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APPLICATION OF DEEP CONVOLUTIONAL NEURAL NETWORKS FOR MANGOSTEEN RIPENESS CLASSIFICATION

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Abstract. *This research investigates Deep Convolutional Neural Networks (Deep CNNs) for classifying the ripeness of mangosteen according to market segments, which can be divided into four groups: export market, domestic market, local market, and ungraded mangosteens. This research is separated into two steps. First, we used the mangosteen dataset and created a model with four architecture models. Second, we selected the model from the first step and added the modification layer. From the experiment, we found that the CNN method using different architecture models provided different accuracy percentages as follows: AlexNet = 75.00%, VGG16 = 77.50%, Inception-v3 = 78.00%, and ResNet50 = 79.00%. We observed that three models overfitted the mangosteen dataset, namely, AlexNet, VGG16, and Inception-v3. Therefore, we focused on the ResNet50 model's accuracy curve, which was not overfitting. We noticed that ResNet50 had a high validation accuracy and was appropriate with the dataset. Hence, we expect that ResNet50 is suitable for classifying mangosteen images and selected it for further improvement to create an efficient model for mangosteen ripeness classification.*
Keywords: Deep learning, Convolutional neural networks, Image classification, Mangosteen ripeness

1. **Introduction.** Thailand is home to a wide variety of tropical fruits unique in their taste, especially the mangosteen whose scientific name is Garcinia mangostana L., a unique fruit with a beautiful shape and good taste; its nickname is "Queen of Fruits" [1,2]. Its meat is soft and juicy and has a sweet and sour taste inside its dark-purple outer shell. It is rich in bioactive substances, including anthocyanins, xanthones, and oligomeric proanthocyanins [3,4], all of which are active ingredients that improve health and have important pharmacological properties. For example, mangosteen's peel and seed contain xanthones, which help build immunity and antioxidants [5]. Mangosteen pulp is also high in fiber and helps with excretion. It also has vitamins and high minerals. Therefore, mangosteen is a popular fruit to eat fresh. It has also been processed into various products as food and medical supplies [6].

Currently, Thailand is one of the world's top producers and exporters of mangosteen to many countries [6]. Therefore, mangosteen is considered a fruit with a high potential for export in Thailand at present as well as in the future. Mangosteen has a tendency to become an increasingly important fruit. As new markets are now opened in many countries, the business of exporting mangosteen to be sold abroad has been expanding and causing the demand for mangosteen to rise, resulting in high prices for good quality products of mangosteen [7] and in the further expansion of planting areas. Mangosteen is a fruit that has rapid postharvest changes, resulting in short shelf life [8]. The estimation

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of ripening periods during harvest is important. If the fruit is harvested too early before ripeness, then it cannot ripen completely. However, if the mangosteen is harvested too much, then it cannot be exported due to constraints on export times [9]. Normally, in the process of producing products for export, the mangosteen fruit is separated according to its color and size [10] based on the market demand. This process requires much labor. Given that mangosteens are harvested in the morning for sale, they must be graded first before being sent and sold to various markets according to market demand. The grading process requires experts with experience in mangosteen grading. The peel color is purple-black during its ripening period, and it is the primary criterion used in determining the maturity index of mangosteen [11], starting with a red spot [10]. Considering that the mangosteen harvest for distribution can be different, the fruit color is considered the main criterion used in the determination of the health and grading of mangosteen. The fruit is usually harvested at different stages according to its color starting from yellow and greenish with scattered pink spots to deep purple. After harvesting, the purple color continues to develop rapidly.

For export markets, mangosteens must at least be in the bloodline (peel surface with red dots or spots), and they will develop into ripened fruits in an acceptable condition when they reach the destination. Given that foreign sales can be at a high price, mangosteens can be selected for export. As for domestic markets, mangosteens with red and purple peels are suitable for consumers' needs. For local markets (for consumption in the provinces), mangosteens in dark purple or whole black are mature products and suitable for they are ready to eat. Ungraded mangosteens with yellow-green or green peels, which indicate unripe fruits or are not yet ready to harvest, are also for local markets.

Therefore, the selection of mangosteen by visual estimation using labor in the maturing stage is inaccurate and inconsistent, especially for long periods and large-scale harvesting [2]. Morning estimates may differ from afternoon results. Laborers who sort and select mangosteen fruits, especially skilled workers, are few. In some periods, fruit merchants, who temporarily have fruit-picking points and packaging plants in the area where mangosteens are purchased, must delay or stop the purchase. The researcher realizes the importance of this problem.

