ICTer 2025

Book of Abstracts

25th International Conference on Advances in ICT for Emerging Regions

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UCSC

Book of Abstracts

25th INTERNATIONAL CONFERENCE ON ADVANCES IN ICT FOR EMERGING REGIONS

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Abstracts of 25th ICTer International Conference (ICTer 2025)

Conference Website: https://icter.lk

MESSAGE FROM THE DIRECTOR

Dr. Ajantha Atukorale

Director
University of Colombo School of Computing
University of Colombo
Sri Lanka

As the Director of the University of Colombo School of Computing (UCSC), it is my great pleasure to extend a warm welcome to all participants, researchers, and practitioners in the field of Computing to the International Conference on Advances in ICT for Emerging Regions (ICTer 2025). ICTer is a continuation of a proud legacy that began with the International Information Technology Conference (IITC), a pioneering event in Sri Lanka's computing research landscape since 1998. Building on this rich history, ICTer has become its successor, reaffirming our commitment to fostering innovation, sharing knowledge, and advancing the frontiers of technology.

In today's fast-evolving digital world, it is essential to create spaces for the exchange of ideas, insights, and research findings. ICTer serves as such a platform bringing together seasoned researchers and young scholars alike to present groundbreaking results, innovative concepts, and practical applications that are shaping the future of computing.

A hallmark of ICTer is that selected high-quality papers will be considered for publication in the prestigious Springer Communications in Computer and Information Science (CCIS) series and ICTer Journal by the UCSC. This offers authors an invaluable opportunity to reach a global audience and contribute meaningfully to the advancement of technology worldwide.

As we come together for ICTer 2025, I encourage you to make the most of this opportunity: engage actively in the sessions, contribute to discussions, build networks, and forge new collaborations. I look forward to the vibrant exchanges, the sharing of knowledge, and the spirit of partnership that will define this conference.

Together, let us shape the future of computing and contribute to a world that is smarter, more connected, and better informed.

MESSAGE FROM THE CONFERENCE CO-CHAIRS

Dr. Randil Pushpananda
Co-Chair, ICTer 2025
University of Colombo School of Computing (UCSC)
Sri Lanka

Dr. Manjusri Wickramasinghe,
Co-Chair, ICTer 2025
University of Colombo School of Computing (UCSC)
Sri Lanka

The International Conference on Advances in ICT for Emerging Regions (ICTer) continues the proud legacy of the International Information Technology Conference (IITC), which has been held in Sri Lanka since 1998. Over the years, ICTer has evolved into a premier platform for presenting and discussing innovative research and technological developments in the field of Information and Communication Technology. The conference particularly emphasizes sustainable and scalable ICT solutions that address the unique challenges faced by emerging regions.

ICTer provides an environment that fosters collaboration between academia and industry, encouraging the exchange of ideas, experiences, and best practices. It serves as a forum for researchers, practitioners, and policymakers to engage in meaningful discussions on emerging trends and future directions in ICT, strengthening the bridge between research and real-world application.

The 2025 edition of ICTer marks an important milestone in the history of the conference. For the first time, the proceedings are published by Springer in the Communications in Computer and Information Science (CCIS) series, reflecting the growing international recognition of the conference's scholarly contributions. Another notable development this year is the introduction of the Industry Track, designed to highlight practical insights, case studies, and innovations from the ICT industry. This new addition enhances the conference's commitment to connecting academic research with industrial practice and real-world technological advancement.

All submissions to ICTer 2025 underwent a rigorous double-blind peer review process to ensure the highest academic standards. The review process was organized into two tracks, the Main Track and the Industry Track. The Main Track received 146 submissions, of which

21 were accepted as full papers and ten were accepted as posters, resulting in an acceptance rate of 21.2 percent. The Industry Track received eight extended abstract submissions, of which three were accepted for presentation.

We extend our sincere gratitude to the Program Committee, Reviewers, and Members of the Organizing Committee for their dedication and professionalism in maintaining the quality and integrity of the review process. We also express our appreciation to all authors for their valuable contributions and to our sponsors and partners for their continued support in making ICTer 2025 a success.

We hope that this collection of papers will serve as a valuable resource for researchers, professionals, and students who are working to advance ICT solutions for emerging regions. It is our belief that the research presented here will inspire further innovation, collaboration, and sustainable technological development across the globe.

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CONFERENCE DAY 1 – AGENDA **Wednesday, 19th November 2025** **Location: Marino Beach Hotel, Colombo, Sri Lanka**	
08:00 AM	Registration
08:30 AM	Inauguration and Introduction of ICTer 2025
08:50 AM	**Welcome Address by the Conference Co-Chair, Dr. Randil Pushpananda**
08:55 AM	**Address by the Director, UCSC, Dr. Ajantha Atukorale**
09:00 AM	**Address by the Chief Guest, Vice Chancellor, University of Colombo, Professor Indika Mahesh Karunathilake**
09:10 AM	**Keynote – Mr. Daniel Johansson, Leading Security Innovation, Cambio Healthcare** Title: AI and CyberSecurity – A Double-Edged Sword
10:05 AM	**Address by the Platinum Partner - Ms. Saumi Kariyawasam, Senior Director Software Engineering, Cambio Software**
10:30 AM	Tea Break
11:00 AM	**Technical Session 01 - AI Assisted Diagnostics & Medical Imaging**
11:00 AM	A Hybrid Adaptive Segmentation Pipeline with NURBS Surface Reconstruction for 3D Liver Tumor Modeling.
11:15 AM	An Explainable Deep Learning Framework for Gallbladder Disease Classification on Ultrasound Images.
11:30 AM	Integrating U-Net Segmentation and TabNet Transfer Learning for Automated Melanoma Detection.
11:45 AM	Early Detection and Severity Assessment of Dysgraphia in Sinhala – Speaking Children Using a Multi-Modal Machine Learning Approach.
12:00 PM	Machine Learning-Based System to Predict Mental Illness Using Blood Biomarkers and Demographic Factors.
12:20 PM	Lunch Break
01:20 PM	**Industry Talk - Softlogic Information Technologies,** **Mr. Buddika Prasanna Edhireweera, Senior Manager Data Science – Generative AI and IoT.**

01:40 PM	**Industry Track**
01:40 PM	Towards Responsible and Compliant AI Systems in SaaS: Transformation to Secure AI System. (X-Venture)
02:00 PM	ParkEase: Enterprise Grade ANPR based Access Control System. (Sri Lanka Telecom PLC)
02:20 PM	Unified Governance for Data, AI, and API in the Era of Industry 5.0 and Beyond. (X-Venture)
02:45 PM	**Technical Session 02 - Environment and Sustainability**
02:45 PM	A Real Time Decision Support System for Selected Commercial Seaweed Species in Sri Lanka: Species Identification, Quality Assessment, and an Ontology Driven Knowledge Database
03:00 PM	Identifying Three-Band Hyperspectral Composites That Outperform RGB for Floating Plastic Detection.
03:15 PM	Integrated Machine Learning and Ontology-Based Approach for Sustainable Weed Management in Paddy Fields
03:30 PM	Advanced Modeling of Inflation Dynamics in Sri Lanka: A Comparative Analysis of Statistical, Machine Learning, Deep Learning, and Hybrid Forecasting Approaches.
03:50 PM	Tea Break
04:05 PM	**Poster Session 01**
04:05 PM	Deep tRF-Net: A Deep Learning Approach for Multi-Class Cancer Classification using tRNA Derived Fragments (tRF) Expression Patterns.
04:08 PM	OWN-Layer Grad-CAM and PIPPC: An Occlusion-Weighted Multi-Layer Approach and a Faithfulness Metric for XAI in Medical.
04:11 PM	MMAD: Multi-model Adversarial Defense for Medical Images.
04:14 PM	An interpretable machine learning model to predict drug addiction among children in Sri Lanka.
04:17 PM	PoPStat–COVID19: Leveraging Population Pyramids to Quantify Demographic Vulnerability to COVID-19.
04:20 PM	Q & A - Poster Session 1
04:30 PM	Day one concluding ...

CONFERENCE DAY 2 – AGENDA **Thursday, 20th November 2025** **Location: Marino Beach Hotel, Colombo, Sri Lanka**	
08:00 AM	Registration
08:30 AM	**Technical Session 03 - Systems, Security & Privacy**
08:30 AM	Leveraging Unintentional Electromagnetic Emissions for Radio Tomographic Imaging
08:45 AM	Matrix-Based Forecasting and Anomaly Detection Framework for Cloud VM Resource Monitoring
09:00 AM	Balancing Privacy and Performance in Federated Learning with Adaptive Differential Privacy and Secure Multi-Party Computation
09:25 AM	**Keynote – Prof. Kasun De Zoysa, University of Colombo School of Computing** Title: From Bits to Qubits: Building Quantum Readiness in Academia and Industry
10:20 AM	Tea Break
10:40 AM	**Technical Session 04 - Language, Speech, & Text Processing**
10:40 AM	Adaptive Fluency and Pronunciation Assessment for Young English Learners in Sri Lanka.
10:55 AM	Unified Detection of Generated Speech: Combining Audio Spectrogram and Text Analysis.
11:10 AM	A Continual Learning Mechanism for Early Brahmi Inscription Translation with Deep Learning.
11:25 AM	Creating Digital Estampages of Sri Lankan Stone Inscriptions using Multispectral Imaging.
11:40 AM	Authorship Identification of Sinhala Poems Using Machine Learning Techniques.
11:55 AM	Possible Distillation for Abstractive Summarization: Reducing Hallucination in Compact LLMs.
12:15 PM	**Poster Session 02**

12:15 PM	Dataset Sensitivity and Scalability in RNN-Based V2X Intrusion Detection.
12:18 PM	Beyond Charging: How Juice Jacking Enables Data Theft and Device Compromise in Android.
12:21 PM	Smart Card Vulnerabilities in Sri Lanka: A Security Assessment Across Service Providers.
12:24 PM	YOLOv8 for Nondestructive Black Pepper Impurity Detection.
12:27 PM	Work Sphere: A Multi-modal Approach to Employee Engagement Detection in Remote Work Environments with Explainable AI.
12:30 PM	Q & A - Poster Session 02
12:45 PM	Lunch Break
01:40 PM	**Keynote – Prof. Thiemo Voigt, Uppsala University, Sweden** Title: Beyond Digital Backscatter
02:30 PM	**Technical Session 05 - Music & Acoustic Processing**
02:30 PM	Dynamic Music Harmonization via Interactive Machine Learning Methods and Genetic Algorithms.
02:45 PM	Genetic Algorithm Based Deep Time Series Similarity Searching Approach for Acoustic Fingerprinting.
03:00 PM	Emotion in the Crowd: SLCSED and a MIR-Enhanced Machine Learning Pipeline.
03:20 PM	Finale and next year promo video
03:45 PM	Awards Ceremony - Best Paper
04:15 PM	Vote of Thanks and Day 2 Concluding ...
04:30 PM	Tea Break

KEYNOTES

INTRODUCTION TO THE KEYNOTE SPEAKER 1

Daniel Johansson

Chief Technical Security Officer
Cambio Healthcare
Sweden

Daniel Johansson is the Chief Technical Security Officer at Cambio Healthcare, where he oversees application security across the company's comprehensive enterprise healthcare product suite. With more than 15 years of experience as a software developer and solutions architect, Daniel has built secure, high-performance systems in both High Performance Computing and the Automotive Industry.

