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AN ENHANCED LIGHTWEIGHT IoT-BASED PIPELINE LEAK DETECTION MODEL

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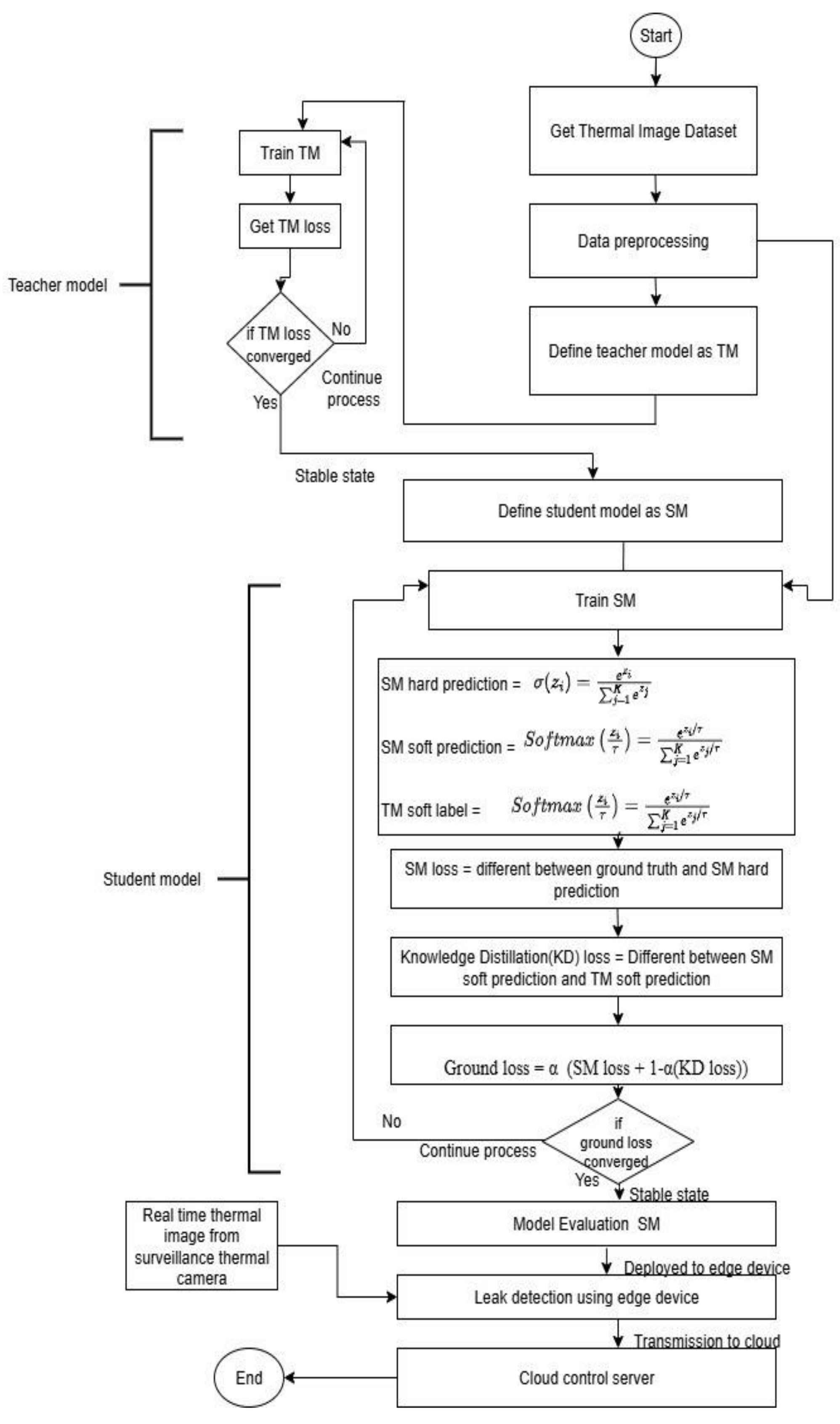
INTRODUCTION & AIM

Pipeline leakages pose significant environmental and economic risks, yet many existing detection methods remain slow, expensive, or unable to detect early-stage leaks with high precision. Thermal imaging, IoT devices, and deep learning offer a promising alternative, but high-resolution thermal images create latency and bandwidth challenges, making real-time deployment difficult on edge devices such as Raspberry Pi.

