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Image-based Analysis for Characterization of Chicken Nugget Quality

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Abstract: Appearance, colors and adhesion characteristics of chicken nugget are important to customer satisfaction and buying decision. These characteristics are generally inspected by human, thus, the inspectors might incorrectly judge. In addition, the results are not quantitatively recorded for further analysis and improvement. Therefore, this study focuses on constructing a measurement instrument for detecting the qualities of chicken nugget, then gage repeatability and reproducibility (GR&R) study is used to ensure that the instrument is capable of distinguishing nugget differences. Since, there are eleven characteristics of chicken nugget are analyzed. The principal component analysis is applied to reduce the number of characteristics from eleven dimensions to only four dimensions. The experiments and data analysis show that the dimension reduction is useful to rapidly detect the abnormality of nuggets and finally help practitioners to improve the process.

Keywords: Chicken nugget quality, Gage repeatability and reproducibility, Image-based analysis, Principal component analysis.

Introduction

Food appearance is one of the most important characteristics of customers buying decision. The need for fast and accurate food inspection is crucial. In this paper, a chicken nugget product is selected as a case study. Chicken nugget production is a semi-frozen food process which includes grinding chicken meat, pressing into bars or desired shapes, coating and deep frying in a short period in order to be stabilized and semi-cooked, then freezing and packing for sale to consumers. Then, consumers will rapidly cook before eating.

The characteristics of chicken nuggets not only affect the customer's buying decision and satisfaction, but also are product indicators for process improvement. However, the current inspections are performed by human. The inspection is considered as a tedious, laborious, costly, time-consuming and inconsistent task. Researchers have used image processing in food quality inspection to alleviate these problems (Du and Sun, [6]; Brosnan and Sun, [5]). Therefore, there is a need of automate instrument associated imagement processing for collecting data and the data will be used for further analysis and process improvement. In our study, we built a prototype of measurement device using image processing and analysis to characterize the nuggets quality.

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However, the device is not fully automated, images are taken manually. Since images provide several characteristics simultaneously, it is difficult to analyze these data; principal component analysis (PCA) is used to determine the relationship between variables and to reduce the number of variables by combining the variables within the same factors or components and introduce new variables that are useful for further analysis.

The objective of this study is to propose image processing and statistical techniques: Gage repeatability and reproducibility (GR&R), Design of experiment and PCA for the analysis and the evaluation of chicken nugget quality. We use image processing-based techniques to collect eleven characteristics of chicken nugget which include chicken meat colors, flour colors, porosity colors, and section areas. Then GR&R is used to ensure that the instrument is capable of distinguishing nugget differences by using only represented colors characteristics in L*a*b* system.

The organization of the paper is begun with method and related topics. Then results and discussion is presented, followed by conclusion at the end.

Methods

In this section, we introduce image processing and analysis, design of experiments, GR&R, PCA, and a proposed framework as follows:

Image Processing and Analysis

Image analysis has been commonly used in food quality inspection (Du and Sun, [6]; Brosnan and

Sun, [5]) for a wide range of products including meat (Barni, *et al.,* [3]; Borggaard, *et al.*, [4]; Fortin *et al.*, [7]), fruits (Li *et al.* [10]), and fish (Karplus, *et al.*, [9]). Image processing analysis generally consists of 5 steps: (1) image acquisition; (2) pre-processing; (3) image segmentation; (4) object measurement and (5) classification.

For chicken nugget inspection, the image processing is implemented to measure the color of chicken meat and battered flour, flour porosity, section-area. The algorithms for color analysis and section-area processing and porosity analysis are coded using MATLAB.

Color Measurement

We measure the color in the L*a*b* system which is an international standard for color measurements, and adopted by the Commission Internationaled' Éclairage (CIE) in 1976. This color model creates a consistent color regardless of devices used to generate the image (e.g., monitor, printer or scanner). L* is the luminance or lightness component, which ranges from 0 to 100, and a* (from green to red) and b* (from blue to yellow) are the two chromatic components, which range from –128 to +127 (256 levels) (Baldevbhai and Anand, [2]).

Section-area and Porosity Measurement

Section-area (the whole cross-section area of nugget) and porosity are indicated by differences of two colors (black and gray) using threshold-based method. This technique is particularly effective for scenes containing solid objects resting upon a contrasting background, which distinguishes the object from the remaining part of the image with an optimal value. (Du and Sun, [6])

Figure 1 is the inspection equipment. The chamber itself consists of three following main elements (Image processing is based on Pedreschi *et al.* [12] and Yuangyai *et al.* []): (1) Four florescence lamps are attached at square 30 cm. above the sample and set at an angle of 45º to nugget location. (2) A Canon EOS 550D camera is located vertically above the sample. The angle between the camera lens axis and the lighting sources is at 45º, the image format is JPEG with resolution 3456 × 2304 and connected to a computer with the USB port. (3) Illuminators and the CDC place inside a mat acrylic box to prevent light and reflection from outside sources, the box size is 50 × 50 × 50 cm. The frame is made of aluminum and is located above the ground 100 cm.

