International Journal of Academic Information Systems Research (IJAISR)
ISSN: 2643-9026
Vol. 8 Issue 4 April - 2024, Pages: 113-119

Pistachio Variety Classification using Convolutional Neural Networks

Ahmed S. Sabah and Samy S. Abu-Naser*

Department of Information Technology,
Faculty of Engineering and Information Technology,
Al-Azhar University - Gaza, Palestine

* Corresponding author: Samy S. Abu-Naser, Email: abunaser@alazhar.edu.ps

Abstract: *Pistachio nuts are a valuable source of nutrition and are widely cultivated for commercial purposes. The accurate classification of different pistachio varieties is important for quality control and market analysis. In this study, we propose a new model for the classification of different pistachio varieties using Convolutional Neural Networks (CNNs). We collected a dataset of pistachio images form Kaggle depository with two varieties (Kirmizi and Siirt). The images were then preprocessed and used to train a CNN model based on VGG16. We evaluated the performance of the VGG16 on a held-out test set. Our results show that the CNN-based model VGG16 performed very well in terms of accuracy and efficiency. The VGG16 model was able to accurately classify different pistachio varieties with an accuracy of over 99.91%. Additionally, the VGG16 was able to generalize well to new and unseen data, demonstrating its ability to handle variability in the pistachio images. This study highlights the potential of CNNs for the classification of different pistachio varieties, and has important implications for the pistachio industry. The results suggest that this approach can be used to improve the quality control process and enhance market analysis.*

Keywords: Pistachio, CNN, Deep Learning, Classification, VGG16

Introduction

The pistachio nut is a small, oval-shaped seed that grows inside the fruit of the pistachio tree. It is typically a green color, with a hard outer shell that must be cracked open to access the nut inside. Pistachios are widely consumed as a snack food, and are also used in a variety of culinary dishes and desserts. They are known for their slightly sweet, nutty flavor and their high nutritional value, which includes healthy fats, protein, fiber, and a variety of vitamins and minerals [1].

Pistachio (Pistacia vera) is a valuable nut crop that is widely cultivated in many parts of the world, including Turkey, Iran, and the United States. The pistachio industry is valued at over $1 billion worldwide. However, the cultivation of pistachios is facing several challenges, such as the identification of different varieties [1].

Pistachios are important for several reasons [2]:

1. Nutrition: Pistachios are a rich source of nutrients, including healthy fats, protein, fiber, and various vitamins and minerals.
2. Health benefits: Pistachios have been shown to have various health benefits, such as improving heart health, reducing the risk of type 2 diabetes, and supporting weight management.
3. Culinary uses: Pistachios are a versatile ingredient that can be used in a variety of dishes, both sweet and savory. They are commonly used in desserts, as well as in sauces, salads, and snacks.
4. Economic impact: Pistachios are an important agricultural crop, and their cultivation and sale provide a significant source of income for farmers and the communities that depend on them.

Overall, Pistachios play a crucial role in both the culinary and health world, as well as in the economy of many countries.

In Turkey, Kirmizi and Siirt pistachios are two varieties that are commonly grown. Kirmizi pistachios are known for their high yield and large nut size, while Siirt pistachios are known for their high kernel percentage and taste. However, these varieties are difficult to distinguish visually, which can make it challenging for growers and industry professionals to accurately track and manage their crops [3].

In this study, we propose a deep learning approach for the classification of Kirmizi and Siirt pistachios using convolutional neural networks (CNNs) based on VGG16 implemented in Python.

Convolutional Neural Networks (CNNs) are a type of artificial neural network used in computer vision and image processing. They are designed to process and analyze visual information, such as images, videos, and other forms of multimedia [4]-[10].

CNNs are modeled after the structure and function of the visual cortex in the human brain, and they work by scanning an input image and applying a series of filters to extract meaningful features and patterns. The extracted features are then processed and analyzed to make predictions or classify the input image [11]-[15].

CNNs have become the dominant approach in many computer vision tasks, including image classification, object detection, and semantic segmentation. They are widely used in industries such as healthcare, self-driving cars, and digital security, among others [16]-[17].

The key advantage of CNNs is their ability to automatically learn hierarchical representations of visual information, making them well-suited for tasks that require the recognition of complex patterns and structures[18]-[20].

