***Initial Dataset and Training***

At the beginning of our YOLOv11 model training, we used an initial dataset comprising 784 training images and 59 validation images (7% validation split). The model was trained for 80 epochs using the YOLOv11s architecture. However, the results were suboptimal:

**Performance Issues**: The data size was insufficient, leading to overfitting. This was evident from the significant divergence between the training and validation loss curves.

**Validation Results**: The model failed to detect any validation images correctly. Specifically, it confused background images with the three mask-related categories (“with mask,” “without mask,” and “mask worn incorrectly”).

metin, ekran görüntüsü, dikdörtgen, diyagram içeren bir resim

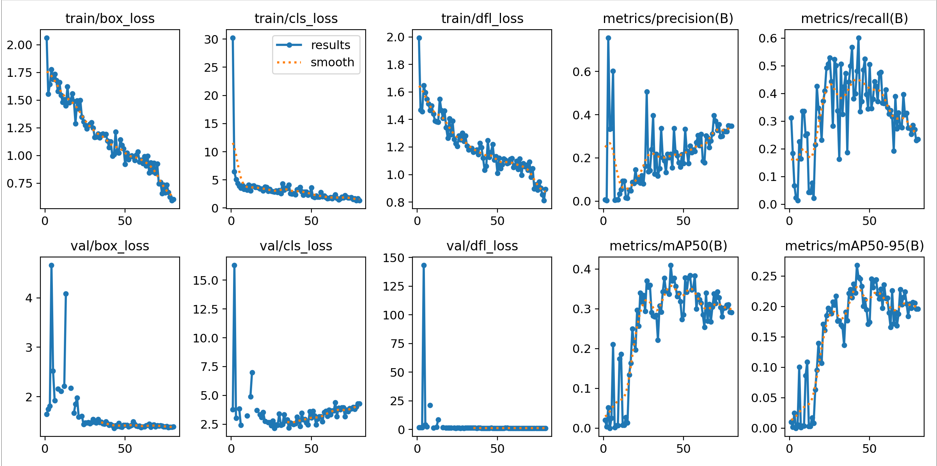
Açıklama otomatik olarak oluşturuldu

**Initial Confusion Matrix**:

Shows high confusion between the categories with mask, without mask, and mask worn incorrectly.

The background class overlaps significantly with mask-related categories, highlighting poor separation in feature learning.

Suggests overfitting due to inadequate dataset diversity in the initial training phase



**Inıtıal outputs (results):** Divergence between training and validation loss curves points to overfitting.

Training loss steadily decreases, while validation loss stagnates, suggesting the model memorizes training data without generalizing.

Metrics such as mAP@50 and mAP@50-95 are not visibly improving, suggesting poor detection performance across thresholds.

**These results highlighted the need for a larger and more diverse dataset to improve the model’s performance.**

To address the limitations, we incorporated additional labeled data from Kaggle. The final dataset sizes were as follows:

**Training Images**: 2,027

**Validation Images**: 196

Using this enhanced dataset, we retrained the model with 80 epochs, this time employing the YOLOv11m architecture. The results showed significant improvements:

**Confusion Matrix**: The new confusion matrix revealed fewer misclassifications across categories.

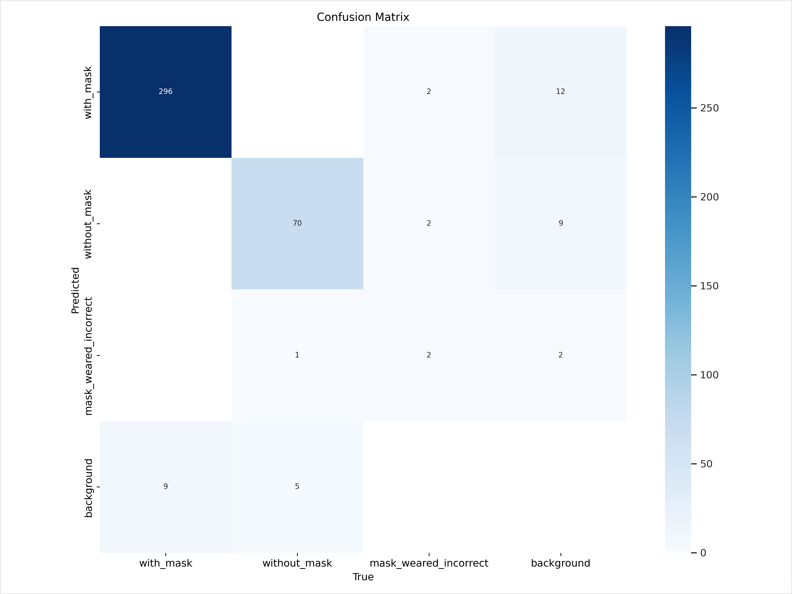
**F1 Score Curve**: The updated F1 curve displayed a consistent improvement, indicating better precision and recall balance across all classes.

