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ORIGINAL

Color in images: a machine vision approach to the measurement of CIEL*a*b* coordinates in bovine loins

El color en imágenes: un enfoque de visión artificial para la medición de coordenadas CIEL*a*b* en lomos de bovino

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ABSTRACT

Electronic machine vision systems bring together a set of technologies and techniques used to capture, process and analyze images to perform a specific task, such as object or measurement pattern recognition. These systems rely on image processing and machine learning algorithms to interpret visual information. Therefore, the objective of this research was the construction of an electronic machine vision system (SVA) for color analysis in bovine (longisimus dorsi) loins based on the CIEL*a*b* color space. The VAS implementation was carried out using the programming language Python 3.9 programming language and the color parameters obtained were compared with those obtained on a Minolta CR-400 colorimeter (CM). Both systems were synchronized to provide the user with information about the color coordinates in the samples of loins stored for 6 days at 4°C. The results obtained showed no significant differences. The results obtained showed no significant differences in the values of the L* parameter, while b* and a* showed significant differences during the storage time of the loins. These results are attributed to the oxidation process of the myoglobin and to factors such as breed, feeding and slaughtering process of the cattle, which affect the color of the samples. The results obtained indicate that VAS could be used for the determination of color during the storage of beef loins in real time, offering a non-invasive and low-cost solution to the actors in the meat chain.

Keywords: Image Analysis; Beef; Colorimeter; Artificial Vision System.

RESUMEN

Los sistemas electrónicos de visión artificial reúnen un conjunto de tecnologías y técnicas utilizadas para capturar, procesar y analizar imágenes que realizaran una tarea específica, como el reconocimiento de objetos o patrones de medida. Estos sistemas se basan en algoritmos de procesamiento de imágenes y aprendizaje automático para interpretar la información visual. Por lo tanto, el objetivo de esta investigación fue la construcción de un sistema electrónico de visión artificial (SVA) para el análisis de color, en lomos de bovino (*longisimus dorsi*) fundamentado en el espacio de color CIEL*a*b*. La implementación del SVA se llevó a cabo utilizando el lenguaje de programación Python 3.9 y los parámetros de color obtenidos fueron comparados con los obtenidos en un colorímetro Minolta CR-400 (CM). Ambos sistemas fueron sincronizados para proporcionar al usuario información acerca de las coordenadas de color en las muestras de los lomos almacenados durante 6 días a 4°C. Los resultados obtenidos, no presentaron diferencias significativas en los valores del parámetro L*, mientras que b* y a* presentaron diferencias significativas durante el tiempo de almacenamiento de los lomos, estos resultados son atribuidos al proceso de oxidación de la mioglobina y a factores como la raza, la alimentación y el proceso de sacrificio de los bovinos, que afectan, el color de las muestras. Los resultados obtenidos indican que el SVA podría ser utilizado para la determinación del color durante el almacenamiento de lomos de bovino en tiempo real, ofreciendo una solución no invasiva y de bajo costo a los actores de la cadena cárnica.

Palabras clave: Análisis de Imagen; Carne de Bovino; Colorímetro; Sistema de Visión Artificial.

INTRODUCTION

Color is one of the organoleptic characteristics that most influences the acceptability of meat and plays an important role in the consumer's purchasing decision (Parra et al., 2021). One of the problems presented by the evaluation of color is the methodology used to obtain significant information, which makes it possible to compare and improve meat products in a versatile, rapid, and on-site manner. Color measurements in foods are usually carried out with digital colorimeters, which, although easy to use and calibrate, have limitations such as cost, specialized maintenance, the size of the measurement area, and the need for contact with the surface to be measured (Sanmartín et al., 2021). Therefore, it is important that color assessment is performed consistently and objectively to obtain reliable and reproducible results that reflect human perception and can be performed in a non-invasive manner (Wu & Sun, 2013).

