Annexure-II

Research Project 1

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Co-Supervisor: Prof. Abhirup Datta, Professor, **Department:** Astronomy, Astrophysics and Space Engineering; **Email:** abhirup.datta@iiti.ac.in; **Website:** https://sites.google.com/iiti.ac.in/abhirupdatta/

Research Project: Cosmic AI Revolution: SKA and AI Transforming Cosmology

The Square Kilometre Array (SKA), the world's largest radio telescope, will revolutionize cosmology by merging cutting-edge observations with artificial intelligence (AI) to probe cosmic dawn, dark energy, and the Universe's fundamental structure.

Mapping Cosmic Dawn: SKA's sensitivity to redshifted 21cm hydrogen emissions enables detailed mapping of the Cosmic Dawn, the era when the first stars and galaxies ionized intergalactic gas. AI techniques like convolutional neural networks (CNNs) and transformers etc., combined with Bayesian inference techniques, will disentangle astrophysical foregrounds from faint signals and reconstruct the ionization history of the Universe and constrain dark matter properties with high accuracy.

Precision Dark Energy Studies: SKA's surveys of 10^6 fast radio bursts (FRBs) and galaxy distributions will refine dark energy models. AI algorithms will analyze FRB dispersion measures to constrain the dark energy equation of state with high precision, surpassing current probes. Machine learning also optimizes pulsar timing arrays to detect gravitational waves, resolving Hubble tension via ""bright siren"" measurements with 0.5% uncertainty in the Hubble parameter.

Testing Cosmological Foundations: SKA-AI synergy challenges the cosmological principle by measuring dipole anisotropies in radio galaxy distributions. Superhorizon perturbations linked to Hubble tension predict redshift-dependent dipoles detectable in SKA's all-sky surveys. AI classifiers will mitigate instrumental biases, enabling robust homogeneity tests.

Tackling Exascale Data: SKA generates ~1 exabyte/day, necessitating AI-driven pipelines for real-time calibration, radio interference removal, and image reconstruction. Reinforcement learning optimizes array configurations, while automated systems deliver science-ready data globally.

By uniting SKA's observational power with AI's analytical rigor, cosmology enters an era of unprecedented discovery, decoding dark energy, validating inflation, and redefining cosmic evolution.

Research Project 2

Supervisor: Dr. Ravinder, Assistant Professor, **Department:** Civil Engineering
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Research Project: Enhanced Ballistic Protection with Ultra High Performance Fibre Reinforced Concrete (UHPFRC): Integrating Topology Optimization, Machine Learning, and 3D Printing.

A synergistic approach utilizing UHPFRC, topology optimization, machine learning and 3D printing techniques offers an exciting opportunities to create efficient ballistic protection systems for various applications. Although, several key challenges exists that currently limit the integrated approach to fabricate such complex systems as mentioned below.

1. Anisotropic behaviour of 3D printed UHPFRC structures and its utilization for optimum configuration for ballistic performance.
2. Efficient topology optimisation procedures to design structures for enhanced ballistic performance.
3. Tailored 3D printing processes optimised for UHPCFRC, ensuring proper fibre alignment and distribution within the printed structure.
4. The influence of printing parameters on the mechanical properties and ballistic performance of 3D-printed UHPFRC.

The research proposal aims to design an optimal 3D printed ballistic protection systems through generative design. The proposed work will integrating these techniques to develop a framework for fabricating optimized UHPFRC structures through generative design and 3D printing for enhanced ballistic performance.

Research Project 3

Supervisor: Dr. Priyank J. Sharma, Assistant Professor, **Department:** Civil Engineering
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Research Project: AI-driven Framework for Agricultural Risk Assessment due to Compound Extremes

