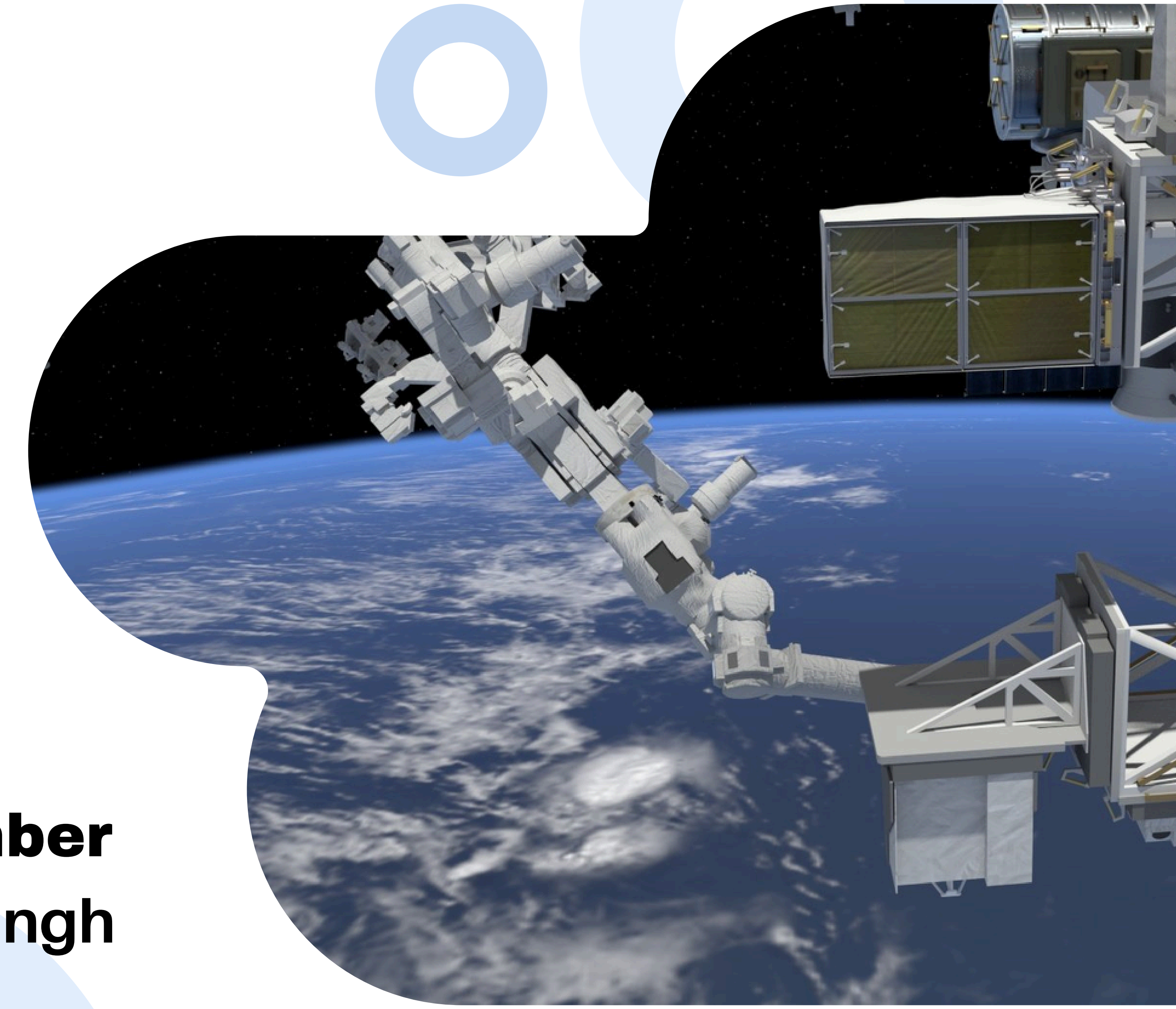
SPACE STATION OBJECT DETECTION

BY TEAM - Vision.AI



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Space Station Object Detection using YOLOv8

Using synthetic data from Duality AI's Falcon digital twin, we built a high-performance object detection model for critical tools in a space station environment.

We trained and fine-tuned a YOLOv8 model using synthetic data of space station tools (toolbox, fire extinguisher, oxygen tank) under varied conditions such as lighting, occlusion, and angle. The final model achieved a high mAP@0.5 and robust class-wise performance. Visualizations, confusion matrices, and failure analysis are included.

