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Image based durian (*Durie azomethines* Linn) sweetness measurement by ResNet50

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Abstract

Development of the capability to determine durian sweetness using a single image is the main objective of this research. The developed system is called the “Durian Sweetness Measurement System” or DSMS. The DSMS employed ResNet50 in the MATLAB toolbox to recognize durian imagery. The system consists of four main subprograms, 1) durian dataset creation, 2) image acquisition, 3) durian sweetness evaluation, and 4) results illustration. The system was used to conduct experiments on 17 Monthong durian pulps in 102 video clips. The DSMS determined that sweetness of the raw, mature and ripe durian was around 14–19, 20–26 and 27–31 ºBrix, respectively. The accuracy of the DSMS is 97.57%, with an average access time of 1.5248 sec per image.

Keywords: Convolutional neural network, Pattern recognition, ResNet50, Sweetness measurement

1. Introduction

Durian, known in Thailand as the King of Fruits, is one of the most expensive and nutrient-rich fruits from Southeast Asia. Durian has many nutrients, including various proteins, carbohydrates (which can be transformed into numerous sugars), calcium, iron, magnesium, zinc, copper, and manganese, as well as Vitamins A, B and C, along with carotene, and other nutrients [1-3]. Durian has not only a creamy sweet taste but also a unique smell. It is a seasonal fruit, with various species across the Asian countries. In Thailand, durian is harvested in the summer (February to May) [4]. There are various durian species in the Southeast Asia countries, as shown in Table 1.

Thailand is the largest global durian trading hub, with a market share of 70–90 percent, while China is the biggest importer of Thai durian. In 2019, Thailand’s durian exports amounted to around 51,187 million Thai baht (THB) or 1,505.5 million USD (1 USD ~ 34 THB). This was approximately 655,362 tonnes of durian sold into the world market. Likewise, Thailand exported 50,072 million THB’s worth of durian, or 501,493 tonnes, in 2020. Thailand sells around 70% of its fresh durian to businesses in China each year [5, 6]. The time between harvest and the fruit being offered for sale should not be longer than 9 days for Monthong and 13 days for Musang King and Ocee [7]. Due to the huge durian trading volume Thailand, the objective of this research is to help traders, merchants and customers measure the sweetness of fresh durian using an image processing method. This approach is non-destructive. Mobile cameras can be used to photograph durian pulp. Then, the DSMS can be used to evaluate the fruit’s sweetness. Sweetness is one of the most important factors impacting durian taste and freshness [8].

Researchers and scientists have employed various equipment and techniques to evaluate durian features such as its species, freshness, maturity, ripeness and sweetness. Researchers used 1) high-performance anion-exchange chromatography with pulsed amperometric detection (HPAEC-PAD), 2) near-infrared spectroscopy (NIR), and 3) a digital pen refractometer to evaluate durian quality. Each of these techniques is briefly discussed below.

Table 1 Popular durian species in Southeast Asia

Thailand	Malaysia	Philippines	Indonesia
Monthong	Musang King (D197)	Pupat	Zibethinus
Cha-Ni	Black Pearl	Duyaya	Kutejensis
Kan-Yao	Red Prawn (D175)	GD69	Dulcis
Long-Lob-Rare	Hong Xia	Native	Excelsus
Pa-Ra-U		Arancillo	Lowianus
Phu-Kaw-Fai			Oxleyanus
Phung-Ma-Ni			Grandiflorus
Ka-Dum-Thong			Graveolens
			Testudinarium

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1.1 HPAEC-PAD

High-performance anion-exchange chromatography with pulsed amperometric detection has been employed to measure substances in durian pulp. Xiao et al. [8] used HPAEC-PAD to conduct experiments on three durian species, Monthong, Musang King and Black Thorn. The experiments identified nutrients in three durian species, as shown in Table 2.

Table 2 Nutrients found durian by Xiao et al. [8]

Durian species	Number of volatile compounds	Number of sugars	Number of organic acids	Number of free amino acids
Monthong	38	4	27	19
Musang King	36	4	27	20
Black Thorn	27	5	27	19

Sangpong et al. [9] and Sirikantaramas et al. [10] used HPAEC_PAD to measure soluble sugars in Monthong durian pulp at three ripening stages, including unripe, mid-ripe and ripe. The experimental results showed that in an unripe stage, both myo-inositol and galactinol had very high values. In a ripe stage, 1-kestose, glucose, fructose, maltose and sucrose had high levels. Only raffinose was in high concentration in the mid-ripe stage.

1.2 Near-Infrared (NIR) spectroscopy

Researchers have applied near-infrared spectroscopy to classify and evaluate durian pulp. Pokhrel et al. [11] classified 415 Monthong durian pulps using inline acquisition of near-infrared spectra, with an accuracy of 85.3%. Sharma et al. [12] demonstrated the use of near-infrared hyperspectral imaging, combined with machine learning, to evaluate three properties of Monthong durian pulp, dry matter (DM), total soluble solids (TSS) and lipid content. Cheepsomsong et al. [13] analyzed 120 Monthong durian samples examining three parameter indices, days after anthesis (DAA), total soluble solids (TSS) and dry matter content (DMC) using near-infrared spectrometry. Ditcharoen et al. [14] showed a non-destructive durian maturity classification using near-infrared spectroscopy. The level of durian maturity was classified into four stages: immature, premature, mature and ripe.

