specifically metalenses, to achieve super-resolution ultrasonic imaging for biomedical applications. Tissue-mimicking phantoms were fabricated, embedding sub-wavelength discontinuities to simulate microscopic biological features. Structured channel metamaterials were employed, and the configuration successfully achieved imaging resolution down to one-third of the operating wavelength, surpassing the Rayleigh diffraction limit. The findings demonstrate significant potential for non-invasive, high-resolution medical diagnostics and advanced biomedical imaging research.

# Evaluation of Welding Defect and Remnant Thickness in Steel Pipes Using Shear Horizontal Ultrasonic Guided Waves with EMAT

**Guide: Prof.Prabhu Rajagopal**



Experimental Setup for Non-Destructive Testing of Steel Pipes Using Ultrasonic Guided Waves

Industrial pipeline systems are commonly used to transport oil, gas and petrochemical products. In-service inspection is required to avoid catastrophic failures and to guarantee the safe operation of pipelines.

Testing large structures using conventional bulk ultrasonic wave techniques is slow because the test region is limited to the area immediately surrounding the transducer. Therefore, scanning is required if the entire structure is to be tested.
Also, A high proportion of these industrial pipelines is insulated, so that even external defects cannot readily be detected without the removal of the insulation which in most cases is prohibitively expensive. There is therefore a need for the development of a quick, reliable method for the detection of defect under insulation.

This study aims to investigate the propagation characteristics of Shear Horizontal (SH) ultrasonic guided waves in steel pipes using Electromagnetic Acoustic Transducer (EMAT) technology, with a specific focus on weld defect and pipe wall remnant thickness.


Srinithya Nerella

Research Scholar


During my MTech, i design experiments and set up EMAT systems to evaluate SH wave propagation, weld defects, and remnant thickness in steel pipes.

Conduct experiments, collect data, and analyze wave behavior under various conditions. Simulation & Validation: Use tools like Abaqus to simulate SH wave propagation and validate results against experiments.

Performance Evaluation: Assess the accuracy and reliability of EMAT-based SH wave techniques for real-world defect detection, including insulated pipes.

## Humphrey A

Research Scholarh

As part of the project, I am responsible for conducting experiments and setting up EMAT systems to evaluate shear horizontal (SH) wave propagation, weld defects, and remnant thickness in steel pipes. I will perform experiments, collected data, and analyzed wave behavior to identify defects. Using Abaqus software, I will simulate SH wave propagation and validated the simulation results against experimental data to ensure accuracy and consistency. Finally, I will do documentation of the findings and preparation of detailed project reports.

## Majji Gopi Krishna

Research Scholar

## Finite Element Modelling and Simulation of Human Tissue with a Focus on Sub-Wavelength Resolution in Viscoelastic Materials for Ultrasonic Inspection

Guide: Prof.Prabhu Rajagopal

This project aims to develop a finite element model of human soft tissues, incorporating their viscoelastic properties to enhance the resolution of ultrasonic imaging beyond the Rayleigh diffraction limit. By integrating metamaterials into simulations, the study seeks to achieve sub-wavelength resolution, enabling finer detail and greater accuracy in ultrasonic inspection. The findings have the potential to significantly improve diagnostic capabilities in medical imaging.

# Ind-RoPRIT: Roller Probe based Reformer Inspection Tube


Ind-RoPRIT

Guide: Prof.Krishnan Balasubramanian

Reformer tubes are vital components in refining and petrochemicals industry. They are utilized in the functioning of the hydrogen generation units in refineries. Due to the high operating temperature of hydrogen reformer furnaces, these tubes experience internal stresses leading to creep damage within the tube walls. Over time, the creep damage mechanisms degrade the structural condition of the tubes eventually leading to rupture.If there is a suddenrupture, there is a likelihood of an unscheduled shutdown of the hydrogen generation unit. When it comes to determining creep damage for reformer tubes, there is an increasing need for operators to use periodicconditional based assessments.

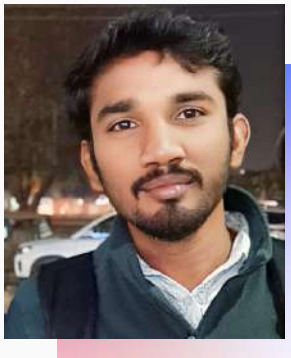
NDE inspection systems are increasingly utilizedin multiple industries as it allowsthem to conductperiodic inspections or continuous monitoring of components to identify defects such as cracks or voids. Despite this, each NDT technique has certain limitations.

Center for Non Destructive Evaluation, IIT MADRAS (CNDE) and Indian Oil Corporation (IOCL) are developing an inspection system which utilizes multiple NDT techniques to perform conditional assessments of reformer tubes. A tube crawler unit was constructed with laser sensors, ultrasonic probes, and inertial measurement unit to inspect reformer tubes.

Nischal Ranjan

Project Staff

I worked on this project involving various sensor technologies, including ultrasonic sensors, lasers, and IMU (Inertial Measurement Unit) sensors. My role was focused on the signal processing aspect, where I was responsible for analysing, extracting meaningful information, and plotting the data signals from these sensors.



## Dinesh Kumar G

Senior Software Developer

Project Staff

I worked on the software side of the project, focusing on programming and creating an interface using LabVIEW. LabVIEW is a powerful platform used for system design and instrumentation, and it's especially useful for handling sensor data, automation, and real-time system control.

## Suresh D

Senior Project Engineer

Project Staff

I was involved in the electronic design aspect of the project, specifically focusing on circuit design and circuit routing, which included creating the necessary hardware to interface with the sensors and ensuring that all components functioned seamlessly.

# 2024 Graduates

# *Design of waveguide metamaterial rod and its applications in Linear & Non-Linear Ultrasonics*

**Sandeep Kumar S R**
Ph.D, M.S

*This research explores the simulation and experimental methods for the development of cylindrical waveguides, leveraging metamaterial principles to enhance ultrasonic guided wave inspection. While metamaterials have garnered significant attention over the past two decades, elastic metamaterials had relatively limited success in practical applications, particularly in the field of ultrasonic non-destructive evaluation (NDE). This research work demonstrates the existence of ultrasonic bandgaps in a ridged metamaterial implemented on a circular rod as an example of a new approach to isolate waveguide modes. The study also focuses on enhancing Nonlinear ultrasonic guided waves, which are exciting tools for remote detection of early-stage damage due to their high-sensitivity and long-range propagation features. The research shows a novel technique using a waveguide metamaterial rod as a mechanical filter to suppress unwanted higher harmonic components in the measured signal. The research also demonstrates the subwavelength focusing and imaging of ultrasonic guided waves in cylindrical rod-like structures. This work contributes significantly to the fundamental understanding and practical design of metamaterials, showcasing their potential for advancing ultrasonic NDE technologies.*

## *Multi-modal data fusion of PAUT with thermography assisted by automatic defect recognition system (M-ADR) for NDE applications*

*Multimodal data fusion method for enhanced defect detection and characterization in metals by integrating phased-array ultrasonic testing (PAUT) and pulsed thermography (PT) into a volumetric dataset followed by robust flaw identification and sizing by incorporating Multimodal Automatic Defect Detection (M-ADR) system a Deep Neural Network (DNN) and Bi-Planar Medial Axis Transform (Bi-MAT)*

**Sudharsan P LI**
M.S

## *Dual-mode second harmonic (DMSH) generation in guided media such as plates and cylinders.*

*Thesis work was based on the experimental and simulation work on nonlinear wave propagation in guided media. The thesis describes the existence of novel dual-mode second harmonic (DMSH) for non-dispersive guided wave (GW) modes, such as the SH0 mode in plates and the T(0,1) mode in cylinders. The newly revealed second harmonic GW mode was sensitive to early material degradation in localised region. This new physics observed in the domain of guided ultrasonic waves is uncovered, which opens up the possibilities for new ways for guided wave NDE and SHM.*