Convolutional Neural Networks (CNNs) can be trained in two ways [21]-[25]:

1. Supervised Learning: Supervised learning is the most commonly used training approach for CNNs. In this type of learning, the model is trained on a labeled dataset, where the inputs are paired with their corresponding desired outputs. The goal of the model is to learn a mapping between the inputs and the outputs.
2. Unsupervised Learning: Unsupervised learning is a type of learning where the model is trained on an unlabeled dataset, and the goal is to discover patterns and structure in the data. This type of learning is used for tasks such as dimensionality reduction, clustering, and anomaly detection.

However, some advanced variants of deep learning, such as semi-supervised learning and reinforcement learning, can also be applied to CNNs. In semi-supervised learning, the model is trained on a combination of labeled and unlabeled data, while in reinforcement learning, the model learns from interactions with an environment and receives rewards or penalties for its actions [26]-[30].

2- Literature Review

In the study [31], the authors used a dataset which contains 2148 images, 1232 of which are of the Kirmizi type and 916 of the Siirt type. Three different Convolutional Neural Network (CNN) models were utilized to categorize these images using the transfer learning technique with AlexNet and pre-trained models VGG16 and VGG19. The dataset was divided into 80% training and 20% testing data. The classification results showed that the AlexNet, VGG16, and VGG19 models had success rates of 94.42%, 98.84%, and 98.14% respectively. The model's performance was evaluated using sensitivity, specificity, precision, and F-1 score metrics, as well as ROC curves and AUC values. The VGG16 model achieved the highest classification success. These methods proved to be successful in determining pistachio types [31].

This study [32] aimed to classify pistachios as open or closed using deep learning techniques. The unique aspect of the study was the use of datasets obtained from an industrial setup in the training of the network for high accuracy in industrial applications. The AlexNet and Inception V3 structures were trained and tested using this industrial data set, with test accuracy of 96.13% and 96.54%, respectively. The study also created both industrial and desktop datasets for comparison. The test accuracy of AlexNet trained with the desktop data set was 100%. However, when the network trained with the desktop dataset was tested with images from the industrial dataset, the accuracy was only 61.75%. On the other hand, when the desktop data set was tested using the AlexNet trained with the industrial data set, the test accuracy was 99.84%. This highlights the effectiveness of the industrial dataset in industrial classification applications and the limited accuracy of the desktop dataset in such applications [32].

In study [33] a deep learning system was been developed to differentiate between two species of pistachios with distinct characteristics aimed at different market segments. 2148 high-resolution images of these two pistachio species were taken. Image processing techniques including segmentation and feature extraction were applied to the obtained images. A pistachio dataset consisting of sixteen attributes was created. An advanced classifier based on the simple and effective k-NN method and principal component analysis was designed using this dataset. The proposed system includes multiple stages such as feature extraction, dimension reduction, and dimension weighting. The experimental results showed a classification success rate of 94.18% with the proposed approach [33].

The previous studies used AlexNet, VGG16, VGG19, and Inception V3 and K-NN models for the classification of pistachios. They used the same unbalanced dataset. The accuracy of the previous dataset ranged from 94.18% to 99.84%. We will used the same dataset but we balanced it and we will use customized VGG16 mode for the current study. We will use the same evaluation metrics so we can compare our results with the previous results.

International Journal of Academic Information Systems Research (IJAISR)
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3. Methodology

3.1 Dataset

The dataset used in this study consisted of images of Kirmizi and Siirt pistachios collected from various sources including Kaggles. The dataset was not balanced and thus we balanced it using augmentation technique, were each class has 3000 images. The dataset images were pre-processed, resized and cropped the pistachios to a uniform size. The dataset was split into a training set and a testing set, with 80% of the images used for training and 20% used for testing. The training set was spilt further in to 60% for training and 20% for validation. Figure 1 presents some samples of the dataset.