1.3 Refractometry

Researchers commonly measure durian sweetness using a refractometer. Tan et al. [15] conducted experiments on durian pulp that had been frozen for 1–12 months. Frozen durian characteristics were then measured, such as its weight loss, moisture content, color, aroma, firmness, texture and taste, using a total soluble solids (TSS) technique. Prasetia et al. [16] developed a technique to examine thirty-day-frozen durian *via* a total soluble solids technique, using a hand-held refractometer (Atago Co, Japan), obtaining measurements between 15–30 ^{o}Brix. Arsa et al. [17] conducted experiments on three species of durian, Monthong, Chanee and Kan-Yao through five stages, young (freshly harvested), mature (3-5 days after harvest), ripe (6-7 days after harvest), ripe+1 (8-9 days after harvest) and overripe (more than 10 days after harvest). They measured total soluble solids of durian using a digital refractometer, showing 8.70, 20.31, 24.99, 25.59 and 28.59 ^{o}Brix for young, mature, ripe, ripe+1 and overripe stages, respectively. Niponsak et al. [18] used a hand-held refractometer (Atago Master-M, Atago Co. Ltd., Tokyo, Japan) to measure the total soluble solids (TSS) or sweetness of durian after three storage periods, initial day, 3 days and 5 days after harvest, with average values of 23.46, 31.74 and 42.54 ^{o}Brix, respectively.

Based on previous research, measuring durian ripeness (sweetness) using high-performance anion-exchange chromatography with pulsed amperometric detection (HPAEC-PAD), and near-infrared spectroscopy are very sophisticated methods that are too complicated for use outside of a laboratory. However, the current research employed a refractometer to measure durian sweetness, which is more suitable for field measurements.

Some researchers employed convolutional neural networks (CNNs) to classify durian maturity. Thipsrirach et al. [19] classified durian maturity using three CNN types, LeNet5, AlexNet and DuNet12, with precision values of 99.11, 98.67 and 99.56%, respectively. Uy and Villaverde [20] classified six durian species, Alcon, Belviz, GD69, Nanam, Puyat and Sulit, with an average precision of 71.43%. Lim and Chuah [21] recognized three species of durian, D24 (Sultan), D175 (Red Prawn) and D197 (Musang King) using a CNN, with a precision of 97.66%. The CNNs in the previous research yielded excellent precision. Therefore, this research adopted a CNN for recognizing durian images and evaluating their sweetness. The main objective of this research is to develop a method to enable people to measure durian sweetness using only a single image.

2. Materials and methods

2.1 System hardware and software specifications

The DSMS was developed on the following computer hardware and software. The central processing unit used an Intel Core i7 operating at 2.90 GHz with 16 GB of RAM. The operating system was Windows 11. MATLAB R2020b (license number 40598465) was used for software development. A Xiaomi, Redmi Note 8 mobile phone, was used for making durian imagery. Its camera specifications are 1) picture resolution = 48 MP, 2) aperture = f/1.8, 3) periscope telephoto = 26mm (wide), 4) sensor size = 1/2.0", 5) pixel size = 0.8 µm and 6) number of video frames = 4K@30fps. To avoid copyright issues, the researchers created their own durian dataset, which is called the "DSMS dataset". The system design used in this research is as follows.

2.2 Durian sampling

This research used four Monthong durians with a total weight of 14.1 kg and 17 pulps, as shown in Table 3. Each durian pulp was used in six video clips. The DSMS conducted the experiment using 102 (17 x 6) durian video clips. The researchers dissected 4.6 kg of durian pulp prior to its imaging, 2 days, 3.7 kg - 4 days, 2.6 kg - 7 days and 3.2 kg - 10 days post-harvest. The Monthong durians

(*Durio zibethinus Linn*) were harvested on June 7, 2023 at Bang Sapan Noi District, Prachuab Khiri Khan, Thailand. All durians were transported to the Faculty of ICT, Mahidol University, Salaya, Nakhon Pathom. Experiments began on June 9, 2023. The samples of a whole durian having a mass of 3.7 kg and its pulp are shown in Figures 1 (a) and (b), respectively.

Table 3 Durian weight and number of pulps in this research

Durian Number	Weight (kg)	Number of pulps	Dissection (days after harvest)
1	2.6	4	7
2	3.2	4	10
3	3.7	4	4
4	4.6	5	2
Total	14.1	17	

