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EVALUATION OF THE FRESHNESS OF MEAT-BASED ON COMPUTER VISION: SYSTEMATIC LITERATURE MAPPING

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ABSTRACT

Diets based on meat consumption increase by the perception of nutritional values; in such a way, more attention is paid by industries, as well as by consumers, to the quality and freshness of this food. Traditional inspection methods are sometimes expensive and destructive, in addition to the knowledge for carrying out such an activity to be held by specialists, being tacit knowledge, and not being available to the final consumer. Automated methods based on computer vision (CV) are presented as an alternative. This study suggests a systematic literature mapping, which resulted in 31 studies that investigate different quality characteristics of meat using CV and future challenges and trends in the application of the technique in the food industry.

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INTRODUCTION

The color of the meat provides an intuitive impression of freshness and the composition of the ingredients. It is not only a comprehensive indicator reflecting differences in muscle biochemistry, physiology, and microbiology but also an essential factor that changes with the life span of fresh meat (YOU *et al*., 2020). Li *et al*. (2016) state that during transport and conservation, meat tends to spoil. Deterioration is defined as a complex dynamic process due to tissue enzymes and chemical reactions, such as oxidation, and are often accompanied by changes in color, smell, and texture. It is imperative to control and evaluate the freshness of the meat before making it available to consumers. According to Arsalane *et al*. (2020), several techniques are used to assess meat samples' freshness. On the one hand, traditional techniques such as microbiological analysis are destructive, laborious, and not suitable for real-time assessment. On the other hand, image analysis methods have recently been used to visually evaluate meat samples based on the color, shape, size, and texture characteristics of the surface. Computer vision is one of those methods. Hau (2015) states that computer vision is a non-destructive, scalable, rapid implementation method suitable for real-time evaluation. This article describes studies that evaluated the quality of beef, pork, chicken, and fish, based on color, using computer vision models. The objective is to understand the existing solutions, hardware used for data collection, a*nd* the challenges faced or perceived by the authors. For that, a systematic mapping of the literature was developed following Kitchenham and Charters (2007).

SYSTEMATIC LITERATURE MAPPING

The literature review was carried out in two moments, with the objective of funneling knowledge, with an exploratory search, of a broader scope being carried out in the first moment. In the second moment, a systematic mapping of the literature (SLM) was carried out, focusing on three worlds: meat, freshness, and solutions. SLM considered the last six years of publications (2015 to 2020). The SLM followed the operational protocol that consists ofthe elaboration of the search string, identification of existing works, extraction of evidence, synthesis of evidence, state of the art exhibition, and other results (KITCHENHAM; CHARTERS, 2007). In this context, the questions that guide the SLM are:

Q1: What are the central computer vision, Machine Learning, or Deep Learning solutions used to classify the quality of beef, pork, chicken, and fish, based on sensory color analysis, analyzed through sample images?
Q2: What equipment and software make up the computer vision system to capture images of meat samples of the solutions found?
Q3: What are the main challenges faced or perceived for adopting computer vision, Machine Learning, or Deep Learning solutions to classify the quality of beef, pork, chicken, and fish, based on sensory analysis of the color analyzed through images of samples?

Searches were made on the search engines ScienceDirect, IEEE Xplore, Springer Link, and Google Scholar, using the following search string: *(method or "computer vision" or "machine vision" or "machine learning" or "deep learning" or "neural network" or "digital image") and (freshness or quality or color) and (beef or pork or chicken or fish or tuna or salmon)*

The guiding criteria for this research are set out below.

Inclusion criteria:

- **IC 1:** Studies that present computer vision, Machine Learning, or Deep Learning solutions to classify the quality of beef, pork, chicken, and fish samples, based on sensory color analysis, analyzed through sample images;
- **IC 2:** Studies published in a journal or conference delimited within the scope of this research.

