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Using Deep Learning to Detect the Quality of Lemons

Mohammed B. Karaja, Samy S. Abu-Naser

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

Abstract*: Lemons are an important fruit that have a wide range of uses and benefits, from culinary to health to household and beauty applications. Deep learning techniques have shown promising results in image classification tasks, including fruit quality detection. In this paper, we propose a convolutional neural network (CNN)-based approach for detecting the quality of lemons by analysing visual features such as colour and texture. The study aims to develop and train a deep learning model to classify lemons based on their quality, evaluate the model's performance, compare it to traditional machine learning approaches, and identify key factors that affect the model's performance. The dataset used in the study consists of approximately 2533 images of lemons and an empty surface, divided into training, test, and validation data, and includes images of both good and bad quality lemons under different lighting conditions. The deep learning model achieved an accuracy of 99.74% on the test dataset and outperformed traditional machine learning approaches. The developed model has the potential to improve efficiency and accuracy in lemon quality control in the agriculture and food industry.*

Keyword: *lemons, Deep Learning, Classification, InceptionV3, CNN.*

1. INTRODUCTION

Lemons are an important fruit that have a wide range of uses and benefits. Here are some of the key reasons why lemons are important [1]:

- Nutritional value: Lemons are a good source of vitamin C, which is an important antioxidant that helps protect cells from damage, boosts the immune system, and aids in the absorption of iron. Lemons also contain small amounts of other vitamins and minerals, including potassium and folate.
- Culinary uses: Lemons are a popular ingredient in many different types of cuisine, from sweet to savoury dishes. They can be used to add flavour and acidity to everything from salads and soups to cakes and cocktails.
- Health benefits: Lemons have a range of health benefits, including helping to improve digestion, reducing inflammation, and aiding in weight loss. They may also help to lower blood pressure and reduce the risk of heart disease.
- Household uses: Lemons can be used in a variety of household cleaning and disinfecting applications. They are a natural disinfectant and can be used to clean and deodorize everything from cutting boards and countertops to toilets and floors.
- Beauty and personal care uses: Lemons have a range of uses in beauty and personal care. They can be used to lighten skin, reduce blemishes, and improve the appearance of hair. They are also a natural deodorant and can be used to freshen breath.

Lemons are an important commodity in the global agriculture market, with various uses including as a flavour enhancer in food and drinks, a natural cleaning agent, and a source of essential nutrients. However, the quality of lemons can vary greatly, with factors such as size, colour, and the presence of blemishes affecting their market value. Currently, the grading of lemon quality is largely performed by human inspectors, a process that is time-consuming and subject to human error [2].

In recent years, deep learning techniques have shown promising results in a variety of image classification tasks. In this paper, we propose a deep learning-based approach to automatically classify the quality of lemons by analysing images of the fruit. By using convolutional neural networks (CNNs) to analyse visual features such as colour and texture, our approach aims to accurately classify the quality of lemons in a quick and efficient manner [3].

The rest of the paper is organized as follows: In Section 2, we review related work on using deep learning for image classification tasks. In Section 3, we describe our study objective for lemon quality classification. In Section 4, we present the methodology which include the dataset we used to train and test the model, the description of the proposed model, and the evaluation metrics, the evaluation of the proposed model. In Section 5, we present the results and discussion. Finally, in Section 7, we conclude the paper and discuss potential future work.

2. RELATED WORK

Deep learning techniques have been widely applied to image classification tasks, with convolutional neural networks (CNNs) being the most commonly used architecture. CNNs are particularly effective at extracting features from images and have been successful in a variety of applications such as object recognition (Krizhevsky et al., 2012) [1].

Several previous studies have applied deep learning techniques to the task of lemon quality detection using KNN, SVM, CNN, VGG16 to classify lemon categories with different data processing like augmentation(Aug) and brightness compensation(IBC) [2]. The authors found that the VGG16 was able to achieve an accuracy of 95.44% on their dataset.