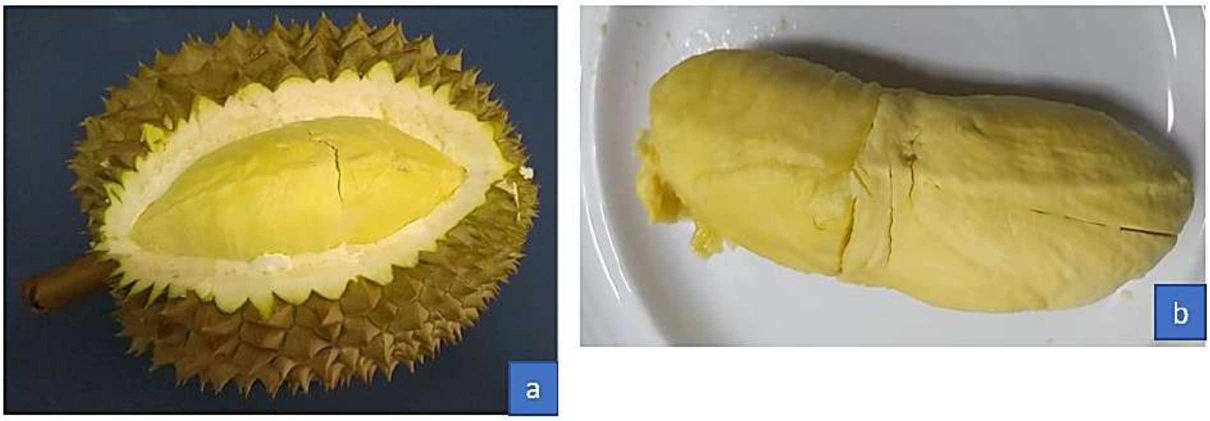

Figure 1 Sample Monthong durian images used in this research (a) a whole durian, and (b) pulp of a durian

2.3 Determination of total soluble content

This research measured each durian pulp in three areas, which are the left, middle and right of the durian pulp. Each measurement used a teaspoon to remove durian pulp that was subsequently crushed in a mortar until the solid durian was homogenized into a durian cream. After that, one drop of durian liquid was used to measure its sweetness using a refractometer (Atago Master-M, Atago Co. Ltd., Tokyo, Japan). The refractometer measured the refractive index of light passing through the liquid. The results were read as °Brix [22]. Inter-sample contamination was avoided by thoroughly cleaning the equipment between sample measurements.

2.4 Convolutional neural network

This research employed a convolutional neural network to recognize durian images. The structure of a convolutional neural network is shown in Figure 2 [12]. The experiments used previously reported research techniques employing the ResNet50 to recognize Monthong durian images. Currently, CNN is one of the most powerful recognition methods to identify unknown images in a dataset, with high accuracy.

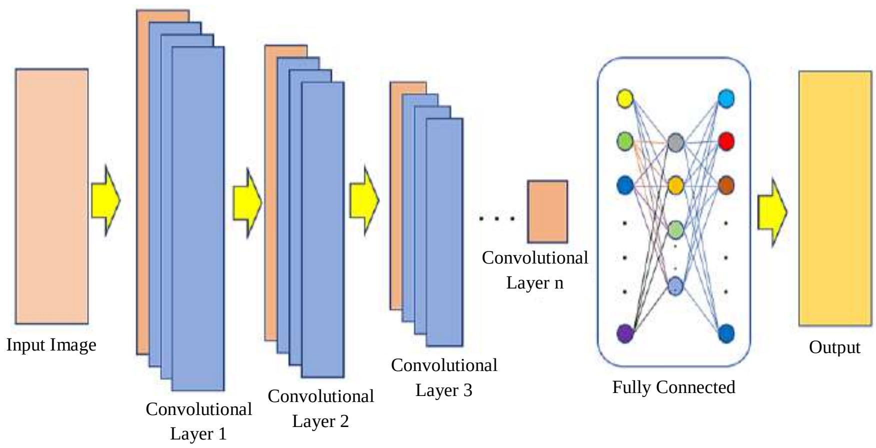

Figure 2 The convolutional neural network architecture

2.5 DSMS conceptual diagram

The DSMS conceptual diagram has three steps, as shown in Figure 3. The first step is capture of a durian pulp image using a mobile phone camera. Then, the durian pulp image is transferred to the computer system to evaluate sweetness. Finally, the system shows durian sweetness to the user, based on the image.

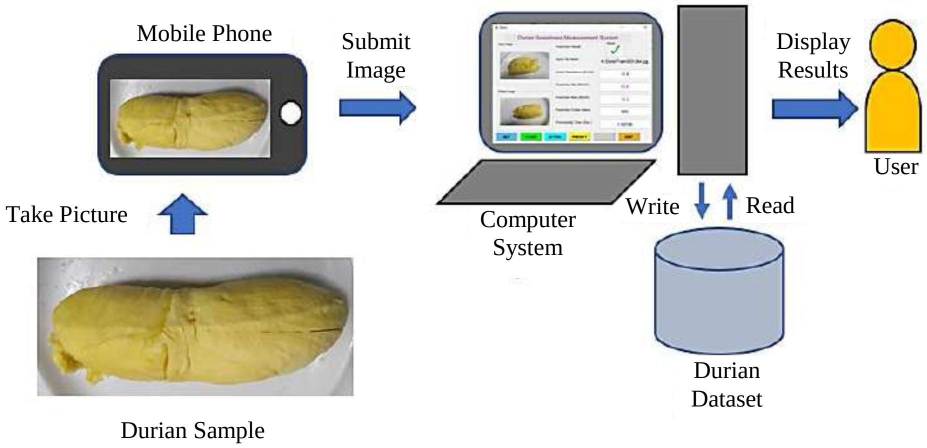

Figure 3 DSMS conceptual diagram

2.6 DSMS state diagram

The DSMS state diagram consists of five states, 1) durian collection, 2) durian dissection, 3) imagery, 4) measuring sweetness and 5) data analysis. This is shown in Figure 4. Each state is detailed as follows.