Exclusion Criteria

- EC 1: Studies not related to the quality classification of beef, pork, chicken, and fish, based on sensory analysis of the color, analyzed through sample images;
- EC 2: Works referring to solutions for the classification of the quality of samples of beef, pork, chicken, and fish, based on sensory color analysis, analyzed through sample images only as future research projects;
- ECCE 3: Incomplete works, drafts, documents for compiling conference proceedings, tutorials, and slide presentations;
- EC 4: Jobs not accessible;
- EC 5: Works not written in English;
- EC 6: Duplicate works, resulting from the same research or with minor changes to a previous publication;
- EC 7: Works not published in the last six years (2015 to 2020);
- EC 8: Books, dissertations, or theses.

The SLM totaled a final sample of 31 articles (available inhttps://bityl.co/4hU7) in the context of this research. The synthesis of the items is shown in Section III.

SUMMARY OF RESULTS

In this Section, each study's syntheses are presented, highlighting the type of meat sample studied and the computational solutions used for the classification of such models through the sensory analysis of their color and, finally, the challenges listed by the authors. The Section is divided into subsections for each type of meat studied.It should be noted that all studies presented include solutions for the analysis of the quality of meat samples (*Q1*), being shown in more or less detail, according to the available information. Not all studies detail the hardware used to capture the samples' images, nor the software used to treat them (*Q2*). The colorimetric features of the samples extracted from the pictures are highlighted. Few studies presented challenges faced for adopting the respective solution or perceived future challenges (*Q3*).

BEEF

Gorbunova *et al*. (2015) developed a method to study the principles of color analysis applied to evaluating the freshness of meat products using the spectral characteristic of the light source used to illuminate the samples. The study presents the color simulation results of meat samples based on data on the content of various forms of myoglobin in different proportions. The spectral characteristic of the light source was used to illuminate the meat sample. The model analyzes the color of the meat samples under an LED light source. Eight meat samples captured by a digital camera were studied. As a result, correlations between the said biochemical indicators of the quality and color of the meat obtained across the machine vision system were found. In another study, Trientin, Hidayat, and Darana (2015) proposed the classification of the freshness of beef through the sensory analysis of the color of samples, using two models: K-Nearest Neighbors (KNN) algorithm and neural network with retro propagation. For the study, the authors captured the samples' images in a controlled environment, using a digital camera, and parameters from the RGB color space were extracted and converted to HSV. The classification model using KNN obtained 75%, while the neural model's best precision with retro propagation was 71.4286%. The KNN model proved to be the best solution.

Adi *et al*. (2015) present a model for determining meat quality based on the K-Nearest Neighbors (KNN) algorithm, using the image processing technique. Image acquisition is conducted vertically, varying the distance between the camera and the sample, camera resolution, and tilt angle. The color of the meat and the fat's coloris represented by the hue image in the RGB and HSV channels. The results indicate that the developed system is capable of acquiring images and identifying the quality of the meat but does not present the obtained accuracy. In another study, Yulianti *et al*. (2016) make use of 30 beef images, captured through a digital camera with 5MP resolution, to classify them as to their freshness, based on analysis of their color. The RGB color space parameters have been extracted. The sample decomposition process could be observed visually based on the change in the color of the meat captured in the successive images. The averages of the color intensity in the R, G, and B channels of the beef image are presented. The percentage of the power of the R channel was the one that most decreased every 4 hours. The most significant drop was between 12 and 16 hours and can be used as a resource to identify fresh and deteriorated meat samples efficiently.

The study by Winiarti, Azhari, and Agusta (2018) proposes identifying the quality of beef by sensory analysis of the color observed in 40 samples photographed by a digital camera. The proposed system captures the sample image and stores it in bpm or JPEG format. The components of the RGB color space are extracted and transformed into the parameters of the HSI color space. For each color of the sample, the histogram is also obtained. The histogram is used to group the meat samples, using the K-Means algorithm, into four categories: very viable, viable, less viable, or unfeasible. The determination of the classes is obtained based on the calculation of the Euclidean distance of each image. Arsalane *et al*. (2018) present an embedded system based on Digital Signal Processor (DSP) with the implementation of the Principal Component Analysis (PCA) and Support Vector Machine (SVM) algorithms to classify and predict the freshness of beef. A data set of 81 beef images was analyzed based on the HSI color space. The beef images were captured by a GigEPRO camera, model GP1503C, with 2592×1944 pixels. The PCA algorithm was used as a projection model, and SVM was used for the classification and identification of beef. The results obtained from the PCA projection model show the projection of three groups representing the freshness of beef meat during the days of refrigerated storage. The SVM algorithm got a 100% success rate of classification and identification. Embedded DSP-based platforms as portable tools can be used to predict or identify the freshness of the sample beef in any environment and in real-time.