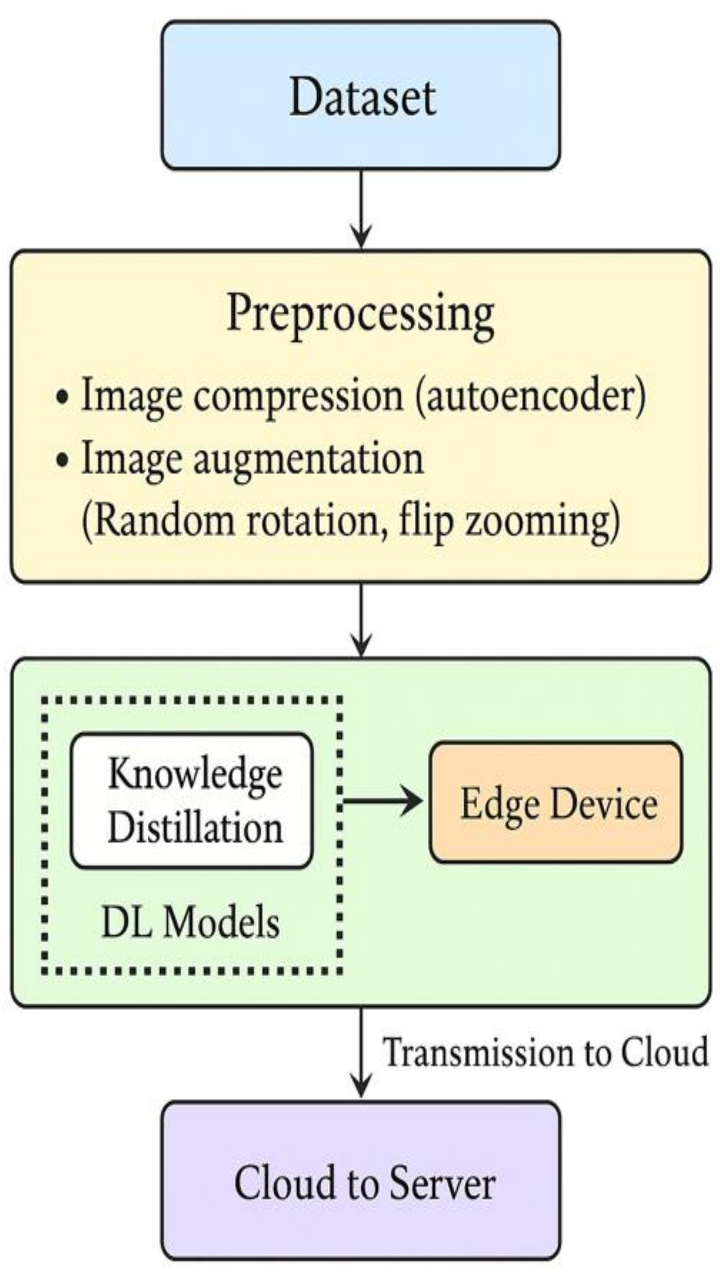
This research aims to develop an enhanced thermal image-based leak detection model that is lightweight, accurate, and deployable in resource-constrained IoT environments. The goal is to combine Convolutional Neural Networks (CNN), Autoencoder compression, and Knowledge Distillation to produce a high-performance model that reduces image size and computational cost while maintaining high detection accuracy for leak and non-leak classification.

METHOD

Thermal images representing leak and non-leak conditions were collected and preprocessed to ensure consistency and clarity. An Autoencoder was first employed to compress the images into compact latent representations, minimizing data size while preserving essential thermal features. These compressed images were passed into a lightweight Convolutional Neural Network designed to extract discriminative spatial patterns associated with pipeline anomalies. Knowledge Distillation was then used to transfer learned representations from a larger teacher network to a smaller student network, improving accuracy without increasing computational cost. The combined architecture was trained using augmented datasets to enhance robustness and evaluated through standard performance metrics.



