DEEP LEARNING FOR AUTOMATIC CLASSIFICATION OF AVOCADO FRUIT MATURITY

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Abstract—*Avocado (Persea Americana), a fleshy fruit with a single seed, has increased in popularity globally, especially in tropical and Mediterranean climates, thanks to its commercial and nutritional value. Rich in bioactive compounds, avocados contribute to the prevention and treatment of various diseases, including cardiovascular problems and cancer. Avocado production in Indonesia, for example, is showing a significant increase, reflecting the growing demand. Avocado ripeness affects shelf life and quality, making the determination of ripeness level a critical aspect of postharvest management. Skin color and pulp firmness change during storage, affecting quality and nutritional value. Proper classification of ripeness is important to reduce post-harvest losses, improve quality and optimize export costs. Recent research shows the use of technologies such as machine learning and YOLO (You Only Look Once) version 9 in real-time detection of avocado ripeness, offering innovative solutions to reduce post-harvest losses and improve distribution efficiency. This approach not only benefits farmers and consumers but also ensures consumer satisfaction and reduces economic losses. This study highlights the importance of real-time detection in monitoring avocado ripeness, where the training process was conducted for 89,280 iterations resulting in a new model for avocado ripeness detection. The final model has a mean Average Precision (mAP) validation value of 84.3%, mAP 84.3% signifies the optimal level of accuracy in object recognition in avocado fruit maturity images using the YOLO model that has undergone an intensive training process.*

Keywords: *avocado maturity, postharvest management, real-time detection, YOLO (You Only Look Once) technology.*

Abstrak—Alpukat (*Persea Americana*), buah berdaging dengan biji tunggal, telah meningkat popularitasnya secara global, terutama di iklim tropis dan Mediterania, berkat nilai komersial dan nutrisinya. Kaya akan senyawa bioaktif, alpukat berkontribusi pada pencegahan dan pengobatan berbagai penyakit, termasuk masalah kardiovaskular dan kanker. Produksi alpukat di Indonesia, misalnya, menunjukkan peningkatan signifikan, mencerminkan permintaan yang meningkat. Kematangan alpukat memengaruhi umur simpan dan kualitas, menjadikan penentuan tingkat kematangan sebagai aspek kritis dalam manajemen pascapanen. Warna kulit dan kekencangan daging buah berubah selama penyimpanan, mempengaruhi kualitas dan nilai nutrisi. Klasifikasi kematangan yang tepat penting untuk mengurangi kerugian pasca panen, meningkatkan kualitas, dan mengoptimalkan biaya ekspor. Penelitian terbaru menunjukkan penggunaan teknologi seperti machine learning dan YOLO (*You Only Look Once*) versi 9 dalam deteksi real-time kematangan alpukat, menawarkan solusi inovatif untuk mengurangi kerugian pasca panen dan meningkatkan efisiensi distribusi. Pendekatan ini tidak hanya menguntungkan petani dan konsumen tetapi juga memastikan kepuasan konsumen dan mengurangi kerugian ekonomi. Studi ini menyoroti pentingnya deteksi real-time dalam memantau kematangan alpukat, dimana proses pelatihan dilakukan sebanyak 89.280 iterasi yang menghasilkan model baru untuk deteksi kematangan buah alpukat. Model akhir memiliki nilai validasi *mean Average Precision* (mAP) sebesar 84.3%, mAP 84.3% menandakan tingkat akurasi yang optimal dalam pengenalan objek pada citra kematangan buah alpukat menggunakan model

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YOLO V9 yang telah menjalani proses pelatihan secara intensif.

