OIL PALM FRESH FRUIT BUNCHES RIPENESS CLASSIFICATION WITH COLOR AND TEXTURE FEATURES EXTRACTION

SHUWAIBATUL ASLAMIAH BINTI GHAZALLI

A thesis submitted in fulfilment of the
requirements for the award of the degree of
Master of Philosophy

Malaysia Japan International Institute of Technology
Universiti Teknologi Malaysia

OCTOBER 2022

DEDICATION

This thesis is dedicated to my parents, who taught me that the best kind of knowledge to have is that which is learned for its own sake. It is also dedicated to my supervisor, who taught me that even the largest task can be accomplished if it is done one step at a time.

ACKNOWLEDGEMENT

In preparing this thesis, I was in contact with many people, researchers, academicians, and practitioners. They have contributed towards my understanding and thoughts. In particular, I wish to express my sincere appreciation to my main supervisor. Without her continued support, understanding and kindness, this thesis would not have been the same as presented here.

I am also indebted to Universiti Teknologi Malaysia (UTM) for funding my Master study. Librarians at UTM, also deserve special thanks for their assistance in supplying the relevant literatures and also Skymind, my previous company who taught me a lot about deep learning and artificial intelligence.

ABSTRACT

High quality palm oil is critical in ensuring Malaysia's competitiveness in the industry. Studies have shown that there is a significant relationship between the quality of palm oil produced and the ripeness of the fruits used in producing the oil. Correct ripeness of the fresh fruit bunches (FFB) produces higher quality and more oil content. Unripe FFB produces less oil and overripe FFB produces oil of low quality. According to Malaysian Palm Oil Board (MPOB), the main factors that determine the ripeness of the oil palm FFB are its colour and the number of its loose fruits. The purpose of this study is to improve the FFB grading accuracy at the plantation field using an image processing approach, which currently the grading is done manually by human graders. Most research in this area are based on FFB images taken at controlled environments with perfect lighting and taken using high-quality cameras. This is quite impractical as the FFB quality must be determined at the harvesting sites before they are sent to the mill for processing. In this research, images used were taken using a common handphone camera at the plantation site after the FFBs were harvested. The analysis combines both the colour and texture features of the FFB, which the colour features of 400 FFB images were analysed using different colour channels, as each colour channel has different responses to the sunlight. The Red Green Blue (RGB) colour channel of the images went through image processing with colour conversion into YCbCr (Y(Green), Cb (Blue), Cr (Red)), which this colour selection is empirically recommended for outdoor images. The results showed that by converting the images to YcbCr, the accuracy of the grading is more promising with increasing of 40% compared to using RGB colour channel. Deep learning was used to identify the colours and textures. In view of small dataset of this study, additional image pre-processing techniques with colour conversion and resizing on raw image data were processed before using them as inputs to the Convolution Neural Network (CNN). The findings showed that with the pre-processing step, even with small dataset, the CNN can produce good FFB ripeness classification with accuracy 74%, with acceptable inferencing time of 3 seconds. In sum, the findings contribute to the development of technology to identify the FFB ripeness in the real plant harvesting scenario by camera.