The first step in this study focuses on developing a framework for identifying the compound and concurrent extremes through statistical machine learning techniques. Individual climate extremes (viz., extreme rainfall, heatwave, drought, coldwave, strong winds, etc.) will be analyzed at the river basin scale. As a next step, a combination of empirical, statistical, artificial intelligence (AI), and/or machine learning (ML) techniques will be applied to identify the compound extreme events arising from individual weather/climate events, which may not necessarily be extreme. Understanding the changes in the compound and concurrent extremes manifested by climate change is vital for sustainable water resources management and disaster mitigation. Appropriate GCMs (Global Circulation Models) will be selected for the study domain, and their outputs will be statistically downscaled, bias-corrected for the variables of interest, and validated against ground-based observations. The linkages between the large-scale coupled oceanic-atmospheric circulations of the Pacific and Indian Oceans, such as El Niño Southern Oscillation (ENSO) and Indian Ocean Dipole (IOD), and the evolution of compound and concurrent extremes, will also be explored using statistical machine learning models. The impact of compound extremes on water stress conditions and agricultural risk will be assessed, and their drivers will be identified. The research products, data, and tools developed in this research study will be made available to all the Government water management agencies, scientists, and parties interested in this work, considering data sharing and privacy protection protocols.

The specific objectives of the research study are:

(i) Identify the compound and concurrent extreme events and diagnose their drivers.

(ii) Analyze the impacts of climate change and climate variability on the compound and concurrent extremes.

(iii) Assess the implications of the compound and concurrent extremes on water scarcity and agricultural risk.

Research Project 4

Supervisor: Dr. Akshay Pratap Singh, Assistant Professor, **Department:** Civil Engineering
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Research Project:

Designing foundations in the field of geotechnical engineering involves addressing multiple interrelated factors, including the mechanical behavior of soils, applied loads, and practical material limitations. Traditional design methods often depend on repetitive calculations and conservative estimates, which can lead to inefficient outcomes, such as excessive use of materials and higher construction costs. In response to these limitations, this study proposes a new optimization approach using reinforcement learning techniques alongside surrogate modeling methods.

The significance of this research lies in its potential to streamline and enhance foundation design processes. By introducing a system that learns and adapts from performance feedback, the reliance on time-consuming simulations can be greatly reduced. Surrogate models—developed from previously collected data and numerical analyses—will be used to estimate essential parameters like bearing capacity, settlement, and cost. These models, based on methods such as Gaussian process regression and neural networks, aim to provide fast yet reliable predictions.

The reinforcement learning component will guide the optimization by exploring various design possibilities and refining choices based on a defined reward structure. This structure will weigh critical factors such as safety margins, material usage, and environmental considerations like carbon emissions. Algorithms such as PPO and DQN will be explored for this purpose.

The main goals of the research are to:

- Build predictive models for soil-structure interaction.
- Apply reinforcement learning to automate foundation optimization.
- Incorporate sustainability into the evaluation process.
- Test the system using actual case studies.
- Develop a practical software tool for engineering use.

Research Project 5

Supervisor: Prof. Manish Kumar Goyal, Professor, **Department:** Civil Engineering
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Research Project: AI-Based Modelling of Air and Water Pollution Impacts on Public Health in India

India faces severe environmental challenges with deteriorating air and water quality significantly impacting public health outcomes across diverse populations. This study aims to quantify the relationship between environmental pollution exposure and health burden in India using advanced artificial intelligence modelling approaches. Machine learning algorithms including random forest, support vector machines, and deep neural networks will be used to analyze comprehensive datasets encompassing air quality indices (PM2.5, PM10), water contamination parameters (heavy metals, pathogens, chemical pollutants), and Global Burden Disease (GBD) data from Indian states and UTs. Satellite imagery, ground-based monitoring stations, and electronic health records will also be integrated to create predictive models for pollution-health associations. This work will offer correlations between particulate matter concentrations and respiratory disease incidence as well as contaminated water sources and waterborne diseases. The AI-based modelling framework will provide a robust tool for real-time health risk assessment and evidence-based environmental policy development in India. Such as novel approach will demonstrate the critical need for stricter emission standards, industrial waste regulations, and renewable energy policies to address pollution sources.

The key objectives of the projects are:

1. To employ AI based algorithms in order to quantify the relationship between environmental pollution exposure and health burden
2. To develop a robust tool for real-time health risk assessment using AI Framework

Research Project 6

Supervisor: Dr. Chandresh Kumar Maurya, Assistant Professor, Computer Science and Engineering Department
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Co-supervisor: Dr. Amit Aggarwal, Professor, AIIMS Bhopal

Research Project:

Access to timely and accurate Radiology diagnostics remains a challenge in India, especially in non-urban areas and for populations less proficient in English. Language barriers and the complexity of medical reports can hinder effective communication between healthcare providers and patients, potentially delaying diagnosis, and treatment in Radiology.