The CIEL*a*b* color space has proven to be one of the most suitable for color assessment in the food area; it correlates numerical color values consistently with human visual perception (Anilkumar et al., 2021). This Cartesian system consists of three axes: L* vertical, informs us of the degree of lightness or brightness of a color (Wyszecki & Stiles, 2000) and can take values between 0 (black) to 100 (white); a* horizontal, indicates the content of red (+a*) or green (-a*); and b* horizontal and perpendicular to a*, which represents the content of yellow (+b*) or blue (-b*).

Studies using VAS for color assessment have focused on converting images obtained using the RGB color measurement system to the CIEL*a*b* system (Larraín et al., 2008). Analysis of pork loin quality using an online VAS and an artificial intelligence model indicated that VAS could provide an effective tool for predicting color and marbling in pork on processing lines in real time (Sun et al.,2018). SVA and embedded systems were used as alternatives to evaluate the freshness of beef, using principal component analysis (PCA) and support vector machines (SVM); the results show that the proposed system can successfully predict freshness, suggesting its feasibility for on-site and real-time use (Arsalane et al., 2020). VAS can accurately determine the color of meat products in CIEL*a*b* space, ensuring the quality of their products through fast and accurate assessment, characteristics that, in turn, can influence consumer perception and business profitability (Nasiri & Mohi, 2021). Altmann et al. (2022) analyzed the methodology of human perception of color differences in raw pork using a computer vision system. Modzelewska-Kapituła & Jun (2022) performed VAS applications in volume and surface area measurement, quality assessment, meat chemical composition determination, and sensory quality prediction. Developing a VAS that can accurately determine color in the CIEL*a*b* space of images in bovine loins is an invaluable tool for the meat industry (Nasiri & Mohi, 2021). Therefore, the development of VAS for color analysis in meat products has become relevant due to its importance as an indicator of meat quality (Nasiri & Mohi, 2021).

METHOD

The project presented below was carried out in two stages. The first stage involved the construction of an artificial vision electronic system (SVA) for the color analysis of Longissimus dorsi bovine loins and their physical components. The loins were acquired from a supermarket in Armenia, Quindío, with Invima certification for their commercialization. The hardware measurement system was programmed in the Python 3.9 system in the second stage. Both systems, duly synchronized, present the CIEL*a*b* coordinates to the user in fresh beef samples (slaughtered on day zero) and stored for six days at four °C, as explained below.

Configuration of the Raspberry Pi 4 for image capture and processing in CIEL*a*b* color space

Table 1. Hardware components used in the construction of the machine vision system (SVA)

	Description	Characteristics
Raspberry pi 4	The Raspberry Pi 4 is a single board computer (SBC) developed by the Raspberry Pi Foundation. It is a newer, more powerful version of the Raspberry Pi series of computers, known for its compact size, low cost, and versatility.	• Processor: Broadcom BCM2711 quad-core processor • RAM memory: 4 GB • GPIO: Retains the GPIO (General Purpose Input/Output) interface that allows connection of external electronic components and peripherals. • Connectivity: Offers a variety of connectivity options, including USB 3.0 and 2.0 ports, Gigabit Ethernet connection, dual-band 802.11ac Wi-Fi and Bluetooth 5.0
Camera	The Logitech PRO C920 is a high-quality webcam that offers an excellent combination of video resolution, image quality, clear audio and ease of use.	• Video resolution: The C920 captures Full HD 1080p video at 30 frames per second. • Automatic lighting correction: Incorporates automatic lighting correction technology that automatically adjusts exposure and white balance.
Lighting	White LED strip, lighting device consisting of a series of white LEDs arranged in an elongated and thin structure.	• The power consumed by the entire strip is 14.9W, which generates a luminous efficacy of 148l m/W.

To ensure efficient capture and processing of high-quality images and the speed needed for the application, the selection of the VAS hardware is crucial. It depends on the level of accuracy and the environment of use. Essential components include high-resolution cameras, image processors, graphics processing units (GPUs), and data storage devices, which must be carefully chosen to ensure the system meets the required functions. The components presented in table 1 were used to construct the obtained VAS.

