Remote Monitoring System of Nuclear Power Plants Using Satellites Leveraging Transfer Learning and Pre-trained Models

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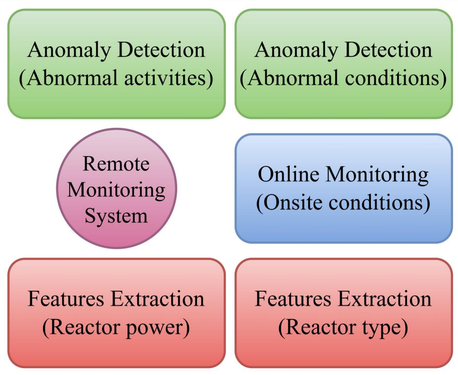
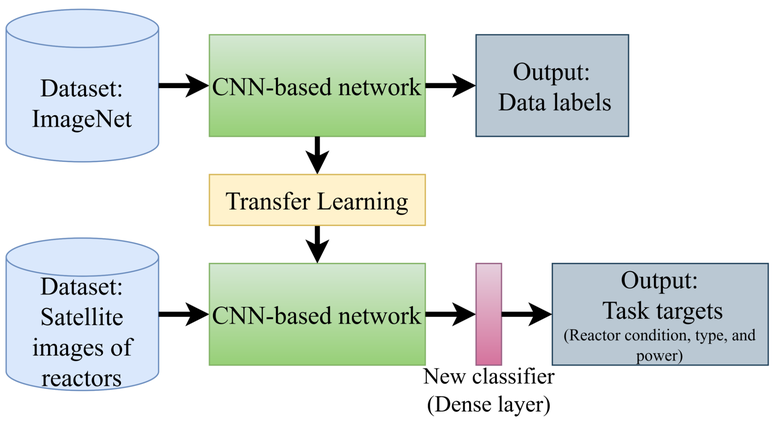
1. Objectives

- Develop a remote monitoring system to capture Nuclear Power Plants' (NPPs) characteristics from satellite images.
- Explore the ability of pre-trained deep-learning models to design systems capable of remote monitoring NPPs and future swarms of microreactors and small modular reactors.



2. Transfer Learning

- Transfer learning is an approach to reuse the pre-trained models based on CNN-based networks.



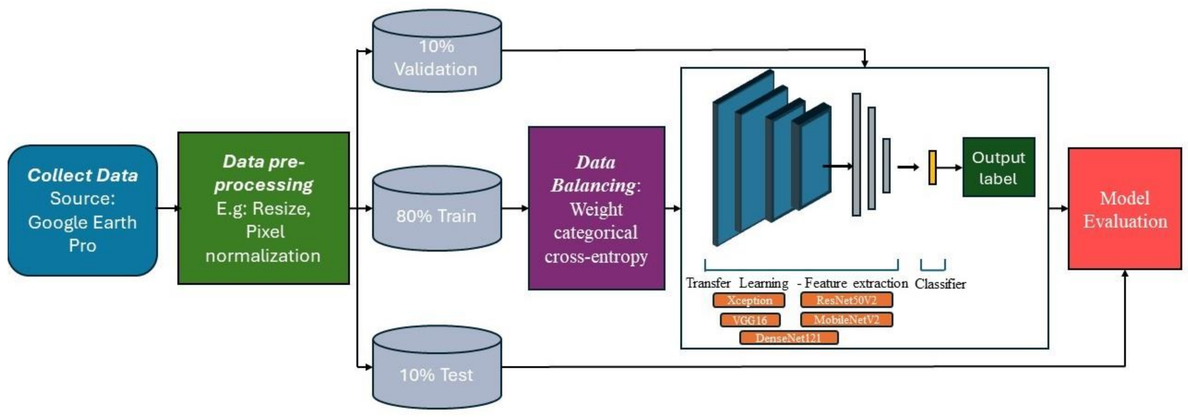
3. Pre-trained Models

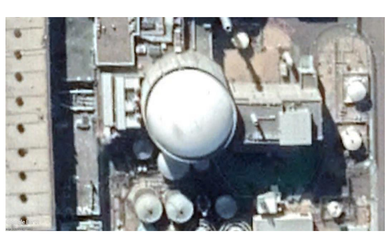
- Five pre-trained models for the transfer learning process were utilized for the monitoring system.

