Research Article

Image Analysis based on Color, Shape and Texture for Rice (*Oryza sativa L.*) Seed Ageing Evaluation System

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ABSTRACT

The objective of this research is to develop a computer system, which can evaluate rice-seed ageing. The system called "rice seed ageing evaluation system or (RiSAES)", evaluated the rice (Oryza sativa L.) seed ageing by using an image processing technique. The RiSAES consists of five modules, namely: 1) image acquisition, 2) image pre-processing, 3) feature extraction, 4) seed ageing evaluation and 5) result presentation. The RiSAES employed color, shape and texture features of rice-seed images to evaluate the ageing. The system applied the artificial neural network (ANN) and convolutional neural network (CNN) to perform the evaluation. The system precision rates are 81.29% and 80.89% for ANN and CNN, respectively. The average evaluation time for ANN is 0.0528 seconds/image and for CNN is 1.6006 seconds/image.

Keywords: Artificial neural network, Color feature, Convolutional neural network, Rice-seed ageing, Shape feature, Texture feature.

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Introduction

Rice is a major food for more than half of the world citizens, especially in Asian, South-American and African, countries [1]. In Thailand, farmers can cultivate two to three rice crops throughout the year. The previous cropping rice-seed considers the ageing or old rice-seed. People measure ageing rice-seed for three main reasons. First, for farmers, the fresh rice-seeds generate more production than aged rice-seeds [2-3]. Second, for consumers, people in South-Asia like aged rice cooking but those in Northeast-Asia like new rice cooking [1]. Finally, for merchants, old rice-seed secures a better price than fresh rice-seed [4]. Scientists and researchers applied various non-destructive techniques, namely 1) near infrared detection, 2) sensor detection and 3) digital image processing techniques to evaluate a rice-seed ageing. Each technique has the following brief details.

Near infrared detection

Li *et al.* used visible/near infrared reflectance (Vis/NIR) to identify rice- seed storage in four time-periods, from 1 year to 4 years. The experiment conducted on 170 images for the training dataset and 40 images for the testing dataset. The proposed chemometrics integrate three techniques, namely, 1) wavelet transform (WT), 2) principal component analysis (PCA) and 3) artificial neural network (ANN) with the precision rate of 97.5% [5].

He *et al.* employed near-infrared hyperspectral image (NIR-HIS) to measure 2,400 rice-seeds vitality in three different years (2015-2017). The experiment employed near infrared in eight wavebands (992, 1012, 1119, 1167, 1305, 1402, 1629 and 1649) for speed and cost effectiveness for the rice-seed measuring system. The developed system employed principal component analysis (PCA) combined with Savizky-Golay (SG) pre-processing algorithm with the precision rate of 94.38% [6].

Sensor detection

Guan *et al.* presented gas chromatography mass spectrometry (GC-MS) to investigate the volatile organic compound (VOC) of rice samples in four periods of time (1, 2, 6 and 12 months). The experimental results indicated 85% [7].

Lin *et al.* applied a colorimetric sensor array based on boron-dipyrromethene (BODIPY) dyes to monitor the organic compounds of rice-seeds in 4 different storage times, which are 1, 3, 7 and 10 month periods. The developed system applied principle component analysis (PCA) and linear discriminant analysis (LDA) to evaluate 20 samples of rice-seeds and 10 samples for testing rice-seed ageing with the precision rate of 94.21% and 98.75 %, respectively [8].

Lin *et al.* employed a colorimetric sensor array on stored rice with COMSOL multi-physics software. The fresh and aged rice sample were 100% identified by principal component analysis (PCA) with designed chamber and 90% by free volatilization chamber [9].

Digital Image processing

Liu, inspected fresh and old rice-seeds by using red-green-blue (RGB) and hue-saturation-intensity (HSI) color. The experiment measured the average RGB and HSI color of fresh and old rice-seeds. The average RGB and HSI colors of fresh rice-seeds are 153-156 for red, 154-157 for green, 44-142 for blue, 60-65 for hue, 5-7 for saturation and 147-153 for intensity. The average RGB and HSI colors of old rice-seeds are 90-99 for red, 89-97 for green, 74-87 for blue, 54-60 for hue, 8-12 for saturation and 84-94 for intensity [10].

Bejo and Sudin applied a digital image processing method to identify mature and immature rice-seeds. The experiment was conducted on 78 Malaysia paddy samples (MR219) with 10 grams each, within 48 hours after harvest. The precision of the classification system is 96.15% [11].

Anami *et al.* illustrated a color-based approach to classify rice-seed ageing in five different periods, namely, 1, 3, 6, 9 and 12 months. The experiment conducted on fifteen paddy varieties and their ageing periods with 3,750 images for the training dataset and 3,750 images for the testing the system. The ageing classification system employed the back-propagation neural network (BPNN) with the precision rate of 93.15% [12].