2.6.1 Durian collection state

This state involved collecting durians from farms. Researchers needed to record the harvest date, durian weights and the number of pulps before conducting experiments.

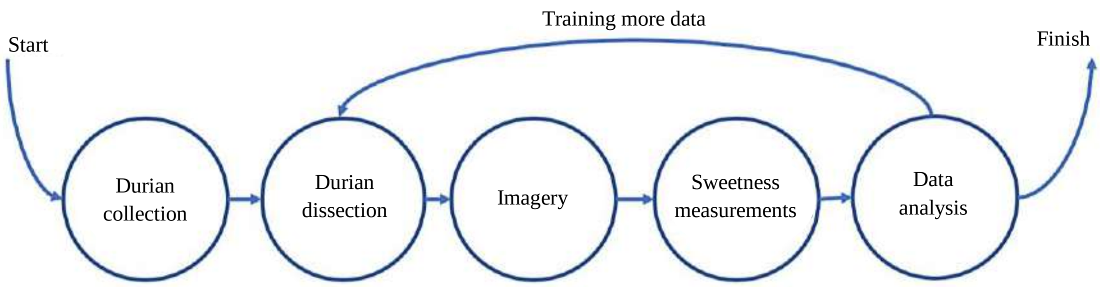

Figure 4 DSMS state transition diagram

2.6.2 Durian dissection state

This state involved dissecting durians using a sharp knife. The researchers needed to completely dissect durian pulp. The raw and mature durian stages were more easily dissected than the ripe stage. This research was conducted using four Monthong durians containing 17 pulps.

2.6.3 Imagery state

Durian pulps were imaged using a simple mobile telephone camera. This research used a rotating platform to position durian pulps through 360º. The mobile camera was positioned 30 cm. behind the rotating platform to make video clips. All 17 durian pulps were imaged producing six video clips for each pulp. Totally, this research used 102 video clips at three ripeness stages, young, mature and fully-ripe stages.

2.6.4 Sweetness measurements

Durian was crushed in a mortar until solid durian became a cream. The resulting material was covered using a filter cloth. After that, the researcher used a press to obtain liquid from the durian. Finally, one drop of durian liquid was used to measure sweetness with a refractometer.

2.6.5 Data analysis state

Durian image files and their sweetness values were stored in an Excel file. A MATLAB toolbox, “confusion.getMatrix” was used to analyze the experimental data. Four statistical values were used to measure system performance. These were accuracy, precision, recall and the F1-score.

2.7 DSMS structure chart

The DSMS chart structure consists of four subprograms, 1) durian dataset creation, 2) image acquisition, 3) sweetness evaluation, and 4) results visualization, as shown in Figure 5. The durian dataset creation subprogram consists of three sub-routines, video frame extraction, training & testing dataset, and dataset validation sub-routines. An image acquisition sub-routine was used to receive durian pulp imagery. The sweetness evaluation subprogram is used to evaluate the range of durian sweetness in ºBrix units. Finally, the results illustration subroutine is used to visualize sweetness from the durian image. The DSMS architecture is shown in Figure 5.

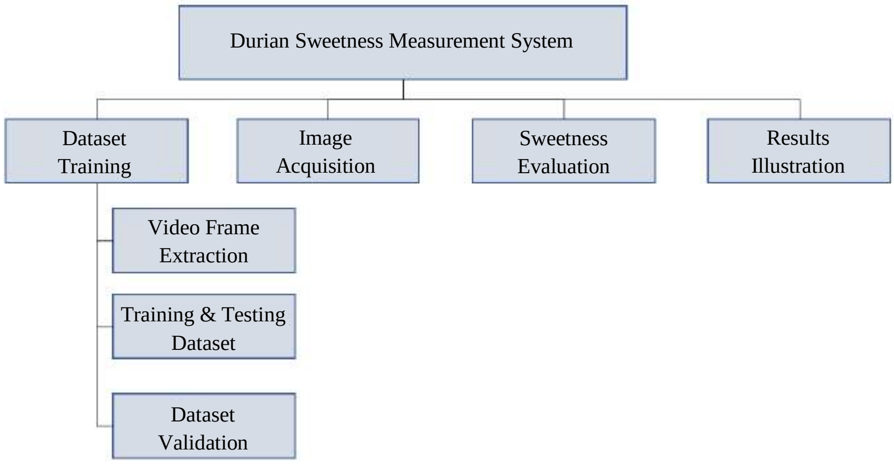

Figure 5 DSMS architecture

2.7.1 Dataset creation subprogram

The DSMS employs ResNet50 to train and test the dataset. ResNet50 is self-learning with a powerful method for image recognition [23]. The DSMS recorded 102 durian pulps from different angles in 102 video clips as each durian pulp was rotated through 360º. Each video clip was taken in full HD using an MP4 file format, with a resolution of 1920 x 1080 x 3 (pixel-width x pixel-height x plane). Normally, the video clip contains 32 frames/sec. There are 1,920 video frames if the system operates for one minute (32 x 60 = 1,920). The DSMS employed a refractometer to measure all 102 pulp sweetness values, taken in the left, middle and right pulp areas. Therefore, each durian image in this system had three associated sweetness values. The DSMS recorded a durian image file name and the three sweetness values, saving them to an Excel file.