In this study, the application of the deep learning technique is presented using Convolutional Neural Networks (CNNs) and is compared with four different structures (i.e., AlexNet, VGG16, Inception-v3, and ResNet50) for optimal mangosteen classification. The study considers the standards and market needs by identifying the types of mangosteen in different types of market delivery, which is classified into four groups of mangosteen: export market, domestic market, local market, and ungraded mangosteens. The main objectives of the study are to sort agricultural products (mangosteens) in the mangosteen distribution by applying technology using computer vision analysis tools for the proper sorting of mangosteen clusters in launching to different market segments to meet market needs and to help increase the efficiency of management and sorting of mangosteen production of workers.

2. **Literature Review.** Fruit ripening refers to the stage during which the fruit is fully grown. Many physiological changes and biochemical reactions occur in this stage. The maturity index is an important factor in determining the shelf life and ripening quality of the fruit to achieve market flexibility and guarantee the quality that is acceptable to buyers [12]. The maturity index of fruit has many values, such as color, flavor, sweetness, and texture. For example, a mangosteen can rapidly change into red color on the tree and after harvest. Its color changes from green to purple-black after harvest, which can be used as a quality guideline for growers, sellers, and consumers for the selection of mangosteen [9]. A fully mature mangosteen is identified by the formation of red streaks

on the outer surface of the peel. The number of strands known as "bloodlines" increases as the fruit matures [13].

Human eye's ability to differentiate colors is based on different retina cell's varying sensitivities to light of different wavelengths. Thus, the perception of color, which is a parameter in measuring the degree of ripeness of the fruit, is an important factor that helps determine the shelf life and quality of fruit ripening. Therefore, considering the appropriate maturity stage in the separation process is necessary. Doing so makes the fruit suitable for transport or export that requires a long time, and it can increase the value of the mangosteen to meet the quality requirements of the consumer market.

The researcher has an idea of how to use the technology method in consideration of mangosteen screening. Based on previous related literature, various image processing technologies can be used to overcome manual labor for any work during harvest and postharvest. Some researchers offer quality assessments and grading of fruits and vegetables. For example, the evaluation of plum fruit maturity [12] uses applied image processing techniques to record plum images in different growth stages. The external quality characteristics of plum, such as color, texture, and size, are then analyzed. The developed system determines the maturity level precisely. A past research identified banana fruit maturity stages to identify four banana growth stages [14]. Other previous research was based on the detection and classification of mangosteen. For example, [15] identified mangosteen using a fuzzy neural network to classify patterns for two different classes and used membership levels with the output of neurons as a learning target. The color components from image processing that influence the maturity of mangosteen were used as input parameters. Riyadi et al. [16] developed an image processing method to optimize the estimation of the mangosteen maturity stage by combining RGB color features and implementing support vector machine. The result showed that the accuracy of estimation can be increased. Mohtar et al. [17] investigated a CNN architecture by using the Inception-v3 model. They revealed that using CNN can classify the ripening stages of mangosteen, with an accuracy of 89.7%. CNN can extract the features of the mangosteen and use the features to classify images according to the maturity index effectively. Therefore, deep learning is an interesting technique, especially when applied to mangosteen classification.

Deep learning today is one of the most advanced technologies used in image analysis in agriculture from planting to harvest. It is precise and famous and can be applied to many types of research, such as classification [18] and clustering. CNN, one of the deep network architectures, is mostly used for image classification [19], object detection, and segmentation. Previous studies on detection and classification based on deep learning were dedicated to applying deep learning to fruit detection industrially, such as Halstead et al. [20], who presented robotic vision systems that can accurately estimate the amount and ripeness of sweet peppers using Faster RCNN. Liu et al. investigated cucumber detection [21] by using ResNet as the backbone of Mask RCNN. Another study proposed to use a framework for fruit classification by using deep learning [22] with six CNN layers and a fine-tuned VGG architecture. Ge et al. [23] used a segmentation method and improved the localization algorithm for strawberry harvesting in farmland. They used a deep CNN to classify strawberries into three classes according to their different ripeness levels. Moreover, Zeng et al. identified bruised and uncracked pears by using a deep learning algorithm based on a small thermal image dataset [24]. Pattansarn and Sriwiboon developed a model for examining and characterizing the quality of Chok-Anan mango [25] with four quality levels. They used deep learning algorithms by CNNs for image processing. Various architectures using CNNs have been proposed. Considering that the CNN network topology can add an infinite number of convolution layers, such as AlexNet [26], VGG16 [27], ResNet50 [28], and Inception-v3 [29], this study can create a model using a pre-trained model: AlexNet, VGG16, Inception-v3, and ResNet50 by first removing the last layer of each pre-trained model and adding a new layer (our modification layers), and then training each model. Subsequently, they are compared to find the best models for establishing the most suitable and effective model to classify the ripeness of mangosteen.