Model	Description	Top-5 Accuracy
VGG16	It has a stack of deep CNNs with 16 layers, including max pooling layers.	90.1%
ResNet50V2	It includes 48 convolution layers, an average and max pooling layers within a residual framework.	93%
DenseNet121	It contains five dense blocks and three transition blocks with 121 layers.	92.3%
Xception	It is based on depthwise separable convolution layers.	94.5%
MobileNetV2	It uses depthwise separable convolution developed for fast object detection and classification.	90.1%

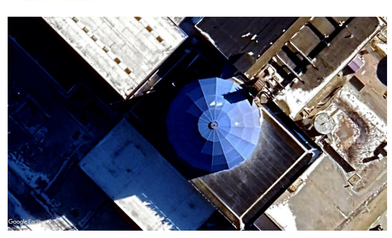
4. Methodology

- Information and locations of NPPs were obtained from the IAEA Power Reactor Information System (PRIS) database.
- This research successfully collected images for 356 reactors with different headings at different camera elevations for a total of 7120 images for six types of reactors.

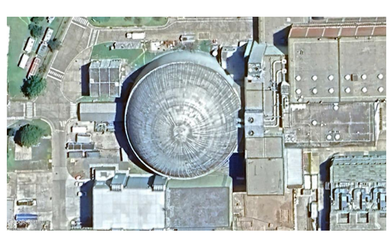




1. PWR

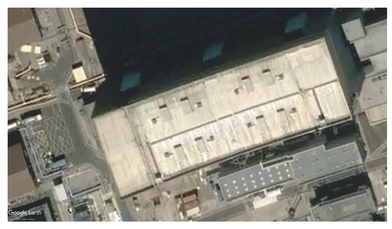


2. BWR

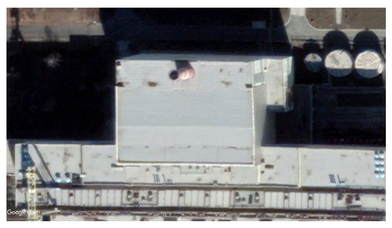


3. PHWR

4. LWGR

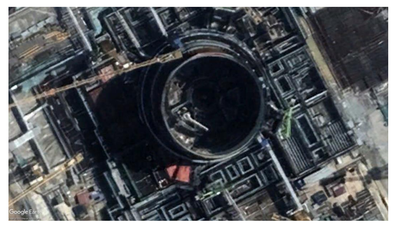


5. GCR



6. FR

7. Operational



8. Under construction

9. Cloud obstructions

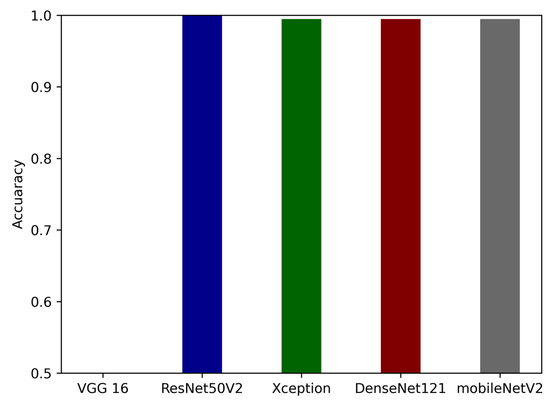
10. Abnormal condition

11. Abnormal activity

5. Results & Discussion

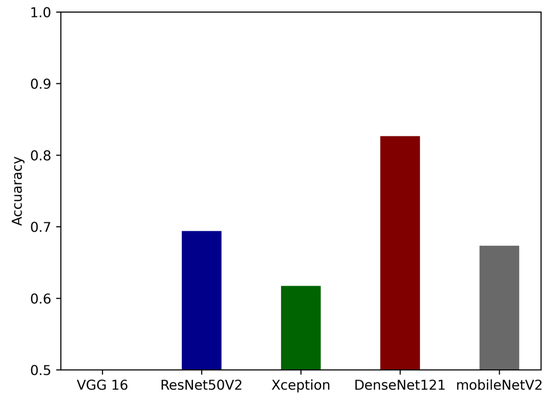
Anomaly Detection – Abnormal conditions

- Anomalies in the reactor caused by abnormal conditions, such as monitoring smoke emissions from any building in the NPP.