**Krishnadas V K**
Ph.d

## *Material characterization using edge wave acoustic microscopy (EWAM)*

**ANOOP U**
M.S

*Thesis discuss about development of an in house Acoustic microscopy setup. The developed Acoustic microscope is optimised and evaluated for high frequency imaging and surface profiling capabilities. The main crux of the thesis is to use the Acoustic microscope for the material characterisation of thick an thin metal samples. The methodology utilises the edge waves from the rim of piezo polymer based transducers (PVDF) for the generation of surface/guided Lamb waves in metal plates. The material is charachterised by measuring the velocity of the surface and guided Lamb wave velocity in thick and thin metal samples respectievly.*

## *Non-destructuve evaluation of CFRP structures using induction thermography*

**Renil Thomas K**
Ph.d M.s

*A novel methodology to inspect unidirectional CFRP composites using induction thermography by incorporating an additional conduction current loop between the composite layers is proposed and demonstrated. A new inspection scheme to use induction thermography to detect fibre breakage and identify fibre breakage orientation by rotating a linear coil at the defect location is proposed and demonstrated on a realistic fibre breakage produced in a controlled fashion in the composite. Numerical model developed in the study provided strong theoretical backin to the experimental observation.*

# *AI models for virtual source phased array ultrasound imaging*

**Thulsiram Gantala**
Ph.D

*I am an Assistant Professor in the Mechanical & Aerospace Engineering Department at IIT, Hyderabad. My PhD thesis research at IIT Madras under the supervision of Prof. Krishnan Balasubramanian was path-breaking and has led to a new subtopic that uses Artificial Intelligence (AI) as the basis for both synthetic simulation generation and data interpretation in the field of ultrasonic NDE. My thesis work is on a unique combination of deep understanding of the wave physics of ultrasound leading to the development of a new NDE imaging technique for improving resolution and reducing the scanning time, the use of generative AI to model the physics of wave interaction with defects leading to the development of a new technique for reducing time and resource, and finally combining these developed techniques for improving the phased array ultrasound inspection techniques and data interpretation using AI-based schemes. My thesis has won wide acclaim globally, including the Best Thesis Award in Data Science at IIT Madras. I also received a Prime Minister fellowship for doctoral research during my PhD studies. I have contributed to developing AI techniques in both classical and quantum forms. My research interests include nondestructive evaluation, materials characterization, wave propagation, ultrasonic imaging, and applied machine learning.*

# *Staircase magnetostrictive patch transducer for broadband frequency excitation*

*Remanant thickness quantification is achieved using a novel Staircase Magnetostrictive Patch (ScaMP) Transducer. ScaMP is a magnetostrictive patch transducer that generates a broadband pure shear horizontal wave mode within plate structures. The study focuses on experimentally determining the cut-off frequency of the SH1 wave mode, subsequently enabling precise estimation of the remaining thickness of the defect.*

**Renjith Puthusseri**
M.S

CNDE

# National Consortium For Non-Destructive Evaluation (NCNDE)

The Way Forward

2023 – 2024

# Introduction

NCNDE was established in November 2024 under CNDE to promote collaborative research in Nondestructive Imaging & Evaluation, Structural Health Monitoring (SHM), and Online process parameter measurements.

The NCNDE aims to tackle the real-world challenges that stakeholders face in non-destructive evaluation (NDE) and structural health monitoring (SHM) through collaborative research and creating top-tier resources for NDE.

### The Major benefits of NCNDE to the members are the following

- Collaborative research reduces research costs by allowing multiple parties to share their investments.
- Industry-focused research driven by the management board of the consortium
- Engaging industries in the early stages of research facilitates the testing of technology in real-world environments.
- Reduction in research cycle time due to inputs at various stages of technology development.
- Accessing cross-industry & cross-platform technologies.
- Likelihood of successfully transitioning to a commercial product.
- Enhanced understanding of risks and regulatory requirements at the project's early stage.
- The members of the consortium are open to recruiting top talent from CNDE.

## Management Board of Consortium

The Management Board is the highest authority of the consortium. It consists of the Director and the Technology Director of CNDE as permanent members. Additionally, the board includes members from the industry platinum category. Furthermore, two members from the University-Platinum category will serve on the board on a rotational basis.

The CEO of the consortium reports to the Management Board. The Board meetings will be chaired by one of the members of the Management Board. Each member of the Board has one vote. The management board is responsible for all the activities of the consortium which includes 1. Project to be funded 2. The policy decision of the consortium. The CEO will communicate the decision taken by the Management Board to all members of the consortium.

## CEO of Consortium

CEO of the consortium with the support of the Management team which consists of the facility, project, and marketing team, and the Executive Assistant will execute projects at CNDE. Director of CNDE and Technology Director of CNDE will oversee the technological aspects of the project. The CEO will report to the Management Board as well as the Director of CNDE.

## The Industrial and Scientic Advisory Committee

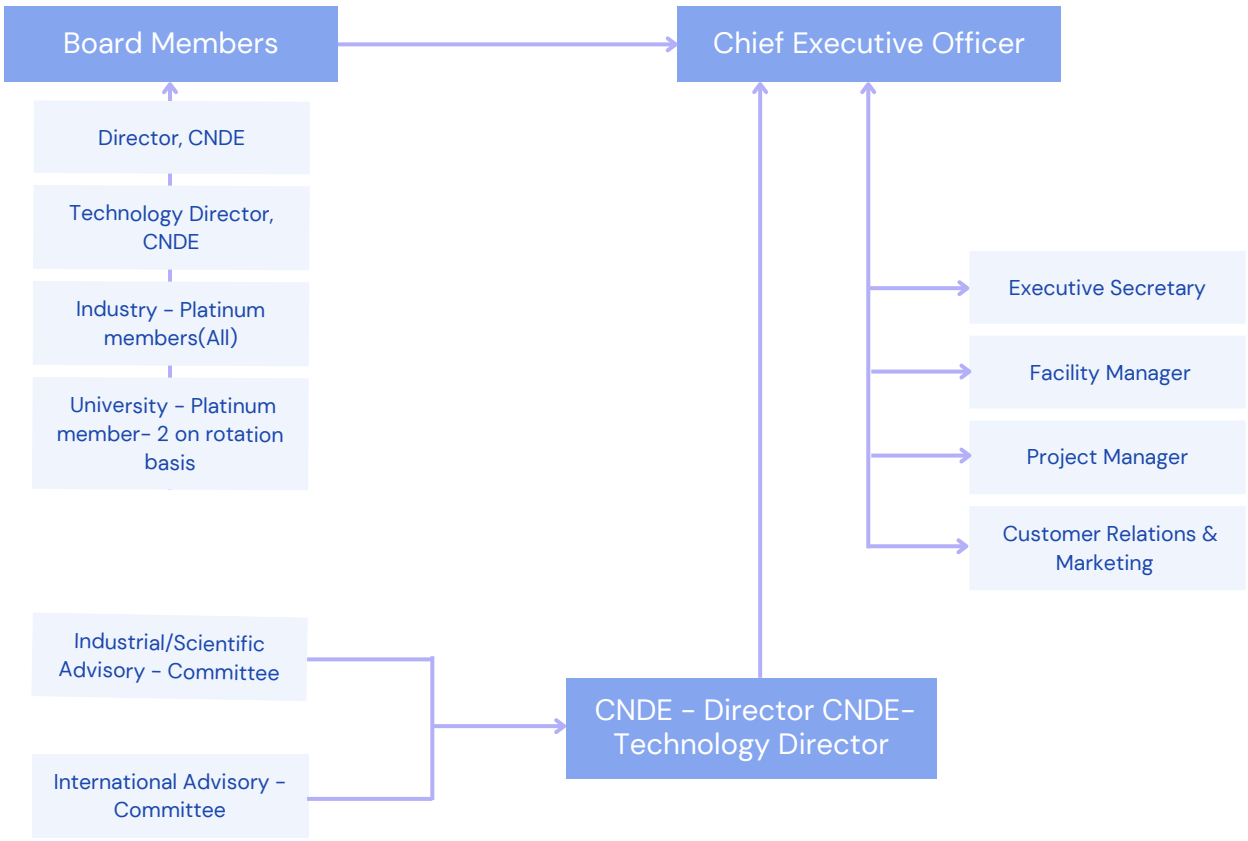
The Industrial and Scientific Advisory Committee will be established by the Director, Technology Director of CNDE, and CEO. This committee will comprise experts from various industries and non-destructive evaluation (NDE) technology f ields. Their role will be to provide technical guidance and direction to the consortium. It will be a committee of ten members.