2.7.1.1 Video frame extraction sub-routine

The DSMS employed 102 durian pulps, each in a separate video clip, then extracted data from 960 frames of the video clip. Totally, the DSMS conducted the experiment with 97,920 video frames containing durian images, which were saved in a .JPG file format. For each of the 960 video frames, the DSMS randomly selected 100 odd frame numbers for a training dataset and 100 even frame numbers for a validation dataset.

2.7.1.2 Training and testing sub-routine

The DSMS was trained on 10,200 video frames (102 x 100), from which 80% were randomly selected (10,200 x 0.8 = 8,160 frames). The remaining 20% (10,200 x 0.2 = 2,040 frames) were used for testing. Researchers can use durian images or extract durian video frames in any image size, and then use ResNet50 to train or test using durian imagery. ResNet50 resized all training and testing durian images to 224 x 224 x 3 pixels (width x height x plane).

2.7.1.3 Validation sub-routine

The DSMS employed 10,200 video frames (102 x 100) for validating the ResNet50. All the validating video frames were stored in an Excel file. The DSMS employed both MATLAB and Excel software to validate ResNet50 performance.

2.7.2 Image acquisition subprogram

The DSMS used cell phone camera images of durian pulp. The durian in this research was classified into three storage stages, young (1-3 days after harvest), mature (4-7 days after harvest) and ripe (more than 7 days after harvest), as shown in Table 4. The mature stage is suitable for consumption because the durian pulp is firm, not too hard or soft. Samples of young, mature and ripe durian stages are shown in Figures 6 (a)–(c), respectively.

Table 4 Comparison among young, mature and ripe durian stages

Stage	Post-harvest	Sweetness (ºBrix)	Pulp condition	Color
young	1-3 days	14 - 19	hard	yellow + green
mature	4-7 days	20 - 26	firm	yellow + gold
ripe	over 7 days	27 - 31	soft	yellow + orange

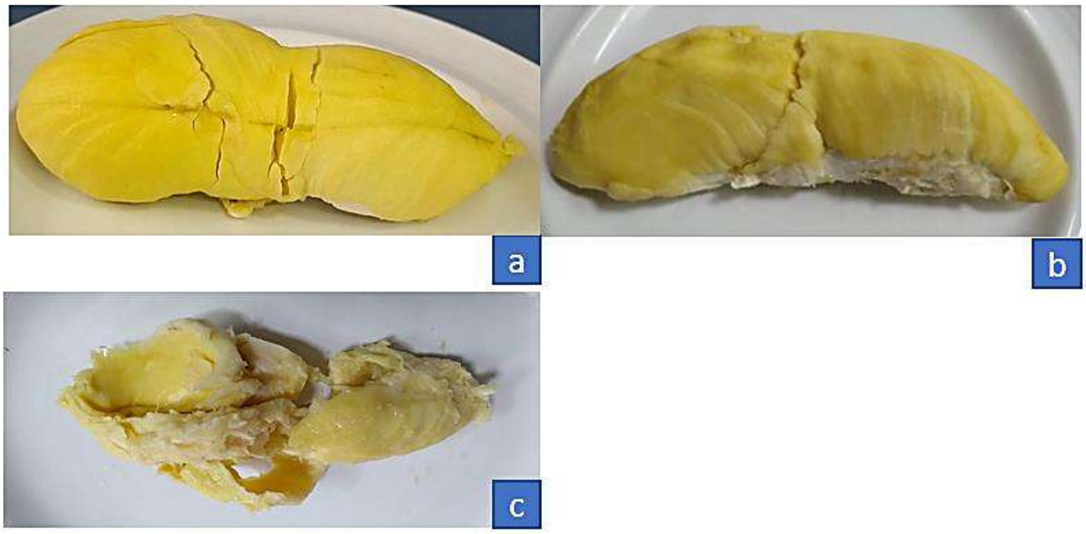

Figure 6 Durian samples of three storage stages in the DSMS (a) young, (b) mature, (c) ripe

2.7.3 Sweetness evaluation subprogram

The DSMS employed ResNet50 for training a durian dataset and also used it to validate durian sweetness by matching an input durian image with all durian images in the training dataset. The DSMS recorded durian images and associated sweetness values (left, middle and right pulp areas) and saved them to an Excel file. Finally, the DSMS illustrated the best image matching to the DSMS graphical user interface (GUI) according to the sweetness value.

2.7.4 Results illustration subprogram

The DSMS shows sweetness evaluation results *via* a graphical user interface (GUI). There are three components in the GUI, a graphics-window, text-boxes and push-buttons, as shown in Figure 7. Each component is described as follows.

The three graphical windows are 1) a graphics-window showing the durian pulp input image, 2) a graphics-window showing the matching durian pulp image, and 3) a graphics-window showing sweetness evaluation results, respectively labelled 1 to 3 in Figure 7. A check-box ☑ symbol is used to represent a correct evaluation while an x-box ☒ represents an incorrect evaluation.

Six text-boxes are show, 1) the input path and filename, 2) the input durian's actual sweetness, 3) the input durian's minimum sweetness evaluation, 4) the input durian's maximum sweetness evaluation, 5) the matching folder name, and 6) the average retrieval time. These are, respectively, labelled 4 to 9 in Figure 7.