ABSTRAK

Minyak sawit berkualiti tinggi adalah penting dalam memastikan daya saing Malaysia dalam industri ini. Kajian menunjukkan terdapat hubungan yang signifikan antara kualiti minyak sawit yang dihasilkan dengan kematangan buah tandan segar (BTS) dalam penghasilan minyak sawit. Kematangan BTS yang betul menghasilkan kandungan minyak yang lebih banyak dan lebih berkualiti. BTS yang tidak matang menghasilkan minyak yang sedikit dan BTS yang terlebih matang menghasilkan minyak yang tidak berkualiti. Menurut Lembaga Minyak Sawit Malaysia (MPOB), faktor utama yang menentukan kematangan BTS adalah warna dan bilangan butir buahnya yang sudah gugur. Tujuan kajian ini adalah untuk meningkatkan ketepatan penggredan BTS di ladang menggunakan pendekatan pemprosesan imej, yang pada masa ini dilakukan dilakukan secara manual oleh penggred manusia. Kebanyakan penyelidikan yang dilakukan sebelum ini adalah berdasarkan imej BTS yang diambil pada persekitaran yang terkawal dengan pencahayaan yang sempurna dan diambil menggunakan kamera berkualiti tinggi. Hal ini agak tidak praktikal kerana secara realiti, kualiti BTS mesti ditentukan di tapak penuaian sebelum dihantar ke kilang untuk diproses. Kajian ini menggabungkan kedua-dua ciri warna dan tekstur BTS, yang mana ciri-ciri warna untuk 400 imej BTS diambil dan dianalisis menggunakan saluran warna yang berbeza, kerana setiap saluran warna mempunyai tindak balas yang berbeza terhadap cahaya matahari. Saluran warna Merah Hijau Biru (RGB) melalui proses imej pemprosesan dengan imej ditukar kepada saluran warna YcbCr(Y(Hijau),Cb(Biru),Cr(Merah)), yang mana pilihan warna ini disyorkan secara empirikal untuk imej yang ditangkap dengan persekitaran luar. Keputusan menunjukkan, dengan menukar saluran warna imej kepada saluran warna YcbCr , ketepatan penggredan lebih meyakinkan dengan peningkatan 40% berbanding menggunakan saluran warna RGB. Pembelajaran dalam digunakan untuk mengidentifikasi warna dan tekstur. Mengikut pandangan set data kecil, tambahan teknik imej pra-pemprosesan dengan penukaran warna dan saiz semula imej dilaksanakan sebelum menggunakannya sebagai input kepada Convolution Neural Netwrok(CNN). Hasil menunjukkan bahawa dengan langkah pra-pemprosesan, walaupun dengan set data kecil, CNN dapat menghasilkan ketepatan klasifikasi kematangan BTS yang baik dengan 74% ketepatan dengan masa inferen yang boleh diterima iaitu 3 saat. Secara keseluruhannya, penemuan ini menyumbang kepada pembangunan teknologi untuk mengenal pasti kematangan BTS dalam scenario penuaian yang sebenar melalui kamera.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF ABBREVIATIONS

AI	-	Artificial Intelligence
ANN	-	Artificial Neural Network
BTS	-	Buah Tandan Segar
CNN	-	Convolution Neural Network
DL	-	Deep Learning
FFB	-	Fresh Fruit Bunches
FFNN	-	Feed Forward Neural Network
HSI	-	Hue, Saturation, Intensity
HSV	-	Hue, Saturation, Value
KNN	-	K-Nearest Neighbour
LAB	-	Lightness, Red/Green Value, Blue/Yellow Value
LBP	-	Local Binary Pattern
GLCM	-	Gray Level Co-Occurrence Matrix
MLP	-	Multi Perceptron Neuron
MPOB	-	Malaysia Palm Oil Berhad
RGB	-	Red Green Blue
ROI	-	Region of Interest
SVM	-	Support Vector Machine
UTM	-	Universiti Teknologi Malaysia
YCBCR	-	Luma, Blue Difference, Red Difference
YIQ	-	Luminance, Chrominance Part
YUV	-	Luma, Blue minus Luma, Red Minus luma
YOLO	-	You Only Look Once

LIST OF SYMBOLS

A	-	Accuracy
Loss	-	Categorical cross entropy
Softmax	-	Softmax Activation Function
R	-	Recall
P	-	Precision
$\sum$	-	Summation

CHAPTER 1

INTRODUCTION

1.1 Introduction

Known as one of the countries that make the palm oil industry as their economic backbone, Malaysia continues to face new challenges in the face of globalization [1]. Being one of the biggest producers and exporters for palm oil and palm oil products, Malaysia has an important role to play in fulfilling the growing global need for oils and fats sustainably [1]. As quality have significant relationship with palm oil content, monitoring and controlling the production of Fresh Fruit Bunches (FFB) is important in the crops industry. There are 3 factors that lead to quality of palm oil : low free of fatty acid, high oil extraction rate (OER) and level ripeness of oil palm fruits[2]. [2],[3] and [4] is believed ripeness is perceived as the main quality indicator and appearance was used as main point to determine the ripeness for FFBs.