ABSTRACT OF THE KEYNOTE ADDRESS 1

AI and Cybersecurity – A Double-Edged Sword

Daniel Johansson

Cambio Healthcare, Sweden

AI now writes phishing emails, maps networks, writes and tweaks malware and automates hacking – yet, the very same techniques sift logs, tighten access and predict breaches. This talk will go through how generative models amplify both offense and defense. We will cover both what's going on today, what's available, what's being reported on as well as making some predictions about the near future.

INTRODUCTION TO THE KEYNOTE SPEAKER 2

Professor Kasun De Zoysa

Deputy Director
University of Colombo School of Computing
Sri Lanka

Prof. Kasun De Zoysa is the Deputy Director and Coordinator of the Center for Digital Forensic (CDF) at the University of Colombo School of Computing (UCSC). He has led national initiatives on cybersecurity, digital forensics, and ICT policy development, contributing to Sri Lanka's digital transformation and resilience efforts.

Prof. De Zoysa has collaborated internationally including with George Washington University, USA, National University of Singapore and Nanyang Technological University in Singapore, and Stockholm University, Uppsala University and Royal Institute of Technology (KTH) in Sweden on projects at the intersection of digital security and governance. His leadership in integrating academic research with national technology strategy positions him as a leading voice in preparing the region for the quantum secure future.

ABSTRACT OF THE KEYNOTE ADDRESS 2

From Bits to Qubits: Building Quantum Readiness in Academia and Industry

Professor Kasun De Zoysa

University of Colombo School of Computing

Quantum computing is no longer a distant frontier. It is a disruptive force that will redefine national security, digital economies, and technological sovereignty. As powerful quantum machines emerge, the encryption systems that safeguard government data, financial transactions, and critical infrastructure will become vulnerable.

This keynote calls for a strategic national response to the post quantum era. It explores how universities, industry, and policymakers can collaborate to build quantum readiness developing skills, research capacity, and migration strategies toward Post Quantum Cryptography (PQC).

INTRODUCTION TO THE KEYNOTE SPEAKER 3

Professor Thiemo Voigt

Department of Electrical Engineering
Uppsala University
Sweden

Thiemo Voigt is a professor at Uppsala University, Sweden, and senior researcher at RISE Research Institutes of Sweden. His research interests are in low-power communication, systems software for networked systems, in-body networking and embedded AI. His work has been cited more than 22000 times and led to several best paper awards.

ABSTRACT OF THE KEYNOTE ADDRESS 3

Towards 6G Ambient IoT with Backscatter and Intermittent Computing

Professor Thiemo Voigt

Uppsala University and RISE

Backscatter communications has reduced the power consumption for communication by several orders of magnitude compared to traditional active low-power radios. While backscatter communications has become an integral part of 6G Ambient IoT, in this talk, I present some of our efforts to go beyond digital backscatter. Analo backscatter completely eliminates all digital parts which on one hand further reduces power consumption but on the other hand poses some new challenges such as the need to desynchronize transmissions. I will also discuss our most recent work that reduces the power consumption of active radios to that of backscatter radios.

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CONFERENCE PAPERS

TECHNICAL SESSION 1

AI Assisted Diagnostics & Medical Imaging

A Hybrid Adaptive Segmentation Pipeline with NURBS Surface Reconstruction for 3D Liver Tumor Modeling

Y. S. Windsor, R. G. N. Meegama

University of Sri Jayewardenepura, Sri Lanka.

Accurate 3D liver tumor models are essential for surgical planning, radiation therapy dose calculation, and treatment response assessment. Current automated segmentation methods either require extensive training data (deep learning) or lack robustness across varying image quality (classical methods). This paper presents a novel hybrid adaptive segmentation pipeline that automatically switches between intensity-based and spatially-regularized Fuzzy C-Means clustering based on local image quality, followed by graph-cut refinement and NURBS surface reconstruction. The key innovation is the adaptive switching mechanism that maintains segmentation accuracy across diverse CT acquisition protocols without requiring training data. On the LiTS dataset, it achieved competitive accuracy (mean Dice ≈ 0.85) with sub-millimeter surface precision (0.6 mm) and minimal volume bias (3%), demonstrating clinical-grade performance for treatment planning applications. The learning-free approach makes it immediately deployable across different scanner types and institutions.

Keywords: *LiverTumor Segmentation, Surgical Planning, Adaptive Clustering, Graph Cuts, NURBS Surface Reconstruction*

An Explainable Deep Learning Framework for Gallbladder Disease Classification on Ultrasound Images

Keerthana Giridharini, Kalhari Walawage

Informatics Institute of Technology, Sri Lanka

Gallbladder diseases such as gallstones, infections, and cancer affect millions worldwide, and early diagnosis is critical for effective treatment. Yet, accurate detection remains difficult because ultrasound images are often noisy and symptoms across conditions appear similar. This problem is even worse in areas with few resources and few radiology experts. While deep learning has shown promise in ultrasound-based disease classification, most existing studies are restricted to binary classification, lack robust preprocessing and segmentation, and provide limited interpretability leaving a clear gap in reliable multi-class diagnostic frameworks. This study addresses this gap by developing a XAI-based deep-learning system capable of classifying nine gallbladder disease types using UIDataGB dataset containing 10,692 annotated ultrasound images. A comprehensive preprocessing pipeline incorporating CLAHE, Gaussian filtering, unsharp masking, and Active Contour segmentation was applied to enhance image quality and emphasize disease-relevant regions. Multiple deep learning approaches were investigated, including a custom CNN, a hybrid model combining VGG16 and ResNet152 through feature-level fusion, and ensemble approaches. The most effective ensemble, integrating the custom CNN with the hybrid model, achieved 99.8% test accuracy and a Cohen kappa score of 0.998, outperforming transfer learning ensembles. Comparative benchmarking further demonstrated superior robustness and classification depth. To ensure clinical trust, eXplainable AI (XAI) methods including Grad-CAM and LIME were applied, providing interpretable visualizations of image regions influencing predictions. By addressing limitations in multi-class diagnosis, preprocessing, and interpretability, the proposed framework delivers a highly accurate and scalable tool for improving early diagnosis and management of gallbladder diseases in emerging healthcare contexts.

Keywords: *Gallbladder Ultrasound Analysis, Deep Learning Models, Explainable Artificial Intelligence (XAI), Multi-Class Disease Classification*

Integrating U-Net Segmentation and TabNet Transfer Learning for Automated Melanoma Detection

Hasini Yasoda Weeraddana, Colambage Hiruni Malsha Fernando, Hewa Dewage Sachini Anuththara Fernando, Edirisuriya Arachchige Minsara Prabhash Suriyaarachchi, Digo Arachchillage Ravindu Thamuda Jayasinghe, Kodikara Arachchillaya Saneera Hemantha Kulathilake

Rajarata University of Sri Lanka, Sri Lanka

Melanoma is the most lethal type of skin cancer and has been rising rapidly in recent decades, where providing a reliable means of early detection can play a crucial role in successfully treating melanoma. Conventional melanoma diagnosis through visual inspection and biopsy is time-consuming, costly, and error-prone. A deep learning-based technique for early melanoma detection can offer a more reliable and efficient solution. The system begins with a preprocessing stage that removes hair artefacts using an inpainting technique, ensuring clear lesion visibility. Preprocessed images are then segmented using a U-Net model, which accurately isolates lesion regions. Clinically relevant features defined by the ABCD criteria: Asymmetry, Border Irregularity, Colour Variation, and Diameter are extracted. These features are input for the classification model to differentiate between Malignant and Benign cases. A Multilayer Perceptron (MLP) neural network is developed for classification, and to further enhance its performance, transfer learning is incorporated through TabNet. These components are integrated into an ensemble framework that combines their predictive strengths. The system is evaluated on a selected subset of the Melanoma Skin Cancer Dataset (a combination of ISIC datasets), consisting of 215 dermoscopic images (180 training, 20 validation, 15 testing) representing diverse lesion morphologies. Performance is assessed using Accuracy, Precision, Recall, F1-score and Confusion Matrix. The integrated model achieves an accuracy of 71%, with a precision, recall, and F1-score of 0.71, outperforming individual models in accuracy and loss reduction, highlighting its potential to power an efficient computer-aided diagnosis system that helps physicians improve efficiency in healthcare practice.

Keywords: *Melanoma, Skin Cancer, Deep Learning, Ensemble Learning*

Early Detection and Severity Assessment of Dysgraphia in Sinhala – Speaking Children Using a Multi – Modal Machine Learning Approach

Sandushi Weraduwa[1], PPG Dinesh Asanka[1], Thilini V. Mahanama[1], Swarna Wijeathunge[2]

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Dysgraphia is a neurological learning disability that impairs handwriting, spelling, and the ability to express thoughts in written form. Despite its significant impact on children's academic performance and psychological well-being, early detection remains a challenge particularly in linguistically and culturally unique settings like Sri Lanka. Existing diagnostic tools are largely developed for English-speaking populations and fail to address Sinhala language-specific characteristics. To bridge this gap, this research introduces the first multi-modal sequential machine learning framework in Sri Lanka for the early detection and severity assessment of Dysgraphia among Sinhala-speaking primary school children. The proposed approach integrates two key components: a Convolutional Neural Network (CNN) utilizing VGG16 for handwriting image analysis, and a Gradient Boosting classifier for interpreting cognitive, behavioral, and personal data. The dataset comprises 373 digitized handwriting samples from 84 children, collected from local schools and a pediatric hospital, using psychological assessments from Indian contexts adapted to Sinhala language materials. Handwriting samples were preprocessed through binarization and color inversion for model input. The handwriting-based Dysgraphia detection model achieved an accuracy of 96%, while the severity assessment model reached 87%. This pioneering multi-modal sequential approach significantly enhances diagnostic precision and reliability, enabling earlier interventions and individualized academic support. The study represents a vital step toward inclusive education in Sri Lanka, leveraging advanced AI techniques to meet a critical need in local learning disability diagnostics.