While advancements in AI have shown promise in medical image analysis and report generation, current Large Language Models are often computationally intensive, requiring significant infrastructure and expertise for deployment. This creates a digital divide, limiting the benefits of AI-powered Radiology diagnostics to well-resourced institutions.

Furthermore, the lack of LLMs specifically trained on Indic languages and Radiology terminologies limits their applicability and accuracy for a significant portion of the Indian population. There is a pressing need for efficient, linguistically diverse, and domain-specific AI models that can bridge these gaps in Radiology.

This proposal seeks funding to develop a suite of Large Language Models (LLMs) foundation model specialized for Radiology report generation of X-Rays, CT scans, MRI, Ultrasound and PET scan images in English and Hindi catering to the diverse linguistic landscape of India. By creating efficient and accessible AI models in English and Hindi, we aim to democratize access to advanced medical diagnostic support in Radiology. Utilizing cutting-edge quantized model architectures, this project prioritizes computational efficiency and reduced hardware requirements, making deployment feasible even in resource-constrained settings. This initiative directly addresses the Meity mission to create impactful AI solutions for societal good, focusing on healthcare accessibility and linguistic inclusivity in the domain of Radiology.

Research Project 7

Supervisor: Dr. Soumi Chattopadhyay, Assistant Professor, **Department:** Computer Science and Engineering; **Email:** soumi@iiti.ac.in; **Website:** https://sites.google.com/site/soumi61/home

Research Project:

The rapid evolution of digital media platforms has dramatically transformed how news is produced, disseminated, and consumed. This project aims to develop a comprehensive system for multi-label, multi-modal, and multi-lingual news recommendation and summarization, with a particular focus on Indian news content from platforms like YouTube, Social/News Feeds. The proposed framework addresses the increasing complexity of multimedia news by integrating content across text, audio, video, and images, while also supporting diverse Indian languages and dialects.

The key objectives of the project are: (a) News Understanding and Labeling – Extracting semantic labels and topics from multimodal news content, (b) Intent Understanding – Identifying whether content aims to inform, persuade, sensationalize, or mislead, (c) Fake News Detection – Assessing credibility and identifying misinformation using cross-modal verification, (d) News Recommendation – Delivering personalized, trust-aware, and diverse content based on user preferences, (e) Multi-source Summarization – Generating concise summaries from diverse news sources across languages and modalities.

The impact of this project is multifold: it enhances news accessibility for users across different linguistic backgrounds, supports informed decision-making by detecting misleading content, and contributes to media literacy by surfacing balanced and credible summaries. It also provides significant value to platform developers, media researchers, and policy makers concerned with combating misinformation and promoting content diversity.

The novelty of this system lies in its unified treatment of multi-label classification, multi-modal fusion, and multi-lingual adaptation in a real-world setting like Indian news. Unlike existing models that handle individual components in isolation, this project integrates them into a single, context-aware pipeline that reflects the diversity, scale, and linguistic richness of India's media landscape.

By bridging technical innovation with social relevance, this project offers a scalable and inclusive solution for trustworthy and intelligent news consumption.

Research Project 8

Supervisor: Dr. Nagendra Kumar, Assistant Professor, **Department:** Computer Science and Engineering **Email:** nagendra@iiti.ac.in; **Website:** https://sites.google.com/view/nagendrak/

Research Project: Hate Speech and Fake News Detection in Social Networks using AI and ML

The rapid growth in the internet and social media users has shown significant changes in how people interact with each other and access information. It has created new opportunities for individuals to connect with different people. However, it has also led to concerns about privacy, security, and the potential for online harassment and misinformation. Hate speech and fake news can fuel existing social divides, potentially leading to unrest, economic losses, or violence. Identifying and stopping the dissemination of hate speech, fake news camouflaged as legitimate news, poses a technological hurdle. This project thus focuses on developing novel Machine Learning, Artificial Intelligence, Natural Language Processing, and Computer Vision methods that can automatically identify such kinds of fake news and hate speech expressed in online platforms. This work focuses on countering this phenomenon in multiple low-resource Indic languages of our country, such as Hindi, Bengali, Tamil, Marathi, Kannada, Telugu, etc. We also develop novel solutions that work for textual and visual content, such as images and videos, using Natural Language Processing, Computer Vision, and Deep Learning techniques. Our proposed solutions help in creating a safer online environment by reducing the risk of online fake news, harassment, and cyberbullying.