Design of Experimental to Reduce the Measurement Variability

Design of experiments (DOE) is the process of planning an experiment to obtain the information concerning factors affecting to experiment responses (Montgomery, D.C. and Runger, G.C., [11]). This study uses a fractional factorial design for six factors (2^{6-2}) to reduce measurement error from possible factors. Then we select only ones providing high contributions to response variability. We use a simulated color paper with ten chicken nuggets-like colors (Figure 2) for the experiments. MINITAB is used for the analysis.

Gage Repeatability and Reproducibility Study

Gage repeatability and reproducibility (GR&R) is a statistical technique used to assess the measurement system whether or not it is capable of distinguishing part differences. In this study, we use a color paper with ten chicken-nugget-like colors as samples (shown in Figure 2) and the factors that no effect on the measurement system. They are analyzed with full factorial design. The computations were carried out by using a balanced ANOVA module in MINITAB.

In the simple statistical model of GR&R, supposed that there are a randomly selected parts and b randomly selected operators in which each operator measures every part n times. The measurement results are represented by y_{ijk} where i = 1, 2, …, a, j = 1, 2, …, b, and k = 1, 2, …, n. The effect model is described as

$$y_{ijk} = \mu + \tau_i + \beta_j + (\tau\beta)_{ij} + \epsilon_{ijk} \quad (1)$$

where τ_i, β_j, $(\tau\beta)_{ij}$ and ϵ_{ijl} are all independent random variables that represent the effect of parts, operators, the interaction of part and operator, and random error, respectively and μ is the overall mean.

Figure 1. Image processing equipment for nugget inspection

Figure 2. Chicken Nugget color-like papers for experiments

Principal Component Analysis

Principal component analysis (PCA) is a variable reduction procedure. It is useful when there is a large number of data sets on a number of variables and it is believed that some redundancy exists in the data sets. In this study, redundancy means that some of the variables are correlated with one another, possibly because they are measuring similar structure. PCA consists of four main steps: study of correlation among the variables, initial extraction of the components, rotation to a final solution, and interpretation of the rotated solution (Jonhson and Wichern, [8]). The new factors obtained from the analysis, are then called principal components.

Results and Discussion

In this section, we present results and discussion of DOE, GR&R, nugget measurement, and PCA as the following.

Design of Experiments to Reduce the Measurement Variability

Once the equipment is completely built, we considered six factors in the measurement system: (A) background color, (B) operator, (C) position (object), (D) number of lamps, (E) outside light, (F) distance (between camera and object). Fractional factorial design (2^{6-2}) was used to screen out these factors. Then images are converted to L, a*, b* values. The experimental results indicate factors that are 5% significance level using general linear model in MINITAB.

Table1, Table 2 and Table 3 display the analysis of variance for L*, a*, and b*, respectively. The results indicate that four factors except operator and outside light are significant at 5% significance level. Therefore, we choose background (B) as black, position (C) as central, number of lamps (D) as two and distances (F) is 22.5 cm. The camera setting is set to manual mode with ISO400, shutter speed 1/60, aperture 5.6, no zoom and no flash, to reduce the variability.

Gage Repeatability and Reproducibility Study

Once the variability of the measurement system is reduced, the different colored papers are measured by two operators with two methods (with or without outside light). Then images are converted to L, a*, b* values for GR&R using ANOVA with MINITAB 16. Due to the space limitation, an example of L* value analysis is shown in Table 4. Based on the *p-values*, it can be concluded that the effect of parts, operators and outside light, and their interaction effects are significant.

Table 1. Analysis of variance for L*

Source	DF	Seq SS	Adj MS	F	P-value
main effects	6	1212.89	202.15	155.45	0.000
operator (A)	1	0.16	0.16	0.12	0.736
background (B)	1	1.56	1.56	1.20	0.299
position (C)	1	0.55	0.55	0.42	0.530
no.Lamp (D)	1	1107.09	1107.09	851.33	0.000
outside light (E)	1	3.04	3.04	2.34	0.157
distance (F)	1	100.48	100.48	77.27	0.000
2-way interactions	15	31.15	2.08	1.60	0.230
total	31	1257.04			

Table 2. Analysis of variance for a*

Source	DF	Seq SS	Adj MS	F	P-value
main effects	6	103.584	17.2641	199.34	0.000
operator (A)	1	0.013	0.0129	0.15	0.708
background (B)	1	56.187	56.1866	648.76	0.000
position (C)	1	17.206	17.2057	198.66	0.000
no.Lamp (D)	1	1.934	1.9340	22.33	0.001
outside light (E)	1	0.191	0.1907	2.20	0.169
distance (F)	1	28.054	28.0544	323.93	0.000
2-way interactions	15	6.302	0.42	4.85	0.008
total	31	110.75			