***Kata Kunci**: kematangan alpukat, manajemen pascapanen, deteksi real-time, teknologi YOLO (You Only Look Once.*

INTRODUCTION

Avocado (Persea Americana) is a commercially valuable fruit cultivated in tropical and Mediterranean climates around the world. In recent decades, avocado fruit has grown in popularity due to increased consumer awareness of its dietary value. Avocado fruit is a fleshy, single-seeded fruit. The fruit has a thick skin and is green or purple-black in colour. Avocado is a climacteric fruit that continues to undergo physiological changes after harvest (Shrestha, 2022). Avocado fruit is very important due to its nutritional and health benefits. It contains bioactive compounds that have been linked to the prevention and treatment of diseases such as macular degeneration, osteoarthritis, cardiovascular problems, and cancer (Adetuyi, et al., 2022). Avocado consumption has been linked to protective effects on human health, including the prevention of cardiovascular disease, diabetes, and certain forms of cancer (Pacheco, et al., 2022). Avocado (Persea Americana) is one of the climacteric fruits that has increased production from year to year. Based on data obtained from BPS, the total avocado production in Indonesia in 2019 reached 40170 quintals, in 2020 it reached 33173 quintals and in 2021 it reached 87377([BPS] Badan Pusat Statistik, 2022). Overall, avocado fruit plays an important role in promoting human nutrition and health.

Determination of the level of maturity is an important factor considering that the level of maturity affects the shelf life, where the higher the level of maturity for avocado fruit (Cho, et al., 2020). Therefore, a postharvest management methodology is needed to determine the ripening stage of avocados to prevent fruit loss due to quality deterioration (Han, et al., 2023). The skin colour and flesh firmness of avocado fruits change during storage. Colour is considered a basic physical property of agrofood products and can be correlated with other quality, other attributes such as nutrition and visual or non-visual defects (Cho, et al., 2020). Classification of avocado fruit ripeness is important to determine optimal consumption ripeness, improve fruit quality, and reduce export costs and losses (Jaramillo-Acevedo, et al., 2020). In addition, classification of avocado fruit maturity is important for many reasons. It helps to reduce post-harvest losses by sorting fruits based on their duration until they are ready to be eaten (Jaramillo-Acevedo, et al., 2020). In addition, it contributes to improved fruit quality and decreased export costs and losses (Al-Dairi et al., 2023). Proper ripeness classification is also beneficial for growers, consumers, vendors (Ronaghi, 2021); (Lin et al. 2020). Overall, avocado ripeness classification is essential to optimise fruit sorting, processing and storage, and to ensure consumer satisfaction and reduce economic losses.

Some research related to avocado fruit maturity has been carried out and obtained quite good results such as research conducted by (Tama, et al., 2022) getting 81% accuracy results, and research using machine learning and deep learning getting quite good results, but for detection in real time has never been done. classifying avocado fruit maturity in real time is important because it can help reduce post-harvest losses by sorting fruit according to its duration until it is ready to eat, ensuring that fruit is not wasted and can be marketed effectively, contributing to improving fruit quality and reducing export costs and losses.

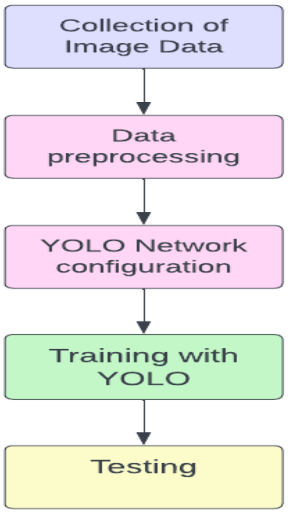
Real-time object detection is an important task in computer vision with various applications. YOLO (You Only Look Once) is a popular algorithm for real-time object detection (Majumder & Wilmot, 2023) which processes the entire image at once and predicts bounding box and class probabilities for identified objects (V, et al., 2022). YoloV5 is an updated version of YOLO, which incorporates a feature pyramid network (FPN) and anchor boxes to improve detection accuracy (Fang, et al., 2023); (Hui, et al., 2024). The YOLO algorithm has shown high performance and fast inference speed, making it widely used and improved in various applications (Diwan, et al., 2023). This research highlights the importance of real-time detection in monitoring avocado ripeness, where the training process was carried out for 89,280 iterations which resulted in a new model for avocado ripeness detection. The final model has a mean Average Precision (mAP) validation value of 84.3%, mAP 84.3% indicates the optimal level of accuracy in object recognition in avocado fruit maturity images using the YOLO V9 model that has undergone an intensive training process.

