Fruit and Vegetable Freshness Detection

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Objective:

The objective of this project is to develop a neural network that can identify the freshness and category of fruit / vegetable images.

Approach:

1. Dataset preprocessing
2. Implement four different models: ***AlexNet, ConvNeXt, EfficientNet, ResNet***
3. Evaluate the performance of each model and identify potential problems
4. Compare the results to find the best solution

Model Input & Output:

Input:

- image of fruit / vegetable

Output:

- fruit / vegetable category that the image belongs to (multiclass classification with nine classes: ***[apple, banana, tomato, orange, potato, capsicum, okra, cucumber, bitter gourd]***)
- freshness of the fruit / vegetable in the image (binary classification: ***[fresh, rotten]***)

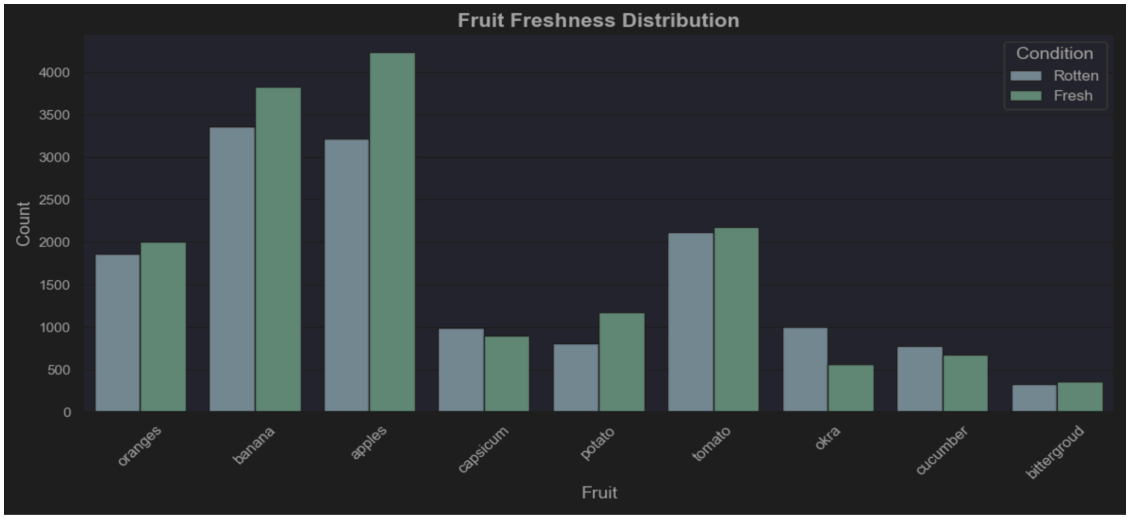
GitHub:
Use the github link to check our source code and sample testing results.
https://github.com/ychen606/freshness-detection/tree/main

Data Processing:

Data acquisition: we got our dataset from https://www.kaggle.com/datasets/swoyam2609/fresh-and-stale-classification, and this dataset has over 30,000 images, it contains 9 types of fruits (Apple, banana, bitter gourd, capsicum, cucumber, okra, oranges, potato, tomato) and vegetables with 2 labels (fresh or rotten). The images were resized to 224x224, and the batch size that we are using is 64.