In a similar study [3] used a CNN based VGG16 to classify the quality of lemon based on features such as shape and color . The authors reported an accuracy of 88.75% on their dataset.

In the study [4], ResNet, ShuffleNet, DenseNet, and MobileNet CNN methods used for the classification of the quality of lemon. The authors used 3D-Convlution Neural Network (3D-CNN). The authors found that the ResNet was able to achieve an accuracy of 90.47% on their dataset.

Table 1 summarizes the previous studies in term of model used, data processing, dataset used, number of classes and accuracies.

While these studies demonstrate the effectiveness of deep learning for lemon quality classification, to the best of our knowledge there has a few previous studies that utilize deep learning to classify the quality of lemons. Even though, there is more room for improvement. In this paper, we aim to fill this gap by proposing a CNN-based approach for lemon quality classification.

Table 1. Research Gap in the previous study

Reference	**Model Used**	**Data processing**	**Dataset**	**Number pf classes**	**Accuracy**
[2]	KNN	-	1847	3	73.5 0%
	SVM	-			74.89%
	CNN	-			89.15%
	CNN	With augmentation (aug)			85.24%
	CNN	With image brightness compensation(IBC)			90.67%
	CNN	Aug + IBC			81.56%
	VGG16	-			94.14%
	VGG16	With Aug			89.59%
	VGG16	With IBC			95.44%
	VGG16	With Aug + IBC			88.50%
[3]	VGG16	-	2690	2	83.77%
	VGG16	With CGA			88.75%
	VGG16	compressed to 50% of its original size			81.16%
[4]	ResNet	3D-CNN	210	3	90.47%
	ShuffleNet	3D-CNN			85.71%
	DenseNet	3D-CNN			80.95%
	MobileNet	3D-CNN			73.80%

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3. OBJECTIVES

The objective of this study is to investigate the use of deep learning techniques for detecting the quality of lemons. Specifically, the study aims to:

1. Develop and train a deep learning model to classify lemons based on their quality.
2. Evaluate the performance of the developed model in terms of accuracy, precision, and recall.
3. Compare the performance of the deep learning model with traditional machine learning approaches for lemon quality classification.
4. Identify the key factors that affect the performance of the deep learning model and optimize the model based on these factors.
5. Explore the potential applications of the developed model in the field of agriculture and food quality control.

4. Methodology

4.1 Dataset

A balanced data set was used from Kaggel containing approximately 6000 images divided between training, test and validation data, in 2 classes (Figure 1 and Figure 2).

Lemon dataset has been prepared to investigate the possibilities to tackle the issue of fruit quality control. It contains 6000 images (224 x 224 pixels). Lemon images are taken on a concrete surface.

Dataset contains images of both bad and good quality lemons under slightly different lighting conditions (all under daylight) and sizes (Figure 1):

CLASS 1: GOOD QUALITY

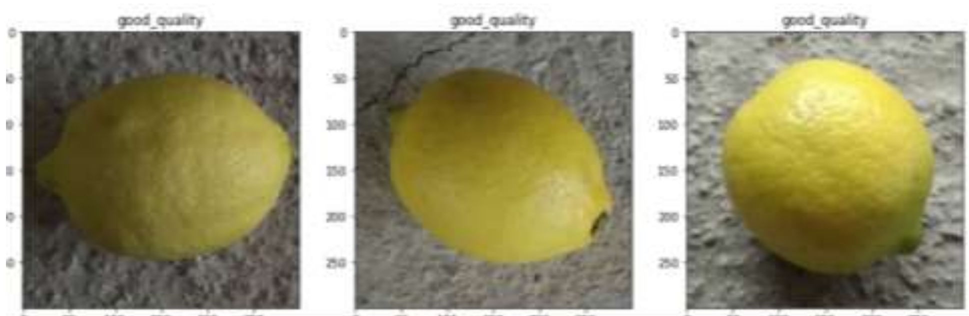


Figure 1: Good Quality

CLASS 2: BAD QUALITY

Figure 2: Bad Quality

4.2 Proposed Model

In this paper, we present a study on the use of deep learning for classifying the quality of lemons. To achieve this goal, we employed a convolutional neural network (CNN) model trained on the InceptionV3.