Table 3. Analysis of variance for b*

Source	DF	Seq SS	Adj MS	F	P-value
main effects	6	3544.91	590.82	139.12	0.000
operator (A)	1	0.13	0.13	0.03	0.866
background (B)	1	3229.51	3229.51	760.45	0.000
position (C)	1	3.90	3.90	0.92	0.361
no.Lamp (D)	1	280.81	280.81	66.12	0.000
outside light (E)	1	0.00	0.00	0.00	0.991
distance (F)	1	30.57	30.57	7.20	0.023
2-way interactions	15	570.96	38.06	8.96	0.001
total	31	4158.34			

The variance of the gauge is estimated as the summation of the variance component estimate of σ^2, σ_β^2, and σ_γ^2 for the results from Table 4.

$$\sigma_{total}^2 = \sigma_{part}^2 + \sigma_{gauge}^2$$
$$\sigma_{\mathrm{total}}^2 = 11.314 + 0 + 0.091 + 0.011 + 0.013 + 0 + 0.015 = 11.444$$
$$\sigma_{\mathrm{gauge}}^2 = 0 + 0.091 + 0 = 0.091$$
$$\sigma_{\mathrm{part}}^2 = 11.314$$

where σ^2 is the random experimental error, σ_τ^2 is the variance component for parts, σ_β^2 is the variance component for operators and σ_γ^2 is the variance component of outside light.

Table 5 shows the results for L*, a*, and b*. The proportion of the variance of the gauge and the variance component of parts for L* a* b* are 0.805% 0.179% and 0.003%, respectively. These values indicate that the variability of the measurement system is very small compared to the variance of parts. Based on 10% acceptable criteria of AIAG (AIAG [1]), therefore, the measurement system is capable of distinguishing nugget differences.

Table 4. Analysis of variance for L*

ANOVA: L versus Part, Operator, Outside light					
Factor	Type	Levels	Values		
part	random	10	1,2,3,4,5,6,7,8,9,10		
operator	random	2	1, 2		
outside light	random	2	1, 2		
Analysis of Variance for L*					
Source	DF	SS	MS	F	P
part	9	407.864	45.318	722.26	0.000 x
operator	1	0.014	0.014	0.56	0.503 x
outside light	1	1.851	1.851	65.35	0.002 x
part*operator	9	0.336	0.037	2.46	0.098
part*outside light	9	0.365	0.041	2.68	0.079
operator*outside light	1	0.003	0.003	0.19	0.671
Error	9	0.136	0.015		
Total	39	410.569			
x Not an exact F-test.					
S = 0.123119 R-Sq = 99.97% R-Sq(adj) = 99.86%					
Variance Error Expected Mean Square for Each					
Source			component		
1 part			11.3139		
2 operator			-0.0006		
3 outside light			0.0911		
4 part*operator			0.0111		
5 part*outside light			0.0127		
6 operator*outside light			-0.0012		
7 Error			0.0152		

Table 5. Comparison variances of the L * a* and b* values

Variance	L*	a*	b*
σ^2_{total}	11.444	7.822	468.284
σ^2_{gauge}	0.0911	0.0139	0.012
σ^2_{part}	11.314	7.745	466.216
% $\sigma^2_{gauge}/\sigma^2_{part}$	0.805%	0.179%	0.003%

Image Processing and Analysis

To analyze the characteristics of chicken nugget, 80 chicken nuggets are randomly selected from a local market.

Color Inspection

The background was removed from the digital image as shown in Figure 3. Then selection-area of chicken meat, batter and porosity of an example to present the neighbors or similar pixel are shown in Figure 4.

The images are analyzed in the L*a*b* system for the color of chicken meat, batter, and porosity.

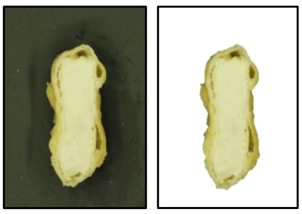

Figure 3. Removing image background

Section-Area and Porosity Inspection

Image background was removed from the pre-processed gray scale image using a threshold of 0.6 to determine porosity and combined with an edge detection technique based on the Laplacian-of Gauss (LoG) operator to determine section-area, shown in Figure 5. Therefore, there are totally 11 characteristics of chicken nugget are analyzed.