The Hosseinpour, Ilkhchi, and Aghbashlo (2019) study present an application based on a neural network embedded in a smartphone to classify the freshness of beef based on texture. The LG G4 H815 smartphone camera was used to capture images from 167 samples. Parameters of the RGB color space have been extracted and converted to the invariant space in gray level lighting. The texture of the pieces was extracted from the latter. An app called "BeefQuality" was developed to assess the beef samples' quality, using Simulinke programming, then compiled for the Java programming language compatible with Android devices. The results showed that the developed application could satisfactorily predict the quality values of new samples with an accuracy of 0.99. The challenge that motivated the development of the application and the relevance of the classification system itself is to extend it for use in real environments, outside of laboratories.

In a recent study, Arsalane *et al*. (2020) propose an embedded computer vision system with four central systems: the lighting system, the processing system, the image acquisition system, and the display system. The acquisition system contains a GigEPRO camera. The Principal Component Analysis method (PCA) was used first to provide visualization of color data sets in a reduced size and second to determine the proposed system's ability to recognize whether meat samples are fresh or not. Support Vector Machine (SVM) algorithm was used to classify the beef samples in the three classes obtained by PCA analysis. The results obtained show a 100% success rate in the classification and identification of measurements within the three categories given by the PCA. Another methodbased on probabilistic neural networks (PNN) for classifying the freshness levels of beef used by Arsalane *et al*. (2020). A classification rate of 93.83% was obtained from the texture associated with the color data set. Finally, the authors used the method of analysis of linear discriminants (LDA) to classify the level of freshness of beef. A classification rate of 82.72% was obtained from the texture associated with the color data set. These results show that the PNN algorithm has better performance regarding the texture classification rate associated with the color. The authors believe that the development of embedded systems is challenging.There are still some challenges in optimizing image processing algorithms (to build miniatures of the images) and the development of new processors capable of evaluating the quality of meat samples in real-time. In a more recent study, Campos *et al*. (2020) present a computer vision system for segmenting meat based on marbling. Image capture took place in an uncontrolled environment. The experiments were carried out using two sets of 82 images, each with 41 longissimusdorsal musclesacquired by different sampling devices. The experimental results using the k-means clustering algorithm showed that the computer vision system performed with more than 98% accuracy and a low number of false positives, regardless of the device used to acquire the images. Finally, Tan, Husin, and Ismail (2020) present a computer vision solution and deep neural network or deep learning (DNN) to predict the quality of beef by determining the sample muscle's color scores. Four hundredsirloin steaks were photographed, and experts assigned the color score of the meat according to the standard color charts. The image was processed and passed through the DNN classifier to determine the beef quality, which obtained an accuracy of 90%.