Research Project 9

Supervisor: Dr. Surya Prakash, Professor, **Department:** Computer Science and Engineering; **Email:** surya@iiti.ac.in; **Website:** https://people.iiti.ac.in/~surya/

Research Project:

The objective of this project is to leverage deep learning techniques for the analysis and diagnosis of eye-related diseases. By utilizing advanced deep learning models, the project aims to accurately detect and classify conditions such as diabetic retinopathy and glaucoma from retinal images. The project promises to enhance early detection, improve diagnostic accuracy, and facilitate timely interventions, ultimately contributing to better patient outcomes and more efficient healthcare delivery. Furthermore, the project will explore the use of additional mechanisms such as Transfer Learning and Attention Mechanisms to enhance performance. It will also investigate Hybrid Models, combining CNNs with Transformer-based architectures. These hybrid models, like the Swin Transformer (SwinT), have demonstrated superior performance in medical image analysis by effectively capturing both local and global features. Additionally, the use of UNet for image segmentation will aid in precisely identifying and isolating regions of interest within retinal scans. By integrating these advanced techniques, the project aims to push the boundaries of current diagnostic capabilities, ensuring more reliable and comprehensive analysis of eye-related diseases.

Research Project 10

Supervisor: Dr. Puneet Gupta, Associate Professor, **Department:** Computer Science and Engineering
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Research Project:

Tuberculosis (TB) remains a leading cause of morbidity and mortality in India. Despite significant efforts under the National Tuberculosis Elimination Program (NTEP), affordable detection remains a critical challenge. Most conventional diagnostic pipelines rely on chest X-rays and molecular tests, both of which require specialized hardware, skilled personnel, and established infrastructure, often lacking in remote and underserved regions. To address these limitations, we propose the development of an affordable and user-friendly multimodal point-of-care TB detection method that leverages the following three complementary modalities and consolidate them using deep neural networks (DNNs):

(a) Cough sound analysis: We will use a smartphone to collect cough sound samples and process them using DNNs such as audio transformers to identify TB-specific acoustic biomarkers. This non-invasive method will enable rapid screening of TB with minimal effort or resources.

(b) AFB (acid-fast bacillus) smear analysis: We will perform this gold standard TB diagnosis analysis by first acquiring images from a novel, portable and cost-effective mobile microscope setup. The collected images will be processed using DNNs to identify AFB, enabling reliable, localized detection without the need for a full laboratory.

(c) Patient history, demographic features, and questionnaire-based tools: We will use this information for improving model performance and contextualizing risk. It complements the others by capturing non-visual cues that may correlate with TB status.

Unfortunately, DNNs are inherently opaque and do not provide explanations for their predictions. Hence, we will incorporate interpretable features as intermediate outputs to enhance transparency, thereby improving trust and supporting its deployment in clinical settings.

Alignment with National Priorities: This proposal aligns with the priorities of India's NTEP, particularly its emphasis on Active Case Finding in low-resource settings. Government initiatives such as the Nikshay platform highlight the urgency and national commitment to early TB detection, treatment adherence, and digital tracking.

Research Project 11

Supervisor: Dr. Ayan Mondal, Assistant Professor, **Department:** Computer Science and Engineering
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Research Project:

The rapid evolution of 6G communication networks is set to revolutionize the healthcare industry by enabling smart, connected, and intelligent healthcare ecosystems. With features such as distributed intelligence, adaptive security and privacy, decentralized trust mechanisms, and advanced computing paradigms, 6G will significantly enhance the efficiency and effectiveness of remote healthcare delivery, including, e.g., real-time monitoring and effective emergency response systems. However, the integration of 6G-enabled remote healthcare poses several challenges, including latency constraints, trust and security concerns, resource optimization, and energy efficiency.