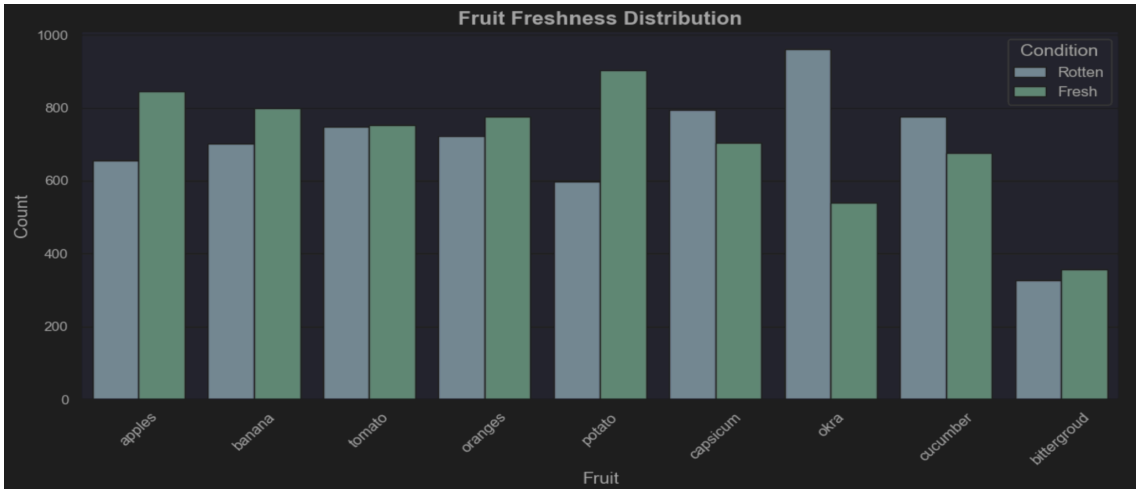
Data augmentation: to artificially increase the dataset's size and diversity, the following data augmentation techniques were applied: Vertical/Horizontal Flip, Rotation, Color Jitter, Random Affine Transformation, Random Perspective, Gaussian Blur, Random Sharpness.

Data rebalance:



(Above is original dataset)

If we look at the data distribution for the original dataset, we will observe that the dataset is highly imbalanced. Instances of apples, bananas, oranges, and potatoes are much more than other fruits (especially apples and bananas). So, what we did was for each fruit having more than 1500 images, we sampled 1500 out of it, and saved it in a new data frame, fruits having less than 1500 images, we will keep as it is. Within this new data frame, we will create our new training, validation, and testing dataset. So, for each model, we will train on two datasets, one is an original imbalanced dataset, another one is a new balanced dataset.



(Above is new balanced dataset)

We believe that balancing the dataset is crucial for achieving computational efficiency and reducing class bias, which is particularly important for real-world applications where fairness and scalability are critical. Although the original dataset has a lot more data, the new balanced dataset provided a more equitable and efficient solution, demonstrating the importance of addressing class imbalance in machine learning workflows.

AlexNet:

Test fruit/vegetable classification results:

Original dataset

Class	Precision	Recall	F1	Support
Apple	1.00	0.99	1.00	1779
Banana	1.00	0.99	1.00	1792
Bittergourd	1.00	0.00	0.00	245
Capsicum	0.00	0.00	0.00	367
Cucumber	0.00	0.00	0.00	534
Okra	0.00	0.00	0.00	594
Orange	0.00	0.00	0.00	791
Potato	0.00	0.00	0.00	648
Tomato	0.00	0.00	0.00	608
Accuracy			0.53	6738
Macro Avg	0.33	0.22	0.22	6738
Weighted Avg	0.61	0.53	0.53	6738

Training time: 45 min

Balanced dataset

Class	Precision	Recall	F1	Support
Apple	0.89	0.96	0.93	225
Banana	0.91	1.00	0.95	225
Bittergourd	1.00	0.82	0.90	103
Capsicum	0.99	0.99	0.99	225
Cucumber	0.98	0.45	0.62	218
Okra	0.67	0.97	0.79	225
Orange	0.96	0.94	0.95	225
Potato	0.91	0.98	0.94	225
Tomato	0.97	0.90	0.93	255
Accuracy			0.90	1896
Macro Avg	0.92	0.89	0.89	1896
Weighted Avg	0.91	0.90	0.89	1896

Training Time: 40 min

Test freshness classification results:

Original dataset

Class	Precision	Recall	F1	Support
Fresh	0.97	0.99	0.98	3245
Rotten	0.99	0.97	0.98	3493
Accuracy			0.98	6738
Macro Avg	0.98	0.98	0.98	6738
Weighted Avg	0.98	0.98	0.98	6738