MATERIALS AND METHODS

The stages in this research illustrate the steps generally taken in the development of an image-based detection system. In the initial stage, the focus is on image data collection followed by image data pre-processing. This pre-processing involves labelling and adjusting the image size to suit the needs of further processing. After that, the next important step is the configuration of the YOLO neural network that is tailored to the characteristics

and distinctive features of the collected image dataset. The training process is then carried out so that the YOLO model can learn from existing image data, forming a new model that is responsive and accurate in detecting certain objects (Diwan, et al., 2023). The final stage of the research focuses on testing the trained model using real-time smartphone camera data, to test the performance and responsiveness of the model in practical situations (Paul et al., 2024).

The steps presented in this research describe the general process of developing an image-based detection system. Starting from data collection, pre-processing, to the formation and training of the YOLO model, each of these important steps is the foundation that ensures responsiveness and accuracy in the detection of the object that is the focus of the research. Testing the model in a real-time environment using smartphone camera data is a crucial final step in evaluating the reliability and accuracy of the developed model. Thus, these steps illustrate the journey from data collection to testing that helps in building a reliable and adaptive detection system to practical situations.



Source : (Research Results, 2023)
Figure 1. Research Scheme

A. Image Data Collection

Image data collection for avocado ripeness detection research covering three classes, namely unripe, ripe, and overripe, is a process that involves capturing images of avocados from various angles and conditions. These images are taken using a camera device that is specially calibrated to capture the critical details that describe the ripeness level of the avocado. This image capture process can be done in the field at the time of harvest, taking into account variations in colour, texture and size of the avocado fruit within each grade. This image data is important for training the ripeness detection algorithm, as each class has different visual characteristics that need to be accurately identified by the system.

After image data collection, the next step is data processing to prepare a suitable dataset for training the avocado ripeness detection model. This processing involves preprocessing the images to adjust the image quality, segmenting the avocado fruit from the background, and tagging each image with the appropriate class label of unripe, ripe, or overripe. Good dataset quality is key in training the detection model, so each image belonging to the three ripeness classes must be represented precisely and accurately. This image data collection is an important foundation in the development of a reliable avocado ripeness detection system to support the agricultural industry in managing harvest more efficiently. Data taken from : https://data.mendeley.com/research-data/?search=avocado%20fruit

B. Data Preprocessing

The image data processing process started with 900 data, consisting of 300 images for each avocado ripeness class, namely unripe, ripe, and overripe. After going through the augmentation process, the total data reached 1365 images covering a wider variety within each class. Of the total data, 1095 images were allocated as training data to train the detection model, while 180 images were used as validation data to test the performance of the model during the training process. Furthermore, 90 images were taken as testing data to measure the accuracy and final performance of the trained detection model.

This proportional split is very important in the development of the avocado ripeness detection model. Larger training data allows the model to learn better and recognise more complex patterns in maturity classification. Validation data helps measure the generalisation ability of the model, while test data ensures that the model can accurately recognise avocado ripeness on a dataset that has never been seen before. With this proportional arrangement, the model can produce consistent and reliable results in classifying avocado ripeness under various conditions.

Table 1. Dataset Distribution

Description	Unripe	Ripe	Over Ripe	Total
Initial Amount	300	300	300	900
After Augmentasi	155	155	155	1365
Training Data	630			630
Validation Data	180			180
Testing Data	90			90

Source : (Research Results, 2023)

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C. YOLO Network Configuration

In the process of configuring YOLO for avocado ripeness detection, determining the batch size is crucial. The use of a batch size of 64 is recommended in the YOLO system for an optimal training process. This batch size is the number of images processed simultaneously in one iteration during model training. With an appropriate batch size, such as 64, the system can process a sufficiently large number of images for each iteration, improving training speed and efficiency. The use of a customized batch size recommended by the YOLO system helps in optimising the learning process of the detection model, ensuring that the model can efficiently and accurately learn avocado ripeness characteristics from the existing image dataset.