3. **Methodology.** This research presents a model used to classify mangosteen images by a deep learning technology – CNN. This section explains the process overview of mangosteen classification for the market segments by a deep CNN, as illustrated in Figure 1. Three main processes are involved, namely, image preparation, pre-trained model modification and training, and model tuning.

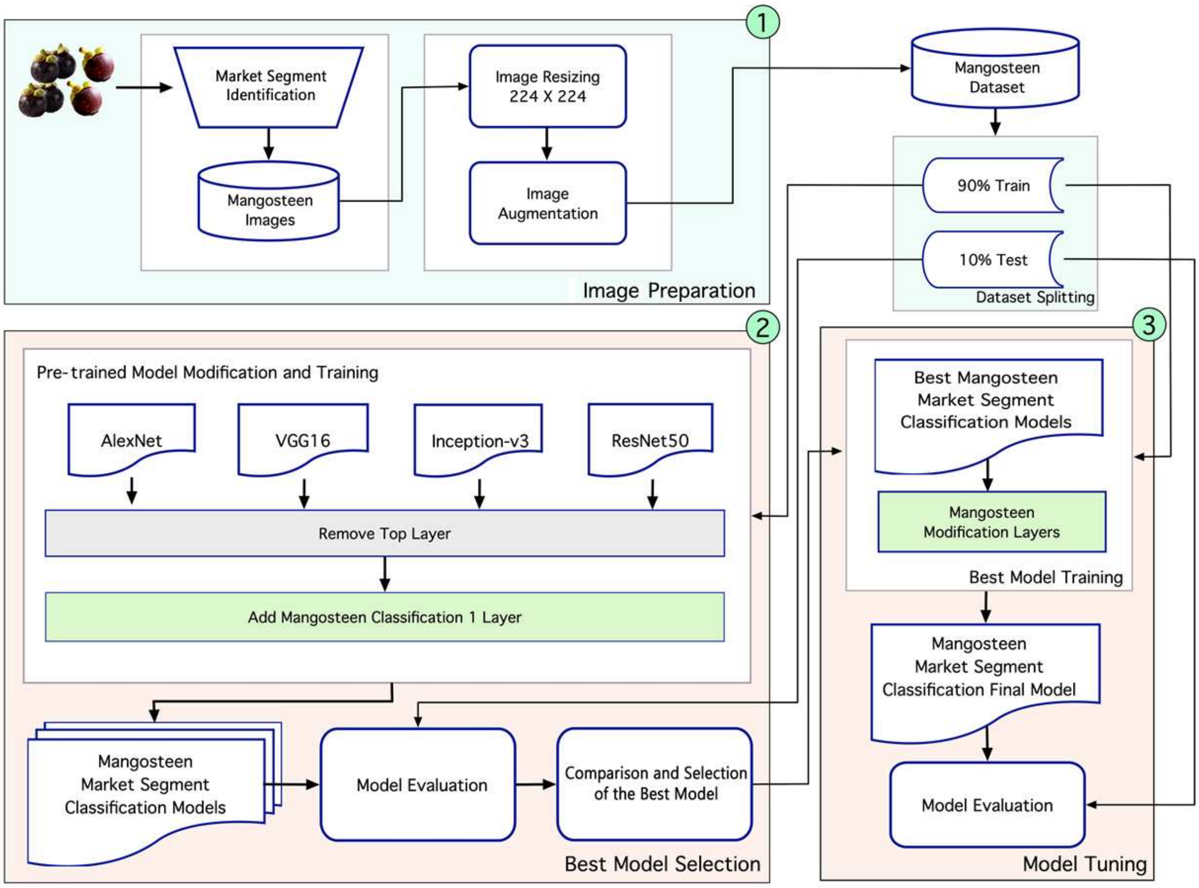


FIGURE 1. Overview of the methodology

3.1. **Data preparation.** In the first process, mangosteen images were collected from traders in Nakhon Si Thammarat Province, Thailand. A total of 528 images of collected mangosteens from three traders were used. One trader is a large trader that exports mangosteens to China. This trader has a mechanic to select a size before classifying a group. The two other traders are small and called local traders. They buy mangosteens from agriculturists and sell them to large traders who are experts in mangosteen grading. Laborers selected one group of mangosteens for classifying and grading the fruit. We took a picture after laborers classified the mangosteens. The mangosteen images were categorized into four different market classes: export market, domestic market, local market, and ungraded mangosteens by setting a white background. However, when we took a picture for export, we found a red spot on the mangosteen skin because the fruit only has a red dot on the green peel, which means it is nearly ripe. This mangosteen can provide categories to the export group. After taking pictures and selecting the best one, we used the standard data augmentation method. Each image was set to a size of 224×224 pixels. The image dataset was processed with random rotation (360, nearest),