Training time: 45 min

Balanced dataset

Class	Precision	Recall	F1	Support
Fresh	0.98	0.95	0.97	933
Rotten	0.95	0.99	0.97	963
Accuracy			0.97	1896
Macro Avg	0.97	0.97	0.97	1896
Weighted Avg	0.97	0.97	0.97	1896

Training Time: 40 min

AlexNet initially had overfitting on the original dataset when doing category classification due to the imbalanced data distribution in the dataset. After training on the new balanced dataset, the problem is resolved. The network performs very well on freshness classification, but no so well on category classification, especially for the okra and cucumber class. Also, a small learning rate and more epochs are required for the network to converge, so the training time is relatively high.

ConvNeXt:

Test fruit/vegetable classification results:

Original dataset

Class	Precision	Recall	F1	Support
Apple	0.95	0.98	0.96	1779
Banana	0.98	0.99	0.99	1792
Bittergourd	0.00	0.00	0.00	245
Capsicum	0.00	0.00	0.00	367
Cucumber	0.00	0.00	0.00	534
Okra	0.00	0.00	0.00	594
Orange	0.00	0.00	0.00	791
Potato	0.00	0.00	0.00	648
Tomato	0.00	0.00	0.00	608
Accuracy			0.52	6738
Macro Avg	0.21	0.22	0.22	6738
Weighted Avg	0.51	0.52	0.52	6738

Training time: 20 min

Balanced dataset

Class	Precision	Recall	F1	Support
Apple	1.00	0.98	0.99	225
Banana	0.97	1.00	0.98	225
Bittergourd	0.99	1.00	1.00	103
Capsicum	1.00	1.00	1.00	225
Cucumber	0.99	0.91	0.95	218
Okra	0.92	0.99	0.95	225
Orange	1.00	0.98	0.99	225
Potato	0.98	1.00	0.99	225
Tomato	1.00	0.97	0.98	255
Accuracy			0.98	1896
Macro Avg	0.98	0.98	0.98	1896
Weighted Avg	0.98	0.98	0.98	1896

Training Time: 18 min

Test freshness classification results:

Original dataset

Class	Precision	Recall	F1	Support
Fresh	0.93	0.93	0.93	3245
Rotten	0.93	0.94	0.93	3493
Accuracy			0.93	6738
Macro Avg	0.93	0.93	0.93	6738
Weighted Avg	0.93	0.93	0.93	6738

Training time: 20 min

Balanced dataset

Class	Precision	Recall	F1	Support
Fresh	0.98	0.96	0.97	933
Rotten	0.97	0.98	0.97	963
Accuracy			0.97	1896
Macro Avg	0.97	0.97	0.97	1896
Weighted Avg	0.97	0.97	0.97	1896

Training Time: 18 min

ConvNeXt initially had the same overfitting problem as AlexNet due to the imbalanced dataset. The problem is resolved on the new balanced dataset. Unlike AlexNet, which performs not so well on category classification, ConvNeXt performs very well on both tasks and is well-balanced on all metrics. Training time is also lower compared to AlexNet, because it takes less epochs.

EfficientNet:

Test fruit/vegetable classification results:

Original dataset

Class	Precision	Recall	F1	Support
Apple	1.00	1.00	1.00	1779
Banana	1.00	1.00	1.00	1792
Bittergourd	0.99	0.99	0.99	245
Capsicum	0.99	0.99	0.99	367
Cucumber	0.99	0.99	0.99	534
Okra	0.99	0.99	0.99	594
Orange	1.00	1.00	1.00	791
Potato	1.00	1.00	1.00	648
Tomato	1.00	1.00	1.00	608
Accuracy			1.00	6738
Macro Avg	1.00	1.00	1.00	6738
Weighted Avg	1.00	1.00	1.00	6738