## International Advisory Committee

The International advisory committee will be formed by the Director and technology director of CNDE which will have Industrial and academic experts from the International Community. Their role is to review the consortium's technology roadmaps and high-risk projects and provide independent feedback to the Consortium.

# Organizational Structure of NCNDE

## Map of the Organization





# Chief Executive Officer

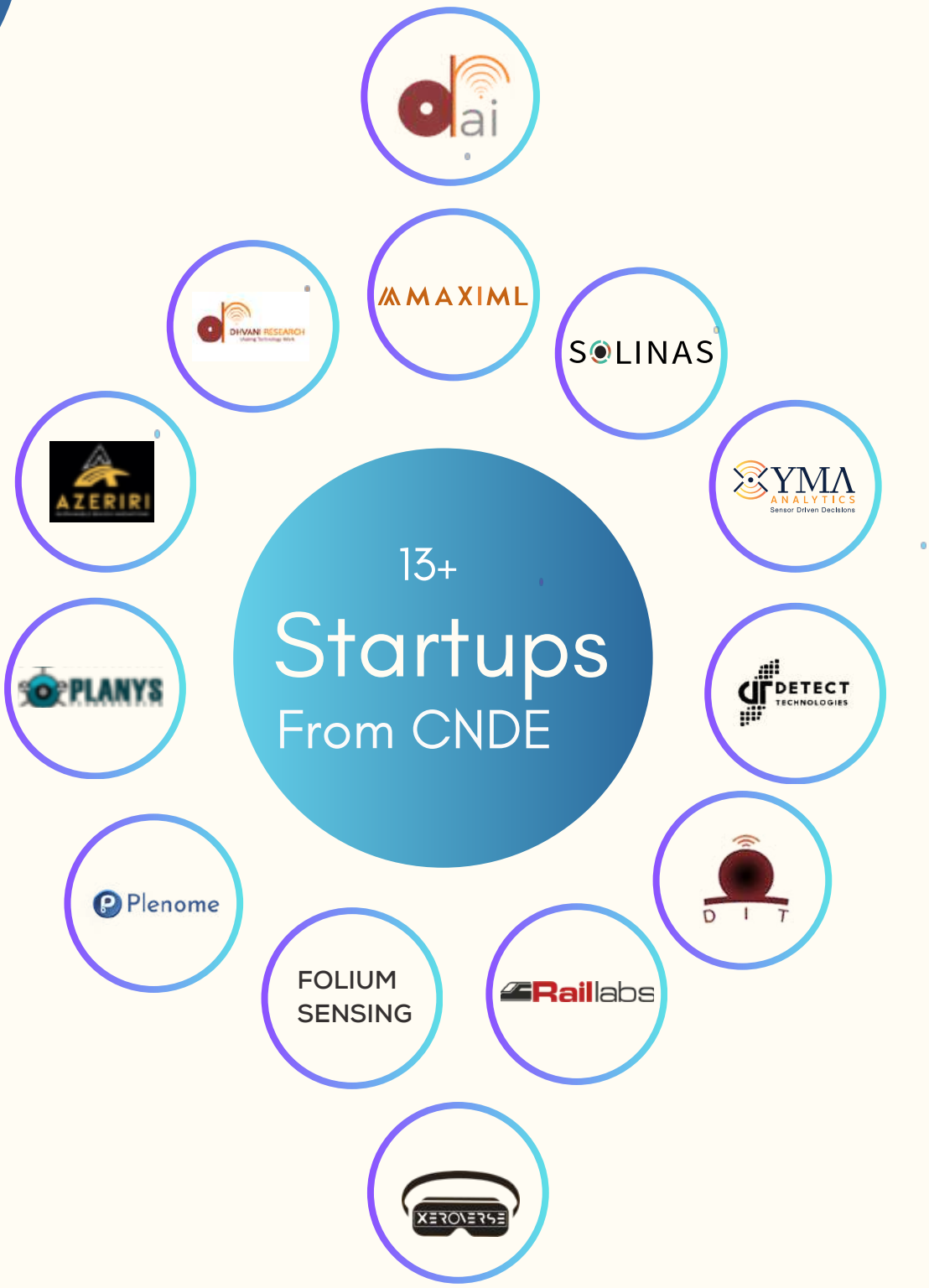
## Venugopal Manoharan

Chief Executive Officer

Mr. V. Manoharan as the first CEO of the Center for Nondestructive Evaluation (CNDE). With over 35 years of expertise in NDE (Nondestructive Evaluation) research, system development, and advanced applications

Mr. Manoharan will oversee CNDE's activities and operations, guiding us in our mission to generate and disseminate knowledge in NDT&E (Nondestructive Testing & Evaluation) technology. His distinguished career includes senior roles as Principal Technologist at VisiConsult – X-ray Systems & Solutions, Senior Scientist at GE Research, and Scientific Officer at the Bhabha Atomic Research Centre (BARC) and Indira Gandhi Center for Atomic Research. His contributions to the field were recognized with the prestigious National NDT award from the Indian Society for Non-Destructive Testing.

Mr. Manoharan holds ASNT Level-III certifications across multiple testing methods (RT, IR, UT, PT, ET) and specializes in Industrial Radiography, digital X-ray imaging, and numerous other advanced NDE techniques. With over 12 patents and 30 technical publications, he has made a profound impact on NDE standards worldwide. Additionally, he currently serves as Chief Controller of Examinations for the National Certification Board, ISNT, and has held leadership roles as Chairman of PFMB.


13+
Startups
From CNDE
dai
MAXIML
SOLINAS
DIVANI RESEARCH
AZERIRI
XYMA
ANALYTICS
Sensor Driven Decisions
PLANYS
DETECT
TECHNOLOGIES
Plenome
D I T
FOLIUM
SENSING
Raillabs
XEROVERSE

# CNDE Startups in 2024

## RailLabs

Raillabs is on a mission to revolutionise railway safety through cutting-edge digital technologies.
In today's rapidly evolving world, ensuring the safety of rail transport has never been more crucial. However, outdated monitoring systems and reliability issues continue to pose significant challenges.
At Raillabs, we see these challenges as opportunities for innovation, driving us to push the boundaries of what's possible in railway safety technology.

## Folium Sensing

Folium Sensing Pvt Ltd is an innovative sensing technology company specializing in Distributed Fiber optic sensing solutions.The company leverages cutting-edge technology to monitor acoustics, temperature, and strain for a wide range of industries, including infrastructure, border security, and industrial automation. Headquartered at IIT Madras Research Park, Folium Sensing is committed to solving real-world challenges through precision sensing, ensuring safety, efficiency, and sustainability.