Malaysia Palm Oil Centre stated that Malaysia currently accounts for 39 % of world palm oil production and 44% of world exports. If taken into account other oils and fats produced in the country, Malaysia accounts for 12% and 27% of the world's total production and exports of oils and fats [1]. Therefore, to maintain the rapid production of palm oil, a lot of effort is needed in palm oil industry itself.

Correct ripeness of the harvested FFB is key to producing higher quality and quantity of palm oil. At present, the ripeness of the oil palm fruit is based on manual sight inspection. This done by palm oil industry worker by using their sight. According to Malaysia Palm Oil Berhad (MPOB), the process for identifying ripeness is based on FFB surface colour and number of loose fruits detached from its bunch. Performing the task is not easy since it requires good knowledge and experience. Moreover, human mistake in manual visual inspection might lead to inaccurate inspection and loss.

The use of machine learning in palm oil industry to contribute more in production of palm oil[5]. Image processing and machine learning have been use in investigating the relationship between quality of the palm oil and its features. This work is one of effort in helping labour shortage issue and moving to fully robotic system in industries. According to Herman et all[6] there have many research done for oil palm fruit ripeness classification based on computer vision, however it has not gained many satisfactory results. Therefore, most of the ripeness grading processes are still done manually by labor works.

1.2 Problem Statement

There have been several studies conducted for oil palm ripeness identification. An intelligent oil palm grading by using optic probe had been done in[7]. This technique are using diod laser to check the firmness of oil palm FFB. Meanwhile, [8] used rule-based expert system of Region Of Interest (ROI) image processing logic to classify the oil palm fruits which yielded 94% of correct classification. Both of this research are taking the FFB into a controlled environment. This is not practical as in the real-world industry, the grader and harvester need to harvest the FFB in outdoor environment and lighting does affect the appearance of colours. RGB values only suitable to be used in constant lighting environment since they are affected by changing light intensities [9].

Studies also show that there are two main factor which involved in determining the ripeness of FFB. They are the surface colour and number of loose fruits. These two factors had to exist together in order to determine ripeness. However, research for determining the number of loose fruits of FFB or by taking texture features of an image is not yet to be gradually research. Loose fruit is very important because it contain more oil content compared to bunches. Loose fruit contains up to 48% oil while bunches only contain 22% oil.

According to Suharjito et all[10] One of the current challenges in fruits ripeness classification research is, the computational resource to detect the ripeness. People need to wait quite some time for the algorithm to determine the level of ripeness. As a result, although the accuracy of the model is high, but the time taken for the inference to complete is high.

1.3 Research Objectives

The objective of this research are :

1. To improve palm oil grading accuracy by taking both colour and texture features in outdoor environment.

2. To develop more accurate image processing algorithm with less inferencing time for palm fruit ripeness classification by implementing Convolution Neural Network.

1.4 Research Scope

Following are the scope of this research :

I. Image used in this work is taken in outdoor environment using 720x1280 pixels resolution

II. Ripeness of FFB determine by both colour and surface area of FFB

III. Using same processor specification Intel(R) Core(TM) i5-9300H CPU @ 2.40GHz for capturing inferencing time.

1.5 Research Significance

This study focuses on solving the ripeness identification of oil palm FFB based on FFB image taken in outdoor environment. It emphasizes the use of both colour and texture of the FFB and classify it using the CNN method. The research is significant in terms of developing a good algorithm for classifying the ripeness level with acceptable inferencing time. The finding of this study may be worth for future investigation and giving ideas in the fields of fruits image grading for higher quality and quantity of palm oil.