The five push-buttons are 1) the get image button to retrieve the input image, 2) the clear button for deleting all GUI values, 3) the actual button to display an input durian image's actual sweetness, 4) the evaluate button to assess an input durian's sweetness from its image, and 5) an exit button to stop the DSMS. These are shown as labels 10 to 14 of Figure 7, respectively.

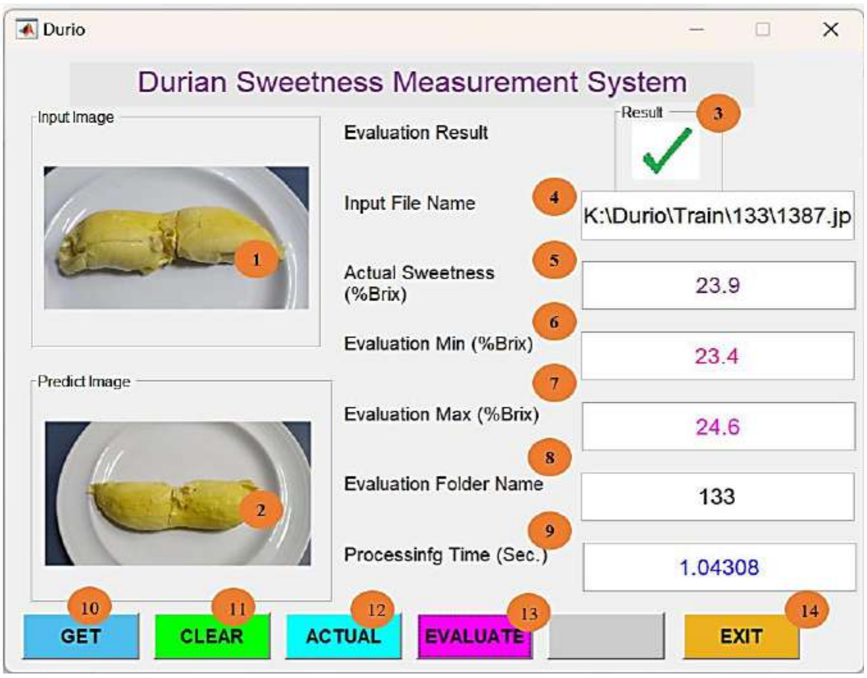

Figure 7 The DSMS graphical user interface

2.8 Accuracy values

Accuracy, precision, recall and F1-scores were used to compare the performance of seven CNN structures, the AlexNet, GoogleNet, Inception V3, ResNet18, ResNet50, ResNet101 and VGG16. The accuracy, precision, recall and F1-score equations are as follows.

2.8.1 Accuracy statistical value

The accuracy value, defined in Equation 1, is the ratio of the number of images matching the correct value and the total number of images.

$$Accuracy = \frac{TP+TN}{TP+FP+TN+FN} \quad (1)$$

2.8.2 Precision statistical value

The precision value is the number of true positives divided by the number of true positives plus the number of false positives, as shown in Equation 2.

$$Precision = \frac{TP}{TP+FP} \quad (2)$$

2.8.3 Recall statistical value

A recall value is the capability of the system to associate an image to other relevant images within a dataset. The recall value is defined as the number of true positives divided by the number of true positives plus the number of false negatives, as shown in Equation 3.

$$Recall = \frac{TP}{TP+FN} \quad (3)$$

2.8.4 F1-score statistical value

The F-score is a harmonic mean of precision and recall. It can be interpreted as a weighted average of the precision and recall. This parameter is shown in Equation 4.

$$F1 - Score = \frac{2\ X\ Precision\ X\ Recall}{Precision+Recall} \quad (4)$$

3. Results

The DSMS used 17 pulps weighing 14.1 kg with 102 video clips of Monthong durian, each having 100 images. Consequently, there were 10,200 images for training the durian dataset using ResNet50, with an average accuracy rate of 97.57%. The training time for the durian dataset was 248.75 sec or 4 min and 8.75 sec. The confusion matrix for training the ResNet50 had 10,004 (102 x 102 x 0.9616) true positive (TP) values, 400 (102 x 102 x 0.0384) false positive (FP), 400 false negative (FN) and 1,050,404 (102 x 102 x 102 – (10,004 + 400 + 400)) true negative (TN), as shown in Table 5. The DSMS also employed 10,200 images of the same 102 durian pulps but recorded imagery under different conditions and from various angles. This was done to validate the ResNet50's pre-training of the DSMS dataset, with an average accuracy rate of 96.54%. The confusion matrix for the ResNet50 validation had 10,044 (102 x 102 x 0.9654) true positive values, 360 (102 x 102 x 0.0346) false positives, 360 false negatives and 1,050,444 (102 x 102 x 102 – (10,044 + 360 + 360)) true negative values, as shown in Table 6. The average access time for evaluating durian sweetness was 1.5248 sec/image.