Training time: 22 min

Balanced dataset

Class	Precision	Recall	F1	Support
Apple	1.00	1.00	1.00	225
Banana	0.99	1.00	1.00	225
Bittergourd	1.00	1.00	1.00	102
Capsicum	1.00	1.00	1.00	225
Cucumber	0.97	0.98	0.97	218
Okra	0.99	0.97	0.98	225
Orange	1.00	1.00	1.00	225
Potato	0.99	1.00	0.99	225
Tomato	1.00	0.99	1.00	255
Accuracy			1.00	1895
Macro Avg	0.99	0.99	0.99	1895
Weighted Avg	0.98	0.99	0.99	1895

Training Time: 9 min

Test freshness classification results:

Original dataset

Class	Precision	Recall	F1	Support
Fresh	0.99	0.99	0.99	3245
Rotten	0.99	0.99	0.99	3493
Accuracy			0.99	6738
Macro Avg	0.99	0.99	0.99	6738
Weighted Avg	0.99	0.99	0.99	6738

Training time: 22 min

Balanced dataset

Class	Precision	Recall	F1	Support
Fresh	0.97	0.97	0.97	925
Rotten	0.97	0.97	0.97	970
Accuracy	0.97	0.97	0.97	1895
Macro Avg	0.97	0.97	0.97	1895
Weighted Avg	0.97	0.97	0.97	1895

Training Time: 9 min

The EfficientNet model has demonstrated exceptional performance in both fruit classification and freshness classification tasks, achieving consistently high metrics for precision, recall, and F1-score, with values approaching or reaching 1.0 across all classes and datasets. The training time for the original dataset was **22 minutes**, whereas the balanced dataset required only **9 minutes**. This represents a **59% reduction in training time**, demonstrating huge computational efficiency gained by balancing the dataset. While the original dataset achieved nearly perfect metrics (precision, recall, and F1-score close to or at 1.0), the balanced dataset achieved slightly lower, yet consistent scores, with metrics ranging between **0.97 and 1.0** for fruit classification and **0.97** for freshness classification. Despite the minor reduction in performance, the balanced dataset maintained an excellent level of classification accuracy and fairness across all classes. The original dataset had significant disparities in class support (e.g., Apple: 1779, Capsicum: 367), which could lead to model bias favoring overrepresented classes. The balanced dataset equalized the support for all classes, ensuring fair representation, which is critical for generalization and reducing bias in the model.

ResNet:

Test fruit/vegetable classification results:

Original dataset

Class	Precision	Recall	F1	Support
Apple	1.00	1.00	1.00	1779
Banana	1.00	1.00	1.00	1792
Bittergourd	1.00	1.00	1.00	245
Capsicum	1.00	1.00	1.00	367
Cucumber	1.00	1.00	1.00	534
Okra	0.99	0.99	0.99	594
Orange	1.00	1.00	1.00	791
Potato	1.00	1.00	1.00	648
Tomato	1.00	1.00	1.00	608
Accuracy			1.00	6738
Macro Avg	1.00	1.00	1.00	6738
Weighted Avg	1.00	1.00	1.00	6738

Training time: 26 min

Balanced dataset

Class	Precision	Recall	F1	Support
Apple	1.00	1.00	1.00	225
Banana	0.99	1.00	1.00	225
Bittergourd	1.00	1.00	1.00	102
Capsicum	1.00	1.00	1.00	225
Cucumber	0.99	0.97	0.98	218
Okra	0.98	0.99	0.98	225
Orange	1.00	1.00	1.00	225
Potato	0.99	1.00	1.00	225
Tomato	1.00	1.00	1.00	255
Accuracy			0.99	1895
Macro Avg	1.00	0.99	0.99	1895
Weighted Avg	0.98	0.99	0.99	1895

Training time: 11 min

Test freshness classification results:

Original dataset

Class	Precision	Recall	F1	Support
Fresh	0.99	0.99	0.99	3245
Rotten	0.99	0.99	0.99	3493
Accuracy			0.99	6738
Macro Avg	0.99	0.99	0.99	6738
Weighted Avg	0.99	0.99	0.99	6738