1.6 Thesis Outline

The thesis is organized as follows:

a) Chapter 2 reviews the literature on certain topics related to the scope of this study. Topics such as colour and texture features of FFB, outdoor environment, and deep learning are discussed in this chapter.

b) Chapter 3 describes the methodology and research process used throughout the study. In this chapter the conduct of the study, information about deep learning, how to create datasets, and the result observed during system evaluation and analysis were discussed.

c) Chapter 4 presents the results and discussion based on the experiments conducted in the study. The analysis and findings are shown in this chapter.

d) Chapter 5 summarizes and concludes the research, as well as discusses the study's limitations and potential future work based on the findings.

REFERENCES

[1] "Malaysian Palm Oil Industry," *MALAYSIAN PALM OIL COUNCIL*, 2012. http://www.mpoc.org.my/Malaysian_Palm_Oil_Industry.aspx (accessed Dec. 07, 2017).

[2] Z. B. Mat Sharif, N. B. Mohd Taib, M. S. Bin Yusof, M. Z. Bin Rahim, A. L. Bin Mohd Tobi, and M. S. Bin Othman, "Study on Handing Process and Quality Degradation of Oil Palm Fresh Fruit Bunches (FFB)," in *IOP Conference Series: Materials Science and Engineering*, 2017, vol. 203, no. 1, doi: 10.1088/1757-899X/203/1/012027.

[3] M. S. M. Alfatni *et al.*, "Oil palm fresh fruit bunch ripeness classification based on rule- based expert system of ROI image processing technique results," *IOP Conf. Ser. Earth Environ. Sci.*, vol. 20, p. 012018, 2014, doi: 10.1088/1755-1315/20/1/012018.

[4] M. H. Razali, I. W. Wan Ismail, A. R. Ramli, M. N. Sulaiman, and M. H. B. Harun, "Technique on simulation for real time oil palm fruits maturity prediction," *African J. Agric. Res.*, vol. 6, no. 7, pp. 1823–1830, 2011, doi: 10.5897/AJAR10.1124.

[5] "My Say: Growing through innovation in agriculture | The Edge Markets." https://www.theedgemarkets.com/article/my-say-growing-through-innovation-agriculture (accessed Mar. 16, 2022).

[6] Herman, A. Susanto, T. W. Cenggoro, Suharjito, and B. Pardamean, "(PDF) Oil Palm Fruit Image Ripeness Classification with Computer Vision using Deep Learning and Visual Attention." https://www.researchgate.net/publication/342618126_Oil_Palm_Fruit_Image_Ripeness_Classification_with_Computer_Vision_using_Deep_Learning_and_Visual_Attention (accessed Aug. 19, 2022).

[7] N. Sari *et al.*, "Klasifikasi Tingkat Kematangan Tandan Buah Segar Kelapa Sawit Menggunakan Probe Optik Ripeness Classification of Oil Palm Fresh Fruit Bunch Using an Optical Probe," *J. Aceh Phys. Soc*, vol. 8, no. 3, pp. 72–

77, 2019, doi: 10.24815/jacps.v8i3.14122.

[8] Z. May and M. H. Amaran, “Automated Oil Palm Fruit Grading System using Artificial Intelligence,” *Int. J. Video Image Process. Netw. Secur. IJVIPNS-IJENS*, vol. 11, no. June, pp. 30–35, 2011, doi: 10.3126/kuset.v6i2.4017.

[9] S. Beier,Paul and Loe, “Weblet Importer,” *Wildl. Soc. Bull.*, vol. 20, no. 4, pp. 434–440, 1994, doi: 10.1002/(SICI)1522-2683(20000101)21:1<27::AID-ELPS27>3.0.CO;2-C.