The project focuses on addressing these challenges by exploring practical approaches to trusted, secure, and low-latency service delivery in future 6G-enabled remote healthcare systems. Focusing on selected use cases such as Remote Patient Monitoring (RPM) and telemedicine, the project investigates lightweight edge-AI methods and architectural models that can improve system responsiveness and resilience. Emphasis is placed on developing and evaluating key enablers like adaptive security mechanisms and decentralized trust models at the edge, with attention to energy efficiency and implementation feasibility. It focuses on designing and validating the most relevant components by implementing a proof-of-concept demonstrating the feasibility of decentralized and trustworthy service delivery for a specific healthcare use case.

The key objectives of the project are:

(i) To explore energy-efficient design principles for edge-enabled 5G/6G network infrastructure supporting IoT-driven healthcare use cases such as Remote Patient Monitoring;

(ii) To develop and evaluate lightweight, resilient edge-AI components that enhance healthcare system robustness against disruptions such as DoS attacks, while supporting data privacy and the continuous operation of critical medical services.

Research Project 12

Supervisor: Prof. Somnath Dey, Professor, **Department:** Computer Science and Engineering
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Research Project:

The primary objective of this research is to develop an effective and accurate system for the early detection and classification of sleep apnea using artificial intelligence (AI) and machine learning (ML) techniques. Sleep apnea is a potentially serious sleep disorder characterized by repeated interruptions in breathing during sleep, often leading to fragmented sleep and low blood oxygen levels. Traditional diagnostic methods, such as polysomnography, are expensive, time-consuming, and not easily accessible to all patients. Therefore, there is a pressing need for cost-effective, scalable, and automated diagnostic solutions.

This study aims to explore various AI and ML algorithms—such as deep learning, support vector machines, random forests, and ensemble models—to analyze physiological signals like electrocardiograms (ECG), oxygen saturation (SpO2), airflow, and audio recordings of snoring and breathing. The research will focus on feature extraction, signal preprocessing, data augmentation, and model training to enhance prediction accuracy and generalizability across diverse patient populations.

A secondary objective is to develop a real-time or near-real-time apnea monitoring system that can be integrated into wearable devices or mobile applications, enabling continuous health monitoring outside clinical environments. The study will also assess the ethical considerations, data privacy issues, and potential biases in AI models to ensure equitable and trustworthy deployment.

Ultimately, this research seeks to contribute to the advancement of AI-driven healthcare by offering a non-invasive, accessible, and efficient method for sleep apnea detection, thereby improving diagnosis rates, patient outcomes, and quality of life.

Research Project 13

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Research Project: Autonomous Robot-Assisted Precision Agriculture: Data-Driven Pest Detection, Disease Prediction, and Growth Analysis Using Computer Vision, Deep Learning, and Genome Analysis

Soybean is an important oilseed crop globally. Recent advancement in genomics has played an important role in the soybean improvement programme. However, losses due to biotic and abiotic stresses have been a major factor for soybean yield loss. Hence innovations are needed in genomic and phenomics data analysis and an integrated approach with AI/ML algorithms which can analyze such large scale and multi-model data to develop crop variety which can be disease resistant, drought resistant and hence improving yield in soybean.

Whole genome sequence data from over 1000 soybean lines will be used for comparative genomics studies. Genomic and transcriptome data from 10 local varieties of soybean will be used for the development of the integrated platform. High-throughput phenotyping will be conducted for phenotyping (images of the crop) and for various agronomic and physiological traits. Unmanned ground vehicles (UGVs) and unmanned aerial vehicles (UAVs) will be used for high throughput phenotyping. Unmanned ground vehicles have played a pivotal role by enabling real-time data collection and automated field management. UGVs, equipped with sensors, navigate fields to monitor soil health, moisture levels, and crop conditions, facilitating precise irrigation and fertilization. UAVs can provide aerial imagery, capturing high-resolution data over large areas to assess crop vigor, detect stress, and map field variability. These vehicles can be integrated with computer vision-based disease detection systems which can handle large scale and multi-modal data and can analyze imagery to identify early signs of plant diseases or pest infestations. By employing machine learning algorithms, these systems can be used to detect subtle visual cues, such as leaf discoloration or abnormal growth patterns, enabling timely interventions. This synergy will minimize chemical use, reduce environmental impact, and boost productivity. For instance, UAVs can cover hundreds of acres daily, while computer vision achieves up to 90% accuracy in disease detection, surpassing traditional methods. Multi-modal analysis of plant health can also be performed by correlating image and genomic data of plant which needs to innovate high performance computing-based data analytics and AI/ML algorithms with advanced deep learning architectures

The objectives of the proposal are as follows:

Task 1: Robotic Instrumentation: Equip UGV and UAV platforms with optical sensors and localization for autonomous field data collection.