CHICKEN

Asmara *et al*. (2017) propose three classifiers to identify the freshness of chicken meat based on the resource of the RGB color channel. The value of the histogram is acquired from samples of the breast, leg, neck, wings, claws, and chicken head. The chicken meat sample data set contains 60 pieces, obtained from 6 chickens. The image is captured using an 8 MP resolution smartphone camera. The first order statistical method is used to reduce the size of the color resource, such as mean, maximum, and sum. The values are submitted to three classification models: Naïve Bayes, Support Vector Machine (SVM), and decision tree C4.5. The freshness of chicken meat is defined in three classes: fresh, medium, and old. The Naïve Bayes model shows 33.33% accuracy, the Support Vector Machine (SVM) model shows 58.33% accuracy, while the C4.5 decision tree model shows 50% accuracy. The low accuracy of the three models suggests further studies and tests of other models. The authors claim that using such models in real environments is challenging since the images' variability can affect the result. Bandara *et al*. (2018) present a project for capturing multispectral imaging that can be used to assess the quality of chicken meat. The system contains a lighting module composed of six LEDs to capture multispectral images from ultraviolet (UV) to near-infrared (NIR) with a resolution of six spectral bands. The LEDs are lit one at a time, and the meat sample images are captured via an Xperia E3 smartphone camera for each LED separately. Finally, all photos of the meat sample, photographed at a specific time, are integrated to form the multispectral image. The pixels of the multispectral image were represented as points in the high dimensional space, which was then reduced to a lower-dimensional area using PCA. The experiment proves the feasibility of using multispectral imaging, with a low-cost image acquisition system, as a non-invasive and non-destructive method for assessing chicken meat quality according to pre-established quality parameters.

Taheri-Garavand *et al*. (2019a) propose intelligent and non-destructive prediction systems for chicken meat's freshness during the deterioration process at 40^0 C. A computer-based method was developed for online assessment of the freshness of chicken meat in a low-cost environment. The system includes a light source, a camera with a CCD sensor (CANON, SX260 HS, 12.1MP resolution), a computer, and image processing software. Thirty samples of chicken legs were collected and labeled by specialists. Three thousand chicken images from 30 models were captured on both sides (with and without skin). Images were acquired in JPEG format. Parameters of the RGB, HSI, and L*a* b* color channels of the samples' texture were extracted using Matlab. A genetic algorithm carried out the selection of features, and then an artificial neural network of topology 33-10-1 was designed for classification, reaching an R^2 accuracy of 98%.

In a more recent study, You *et al*. (2020) propose a computer vision method, using image capture with XiaomiMIX 2S smartphone camera. The technique is to classify, through the color analysis of chicken meat samples, their freshness levels. The authors point out that, although inexpensive and scalable, the use of different smartphone cameras to capture pieces of chicken meat can generate different hues for equal colors, which is a challenge to be faced. Significantly, some smartphones tend to use a warm tone, while others tend to use a cold style. In this way, the color can affect the visual effect of the captured image and make it unreliable to assess the meat sample's quality. The study proposes the use of a printed card containing blocks of predefined standard colors as a way to correct such distorted effects and encourage the use of meat sample classification systems, with images collected by various devices. The color card is placed next to the chicken meat sample, and the image captures both. An algorithm is proposed to compare each color block of the card against the colors present in the meat sample and then correct it. With the colors updated, a grouping model is used to separate the images of the chicken meat samples intothree quality levels. The method was tested on 106 chicken samples. The authors conclude that the proposed model facilitates data collection since it allows the pool by several digital cameras, making it cheaper and reducingthe data set's construction (dataset). It should be noted that the proposed model uses previously untagged images, which represents a fundamental approach in contexts where specialists are not found for the sample labeling task.

PORK

Sun *et al*. (2016) presented a study using the linear and stepwise regression method to classify color images of loin samples. One hundred loin samples with color scores labeled by experts, with points from 1 to 5, were selected to determine the correlation values between the measurements of the Minolta CR-400 colorimeter and the image processing capabilities. The image acquisition system consists of three components: a camera with a CCD sensor, model MVVS141FM/C; two adjustable white LED lighting systems model YX-BL25040, and a personal computer. A dark lighting box is designed to prevent lighting from other sources outside the system. All images acquired were 1392×1040 pixels and were stored in BMP format for further analysis. Eighteen color features of the image were extracted from three color spaces: RGB, HSI, and L*a*b* (this last were acquired through a Minolta CR-400 colorimeter). When comparing the L*a*b* values of the colorimeter with the values obtained from the images, the correlations were significant (P <0.0001) for L * (0.91), for a * (0.80), and b * (0.66). Two regression models were used to evaluate the results of the prediction of pork color attributes. The proposed linear regression model obtained a determination coefficient (R^2) of 0.82, while the stepwise regression model obtained R^2 of 0.70. These results indicate that computer vision methods can be used as a tool to predict the color attributes of pork. According to the authors, given the high precision, there was no need for tests with other classifiers. Another study, carried out by Li *et al*. (2016), proposes a computer vision system for rapid and non-destructive detection of the freshness of pork using a light scattering technique. Three parts make up the system: a laser lighting system,a camera with a resolution of 640×480 pixels, and a computer.