FlowChart of the Training Process

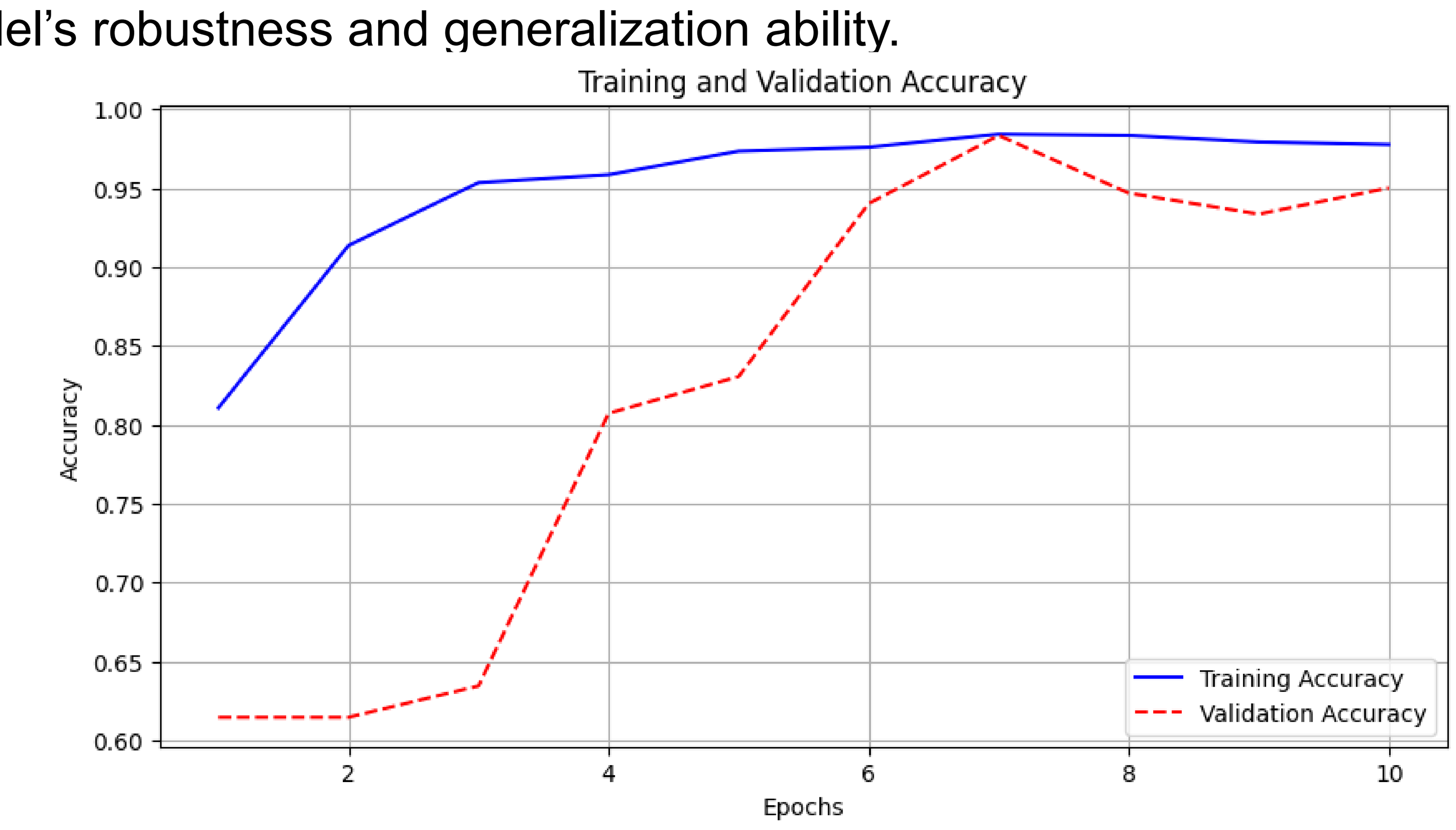


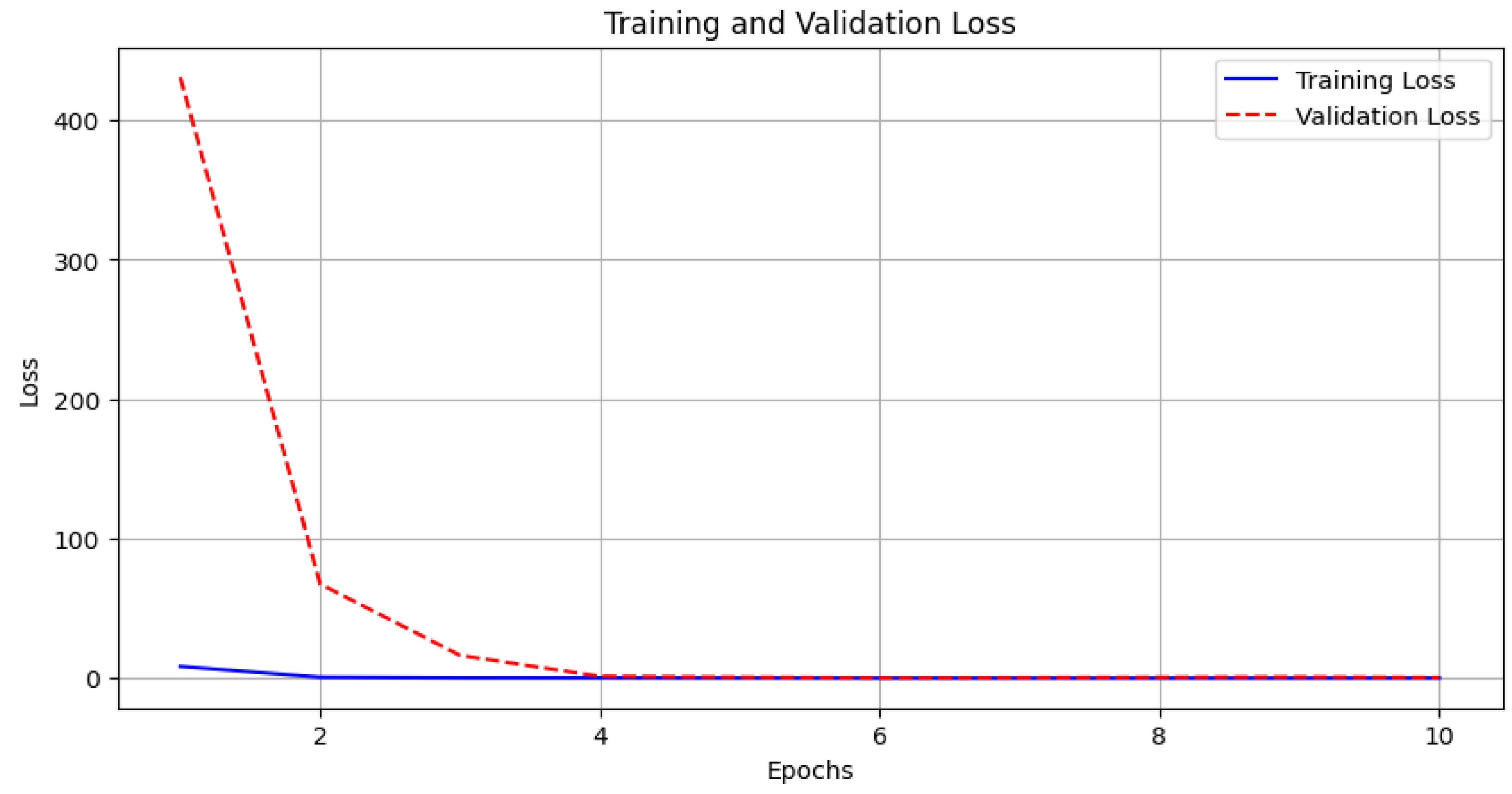
Proposed Frame work

RESULTS & DISCUSSION

The proposed CNN + KD + AE model demonstrated strong performance while remaining lightweight for IoT deployment. The model achieved 98% accuracy, 97% precision, 98% recall, and a 0.97 F1-score. These results show that the Autoencoder effectively preserved essential thermal features while reducing data size, and Knowledge Distillation allowed the student model to match the performance of larger networks.

Compared to baseline models, the proposed model outperformed others such as MobileNetV2 (91%), InceptionV3 (84%), and ResNet (61%). It also showed significantly reduced parameter count of 1M and model size of 4.3MB, making it suitable for real-time edge computing. The training and validation curves indicated fast convergence and minimal overfitting, confirming the model's robustness and generalization ability.





Accuracy and loss curves for the proposed model work

CONCLUSION

This work presents a lightweight, high-performance thermal image-based leak detection model tailored for IoT and edge computing environments. By combining Autoencoder compression, CNN feature extraction, and Knowledge Distillation, the system achieves fast, accurate detection with reduced computational demands. The findings demonstrate the potential of deploying advanced leak detection directly on resource-limited hardware, enabling faster response times and more reliable monitoring of critical pipeline infrastructure.

FUTURE WORK

Future work will extend this system by deploying the model on actual IoT hardware and testing in real pipeline environments under different weather and lighting conditions. Expanding the dataset with more varied thermal images to improve generalization.