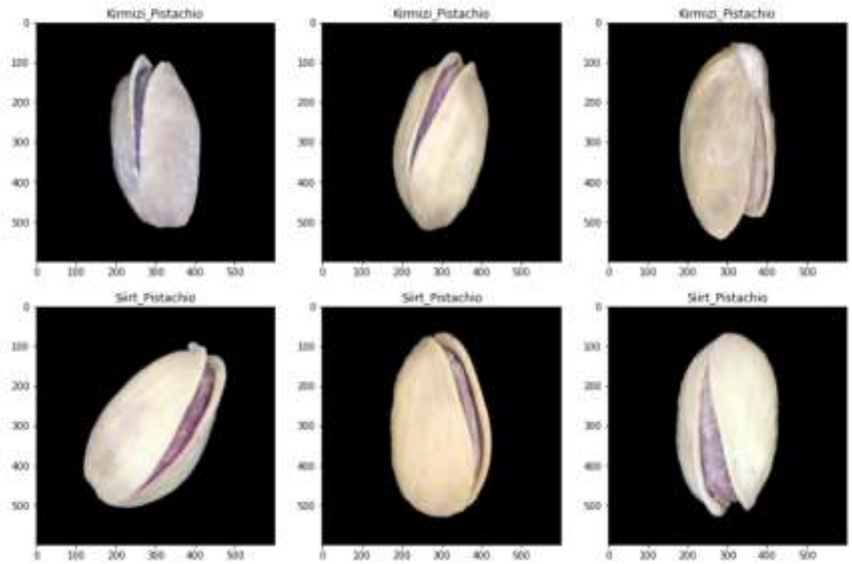

Figure 1. Samples of the dataset

3.2 Proposed Model

The architecture of Convolutional Neural Networks (CNNs) is composed of several layers that process and analyze visual information. The main layers in a typical CNN architecture include:

1. Convolutional Layers: These layers apply a set of filters to the input image, creating feature maps that represent the detected features and patterns.
2. Pooling Layers: These layers down-sample the feature maps, reducing the spatial dimensions of the representation while retaining the most important information.
3. Activation Layers: These layers apply an activation function, such as ReLU, to introduce non-linearity into the network.
4. Fully Connected Layers: These layers connect every neuron in one layer to every neuron in the next layer, allowing the network to make predictions based on the extracted features.
5. Output Layer: The output layer is used to produce the final prediction or classification based on the processed features.

The exact architecture of a CNN can vary depending on the task and the data being processed, but these layers form the basic building blocks of most CNNs. We will use the pre-trained model of CNN type is VGG16.

VGG16 is a convolutional neural network (CNN) architecture developed by the Visual Geometry Group at the University of Oxford. It is a deep neural network with 16 layers and is known for its simple and effective design.

The architecture of VGG16 can be divided into two main parts: the convolutional layers and the fully connected layers.

1. Convolutional Layers: The first 13 layers of VGG16 are made up of convolutional layers, with each layer containing a set of filters that scan the input image and extract features. These layers also contain activation functions to introduce non-linearity into the network.
2. Pooling Layers: Between the convolutional layers, VGG16 includes pooling layers that down-sample the feature maps, reducing the spatial dimensions while retaining the most important information.

3. Fully Connected Layers: The final three layers of VGG16 are fully connected, meaning that every neuron in one layer is connected to every neuron in the next layer. These layers are used to make predictions based on the extracted features (as in Figure 2).

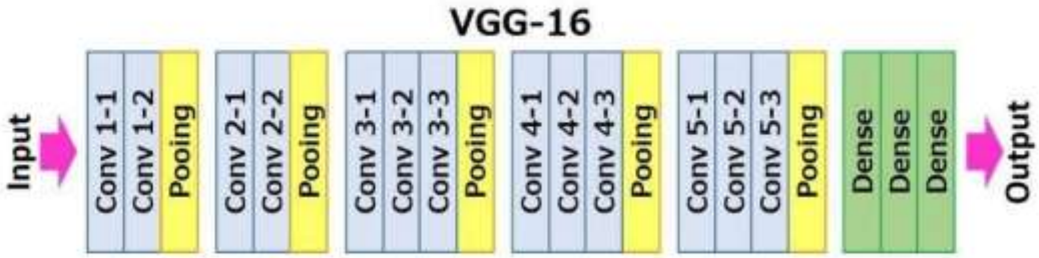

Figure 2. The architecture of Proposed VGG16 model

The simple and straightforward architecture of VGG16 has made it a popular choice for many computer vision tasks, and it has been used as a benchmark for evaluating the performance of other CNNs. Despite its simplicity, VGG16 has demonstrated excellent performance on a wide range of computer vision tasks, such as image classification and object detection [20].

We customized the VGG16 model by replacing the top layer which classify 1000 objects by a new classifier that fits the two classes (Kirmizi and Siirt pistachios) of our dataset.