Training time: 26 min

Balanced dataset

Class	Precision	Recall	F1	Support
Fresh	0.97	0.98	0.98	925
Rotten	0.98	0.97	0.98	970
Accuracy	0.98	0.98	0.98	1895
Macro Avg	0.98	0.98	0.98	1895
Weighted Avg	0.98	0.98	0.98	1895

Training Time: 11 min

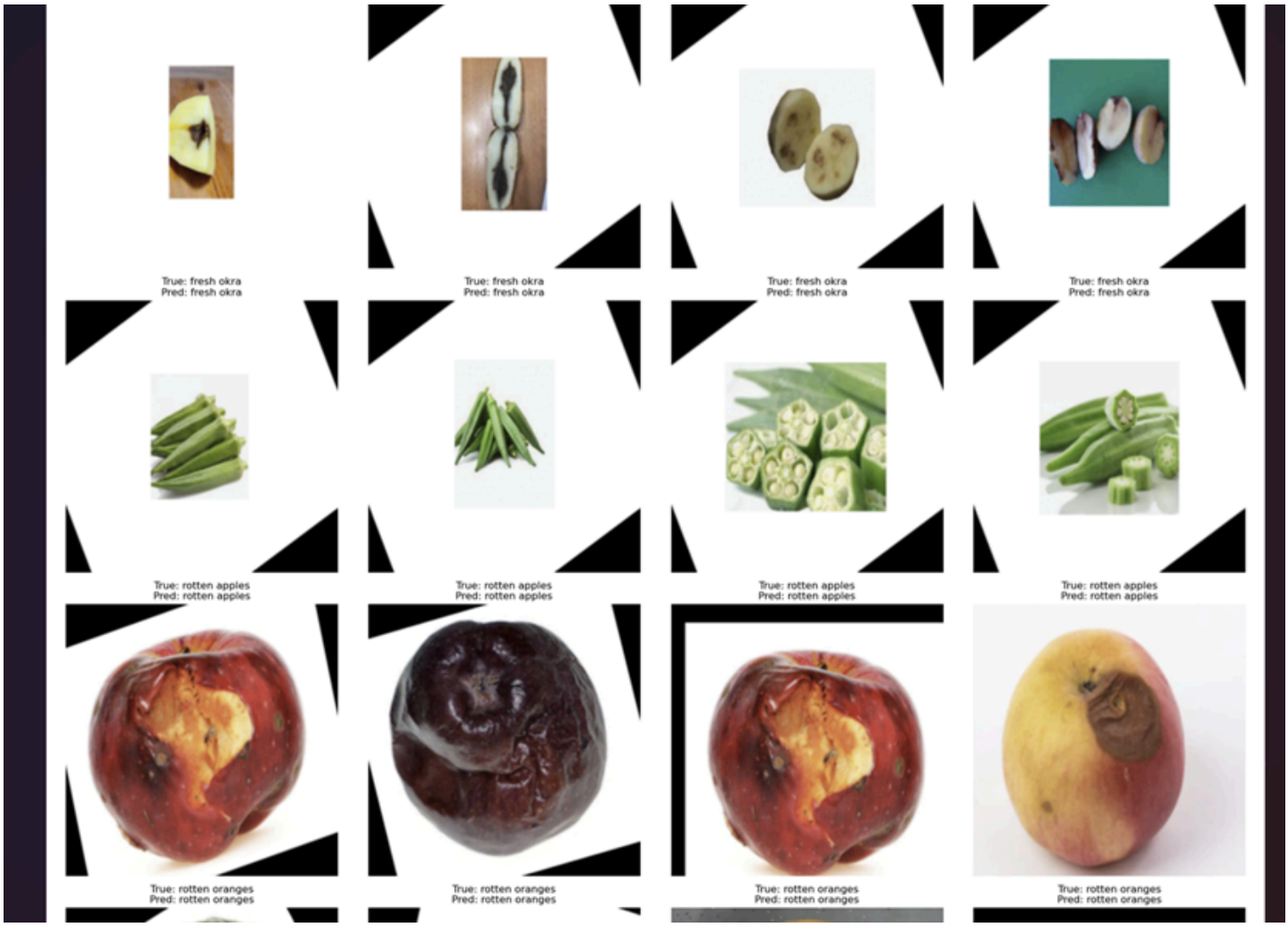
The ResNet model demonstrated exceptional performance across both fruit classification and freshness classification tasks, achieving consistently high precision, recall, and F1-scores for both the original and balanced datasets. For the original dataset, the model achieved nearly perfect metrics across all categories, with values reaching 1.0, but this came with a longer training time of **26 minutes**. In contrast, the balanced dataset exhibited slightly lower metrics, with F1-scores ranging from **0.98 to 1.0**, but required significantly less training time at **11 minutes**, representing a **58% reduction in training time**. Moreover, balancing the dataset addressed disparities in class support, ensuring fair representation of all categories. While the original dataset provided superior accuracy for overrepresented classes, it risked bias due to uneven class distribution (e.g., Apple: 1779, Capsicum: 367). The balanced dataset effectively mitigated this risk, providing equitable support for all classes and promoting better generalization.