Ninetyimages of thirtypigs were captured, and then texture analysis was used to extract variables characteristic of the region of interest (ROI) from the image. An adaptive classification algorithm boosting linear discriminant analysis (AdaBoost - OLDA) was proposed for modeling and compared with two traditional classification algorithms: linear discriminant analysis (LDA) and Support Vector Machine (SVM). The experimental results showed that the classification results obtained by the AdaBoost - OLDA algorithm are superior to the LDA and SVM algorithms and reached a classification rate of 100% in the prediction sets. This study demonstrates that the light scattering technique developed can detect meat freshness in a non-invasive way. Sun *et al*. (2018a), in another study, investigated the freshness of pork using characteristics of its color observed in digital images.

The study compared the performance of the Support Vector Machine (SVM) classifier and traditional regression methods. The sample consisted of 685 pork ribs. Color space parameters L*a*b* were extracted using a Minolta CR-400 colorimeter. For each image, transformations of the RGB color space parameters for the HSI and L*a*b* color spaces were performed. SVM accuracy was 73.4%. Traditional regression methods were also tested, reaching an accuracy of 68.3%. The authors conclude that the colorimeter's use limits the sample range, not getting the entire region of interest, and computer vision systems are more efficient. In yet another study, Sun *et al*. (2018b) designed a computer vision system to measure pork's freshness under the industry's speed requirement.

The computer vision system designed for capturing images consists of an industrial camera (NI 1776C) with a lens (LMVZ4411), a polarized lighting lens (DL180), and a Lenovo laptop. Parameters were extracted in the RGB, HSI, and L*a*b* color space for each sample's texture aspects. Models based on linear regression and Support Vector Machine (SVM) were used to classify the pork samples based on their color, obtaining R^2 precision of 0.27 and 0.79, respectively. The authors suggest studies with other classification algorithms in an attempt to getmore incredibleaccuracy. In a more recent study, Alcayde, Elijorde, and Byun (2019) implemented and evaluated a system that estimates the age of pork using the characteristics of the RGB color space. The images were captured using a high-resolution digital camera and LED lighting. Several photos were captured between day 0 (fresh meat) and day 7 (non-fresh beef). The RGB parameters have been extracted. A software coded in C# to calculate the euclidean distance between two points in the RGB color space. In the evaluation, the result established that the meat's color could estimate the age of the pork.

FISH

Elmasry *et al*. (2015) presented a study to provide a convenient and non-invasive method to estimate the freshness of the TrachurusJaponicus fish in a frozen state, using autofluorescence spectroscopy in conjunction with the multivariate analysis of fluorescence excitation-emission matrices (EEM). The fluorescence data extracted from different freshness conditions were pre-treated and reorganized to resolve fish fluorescence spectra from overlapping signals and dispersion profiles to detect and characterize freshness changes. The actual freshness values of the examined fish samples were then determined by traditional chemical analysis using the high-performance liquid chromatography (HPLC) method and expressed as K values. The EEM fluorescence data and the actual freshness values were modeled using partial least squares regression (PLS), and a new algorithm was proposed to identify the ideal combinations of excitation and emission of wavelengths being used as perfect predictors. The results revealed that the frozen fish's freshness could be accurately predicted with an R^2 of 0.89. This study demonstrated that the autofluorescence spectroscopy associated with the proposed technical approaches has a high potential in the non-destructive detection of the fish's freshness in the frozen state. Dutta *et al*. (2016) propose an automatic, efficient, and non-destructive image processing method for segmenting tissues and classifying the fish sample's freshness. Aquarium fish were removed and placed in ice water for sudden death to avoid rigor mortise. The fish were subsequently preserved for the study in termcol boxes. Gill images, with 601x361 pixels, were captured with the NIKON D90 digital camera on the first day and at two-day intervals for up to thirteen days. The proposed method involves image analysis of the gills and extraction of characteristics from the red channel, followed by the study of features of the wavelet transform's coefficients. The branchial tissues of the fish sample are automatically segmented using a grouping-based method, and their resources are strategically extracted in the wavelet transformation using the Haar filter. The first, second, and third-level decomposition in the wavelet domain is performed, and the coefficients obtained at each level were analyzed to predict the freshness of the fish sample. The experimental results indicate a pattern of monotonic variation of the coefficients at the third level of decomposition, and these coefficients give an indication of the quality of the fish and represent discriminatory behavior keeping a relationship with the number of days passed. The authors suggest that the current protocol can be applied to different varieties of fish.