To ensure the proper functioning of the VAS, a black film was placed on the outer surface of the equipment, which prevents the passage of light into the measuring compartment of the sample image (figure 1), which is covered by a white film on the inside. Both films eliminate the interference of external light and stabilize the reflection of the light inside the measuring compartment.

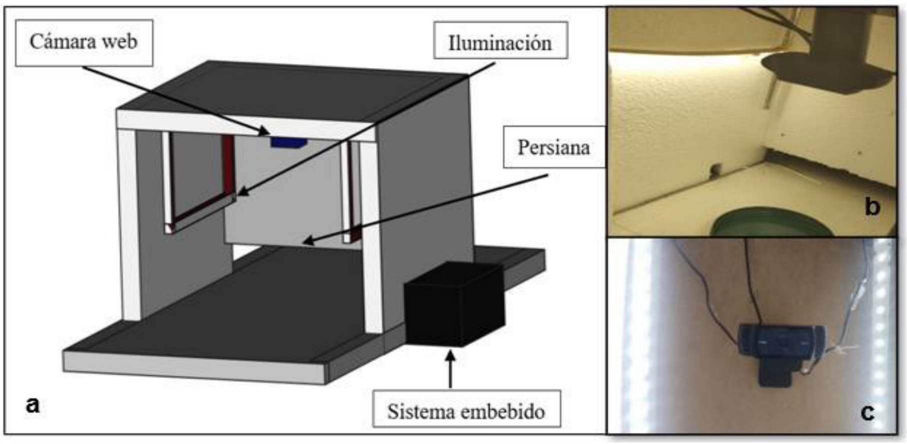

Figure 1. a) Machine Vision System (SVA) for color measurement and analysis of bovine loin samples, b) Internal compartment of the SVA, c) Positioning of the camera and the illumination system

Image acquisition process in the Machine Vision System (SVA)

For the implementation of a VAS according to the requirements proposed and taking into account the characteristics of the hardware acquired, we proposed the design of software that allows the calibration of the camera and the detection of the color of the bovine loins, following the stages proposed in the block diagram shown in figure 2. An embedded system conforms to the central axis of this stage; such a system was implemented in a Raspberry Pi 4, running the Raspberry Pi OS, which is in charge of capturing the image, segmenting it, resizing it, storing it, and delivering a response in terms of the CIEL*a*b* system to the user.

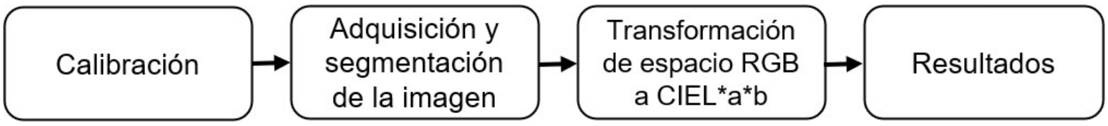

Figure 2. Stages established in the design and construction of the software for the Machine Vision System (SVA)

Once the synchronization of the equipment was completed, the calibration stage was performed. The focal length and optical center obtained in the camera calibration matrix are presented in table 2. These values were used in the calibration function to obtain a better image resolution at the moment of capturing the focal length (fx, fy), optical centers (cx, cy), and the comparison of the image obtained in the uncalibrated camera, as shown in figure 3.

Table 2. Logitech PRO C920 camera intrinsic parameter values

Parameters	Value
fx	956,602
fy	103,179
cx	291,159
cy	73,680

A Logitech PRO C920 camera was used to determine the color, which offers advantages such as capturing a large amount of spatial information, the ability to measure surfaces of various sizes, availability of a wide range of models at more affordable prices and does not require direct contact with the surface to be measured.

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However, using theoretical models, the information obtained in color space Red, Green, and Blue (RGB) must be transformed to CIEL*a*b* color space (Castellanos et al., 2022). The parameters and equations used at this stage are presented in table 3.