Keywords*: CNN-VGG16, Dysgraphia, Learning Disability Detection, Multi-modal Machine Learning, Sinhala Language*

Machine Learning – Based System to Predict Mental Illness Using Blood Biomarkers and Demographic Factors

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Mental health disorders are a growing global concern, yet diagnosis often depends on subjective and time-consuming assessments, which can delay treatment and overlook comorbidity. This study introduces a multi-output machine learning model that integrates blood biomarkers and demographic factors to predict individualized risk scores for five common disorders: anxiety, depression, ADHD, OCD, and schizophrenia. A dataset of 2,500 clinically diagnosed cases was compiled from the UK Biobank and the National Institute of Mental Health in Sri Lanka, with diagnostic labels confirmed through DSM-based assessments and validated clinical interviews. Input features included cytokines, cortisol, metabolic markers, age, and gender, selected based on prior evidence linking biomarkers to psychiatric outcomes. Several models were evaluated, and XGBoost demonstrated the strongest performance, achieving a mean RMSE of 0.19 and an R^2 of 0.76 under 10-fold cross-validation. By producing continuous risk values rather than binary outcomes, the system enables more nuanced assessment of individual vulnerability and accommodates comorbid conditions. These findings highlight the feasibility of biomarker-driven predictive modeling as a data-driven approach for earlier detection, risk stratification, and improved clinical decision-making in mental health care.

Keywords: *Mental health, machine learning, biomarkers, XGBoost, multi-output regression, risk prediction, comorbidity, early detection*

TECHNICAL SESSION 2

Environment and Sustainability

A Real Time Decision Support System for Selected Commercial Seaweed Species in Sri Lanka: Species Identification, Quality Assessment, and an Ontology Driven Knowledge Database

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Uva Wellassa University of Sri Lanka

Seaweed, with significant economic and ecological potential, are becoming an increasingly important export product for Sri Lanka. Proper identification and quality assessment are crucial for accurate traceability and export authentication to prevent species depletion due to overexploitation and ensure sustainable utilization. This study aims to develop a model that utilizes image pro cessing techniques focusing on color, shape, and texture combined with machine learning and ontology, to identify, evaluate the quality of, and provide information about selected economically significant seaweed species. The study tar gets *Sargassum crassifolium, Kappaphycus alvarezii, Padina antillarum, Ulva lactuca,* and *Gracilaria corticata*, with primary data collected from seaweed farms and wild collection sites in Jaffna, Valaippaadu, Mannar, and Talpe, Sri Lanka. Images were resized to 600x600 pixels, and species identification was performed by categorizing them into folders, while quality assessment involved classifying them as "Good" or "Rejected." Various image processing techniques were used to develop identification and quality assessment models. The final identification model, combining histogram equalization, canny edge detection, contour analysis, and local binary patterns, achieved 92.67% accuracy with Random Forest. For quality assessment, *Padina antillarum* used histogram equalization, contour analysis, and gabor filters, with SVM reaching 95% accuracy. *Ulva lactuca* used color moments, canny edge detection, and GLCM, achieving 96% with Random Forest. *Kappaphycus alvarezii* used histogram equalization, color moments, contour analysis, and gabor filters, reaching 89%. An ontology devel oped from the collected data for easy querying and information retrieval about the species.

Keywords: *Seaweed Identification, Seaweed Quality Assessment, Ontology, Image Processing, Machine Learning*

Identifying Three-Band Hyperspectral Composites That Outperform RGB for Floating Plastic Detection

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Floating plastic pollution poses severe environmental risks, requiring precise and efficient detection methods. While Hyperspectral Imaging (HSI) offers rich spectral detail for identifying plastic types, its high dimensionality and processing demands limit real-time applications. This study investigates whether compact three-band hyperspectral composites can outperform RGB in object level plastic detection while remaining compatible with standard detection models. Using a publicly available dataset collected with Specim FX10 and FX17 cameras, object-level annotations were aligned and used to create a balanced synthetic dataset. Six statistically discriminative bands were selected through ANOVA testing, from which 20 three-band combinations were evaluated across YOLO, Faster R-CNN, and RetinaNet models. Results demonstrate that several composites consistently outperformed RGB baselines, particularly for HDPE and PP classes, with notable contributions from bands near 990 nm, 1335 nm, and 1702 nm. These improvements were achieved without modifying model architectures or training parameters. Band frequency analysis further revealed model-specific and class-specific patterns in optimal wavelengths. This work highlights the potential of reduced-band hyperspectral inputs for accurate, scalable detection of floating plastics, providing a step toward more resource efficient sensing systems suited for dynamic aquatic environments.

Keywords: *Floating plastic detection, Hyperspectral band selection, Three band composites, Object detection models.*

Integrated Machine Learning and Ontology-Based Approach for Sustainable Weed Management in Paddy Fields

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This research investigates the challenges of identifying and managing five major weed species in Sri Lankan paddy fields, namely Echinochloa colona, Echinochloa crus-galli, Cyperus rotundus, Monochoria vaginalis, and Ludwigia perennis using advanced computing techniques. A dataset of 3,200 data points, comprising both primary and secondary data, was utilized. Expert-labeled primary images were preprocessed using noise reduction, followed by data augmentation techniques such as rescaling, shearing, zooming, and horizontal flipping to ensure robust feature extraction. Using a Convolutional Neural Network (CNN) with seven hidden layers and a categorical cross-entropy loss function and Adam optimizer, texture, shape, edge, and contextual features were extracted. These features were then input into both Support Vector Machine (SVM) and Random Forest (RF) classifiers. The RF model achieved a higher accuracy of 98.75%, outperforming the SVM's 97%, and was selected for the final implementation. Moreover, a formal ontology was developed to manage domain knowledge of weed control strategies. Thirty competency questions guided its development, covering control strategies across initial, mid, and extreme growth stages. Evaluation confirmed that the ontology could accurately answer all questions, demonstrating its potential for precise weed management. Integration of the RF model with the ontology enabled automated decision-making. The system performed well in identifying mid-stage weeds, though it showed limitations at early stages. This hybrid approach offers significant advancements in the accurate identification and management of weeds in Sri Lankan agriculture.

Keywords: *Convolutional Neural Network, Random Forest, Ontology, Weed management.*

Advanced Modeling of Inflation Dynamics in Sri Lanka: A Comparative Analysis of Statistical, Machine Learning, Deep Learning, and Hybrid Forecasting Approaches

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Inflation significantly influences national economic activities and serves as a vital indicator for monetary policy formulation. In Sri Lanka, most prior studies have concentrated on Traditional Time Series (TTS) and Machine Learning (ML) models, with limited exploration of Deep Learning (DL), ensemble, and hybrid approaches, especially those employing systematic hyperparameter optimization. Moreover, recent economic disruptions, such as the COVID-19 pandemic and the 2022 economic crisis, have not been adequately incorporated into previous analyses. This study provides a comprehensive analysis of univariate one-step-ahead inflation forecasting using diverse modeling approaches. TTS models, including Auto Regressive Integrated Moving Average (ARIMA) and Seasonal ARIMA (SARIMA), were benchmarked against ML models (Random Forest, XGBoost, Support Vector Regression (SVR)) and DL models (Feedforward Neural Networks (FNN), Long Short-Term Memory (LSTM), Convolutional Neural Networks (CNN)). Hybrid approaches were explored, including simple and weighted averaging ensembles, where weights were based on evaluation metrics, and residual-based hybrid models (SVR-CNN, SVR-LSTM, SVR-FNN). Hyperparameter optimization was performed using Optuna with time series cross-validation. Monthly Colombo Consumer Price Index (CCPI) headline inflation data from January 2000 to March 2025 were analyzed across multiple train-test splits (70:30, 80:20, 90:10), with the 90:10 split yielding the best results. Models were evaluated using RMSE, MSE, MAE, and R2. While SARIMA captured seasonality effectively, ML and DL models improved forecasting accuracy. Additionally, error-weighted ensemble models and the simple averaging ensemble model further enhanced forecasting performance. While the MAE-weighted ensemble model slightly outperformed the others in numerical error metrics, the Diebold-Mariano test indicated that the proposed simple average ensemble model and error-based weighted average ensemble models provided competitive performance.

Keywords: *Inflation, Machine Learning, Time Series, Hybrid Models.*

TECHNICAL SESSION 3

Systems, Security & Privacy

Leveraging Unintentional Electromagnetic Emissions for Radio Tomographic Imaging

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Radio Tomographic Imaging (RTI) is a promising technique for imaging non-line-of-sight areas. RTI uses radio frequency signals to create a map of the area of interest (AoI) by analyzing changes in signal strength caused by the presence or movement of objects within a network of wireless transmitters and receivers. However, current implementations require complex setups with multiple transceivers and costly, dedicated radio circuits. These systems are difficult to use in embedded and IoT applications and are highly sensitive to terrain and surface structure variations, which can significantly impact signal propagation. We investigate an alternative approach that exploits the unintentional electromagnetic (EM) emissions from computing devices to detect the effect of a human presence on the link between the device and the antenna. We conduct experiments in three different environments with a stationary person in the link using EM emissions of a single desktop PC with an Intel i5-7400 CPU. Our results demonstrate that an object in line of sight between the signal source and the receiver causes variations in the received signal from 0.65 to 3.52 dB, dependent on the AoI and the surroundings. Our results also show that changes can be detected up to 2.4 m from the signal source in a cluttered indoor environment and up to 3 m in an outdoor environment. Our findings further indicate that unintentional EM emissions from electronic devices can enable passive human detection without the need for purpose-built transmitters. Therefore, our approach can be extended to RTI.

Keywords: *Radio Tomography, Electromagnetic emissions, Far field antenna, HackRF*

Matrix-Based Forecasting and Anomaly Detection Framework for Cloud VM Resource Monitoring

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This study introduces a mathematical framework that utilizes matrix factorization to model and detect anomalies in virtual machine (VM) resource utilization in cloud computing settings. The approach employs Singular Value Decomposition (SVD) on time-series data to extract dominant patterns in resource consumption and to predict future usage trends. To enhance the robustness of anomaly detection, an Exponential Moving Average (EMA) is applied to smooth the forecast errors, which helps mitigate the effects of transient noise and short-term variability. The framework emphasizes computational efficiency and transparency, addressing some of the drawbacks associated with more complex and less interpretable models. The method was evaluated through experiments on synthetic datasets designed to replicate realistic work-load fluctuations and burst anomalies. Results across various test cases indicate that the model reliably differentiates normal usage from anomalies and maintains balanced performance in both over-prediction and under-prediction scenarios. This framework provides a practical and interpretable tool for resource monitoring that can be readily integrated into cloud infrastructures requiring prompt and explainable decision-making support.

Keywords*: Cloud Resource Management, Anomaly Detection, Matrix Factorization, Exponential Moving Average, Singular Value Decomposition.*

Balancing Privacy and Performance in Federated Learning with Adaptive Differential Privacy and Secure Multi-Party Computation

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Federated Learning (FL) enables collaborative model training without sharing raw data, but exchanged updates remain vulnerable to inference attacks. While Differential Privacy (DP) adds noise to protect privacy, client-side noise in methods like Adaptive DP-FL introduces high variance and relies on server trust. Secure Multi-Party Computation (SMPC) safeguards updates via secret sharing but lacks integration with differential privacy. We propose a hybrid FL framework combining adaptive DP-FL with SMPC. Clients clip gradients adaptively and secret-share updates across non-colluding servers. Servers reconstruct only the global sum, add a single calibrated Gaussian noise term, and account privacy using R´enyi DP. This design reduces sensitivity by $1/K$, cuts noise variance, and streamlines privacy accounting. Experiments on MNIST and Fashion-MNIST under varying budgets show improved accuracy over the baseline, demonstrating enhanced privacy–utility trade-offs for sensitive applications.