Based on the previous researches, there is no doubt that image processing is one of the best methods to measure rice-seed ageing because it is a nondestructive method and easily accessible for the farmers. This research is extended from Lurstwut and Pornpanomchai research in rice seed germination evaluation by image processing technique [13]. There are four important factors for evaluated rice-seed ageing, which are 1) rice-seed species, 2) evaluation technique, 3) period interval of rice-seed and 4) the size of experimental dataset. Therefore, the objective of this research is to develop a computer system, which can help people to measure rice-seed ageing by image processing method. The details of the RiSAES is described in the next section.

Materials and Methods

The RiSAES was developed on the following computer hardware and software. The Intel(R) Core i5™ 6500 CPU @ 3.2 GHz (Intel's headquarters is in Santa Clara, CA, USA) was used as the central processing unit and Windows 10 was the software system (Microsoft Corp.; Redmond, WA, USA). The MATLAB R2020b (The Math Works Inc.; Natick, Massachusetts, USA) with license number 40598465 was the developing software. The digital cameras used in this research were the Huawei Y9 (Huawei Technologies Co., Ltd., Shenzhen, China). The Thai rice (*Oryza sativa L.*) seeds in this research are called “khao hom pha thum”.

Conceptual diagram

The RiSAES conceptual diagram starts with a user using a mobile phone to take a rice-seed image. Then the rice-seed image is submitted to a computer system for evaluating the seed ageing. After that, the system compares the rice-seed image with all rice-seed images in the system database. Finally, the RiSAES displays the evaluation ageing results, as shown in Figure 1.

System structure chart

The RiSAES system structure chart is composed of five main modules, namely: 1) image acquisition, 2) image modules, 3) feature extraction, 4) seed ageing evaluation and 5) result presentation. Each module has the following details.

Image acquisition

This module captures rice-seed images, which are arranged on a plastic-tray in three rows and four columns, as shown in Figure 3. Each rice-seed is labeled by using row number and column alphabet in an electronic spreadsheet style. The rice-seed images are taken with an un-controlled environment in 20 week periods and the format of the input image should be a .JPG file.

