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Evaluation of the influence of digital camera acquisition parameters for the accuracy of colourimetric measurements

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ABSTRACT
Law 9972 of 2000 instituted the classification of vegetable products, by-products, and waste of economic value, making their classification mandatory when intended for human consumption, in purchase and sale operations, and at ports and airports when destined for export. The classification of these vegetables consists of separating the product into different categories of quality according to their peculiarities, forming homogeneous batches, as well as determining the quality based on official standards. Among the quality standards to observe in this classification process are shape, size, weight, defects in the skin, and colour, which will be the focus of this work. Currently, a great portion of this classification process is carried out manually, based on the knowledge and experience of operators. With a focus on automating this type of process, studies in the field of computer vision are being developed with the aim of autonomously reproducing the classification of fruits and vegetables usually carried out by trained operators. However, in various applications in the current literature, digital cameras are used to extract quantitative measurements. These pieces of information require metrological analyses such as any other conventional measurement system. In such sense, this paper proposes a study to evaluate the errors in the application of a digital camera for colour measurement. Different tests compared numerical aperture, exposure time, and ISO parameters with the results of a colourimeter using a colour chart as a measurand. The goal is to evaluate the repeatability and estimate the error curves of a conventional sensor when applied to colour metrology. This study is an important step in ensuring the reliability of colour measurements using digital cameras for automatic fruit and vegetable classification systems.

Section: RESEARCH PAPER

Keywords: Computer vision; colorimetry; food quality

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1. INTRODUCTION

The evaluation of visual aspects of food holds paramount importance as it exerts a substantial impact on consumer perception, satisfaction, and purchasing decisions. Moreover, visual assessments serve the purpose of identifying and rectifying any deviations or flaws that might compromise the overall quality of food items. In this regard, metrology assumes a vital role in the evaluation of food, as it provides precise and accurate measurements that uphold quality, safety, and consistency within the food industry. Notably, image metrology specialises in visual analysis and measurement techniques that are indispensable for appraising diverse facets of food quality and desirability. Through the implementation of image metrology, the field enables the assessment of attributes such as colour, texture, shape, and size, which significantly contribute to the visual appeal and freshness of food.

The utilisation of metrology for ensuring food quality has received significant attention in academic research. A noteworthy investigation focused on employing colour measurement techniques to assess the quality of potato samples [1]. Similarly, Mohammad et al. (2017) [2] employed colour measurement methods to improve the drying processes of kiwifruits. Although both studies acknowledge the calibration procedures implemented in their respective systems, they overlook the potential impact of camera acquisition parameters on the measurement outcomes. This oversight is also evident in other relevant studies, such as Gökmen and Sügüt (2007) [3], León et al. (2006) [4], and Masawat et al. (2015) [5], Sudsawat, S. and Limhengha, S. (2024) [6] and Heng, C. et al (2021) [7]. While the studies mentioned above have not explicitly addressed the parameters of image acquisition, it is crucial to emphasise the significance of metrology in assessing the quality of food, particularly with respect to its colour. This fact underlines the need for a thorough consideration of the overall influencing factors to ensure the precision and reliability of measurements.

This article presents a study that aims to evaluate the impact of camera acquisition parameters, specifically ISO, aperture, and exposure time, on colour measurements. The primary objective of this research is to determine the extent to which these parameters influence colour measurements by calculating the measurement error in relation to the measurements obtained from a standardised colourimeter. By gaining insights into the influence of these parameters on colour measurement, it becomes possible to confirm their significance in colour measuring systems. Such understanding is crucial for enhancing the accuracy and reliability of colour measurement techniques and their practical application within the food industry.

2. COLOUR MEASURING SYSTEM

The study required the establishment of a robust and controlled measurement system. The setup involved a Canon T3 digital camera, a 24-ColorChecker colour plate, and a D65 lamp with a colour temperature of 6500 K. Careful positioning of these components on a Newport I-2000 Series anti-vibration table was undertaken to ensure stability and accuracy. To minimise any potential interference from external lighting, the entire system was securely enclosed within a black box. The versatility of the setup allowed for the precise adjustment of the colour checker's position, achieving the desired 45°/0° geometry where the lamp was positioned at 45 degrees and the camera at 0 degrees, as illustrated in Figure 1.