Conclusion:

Model	Accuracy (freshness)	Accuracy (fruit/vegetable type)	Training time (minutes)
AlexNet (original dataset)	0.98	0.53	45
AlexNet (balanced dataset)	0.97	0.90	40
ConvNeXt (original dataset)	0.93	0.52	20
ConvNeXt (balanced dataset)	0.97	0.98	18
EfficientNet (original dataset)	0.99	1.00	22
EfficientNet (balanced dataset)	0.97	1.00	9
ResNet (original dataset)	0.99	1.00	26
ResNet (balanced dataset)	0.98	0.99	11

AlexNet (original dataset) and ConvNeXt (original dataset) have serious overfitting issues. AlexNet (balanced dataset) manages to solve overfitting, but its performance on fruit/vegetable type is almost 10 percent behind other models in terms of accuracy, and its training time is too long.
ConvNeXt (balanced dataset), EfficientNet (original dataset), and ResNet (original dataset) all have very good accuracy, but still take quite some time to train.
EfficientNet (balanced dataset) and ResNet (balanced dataset) have similar levels of performance on accuracy compared to the last three models mentioned above, but they have significant improvement on training time.
After considering their performance on both the freshness and fruit/vegetable type classification tasks, **ResNet (balanced dataset) is decided to be the best solution** for the problem this project aims to solve.