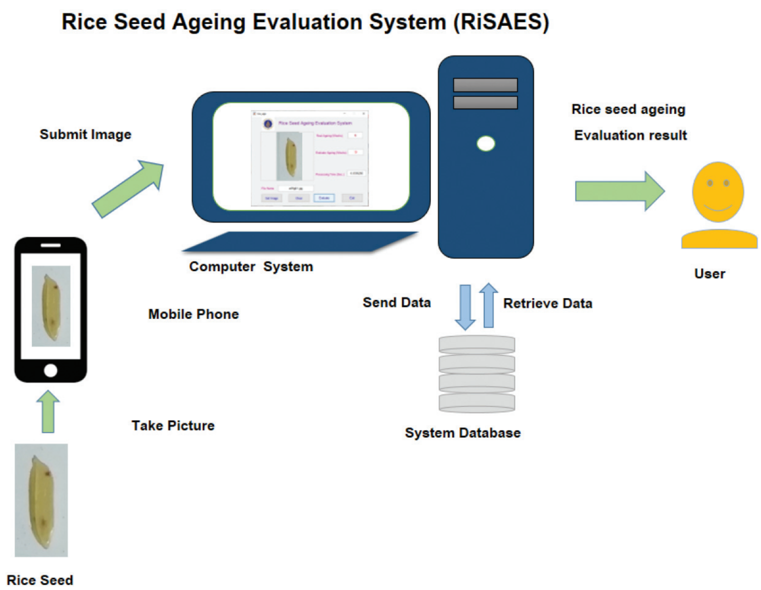

Figure 1 The RiSAES conceptual diagram

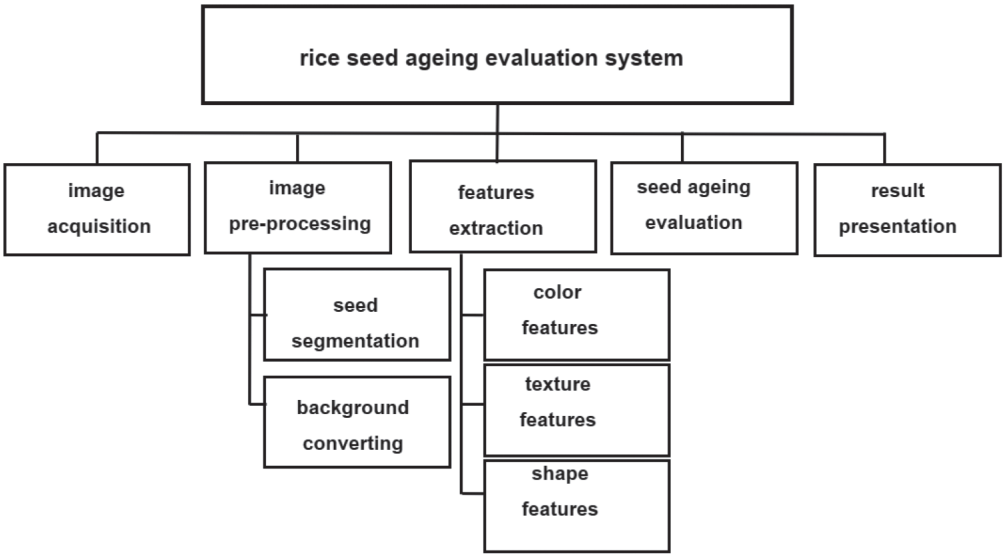

Figure 2 The RiSAES system structure chart

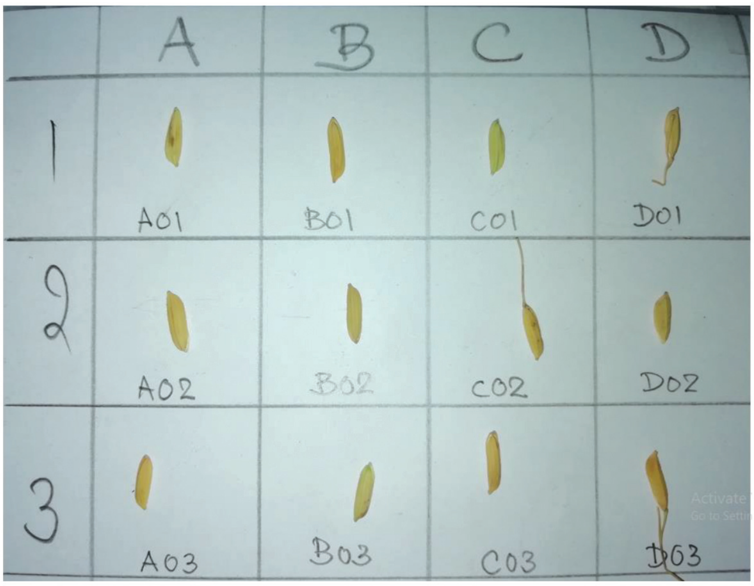

Figure 3 an arrangement of rice-seed images in RiSAES

Image preprocessing

The image pre-processing module consists of two sub-modules, which are image segmentation and image background conversion. Each sub-module has the following details.

Image segmentation

This sub-module manually segments the rice-seed images into an individual seed image. The segmentation images of the rice-seed labelled A12 between the first week to the twentieth week are shown as Figure 4 (a) to Figure 4 (t), respectively.

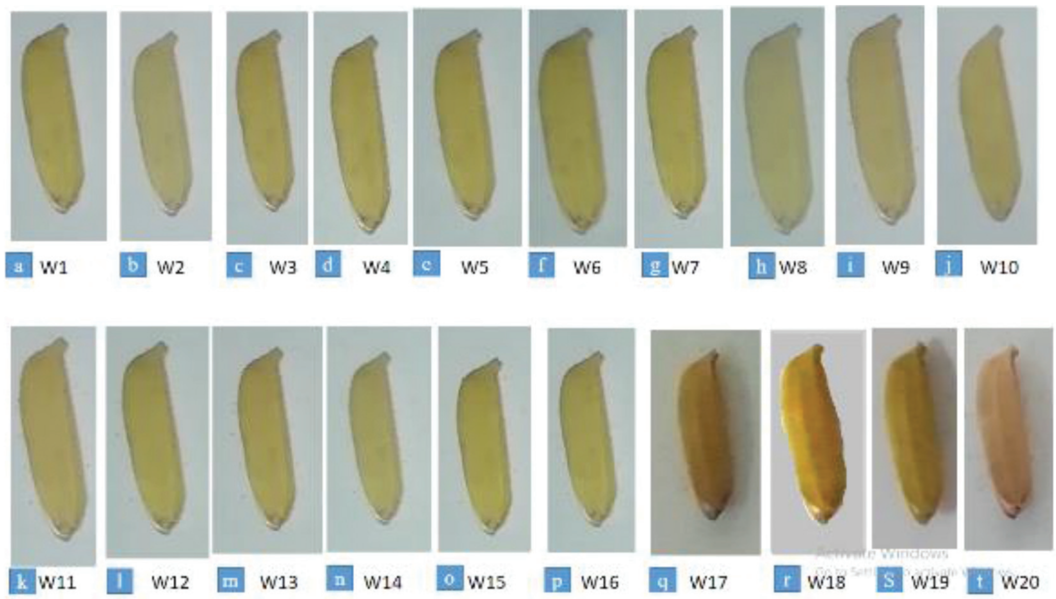

Figure 4 the images of the same rice-seed between twenty week

Background conversion

This sub-module converts the background of the segmentation rice-seed to a black color. A rice-seed after segmentation is shown in Figure 5 (a) and the rice-seed on a black background is shown in Figure 5 (b). The black color has red-green-blue (RGB) values equal to zeroes. The zero value has no effect when the system calculates the mean of RGB color.