[10] Suharjito, G. N. Elwirehardja, and J. S. Prayoga, “Oil palm fresh fruit bunch ripeness classification on mobile devices using deep learning approaches,” *Comput. Electron. Agric.*, vol. 188, p. 106359, Sep. 2021, doi: 10.1016/J.COMPAG.2021.106359.

[11] J. E. Smith, “Biological identification methods,” *Nature*, vol. 278, no. 5705. pp. 673–674, 1979, doi: 10.1038/278673c0.

[12] *Computer Vision and Image Processing in Intelligent Systems and Multimedia ... - Google Books*. .

[13] J. Wu, B. Zhang, J. Zhou, Y. Xiong, B. Gu, and X. Yang, “Automatic Recognition of Ripening Tomatoes by Combining Multi-Feature Fusion with a Bi-Layer Classification Strategy for Harvesting Robots,” *Sensors 2019, Vol. 19, Page 612*, vol. 19, no. 3, p. 612, Feb. 2019, doi: 10.3390/S19030612.

[14] K. Tan, W. S. Lee, H. Gan, and S. Wang, “Recognising blueberry fruit of different maturity using histogram oriented gradients and colour features in outdoor scenes,” *Biosyst. Eng.*, vol. 176, pp. 59–72, Dec. 2018, doi: 10.1016/J.BIOSYSTEMSENG.2018.08.011.

[15] F. S. Mim, S. M. Galib, M. F. Hasan, and S. A. Jerin, “Automatic detection of mango ripening stages – An application of information technology to botany,” *undefined*, vol. 237, pp. 156–163, Jul. 2018, doi: 10.1016/J.SCIENTA.2018.03.057.

[16] T. S. Peng, D. Hj, and Z. Shafie, “PANDUAN PENGGREDAN BUAH TANDAN SEGAR SAWIT UNTUK PEKEBUN KECIL,” 2017, Accessed: Mar. 16, 2022. [Online]. Available: www.mpob.gov.my.

[17] Malaysian Palm Oil Board, "MANUAL PENGGREDAN BUAH KELAPA SAWIT," *2017*. http://wskj.mpob.gov.my/pnp/gredffb.htm (accessed Jul. 23, 2018).

[18] P. B. Pathare, U. L. Opara, and F. A. J. Al-Said, "Colour Measurement and Analysis in Fresh and Processed Foods: A Review," *Food Bioprocess Technol.*, vol. 6, no. 1, pp. 36–60, Jan. 2013, doi: 10.1007/S11947-012-0867-9.

[19] A. M. Vyas, B. Talati, and S. Naik, "Colour Feature Extraction Techniques of Fruits: A Survey," *Int. J. Comput. Appl.*, vol. 83, no. 15, pp. 15–22, 2013, doi: 10.5120/14524-2915.

[20] "Feature Extraction Techniques. An end to end guide on how to reduce a… | by Pier Paolo Ippolito | Towards Data Science." https://towardsdatascience.com/feature-extraction-techniques-d619b56e31be (accessed Mar. 16, 2022).

[21] M. N. Abdullah *et al.*, "Colour Features Extraction Techniques and Approaches for Content-Based Image Retrieval (CBIR) System," *J. Mater. Sci. Chem. Eng.*, vol. 9, pp. 29–34, 2021, doi: 10.4236/msce.2021.97003.

[22] R. P. Salunkhel and A. A. Patif, "Image Processing for Mango Ripening Stage Detection : RGB and HSV method," pp. 362–365, 2015.

[23] N. Jamil, A. Mohamed, and S. Abdullah, "Automated grading of palm oil Fresh Fruit Bunches (FFB) using neuro-fuzzy technique," in *SoCPaR 2009 - Soft Computing and Pattern Recognition*, 2009, pp. 245–249, doi: 10.1109/SoCPaR.2009.57.