Task 2: Dataset Acquisition and Curation: Gathering datasets for model development and further developing UGV/UAV navigation and autonomy.

Task 3: Plant Detection and Leaf Localization: Enabling efficient segmentation and analysis for on-robot of image data.

Task 4: Leaf Analysis and Disease Detection: Implementation of multi-modal deep learning based plant disease/pest infestation analysis using images and genome sequences [1,2].

Task 5: Pesticide administration through UAVs: Development of ways to decide the pesticide quantity required and implementation of a methodology for spraying.

Task 6: Model Deployment: Field testing of on-robot, on-drone, and hybrid (robot + data centre models) deployment of deep learning models for crop analysis.

Task 7: Comparative genomics studies for identification of key genes associated with soybean diseases

Research Project 14

Supervisor: Dr. Sharad Kumar Singh, Assistant Professor, **Department:** Electrical Engineering
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Research Project:

The proposed research focuses on the development of intelligent and scalable algorithms for Multi-Agent Path Finding (MAPF) in warehouse environments using Artificial Intelligence (AI). With the rapid adoption of automation in modern warehouses, fleets of autonomous mobile robots are now deployed to transport goods efficiently. However, coordinating multiple agents in real-time without conflicts such as collisions, deadlocks, or delays remains a significant challenge, especially in densely populated and dynamic environments.

This research aims to design AI-driven algorithms that enable decentralized, conflict-free, and computationally efficient path planning for multiple agents. The core objective is to incorporate multi-agent reinforcement learning (MARL), and heuristic-guided Mixed-Integer Programming Based Optimization to improve coordination, adaptability to dynamic obstacles, and real-time responsiveness. We will investigate strategies that combine graph-based planning (like A, conflict-based search) with learning-based components that allow agents to predict congestion and adapt their paths proactively.

The expected impact includes enhanced throughput, reduced operational costs, and improved safety in warehouse automation systems. The outcomes will directly benefit industries relying on smart logistics, e-commerce fulfilment, and autonomous robotics. Furthermore, the developed methodologies can generalize to other domains like Airport Ground Traffic, Automated Parking Systems, and Drone fleet management. This research aligns with IndiaAI's mission to advance core AI technologies for scalable real-world applications in logistics and manufacturing.

Research Project 15

Supervisor: Prof. Ram Bilas Pachori, Professor (HAG), **Department:** Electrical Engineering
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Research Project: Artificial intelligence in signal processing framework for analysis and classification of biomedical signals

The main purpose of this thesis is to design artificial intelligence (AI)-based signal processing frameworks for automated analysis and classification of biomedical signals such as electroencephalogram (EEG), magnetoencephalogram (MEG), electrocardiogram (ECG), etc., to enable diverse biomedical applications, including clinical diagnostics and advanced brain-computer interface (BCI) systems. Traditional diagnostic procedures for neurological and physiological diseases are often time-consuming, require experts, and are inaccessible in remote. Therefore, there is a critical need for an automated AI-driven system capable of analyzing biomedical signals in real-time for detection of conditions like sleep apnea, depression, Parkinson's disease, epilepsy, myocardial infarction, motor-related impairments, and enabling practical BCI applications for diagnosis, monitoring, and assistive technologies. The proposed work will develop AI-based frameworks to classify the different disease conditions based on the extracted abnormal patterns from ECG, EEG, and MEG signals, and will facilitate disease diagnosis and support BCI system for clinical applications. To enhance the identification of discriminative neurological and physiological signal patterns, advanced signal decomposition techniques will be employed. The most relevant features will be computed for automated classification of disease conditions using machine learning and deep learning-based AI-models. Furthermore, to make it compatible with clinical applications, proposed AI model will be deployed on the portable hardware device and validate the performance for real case studies. The developed AI-model-based frameworks can greatly assist in the monitoring of neurological and physiological diseases, reducing the diagnostic burden on clinicians. Additionally, it will support practical BCI applications, such as assistive technologies for motor impairments, and contribute to develop more efficient system for clinical support. Overall, this project has the potential to bridge critical gaps in healthcare by providing a scalable, cost-effective, and automated solution for diseases diagnosis and BCI in clinical practices.