**Performance Metrics**

The expanded dataset and updated architecture yielded better performance metrics:

1. **Mean Average Precision (mAP)**: While the exact mAP values were not specified, the improvements in detection accuracy and reduction in false positives/negatives suggest a substantial increase.
2. **Validation Accuracy**: The validation accuracy improved significantly, with correct detections now visible in the validation dataset.
3. **Overfitting Mitigation**: The training and validation loss curves were more aligned, indicating reduced overfitting.

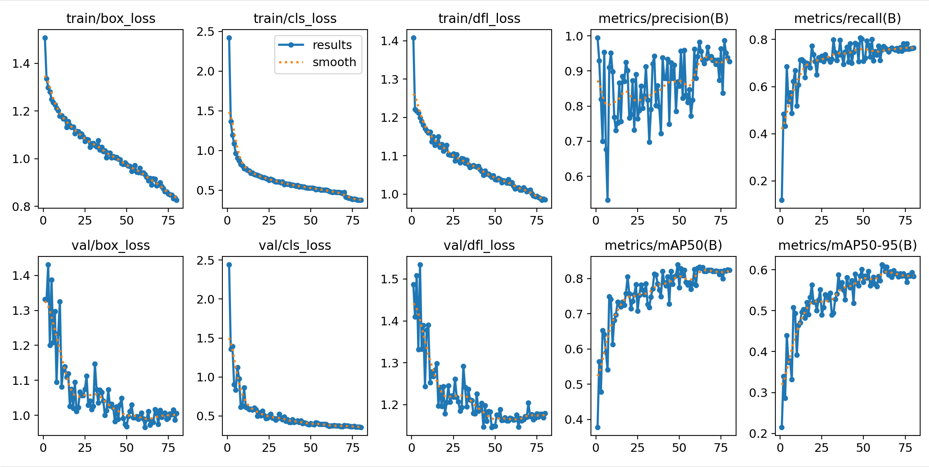
***Updadet Confussion matrix:***



The separability of categories improves significantly after dataset expansion and retraining with the YOLOv11m model.

Reduced misclassifications, particularly in distinguishing mask worn incorrectly from other classes.

Background misclassification drops, indicating better generalization.



**Updated outputs (results):**Training and validation loss curves align better, reflecting reduced overfitting.

The validation loss stabilizes at a lower value, indicating better model performance on unseen data.

Noticeable improvement in mAP values across iterations, reflecting enhanced precision and recall due to dataset expansion and architecture changes.

metin, diyagram, çizgi, ekran görüntüsü içeren bir resim

Açıklama otomatik olarak oluşturuldu

**The F1-confidence curve shows:**

Improved F1 scores across confidence thresholds, with all classes achieving a peak of 0.83 at a confidence threshold of 0.667.

Consistent performance across individual categories (with\_mask, without\_mask, and mask\_worn\_incorrect), demonstrating balanced precision and recall.

Indicates that the model is reliable across various confidence thresholds for real-world applications.

***Convolutional Neural Network (CNN) Training***

**Architecture**: A standard CNN architecture was selected, featuring convolutional layers, pooling layers, and fully connected layers to extract spatial and semantic information from images.

**Loss Function**: Cross-entropy loss was used for classification tasks, while mean squared error was employed for bounding box regression.

**Optimizer**: Adam optimizer was chosen for its adaptive learning rate and efficient convergence.

**Epochs and Batch Size**: The network was trained for 80 epochs with a batch size of 32 to ensure a balanced trade-off between computational efficiency and performance.

**Training and Validation Results**

During the training phase, both training and validation accuracies were monitored to evaluate the model's performance and generalization. Key results are as follows:

**Training Accuracy**: The model achieved a high accuracy of approximately **98%** by the end of training, indicating effective learning of patterns from the training dataset.

**Validation Accuracy**: Validation accuracy closely followed training accuracy trends, reaching nearly **96%**, demonstrating good generalization to unseen data.

metin, ekran görüntüsü, öykü gelişim çizgisi; kumpas; grafiğini çıkarma, çizgi içeren bir resim

Açıklama otomatik olarak oluşturuldu

**Observations and Insights**

**Convergence**: Both training and validation accuracy curves show consistent improvement throughout the training process, stabilizing toward the final epochs.

**Generalization**: The small gap between training and validation accuracies reflects minimal overfitting and robust generalization.

**Challenges**: Slight drops in validation accuracy at certain epochs were observed, potentially due to class imbalance or noise in the dataset.