Sample Results:
Below are some testing results from **ResNet:**



True: rotten cucumber
Pred: rotten cucumber

True: rotten cucumber
Pred: rotten cucumber

True: rotten cucumber
Pred: rotten cucumber

True: rotten cucumber
Pred: rotten cucumber

True: fresh oranges
Pred: fresh oranges

True: fresh oranges
Pred: fresh oranges

True: fresh oranges
Pred: fresh oranges

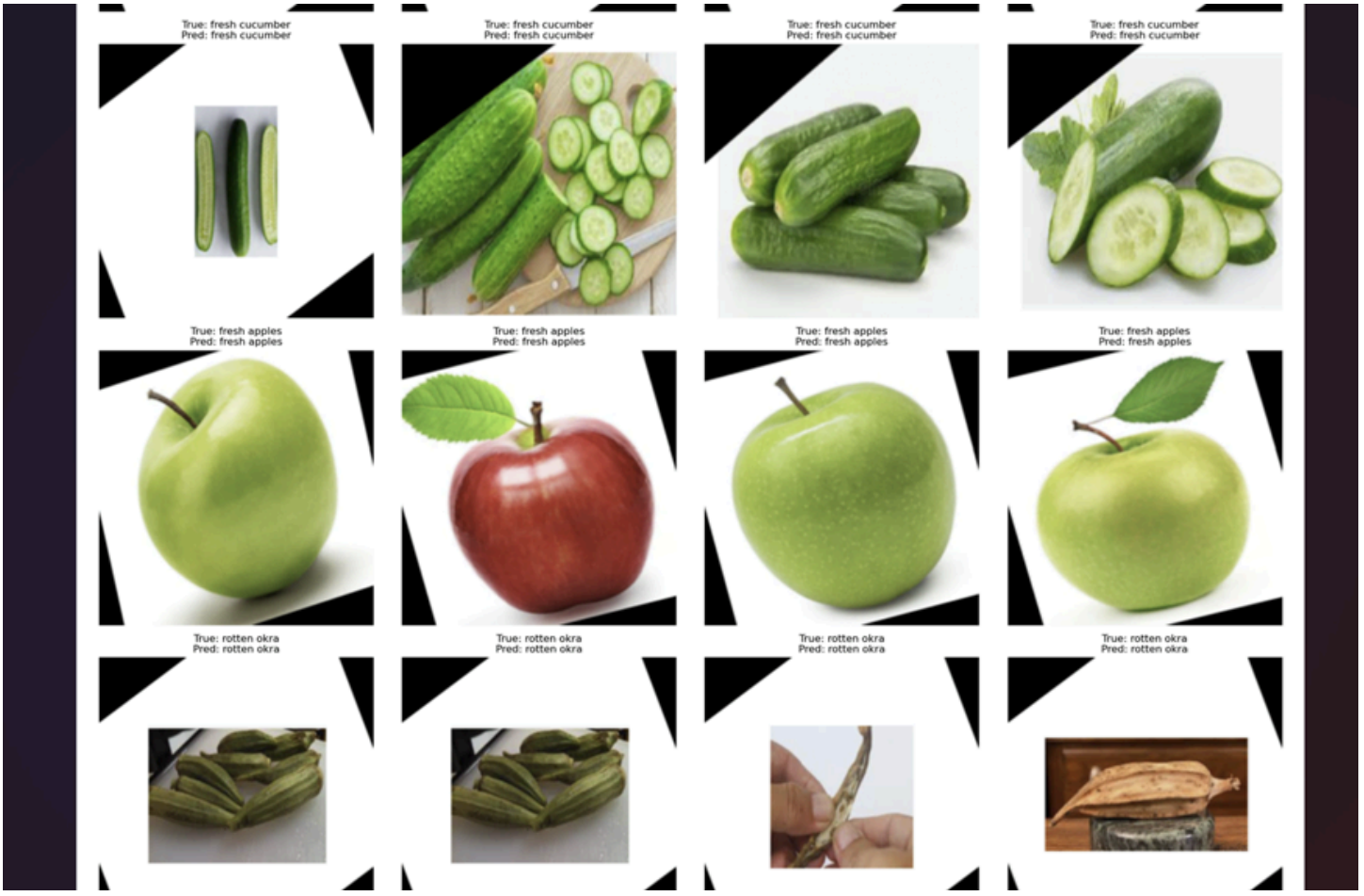
True: fresh oranges
Pred: fresh oranges

True: rotten potato
Pred: rotten potato

True: rotten potato
Pred: rotten potato

True: rotten potato
Pred: rotten potato

True: rotten potato
Pred: rotten potato


True: fresh cucumber
Pred: fresh cucumber
True: fresh cucumber
Pred: fresh cucumber
True: fresh cucumber
Pred: fresh cucumber
True: fresh cucumber
Pred: fresh cucumber
True: fresh apples
Pred: fresh apples
True: fresh apples
Pred: fresh apples
True: fresh apples
Pred: fresh apples
True: fresh apples
Pred: fresh apples
True: rotten okra
Pred: rotten okra
True: rotten okra
Pred: rotten okra
True: rotten okra
Pred: rotten okra
True: rotten okra
Pred: rotten okra