Research Project 16

Supervisor: Prof. Vimal Bhatia, Professor (HAG), **Department:** Electrical Engineering
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Research Project:

Over the past five years, AI/ML has witnessed a major paradigm shift from the so-called “big data” paradigm, in which large volumes of data are collected and processed at a central cloud, towards a “small data” paradigm. In the small/distributed data collection from Internet-of-Things (IoT) devices, a set of distributed agents or devices must process their data in-situ at the edge of a wireless or computing system. This paradigm shift meant that the classical centralized ML approaches that require large training datasets to effectively perform inference tasks are no longer applicable. Such distributed learning solutions in essence must be cognizant of the multi-agent, and distributed nature of the emerging small data-based applications and systems.

The real-world use of this paradigm shift towards distributed learning can be exemplified in the context of IoT as well as future mobile and connected devices with autonomy (e.g., connected self-driven vehicles or autonomous drones). In such systems, each device collects its own, individualized dataset, that is often private, and, collectively, the devices must be able to train a model while overcoming their local data scarcity. In such scenarios, exchange of raw data is often undesirable (due to privacy reasons) or, in some cases, even infeasible (due to communication and computing constraints.

The sheer number of devices working at low power needs a completely new design. This calls for revolutionary and high-risk early analysis and design ideas to be implemented. As we move towards a multi-radio access network (multi-RAT) and heterogenous networks (HetNet) with many of the radio heads having limited compute and memory, the design development of Fog and Cloud based computing and networks is needed. There are various challenges in realizing an efficient and effective distributed learning paradigm in IoT and wireless systems, which needs addressing through architectural, algorithmic, privacy, scalability and efficiency perspectives.

Research Project 17

Supervisor: Prof. Shailesh I. Kundalwal, Professor, **Department:** Mechanical Engineering
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Research Project:

In the proposed work, a novel machine-learned interatomic potential (MLIP) will be developed thoroughly by discussing the step–by–step MLIP creation process using precise but limited data to study the mechanical properties of nanostructures like carbon nanotubes, graphene etc. An ab initio molecular dynamics and classical molecular dynamics simulation techniques will be used in conjunction to develop the machine learning procedure to construct an effective interatomic potential. Such a novel approach will demonstrate significant improvements in the accuracy of prediction of mechanical properties of nanostructures compared to prior studies, highlighting the effectiveness of MLIP in achieving higher precision with minimal computational cost. This work will offer comprehensive analysis and theoretical exploration, delivering valuable insights into MLIP and the mechanical properties of nanostructures, and will pave the way for future applications in materials science and engineering.

Research Project 18

Supervisor: Prof. Pavan Kumar Kankar, Professor, **Department:** Mechanical Engineering;
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Research Project: Condition Monitoring of Centrifugal Pumps Using Machine Learning Techniques

Centrifugal pumps are critical components in industrial systems, widely used in sectors such as water treatment, oil and gas, chemical processing, and manufacturing. Unexpected failures can lead to costly downtimes, safety hazards, and inefficiencies. Traditional condition monitoring techniques—based on vibration analysis, temperature, and acoustic signals—often require expert interpretation and are reactive in nature. This research project proposes the integration of machine learning (ML) techniques to enhance the condition monitoring of centrifugal pumps, enabling predictive maintenance and early fault detection.

Impact:

Implementing machine learning algorithms for pump condition monitoring promises significant improvements in operational reliability and maintenance efficiency. By training models on historical sensor data (vibration, pressure, flow rate, temperature), it becomes possible to identify early signs of wear, imbalance, cavitation, and bearing faults. This proactive approach reduces unplanned downtimes, lowers maintenance costs, and extends equipment life. Moreover, the use of data-driven models minimizes dependence on manual diagnostics, making the system scalable and adaptable across different pump types and operating conditions. Such a smart monitoring system aligns with Industry 4.0 objectives, enhancing the digital transformation of industrial maintenance practices.