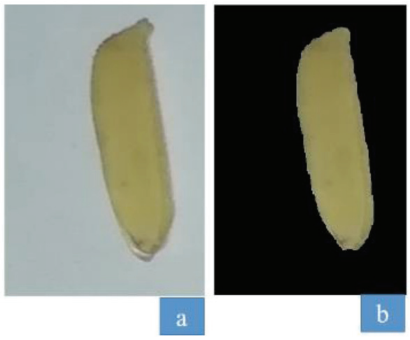

Figure 5 (a) a segmentation rice-seed (b) the rice-seed on the black background

Feature Extraction

The RiSAES employs three rice-seed main features, which are color, texture and shape features. The color feature consists of seven feature-values. The texture feature consists of five feature-values and shape feature contains eight feature-values. Each feature has the following details.

Color feature extraction

Many researchers illustrated color features to identify the rice-seeds. For example, Srikaeo and Panya presented the L^*, a^*, b^*, color level for measuring rice-seeds during 1 month to 6 month ageing [14]. Liu evaluated rice-seed ageing by red-green-blue (RGB) and hue-saturation-intensity (HSI) color [10]. Therefore, the RiSAES employed seven color features, namely: 1) mean of the red color, 2) mean of the green color, 3) mean of the blue color 4) mean of the gray color, 5) mean of lightness (L^*), 6) mean red-green component of a color (a^*) and 7) mean yellow-blue component of a color (b^*).

Texture feature extraction

Keawpeng and Venkatachalem, and Zhou *et al.* presented rice-seed texture as one attribute to measure rice-seed ageing [1, 15]. Therefore, the RiSAES applies MATLAB with the gray-level co-occurrence matrix (GLCM) represented by $P_{i,j}$ in five texture features, namely: entropy, energy, correlation, contrast and homogeneity. The short description and formula of each statistical value is shown in Table 1.

Table 1 The GLCM statistics and explanation.

Statistic	Short description	Formula
Entropy	Measures the disorder of an image and it achieves its largest value when all elements in P matrix are equal.	$\sum_{i\,j}^{N} P_{(i,j)} * Log_2 P_{(i,j)}$
Energy	Measures the uniformity of the texture that pixel pairs represent.	$\sum_{i,j=0}^{N-1} (P_{i,j})^2$
Correlation	Measures the linear dependency of gray levels on those of neighboring pixels.	$\sum_{i,j=0}^{N'1} P_{ij} \frac{(i-\mu)(j-\mu)}{\sigma^2}$
Contrast	Measures the local variations in the gray-level co-occurrence matrix.	$\sum_{i,j=0}^{N-1} \lvert i-j \rvert^2 * P_{ij}$
Homogeneity	Measures the local variations in the gray-level co-occurrence matrix. Measures the smoothness of the gray level distribution of the image.	$\sum_{i,j=0}^{N-1} \frac{P_{ij}}{1+(i-j)^2}$

$P_{(i,\,j)}$ is the entry in a normalized gray-tone spatial-dependence matrix
n is the number of distinct gray levels in the quantized image.
μ_i, μ_j, σ_i and σ_j represents the mean and standard deviations of $P_{(i,\,j)}$.

Shape feature extraction

Finally, the RiSAES applied eight shape features, namely: 1) major axis length, 2) minor axis length, 3) the aspect ratio calculated by the major axis length divided by minor axis length, 4) rice-seed perimeter, 5) rice-seed area, 6) perimeter and area ratio, 7) counting of white pixels of the Sobel edge detection and 8) counting of white pixels of the Canny edge detection.

The calculations of 20 features in Figure 5 (b) are:

1) mean red color = 32.7840
2) mean green color = 31.3144
3) mean blue color = 19.2659
4) mean gray color = 30.3632
5) mean L^* color = 12.5866
6) mean a^* color = 01.2652
7) mean b^* color = 06.5653
8) entropy = 1.6040
9) energy = 0.6467
10) correlation = 0.9784
11) contrast = 0.1134
12) homogeneity = 0.9915

13) major axis length = 263.6837
14) major axis length = 75.6815
15) aspect ratio = 3.4841
16) perimeter = 574.6840
17) area = 15363.00
18) area-perimeter ratio = 26.7330
19) Sobel edge = 240.00
20) Canny edge = 667.00

Rice-seed ageing evaluation

The RiSAES employed two neural network techniques, namely feed-forward artificial neural networks (ANN) and convolutional neural networks (CNN) or deep-learning method to measure a rice-seed ageing. The architecture of the artificial neural networks that the researchers have chosen to use consists of twenty input nodes, two-hundred-fifty-six hidden nodes and twenty output nodes (as shown in Figure 6). The twenty input nodes are the number of 20 features of a rice-seed image and the twenty output nodes are the results to show number of weeks after harvest between the first week to the twentieth week. The number 256 hidden nodes based on the experimental results.

