



Classification of Strawberry Maturity Level from Images Using Supervised Classifiers and Convolutional Neural Networks as Feature Extractors

Érika Kayoko Hamaguti and Fabricio Aparecido Breve



Fabricio Breve
São Paulo State University –
UNESP, Brazil
fabricio.breve@unesp.br



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Motivation

Strawberry is a perishable and non-climacteric fruit.

- It does not continue to ripen after harvest.

It is cultivated worldwide and is very popular for its sweetness, taste, and nutrients.

The strawberry growth cycle has three main phases: flowering, fruiting, and ripening.

There is no single standard for determining the ripening stage of strawberries.

- Farmers still need to inspect them manually.
 - Inefficient and time-consuming.



[21] Ibba, P., Tronstad, C., Moschetti, R., Mimmo, T., Cantarella, G., Petti, L., Martinsen, Ø.G., Cesco, S., Lugli, P.: Supervised binary classification methods for strawberry ripeness discrimination from bioimpedance data. *Scientific reports* 11(1), 11202 (2021)

Objectives

- **Goal:**
 - Develop an automatic system to predict the maturity of strawberries.
- **Strategy:**
 - Evaluate 71 Convolutional Neural Network (CNN) architectures to extract groups of deep features.
 - Feed each group to 10 different supervised classifiers.
 - Find the best combination of CNN and classifier for this task.

Datasets

[10] Elhariri, E., El-Bendary, N., Saleh, S.M.: Strawberry-ds: Dataset of annotated strawberry fruits images with various developmental stages. Data in Brief 48, 109165 (2023).

[25] Pérez-Borrero, I., Marín-Santos, D., Gegúndez-Arias, M.E., Cortés-Ancos, E.: A fast and accurate deep learning method for strawberry instance segmentation. Computers and Electronics in Agriculture 178, 105736 (2020).

Strawberry-DS1 [10]

- 247 images.
- 170 labeled as “Harvest”
- 77 labeled as “Not_Harvest”
- 3840x2160 pixels.



StrawDI_Db12 [25]

- 3100 images.
- 1780 labeled as “Harvest”
- 1320 labeled as “Not_Harvest”
- 1008x756 pixels.



CNN Architectures

- 71 evaluated architectures.
- Weights pre-trained on the Imagenet dataset.
- Principal Component Analysis (PCA) to reduce dimensionality.
 - 90% to 99% variance preservation in 1% steps.
 - 71 CNN x 10 classifiers x 10 PCA configurations = 7100 combinations.

Architecture	Reference
VGG16, VGG19	[29]
ResNet50, ResNet101, ResNet152	[16]
ResNet50V2, ResNet101V2, ResNet152V2	[17]
ResNetRS50, ResNetRS101, ResNetRS152 , ResNetRS200 , ResNetRS270 , ResNetRS350 , ResNetRS420	[5]
InceptionV3	[31]
InceptionResNetV2	[30]
DenseNet121, DenseNet169, DenseNet201	[20]
Xception	[9]
MobileNet	[19]
MobileNetV2	[28]
MobileNetV3Large, MobileNetV3Small	[18]
NASNetLarge , NASNetMobile	[35]
EfficientNetB0 , EfficientNetB1 , EfficientNetB2 , EfficientNetB3 , EfficientNetB4 , EfficientNetB5 , EfficientNetB6 , EfficientNetB7	[32]
EfficientNetV2B0 , EfficientNetV2B1 , EfficientNetV2B2 , EfficientNetV2B3 , EfficientNetV2S , EfficientNetV2M , EfficientNetV2L	[33]
RegNetX002, RegNetX004, RegNetX006, RegNetX008, RegNetX016, RegNetX032, RegNetX040, RegNetX064, RegNetX080, RegNetX120, RegNetX160, RegNetX320, RegNetY002, RegNetY004, RegNetY006, RegNetY008, RegNetY016, RegNetY032, RegNetY040, RegNetY064, RegNetY080, RegNetY120, RegNetY160 , RegNetY320	[26]
ConvNeXtTiny, ConvNeXtSmall, ConvNeXtBase, ConvNeXtLarge , ConvNeXtXLarge	[22]