To establish a reliable reference for measurements, a ColorFlex colourimeter from the HunterLab model was employed. This device served as a standardised measurement source, enhancing the accuracy and consistency of the results obtained. Figure 2 visually depicts the 24-ColorChecker colour plate utilised in the study, which featured numbered coloured squares, including gradations of black and white.

The camera control was supported by two MATLAB routines. The first routine allowed the systematic capture of a predefined number of photos, including varying parameters to capture the desired range of data. The second script accessed the generated photo folder, allowing the selection of 24 points within the image that corresponded to the central regions of the colour chart squares. These points were subsequently expanded into 50 × 50 pixel squares, enabling precise colour calculations and the derivation of average values in terms of $L^*a^*b^*$ colour space for each selected point in every image. The functioning of the program is illustrated in Figure 3.

3. EVALUATION OF ACQUISITION PARAMETERS

To evaluate the impact of camera acquisition parameters on colour measurements a total of three tests were conducted, with each test featuring a distinct aperture value (1.8f, 5.6f, and 36f). During each test, data collection involved the measurement of seven specific points while systematically adjusting the ISO settings. The ISO range covered values from 100 to 6400, with intermediate increments of 200, 400, 800, 1600, and 3200. Furthermore, configuring the camera with a specific combination of aperture and ISO and manually adjusting the exposure time in the camera allowed the achievement of optimal image exposure. The exposure time for each combination of aperture and ISO is shown in Table 1.

The ΔE (Equation 1) and ΔH (Equation 2) parameters

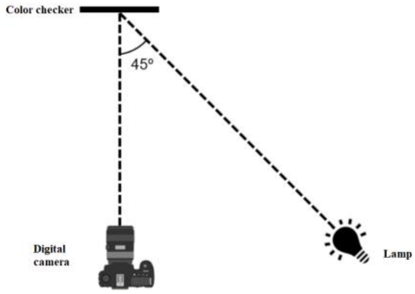


Figure 1. Setup Schematics.

Figure 2. 24-ColorChecker colour plate.

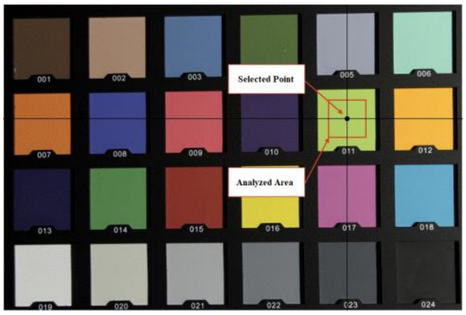


Figure 3. Representation of point selection in the images.

Table 1. Exposure time in seconds for each combination of aperture and ISO.

Aperture/ISO	1.8f	5.6f	36f
100	1/15	2/5	15
200	1/30	1/5	8
400	1/60	1/10	4
800	1/125	1/20	2
1600	1/250	1/40	1
3200	1/500	1/80	1/2
6400	1/1000	1/160	1/4

$$\Delta E = \sqrt{(L_1 - L_2)^2 + (a_1 - a_2)^2 + (b_1 - b_2)^2} \quad (1)$$

$$\Delta H = \sqrt{(a_1 - a_2)^2 + (b_1 - b_2)^2} \,. \quad (2)$$

were chosen for the analysis over the individual errors of the $L^*a^*b^*$ colour space. This decision aimed to condense the values of the coordinates (L^*, a^*, b^*) into a single error value, in the case of ΔE, and to condense the values of the coordinates (a^*, b^*) into a single ΔH value. These errors are relative to the measurements obtained from the ColorFlex colourimeter. This approach simplifies the interpretation of results by significantly reducing the total amount of data to be analysed. To further narrow the scope of the analysis, a single colour was selected from the 24-ColorChecker colour plate. Colour 9, positioned centrally within the palette, was selected for analysis. Considering all 24 colours would substantially increase the data volume to be analysed, compromising the efficiency and conciseness of the analysis:

The ColorFlex colourimeter, a calibrated instrument with a calibration certificate, was utilised in this study as the reference for colour measurements. The measurements obtained from the ColorFlex colourimeter were used to calculate the ΔE and ΔH errors, which quantify the colour differences between the measured colours and the reference colours. These errors provide a valuable metric for assessing the accuracy of colorimetric measurements. Each colour was individually measured using the ColorFlex colourimeter, guaranteeing meticulous data acquisition and minimising any potential variation. This standardised approach, using the ColorFlex colourimeter and the calculated errors, allowed for consistent and reliable colour comparisons throughout the experiment.