[24] F.-R. A. Thomas S.Y. Choong, Saad Abbas, Abdul Rashid Shariff, Rohaya Halim, Mohd Halim S. Ismail, Robiah Yunus, Salmiaton Ali, "Digital Image Processing of Palm Oil Fruits," *Int. J. Food Eng.*, vol. 2, no. 2, pp. 1556–3758, 2006, doi: 10.2202/1556-3758.1090.

[25] K. H. Ghazali, R. Samad, W. Arshad, and R. A. Karim, "Image Processing Analysis of Oil Palm Fruits for Automatic Grading."

[26] D. Zhang, D. Lee, B. J. Tippetts, and K. D. Lillywhite, "Date maturity and

quality evaluation using color distribution analysis and back projection," *J. Food Eng.*, vol. 131, pp. 161–169, 2014, doi: 10.1016/j.jfoodeng.2014.02.002.

[27] C. Garrido-Novell, D. Pérez-Marin, J. M. Amigo, J. Fernández-Novales, J. E. Guerrero, and A. Garrido-Varo, "Grading and color evolution of apples using RGB and hyperspectral imaging vision cameras," *J. Food Eng.*, vol. 113, no. 2, pp. 281–288, Nov. 2012, doi: 10.1016/J.JFOODENG.2012.05.038.

[28] N. Fadilah, J. M. Saleh, H. Ibrahim, and Z. A. Halim, "Oil palm fresh fruit bunch ripeness classification using artificial neural network," in *2012 4th International Conference on Intelligent and Advanced Systems (ICIAS2012)*, Jun. 2012, pp. 18–21, doi: 10.1109/ICIAS.2012.6306151.

[29] "visguide3." https://www.oclc.org/research/publications/library/visguides/visguide3.html (accessed Mar. 09, 2022).

[30] W. I. W. Ishak and R. M. Hudzari, "Image based modeling for oil palm fruit maturity prediction," *J. Food Agric. Environ.*, vol. 8, no. 2, 1, pp. 469–476, 2010.

[31] M. Z. Abdullah, L. C. Guan, and B. M. N. Mohd Azemi, "Stepwise discriminant analysis for colour grading of oil palm using machine vision system," *Food Bioprod. Process. Trans. Inst. Chem. Eng. Part C*, vol. 79, no. 4, pp. 223–231, 2001, doi: 10.1205/096030801753252298.

[32] M. K. Shabdin, A. R. M. Shariff, M. N. A. Johari, N. K. Saat, and Z. Abbas, "A study on the oil palm fresh fruit bunch (FFB) ripeness detection by using Hue, Saturation and Intensity (HSI) approach," *IOP Conf. Ser. Earth Environ. Sci.*, vol. 37, no. 1, 2016, doi: 10.1088/1755-1315/37/1/012039.

[33] M. K. Shabdin *et al.*, "IOP Conference Series: Earth and Environmental Science You may also like A study on the oil palm fresh fruit bunch (FFB) ripeness detection by using Hue, Saturation and Intensity (HSI) approach," doi: 10.1088/1755-1315/37/1/012039.

[34] "View of Image Analysis Techniques for Ripeness Detection of Palm Oil Fresh Fruit Bunches." https://elektrika.utm.my/index.php/ELEKTRIKA_Journal/article/view/192/10

2 (accessed Mar. 16, 2022).

[35] N. Sabri, Z. Ibrahim, and D. Isa, "Evaluation of color models for palm oil fresh fruit bunch ripeness classification," *Indones. J. Electr. Eng. Comput. Sci.*, vol. 11, no. 2, pp. 549–557, Aug. 2018, doi: 10.11591/IJEECS.V11.I2.PP549-557.

[36] "Laman Web Rasmi RISDA Pulau Pinang - Panduan Pekebun Kecil (Kelapa Sawit)." https://www2.risda.gov.my/pulaupinang/Panduan Pekebun Kecil - Kelapa Sawit.html#Tajuk1 (accessed Jul. 23, 2018).