Objectives:

1. To collect and preprocess relevant sensor data from centrifugal pumps under various operating conditions.
2. To explore and evaluate suitable machine learning algorithms for fault detection and prediction.
3. To develop a real-time condition monitoring framework that integrates the ML model with industrial IoT (IIoT) platforms.
4. To validate the system through simulation and/or experimental setups, comparing it with traditional monitoring methods.
5. To propose a scalable solution for predictive maintenance of centrifugal pumps in diverse industrial settings.

This research aims to bridge the gap between traditional mechanical diagnostics and modern data-driven approaches, enhancing the reliability and intelligence of pump maintenance systems.

Research Project 19

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Co-Supervisor: Prof. Raghunath Sahoo, Professor, **Department:** Physics;
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Research Project: Design and development of advanced materials for beampipe applications in particle accelerators

Beampipes are critical components in particle accelerators, serving as the vacuum chambers through which particle beams travel. In the early days of particle accelerators, beampipes were typically simple cylindrical tubes made of materials like stainless steel or copper. These pipes served primarily to guide and contain particle beams as they traversed through the accelerator complex. However, with advancements in accelerator technology and the emergence of high-energy collider experiments, the demands on beampipes grew more complex. As the beam energies increased, the choice of materials for beampipes became critical. Materials needed to withstand high vacuum conditions, intense radiation levels, and potential impacts from particle collisions. Stainless steel, beryllium are commonly used due to their favorable mechanical properties and compatibility with ultra-high vacuum environments, along with their sensitivity towards high energy radiation and signal-to-background ratio. In our recent paper [K. Singh et al., Physical Review Accelerators and Beams, Volume 28, April 08 2025, pp. 043101-1 to 043101-9]; we reported design and development of advanced material with a high figure of merit (FoM) for beampipe applications in low particle accelerators. Machine learning algorithms have been used to predict the phase(s), low density, and high radiation length of designed Al-Ti-V alloys. Alloys with various compositions for single-phase and dual-phase mixtures, liquidus temperature, and density values are obtained using Latin hypercube sampling method in TC Python Thermo-Calc software. Further, we experimentally verify the elastic modulus of the developed alloy and compute the FoM equal to 0.416, which is better than other existing materials for beampipes in low-energy experiments. Similarly, we are working on research problem to develop advanced material with an aim to obtain higher radiation length (Xo) as compared to existing Beryllium (Be) material in high experiments

(Operating in TeV energy range) by bringing synergy between computational (AI/ML & ICME) and experimental techniques.

Research Project 20

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Research Project: Developing Robust and Scalable Shallow and Deep RVFL Variants

Random Vector Functional Link (RVFL) networks and their deep extensions, such as deep RVFL (dRVFL) and ensemble deep RVFL (edRVFL), provide an efficient alternative to traditional artificial neural networks by utilizing fixed random weights and closed-form solutions. However, despite their advantages, these models suffer from two major limitations: (i) sensitivity to noise and outliers due to squared error loss and (ii) computational inefficiencies arising from matrix inversion. To address these challenges, we aim to develop both shallow and deep variants of RVFL that integrate a modified version of the recently introduced RoBoSS loss function. This robust loss function mitigates the impact of noisy and outlier samples by applying controlled penalties, enhancing model stability and generalization. Additionally, we reformulate the optimization process to eliminate matrix inversion, significantly improving computational efficiency and scalability for large-scale and high-dimensional data.

Research Project 21

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Research Project: AI-ML in Earthquake Data Science for Seismic Pattern Analysis

This project aims to apply Artificial Intelligence (AI) to analyze seismic data for earthquake prediction and risk assessment. Using algorithms like CNNs and LSTMs, the study will detect patterns, classify events, and predict aftershocks from real-time and historical seismic data. The goal is to enhance early warning systems and support disaster preparedness by providing faster, more accurate insights into seismic activity. This interdisciplinary approach bridges geophysics with data science to improve our understanding and response to earthquake hazards.