# VISITOR HIGHLIGHTS

## Deputy Chief of Army Staff Lt.Gen. Rakesh Kapoor.

Deputy Chief of Army Staff Lt.Gen. Rakesh Kapoor visited our CNDE lab. His visit is a true privilege, reflecting a shared commitment to advancing innovation and excellence.We showcase some of our latest developments through two cutting-edge demonstrations, which represent the hard work and dedication of our talented team.

John Iman From Varex visited CNDE


TDK Europe visited CNDE


## Deputy Chief of Defence Staff Vice Admiral Sanjay Vatsayan visited CNDE

## Saint-Gobain team visited CNDE

# CNDE AWARDS

2023-2024

# Vigyan Yuva- Shanti Swarup Bhatnagar Award

## 22 August 2024

Prof. Prabhu Rajagopal has been honored with the prestigious Rashtriya Vigyan Puraskar: Vigyan Yuva Shanti Swarup Bhatnagar Award. The award was presented by President Droupadi Murmu at the Rashtrapati Bhavan as part of the 2024 Rashtriya Vigyan Puraskar ceremony.

This recognition is a testament to Prof. Rajagopal's outstanding contributions to Technology and Innovation. We are incredibly proud of this remarkable achievement!

# 💡 Automation and Artificial Intelligence in Aviation Maintenance: A New Paradigm

## 17 September 2024

Exciting times ahead at AVIAMAT 2024, organized by the Indian Air Force in New Delhi! We are honored to share that Krishnan Balasubramanian received an award from the Indian Air Force ✈️ for his exceptional contributions to the field of automation and AI in aviation maintenance.

This recognition highlights the growing importance of innovative technologies in transforming aviation operations and setting new benchmarks for the industry.

# Professor Prabhu Rajagopal Invited as Honorary Fellow of ISNT

## 29 November 2024

The Indian Society for Non-Destructive Testing (ISNT) has extended an invitation to Dr. Prabhu Rajagopal to become an Honorary Fellow of the Society. This esteemed recognition highlights Dr. Rajagopal's significant contributions to the development and application of Non-Destructive Testing (NDT) techniques, as well as his guidance in advancing NDE practices to ensure the reliability of products and systems.

ISNT, established in 1972, brings together professionals from India and abroad to foster R&D, human resource development, and the industrial application of NDT techniques. The Society has greatly benefited from the contributions of distinguished Honorary Fellows, and Dr. Rajagopal's association is expected to further inspire and strengthen its mission.

# Professor K. Balasubramanian Elected Fellow of Indian Academy of Sciences

## 1 January 2025

Professor K. Balasubramanian, Department of Mechanical Engineering, IIT Madras, has been elected to the Fellowship of the Indian Academy of Sciences. This prestigious recognition highlights his exceptional contributions to science and research.

Established in 1934, the Academy brings together India's leading scientists to advance scientific knowledge and education. As a Fellow, Professor Balasubramanian will play a significant role in promoting science and fostering impactful collaborations.

# STUDENTS ACHIEVEMENTS

**Subhash N.**

Best presentation in biomedical stream, "International Conference on Next Generation Technologies: Design and Manufacturing, IIT Madras, 2024", for the work "Application of Terahertz imaging for QA/QC of biocompatible implants".

**Loheshwaran C**

Kris Gopalakrishnan-IITM Alumnus funded Joint Degree Programme Scholarship

# CONFERENCE AND EXHIBITION


# ICNGT 2024: THE FUTURE OF DESIGN AND MANUFACTURING

As technology advances, design and manufacturing are becoming more complex and innovative. ICNGT 2024 at IIT Madras brings together experts to discuss the latest trends and challenges in this field. From AI-powered design tools to advanced manufacturing techniques, this conference explores the future of product development. Our Prof. Prabhu Rajagopal delivered a presentation on Technology and Innovation


*Robotic and waveguide sensor technologies for remote inspection of engineering structures - the speech of our Prof. Prabhu Rajagopal at the BINDT NDT 2024 61st Annual Conference in the UK*


*Prof Krishnan Balasubramanian, participation in CENDTS2024 in Jamshedpur organised by ISNT Jamshedpur Chapter*


*Delivering Keynote Address at the Malaysian NDT Conference and Exhibition MINDTCE2024. Received token of appreciation from President of APFNDT.*

23
-
24

# MEDIA


Prof. Rajagopal compered as India's Vice President Shri Jagdeep Dhankar ji inaugurated IIT Madras's premier Sudha and Shankar Innovation Hub

## MEDIA HIGHLIGHTS

# MEDIA

## Professor Krishnan Balasubramanian - podcast with Askiitm

In the podcast, Prof. Krishnan Balasubramanian sheds light on NDE's significance, discusses ICSR, IP policy, the importance of startups in technology transfer, and the GDC's role in empowering academicians. He also shares insights into the successful startups born from CNDE's research.

We encourage everyone to listen to the insightful conversation and gain valuable knowledge from Prof. Krishnan Balasubramanian expertise.


## Professor Prabhu -podcast with Askiitm

Prof. Prabhu Rajagopal talks about the incredible transformation at IIT Madras. How IIT-M built an ecosystem where a student tinkering in the Center for Innovation today could lead a groundbreaking startup tomorrow. He briefed about deep tech and translational technologies and various startups from IIT-M

# MEDIA


## *Feature on Dr Rajagopal for development of HomoSEP robot by CORE projects from Madras Branding Company*

In November 2023, the CORE project at IIT Madras, led by Professor Prabhu Rajagopal (Department of Mechanical Engineering), achieved a significant milestone with the development of the HomoSEP robot. This innovation directly addresses the dangers of manual scavenging, a critical issue in India. The HomoSEP robot offers a mechanized solution for sewage management, significantly improving worker safety and efficiency. Professor Rajagopal and his team, including students Divanshu, Bhavesh, and Srihari, designed the robot to break down solid sludge and then safely extract the remaining material. This project exemplifies IIT Madras's commitment to impactful research and societal benefit. The technology is being further developed by the startup Solinas, led by Divanshu.


## *Feature in NDTV on submersible robotic inspections by Planys*

Planys Technologies, a start-up incubated by the IIT Madras Incubation Cell, has developed cutting-edge submersible robots that are transforming the marine inspection industry. These robots address the complex challenges of inspecting critical underwater infrastructure, including bridges, dams, ports, ships, and submarines, offering significant improvements in safety, efficiency, and cost-effectiveness. With a current valuation of $15 million, Planys showcases the impact of IIT Madras's support for deep-tech ventures. Professor Prabhu Rajagopal, a co-founder of Planys, highlights the growing recognition of Chennai as a hub for innovative start-ups.

# MEDIA

## *Panel discussion on Startups- Opportunities and Challenges' at the Madras Management Association*

Prof. Prabhu Rajagopal was a key participant in a panel discussion hosted by the Madras Management Association (MMA) on September 4, 2023, titled 'Startups - Opportunities and Challenges.' The discussion examined the 'Start-Up India' initiative and its impact on the Indian startup ecosystem. Topics covered included the initiative's policy framework, economic contributions, role in fostering technological innovation, global outreach, and strategies for addressing challenges faced by new ventures. The panel emphasized the initiative's contribution to youth empowerment, increased investor confidence, and the development of a thriving startup culture.

## Professor Prabhu Rajagopal currently ongoing series on Innovation Sutras

The Innovation Sutras' series, authored by Prof. Prabhu Rajagopal (April 2023-ongoing), highlights IIT Madras's leading role in deep-tech innovation and entrepreneurship. The series emphasizes the importance of translating research into practical solutions, reflecting IIT Madras's commitment to impactful innovation.