Table 5 DSMS training confusion matrix

	Actual class	
	Positive	**Negative**
Prediction Positive	10,004 (TP)	400 (FP)
Prediction Negative	400 (FN)	1,050,404 (TN)

Table 6 DSMS validation confusion matrix

	Actual class	
	Positive	**Negative**
Prediction Positive	10,044 (TP)	360 (FP)
Prediction Negative	360 (FN)	1,050,444 (TN)

The accuracy and loss graphs for training the ResNet50 are shown in Figures 8 (a) and 8 (b), respectively. The setting parameters for training the ResNet50 have an epoch per iteration, a 0.01 learning rate and a maximum of 16 epochs. Based on the experimental results, correct and incorrect sweetness evaluation results are illustrated in Figures 9 (a) and (b), respectively.

Figure 8 Accuracy and loss curves for training the ResNet50 in the DSMS

In Figure 9 (a), the actual sweetness is 23.9 ºBrix, but the evaluated sweetness is 23.4–24.6 ºBrix. In Figure 9 (b), the actual sweetness is 25.1 ºBrix, but the evaluated sweetness is 26.4–27.8 ºBrix.

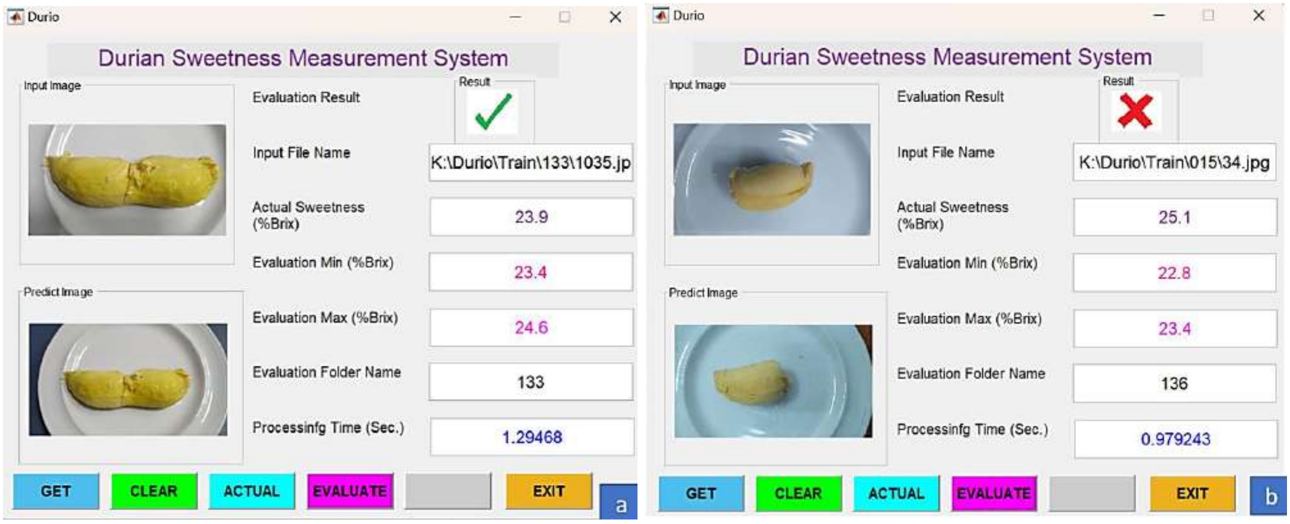

Figure 9 DSMS GUI screens for (a) correct, and (b) incorrect evaluations

Moreover, the DSMS employed four statistical values for checking the system performance, 1) accuracy, 2) precision, 3) recall, and 4) F1-score. All statistical values were calculated from the confusion matrix from its 1) true positive (TP), 2) false positive (FP), 3) true negative (TN), and 4) false negative (FN) values. Each statistical value has the following details [14].

This research was conducted on seven different convolutional neural networks, 1) Alex Net, 2) Google Net, 3) InceptionV.3, 4) ResNet18, 5) ResNet50, 6) ResNet101, and 7) VGG16, all using the same DSMS dataset. These seven different convolutional neural network types are supported by the MATLAB 2020b version. Comparisons of accuracy, precision, recall, F1-score follow Equations 2.1–2.4, respectively. Training times in seconds are shown in Table 7. VGG16 requires the longest time, while ResNet50 has the shortest time for training the dataset. AlexNet gives the lowest accuracy and ResNet50 yields the highest accuracy rates. Therefore, this research employed ResNet50 in subsequent experiments.

Table 7 Performance comparison among various CNNs

CNN	Accuracy	Precision	Recall	F1-Score	Time (sec)
Alex Net	0.3394	0.6079	0.3394	0.4355	197.5707
Google Net	0.9683	0.9695	0.9683	0.9689	511.1819
Inception V3	0.9556	0.9574	0.9556	0.9565	1,072.6000
ResNet18	0.9519	0.9531	0.9519	0.9525	683.8742
ResNet50	**0.9757**	**0.9743**	**0.9757**	**0.9730**	**461.2567**
ResNet101	0.3880	0.5443	0.3880	0.4223	1,170.1000
VGG16	0.4622	0.6179	0.4622	0.5288	1,911.7000

4. Discussion

This section examines three factors impacting durian sweetness, 1) production of liquid durian samples, 2) Monthong durian's sweetness comparison using various techniques and equipment, and 3) fruit sweetness measurements in earlier research.