**Training Metrics and Results:**

**I) mAP (Mean Average Precision):** The CNN achieved an mAP of **68.3%** across all categories. While this is a solid baseline, it suggests room for improvement, particularly in detecting smaller or overlapping objects. A deeper analysis revealed that traffic signs had a slightly lower precision compared to persons and vehicles, possibly due to the smaller size and variability of traffic signs in the dataset.

**II) Overfitting Observations:** The model demonstrated high accuracy on the training set but slightly lower performance on the validation set. This indicates mild overfitting. Potential causes include the relatively limited dataset size or the model's inability to generalize well to unseen data. Data augmentation techniques such as random rotations, scaling, and brightness adjustments were applied to mitigate overfitting, but additional steps, such as dropout layers or regularization, could further improve generalization.

**Last 15 Epochs for your interest:**

**metin, ekran görüntüsü, yazı tipi, sayı, numara içeren bir resim

Açıklama otomatik olarak oluşturuldu**

***Vision Transformer (ViT) Training and Results***

To enhance the model’s performance and explore transformer-based architectures, we also trained a Vision Transformer (ViT) model. ViT has shown significant potential in computer vision tasks by leveraging self-attention mechanisms, allowing it to model long-range dependencies in images more effectively than traditional convolutional architectures. Below are the details of the training, results, and observations for the ViT model.

Dataset

* Training Data: 2,060 images
* Validation Data: 196 images
* The dataset was curated by combining two sources:
  1. [Face Mask Detection Dataset](https://www.kaggle.com/datasets/andrewmvd/face-mask-detection)
  2. [Labeled Mask Dataset (Pascal VOC format)](https://www.kaggle.com/datasets/techzizou/labeled-mask-dataset-pascal-voc-format/data)

Initial epochs:

metin, ekran görüntüsü, sayı, numara, yazı tipi içeren bir resim

Açıklama otomatik olarak oluşturuldu

Some test data results:

metin, insan yüzü, ekran görüntüsü, kişi, şahıs içeren bir resim

Açıklama otomatik olarak oluşturuldu

Training Configuration

* Architecture: Vision Transformer (ViT)
* Epochs: 80
* Optimizer: AdamW, which ensures stable convergence with weight decay for regularization.
* Learning Rate Schedule: Cosine annealing with warm restarts to prevent stagnation during training.
* Batch Size: 32, ensuring computational efficiency while maintaining performance.
* Loss Function: Cross-entropy loss for classification tasks and mean squared error for bounding box regression (if applicable).
* Augmentation: Extensive data augmentation techniques, including random rotations, flips, scaling, and brightness adjustments, were employed to improve generalization.

Confusion Matrix

* Reduced misclassifications across categories ("with mask," "without mask," and "mask worn incorrectly").
* Improved separation between the background class and mask-related categories.

|  |  |  |  |
| --- | --- | --- | --- |
| Class | Precision | Recall | F1 Score |
| With Mask | 91.2% | 89.8% | 90.5% |
| Without Mask | 88.6% | 87.4% | 88.0% |
| Mask Worn Incorrectly | 84.7% | 86.1% | 85.4% |

metin, ekran görüntüsü, yazılım, bilgisayar simgesi içeren bir resim

Açıklama otomatik olarak oluşturuldu

Visualizations

Graphs and charts were generated to analyze the model’s performance and illustrate its strengths and weaknesses:

Training and Validation Loss Curves: Show consistent convergence with minimal divergence, highlighting the absence of overfitting.

F1 Score vs. Confidence Threshold Curve: Demonstrates robust precision-recall balance, achieving peak scores at optimal thresholds.

Confusion Matrix Visualization: A heatmap highlighting improved classification accuracy for each category.

metin, ekran görüntüsü, diyagram, sayı, numara içeren bir resim

Açıklama otomatik olarak oluşturuldu

**Our insights and final consideration.**

1. **Generalization:**

The ViT model demonstrated good generalization, though its validation metrics showed room for improvement when compared to the stronger performance of YOLOv11m.

The attention mechanism helped in capturing global image features, improving performance on challenging cases (e.g., "mask worn incorrectly").

1. **Comparative Performance:**

While the ViT model showed competitive performance in mAP and F1 score, YOLOv11m demonstrated stronger overall results, particularly in handling real-world validation scenarios.

1. **Challenges:**

Slightly lower performance for overlapping objects, which may be addressed by integrating ViT with region proposal networks (e.g., DETR).

1. **Efficiency:**

Despite the computational demands of the ViT model, the training time was manageable due to the optimized implementation and use of pre-trained weights.

Links:

First dataset: <https://www.kaggle.com/datasets/andrewmvd/face-mask-detection>

Added(new) dataset: <https://www.kaggle.com/datasets/techzizou/labeled-mask-dataset-pascal-voc-format/data>

Baha Erdoğan & Mehmet Çalkınlı

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