In a study to classify salmon quality, Sture *et al*. (2016) present a computer vision system to capture and process 3D images of salmon samples based on their color. The images contain a scanning cross-section in 360^0. The classes used to describe the salmon are upper, standard, and production. The 3D technology presented allows geometric and color information to be used to detect deformities and wounds automatically. The custom camera system combines knowledge from three different high-speed cameras, using a line-scanning technique, to form a complete 3D image of the salmon as it travels on a conveyor belt. This approach benefits from making all geometric information available for analysis while providing color information on both sides of the fish. For each camera, a region of the salmon was photographed (with 105 salmon in the data set). The processing of the acquired images was transferred to a GPU. The average of the HSL color space was used as a resource, and the injured region's sizeconcerning the salmon's size. The extracted parameters were delivered to a classifier based on Support Vector Machine (SVM), obtaining 86% accuracy. According to the authors, the small size of the data set is a limitation of the study. It presents itself as challenging to the correct interpretation of data obtained in 3 dimensions. The study Ghasemi-Varnamkhasti *et al*. (2016) aimed to evaluate the freshness and quality of the cultivated shrimp (litopenaeusvannamei) during nine days of storage ice, at a temperature of 0^0 C using image processing technique. The image processing system consisted of a darkroom and lighting system, digital camera, computer hardware, and software. For adequate lighting of the shrimp samples, some white and yellow LED lamps were installed in the upper part of the darkroom. A PowerShot camera with a CCD sensor (Sony DSC-w530) was used to obtain shrimp samples' images. The camera was connected to a laptop ASUS via the USB port. Thirty-six color parameters from 80 shrimp images were extracted: mean and variance of red (r), green (g), blue (b), lightness tone (h), saturation (s), value (v), luma information (iey), luma component (y), chroma component (cr), luminosity (L*), redness (a*), yellowing (b*), chroma (c) and hue (h). Different computational approaches, such as linear discriminant analysis (LDA), quadratic discriminant analysis (QDA), KNN, and discriminant partial least squares regression (D-PLS), were used to examine the parameters and classify the freshness of the shrimp. Classification accuracy of 90%, the best classifier being the LDA. The authors suggest that similar systems can be used to classify the shrimp's freshness online, with the capture of images made with smartphone cameras.