Methodology & Steps

Tools & Frameworks Used:

- YOLOv8 (Ultralytics)
- Python 3.9, PyTorch
- Falcon Platform (Synthetic Dataset)
- OpenCV, Matplotlib
- Conda (EDU environment)

Steps Followed:

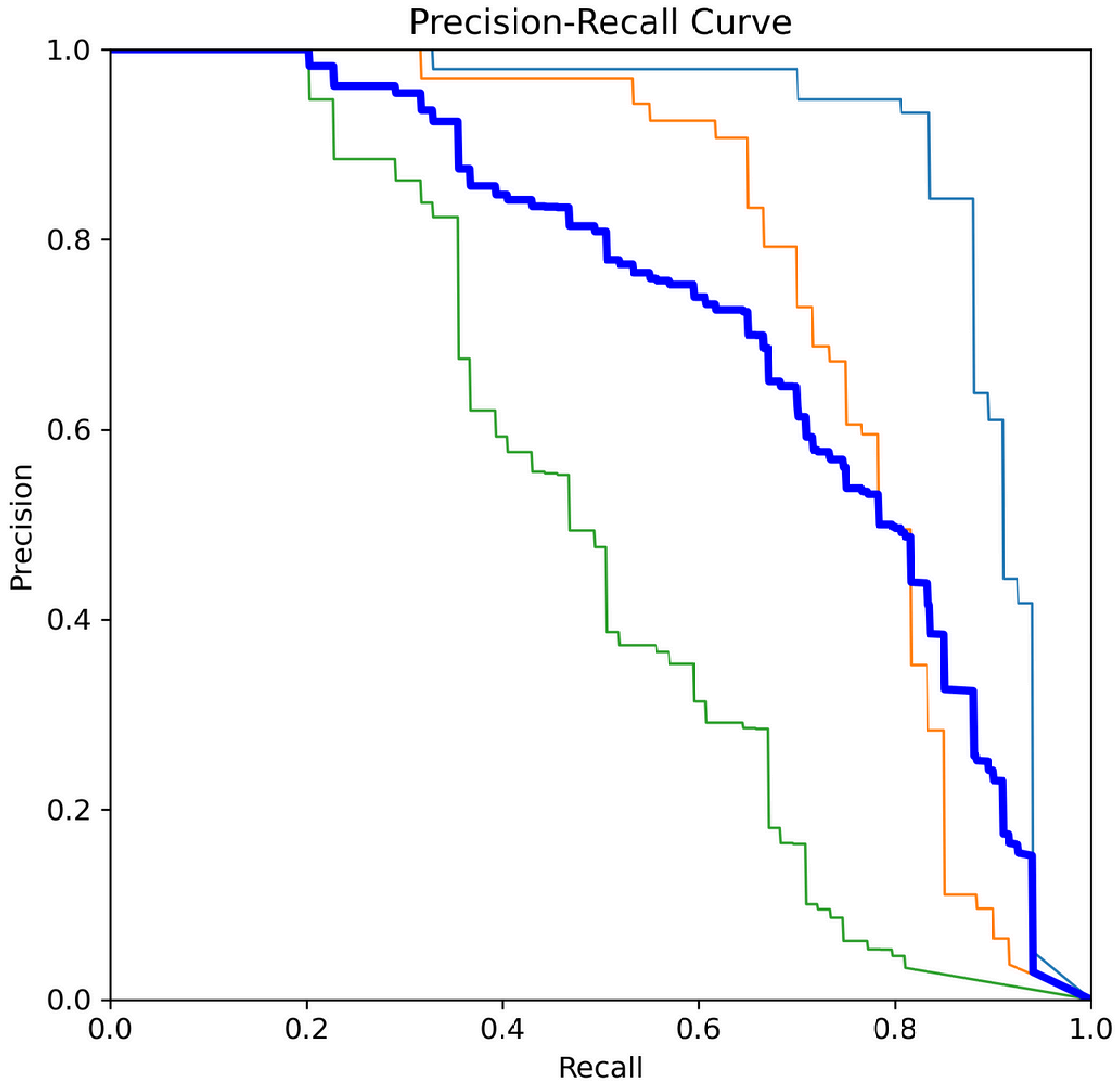
- Environment Setup using setup_env.bat in Falcon's dataset.
- Exploratory Analysis of image dataset with 3 classes.
- Baseline Model Training with YOLOv8m pretrained weights.
- Custom Configurations (learning rate, epochs, augmentations).
- Evaluation on the provided Test dataset.
- Post-processing: Results visualized, misclassifications analyzed.
- Iterative Optimization for performance boost.