### Sutra 1: Innovation bridges ideas and implementation

Innovation bridges ideas and implementation, driving new products and solutions. IIT Madras fosters this through various initiatives, resulting in impactful startups and top innovation rankings. True innovation isn't just creation, but the ability of a solution to navigate the "valley of death" between concept and deployment by addressing market needs, cost, and scalability. This requires overcoming challenges and outcompeting alternative approaches, ultimately achieving successful productization and market entry.

# MEDIA

## Sutra 2: At the root is the joy of discovery

A thriving innovation culture requires platforms for playful exploration and discovery. IIT Madras's CFI, a vibrant maker space, exemplifies this, fostering student-led innovation through hands-on projects and competition teams. Gamified environments like these cultivate teamwork, problem-solving skills, and a joy of discovery crucial for innovation. While academic settings readily embrace this approach, industries can also foster innovation by gamifying routine projects, as demonstrated by the Indian auto industry and space program. Cultivating a joy of discovery is key to amplifying an organization's innovation potential.

## Sutra 3: Theory needs to be grounded in practice

Innovation thrives on the interplay of theory and practice. Deep theoretical understanding, validated through practical experimentation, fuels true innovation. This applies to all stages of product development. At IIT Madras, researchers overcame fabrication challenges by applying their understanding of the physics of metamaterials. The CFI's 3D Printing Club exemplifies practical learning, leading to an innovative, cost-effective extruder. Startups like Planys Technologies bridge the gap between theory and real-world application through their ROV-based ultrasonic testing system. Established companies like Butterfly and TTK Prestige demonstrate the power of user feedback in driving innovation. India's space and nuclear programs further showcase the success of combining theoretical knowledge with practical application.

## Sutra 4: Working at the intersection of disciplines brings synthesis

Innovation flourishes at the intersection of disciplines. The concept of "Gesamtkunstwerk," or a total work of art, highlights the power of integrating multiple domains, as exemplified by influential art movements and the Bauhaus school. This interdisciplinary approach has revolutionized fields like automotive design, where aesthetics and engineering converge. Large-scale scientific projects, such as space and nuclear programs, also demonstrate the value of collaboration between diverse specialists. This "synthesis," as described by Kant, generates new insights through intuition. Cross-disciplinary teamwork has driven groundbreaking innovations, from the internet to GPS. IIT Madras, with its emphasis on multi-art training, fosters this spirit of interdisciplinary collaboration, leading to impactful innovations and products.

# MEDIA


## Talk at SAP India's 'Global Bharat Movement: Innovation Roadshow'

Prof. Prabhu Rajagopal spoke at SAP India's 'Global Bharat Movement: Innovation Roadshow' on the theme of 'India: The New Global Innovation Hub.' He showcased how IIT Madras is driving innovation through research, technology development, and commercialization, citing examples of startups addressing real-world challenges in sectors like infrastructure, utilities, and manufacturing.

## Driving Innovation at IIT Madras: All India Radio Interview

An interview with Professor Prabhu Rajagopal about innovation at IIT Madras. He discusses two impactful innovations: Planys Technologies, creating robots for infrastructure inspection, and the HomoSEP robot for cleaning septic tanks, eliminating manual scavenging. He then explains the role of IIT Madras's Center for Innovation (CFI), a maker space providing students with hands-on experience, fostering teamwork, and enabling them to build complex projects like racing cars. The CFI also nurtures startups through a startup nursery and entrepreneurship training. The interview highlights the connection between innovation, social impact, and the startup ecosystem.

# CNDE Publications

| S.NO | TITLE | AUTHORS | JOURNAL | PUBLISHER |
|---|---|---|---|---|
| 1 | *DATA-DRIVEN AI FOR THE AUTOMATED CLASSIFICATION OF THE ISOTHERMAL HEAT-TREATED THERMAL BARRIER COATINGS USING PULSED INFRARED THERMOGRAPHY* | SRUTHI KRISHNA KUNJI PURAYIL, KRISHNAN BALASUBRAMANIAM | JOURNAL OF PHYSICS D: APPLIED PHYSICS | IOP PUBLISHING |
| 2 | *THICKNESS MEASUREMENT OF POLYCHLOROTRIFLUOROETHYLENE COATING OVER METALLIC SEAL USING TERAHERTZ TIME-DOMAIN SPECTROSCOPY* | B NIDHEESH KUMAR, MC SANTHOSH KUMAR, A MERCY LATHA, SACHINLAL AROLIVEETIL, M NALLAPERUMAL, KRISHNAN BALASUBRAMANIAM, S REMAKANTHAN, KK MOIDEENKUTTY, SHYAM S NAIR, L MOHAN KUMAR | NONDESTRUCTIVE TESTING AND EVALUATION | TAYLOR & FRANCIS |
| 3 | *NONDESTRUCTIVE EVALUATION OF AIRCRAFT STEALTH COATING BY TERAHERTZ-TIME DOMAIN SPECTROSCOPY: EXPERIMENTAL AND NUMERICAL INVESTIGATION* | SACHINLAL AROLIVEETIL, NITHIN PUTHIYAVEETIL, KRISHNAN BALASUBRAMANIAM | NONDESTRUCTIVE TESTING AND EVALUATION | TAYLOR & FRANCIS |
| 4 | *DATA-DRIVEN SIMULATION-ASSISTED-PHYSICS LEARNED AI (DPAI) FOR HEAT DIFFUSION IN LARGE GRAIN POLYCRYSTALLINE MATERIALS* | NISHI BHEMANI, THULSIRAM GANTALA, KRISHNAN BALASUBRAMANIAM | PHYSICA SCRIPTA | IOP PUBLISHING |
| 5 | *FREQUENCY SWEEP STUDY ON THE GENERATION OF DUAL-MODE SECOND HARMONICS (DMSH) ON AN ISOTROPIC NONLINEAR ELASTIC CYLINDRICAL ROD BY T (0, 1) MODE* | KRISHNADAS V KANAKAMBARAN, KRISHNAN BALASUBRAMANIAM | JOURNAL OF SOUND AND VIBRATION | ACADEMIC PRESS |
| 6 | *MULTI MODAL DATA FUSION OF PAUT WITH THERMOGRAPHY ASSISTED BY AUTOMATIC DEFECT RECOGNITION SYSTEM (M-ADR) FOR NDE APPLICATIONS* | PL SUDHARSAN, THULSIRAM GANTALA, KRISHNAN BALASUBRAMANIAM | NDT & E INTERNATIONAL | ELSEVIER |
| 7 | *CUT-OFF THICKNESS IDENTIFICATION OF DEFECTS WITH SINGLE AND TWO-STEP GEOMETRIES USING SH1 MODE CONVERSION* | NIVED SURESH, KRISHNAN BALASUBRAMANIAM | JOURNAL OF NONDESTRUCTIVE EVALUATION | SPRINGER US |
| 8 | *HIGH-RESOLUTION INDUCTION THERMOGRAPHY FOR DETECTION OF MICRO-CRACKS IN TI-6AL-4V ALLOYS* | NITHIN PUTHIYAVEETTIL, JALAJ KUMAR, KRISHNAN BALASUBRAMANIAM | QUANTITATIVE INFRARED THERMOGRAPHY JOURNAL | TAYLOR & FRANCIS |
| 9 | *UNCOVERING THE HIDDEN STRUCTURE: A STUDY ON THE FEASIBILITY OF INDUCTION THERMOGRAPHY FOR FIBER ORIENTATION ANALYSIS IN CFRP COMPOSITES USING 2D-FFT* | RENIL THOMAS KIDANGAN, SREEDHAR UNNIKRISHNAKURUP, CV KRISHNAMURTHY, KRISHNAN BALASUBRAMANIAM | COMPOSITES PART B: ENGINEERING | ELSEVIER |
| 10 | *EXPERIMENTAL VALIDATION OF BEAM POINTING ERROR IN TILED-ARRAY COHERENT BEAM COMBINING* | SATYAJIT MAJI, VISWANATHAN SANKAR, CL LINSLAL, MS SOORAJ, BALAJI SRINIVASAN | - | IEEE |
| 11 | *SNR ENHANCEMENT IN TE OTDR VIA MULTI NYQUIST ZONE AVERAGING* | MIGUEL SORIANO-AMAT, NEETHU SASIKUMAR, CAMILO ESCOBAR-VERA, BALAJI SRINIVASAN, SONIA MARTIN-LOPEZ, MIGUEL GONZALEZ-HERRAEZ, MARÍA R FERNÁNDEZ-RUIZ | - | IEEE |
| 12 | *COHERENT SPECTRAL AVERAGING ON TIME-EXPANDED ΦOTDR* | MIGUEL SORIANO-AMAT, NEETHU SASIKUMAR, BALAJI SRINIVASAN, SONIA MARTIN-LOPEZ, MIGUEL GONZALEZ-HERRAEZ, MARÍA R FERNÁNDEZ-RUIZ | - | OPTICA PUBLISHING GROUP |
| 13 | *2D MATERIAL BASED FLUORESCENT OPTICAL FIBER FOR EARLY DETECTION OF PARTIAL DISCHARGE* | SK AMIZHTAN, R SARATHI, BALAJI SRINIVASAN, BANNUR NANJUNDA SHIVANANJU | IEEE SENSORS JOURNAL | IEEE |
| 14 | *SHORT-PULSE GENERATION FROM ACTIVE MODE LOCKING WITH RF FREQUENCY COMB* | D PAVITRA VARSHA, SIVA SUBRAMANIYAM CN, BALAJI SRINIVASAN, DEEPA VENKITESH | - | IEEE |
| 15 | *PERFORMANCE INVESTIGATION OF DUAL STAGE NESTED LOOP CONFIGURATION FOR SCALABLE COHERENT BEAM COMBINATION* | MS SOORAJ, SATYAJIT MAJI, VISWANATHAN SANKAR, CL LINSLAL, DEEPA VENKITESH, BALAJI SRINIVASAN | - | OPTICA PUBLISHING GROUP |