Keywords: *Federated Learning, Differential Privacy, Secure Multi-Party Computation, Shamir's Secret Sharing, R´enyi Differential Privacy*

TECHNICAL SESSION 4

Language, Speech, & Text Processing

Adaptive Fluency and Pronunciation Assessment for Young English Learners in Sri Lanka

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English speaking and read-aloud skills are an expertness which should develop from childhood. To achieve this, proper pronunciation of words and fluency should be considered from the early stages of learning. In Sri Lanka, from middle childhood, schools tend to build up students' multilingual abilities by teaching the English language. Even though the schools provide resources for students to learn, the individual attention received by each student may vary during the classroom session. Some students may pick up the correct speaking skills, while some struggle. This research paper proposes a comprehensive assistant tool for English pronunciation and fluency monitoring, targeting students under twelve years. This proposed solution will facilitate teachers monitoring each student's performance with a click. The solution fills the gap in tracking student's English read-aloud and speaking progress. Moreover, students will have an interactive web application interface to speak out the text provided based on their grade and tailored difficulty level. The fluency and pronunciation scoring system uses models and libraries, such as Whisper, Gentle, CatBoost regression model, Librosa, difflib, and a custom prosody-aware mod el. The models are tuned with voice datasets of native and non-native students under age twelve for better accuracy. Model training is done using open-source datasets available in Kaggle and Zendoo by fine tuning, the CatBoost model achieved approximately 5.8% improvement and triplet classification accuracy 1.15% improvement. The adaptive sentence difficulty and targeted training used in these results enable the results to be effective for automated fluency and pronunciation assessment.

Keywords: *English fluency assessment, English pronunciation evaluation, Adaptive text difficulty, English speech recognition for children.*

Unified Detection of Generated Speech: Combining Audio Spectrogram and Text Analysis

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The study presents a multi-model framework for audio spoof detection that integrates both acoustic and linguistic cues to enhance classification robustness. While conventional methods rely primarily on spectrogram analysis using convolutional neural networks, they often overlook the linguistic inconsistencies present in spoofed speech. To ad dress this limitation, the proposed approach combines deep features extracted from Mel spectrograms with semantic coherence representations derived from transcribed speech. Visual features are obtained using the fine-tuned AlexNet architecture, while a fine-tuned Sentence Transformer model is used to capture linguistic patterns. The fused feature representations are processed by a feedforward neural network for binary classification. Experimental analysis demonstrates that the multi-model system offers significant improvements over uni-model baselines. The results validate the effectiveness of combining acoustic and semantic information, providing a more comprehensive and reliable framework for real-world spoof detection applications.

Keywords: *Spoof detection, Audio-text fusion, Spectrogram analysis, Coherence analysis, Sentence transformers, Speech processing, Multi model learning*

A Continual Learning Mechanism for Early Brahmi Inscription Translation with Deep Learning

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The manual recognition and translation of ancient inscriptions are significantly hindered by data scarcity and the limitations of current automated systems. Most existing solutions depend on large, annotated datasets to achieve high accuracy, which is impractical in this domain due to the limited availability of labeled data. Furthermore, the dynamic and evolving nature of inscription studies renders static models prone to obsolescence. This paper introduces a novel continual learning framework focused on the translation of Early Brahmi inscriptions in Sri Lanka. The proposed system combines a YOLO-based character recognition module with a Transformer-based neural machine translation (NMT) model, enhanced through transfer learning techniques. To address data scarcity and obsolescence, the system employs both incremental and active learning strategies, enabling continuous adaptation without catastrophic forgetting or the need for full retraining. The effectiveness of this approach is demonstrated through proto type implementation. Experimental results show that the YOLOv11 character recognition model achieved a mean Average Precision (mAP) of up to 95.2%, while translation performance improved from a BLEU score of 70.43 in the initial training cycle to 81.04 in the third cycle (second retraining).

Keywords*: Early Brahmi, YOLO-based Character Recognition, Transformer based NMT, Continual Learning, Incremental Learning, Active Learning.*

Creating Digital Estampages of Sri Lankan Stone Inscriptions using Multispectral Imaging

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Stone inscriptions are of immense historical and cultural im portance, but are progressively becoming illegible due to natural weathering, erosion and vandalism. This paper presents a novel approach to enhance the readability of stone inscriptions using multispectral imaging. Traditional methods such as estampages are weather-dependent and prone to human error. The proposed multispectral imaging-based system combines advanced techniques such as spectral enhancement based on Kubelka–Munk theory, multispectral band selection, and deep learning–based preprocessing models (U-Net, ResNet) to significantly improve legibility, providing a non-invasive and efficient method for documenting and preserving ancient inscriptions. Results demonstrate that our U Net–based preprocessing pipeline achieved a peak PSNR (Peak Signal-to Noise Ratio) of 15.33 dB and reduced FID (Fr´echet Inception Distance) to 518, while expert evaluation showed a 58.7% preference for digital estampages over traditional methods. This demonstrate the system's potential for integration into existing archaeological workflows, improving both accuracy and time efficiency in inscription documentation.

Keywords: *multispectral imaging, epigraphy, stone inscriptions, digital estampages, archaeology, archaeological documentation*

Authorship Identification of Sinhala Poems Using Machine Learning Techniques

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Authorship identification in literary works has several practical ap plications such as academic integrity verification, copyright protection and forensic linguistics. Sinhala poetry, with its deep cultural and historical significance presents a unique challenge due to its rich stylistic elements and linguistic complexities. This study aims to develop a computational model for authorship identification in Sinhala poems using machine learning techniques. A dataset of 300 poems from 10 authors, with 30 poems per author, was used for this study. This study was done under several experiments to identify the best data trans formation method and to compare the performance of different machine learning techniques. Cross-validation was used throughout the study to ensure robust evaluation, while accuracy metric was selected as the primary performance met ric. Grid search was used to fine tune the hyper parameters of the model. Among the evaluated approaches, the hyper parameter tuned CNN model using TF-IDF with unigram configuration achieved the best accuracy. These findings highlight the potential of machine leaning techniques, combined with optimized text representation techniques, for effective authorship identification in Sinhala poems. The main limitation of this research lies in the size and scope of the dataset, which defines the boundaries of the study's conclusions.

Keywords: *Authorship Identification, Natural Language Processing, Deep Learning*

Possible Distillation for Abstractive Summarization: Reducing Hallucination in Compact LLMs

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Large language models (LLMs) have excells strong performance in Natural Language Processing tasks. Text summarization is one among them, But the knowledge is limited in the context of subjective ness in the summarized text. And it may able to hallucinated itself by the chain of prompts. The knowledge regarding context is not specific for low resource models, rather, predicting the next tokens. In this work, we explore possible distillation a practical approach to transferring summarization capabilities from high-capacity teacher models to compact student models. Specifically, we distill knowledge from four powerful teacher models LLaMA 3.1 (90B), Falcon (40B), Gemma2 (27B), and Qwen2.5 (72B) into student models of significantly smaller size (8B, 7B, 2B, and 7B, respectively). And it evaluated through the benchmark metrics such as ROUGE-L, BLEU, and METEOR. Our results show that while student models exhibit strong summarization capabilities, but they suffer from knowledge loss and hallucination. Teacher models are slow but good in context aware summarization. The distilled model perform moderatively faster than the teacher and hallucination free than the student in subjective sense. Distilled Qwen achieved the best performance with ROUGE-L of 0.6900, BLEU of 49.47, and METEOR of 0.6850, whereas other distilled models like Gemma2 and Falcon showed low performance compared to Distilled Qwen. These findings highlight the challenge of preserving factual integrity in compact models and motivate distillation as a viable method to reduce hallucination while maintain ing summary quality. The entire code implementation can be found at :https://github.com/Abishethvarman/KD-Text-Summarization.

Keywords: *Abstractive Text Summarization, Knowledge Distillation, Large Language Models, Task Specific Distillation, Hallucination*

TECHNICAL SESSION 5

Music & Acoustic Processing

Dynamic Music Harmonization via Interactive Machine Learning Methods and Genetic Algorithms

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Music harmonization breathes life into melody, layering it with chords and patterns that add richness, dimension, and emotional nuance. It's not just about sound, it's about connection. This study explores the art of harmonization, placing emotional expression at its core. By recognizing the feelings embedded within melodies, the research blends machine learning with musical intuition. Using machine learning, the system learns to sense the emotion-al essence of a tune whether joyful, somber, or somewhere in between. These emotional cues guide a genetic algorithm, which evolves chord progressions that don't just fit the melody, they enhance its soul. Features extracted from audio signals shape the algorithm's understanding, while classification tools sort emotions with growing precision. The result is a creative interplay between human feeling and computational logic. The artificial neural network, with an emotion recognition accuracy of 60%, becomes the ear; the genetic algorithm, crafting harmonies through countless generations, becomes the heart. Together, they compose music that resonates not just sonically, but emotionally, blurring the lines between algorithm and art.

***Keywords**: congruence, cepstrum, filter bank processing, formant, gradient descent, mel-frequency cepstral coefficients*

Genetic Algorithm Based Deep Time Series Similarity Searching Approach for Acoustic Fingerprinting

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With the exponential growth in music consumption, the demand for robust audio identification systems has intensified, especially for copyright detection and content-based retrieval. Acoustic fingerprinting, which identifies audio using unique spectral features, is a core technique in this domain. In this study, we propose a novel Deep Time Series Similarity Searching (DTSSS) framework for audio fingerprinting, leveraging a Long Short-Term Memory (LSTM)-based Siamese Neural Network. A key innovation of this work is the integration of a Genetic Algorithm (GA) to optimize hyperparameters critical to model performance. To enhance robustness, audio degradations such as noise, pitch, and tempo alterations were applied during data augmentation. The proposed system significantly outperforms the Shazam algorithm, achieving an accuracy of **64.44%** compared to Shazam's **21.22%** on the same dataset of degraded audio. This result highlights the potential of combining deep learning with evolutionary optimization for high-fidelity, real world audio retrieval systems.