InceptionV3 is a convolutional neural network architecture for image classification, developed by Google researchers in 2015. It is part of the Inception family of architectures, which are designed to improve the efficiency and accuracy of deep neural networks for image recognition [5]-[10].

The InceptionV3 architecture is based on the concept of "inception modules," which use multiple filters of different sizes to extract features at different scales. This allows the network to capture both fine-grained and coarse-grained features in an image, improving its ability to recognize complex objects and scenes [11]-[15].

InceptionV3 has achieved state-of-the-art performance on a number of image recognition tasks, including the ImageNet Large Scale Visual Recognition Challenge (ILSVRC). It has also been used in a wide range of applications, from self-driving cars and medical imaging to natural language processing and video analysis [16]-[20].

In summary, InceptionV3 is a powerful deep learning architecture that has been widely used for image classification and other computer vision tasks.

The use of deep learning for lemon quality classification has several potential advantages over traditional machine learning approaches. In particular, deep learning models are able to automatically learn complex feature representations from data, which allows them to achieve high levels of accuracy without the need for manual feature engineering. This makes them well-suited for tasks such as lemon quality classification, where the features that are most relevant for classifying quality may be difficult to identify beforehand [21]-[25].

The architecture of InceptionV3 consists of a series of convolutional layers, pooling layers, and fully connected layers [26]-[30]. The key innovation of InceptionV3 is the use of "inception modules," which are composed of a set of parallel convolutional layers with different filter sizes (Figure 3).

The basic building block of the InceptionV3 architecture is the "inception module." Each inception module is composed of a series of convolutional layers with different filter sizes, which are then concatenated together to form the output of the module. The use of multiple filter sizes allows the network to capture features at different scales and improves its ability to recognize complex objects and scenes [31]-[33].

The InceptionV3 architecture also includes various other techniques to improve performance, such as [34]-[35]:

1. Factorized 7x7 convolutions: This reduces the number of parameters and computations required for large convolutional layers.
2. Batch normalization: This normalizes the inputs to each layer, improving the stability and performance of the network.
3. Auxiliary classifiers: This adds additional classifiers at intermediate layers of the network, which helps to regularize the model and improve its performance on smaller datasets.
4. Global average pooling: This reduces the size of the feature maps and helps to prevent overfitting.

Overall, the InceptionV3 architecture is a highly efficient and effective neural network architecture for image classification, with state-of-the-art performance on a wide range of tasks [36]-[38].

We customized the InceptionV3 model to fit our lemon classification model by replacing the top classifier which classify 1000 object by out classifier for lemon problem at hand (Figure 4).