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| 16 | *EXCITATION OF WHISPERING GALLERY MODES IN A MICROBOTTLE RESONATOR USING AN OPTICAL BEAM CARRYING ORBITAL ANGULAR MOMENTUM* | SURESH CHEJARLA, ANEESH V VELUTHANDATH, GANAPATHY SENTHIL MURUGAN, BALAJI SRINIVASAN | - | OPTICA PUBLISHING GROUP |
| 17 | *DEVICE DEPENDENT DISTORTION CORRECTION IN TIME-STRETCH PHOTONIC ANALOG TO DIGITAL CONVERTERS USING DEEP NEURAL NETWORKS* | MANDEEP SINGH, JOYDIP DUTTA, SJ SREERAJ, VISWANATHAN SANKAR, BALAJI SRINIVASAN, LAKSHMI NARASIMHAN THEAGARAJAN, DEEPA VENKITESH | - | OPTICA PUBLISHING GROUP |
| 18 | *AN ADAPTIVE OPTICAL TECHNIQUE FOR STRUCTURED BEAM GENERATION BASED ON PHASE RETRIEVAL USING MODIFIED GERCHBERG–SAXTON ALGORITHM* | DEBDUTTA BASU, SURESH CHEJARLA, SATYAJIT MAJI, SHANTI BHATTACHARYA, BALAJI SRINIVASAN | OPTICS & LASER TECHNOLOGY | ELSEVIER |
| 19 | *DISTRIBUTED TEMPERATURE SENSING SYSTEM BASED ON RAMAN-OPTICAL TIME DOMAIN REFLECTOMETRY* | KISHORE KUMAR, VENKATESH VARADHAN, BALAJI SRINIVASAN | - | IEEE |
| 20 | *NONDESTRUCTIVE EVALUATION OF MECHANICAL HEART VALVE DISC THICKNESS DEGRADATION DUE TO ACCELERATED DURABILITY TEST USING THZ-TDS MEASUREMENTS* | NN SUBHASH, CV MURALEEDHARAN, KRISHNAN BALASUBRAMANIAM | NONDESTRUCTIVE TESTING AND EVALUATION | TAYLOR & FRANCIS |
| 21 | *INDUCTION THERMOGRAPHY FOR UNIDIRECTIONAL CFRP COMPOSITES: A NOVEL INSPECTION APPROACH THROUGH GLOBAL CURRENT PATH INTEGRATION* | RENIL THOMAS KIDANGAN, SREEDHAR UNNIKRISHNAKURUP, CV KRISHNAMURTHY, KRISHNAN BALASUBRAMANIAM | COMPOSITE STRUCTURES | ELSEVIER |
| 22 | *METAMATERIAL ENHANCED SUBWAVELENGTH IMAGING OF INACCESSIBLE DEFECTS IN GUIDED ULTRASONIC WAVE INSPECTION* | JOHN KIPROTICH BIRIR.MICHAEL JAMES GATARI, MOHAMED SUBAIR SYED AKBAR ALI , PRABHU RAJAGOPAL | NDT & E INTERNATIONAL | ELSEVIER |
| 23 | *TUNABLE ACOUSTIC SUPERSCATTERER COMPOSED OF MAGNETORHEOLOGICAL FLUID AND MAZE-LIKE METASURFACE* | VINEETH P. RAMACHANDRAN,PRABHU RAJAGOPAL | JOURNAL OF SOUND AND VIBRATION | ELSEVIER |
| 24 | *GRADED ELASTIC WAVEGUIDE METAMATERIAL ROD FOR UP-CONVERSION OF LONGITUDINAL AXISYMMETRIC GUIDED ULTRASONIC WAVE MODES* | S. R. SANDEEP KUMAR,VINEETH P. RAMACHANDRAN, KRISHNAN BALASUBRAMANIAM AND PRABHU RAJAGOPAL | IEEE OPEN JOURNAL OF ULTRASONICS, FERROELECTRICS, AND FREQUENCY CONTROL | IEEE |
| 25 | *SLEEVED WAVEGUIDE ULTRASONIC SENSOR FOR MONITORING CONCRETE HEALTH* | WILSON M KAIRU,MICHAEL J GATARI, SIPHILA W MUMENYA AND PRABHU RAJAGOPAL | STRUCTURAL HEALTH MONITORING | SAGE PUBLICATIONS |
| 26 | *ROBOTIC ULTRASONIC PULSE VELOCIMETRY FOR SUBMERGED CONCRETE ASSETS* | SUSHEEL PATIL,ASHISH ANTONY JACOB,VINEET UPADHYAY, TANUJ JHUNJHUNWALA, PRABHU RAJAGOPAL AND KRISHNAN BALASUBRAMANIAN | JOURNAL OF NON-DESTRUCTIVE TESTING AND EVALUATION (JNDE) | INDIAN SOCIETY FOR NON-DESTRUCTIVE TESTING (ISNT) |
| 27 | *SPARSE SAMPLED VISUALIZATION OF ULTRASONIC GUIDED WAVES FOR DEFECT IDENTIFICATION IN PLATE STRUCTURES* | JAGADEESHWAR TABJULA, SRIJITH KANAKAMBARAN, PRABHU RAJAGOPAL, BALAJI SRINIVASAN | NDT & E INTERNATIONAL | ELSEVIER |
| 28 | *BANDWIDTH-LIMITED PASSIVE SUPPRESSION OF CYLINDRICAL SOURCE RADIATION USING METAMATERIAL BASED ACOUSTIC SUPERSCATTERERS* | VINEETH P. RAMACHANDRAN,PRABHU RAJAGOPAL | JOURNAL OF SOUND AND VIBRATION | ELSEVIER |
| 29 | *S0 LAMB MODE SCATTERING STUDIES IN LAMINATED COMPOSITE PLATE STRUCTURES WITH SURFACE BREAKING CRACKS; INSIGHTS INTO CRACK OPENING BEHAVIOR* | S. GUPTA,PRABHU RAJAGOPAL | ULTRASONICS | ELSEVIER |
| 30 | *ENHANCED PIEZOELECTRIC ENERGY HARVESTING BASED ON SANDWICHED PHONONIC CRYSTAL WITH EMBEDDED SPHERES* | SUBRAHMANYAM GANTASALA,TIJU THOMAS AND PRABHU RAJAGOPAL | PHYSICA SCRIPTA | IOP PUBLISHING LTD |