4.1 Durian liquid production

Earlier researchers determined durian sweetness using total soluble solids (TSS) measurements. Sangpong et al. [9] homogenized 20 mg of durian in 200 µL of distilled water. The homogenate was centrifuged at 14,000 g at 18° C for 20 min. After that, a digital refractometer (Hanna Instruments, RI, USA) was used to measure durian sweetness. Sharma et al. [12] mixed 5 g of durian with 15 g of distilled water in an aluminum container having a diameter and height of 5 cm and 3 cm, respectively, followed by swirling and refrigerating the mixture. Then, the clear fraction the durian supernatant was measured for its sweetness using a digital pen refractometer (Atago Co. Ltd., Tokyo, Japan). Niponsak et al. [18] blended one part of fresh durian with three parts of water on a mass basis, and then centrifuged this sample for 20 min at 5,000 g. After that, they measured durian sweetness using a hand-held refractometer (Atago Co. Ltd., Tokyo, Japan). The TSS method is too complex for field measurements of durian sweetness as it requires a fully equipped laboratory.

Some researchers employed simpler methods to produce liquid durian than a TSS method. Prasetia et al. [16] squeezed fresh durian to produce liquid samples and then used a pocket refractometer (Atago Co. Ltd., Tokyo, Japan) to measure its sweetness. The current research crushed durian to produce liquid samples, then used a refractometer (Atago Co. Ltd., Tokyo, Japan) to measure sweetness.

4.2 Monthong durian sweetness comparison using various methods

Durian sweetness is a key factor to determine its quality, including its taste [8]. Researchers have employed various equipment and techniques to evaluate durian sweetness, as shown in Table 8. Xiao et al. [8] found Monthong durian sweetness to be ~22.03 ºBrix. Pokhrel et al. [11] evaluated Monthong durian sweetness as <22 ºBrix for raw (young) durian, 22–28 ºBrix for mature durian, and >28 ºBrix for ripe durian. Arsa et al. [17] measured Monthong durian sweetness as 24.90 ºBrix. Niponsak et al. [18] showed Monthong durian sweetness of around 23.58 ºBrix. Our experimental results are similar to durian sweetness measurements in earlier research, with young, mature and ripe durians having average sweetness values of 15.81, 21.65 and 28.47 ºBrix, respectively.

4.3 Fruit sweetness measurements

Earlier researchers employed image processing techniques to evaluate sweetness of several fruit types. Ittatirut et al. [24] employed an artificial neural network (ANN) to evaluate apple sweetness. The experiments were conducted using MATLAB software on 1,248 apple images, with an average precision rate of 84.34%. Chomtip et al. [25] evaluated (Musa acuminata Triploid AAA, Cavendish) banana or Kluay Hom Thong (its Thai name) sweetness using color and textural features. The developed system employed the Euclidean distance method to conduct the experiments on 1,682 banana images, with an average precision rate of 99.27%. Therefore, the DSMS employed a CNN, which is one of the most powerful techniques for image processing, to recognize and evaluate durian sweetness, with an average accuracy of 97.57%.

Table 8 Comparison among various methods of measuring durian sweetness

Author	Durian species	ºBrix	Methods/Equipment	Sample size
Tagubase et al. [3]	Puyat	18.33	HPLC-RID (Chromatography)	50 fruits
	Duyaya	14.60		
	GD69	18.40		
	Native	19.43		
	Arancillo	20.47		
Xiao et al. [8]	Black Thorn	22.33	HPAEC-PAD and Electronic tongue	n/a
	Musang Kung	22.03	(TS-5000Z, Insent Company, Japan)	
	Monthong	21.02		
Pokhrel et al. [11]	Monthong			
	Mature	>28	Dry matter content and refractometer	415 pulps
	Moderately mature	22-28		
	Immature	<22		
Arsa et al. [17]	Monthong	24.90	TSS and refractometer	15 fruits
	Chanee	25.11		
	Kanyao	25.42		
Niponsak et al. [18]	Monthong	23.58	TSS and hand-held refractometer	n/a
Current Study	Monthong			
	Young	15.81	Crush and squash and refractometer	4 fruits
	Mature	21.65		17 pulps
	Ripe	28.47		102 videos

5. Conclusion

The DSMS fulfills the objective of this research, which is to develop a computer system for evaluating durian sweetness using only a single image. Its dataset consists of 102 durian pulps and 20,400 of their images, 10,200 images for a training dataset and the remaining 10,200 images for a validation dataset. The average accuracy rates of the system are 97.57% for training the dataset and 96.54% for the system validation. Average access time of the system is 1.5248 sec/image. The DSMS also compares its performance with that of various kinds of CNNs and the experimental results show a state-of-the-art image-based durian sweetness evaluation.

This research can help traders, farmers and consumer groups to evaluate durian quality with a single image before trading their durian. Researchers can apply techniques in this research to measure the sweetness of other kinds of fruits, such as oranges, rambutans, lynchee, longkong, sugar apples, papaya, jackfruit, and guava, among others. A mobile phone application based on this research can be developed.

The limitation of this research is primarily the expense of durian to conduct the experiments. The researchers need not only more pulps for a durian training dataset but also more species to build a larger dataset. Normally, large datasets have higher precision than smaller ones. Moreover, farmers will have more confidence in a larger durian dataset.

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7. References

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