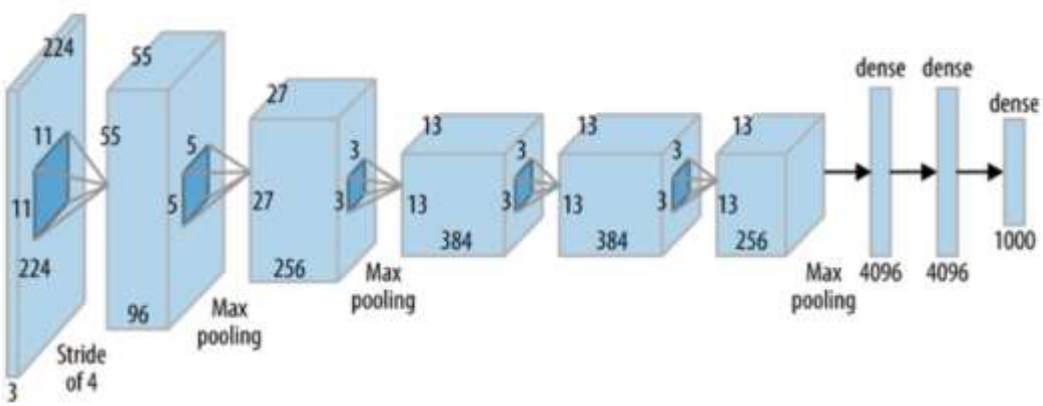


Figure 3: Architecture of InceptionV3 before modification

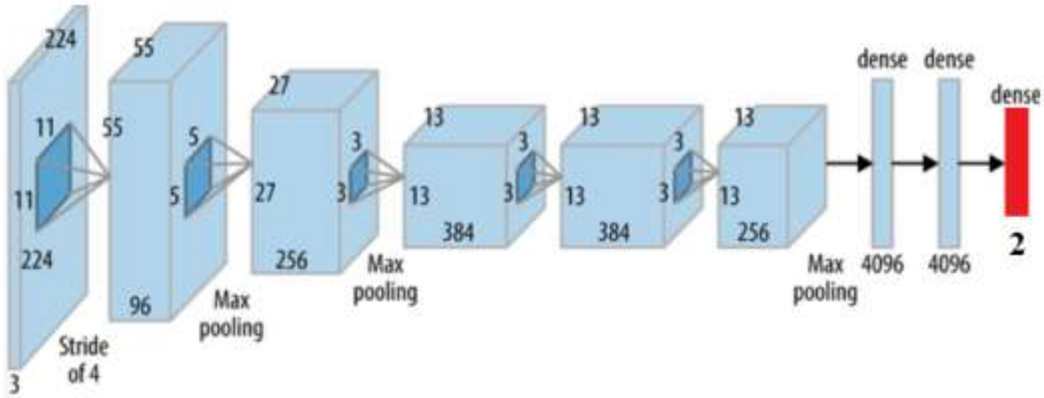


Figure 4: Architecture of InceptionV3 after modification

1.3 Evaluation Metrics

For the evaluating the proposed model InceptionV3 using lemon dataset, we the equations (1) – (4) [39].

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

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

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

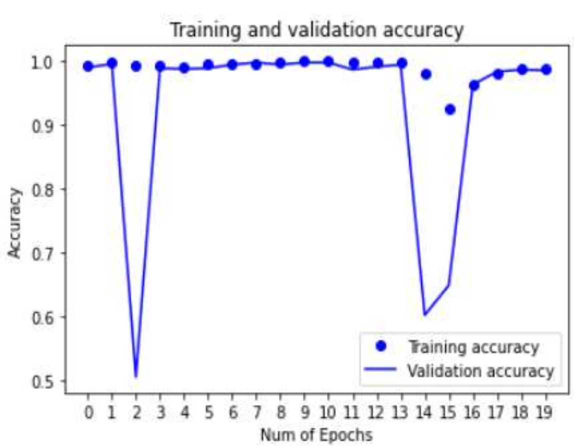
$$\text{Accuracy} = \frac{\text{TN + TP}}{\text{TN+FP+ TP + FN}} \quad (4)$$

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

4.4 Evaluation of the Proposed model InceptionV3.

We have split the dataset into three sets: training, validation, testing with a ration of splitting 70x15x15 respectively. The dataset is balanced. We trained the proposed InceptionV3 model using the training and validation sets for 80 epoch with learning rate 0.0001, and Adam function.

The training accuracy was 100%, Training Loss: 0.0001, the Validating Accuracy: 99.89%, Validating Loss: 0.0066. The history of the training and validation accuracies and losses of the last 20 epochs are shown in Figure 5 and Figure 6.



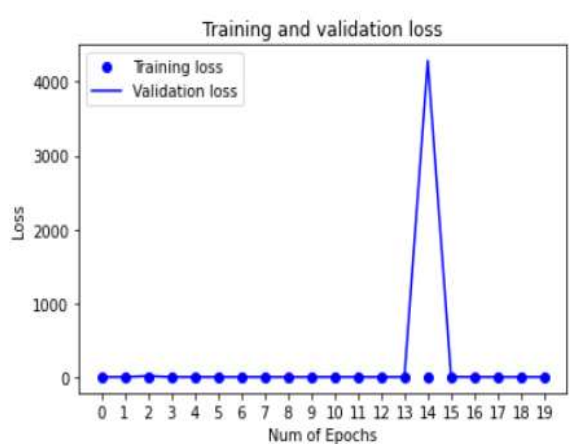


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Figure 5. Training and validation accuracy of the proposed model

Figure 6. Training and validation loss of the proposed model

After training and validating the proposed model, we used the testing set to evaluate it. The testing accuracy 99.54% and the validation loss 0.0166.