This research employed the ResNet50 in the MATLAB toolbox pre-trained convolutional neural network. The ResNet50 contains fifty layers, which can train and match more than a million images. Erdem et al. illustrated the ResNet50 architecture as shown in Figure 7 [16]. The ResNet50 convolution neural network architecture consists of the input image layer connected to a set of feature extraction layer, which consists of convolution layer and visualization target. After that, the feature extraction layer sent the data to the fully connected layers to the classification result at the end. This research feeds a rice-seed image for the CNN input and gets a matching result from classification result.

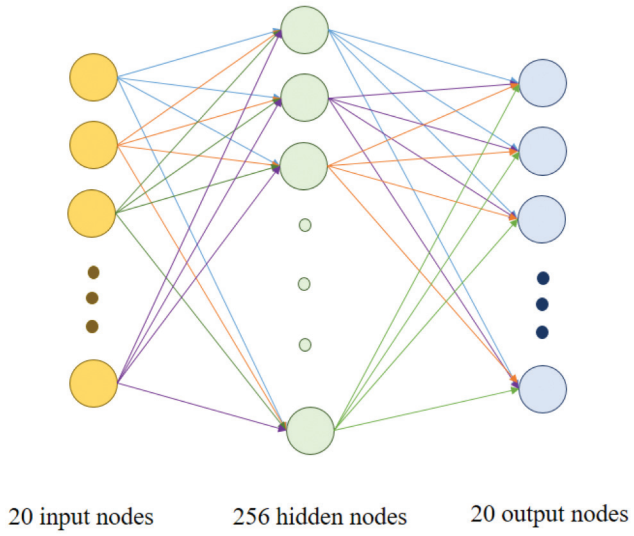

Figure 6 The artificial neural networks (20-256-20) structure in this research

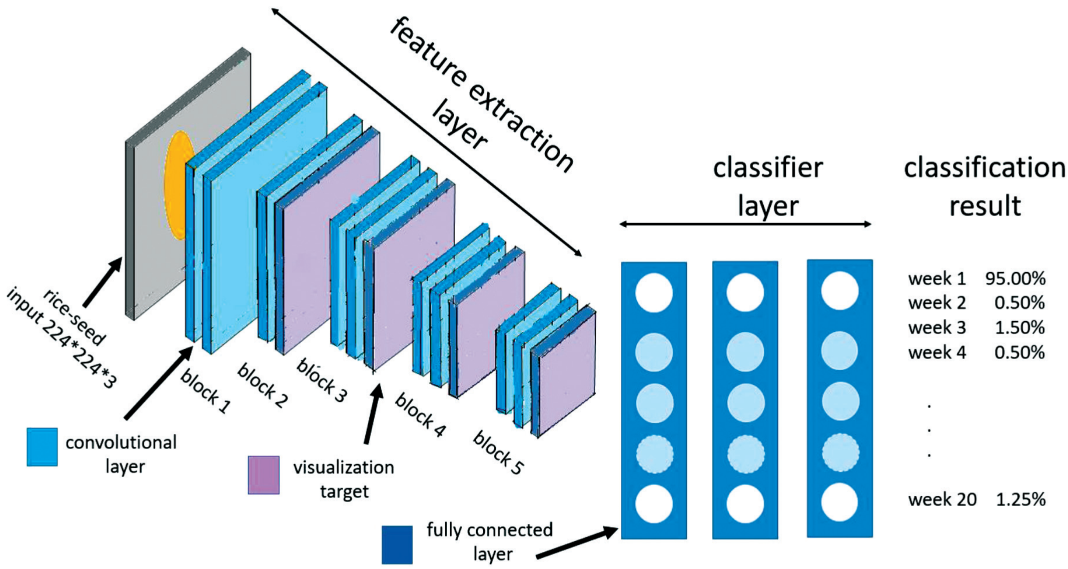

Figure 7 The convolutional neural networks structure in this research

Result Presentation

This section shows the rice-seed ageing evaluation results. The RiSAES graphic user interface (GUI) consists of a display graphic window to show an evaluated rice-seed, four display text boxes and four push buttons as shown in Figure 8. The RiSAES graphic user interface has the following details.