Supervised Classifiers

Classifier	Reference
Support Vector Machine (SVM)	[7]
Linear Support Vector Machine (LSVM)	[11]
Logistic Regression (LR)	[7]
K-Nearest Neighbors (KNN)	[7]
Gaussian Naïve Bayes (GNB)	[7]
Decision Tree (DT)	[7]
Gradient Boosting (GB)	[13]
Histogram-based Gradient Boosting (HGB)	[2]
Random Forest (RF)	[8]
Perceptron	[7]

Implementation

- Python 3
- TensorFlow
 - CNN implementations
- Scikit-learn
 - Supervised Classifiers
- Google Colab – free version
 - 12.67 GB of RAM
 - Different hardware configurations in each connection.



Methodology

- For each combination of CNN + PCA configuration + Classifier:
 - Training **with** and **without** weight balancing.
 - Except for KNN, NB, and GB.
 - *K*-Fold Cross Validation with $k = 5$
- Evaluation metrics:
 - Accuracy
 - F1-Score
 - Recall
 - Precision

Results for Strawberry-DS (Best 10)

Techniques	Balanced	PCA	Accuracy	F1-Score	Recall	Precision
VGG16 + GB	No	0.97	0.7796	0.8512	0.9118	0.7991
VGG19 + P	No	0.96	0.7592	0.8509	0.9824	0.7517
VGG19 + HGB	Yes	0.90	0.7837	0.8468	0.8456	0.8293
VGG19 + HGB	No	0.90	0.7796	0.8467	0.8882	0.8120
ConvNeXtTiny + LR	No	0.90	0.7796	0.8449	0.8706	0.8226
VGG19 + GB	No	0.91	0.7714	0.8448	0.9059	0.7932
VGG19 + LR	No	0.93	0.7592	0.8424	0.9294	0.7704
ConvNeXtBase + SVM	Yes	0.94	0.7388	0.8385	0.9706	0.7350
VGG19 + LR	Yes	0.95	0.7510	0.8367	0.9118	0.7697
VGG19 + RF	Yes	0.90	0.7265	0.8358	1.0000	0.7184

Results for StrawDI_Db1 (Best 10)

Techniques	Balanced	PCA	Accuracy	F1-Score	Recall	Precision
ConvNeXtBase + GB	No	0.91	0.7694	0.8111	0.8612	0.7666
ConvNeXtBase + HGB	No	0.93	0.7677	0.8105	0.8646	0.7630
ConvNeXtBase + HGB	Yes	0.91	0.7665	0.8067	0.8483	0.7691
ConvNeXtBase + SVM	No	0.90	0.7213	0.7965	0.9494	0.6861
ConvNeXtSmall + GB	No	0.95	0.7471	0.7921	0.8393	0.7501
ConvNeXtSmall + HGB	No	0.91	0.7442	0.7916	0.8455	0.7443
ConvNeXtSmall + SVM	No	0.90	0.7223	0.7878	0.8978	0.7019
ConvNeXtSmall + HGB	Yes	0.92	0.7458	0.7869	0.8169	0.7593
ConvNeXtTiny + HGB	No	0.91	0.7319	0.7847	0.8500	0.7291
ConvNeXtSmall + SVM	Yes	0.90	0.7326	0.7818	0.8337	0.7361

Conclusions

- CNNs have proven effective in classifying strawberry maturity levels.
 - Due to their ability to extract detailed features from images.
- The best results were achieved using:
 - Feature Extractors:
 - ConvNeXt and VGG families
 - Classifiers:
 - Gradient Boosting
 - Histogram-Based Gradient Boosting
 - Support Vector Machines
 - PCA retaining 90~97% of the variance.



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