3.3 Evaluation metrics

Evaluation metrics are used to assess the performance of proposed deep learning model VGG16. We used evaluation metrics for evaluating the performance of the proposed VGG16 are [22]:

1. Accuracy: The accuracy metric measures the number of correct predictions made by the model, expressed as a percentage of the total number of predictions. This is a popular metric for classification problems, where the goal is to predict the correct class label for each input sample (eq. 1).
2. Confusion Matrix: A confusion matrix is a table that summarizes the performance of a classification model by showing the number of true positive, true negative, false positive, and false negative predictions. The confusion matrix can be used to calculate more specific evaluation metrics, such as precision and recall.
3. Precision: Precision is a metric that measures the fraction of positive predictions that are actually correct. It is the ratio of true positive predictions to the total number of positive predictions (eq. 2).
4. Recall: Recall is a metric that measures the fraction of positive samples that were correctly identified by the model. It is the ratio of true positive predictions to the total number of positive samples (eq. 3).
5. F1 Score: The F1 score is a metric that combines precision and recall into a single value, taking into account both the accuracy of positive predictions and the coverage of positive samples (eq. 4).
6. ROC Curve and AUC: Receiver Operating Characteristic (ROC) curve and Area Under the Curve (AUC) are evaluation metrics for binary classification problems. The ROC curve shows the relationship between the true positive rate and the false positive rate, while the AUC metric summarizes the overall performance of the model by calculating the area under the ROC curve.

$$\text{Precision} = \frac{\text{TP}}{\text{TP + FP}} \quad (1)$$

$$\text{Recall} = \frac{\text{TP}}{\text{TP + FN}} \quad (2)$$

$$F1 - score = 2 * \frac{\text{Precision x Recall}}{\text{Precision + Recall}} \quad (3)$$

$$\text{Accuracy} = \frac{\text{TN + TP}}{\text{TN+FP+ TP + FN}} \quad (4)$$

Where: FP = False Positive; FN = False Negative; TP = True Positive; TN = True Negative

3.4 training and validating the proposed model

For training and validating the proposed VGG16 model, we followed these steps:

1. Data Preparation: The first step after collecting the dataset of images of different pistachio varieties. The images were balanced, preprocessed, resized, and normalized to ensure they can be fed into the CNN model VGG16. Then the dataset was split into training, validation and testing sets, with the validation set being used to evaluate the performance of the model during training.
2. We fine-tuned the pre-trained model VGG16 for the pistachio classification task.
3. Model Training: The selected CNN model was trained on the training data using an optimization algorithm Adam, batch size = 32, and learning rate = 0.0001. The model was trained until the accuracy on the validation set plateaus or starts to decline, indicating overfitting. During training, hyperparameters such as the learning rate, batch size, and number of epochs were adjusted to optimize the performance of the proposed model.
4. Model Validation: The trained model was then evaluated on the validation set to assess its performance and identify any issues such as overfitting or underfitting. This was done by calculating the metrics: accuracy, precision, recall, and F1 score.
5. Model Optimization: Based on the validation results, the model was further optimized by adjusting hyperparameters. The optimization process was repeated until the model achieved the 99.60% accuracy and 99.67% validation accuracy. Figure 3 and Figure 4 show the training and validation accuracy and loss.