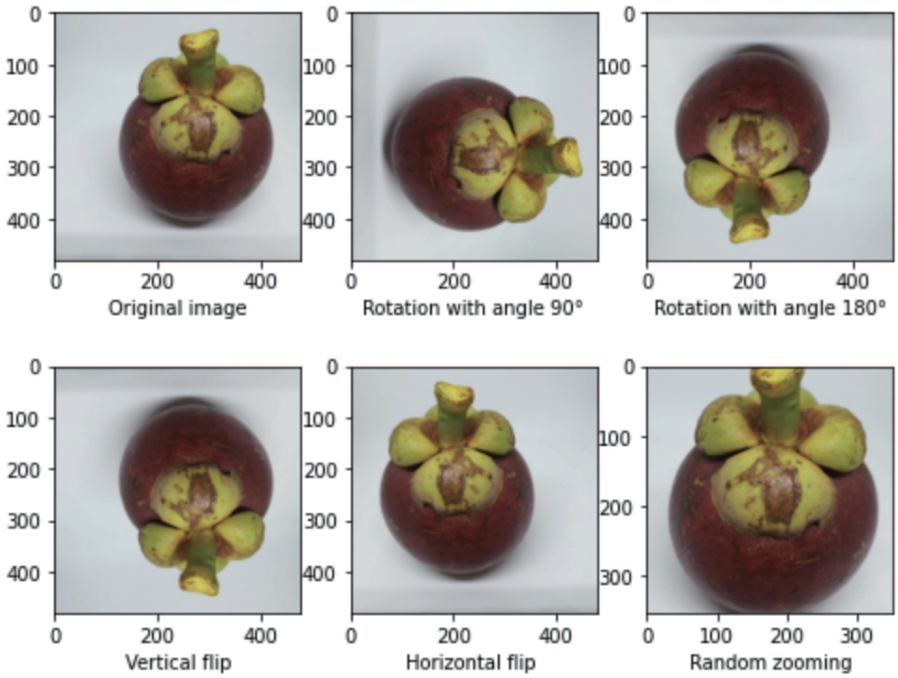


Figure 2. Examples of mangosteen images from data augmentation

zoom (0.1), horizontal shifting and vertical shifting (0.05), and horizontal flip and vertical flip (0.05). The dataset of the total number in this study consists of 880 mangosteen images. The mangosteen images are shown in Figure 2.

3.2. **Pre-trained model modification and training.** In the second process, we used the pictures that were augmented for input data for model training. This part used well-known, four pre-trained CNN models for establishing the most suitable and effective model for classifying mangosteens, namely, AlexNet, VGGNet, Inception-v3, and ResNet50. We took a network trained on an ImageNet domain for source task and adapted our dataset for mangosteen domain. Each model trained in 300 epochs, 32 batch sizes, and 0.00001 learning rate. Then, we evaluated AlexNet, VGGNet, Inception-v3, and ResNet50. Subsequently, we selected the most accurate model for classifying mangosteen images into suitable market segments.

3.3. **Model tuning.** In the third process, the classification layer of the best model was slightly modified. We added three batch normalizations, two dropouts, and another layer in detail, which are displayed in Figure 3. On the top layer, we added Mangosteen Classification Layer 1 as an input to the selected best model to adjust the network structure for an improved performance. In this part, we configured the model trained in 300 epochs, 32 batch sizes, and 0.00001 learning rate, same as the previous stage.