In another study, Issac, Dutta, and Sarkar (2017) present a computer vision system to determine the freshness of fish based on the gills' texture. The authors state that a problem commonly faced is the accurate and consistent segmentation of the region of interest (ROI) that will be used for resource extraction. Another problem arises from the variability in the quality of the images, which may have variations in lighting and shooting distance, which may influence the observed sample's color. The fish were placed in an aquarium and, at the time of the experiment, were transferred to ice water, which results in the sudden fish's death, avoiding rigor mortise. The camera used to capture images of the fish was a NIKON D90. A method to analyze the freshness of the fish was developed and used the gills' color as a parameter. A data set with 144 samples were analyzed. Parameters of the RGB color space were initially extracted and then converted to HSV, with the saturation channel as a parameter analyzed using first-order statistics. The performance of the proposed method was reported in terms of computational time and resource extraction from the segmented ROI. The total time required for the complete analysis reaches 3.76 s per sample, which, according to the authors, is encouraging enough for the development of any application in real-time. In another study, Listyarini *et al*. (2017) propose the measurement of the deterioration of fish meat through natural extraction of its color, subsequent exposure of the samples to different temperatures, under the presence of a colorimetric label that changes color (made from cellulose paper). The fish used in this study is Rastrelliger fish obtained from a local market in Depok, Indonesia. For the experiment, the fish meat is placed in a clear glass bottle. The colorimetric labels are hung inside the bottle with the fish meat, without contact with the sample. Images of the title were captured after storage, and color change, caused by the fish's deterioration (gas emitted by the fish when the deterioration process occurs), can be observed. In each condition, the colors, through the parameters of the RGB color space, of the label were extracted through digital images captured by a Canon EOS 75D camera. From the study, it can be inferred that the colorimetric label used for the detection of fish deterioration is marked by the change in color from purplish pink when the condition of the fish is fresh to purplish-blue when the fish is damaged. It is proven that monitoring the deterioration of fish can be done practically and straightforwardly using colorimetric labels.

Sengar *et al*. (2018) propose a method for identifying fish freshness using the skin as the focal tissue for analysis and design a model that uses statistical characteristics of the skin tissue. According to the authors, the appearance of skin changes, from a very bright scale, passing through bright, opaque. The skin tissue is selected as the region of interest, RGB color space parameters are converted to HSV color space parameters. In total, 42 images of samples are used to train the model, while 30 images are used for testing. A NIKON D90 digital camera is used to capture images. The average in the HSV color space is selected as the final resource. The model showed 96.6% accuracy. In a recent study, Lugatiman *et al*. (2019) presented an Android-compatible application that uses parameters for digital image processing to assess the freshness of YellowFin tuna meat through color. To build the classification model, the researchers created a studio box to attach a 1080p Raspberry Pi camera, responsible for capturing the tuna meat's image and storing it wirelessly in the gallery of a smartphone. The application contains KNN classification algorithms and has been trained with parameters of the RGB color space of 60 samples of tuna meat. The training samples were classified in terms of freshness: excellent, useful, and acceptable, with an accuracy of 86.6%. The authors encourage other classifiers to increase accuracy and highlight the challenge of analyzing and further classifying images from uncontrolled environments.

In another study, Taheri-Garavand *et al*. (2019b) propose a method based on the artificial neural network to assess the freshness of the common carp (Cyprinuscarpio) during storage on ice. Sample images were captured using a CCD digital camera. After pictures of 1344 samples were captured, parameters of the RGB, HSI, and L*a*b color spaces were extracted. The Artificial Bee Colony-Artificial Neural Network (ABC-ANN) hybrid algorithm was applied to select the best resources. The Support Vector Machine (SVM), KNN, and Artificial Neural Network (RNA) algorithms, as the most common methods, were used to classify fish images. The accuracy of the KNN classifier was 90.48%, whilethe SVM classifier's accuracy was 91.52%. The artificial neural network model obtained the best precision (93.01). In this system, the input layer consists of 22 neurons based on the color spaces' characteristic features, ten hidden neurons, and four classes in the output layer, including fresher, fresher, reasonably relaxed, and spoiled. The results demonstrate the high performance of the RNA classifier for assessing the freshness of common carp during ice storage as a fast, accurate, non-destructive, real-time, and automated method. In a more recent study, Lalabadi, Sadeghi, and Mireei (2020) proposed digital image analysis to assess the freshness of trout by tracing the color attributes of their eyes and gills. A computer vision system containing a color digital camera (SONY Cyber-shot DSC-W220) was built to collect the images with an optical resolution of 12.1 megapixels. The database consists of 400 color images captured from the right and left gills and eyes from 20 fish samples. The color components were extracted in RGB, HSV, and L*a*b* and then subjected to classification models based on artificial neural networks (RNAs) and Support Vector Machine (SVMs). The general precision of the developed models demonstrated that the ANN surpassed the SVM. The ANN-based on the characteristics extracted from the eyes of the images was able to predict the classes. The accuracy is estimated at 84%. The precision of the network with the resources extracted from the gills' images as inputs were 96%. The study concludes that the characteristics of gills describe the variation in freshness based on storage durations more efficiently than those extracted from the eyes.