[37] R. Mohebian, M. A. Riahi, and O. Yousefi, "Detection of channel by seismic texture analysis using Grey Level Co-occurrence Matrix based attributes," *J. Geophys. Eng.*, vol. 15, no. 5, pp. 1953–1962, Oct. 2018, doi: 10.1088/1742-2140/AAC099.

[38] A. Humeau-Heurtier, "Texture feature extraction methods: A survey," *IEEE Access*, vol. 7, pp. 8975–9000, 2019, doi: 10.1109/ACCESS.2018.2890743.

[39] T. Ojala, M. Pietikäinen, and D. Harwood, "A comparative study of texture measures with classification based on featured distributions," *Pattern Recognit.*, vol. 29, no. 1, pp. 51–59, Jan. 1996, doi: 10.1016/0031-3203(95)00067-4.

[40] A. Satpathy, X. Jiang, and H. L. Eng, "LBP-based edge-texture features for object recognition," *IEEE Trans. Image Process.*, vol. 23, no. 5, pp. 1953–1964, 2014, doi: 10.1109/TIP.2014.2310123.

[41] S. A. Magalhães *et al.*, "Evaluating the Single-Shot MultiBox Detector and YOLO Deep Learning Models for the Detection of Tomatoes in a Greenhouse," *Sensors 2021, Vol. 21, Page 3569*, vol. 21, no. 10, p. 3569, May 2021, doi: 10.3390/S21103569.

[42] "What is Deep Learning? | IBM." https://www.ibm.com/cloud/learn/deep-learning (accessed Mar. 16, 2022).

[43] D. Albert-Weiß, E. Hajdini, M. Heinrich[2], and A. Osman, "CNN FOR RIPENESS CLASSFICATION OF WATERMELON FRUITS BASED ON ACOUSTIC TESTING," Accessed: Mar. 10, 2022. [Online]. Available:

http://www.ndt.net/?id=25569.

[44] K. He, X. Zhang, S. Ren, and J. Sun, "Deep Residual Learning for Image Recognition," *Proc. IEEE Comput. Soc. Conf. Comput. Vis. Pattern Recognit.*, vol. 2016-Decem, pp. 770–778, Dec. 2015, doi: 10.48550/arxiv.1512.03385.

[45] "Understanding ResNet50 architecture." https://iq.opengenus.org/resnet50-architecture/ (accessed Mar. 16, 2022).

[46] S. Purushotham, R. Sukumar, and H. Nambisan, "Classification of fruits and vegetables using ResNet model." https://www.researchgate.net/publication/354055891_Classification_of_fruits_and_vegetables_using_ResNet_model (accessed Mar. 10, 2022).

[47] "YOLO: Real-Time Object Detection." https://pjreddie.com/darknet/yolo/ (accessed Mar. 16, 2022).

[48] "Classifai." https://classifai.ai/ (accessed Mar. 10, 2022).

[49] D. Albert-Weiß, E. Hajdini, M. Heinrich[2], and A. Osman, "CNN FOR RIPENESS CLASSFICATION OF WATERMELON FRUITS BASED ON ACOUSTIC TESTING," Accessed: Mar. 24, 2022. [Online]. Available: http://www.ndt.net/?id=25569.

[50] N. Fadilah and J. Mohamad-Saleh, "Color Feature Extraction of Oil Palm Fresh Fruit Bunch Image for Ripeness Classification." Accessed: Jul. 27, 2018. [Online]. Available: http://www.wseas.us/e-library/conferences/2014/Malaysia/ACACOS/ACACOS-06.pdf.

[51] "YUV, YIQ and YCbCr Colour Spaces - RGB & YCbCr Colour Spaces." https://1library.net/article/yuv-yiq-ycbcr-colour-spaces-ycbcr-colour-spaces.z3j7987y (accessed Aug. 19, 2022).