4. **Experimental Results.** We chose the NVIDIA Graphics Processing Unit (GPU) as a tool for testing the deep learning to enable processing on the GPU in conjunction with an 8 GB NVIDIA GeForce RTX 2080Ti GPU. This work performed in Python using Keras and TensorFlow libraries for training the mangosteen dataset by CNNs in four different architectures: AlexNet, VGG16, Inception-v3, and ResNet50 in the first step. Figure 4 presents the experimental results showing the learning capabilities of the trained models in terms of validation accuracy and validation loss. The values of each model were as follows: AlexNet 75.00% = 0.5947, VGG16 77.50% = 0.5239, Inception-v3 78.00% = 0.6083, and ResNet50 79.00% = 0.7123. Thus, we concluded that three models overfitted the mangosteen dataset: AlexNet, VGG16, and Inception-v3. We then focused on the ResNet50 model's accuracy curve, which was not overfitting. Moreover, ResNet50 had

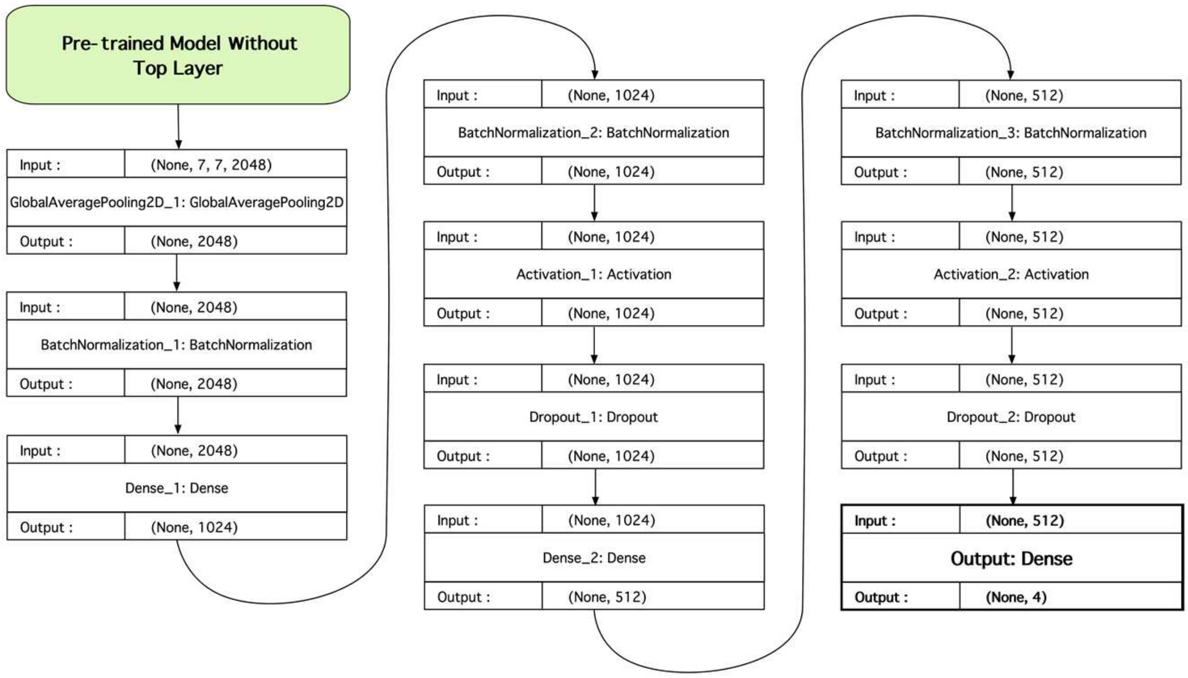


FIGURE 3. Details of the pre-trained modified classification model

a high validation accuracy and was appropriate with the dataset. Hence, we expected that ResNet50 is suitable for classifying mangosteen images and selected it for further improvement to create an efficient model for mangosteen ripeness classification.

As ResNet50 model had been selected previously, we removed the top layer and added the classification layer of ResNet50 in the second step, as illustrated in Figure 3. The result from the experiment indicated the enhancement of the pre-trained model and the modification based on the ResNet50 model.

The accuracy percentage achieved by the improved model was 85.00%, whereas the accuracy of ResNet50 was 79.00%. Thus, the improved model has a better accuracy than ResNet50. Figure 5 illustrates the validation accuracy and validation loss during the model training of the modified ResNet50 architecture. As a result, the mangosteen dataset was appropriate for the modified model because it was not overfitting.