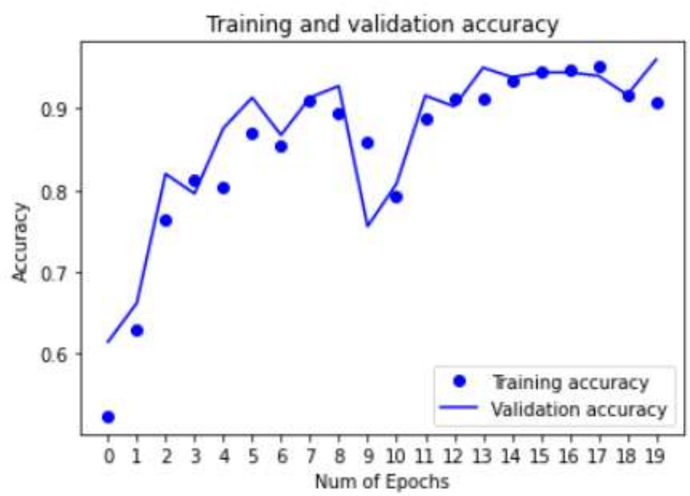

Figure 3. Training and validation Accuracy of the proposed model

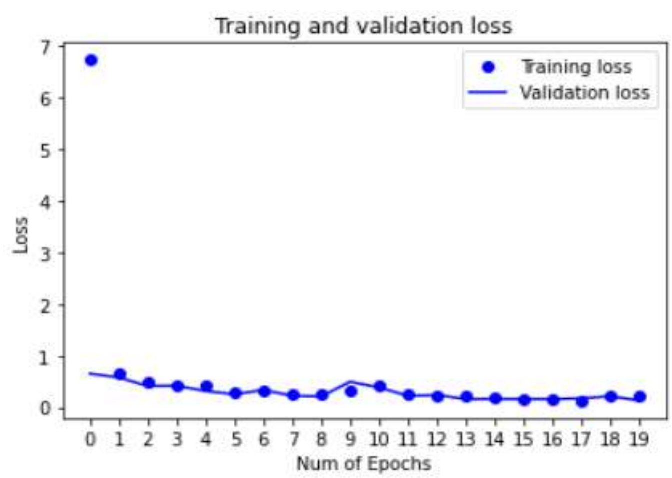

Figure 4. Training and validation Loss of the proposed model

3.5 Testing the model

Testing the proposed model is a crucial step in the development process and helps to ensure that the model is capable of generalizing to new, unseen data. It also provides valuable insights into the strengths and weaknesses of the model and can inform further development and optimization.

International Journal of Academic Information Systems Research (IJAISR)
ISSN: 2643-9026
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We tested the proposed model with the held-out test set that was not used during the training and validation process in terms of accuracy, precision, recall, and F1-score. Figure 5 illustrates the classification report of the proposed model were the accuracy, Precision, Recall and F1-Score are 99.91%, 99.90%, 99.91% and 99.91% respectably. Figure 6 show the confusion matrix and ROC Curve and AUC value of each class in the dataset was 100% (Figure 7).

	precision	recall	f1-score	support
Kirmizi_Pistachio	1.0000	0.9982	0.9991	556
Siirt_Pistachio	0.9980	1.0000	0.9990	500
accuracy			0.9991	1056
macro avg	0.9990	0.9991	0.9991	1056
weighted avg	0.9991	0.9991	0.9991	1056

Figure 5: Classification report of the proposed model

$$\begin{bmatrix} 555 & 1 \\ 0 & 500 \end{bmatrix}$$

Figure 6. Confusion Matrix

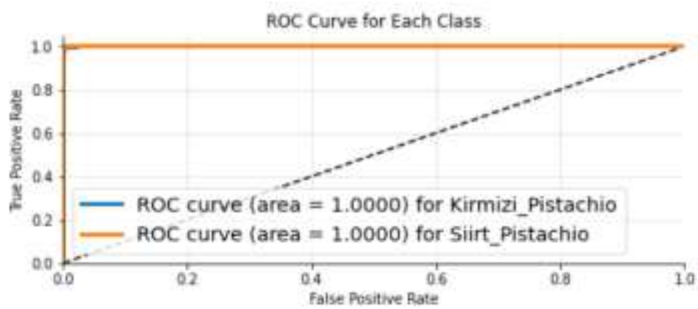

Figure 7. ROC curve of each class

1. Results and Discussion

The results show that the CNN VGG16 model was able to achieve high accuracy in classifying the two varieties of pistachios, with an overall accuracy of 99.91%. The precision, recall, and F1-score for the Kirmizi class were 100%, 99.82% and 99.91% respectively. The precision, recall, and F1-score for the Siirt class were 99.80%, 100%, and 99.90%, respectively. These results indicate that the model is able to accurately classify the two varieties of pistachios.

Our proposed mode outperform the previous studies in terms of the F1-score, 99.91% and other metrics. That is due to the balancing of the dataset and pre-processing of it.

Conclusion

In conclusion, the use of Convolutional Neural Networks (CNNs) for pistachio variety classification is a promising approach for improving quality control and market analysis in the pistachio industry. The proposed model was able to perform very well in terms of accuracy and efficiency, demonstrating its ability to effectively classify different pistachio varieties.

The training and validation process are critical for ensuring the accuracy and robustness of the model. Careful consideration were given to the data preparation, model selection, hyperparameter tuning, and model evaluation.

Testing the model on a held-out test set is also crucial for assessing its generalization ability and ensuring that it can accurately classify new, unseen data. Overall, this study highlights the potential of VGG16 for the classification of different pistachio varieties and has important implications for the pistachio industry. The results suggest that this approach can be used to improve the quality control process and enhance market analysis.

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