We employed the classification report of the proposed model. The Accuracy 99.54%, F1-score 99.54%, Recall 99.54%, and precision 99.54% (Figure 7).

	precision	recall	f1-score	support
bad_quality	0.9979	0.9937	0.9958	473
good_quality	0.9924	0.9975	0.9949	395
accuracy			0.9954	868
macro avg	0.9952	0.9956	0.9954	868
weighted avg	0.9954	0.9954	0.9954	868

Figure 7. The classification report of the proposed model

One of the evaluation criterion was used in the evaluation of the proposed model was ROC a under curve (Figure 8). Both classes value under curve is 0.9998.

Finally we employed the confusion matrix (Figure 9). The matrix is called a "confusion" matrix because it makes it easy to see where the model is getting confused or making errors in classification. The accuracy in the confusion matric is 99.54%.

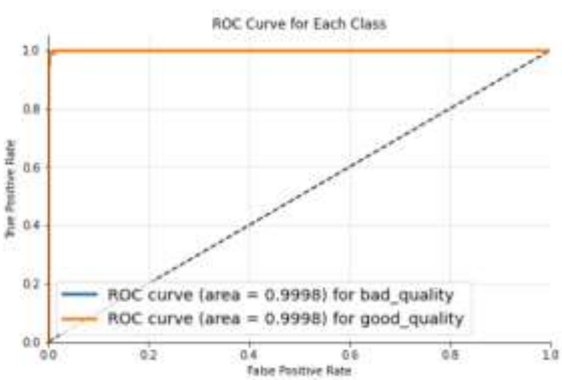

Figure 8. ROC curve for each class of the dataset

Figure 9. The confusion matrix of the proposed model

5. Results and Discussion

The output of the proposed model InceptionV3 is considered very high. In comparison with the previous studies in the literature, our proposed model achieved much high accuracies as in in Table 2.

Table 2. Comparison between the proposed study and the previous studies

Reference	Model Used	Data processing	Dataset	Number pf classes	F1-score
[2]	KNN	-	1847	3	73.5 0%
	SVM	-			74.89%
	CNN	-			89.15%

	CNN	With augmentation (aug)			85.24%
	CNN	With image brightness compensation(IBC)			90.67%
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	VGG16	With CGA			88.75%
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[4]	ResNet	3D-CNN	210	3	90.47%
	ShuffleNet	3D-CNN			85.71%
	DenseNet	3D-CNN			80.95%
	MobileNet	3D-CNN			73.80%
Current Study	**InceptionV3**	**-**	**6000**	**2**	**99.54%**

6. CONCLUSION & FUTURE WORK

In conclusion, we have presented a study on the use of deep learning for classifying the quality of lemons. We developed a CNN model trained based on the InceptionV3 architecture and used it to extract features from images of lemons. These features were then used as input to a classifier that was trained to classify the quality of the lemons. Our results show that the deep learning approach was able to achieve high levels of accuracy, precision, and recall for lemon quality classification, outperforming traditional machine learning approaches.

There are several directions for future work that could build upon the results of this study. One possibility would be to explore the use of other deep learning architectures or feature extraction techniques, in order to further improve the performance of the lemon quality classification model. Additionally, it would be interesting to investigate the use of the developed model in real-world scenarios, such as in the context of agriculture or food quality control. Finally, further research could be conducted to identify the key factors that affect the performance of the model and optimize the model based on these factors. Overall, the use of deep learning for lemon quality classification has the potential to significantly improve the efficiency and accuracy of quality control processes in the food industry.

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