Keywords: *Music Information Retrieval, Acoustic Fingerprinting, Genetic Algorithm, Hyperparameter Optimization*

Emotion in the Crowd: SLCSED and a MIR Enhanced Machine Learning Pipeline

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Understanding crowd emotions through sound is critical for applications in event monitoring, public safety, and mental health studies. However, there has been a notable gap in the availability of specialized datasets and robust models for classifying crowd sound emotions. To address this, a comprehensive Sri Lankan Crowd Sound Emotion Dataset (SLCSED) was developed to support future research. Further, the study proposes a computational framework based on Music Information Retrieval (MIR) techniques, combined with advanced machine learning algorithms, to perform emotion classification in crowds. Feature extraction was performed using the MIR method. Principal Component Analysis was applied as a dimensionality reduction technique. Various machine learning and transfer learning classifiers, including TabNet, LightGBM, and Multi-Layer Perceptron, were evaluated. The results demonstrated highly promising outcomes, with the LightGBM and MLP classifiers achieving up to 99.95% validation accuracy on the Emotional Crowd Sound Data (ECSD) dataset and the Multi-Layer Perceptron achieving 99.95% on the SLCSED dataset without dimensionality reduction. These findings highlight the effectiveness of MIR-based feature engineering combined with carefully selected classifiers for crowd emotion detection. This work not only fills a major gap by introducing a localized and richly annotated dataset but also presents a robust methodological pipeline with MIR techniques for crowd sound emotion recognition, paving the way for future applications in real-world monitoring and psychological analysis.

Keywords: *Multi-Layer Perceptron, Music Information Retrieval, Principal Component Analysis*

POSTER SESSION 1

Deep tRF – Net: A Deep Learning Approach for Multi – Class Cancer Classification using tRNA Derived Fragments (tRF) Expression Patterns

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tRNA-derived fragments (tRFs) have emerged as a unique class of short noncoding RNAs (sncRNAs) that have garnered significant attention in recent decades, particularly due to their correlation with various types of cancer. Tumor samples from diverse cancer types consistently exhibit dysregulated expression of tRFs, defined as either upregulation or downregulation compared to normal tissue. Our objective is to present a deep learning algorithm capable of recognizing these dysregulated tRF expression patterns and leveraging them to accurately classify cancer types. This study introduces a computational approach that utilizes tRFs as biomarkers, offering promising implications for cancer detection. We used convolutional neural networks (CNNs) to analyze tRF expression profiles from 10,567 samples spanning 31 distinct cancer types. Developing a highly accurate and sophisticated model architecture posed significant challenges due to the complexity and imbalance of the dataset. To address the class imbalance problem, we applied the SMOTE (Synthetic Minority Oversampling Technique) upsampling method, ensuring consistent feature representation and enhancing the generalizability of the model. Our optimized model achieved a classification accuracy of 94.42%, demonstrating the strong potential of tRF expression patterns as a reliable computational diagnostic tool. This method not only facilitates accurate cancer type classification but also provides perspectives for early detection and personalized treatment strategies. Overall, our findings underscore the promise of dysregulated tRFs as robust biomarkers, paving the way for advancements in cancer research and clinical practice.

Keywords: *Deep Learning, Cancer Type Prediction, tRNA-Derived Fragments, tRFs, Convolutional Neural Network*

OWN – Layer Grad – CAM and PIPPC: An Occlusion – Weighted Multi – Layer Approach and a Faithfulness Metric for XAI in Medical Image Classification

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Artificial Intelligence (AI) has made remarkable progress in healthcare, but its "black-box" nature poses challenges for explainability and trust in medical decisions. Explainable AI (XAI) techniques aim to illuminate model decisions. This study proposes two novel contributions: Occlusion-weighted N-layer Grad-CAM (OWN-Layer Grad CAM), which enhances traditional Grad-CAM by integrating a statistically grounded occlusion weighting scheme across multiple convolutional layers, and Perturbation-Induced Predicted Probability Change (PIPPC) metric, which offers a quantitative, faithfulness-based evaluation of XAI methods by measuring the impact of input perturbations on model output probabilities. Evaluations on chest X-ray (CXR), computed tomography (CT), magnetic resonance imaging (MRI), and ultra sound, benchmark OWN-Layer Grad-CAM against popular XAI methods: Grad-CAM, SHAP, LIME, and Occlusion Sensitivity. Results indicate that OWN-Layer Grad-CAM outperforms existing XAI techniques for CXR and MRI, while performing equally well alongside Grad-CAM for CT. These methods enhance explainable medical AI diagnostics under SAFE AI paradigm.

Keywords: *XAI, Grad-CAM, Medical Imaging, Deep Learning, Image Classification*

MMAD: Multi – model Adversarial Defense for Medical Images

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Adversarial attacks cause great harm to artificial intelligence systems deployed in medical imaging, these perturbations are invisible to the naked human eye at very low intensities but still can lead to di agnostic misclassifications and compromise patient care. This research proposes a novel defense framework specifically designed for medical imaging systems, with a focus on Magnetic Resonance Imaging (MRI). This framework introduces a hybrid classification model that integrates Vision Transformer (ViT), Convolutional Neural Network (CNN), and Spiking Neural Network (SNN) components with an attention-based fusion mechanism, enhancing adversarial detection. Furthermore, a two phase purification system was developed using the U-Net-style generator, which was refined in phase two using a PatchGAN-based discriminator fine-tuning to restore adversarial corrupted images while maintaining structural fidelity. The experimental results on the brain tumour magnetic resonance imaging dataset demonstrate that the proposed hybrid classifier achieves 97.89% accuracy in detecting FGSM attacks, 92.47% accuracy in clean images, and 86.93% accuracy in detecting BIM. At the same time, a drop in performance with 41.78% detection accuracy for PGD was noticeable. The classifier was tested on the MINIST stan dard benchmarking dataset, which showed promising results in detecting FGSM with an accuracy of 98%, BIM with an accuracy of 96%, and PGD with 90.40% and 100% on clean images. The purification model achieved an impressive peak PSNR of 34.61 and SSIM of 0.9551 demonstrating its effectiveness in reconstructing images and removing adversarial per turbation on brain tumour MRI dataset, furthermore maintaining good performance on clean images balancing the trade-off. This research con tributes to algorithm design for detecting subtle adversarial patterns and also focuses on making the complex models run in resource constraint environment efficiently.

Keywords: *Adversarial Machine Learning, · Vision Transformer · U-Net · GAN-based purification · Computer Vision · Spiking Neural Network · convolutional neural network.*

An Interpretable Machine Learning Model to Predict Drug Addiction Among Children in Sri Lanka

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Drug addiction among youth poses a growing threat to public health and social stability in Sri Lanka, particularly within school-aged populations. Drug abuse contributes to a range of severe consequences, including family breakdown, rising legal disputes, weakened social cohesion, deteriorating health, declining educational outcomes, and, in extreme cases, premature death. Despite its severity, early-stage identification and intervention mechanisms remain limited, especially in rural and underserved regions. This study aims to develop a machine learning-based predictive model to assess the risk of drug addiction among children by analyzing behavioral, familial, and environmental factors. A structured questionnaire was designed and administered to 1,000 participants comprising both individuals with and without a history of drug addiction from schools, rehabilitation centers across the country and the general public. Exploratory data analysis and preprocessing were conducted to handle missing values and transform questionnaire responses into categorical variables, ensuring the dataset was suitable for machine learning applications. To identify the most effective model, four classification algorithms—Decision Tree, Random Forest, Sup port Vector Machine, and Logistic Regression were implemented and evaluated. Among them, the Decision Tree classifier yielded the best performance with an accuracy of 99.65% and an F1-score of 0.995, demonstrating strong predictive power. A Python Tkinter software interface was developed to support community-level deployment of the Decision Tree model, enabling early risk detection and prevention through a user-friendly survey response system. The primary contribution of this study lies in integrating field data with predictive analytics to address a critical national issue and provide actionable recommendations.

Keywords: *Interpretable Machine Learning, Drug Addiction Prediction, Sub stance Abuse Risk Factors, Children, Sri Lanka, Classification Model.*

PoPStat – COVID19: Leveraging Population Pyramids to Quantify Demographic Vulnerability to COVID – 19

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Understanding how population age structure shapes COVID 19 burden is crucial for pandemic preparedness, yet common summary measures such as *median age* ignore key distributional features like skew ness, bimodality, and the proportional weight of high-risk cohorts. We extend the PoPStat framework, originally devised to link entire population pyramids with cause-specific mortality by applying it to COVID-19. Using 2019 United Nations World Population Prospects age–sex distributions together with cumulative cases and deaths per million recorded up to 5 May 2023 by Our World in Data, we calculate *PoPDivergence* (the Kullback–Leibler divergence from an optimised reference pyramid) for 180+ countries and derive *PoPStat–COVID19* as the Pearson correlation between that divergence and log-transformed incidence or mortality. Optimisation selects Malta's old-skewed pyramid as the reference, yielding strong negative correlations for cases ($r = -0.86$, $p < 0.001$, $R^2 = 0.74$) and deaths ($r = -0.82$, $p < 0.001$, $R^2 = 0.67$). Sensitivity tests across twenty additional, similarly old-skewed references con firm that these associations are robust to reference choice. Benchmarking against eight standard indicators like gross domestic product per capita, Gini index, Human Development Index, life expectancy at birth, me dian age, population density, Socio-demographic Index, and Universal Health Coverage Index shows that *PoPStat–COVID19* surpasses GDP per capita, median age, population density, and several other traditional measures, and outperforms every comparator for fatality burden. *PoP Stat–COVID19* therefore provides a concise, distribution aware scalar for quantifying demographic vulnerability to COVID-19.

Keywords: *population pyramid, COVID-19 mortality, demographic distribution, PoPStat, PoPDivergence*

POSTER SESSION 2

Dataset Sensitivity and Scalability in RNN – Based V2X Intrusion Detection

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This study presents a systematic evaluation of recurrent neural network (RNN) architectures, including standard RNN, Long Short Term Memory (LSTM), and Gated Recurrent Unit (GRU) for detecting temporal anomalies in Vehicle-to-Everything (V2X) communication. Using six stratified subsets (20K–200K samples) from the VeReMi Ex tension dataset, we assess each model's performance across classification accuracy, F1 score, inference latency, and resource usage. The results re veal that while increased dataset size enhances detection performance, marginal gains diminish beyond 120K samples. Among the evaluated models, GRU demonstrates the most favorable balance between detection accuracy and computational efficiency, highlighting its suitability for real-time intrusion detection in resource-constrained vehicular environments.

Keywords: *Edge Computing · V2X Security · Attack Detection · Data Sensitivity · RNN · LSTM · GRU · VeReMi · IDS*

Beyond Charging: How Juice Jacking Enables Data Theft and Device Compromise in Android

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This paper investigates security threats to mobile devices from untrusted chargers, focusing on data theft through USB connections. The experiments were carried out on four Android devices using various tools, including the O.MG cable, Vysor, ADB, and Scrcpy. The study examined four scenarios: default settings, enabling developer mode and USB debugging, using an O.MG cable with an unlocked phone, and testing data theft with a locked phone. The results revealed that devices with USB debugging and developer options enabled were highly vulnerable to unauthorized access and malware injection. In contrast, locked devices with debugging disabled showed greater resistance. Furthermore, when the O.MG cable was connected to a locked device, the payload could not execute, making it more secure. However, on unlocked devices, the cable was able to run malicious commands and exfiltrate data, highlighting a significant risk. These findings emphasize the importance of disabling USB debugging, keeping devices locked while charging, and strictly avoiding untrusted charging sources. This research contributes to understanding USB-based attacks and provides practical recommendations for enhancing mobile device security.