# CNDE
# Patents filed in India

| S.NO | TITLE | TYPE | INVENTORS | DEPARTMENT | PATENT NO | PATENT DATE | ATTORNEY |
|---|---|---|---|---|---|---|---|
| 1 | A SYSTEM FOR MONITORING FLOW OF FLUID THROUGH A PIPELINE | PATENT | KRISHNAN BALASUBRAMANIAM | MECHANICAL ENGINEERING | - | - | K & S PARTNERS |
| 2 | A SYSTEM AND A METHOD FOR DETECTING AND CHARACTERIZING A DEFECT IN AN OBJECT USING GUIDED WAVE INSPECTION | PATENT | KRISHNAN BALASUBRAMANIAM | MECHANICAL ENGINEERING | 506122 | 01-02-2024 | K & S PARTNERS |
| 3 | A MECHANICAL METAMATERIAL TRANSDUCER ADD-ON (METRADD) FILTER FOR ENHANCING OR SUPPRESSING NONLINEAR SIGNATURES | PATENT | KRISHNAN BALASUBRAMANIAM, SANDEEP KUMAR S R | MECHANICAL ENGINEERING | 540342 | 31-05-2024 | ESHWARS HOUSE OF CORPORATE & IPR LAWS |
| 4 | METHOD AND SYSTEM FOR DETERMINING MATERIAL PROPERTY OF SAMPLE USING EDGE WAVEFRONT SIGNAL | PATENT | KRISHNAN BALASUBRAMANIAM | MECHANICAL ENGINEERING | 540337 | 31-05-2024 | K & S PARTNERS |
| 5 | STAIRCASE SHAPED MAGNETOSTRICTIVE PATCH (SCAMP) TRANSDUCER | PATENT | KRISHNAN BALASUBRAMANIAM | MECHANICAL ENGINEERING | 530411 | 27-03-2024 | K & S PARTNERS |
| 6 | A FUNCTIONALITY FOCUSED HYBRID DESIGN OF AN OBSERVATION CLASS BIO-INSPIRED UNDERWATER REMOTELY OPERATED VEHICLE | PATENT | PRABHU RAJAGOPAL | MECHANICAL ENGINEERING | 538228 | 16-05-2024 | ESHWARS HOUSE OF CORPORATE & IPR LAWS |
| 7 | REMOTELY OPERABLE UNDERWATER ROBOTIC SYSTEMS | PATENT | PRABHU RAJAGOPAL | MECHANICAL ENGINEERING | 516897 | 28-02-2024 | RAJASEKARAN ASSOCIATES |
| 8 | AN AUTOMATED SURFACE AND UNDERWATER INSPECTION ROBOT WITH SPLIT HULL | PATENT | PRABHU RAJAGOPAL | MECHANICAL ENGINEERING | 474777 | 29-11-2023 | RAJASEKARAN ASSOCIATES |
| 9 | BIMETALLIC LENSES FOR FOCUSING ULTRASOUND | PATENT | PRABHU RAJAGOPAL | MECHANICAL ENGINEERING | 548806 | 27-08-2024 | EDIPLIS COUNSELS |
| 10 | SEGMENT ACTUATED SHAPE MEMORY ALLOY BASED SMART FLEXIBLE MANIPULATOR | PATENT | PRABHU RAJAGOPAL | MECHANICAL ENGINEERING | 495614 | 08-01-2024 | K & S PARTNERS |
| 11 | A DEVICE AND A METHOD FOR IMAGING A FREEZE ZONE OF A CRYOSURGICAL PROCESS | PATENT | PRABHU RAJAGOPAL | MECHANICAL ENGINEERING | 531852 | 05-04-2024 | K & S PARTNERS |
| 12 | A HERMETICALLY SEALED DEVICE TO REALIZE PHONON ANTIBUNCHING AND METHOD THEREOF | PATENT | PRABHU RAJAGOPAL | MECHANICAL ENGINEERING | 544816 | 12-07-2024 | K & S PARTNERS |
| 13 | A SYSTEM FOR BLOCKCHAIN BASED MICROBLOGGING AND A METHOD THEREOF | PATENT | PRABHU RAJAGOPAL | MECHANICAL ENGINEERING | 530474 | 27-03-2024 | EDIPLIS COUNSELS |
| 14 | A HOMOGENIZING DEVICE FOR MIXING SLUDGE OF A SEPTIC TANK | PATENT | PRABHU RAJAGOPAL | MECHANICAL ENGINEERING | 453309 | 21-09-2023 | K & S PARTNERS |
| 15 | A FEEDING MECHANISM FOR A DRILLING SYSTEM | PATENT | PRABHU RAJAGOPAL | MECHANICAL ENGINEERING | 454084 | 25-09-2023 | K & S PARTNERS |
| 16 | A SMART MEDICAL DEVICE GATEWAY FOR ELECTRONIC MANAGEMENT OF HEALTH AND MEDICAL RECORDS | DESIGN PATENT | PRABHU RAJAGOPAL | MECHANICAL ENGINEERING | 381486-001 | 25-01-2024 | EDIPLIS COUNSELS |
| 17 | FUEL-FREE INTEGRATED FURROW MAKER AND SEED DISPENSER | DESIGN PATENT | PRABHU RAJAGOPAL | MECHANICAL ENGINEERING | 409128-001 | 26-04-2024 | EDIPLIS COUNSELS |