D. Training with YOLO

The YOLO model applied in this study has a neural network structure consisting of several convolutional layers with a 3 × 3 kernel and a max-pooling layer with a 2 × 2 kernel, as seen in Figure 2. The last convolutional layer uses a 1 × 1 kernel that aims to reduce the data to a grid size of 13 × 13 × 40. The 13 × 13 dimension represents the grid size of the input image processed by the model, while the number 40 is obtained from the sum according to the filter formula used in that layer.

This shows that the YOLO model has been specifically designed with a neural network structure that allows processing images of 13 × 13 grid size with success in extracting information related to avocado ripeness from the given image data.

E. Testing

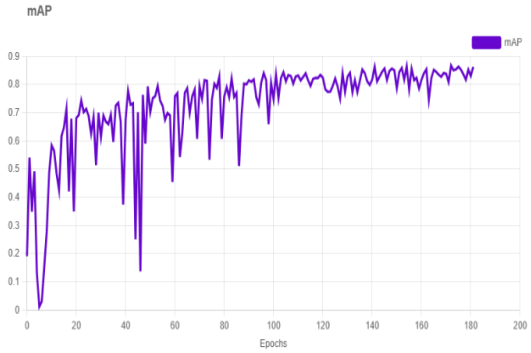
Testing is done in real-time using a smartphone camera as the main tool. The use of a smartphone camera is a test method used to measure accuracy in detecting the ripeness level of avocados by utilising a pre-trained detection model. In this testing process, the smartphone camera acts as an image capture tool that allows direct evaluation of the responsiveness and accuracy of the detection model to avocado fruit objects in real situations, presenting real-time data to evaluate model performance more carefully.

RESULTS AND DISCUSSION

This study documents avocado fruit ripeness results in real-time using the YOLO (You Only Look Once) approach in image analysis. This method enables precise and efficient identification and classification of avocado fruit ripeness, allowing accurate direct observation of changes in fruit ripeness in an instantaneous and continuous manner tailored to the research scheme.

a. Training Results

The training process was carried out as many as 89,280 iterations which resulted in a new model for avocado ripeness detection. The final model created has a mean Average Precision (mAP) validation value of 86.4%, as seen in Figure 2. The mAP figure of 86.4% signifies an optimal level of accuracy in object recognition in avocado fruit ripeness images using the YOLO model that has undergone an intensive training process. This confirms that the model is able to very well identify avocado fruit ripeness in the image, showing a maximum level of accuracy in ripeness classification.

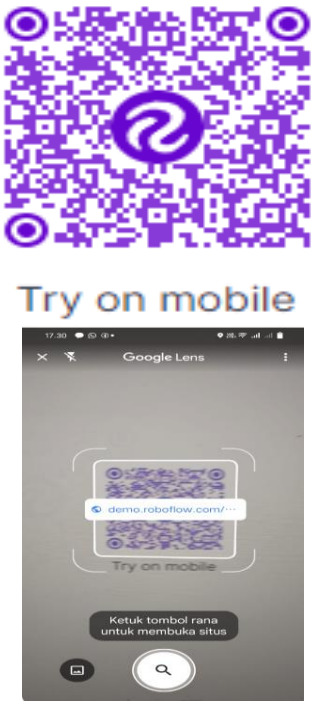


Source : (Research Results, 2023)

Figure 2. mean Average Precision (mAP)

b. Test Results on smartphone camera

To conduct initial testing, it is done by scanning the barcode that has been built with YOLO for all smartphone cameras using Google Lens as shown in Figure 3.