A study by Taheri-Garavand *et al*. (2020) proposes a computer vision system to detect common carp's freshness through the application of a deep convolutional neural network (CNN). Images of 48 typical carp samples were captured by the same computer vision system used in Taheri-Garavand *et al*. (2019a). To classify fish images based on freshness, first, the VGG-16 architecture was applied to extract resources from fish images automatically. So a classifier based on a CNN was built by dropout and dense layers. Four freshness classifications were used in the output layer of the neural network. The results obtained showed the classification accuracy of 98.21%, indicating that the proposal based on CNN has less complexity and greater precision than traditional classification methods. The authors encourage the development of an application for smartphones in which consumers can determine the fish's freshness through image capture using the camera of their devices. Finally, Moon *et al*. (2020) propose the assessment of the freshness of salmon, beef, and tuna meat using spectral data from the visible region (VIS) and near-infrared (NIR), obtained from the samples using the commercial spectrometer LinkSquare, designed by the authors.

An artificial intelligence platform based on convolutional neural networks (CNN) was used to analyze the spectral response data. The machine-learning algorithm was developed by the authors' company. The samples used were composed of unfrozen salmon, frozen tuna, and beef. The spectra of three Atlantic salmon samples, three Pacific salmon samples, eight tuna meat samples, and eightbeef samples were digitized to create a training data set. At the same time, the spectrum of twelve Atlantic salmon samples, twelve Pacific salmon samples, nine tuna samples, and eight beef samples were checked for a verification data set. Three categories (fresh, probably spoiled, and spoiled) for each type of food were coded correctly and provided as output vectors for the last layer connected to the neural network. The accuracy of the model was 85% for salmon (84% for Atlantic salmon and 85% for Pacific salmon), 88% for tuna, and 92% for beef, indicating that the portable VIS/NIR spectrometer used in conjunction with classification based on CNN can assess the freshness of food with high precision.

Conclusion

This article promoted a systematic mapping of the literature, resulting in 31 studies on computer vision solutions to classify the freshness of meat samples based on their color. It is understood that the computer vision technique was recognized as an efficient tool to assess the quality of meat products. The studies, in general, use the computer vision method, capturing images of meat samples in controlled environments, extracting characteristics from the color spaces. These characteristics are then subjected to traditional classification algorithms, such as Machine Learning algorithms and Deep Learning techniques. High accuracy was found. According to studies, computer vision technology has advantages over conventional methods of assessing the freshness of food, such as the process is non-destructive, it is scalable, it is hygienic, it has low cost, and can be used by non-specialists. The hardware used, as well as the challenges associated with this method,were also discussed. From the SLM, it was concluded that the computer vision technology has the potential to be adopted as a food freshness classification tool, within the quality area, in industries.

Suggestions and future works

It is understood that the ease of data production due to the evolution of the internet and the availability of technologies such as the Internet of Things (IoT) and 5G, as well as the development of processors with greater capacity for parallelism, make the computer vision technique more applicable in various contexts. Among these, the food area stands out as a potential beneficiary. Applications using computer vision are expected to be available online and embedded in smartphones, assessing food quality available to the final consumer. For this, it is understood the need for further research and development in hardware and software. It is suggested as future lines of research for the classification of meat freshness: tests with images captured with different digital cameras, in a real and uncontrolled environment; tests of other Machine Learning algorithms to identify classifiers with greater accuracy; and trials of the use of images of samples associated with convolutional neural networks. Nevertheless, it is understood to be a limiting factor, the classification of freshness only using sensory analysis of the color, suggesting the junction of it, with sensory analysis of the sample's odor through equipment that simulates the human nose.

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