4. RESULTS

As mentioned before, this study focuses on the evaluation of the behaviour of the digital camera in colour capture according to its acquisition parameters. For this purpose, 10 measurements (10 images) were taken for each configuration shown in Table 1. This allows us to investigate how the camera captures colour when the lens aperture allows for lower and higher light inputs. The variation in ISO allows us to assess whether the sensitivity adjustments made by the camera affect the colour after the digitised image. Thus, with all the possible variations, a total of 210 images were evaluated.

Table 2 shows the average results for different ISO values at an aperture of 1.8f. The results for an aperture of 5.6f are presented in Table 3, and Table 4 for an aperture of 36f. The tables also display the ΔE and ΔH values when comparing the results with the reference value for the new colour number of the standard obtained with the colourimeter, which was $L = 50.48 \cdot a^{*} = 43.89 \cdot e \cdot b^{*} = 11.89$.

As a way to make the obtained results visible, Table 5 exemplifies in colours the variations in aperture according to the changes in ISO. For the visual evaluation of errors, Figure 4 displays the colour representation of the values obtained as references in the colourimeter.

Figure 4. Example of reference value.

Analysis

As a way to identify possible variations in colour measurements based on parameter changes, Table 5 can be observed in two different ways. By looking at the colours vertically, the influences of the lens aperture can be evaluated. On the other hand, by observing the colours horizontally, the influences of ISO can be assessed.

To obtain numerical descriptions of these two evaluations simultaneously, the factorial experiment analysis technique was applied with Aperture (represented by f-stops: f1.8, f5.6, and f36) and ISO as a factor divided into several levels. For the Aperture

Table 2. L^*, a^*, b^*, ΔE and ΔH for the Color9 with 1.8f aperture.

Aperture/ISO	L^*	a^*	b^*	ΔE	ΔH
100	65.72	49.29	14.57	16.39	6.03
200	66.18	49.40	14.57	16.85	6.12
400	66.40	49.56	14.58	17.11	6.28
800	66.20	49.55	14.42	16.89	6.20
1600	65.31	47.40	13.73	15.42	4.77
3200	59.60	49.35	15.40	11.19	7.72
6400	61.87	47.81	13.94	12.22	5.93

Table 3. L^*, a^*, b^*, ΔE and ΔH for the Color9 with 5.6f aperture.

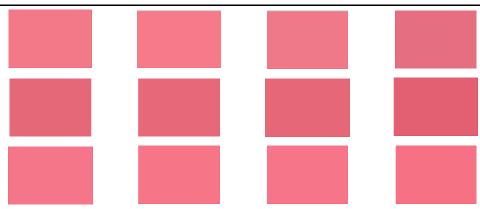
Aperture/ISO	L^*	a^*	b^*	ΔE	ΔH
100	60.40	50.58	16.24	12.73	7.98
200	60.63	50.76	16.36	13.04	8.19
400	60.67	51.04	16.23	13.18	8.36
800	60.45	50.87	16.17	12.89	8.18
1600	60.41	51.01	16.16	12.94	8.30
3200	59.16	53.07	17.46	13.80	10.74
6400	58.41	52.68	17.18	12.97	10.29

Table 4. L^*, a^*, b^*, ΔE and ΔH for the Color9 with 36f aperture.

Aperture/ISO	L^*	a^*	b^*	ΔE	ΔH
100	65.64	50.75	15.01	16.92	7.54
200	65.80	51.08	15.16	17.23	7.90
400	65.86	51.33	15.18	17.40	8.14
800	65.61	51.32	14.95	17.13	8.03
1600	65.63	51.40	15.03	17.20	8.14
3200	65.22	53.71	15.93	18.16	10.62
6400	64.91	53.57	16.15	17.89	10.58

Table 5. Example of colour variation for the different measurement parameters.