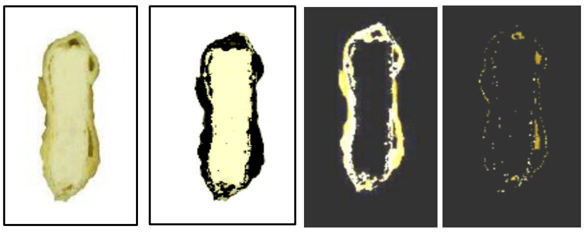

Figure 4. Color-based image segmentation

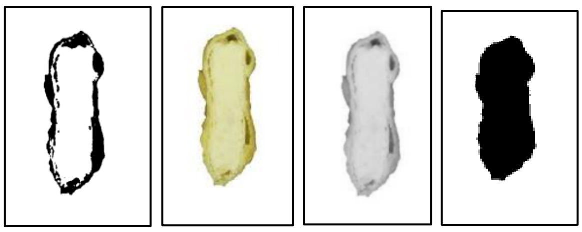

Figure 5. Image segmentation with threshold and edge detection technique

Table 6. Correlation matrix of 11 characteristics

variable	1L*	1a*	1b*	2L*	2a*	2b*	3L*	3a*	3b*	area	pore
1L*	1										
1a*	-0.813	1									
1b*	-0.507	0.040	1								
2L*	-0.85	0.166	-0.207	1							
2a*	0.159	-0.217	0.107	-0.637	1						
2b*	0.080	-0.106	0.074	-0.180	0.694	1					
3L*	0.243	-0.242	-0.134	-0.125	0.058	-0.017	1				
3a*	0.114	-0.023	-0.105	0.233	0.013	0.094	-0.136	1			
3b*	0.277	-0.246	-0.159	-0.040	0.107	0.075	0.868	0.012	1		
Area	0.046	-0.061	0.199	-0.190	0.196	0.001	-0.127	0.137	-0.169	1	
pore	0.183	-0.057	-0.226	-0.031	0.286	0.183	-0.096	0.055	-0.114	-0.036	1

Table 7. Results of principal component analysis

	PC1	PC2	PC3	PC4	PC5	PC6	PC7	PC8	PC9	PC10	PC11
Eigenvalue	2.6483	2.1194	1.6305	1.2405	1.0842	0.8089	0.636	0.5501	0.1351	0.1011	0.0459
Proportion	0.2410	0.1930	0.1480	0.1130	0.0990	0.0740	0.058	0.0500	0.0120	0.0090	0.0040
Cumulative	0.2410	0.4330	0.5820	0.6940	0.7930	0.8670	0.924	0.9740	0.9870	0.9960	1.0000

Principal Component Analysis

There are 11 characteristics of chicken nugget characterized by our measurement instrument. These characteristics are as follows: The colors of chicken meat representations which are *1L*, 1a** and *1b**. The colors of batter representation are 2L*, *2a** and *2b** and the colors of porosity representation are *3L*, 3a** and *3b**. Section-area is represented by *the area*. Porosity is represented by *pore*. Then they are analyzed using principal component analysis to reduce the number of characteristics.

Table 6 shows the correlation matrix between variables which is used to indicate the grouping variable. Eigenvalue of each principal component (PC) is considered and shown in Table 7. Four main Eigenvalues (PC1 to PC4) are considered because they have accounted for 69.4% or it can explain the total variation of the 11 variables for 69.4%. The PC1, PC2, PC3, and PC4 are composed of original variables and they are shown in Eq. 2 to Eq 5. These equations are the relationship in the linear form of variables in each principal component.

$$PC1 = (-0.227)2L^* + (0.437)2a^* + (0.423)2b^* \quad (2)$$
$$PC2 = (0.460)3L^*+(-0.201)3a^*+(0.443)3b^* \quad (3)$$
$$PC3 = (-0.468)1L^* + (0.462)1a^* \quad (4)$$
$$PC4 = (-0.447)1b^* + (0.315)2L^* + (-0.392)\, area + (0.375)\, pore \quad (5)$$

It is important when interpreting the underlying relationships of the variables in each component. We interpret each PC as follows: (a) The PC1 is associated with the color of the batter, thus PC1 is named *"the component of batter quality"*. (b) The PC2 is associated with the color of the porosity, thus PC2 is named *"the component of depth-porosity quality"*. (c) The PC3 is associated with the color of the chicken meat, thus PC3 is named *"the component of chicken meat quality"*, and (d) The PC4 consists of a variety of variables that is related to the overall appearance of chicken nuggets are associated, thus PC4 is named *"the component of appearance quality"*.

Conclusion

In this study, we proposed a framework for using image processing for characterization of chicken nugget quality. Design of experiment is used to consider the factor associated with the system in order to reduce the measurement variability. Then gage repeatability and reproducibility is used to assess the measurement system variation of the color-based image processing equipment. Since there are 11 characteristics of chicken nugget are analyzed with image processing which include chicken meat color, battered flour color, section-area, and porosity. The principal component analysis is applied to reduce the number of characteristics from eleven to only four characteristics are followed PC1 for the component of batterquality, PC2 for the component of depth-porosity quality, PC3 for the component of chicken meat quality and PC4 for the component of appearance quality.

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