Table 3. Characterization of color in bovine loins: equations and specialized equipment

Parameters	Equations	Color measurement equipment
Brightness: L*	L* = 116 $(Y^{1/3}/Yn)$− 16 Ec. (1)	
Coordinate coordinate: a*	a* = 500 $[(X^{1/3}/\ Xn) - (Y^{1/3}/Yn)]\ Ec.$ (2)	
Coordinate coordinate: b*	b* = 200 $[(Y^{1/3}$/Yn)− $(Z\ ^{1/3}$Zn] $Ec.$ (3)	*Colorimeter CR-400* (Konica Minolta Sensing Americas. ,2023)

In order to establish a comparison parameter, color measurements were made in the VAS and the Konica Minolta CR-400 colorimeter (table 3), taking the color coordinates L*, a*, and b* in five points of each sample of fresh beef loins and stored for six days, the reported values were calculated as the average of these measurements. The determination and expression of color were carried out based on the CIEL*a*b* coordinates (table 3) and reflectance values (CIE, 1976), obtaining the coordinates: Luminosity (L*), red-green (a*), yellow-blue (b*), directly from the equipment.

RESULTS AND DISCUSSION

The results obtained during the realization of the project are presented below; once the construction of the electronic system and the programming of the VAS hardware measurement system in its structural form were completed, a compartment was built for the acquisition of the images, which functions as the main structure of the equipment it supports the sample of bovine loins to be analyzed and the other components, as shown in figure 1.

Image capture and extraction of CIEL*a*b* coordinates in the VAS

The image capture process performed by the VAS is fundamental for the acquisition of visual data that will be used in the analysis of the color of the spines and subsequent analysis. Figure 3 shows the different stages performed in SVA during image capture, calibration, and segmentation. Initially, the environment and the sample of bovine loins were prepared, ensuring optimal illumination and alignment conditions that allowed an accurate capture of the image (figure 3a). The focal length and optical center obtained in the camera calibration matrix are presented in table 2. These values are used in the calibration function to obtain a better image resolution at the time of capture and compare with the image obtained in the uncalibrated camera.

The image was captured using the Logitech PRO C920 camera, and an analysis process was performed to reduce noise and improve its quality. Contrast and color correction adjustments were also made to optimize its usefulness in subsequent analyses (figure 3b). Once the previous process was finished, image segmentation was performed to identify the region of interest (ROI) within the complete image of the bovine loin obtained (figure 3c). This segmentation involved using advanced image processing techniques, such as thresholding and feature detection, to distinguish the ROI from the background and other irrelevant elements. The identified region of interest becomes the main focus of further analysis and applications, allowing feature detection, pattern recognition, and decision-making based on accurate and relevant visual information.

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a) Uncalibrated image b) Calibrated image c) Segmented image

Figure 3. Image of bovine loin a) before and b) after the calibration process, and c) segmented image

Once the previous steps were completed, the measurement was performed, and the values of the parameters L*, a*, and b* were extracted from the image obtained from the bovine loin. The image acquired by Python 3.9 software was converted from RGB space to CIEL*a* b* space, using equations (1), (2), and (3) presented in table 3. The system calculates the mean of the Luminance (L*), red-green (a*), and yellow-blue (b*) coordinates. Finally, the user will be able to visualize in the interface the two components facing the original image of bovine loins during the days (0-6) of storage at four °C, as presented in table 4.

Comparison between the color measurements obtained in the Machine Vision System (SVA) and the Minolta CR-400 Colorimeter (CM)

The color coordinates L*, a*, and b*, obtained in the VAS, were compared with those obtained in the CM and presented in table 4. In order to obtain the color values in the CM, it was necessary to take measurements in several sections of the sample and obtain average values because the analysis area of the colorimeter is approximately 8 mm in diameter and was not able to cover the total area of the meat samples, connective tissue and intramuscular fat that could influence the colorimetric characteristics of the lean part of these (Girolami et al., 2013).