	ISO 100	ISO 400	ISO 1600	ISO 6400
f1.8				
f5.6				
f36				



factor, three levels were used, and for the ISO factor, seven levels were considered (100, 200, 400, 800, 1600, 3200, 6400).

The technique consists of describing the measurements following the model represented by equation (3), where Y_{ijk} represents each of the 210 measured values considering each aperture-i and each ISO-j for all k-th repetitions. The model assumes that each of these measured values is composed of an average value (μ) and the influences of the Aperture and ISO factors, along with a random error (ε), represented respectively by α, β, and ε.

$$Y_{ijk} = \mu + \alpha_i + \beta_j + (\alpha\beta)_{ij} + \varepsilon_{ijk} , \qquad (3)$$

Considering the model from equation 1, an Analysis of Variance (ANOVA) test is then applied to test the hypothesis of whether the values of α and β are equal to zero or different from zero. For example, if there is statistical evidence to consider α equal to zero, it means that the aperture does not influence the

Table 6. ANOVA results.

	ΔE		
	***F*-value**	***P*-value**	**Conclusion**
Aperture	47.67	9.99×10^{-11}	$\alpha \neq 0$
ISO	0.15	0.70	$\beta = 0$
	ΔH		
	***F*-value**	***P*-value**	**Conclusion**
Aperture	38.50	2.96×10^{-9}	$\alpha \neq 0$
ISO	40.65	1.17×10^{-9}	$\beta \neq 0$

Y_{ijk} results. The same analysis is carried out for ISO using the parameter β.

The same procedure was carried out for the evaluation of ΔE and ΔH, with the aim of assessing whether the configurations also affect the brightness of the images. The results are presented in Table 6.

The results obtained from the ANOVA allow us to observe different important behaviours to understand how the camera's acquisition parameters influence the colour values of the images.

One key point is that regardless of whether we consider the behaviour of L, a, and b or just a and b, the aperture significantly influences the colour values. A second consideration based on the results is the influence of ISO sensitivity in the images. When considering the L values for calculating ΔE, ISO variation does not show significant variations in the color results, which is not the case when the L values are excluded for calculating ΔH.

In practical terms, imagining each colour as a position in a three-dimensional space, the values being considered close to each other means that the Euclidean distance between the points is statistically insignificant, indicating that the sensitivity correction based on light is accurately performed by the system.

5. CONCLUSION

This research is an extension of studies on the evaluation of the applicability of digital cameras for colorimetric measurements. In this stage, the influences of the acquisition parameters, such as lens aperture and ISO sensitivity control, were assessed. These parameters have been neglected in recent literature that uses digital cameras for colour measurement.

For the evaluation, a colour was used as a reference standard, previously measured with a colourimeter. Measurements were conducted by varying the parameter conditions on a setup with consistent illumination throughout the process.

The results were analysed using analysis of variance (ANOVA), and it was confirmed, with a statistical significance level of 0.05, that the numerical aperture values and ISO sensitivity are significant for representing colours. Another important conclusion is that different literature uses various parameters to compare colour values in quality control or product classification. The main parameters used are ΔE and ΔH. The difference between these parameters lies in the use of the L value in ΔE, which is not the case in ΔH.

The results of this experiment indicate that for applications using ΔE as an analysis parameter, ISO values can be used to correct lighting deficiencies in experiments or production lines without compromising the results. However, for experiments where ΔH parameters are used, a precise evaluation of errors according to the camera settings during measurements is necessary.

It is possible to observe in the results the significance of the opening in the values of L and consequently in the coordinates a^* and b^*. In future studies, tests will be carried out to evaluate whether the differences obtained are systematic errors or whether it is possible to find configurations that provide values for the colour coordinates with smaller differences when compared to the values obtained by the colourimeter.

AUTHORS' CONTRIBUTION

Author Pedro B. Costa contributed to the article by: Conceptualization, Formal analysis, Software. Laisa C. Dias contribution is credited for: Methodology, Investigation, Writing – original draft and Writing – review & editing. Isadora L. R. Amorim for Methodology and Investigation. Artur E. Moura for Writing – original draft, Methodology and Software

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