- Except for VGG16, the other pre-trained models exhibit promising results, indicating their proficiency in detecting abnormal reactor conditions.



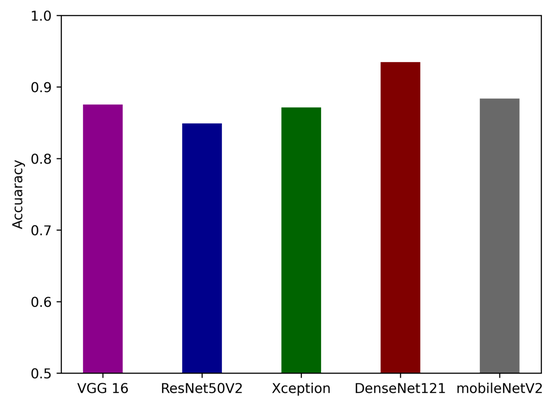
Anomaly Detection – Abnormal activities

- Anomalies in the reactor caused by abnormal activities, such as monitoring the appearance of extra buildings or objects.
- DesNet121 has the highest capability to detect abnormal activities on the site of the NPP.



Online Monitoring– Onsite conditions

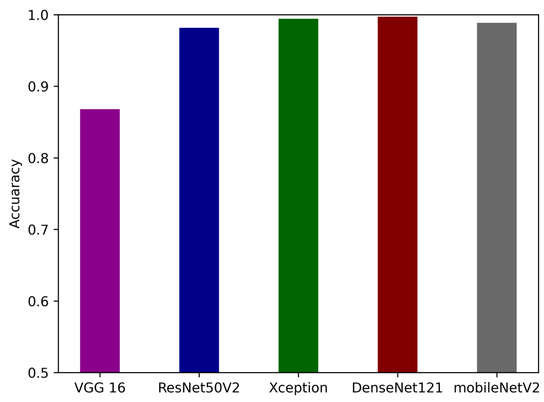
- Diverse scenarios were introduced to evaluate the ability to identify and distinguish normal and abnormal conditions.
- For example, the ability to detect normal conditions with weather obstruction rather than showing anomalies.

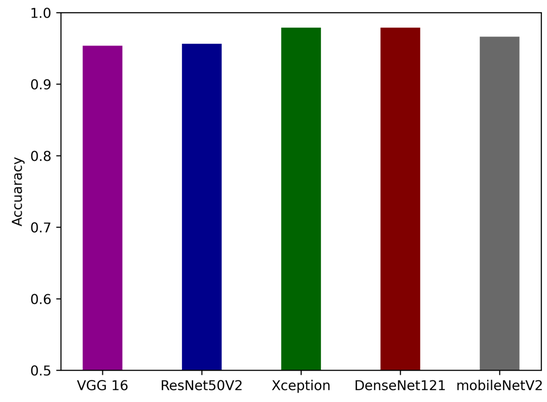


Features Extraction – Reactor type

Features Extraction – Reactor power

- To demonstrate the ability to characterize reactor features remotely, the model was used to classify all currently operational commercial NPPs based on their type and power using satellite images.





6. Conclusions

- This research has trained a machine-learning model to explore the possibility of remotely characterizing and monitoring reactor features.
- It demonstrated the satellites' capability to observe and analyze reactor characteristics remotely, independent of the conditions on the ground.
- It was found that the pre-trained model DensNet121 consistently performs better in all tasks.

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