Keywords: *Untrusted Chargers, Data Theft, Developer Mode, USB de bugging, O.MG cable*

Smart Card Vulnerabilities in Sri Lanka: A Security Assessment Across Service Providers

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Smart cards are widely used in banking and telecommunications for their enhanced security over magnetic stripes, incorporating cryptographic chips compliant with standards like ISO/IEC 14443 and EMV. However, they remain vulnerable to attacks. This study experimentally evaluates the security of Sri Lankan smart cards using Flipper Zero and HackRF One. Eleven NFC reading scenarios were tested, resulting in Total Security Scores for five cards, with the Bank 1 card scoring highest (0.490) and the Bank 4 card lowest (0.297). While jamming and replay attacks were unsuccessful due to robust EMV anti-collision mechanisms and strict ISO/IEC 14443 physical-layer specifications, the extracted card data (number and expiration date) was found to be critically vulnerable to exploitation. Practical verification confirmed that entering only this data was sufficient to initiate free trials on platforms like Adobe Pro in multiple countries (e.g., USA, UK), which automatically convert to paid subscriptions. This demonstrates a significant real-world risk where stolen card data can be monetized despite the cards' physical security protections.

Keywords: *Smart cards, NFC security, Flipper Zero, jamming attacks, replay attacks*

YOLOv8 for Nondestructive Black Pepper Impurity Detection

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Food adulteration in spices undermines quality and safety, especially in countries like Sri Lanka where black pepper is economically important. Traditional laboratory tests can identify adulterants but are costly, time-consuming, and destructive. Non-destructive computer vision methods offer rapid and inexpensive alternatives for on-site inspection. In this work, we propose a YOLO-based object detection pipeline to detect foreign impurities (e.g., papaya seeds, sand) in black pepper images. We collected and annotated a custom dataset of 748 pepper im ages (about 37,900 labeled instances) using the Roboflow platform, with two classes: *Pure-Black-Pepper* and *Impurity*. Images were preprocessed (resized to 640×640, adaptive contrast) and augmented. A YOLOv8s model was fine-tuned on this dataset (batch size 16, SGD optimizer, 640 image size) for 100 epochs. On the held-out test set, the model achieved high accuracy (mAP@0.5 = 0.952, mAP@0.5:0.95 = 0.712; Impurity mAP@0.5:0.95 = 0.608, Pure-Pepper mAP@0.5:0.95 = 0.815). Additionally, a comparative evaluation of three different versions of YOLO shows that YOLOv8s achieve best performance metrics on black pepper impurity detection. Future work includes improving precision to reduce false positives and deploying the model in a mobile app for real-time impurity detection.

Keywords: *Computer Vision · YOLO · Black Pepper · Adulteration Detection · Food Safety · Deep Learning*

Work Sphere: A Multi – modal Approach to Employee Engagement Detection in Remote Work Environments with Explainable AI

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The COVID-19 pandemic accelerated the adoption of remote work, creating new challenges for monitoring employee engagement in virtual work place settings. Existing monitoring systems predominantly focus on activity metrics like mouse activity, screen time, and keyboard monitoring without capturing the emotional dimensions (human side) of engagement. Most commercial solutions operate as "black boxes," and in this AI era, they generate decisions without explanations, which fosters distrust among employees. Additionally, current approaches fail to respect privacy concerns, with studies showing 89% of remote workers express concerns about surveillance misuse. Current systems tend to use either visual cues or behavior tracking but rarely combine them. Most of the time, systems lack limited real-time intervention capabilities. These limitations restrict the effectiveness and adoption of engagement monitoring solutions, and there is no comprehensive multimodal system that addresses all these limitations under one umbrella. This study presents Work Sphere, a novel multi-modal approach to employee engagement detection that integrates visual analysis of facial expressions with both basic emotions and complex emotions (workplace-related emotions), eye gaze, and head pose with behavioral metrics through a dynamic weighting mechanism. The study employs explainable AI techniques to enhance transparency and implements privacy-preserving methods including ephemeral processing of visual data. Using transfer learning with MobileNetV2 and Effi cientNetB0 architectures, the approach achieves 76% agreement with human ex perts on engagement assessment despite individual models showing moderate ac curacy (61.5%). Testing across varying environments demonstrates robust performance, particularly in our innovative dynamic weighting system that adapts based on detected attention states. This study addresses critical gaps in existing engagement detection technologies by balancing effective monitoring capabilities with ethical considerations, offering a practical multimodal solution for sup porting employee engagement in increasingly distributed work environments.

Keywords: *employee engagement, explainable AI, multi-modal detection, remote work*

INDUSTRY TRACK

Towards Responsible and Compliant AI Systems in SaaS: Transformation to Secure AI System

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Keywords: SaaS AI Integration; Artificial Intelligence; Multi-Tenancy Complexity; Data Privacy; Regulatory Compliance; Real-Time Performance; Scalable AI Solutions; Infrastructure Readiness; AI Adoption Challenges; Business Requirements Clarity, Data Readiness, AI Governance Frameworks; Organizational Capabilities; Performance Measurement; Kanban Board System; Data Pipelines; Machine Learning Pipelines; API Audit; Governance Requirements; Ethical AI Guidelines; Continuous Governance; Phased Implementation; AI Scalability; Return on Investment; Governance Maturity; Risk Reduction; Audit Readiness; Cost Efficiency; Customer Engagement; Operational Agility; Business Value; Change Management; Scalable Architectures; KPI Definition

1. Introduction

The Software-as-a-Service (SaaS) industry stands at a critical inflection point where artificial intelligence integration has evolved from a competitive advantage to a business necessity. Current market data reveals that AI has generated 279 billion in global revenue in 2024, with projections reaching 1.8 trillion by 2030 [1].

However, despite widespread recognition of AI's transformative potential, the path to successful integration remains fraught with challenges. Recent comprehensive surveys paint a sobering picture of AI adoption struggles across industries. Boston Consulting Group's 2024 research involving 1,000 CxOs across 59 countries reveals that 74% of companies struggle to achieve and scale value from AI initiatives [2]. This statistic becomes even more concerning when considering that only 22% of firms are actively integrating AI across business operations and tech products, according to CompTIA's IT Industry Outlook 2024[3]. The SaaS sector faces unique challenges in AI integration due to multi-tenancy complexity, as applications must serve diverse customer bases with varying data patterns and requirements. Real-time performance demands and customer expectations for instant responses often conflict with AI processing requirements. Handling customer data across jurisdictions introduces complex regulatory challenges around data privacy and compliance. AI solutions must also scale seamlessly with customer growth and usage patterns, yet existing SaaS architectures often lack the infrastructure needed to support AI workloads, adding further integration complexity.

This research study explores the gap between AI adoption goals and implementation realities in the SaaS industry by identifying key integration challenges and analyzing market data to uncover trends, barriers, and opportunities.

2. Methodology

To gain a well-rounded understanding of the real-world obstacles in AI adoption within the SaaS sector, our research adopted a multi-pronged approach as described below.

2.1. Market Research Approach

We combined qualitative interviews and quantitative surveys to investigate challenges in AI adoption across SaaS applications.

Qualitative Analysis through Interviews.

A total of 38 qualitative interviews were conducted with senior stakeholders representing multiple functional areas in 11 SaaS Organizations. These included the Chief Product Officer, Chief Security Officer, Chief Data Officer, Head of IT / Head of Data, Business Analysts, Data Analysts, and Developers. The interviews were carried out through a combination of design thinking workshops and one-on-one discussions. This approach allowed participants to share their experiences, concerns, and expectations in their own words, rather than being constrained by predefined response categories. The discussions raised themes such as organizational readiness for AI, integration challenges, governance practices, skill gaps, and perceived risks and opportunities.

This enabled the collection of in-depth perspectives and the validation of emerging patterns related to AI readiness and integration.

Quantitative Market Analysis through Online Survey

We conducted a descriptive analysis of existing research and industry reports from leading consulting firms and organizations, including the BCG Global AI Survey (2024) [3], McKinsey State of AI Report [4], and SaaS Alliance industry insights to derive the AI Capabilities Maturity Scoring Framework [8].

An online survey [9] was then designed using the aforementioned analysis to capture structured feedback across key dimensions of AI adoption across the sample of 11 SaaS Organizations.

2.2. Deriving Outcomes

The AI Capabilities Maturity Scoring Framework was applied to assess organizational capabilities across four key domains: Data, API, AI, and Integrations. Each domain was scored on a scale from Level 1 (Initial) to Level 5 (Optimized). The qualitative responses were taken according to a scoring scale and mapped to numerical values. This ensured that the richness of stakeholder perspectives directly informed the structured scoring process, providing both qualitative depth and quantitative depth in the findings.

2.3. Scoring Method

Each capability area was assigned a score (1–5) based on survey responses. Overall maturity was calculated as the average of all four scores:

$$Overall\ Maturity = \frac{Data + API + Integrations + AI}{4}$$

Weighting was optionally applied when some domains were deemed more critical (e.g., Data 30% , API 25% , Integrations 20% , AI 25%).

2.4. Challenge identification framework

Based on the above market research and industry analysis, five primary challenges were identified as affecting SaaS AI Adoption. The key challenges include ambiguous, ad-hoc,

and 2 poorly documented business requirements, deficits in infrastructure and data readiness, gaps in governance policy and compliance, limitations in organizational capacity, and challenges in key performance measurement and optimization.

The first challenge relates to ambiguous, ad-hoc, and poorly documented business requirements. Many organizations rush into AI adoption without establishing a well-defined roadmap. They often have only a broad vision but lack detailed steps on how AI should integrate into existing processes. This makes it difficult to align AI initiatives with the organization's strategic goals, leading to wasted investments and confusion among stakeholders.

The second challenge is associated with the deficits in infrastructure and data readiness. AI requires reliable infrastructure and high-quality data to function effectively and securely. However, many SaaS organizations still rely on legacy systems that are not optimized for modern AI workloads. Additionally, data is often fragmented, siloed, inconsistent, or poorly governed; which results in inaccurate outputs and undermines trust in AI-driven insights and operations.

The third challenge relates to gaps in governance policy and compliance. While AI intro duces powerful capabilities, it also raises risks around data privacy, security, and ethical use. Because many companies lack comprehensive governance frameworks to ensure transparency and accountability in decision-making. This exposes them to regulatory risks and reputational damage, especially in industries with strict compliance requirements such as healthcare or finance.