The display graphic window shows a close-up of a rice-seed-image, shown as Figure 8, label 1. The four display text boxes have the following details:

1. The display of the real rice-seed ageing result box as shown in Figure 8, label 2
2. The display of the evaluated rice-seed ageing result box as shown in Figure 8, label 3
3. The display of the processing time value as shown in Figure 8, label 4
4. The display of the rice-seed file name as shown in Figure 8, label 5

The four push buttons have the following details:

1. The get image button for getting a rice-seed image as shown in Figure 8, label 6
2. The clear button for clearing all RiSAES system values as shown in Figure 8, label 7
3. The evaluation button for analyzing a rice-seed ageing as shown in Figure 8, label 8
4. The exit button for exiting the system as shown in Figure 8, label 9.

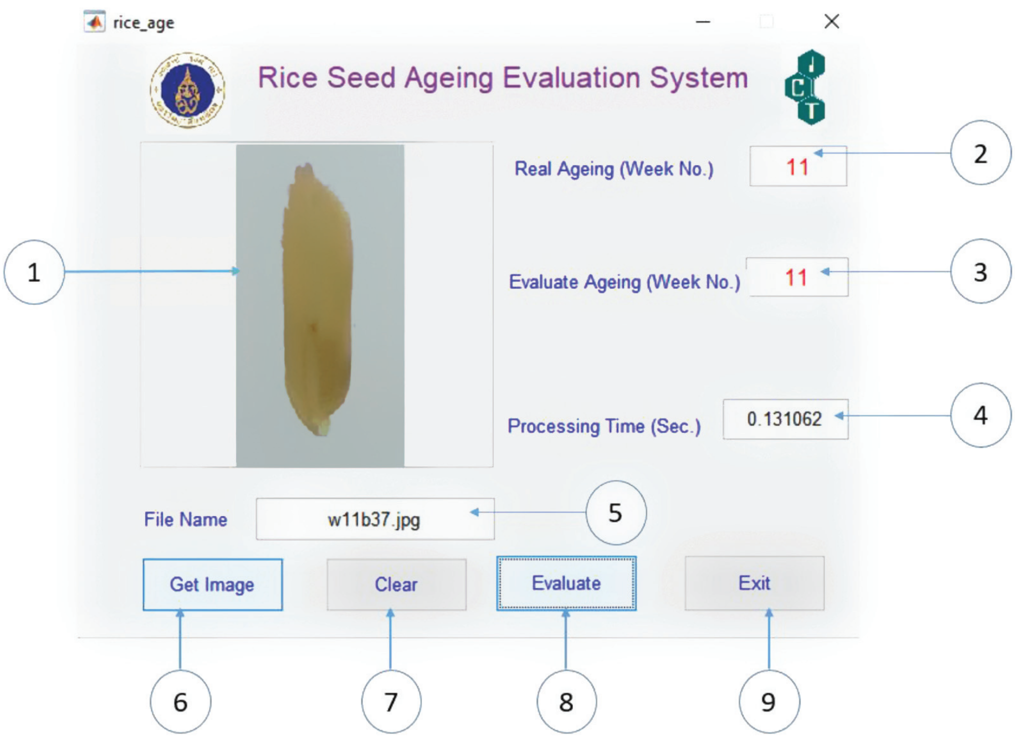

Figure 8 the graphic user interface of RiSAES

Results and Discussion

Experimental results

The RiSAES conducted the experiment with a simple mobile phone camera, so farmers can easily access the equipment. There are 8,400 Thai rice-seed (*Oryza sativa L.*) images in the system dataset, in which 420 images per week were taken during 20 weeks (during 30 September 2019 to 5 February 2020, in Bangkok, Thailand). The RiSAES employed an artificial neural network (ANN) and the ResNet50 (CNN) to evaluate rice-seed ageing. The three evaluation periods are ± 0 or 1 week duration time, ± 1 or 2 weeks duration time and ± 2 or 1 month duration time. The precision rates for evaluating by the ANN in three different time intervals are 65.29%, 74.01% and 81.33%, respectively and by the CNN are 57.08%, 70.97% and 80.89%, respectively (as shown in Table 2).

Table 2 The precision rates comparison between ANN and CNN.

Time interval	Ann (%)	CNN (%)
± 0 (1 week)	65.29	57.08
± 1 (2 weeks)	74.01	70.97
± 2 (1 month)	82.38	80.89

Moreover, the training time for the rice-seed dataset of the ANN is 5.4298×10^{5} seconds or 6 days, 6 hours, 49 minutes and 40 seconds and the CNN is 1.9035×10^{4} seconds or 5 hours, 17 minutes and 15 seconds, as shown in Table 3. The average evaluation time for the ANN is 0.0529 seconds/image and the CNN is 1.6006 seconds/image (as shown in Table 3).

Table 3 Training time and average evaluation time comparison between ANN and CNN.