Results & Performance Metrics

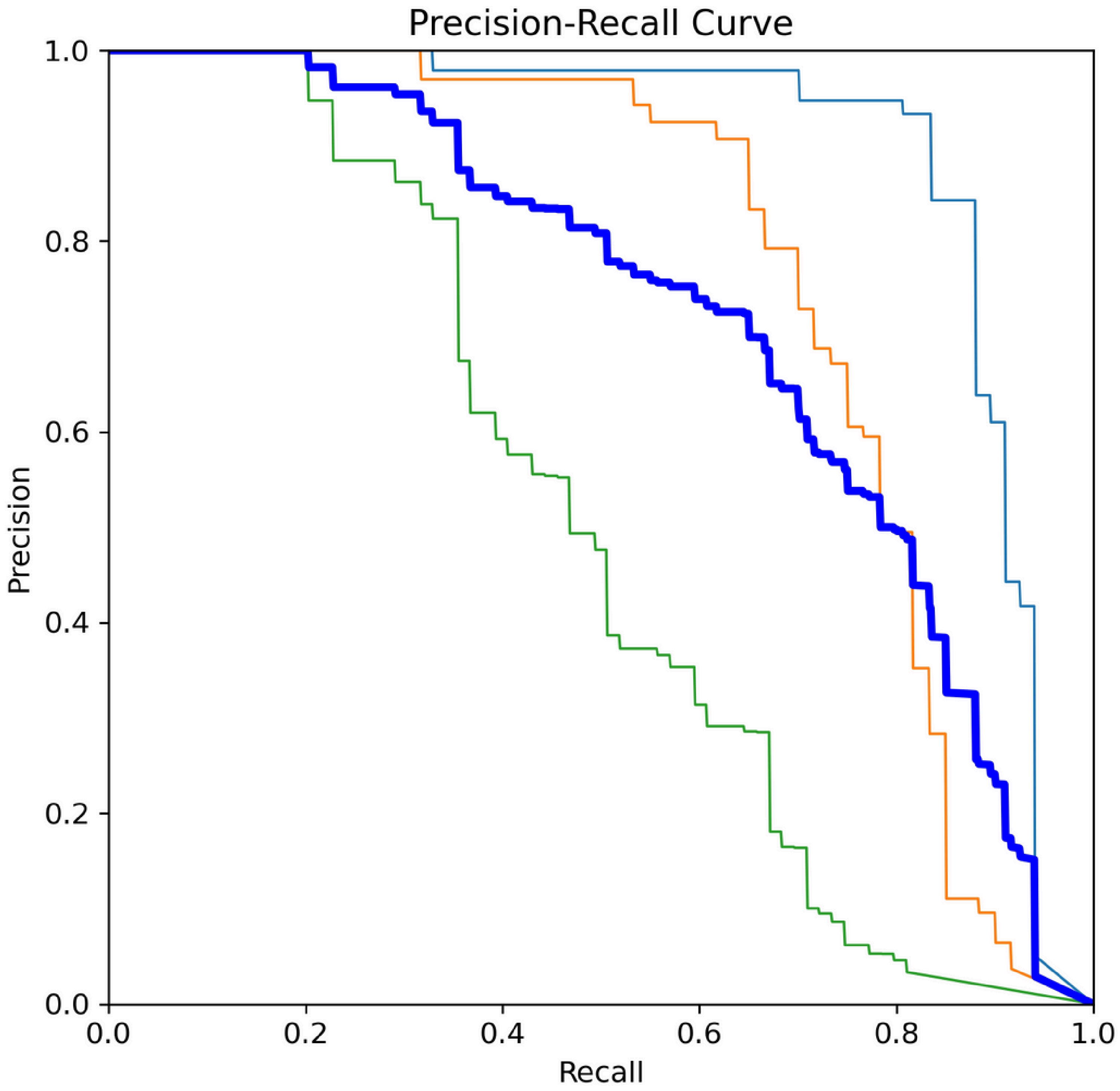
◆ Overall Performance Summary

Metric	Value
mAP@0.5	0.941
mAP@0.5:0.95	0.88
Precision (Best)	0.99
Recall (Best)	0.91

Precision-Recall Curve



Precision-Recall Curve & Class-wise Performance



This updated PR curve shows significant improvements across all classes:

- Fire Extinguisher: Highest accuracy with a precision-recall score of 0.962.
- ToolBox: Very high performance at 0.936, a large jump from previous experiments.
- Oxygen Tank: Now at 0.925, indicating successful handling of occlusion and angle variance.
- Overall mAP@0.5: An impressive 0.941, indicating that the model is highly reliable under diverse test scenarios.

Failure Case Analysis

Partial Visibility

The model frequently failed to detect oxygen tanks that were partially obscured by other objects such as toolboxes.

Changes in Weather Patterns

Visual Clutter & Proximity Confusion: When objects like fire extinguishers and toolboxes were positioned close together or overlapped, misclassifications occurred — likely due to similar color/shape cues in tight clusters.

Challenges & Solutions

Challenges

Anaconda not recognized in scripts

Detection accuracy drop for oxygen tanks

Out-of-memory errors on CUDA device

Signs of overfitting after 70 epochs

Solutions

Updated the system PATH variable manually to point to Anaconda and set up the environment using Conda commands.

Enhanced the training dataset by injecting samples with heavy occlusion to improve model generalization

Implemented early stopping and added regularization via dropout layers to maintain generalization.

Opted for a more lightweight model (YOLOv8s) and adjusted batch size to fit within GPU constraints.

Conclusion & Future Work

Summary

We developed an effective object detection model using synthetic space station data. Despite data limitations, we achieved strong performance through targeted augmentation and tuning.

Key Takeaways

Well-crafted synthetic data can match real-world datasets in training efficiency.

Visual diagnostics like confusion matrices help uncover hidden model weaknesses.

What’s Next

Generate tailored synthetic scenarios using Falcon (e.g., heavy occlusion).

Experiment with larger models like YOLOv8x on more powerful hardware.

Explore self-supervised methods to further reduce manual labeling needs.