The fourth challenge involves limitations in organizational capacity. Even with strong infrastructure, many firms struggle with limited budgets, shortages of skilled AI professionals, and resistance to change within teams. Employees may lack training and guidance to work with AI tools; and leadership often underestimates the cultural and operational changes required for successful adoption. As a result, promising AI adoption stall or fail to scale.

Finally, the fifth challenge highlights challenges in key performance measurement and optimization. Implementing AI is not a one-time task; it requires continuous development, monitoring and improvement. Yet, many organizations lack clear performance indicators or frameworks to evaluate the success of their process adoption. Without robust metrics and feedback loops, it becomes difficult to identify weaknesses, optimize models, and demonstrate business value over time.

3. Solution

Qualitative and quantitative analyses indicate that a significant portion of the challenges in AI adoption stem from the processes currently employed within organizations. These kinds of deficiencies in the organizations were also observed during API adoption back then in the industry. Hence, API governance processes were introduced to mitigate API adoption difficulties. Similarly, AI Governance Process can be introduced to mitigate AI adoption shortcomings.

Drawing on this insight, we developed a structured governance process supported by our approach, which has already been successfully applied to address such organizational issues in API strategies. Building on these results, we propose that an identical approach can be effectively translated to AI Integration, providing organizations with a systematic framework to ensure readiness, compliance, and sustainable adoption.

Based on our industry experience, market analysis, and research findings, we developed a comprehensive 5-step approach that addresses the identified challenges.

3.1. Step 1: Document Business Requirements

Use a visual Kanban board to document AI use cases, track progress, manage expectations, foster collaboration, and align AI initiatives with business goals.

3.2. Step 2: Audit Data and System Infrastructure

To assess organizational AI readiness and integration potential, a detailed assessment of organizational assets (APIs, Data, AI Tools, and Terminology) can be conducted using the tool. This evaluation considered four critical dimensions in the audit report such as APIs, Data, AI Tools, and Terminology. First, APIs should be examined in terms of their availability, documentation quality, standardization, and interoperability. Second, data sources should be assessed with respect to accessibility, data quality, completeness, and adherence to privacy and security requirements. Third, the review encompassed AI tools, focusing on the extent to which current AI/ML solutions are in use, their scalability, integration capability, and alignment with business objectives. Finally, attention should be given to terminology and standards, with an emphasis on evaluating the consistency of definitions, taxonomy, and communication across teams.

This assessment will provide a clear image of the organization's AI readiness and the potential for seamless integration into existing systems.

3.3. Step 3: Document Data Pipelines, Machine Learning Pipelines, and APIs

Map compliance needs, conduct risk assessments, and define organizational policies. Ethical AI guidelines such as covering fairness, bias mitigation, and transparency can be included to build trust among the users. Identifying these requirements as early as possible, prevents misalignment with the compliance requirements. This allows the organization to ensure the readiness for regulatory scrutiny.

3.4. Step 4: Identify Governance Requirements

Map compliance needs, conduct risk assessments, and define organizational policies. Ethical AI guidelines such as covering fairness, bias mitigation, and transparency can be included to build trust among the users. Identifying these requirements as early as possible, prevents misalignment with the compliance requirements. This allows the organization to ensure the readiness for regulatory scrutiny.

3.5. Step 5: Define Governance Process

Establish continuous governance practices through design reviews, regular assessments, and lifecycle management of AI workflows. Monitoring frameworks and feedback loops is in place to detect drift, compliance gaps, or performance degradation. These mechanisms ensure governance remains a living and adaptive process.

Our process follows a phased implementation approach to ensure smooth integration and long-term success:

Phase 1: Assessment and Planning (Weeks 1–4) Conduct readiness assessments, align stakeholders, establish governance, and configure the tool to meet organizational needs.
Phase 2: Implementation (Weeks 5–12)
Deploy the tool incrementally, coach teams, build capabilities, and execute a pilot AI adoption.

Phase 3: Optimization and Scaling (Weeks 13–24)
Monitor performance, optimize deployments, scale successful use cases, and embed continuous improvement practices.

In summary, the proposed governance process offers a structured and evidence-based pathway to address the challenges of AI adoption. This framework enhances organizational readiness, regulatory compliance, and long-term sustainability in AI adoption. This five-step approach thus contributes to building accountable, transparent, and resilient AI practices that can be systematically scaled across the enterprise.

4. Results

Our assessment revealed that out of the 11 SaaS organizations, seven were positioned at Level 2 (Emerging) and four at Level 4 (Managed), with none reaching Level 1, 3, or 5. This indicates that while most organizations have moved past the initial stage of AI adoption, they remain concentrated in the emerging and managed levels, highlighting both progress and untapped potential for optimization.

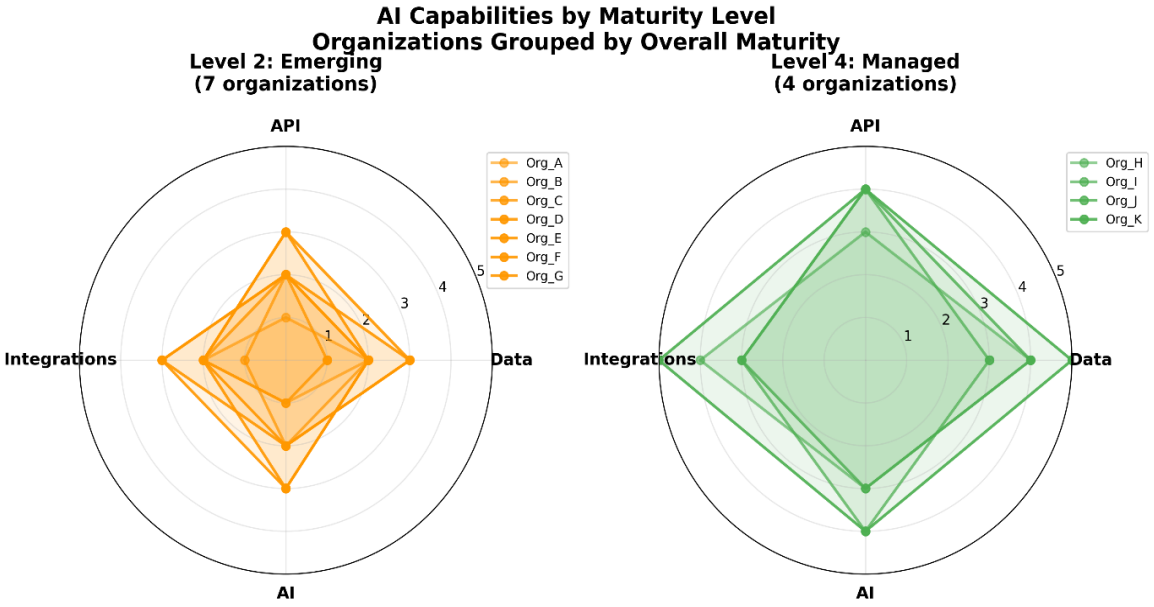

Figure 1.: Distribution of Artificial Intelligence capabilities across the sample of 11 SaaS organizations, grouped by maturity levels.

The implementation of our 5-step AI transformation approach across a set of 11 SaaS organizations demonstrated clear improvements in AI scalability, return on investment, and governance maturity.

Organizations that adopted our approach were able to move beyond pilot-stage experiments and achieve meaningful, scalable AI deployments. They reported significantly faster realization of business value from their AI initiatives, with quicker transitions from planning to tangible results.

In terms of governance and compliance, organizations achieved strong alignment with regulatory standards and established robust internal controls. This proactive approach led to a notable reduction in AI-related risks and improved audit readiness across the board.

Cost efficiency was another major area of impact. The structured methodology helped reduce the financial burden of AI development by streamlining workflows, improving resource utilization, and minimizing inefficiencies in deployment. At the same time,

technical teams 5 experienced noticeable gains in productivity and collaboration, resulting in smoother execution of AI projects.

From a business perspective, the tool enabled organizations to unlock new revenue opportunities and enhance customer engagement through more effective use of AI-powered features. Companies also reported improvements in customer satisfaction, retention, and overall operational agility, with AI helping to automate tasks and accelerate product delivery cycles.

In industries like finance, healthcare, and e-commerce, these tools help organizations strengthen compliance, improve the accuracy of their models, and deliver business outcomes that align with each sector's needs.

Finally, our approach demonstrated its flexibility and scalability by delivering consistent results across organizations of varying sizes and complexities. It supported sustained AI performance over time, enabling continuous improvement and long-term value creation.

5. Conclusion

Our research highlights that the primary challenges in AI integration are rooted in organizational and process-related issues rather than technology or algorithms. The structure of our 5-step approach aligns with this insight by emphasizing business alignment, governance, and process optimization, supported by infrastructure readiness and integrated AI capabilities.

A significant gap exists between the aspiration to implement AI and the reality of achieving scalable results. This gap often arises from rushed implementation, lack of governance, poor change management, and unprepared systems. Our methodology addresses these root causes through a structured and holistic approach.

A systematic AI integration strategy creates meaningful business advantages. Organizations that follow a structured method benefit from faster deployment, improved implementation quality, scalable architectures, and more effective risk mitigation, leading to greater resilience and innovation capacity.

While effective, the tool requires commitment to change management and sustained resource investment. Implementation timelines and efforts may vary based on industry demands, particularly in sectors with strict regulatory requirements. Organizations must also remain responsive to technological changes and evolving compliance standards.

Organizations should approach AI integration with deliberate planning rather than speed, establish governance frameworks from the outset, and focus on preparing their teams and processes before deploying technology. Early KPI definition and scalable system design are essential for long-term success and cost-efficiency.

Future research should explore the long-term impact of structured AI implementation, refine approaches for specific industries, examine how emerging technologies integrate with existing systems, and adapt governance frameworks to meet global regulatory standards.

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ParkEase: Enterprise-Grade ANPR-Based Access Control System

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KEYWORDS: Automated Number Plate Recognition, Edge Computing, Cloud Backend, IoT, Parking Management

1. Introduction

Urban parking infrastructures confront inefficiencies due to underutilization, congestion, and revenue losses [1][2]. ParkEase proposes a hybrid edge-cloud AI solution integrating Automated Number Plate Recognition (ANPR) to automate parking access with enhanced responsiveness and operational continuity under varying network conditions [1][2][3].

2. Method

ParkEase consists of three primary layers:

Edge Layer: Jetson Nano devices implement ANPR locally using YOLOv8n, delivering sub-200ms latency and controlling gates via ultrasonic sensors to ensure safety.[2][3]

Cloud Backend: Operated via a Laravel framework (Laravel 10 with MySQL 8.0+), it administers user management, parking permissions, and centralized monitoring. [4][5][6]

User Interface: APIs enable seamless interaction through web and mobile clients.

Vehicles approaching are identified by cameras; edge devices process plate recognition and transmit data to the cloud for validation and spot allocation. Confirmation commands then actuate gates and update LED displays. Local edge decisions support autonomous operation during intermittent connectivity, minimizing latency and bandwidth usage [1][2].