Source : (Research Results, 2023)

Figure 3. Barcode from YOLO to The Link Demo

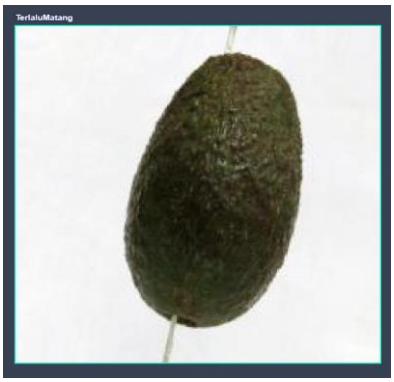
One of the test results on an image with an avocado object can be seen in Figure 4. Based on Figure 4, the object recognition accuracy using a smartphone camera is 99%. Object recognition on video can give different accuracy results when the recognised object moves position.

Source : (Research Results, 2023)
Figure 4. Demo of Detection Result Image with Unripe Category

Figure 4 is a demo of a ripeness detection result for an avocado fruit in the "Unripe" category, showing a green avocado fruit placed on a white background. The avocado fruit displays the typical characteristics of ripeness that has not yet been reached; an oval shape with a light green colour, a smooth skin without brown spots or indentations, and still attached to the stalk. The text accompanying the image, "Unripe," explains that the avocado has not reached the ideal level of ripeness for consumption. This image can educate users about the characteristics of a ripe avocado, which usually has a darker skin and brown spots, as well as soft and creamy flesh. By illustrating the visual difference between unripe, ripe and overripe avocados, this image can help in choosing the right avocado for consumption.

Source : (Research Results, 2023)
Figure 5. Demo Image of Detection Result with Ripe Category

Figure 5 shown depicts an avocado fruit with a "Ripe" category that matches its category. The avocado has an elongated shape with a dark green colour. The skin appears smooth with some brown patches visible on the underside. In addition, this avocado fruit has been detached from the stalk. In this experiment, the results obtained are suitable for the classification of avocado ripeness.



Source : (Research Results, 2023)
Figure 6. Demo Image of Detection Result with Over Ripe Category

Figure 6 is a demo of the detection results using the "Overripe" category with an experiment conducted in real-time using the YOLO model. The image shows an avocado fruit that has reached an excessive level of ripeness. This avocado is characterised by an oval shape but with a darker skin colour, looking very dark green and even brown. It appears that the skin has developed some brown patches in various parts, showing signs of overripe. In the context of experimenting with the YOLO model in real-time, this image provides a clear picture of the level of ripeness of an avocado that has passed its ideal ripeness point.

Based on several experiments, it was found that the model built with YOLO for the classification of avocado ripeness in real time obtained significant results and the accuracy results exceeded the research conducted by (Tama, et al., 2022) here the accuracy obtained was only 81%.

CONCLUSION

Avocado ripeness classification is an important aspect of post-harvest management and distribution. This process affects the fruit's shelf life, skin colour, flesh firmness and quality during storage. Determining the right ripeness helps in effective management and also reduces costs and export losses. This classification also provides benefits to growers, consumers, and vendors, ensuring consumer satisfaction and reducing economic losses. This study emphasises the importance of real-time detection in monitoring avocado ripeness. This study highlights the importance of real-time detection of avocado

ripeness, which is an area of research that has not been done before. The method of using YOLO (You Only Look Once) to monitor avocado ripeness directly at the time of ripeness change is an innovative step. This research highlights the importance of real-time detection in monitoring avocado ripeness, where the training process was carried out for 89,280 iterations which resulted in a new model for avocado ripeness detection. The final model has a mean Average Precision (mAP) validation value of 84.3%, mAP 84.3% indicates the optimal level of accuracy in object recognition in avocado fruit maturity images using the YOLO V9 model that has undergone an intensive training process. Further research can improve the accuracy of avocado ripeness detection in more diverse test conditions, such as light and background variations or integrate other sensor or image processing technologies that can assist in detecting avocado ripeness more accurately and efficiently in real situations.

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