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| 18 | GUIDED WAVE MODE SELECTED ULTRASONIC TRANSUCERS FOR LEAVE-IN-PLACE HIGH BULK-NONDESTRUCTIVE EVALUATION, BASED ON MAGNETOSTRICTIVE AMORPHOUS METALLIC STRIPS | PATENT | PRABHU RAJAGOPAL | MECHANICAL ENGINEERING | 433040 | 29-05-2023 | ESHWARS HOUSE OF CORPORATE & IPR LAWS |
| 19 | A METHOD OF MANUFACTURING A SLIT MASK FOR IN-SITU LASER ULTRASONIC INSPECTION OF ADDITIVELY MANUFACTURED COMPONENTS | PATENT | PRABHU RAJAGOPAL | MECHANICAL ENGINEERING | 420162 | 02-02-2023 | ESHWARS HOUSE OF CORPORATE & IPR LAWS |
| 20 | SPHERICAL ROBOT FOR INTERNAL INSPECTION OF PIPELINES | PATENT | PRABHU RAJAGOPAL | MECHANICAL ENGINEERING | 437412 | 05-07-2023 | DEEPTECH IP & CONSULTANT |
| 21 | A MODULAR UNDERWATER VEHICLE ASSEMBLY AND METHOD THEREOF | PATENT | PRABHU RAJAGOPAL | MECHANICAL ENGINEERING | 511481 | 16-02-2024 | EDIPLIS COUNSELS |
| 22 | A MECHANICAL METAMATERIAL TRANSDUCER ADD-ON (METRADD) FILTER FOR ENHANCING OR SUPPRESSING NONLINEAR SIGNATURES | PATENT | PRABHU RAJAGOPAL | MECHANICAL ENGINEERING | 540342 | 31-05-2024 | ESHWARS HOUSE OF CORPORATE & IPR LAWS |
| 23 | ARTIFICIAL INTELLIGENCE ENABLED REMOTELY OPERATED UNDERWATER VEHICLE (AI-ROV) FOR HULL INSPECTION | DESIGN PATENT | PRABHU RAJAGOPAL | MECHANICAL ENGINEERING | 349618-002 | 25-01-2023 | EDIPLIS COUNSELS |
| 24 | METHOD AND APPARATUS FOR DYNAMIC MATCHING OF FIBER BRAGG GRATINGS FOR DYNAMIC INTERROGATION | PATENT | BALAJI SRINIVASAN | ELECTRICAL ENGINEERING | 536709 | 03-05-2024 | IPMETRIX CONSULTING GROUP |
| 25 | METHOD AND APPARATUS FOR PERFORMING HIGH SPEED SWITCHING USING OPTICAL COMPONENTS | PATENT | IITM PRAVARTAK TECHNOLOGIES FOUNDATION, BALAJI SRINIVASAN | ELECTRICAL ENGINEERING | - | - | REMFRY & SAGAR |
| 26 | REPETITION RATE INDEPENDENT STABILIZATION OF ACTIVE HARMONIC MODE-LOCKED FIBER LASER | PATENT | DEEPA VENKITESH | ELECTRICAL ENGINEERING | 545507 | 22-07-2024 | REMFRY & SAGAR |
| 27 | TWO-DIMENSIONAL (2D)MATERIAL BASED FLUORESCENT OPTICAL FIBER SENSOR FOR PARTIAL DISCHARGE DETECTION IN TRANSFORMERS AND METHODS THEREOF | PATENT | SHIVANANJU B N | ELECTRICAL ENGINEERING | 538500 | 17-05-2024 | SV&R PARTNERS |

# CNDE
# Patents filed in other countries

| S.NO | TITLE | INVENTOR | COUNTRY | TYPE | APPLICATION NO | PUBLICATION NO | PUBLICATION DATE | STATUS |
|---|---|---|---|---|---|---|---|---|
| 1 | A SYSTEM FOR MONITORING FLOW OF FLUID THROUGH A PIPELINE | KRISHNAN BALASUBRAMANIAM | US | PATENT | 18/016,654 | US-2023-0288236-A1 | 14-09-2023 | DOCKETED NEW CASE - READY FOR EXAMINATION 12/09/2023 |
| 2 | STAGGERED MAGNET ARRAY (SMA) BASED ELECTROMAGNETIC ACOUSTIC TRANSDUCER (EMAT) | KRISHNAN BALASUBRAMANIAM | US | PATENT | 17/779,628 | US-2023-0018319-A1 | 19-01-2023 | NON FINAL ACTION MAILED 14/06/2024 |
| 3 | METHOD AND SYSTEM FOR REMOTELY MEASURING PROPERTIES OF A FLUID | KRISHNAN BALASUBRAMANIAM | US | PATENT | 18/033,451 | US 2023-0400433 A1 | 14-12-2023 | DOCKETED NEW CASE - READY FOR EXAMINATION 29/09/2023 |
| 4 | METHOD AND SYSTEM FOR GENERATING TIME-EFFICIENT SYNTHETIC NON-DESTRUCTIVE TESTING DATA | KRISHNAN BALASUBRAMANIAM | US | PATENT | 18265701 | US 2024-0119199 A1 | 11-04-2024 | DOCKETED NEW CASE - READY FOR EXAMINATION 05/02/2024 |
| 5 | AN APPARATUS FOR DETERMINING SURFACE TEMPERATURE OF AN OBJECT AND A METHOD THEREOF | KRISHNAN BALASUBRAMANIAM | PCT | PATENT | PCT/IN2023/050241 | WO/2023/181056 | 28-09-2023 | APPLICATION - PUBLISHED |
| 6 | A SYSTEM AND METHOD FOR ULTRASOUND IMAGING USING ARBITRARY VIRTUAL ARRAY SOURCES OF APERTURE EXCITATION | KRISHNAN BALASUBRAMANIAM | PCT | PATENT | PCT/IN2023/050487 | WO/2024/084493 | 25-04-2024 | APPLICATION - PUBLISHED |
| 7 | METHOD AND SYSTEM FOR DETERMINING MATERIAL PROPERTY OF SAMPLE USING EDGE WAVEFRONT SIGNAL | KRISHNAN BALASUBRAMANIAM | PCT | PATENT | PCT/IN2023/050886 | WO/2024/069647 | 04-04-2024 | APPLICATION - PUBLISHED |
| 8 | STAIRCASE SHAPED MAGNETOSTRICTIVE PATCH (SCAMP) TRANSDUCER | KRISHNAN BALASUBRAMANIAM | PCT | PATENT | PCT/IN2023/050714 | WO/2024/121857 | 13-06-2024 | APPLICATION - PUBLISHED |
| 9 | PRESSURE SENSITIVE ADHESIVE TAPE BASED FLEXIBLE STRAIN SENSOR AND METHOD OF PREPARATION THEREOF | RAMAPRABHU S | PCT | PATENT | PCT/IN2023/050267 | WO/2023/181063 | 28-09-2023 | APPLICATION - PUBLISHED |
| 10 | SEISMOBRICK UNIT CELL FOR PROTECTION OF BUILDINGS AND EQUIPMENT AGAINST LOW-FREQUENCY SEISMIC SURFACE DISTURBANCES. | DR. PRABHU RAJAGOPAL, MR. MAHESHWARI HARSHKUMAR KAMLESHBHAI | PCT | PATENT | PCT/IN2023/050707 | WO/2024/023838 | 01-02-2024 | APPLICATION - PUBLISHED |
| 11 | A SYSTEM AND METHOD FOR ULTRASONIC FAR-FIELD SUPER RESOLUTION IMAGING USING HYPERLENS AND WAVEGUIDE | DR. PRABHU RAJAGOPAL, MR. MOHAMED SUBAIR SYED AKBAR ALI | PCT | PATENT | PCT/IN2023/050719 | WO/2024/023844 | 01-02-2024 | APPLICATION - PUBLISHED |
| 12 | SECURE AND INTEROPERABLE FEDERATED BLOCKCHAIN HEALTH RECORD ECOSYSTEM | DR. PRABHU RAJAGOPAL, MR. ANIRUDH VARNA, MR. VINESH RAJA VIJAYARAJ, MR. VIJAYARAJA RATHINASAMY | PCT | PATENT | PCT/IN2024/050147 | WO/2024/171219 | 22-08-2024 | APPLICATION - PUBLISHED |
| 13 | A SYSTEM AND METHOD FOR SECURE MANAGEMENT OF ELECTRONIC HEALTH AND MEDICAL RECORDS. | DR. PRABHU RAJAGOPAL, MR. VIJAYARAJA RATHINASAMY | PCT | PATENT | PCT/IN2024/050262 | WO/2024/189650 | 19-09-2024 | APPLICATION - PUBLISHED |
| 28 | A MECHANICAL METAMATERIAL TRANSDUCER ADD-ON ( METRADD) FILTER FOR ENHANCEMENT OF LINEAR AND NONLINEAR ULTRASONIC DAMAGE DETECTION | PROF. KRISHNAN BALASUBRAMANIAN,PROF. PRABHU RAJAGOPAL, SANDEEP KUMAR, VK KRISHNADAS | PCT | PATENT | PCT/IN2024/050784 | | 12-06-2024 | PENDING |

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