From Figure 6, the confusion matrix points out that the performance of the classification model of the domestic class had the least accuracy among the four classes. The classification in the export class was incorrect due to the similarity of the mangosteen peel's color. Nevertheless, the classifications in the export and ungraded classes were correct because the mangosteens in the export class must have a bloodline (the peel surface with red dots or spots) on their peel, and those in the ungraded class had no red dots on their peel.

5. **Conclusions.** This research presents the application of deep learning techniques by using CNNs and comparing four different architectures (AlexNet, VGG16, Inception-v3, and ResNet50) to achieve the optimal mangosteen classification and to properly classify mangosteens into suitable market segments. The study also contributes to the accomplishments of fulfilling market demands and increasing the efficiency of mangosteen production management and grading of workers. The methodology is to apply pre-trained learning CNN models for classifying mangosteen images into different market segments. Various studies on CNN models are presented for comparison to seek the optimal model. The research results indicate that the deep learning model is suitable to classify mangosteen

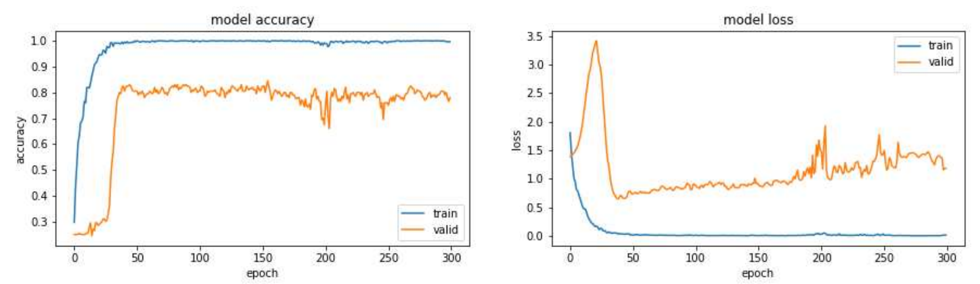
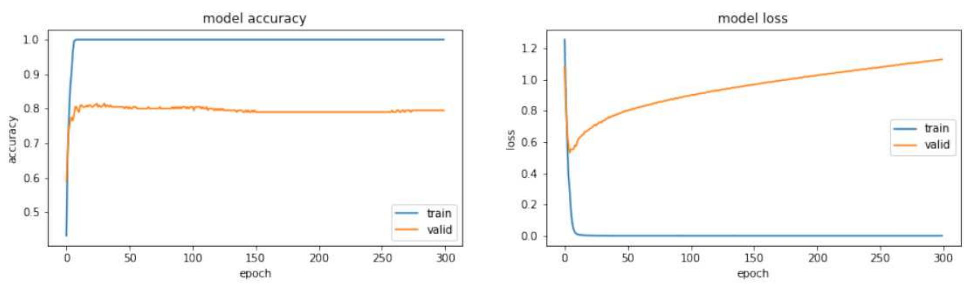
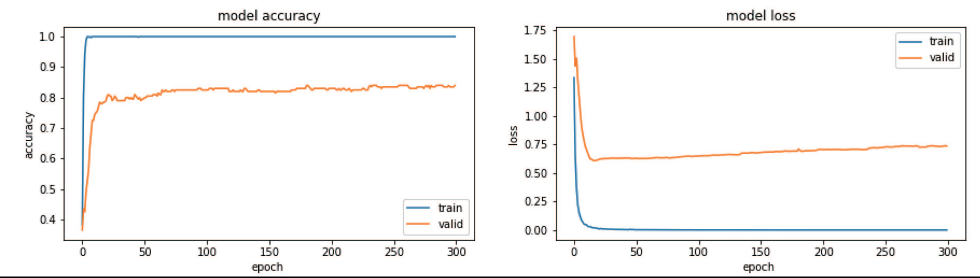
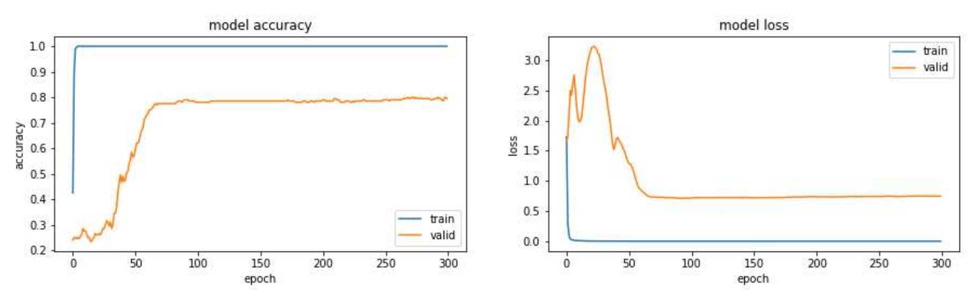
AlexNet	
VGG16	
Inception-v3	
ResNet50	