Time	ANN	CNN
Training dataset (seconds)	5.4298×10^{5}	1.9035×10^{4}
Average evaluation time (seconds/image)	0.0529	1.6006

The RiSAES employed a MATLAB function called "confusion.getMatrix" to calculate statistical values for measuring the system performance. The calculation procedures are:

1) construct a multi-class confusion matrix size 20×20 of 8400 rice-seed images, as shown in Table 4. The number 20 is the period between 1-20 weeks after cultivated.

2) convert multi-class confusion matrix to a true positive (tp), false positive (fp), false negative (fn) and true negative (tn), as shown in Table 5.

3) calculate the statistical values, namely: accuracy, sensitivity, specification, precision, of week number 1 to week number 20 by using Equation (1)-(4) [17], as shown in Table 6.

$$\text{accuracy} = (tp+tn)/(tp+fp+fn+tn) \quad (1)$$

$$\text{sensitivity} = tp/(tp+fn) \quad (2)$$

$$\text{specification} = tn/(fn+tn) \quad (3)$$

$$\text{precision} = tp/(tp+fn) \quad (4)$$

4) find an average value of an accuracy, a sensitivity, a specificity and a precision from twenty weeks, which have the following value:

accuracy: 0.8156
sensitivity: 0.8156
specificity: 0.9903
precision: 0.8238

Table 4 A confusion matrix dimension 20×20.

332	0	0	20	3	22	2	0	4	11	7	0	0	0	0	0	0	0	1	0
0	277	0	0	5	11	5	29	53	8	31	0	0	0	0	0	0	1	1	0
0	0	268	0	0	40	33	2	9	21	47	0	1	0	0	0	0	0	0	0
24	0	0	353	0	0	17	0	3	13	10	0	1	0	0	0	0	0	0	0
4	7	0	1	358	0	0	3	1	9	15	8	4	1	10	0	0	0	0	0
14	19	18	1	0	345	0	0	6	7	11	0	0	0	0	0	0	0	0	0
1	13	8	20	1	0	348	0	0	10	19	1	0	0	0	0	0	0	0	0
0	23	0	1	0	0	0	397	0	0	0	0	0	0	0	0	0	0	0	0
1	66	1	0	2	11	0	0	338	0	0	0	0	1	0	0	0	0	1	0
21	29	15	28	12	43	16	0	0	253	0	0	1	0	1	0	0	0	2	0
5	25	9	7	16	17	20	0	0	0	322	0	0	0	0	0	0	0	0	0
0	5	3	2	4	16	4	0	4	0	0	285	0	0	87	8	0	0	3	0
0	0	0	1	0	1	1	0	0	0	0	0	402	0	0	3	1	0	12	0
0	2	0	0	0	1	0	1	2	1	0	0	0	412	0	0	0	0	2	0
0	0	0	0	1	2	2	0	0	0	0	72	0	0	341	0	0	0	3	0
0	0	1	1	0	0	1	0	1	0	0	53	67	0	0	169	0	0	128	0
0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	411	0	1	8
0	0	0	0	0	0	0	0	0	0	3	0	1	1	0	0	0	416	0	0
0	1	0	0	0	0	0	0	0	1	0	0	7	4	0	0	0	1	407	0
0	0	0	0	0	0	0	0	0	0	1	0	0	1	0	0	1	0	0	417

Table 5 Multi-class confusion matrix output

Week number	True Positive	False Positive	False Negative	True Negative
1	332	70	70	7928
2	277	190	144	7789
3	268	55	153	7924
4	353	82	68	7897
5	358	44	63	7935
6	345	164	76	7815
7	348	101	73	7878
8	397	35	24	7944
9	338	83	83	7896
10	253	82	168	7897
11	322	144	99	7835
12	285	134	136	7845
13	402	82	19	7897
14	412	8	9	7971
15	341	98	80	7881
16	169	11	252	7968
17	411	2	10	7977
18	416	2	5	7977
19	407	154	14	7825
20	417	8	3	7972

Table 6 statistical values of each week

Week number	Accuracy	Sensitivity	Specificity	Precision
1	0.03952	0.82587	0.99125	0.826
2	0.03298	0.65796	0.97619	0.593
3	0.03191	0.63658	0.99311	0.83
4	0.04202	0.83848	0.98972	0.811
5	0.04262	0.85036	0.99449	0.891
6	0.04107	0.81948	0.97945	0.678
7	0.04143	0.8266	0.98734	0.775
8	0.04726	0.94299	0.99561	0.919
9	0.04024	0.80285	0.9896	0.803
10	0.03012	0.60095	0.98972	0.755
11	0.03833	0.76485	0.98195	0.691
12	0.03393	0.67696	0.98321	0.68
13	0.04786	0.95487	0.98972	0.831
14	0.04905	0.97862	0.999	0.981
15	0.0406	0.80998	0.98772	0.777
16	0.02012	0.40143	0.99862	0.939
17	0.04893	0.97625	0.99975	0.995
18	0.04952	0.98812	0.99975	0.995
19	0.04845	0.96675	0.9807	0.725
20	0.04964	0.99286	0.999	0.981