Table 4. CIEL* a* b* coordinates in beef loin samples during storage time at four °C, acquired in the Machine Vision System (SVA) and the Minolta CR-400 Colorimeter (CM)

Sample	Storage time	CIEL coordinate values *a* b*	
		SVA	CM
	Día 0	L*: 59.61186178 a*: 5.3776992 b*: -8.3727804	L*: 60.48523865 a*: 5.96368978 b*: -9.44569322
	Día 1	L*: 58.27551214 a*: 5. 64158818 b*: -9.77889147	L*: 58.26325783 a*: 5. 89857451 b*: -10.80364578
	Día 2	L*: 50.12012421 a*: 2.64234985 b*: -4.39190818	L*: 49.85823695 a*: 2.59834857 b*: -5.52364735
	Día 3	L*: 51.35447075 a*: 2.35686958 b*: -4.21038999	L*: 50.56891525 a*: 2.56457985 b*: -4.32659524

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	Día 4	L*: 61.63334934 a*: 3.06043796 b*: -4.96354232	L*: 50.85621394 a*: 3.84785622 b*: -5.29425367
	Día 5	L*: 48.91479247 a*: 2.94847217 b*: -4.34895065	L*: 49.09458236 a*: 3.52584793 b*: -3.95864127
	Día 6	L*: 48.23733609 a*: 1.46530337 b*: -2.86972267	L*: 48.18945633 a*: 1.98647817 b*: -3.99857426

Samples: Bovine loins, Equipment: SVA: machine vision system, CM Minolta colorimeter, storage time (Dia 0-6), L*, a* and b* color coordinates.

The values obtained in the VAS of beef loin samples represent the sample as a whole. They can be observed from the equipment monitor, making it possible to guarantee homogeneous measurements of the lean parts or those of interest to the researcher. The values obtained for the L* coordinate showed similar trends in the two measuring devices for the beef tenderloin samples. This coordinate is related to the total pigment contained in the meat, making the product darker or more opaque, as can be seen in table 4. The values of L* decrease with storage time, indicating that L* is useful for differentiating the color between meat samples during storage time (Xing et al., 2007).

The a* coordinate is related to myoglobin content, and the b* coordinate is related to myoglobin states (Perez et al., 1998). The values obtained for the a* and b* coordinates showed significant differences between the two measuring devices. They decreased during the first hours of storage, corresponding to the meat's oxidation stage, causing more pronounced changes in b*; this behavior can also be attributed to the reflected and refracted light of the myoglobin and myoglobin layers (Girolami et al., 2013). Another factor that could influence the values obtained for a and b* is attributed to the methodology used for image capture in the Minolta Colorimeter and to factors such as breed, cattle feed, and slaughter process that affect the oxidation process of myoglobin and, therefore, the color of the meat samples during storage time.

The processes described above, from constructing the electronic machine vision system to designing the software for color analysis in bovine loins, have culminated in significant and promising results. These results clearly show the feasibility and efficacy of the system developed for color evaluation in fresh and stored beef samples.

CONCLUSIONS

The color values obtained through the application of the CIEL*a*b* coordinates and their comparison with the Minolta CR-400 Colorimeter in the samples of fresh beef loins and during the storage time did not present significant statistical differences about the L* values, the values obtained for a* and b* presented statistical differences attributed to the methodology used for the capture of the image in the Minolta Colorimeter and to factors specific to beef.

The results established that the artificial vision system can measure fresh beef loins' color during storage time in a simple, fast, non-invasive, real-time, and low-cost manner.

This technological tool will allow meat producers, marketers, and processors to take appropriate management measures to obtain quality products with high consumer acceptance. It also constitutes, at present, an important open field of research and an excellent opportunity for electronics and agribusiness, aiming at the generation of science and technology itself.

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CONFLICT OF INTEREST

The authors declare that there is no conflict of interest.

AUTHORSHIP CONTRIBUTION

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