Figure 4. Training and validation accuracy of various CNN architectures

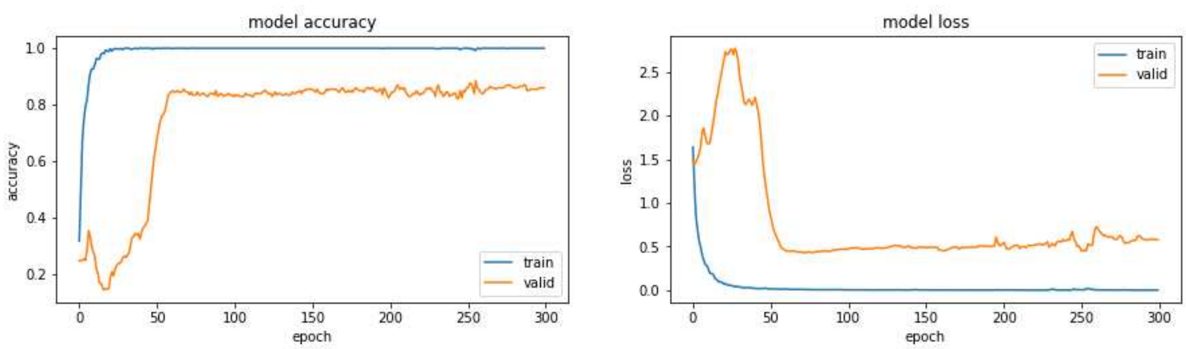


Figure 5. Training and validation accuracy of the modified ResNet50 architecture

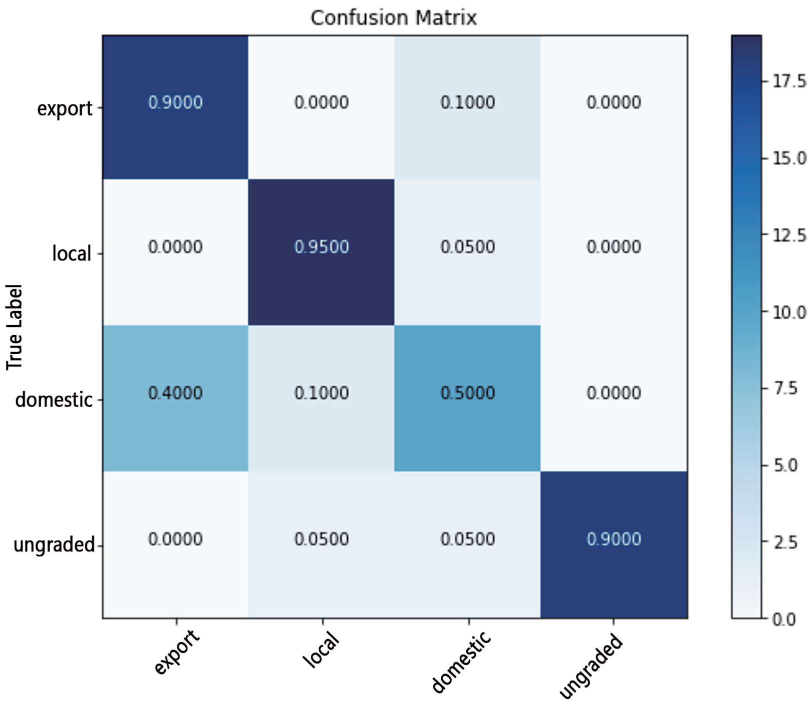


FIGURE 6. Confusion matrix of the modified ResNet50 architecture

for grading into appropriate market segments. In the first step, we used four CNN models: AlexNet, VGG16, Inception-v3, and ResNet5. In the second step, we selected a suitable model for further performance improvement. We also modified the ResNet50 model, resulting in 85.00% of classification accuracy, which was the highest value of this experiment.

For further research, we will collect other mangosteen image datasets to improve the classification and learning efficiency of the model for automatic systems software and hardware tools development. This research will be a great contribution to mangosteen product promotion in the future.

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