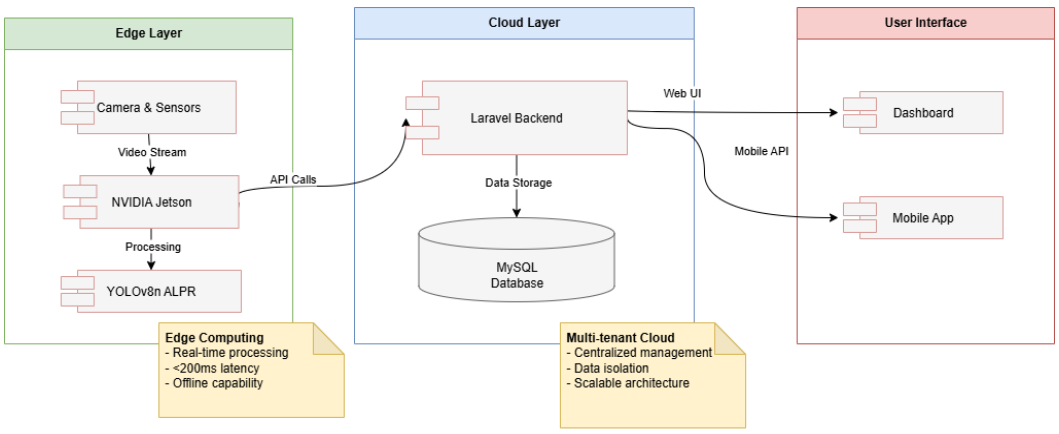

Figure 1. ParkEase System Architecture Overview

3. Results

The prototype demonstrated approximately 95% ANPR accuracy in real-world lighting variations. System components status [2].

- ANPR engine operational with robust recognition across diverse lighting.[2]
- Edge processing and gate control fully integrated.[3]
- Backend under development, facilitating access control and user management.[6]
- Hardware integration confirmed sensor and relay performance.
- GUI provisioned both automated and manual operation modes.

Case Study: Prototype Evaluation

Analysis of more than 700 vehicle images achieved more than 80% recognition accuracy for front and rear plates via advanced preprocessing and deployment of Gemini OCR API.[8] Testing reveals effective low-latency operations, environmental robustness, and safe gate actuation, validating ParkEase as a viable automated parking management system [1][2][8].

Table 1: Character-level accuracy results of several VLMs

Method	Number of correctly predicted characters	Character-level Accuracy %
VILA	1457	83.21%
LLaVA-NeXT-7b	1417	80.93%
Gemini 1.5 flash	1643	93.80%
LLaVA-NeXT-34b	1504	85.90%
Gemini 1.5 Pro	1643	93.80%
Llama 3.2 Instruct	1635	93.38%
Claude 3.5 Sonnet	1625	92.80%

4. Discussion

This hybrid design leverages local AI to reduce network dependency and latency while centralizing control in the cloud for scalability and management. Safety enhancements through sensor-informed gate mechanisms are integral to system reliability. Ongoing improvements target increased ANPR resilience to environmental variabilities and backend scalability for enterprise applications and smart city integration [1][2].

5. Conclusion

ParkEase demonstrates the feasibility of scalable, edge-enabled IoT platforms for secure, low-latency automated parking systems. Future directions include fine-tuning recognition models, expanding environmental adaptability, and fostering interoperability within urban mobility ecosystems [1][3][2].

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Unified Governance for Data, AI, and API in the Era of Industry 5.0 and Beyond

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1. Introduction

The transition to Industry 5.0 and beyond represents a paradigm shift from the automation-centric ethos of Industry 4.0 to a human-centric, sustainable, and resilient industrial ecosystem [1, 5]. This evolution necessitates a comprehensive rethinking of governance frameworks across data, artificial intelligence (AI), and application programming interfaces (APIs) [6, 7]. Traditional siloed governance models are proving insufficient in managing the interconnected and dynamic nature of modern technological systems [8, 9]. As a result, there is an urgent need for unified governance frameworks that address regulatory compliance, environmental sustainability, and ethical AI deployment in an integrated manner [6, 10].

The European Union's AI Act, which came into force in 2024, alongside expanding Environmental, Social, and Governance (ESG) reporting mandates, introduces multifaceted compliance challenges across industries [2, 11]. Organizations are increasingly burdened with coordinating governance activities across data stewardship, AI oversight, and API security—while aligning with Industry 5.0's foundational principles of human-centricity, sustainability, accountability, transparency and resilience [5, 8, 12].

To address these challenges, we propose a unified governance framework and a supporting digital platform [6]. Together, they enable real-time monitoring and management of governance processes across traditionally siloed domains [9, 10].

2. Methodology

Our research was conducted through a combination of structured interviews and interactive workshops with industry partners across multiple sectors. In total, we carried out 38 qualitative interviews with senior stakeholders representing multiple functional areas in 11 SaaS organizations. Participants included Chief Product Officers, Chief Security Officers, Chief Data Officers, Heads of IT and Data, Business Analysts, Data Analysts, and Developers. These interviews were conducted through a mix of design thinking workshops and one-on-one discussions. We focused on governance practices within three critical domains: Data Governance (privacy, data quality, and lifecycle management), AI Governance (model evaluation, bias detection, risk analysis, and regulatory compliance), and API Governance (versioning, security, performance, and integration strategies).

The study applied a five-pronged qualitative research methodology, aimed at capturing both the current state and the maturity of governance practices:

Governance Framework Assessment – Evaluated the presence and maturity of governance structures, and how information and data are shared across cross-functional teams.

Business Intelligence (BI) Pipeline and API Mapping – Documented reporting architectures across regional and international operations, identifying dependencies and gaps in BI data flows and APIs.

ESG Data Collection and Coordination – Investigated processes for ESG data acquisition, stakeholder alignment, and the coordination barriers affecting ESG reporting. Mainly the governance part was focused to understand the approaches for secure, explainable, and ethical systems in an organization.

Data Governance Forums and Process Audits – Explored the organizational forums in place for data governance, the storage and lineage of data assets, and the mechanisms for activity tracking and responsibility tracing.

AI Integration and Adaptability Challenges – Examined organizational readiness for AI integration, including adoption of modern paradigms such as Model Context Protocol (MCP) and Application-to Application (A2A) integration patterns.

2.1. Key Findings

Through this analysis, we identified five systemic challenges impeding progress toward Industry 5.0 and beyond:

Fragmented Organizational Structures, resulting in coordination and accountability gaps. Regulatory Silos, with disconnected compliance approaches across data, AI, and APIs. Limited ESG Integration, where ESG objectives are not systematically embedded into governance workflows. Data Security and Leak Prevention, lacking consistent enforcement and monitoring. Governance Inflexibility, with current frameworks unable to adapt to rapidly emerging technologies.

2.2. Governance Solution Design

In response to these challenges, we developed a Unified Governance Solution, consisting of two integrated components:

Service component: Development of bespoke governance cultures through consultations, stakeholder workshops, and leadership coaching to embed governance into organizational DNA.

Platform component: Integration of a Unified Governance Platform capable of orchestrating governance processes across data, AI, and APIs.

This unified governance solution is structured around five foundational principles: Holistic Visibility – enables end-to-end oversight across all governance domains; Human-Centric Accountability – reinforces ethical oversight by empowering human stakeholders to maintain control over automated and AI-driven processes; Adaptive Resilience – equips organizations to dynamically respond to new risks, regulatory shifts, and technological changes; Transparency and Traceability – ensures auditability and visibility into decisions, fostering proactive compliance and operational integrity; Environmental and Organizational Sustainability – aligns long-term business continuity with environmental, social, and governance (ESG) objectives.

2.3. Pilot Evaluation

Following the solution design, the unified governance model was introduced to participating industry partners. Its effectiveness was evaluated through feedback loops, scenario-based simulations, and key performance metrics such as risk reduction, compliance coverage, and organizational alignment with ESG and AI-readiness objectives.

3. Results

To evaluate the impact of the unified governance framework, we conducted a post-implementation assessment using a structured questionnaire distributed to stakeholders across the ten participating organizations. The assessment focused on three key performance dimensions:

Compliance Cost Reduction – measuring the reduction in time, resources, and overheads required to meet regulatory requirements post-implementation.

Incident Response Time Reduction – assessing the improvement in responsiveness to data, AI, and API-related incidents, including data breaches, model misbehaviour, or integration failures.

Stakeholder Trust Enhancement – gauging perceptions of trust and accountability among internal stakeholders (e.g., governance officers, data scientists, IT teams) and external entities (e.g., regulators, ESG auditors).

The results were quantified through a combination of self-reported estimates, internal audit comparisons, and qualitative feedback from governance forum participants.

Metric	Improvement (%)
Compliance Cost Reduction	40%
Incident Response Time Reduction	60%
Stakeholder Trust Enhancement	35%

These improvements demonstrate the tangible benefits of a unified governance strategy. Organizations reported a 40% decrease in compliance-related operational costs by consolidating fragmented workflows and reducing audit preparation time. Incident response times improved by 60%, largely due to centralized visibility, clearer accountability, and automated alerting mechanisms. Additionally, stakeholder trust increased by 35%, attributed to enhanced transparency, traceability, and demonstrable alignment with ethical and regulatory standards.

These findings validate the framework’s practical value and its potential to act as a catalyst for Industry 5.0 transformation.

4. Discussion

The adoption of a unified governance framework enables organizations to address the growing complexity and interdependence of data, AI, and API systems. By harmonizing governance processes across these domains while maintaining the nuances of domain

specific controls organizations gain a strategic advantage in achieving regulatory compliance, reducing risk, and fostering a culture of accountability.

Notably, the unified approach enhances regulatory alignment by creating centralized policies and traceability mechanisms, operational agility by reducing response times to incidents and changes, and stakeholder engagement through increased transparency and structured decision-making processes. These benefits are particularly relevant as organizations contend with the dual pressures of technological advancement and intensifying regulatory scrutiny, including evolving ESG mandates and AI governance requirements.

The findings affirm that integrated governance is not merely a compliance exercise; it is a catalyst for sustained digital maturity, ethical AI adoption, and cross-functional collaboration.

5. Conclusion

The unified governance solution presented in this study equips organizations to meet the multifaceted demands of Industry 5.0 and beyond a future marked by human-centric innovation, environmental sustainability, and technological convergence. By embedding scalable, adaptive, and compliant oversight across data, AI, and API domains, this framework offers a holistic solution for both operational excellence and strategic transformation.

Furthermore, this unified governance solution strengthens regulatory compliance, enhances ethical deployment of intelligent systems, and promotes responsible innovation. It enables organizations to meet current governance obligations while laying the groundwork for future readiness in the face of emerging risks and transformative technologies. As industries advance, this governance approach serves as a foundational structure for maintaining resilience, fostering trust, and supporting sustainable growth in the era of industry 5.0 and beyond.

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