Discussion

The difficulty of this system is to evaluate ageing of a same rice-seed image, which is taken in a different period. The characteristics or features of the same rice-seed image are almost the same in a short period, but on the other hand the characteristics of a rice-seed of a long period are more different. For example, the color feature will change from yellow to light brown, the shape feature will reduce from an oval shape to a smaller oval shape and the texture feature will change from a fresh seed texture to a dry seed texture. This is the main reason, why the precision rates of a month period are higher than a week period. The features of long period images are more different than a short period image (as shown in Table 2).

This research employed two different neural network architectures, namely a feed foreword neural network or artificial neural network (ANN) and a convolution neural network (CNN) or deep learning algorithm. Both neural network architectures generated a little different precision rates between three-time intervals. The ANN architecture gives precision rates of 65.29%, 74.01% and 81.33% and the CNN architecture gives precision rates of 57.08%, 70.97% and 80.89% for 1 week, 2 weeks, 1-month period, respectively.

The main difference is the time consumption for training both neural network architectures. The ANN with 20 input nodes, 256 hidden nodes and 20 output nodes (20-256-20) trains more than 6 days but the ResNet50 (CNN) in MATLAB toolbox trains for about five hours. Nevertheless, an average evaluation time of the ANN is 0.0529 seconds/image, faster than the CNN of 1.6006 seconds/image (as shown in Table 3). The ANN uses the whole picture with full connection in every neural-nodes to evaluate a rice-seed ageing. On the other hand, the CNN uses only the part of the image that joins with convolution layers, which connects to the fully connection layer to evaluate a rice-seed ageing. That is the reason why the ANN takes a longer training time than the CNN, but the evaluating times of both neural-networks are very fast, which are less than 2 seconds/image.

Many researchers conducted rice-seed ageing evaluation in many techniques, as shown in Table 7. Liu et al. evaluated only a fresh and an old rice-seed by color and histogram method [10]. Bejo and Sudin evaluated only a mature and an immature rice-seed by taking a group of rice-seed in one image [11]. Anami et al. evaluated a group of rice-seed images between the long periods 1, 3, 6, 9 and 12 months [12]. Lin et al. employed color features to evaluate rice-seeds in 1, 3, 7 and 10 months [9]. There are many factors to evaluate rice-seed ageing, namely:

1) rice-seed species, some researchers used a group of rice images to evaluate but some researchers used a rice seed to evaluate seed ageing. A group rice seeds is easier to evaluate seed ageing than a single seed because color features of group rice seeds are easy to extract and show more different values between each period.

2) evaluation techniques, research applied many matching techniques, namely: ANN, CNN, PCA, LDA, histogram, Otsu edge detection etc. There is no consensus which technique is the best.

3) evaluation period interval, some researchers evaluated between two different seed categories, such as fresh and old seed, mature and immature rice seeds.

4) size of a dataset, some researchers conducted on a very small dataset (less than 100 rice seeds).

Therefore, it is difficult to compare the precision rates of all the research in Table 7

Table 7 A comparison of some rice-seed ageing evaluation researches.

Author (year)	Feature/technique	Period interval	Dataset size (images)	Precision rates (per cent)	Ref.
Liu (2010)	color/histogram	fresh and old	200	n/a	[10]
Bejo and Sudin (2014)	thresholding/Otsu	mature and immature	78	96.15	[11]
Anami et. al (2017)	color/ANN	1, 3, 6, 9 and 12 months	7,500	93.15	[12]
Lin (2019)	color/PCA, LDA	1, 3, 7 and 10 months	72	98.75	[9]
This research (2021)	color, shape, texture/ ANN, CNN	1 to 20 weeks	8,400	81.33	

Conclusion

The RiSAES fulfills the objective of this research, which is to develop a computer system to evaluate rice-seed ageing. The RiSAES dataset size consists of 8,400 images, of which 420 rice-seed images were taken weekly for 20 weeks. The system employed both the feed-foreword artificial neural network and convolution neural network architecture to evaluate rice-seed ageing with the precision rate of 81.29% and 80.89%, respectively. The average evaluation time for artificial neural network is 0.0529 seconds/image and the convolution neural network is 1.6006 seconds/image. The training dataset time for artificial neural network is 5.4298×10^{5} seconds and the convolution neural network is 1.9035×10^{4} seconds. The RiSAES is a non-destructive method for helping not only farmers to store viable seeds for planting in the next crop and to bargain for the price with the merchant but also for helping people to select favorite rice-seed ageing for cooking.

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