PalArch's Journal of Archaeology of Egypt / Egyptology

APPLICATIONS OF COLOUR MODELS IN THE FOOD PROCESSING INDUSTRY: A SYSTEMATIC REVIEW

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Dr. Saddam Rateb Darawsheh: Applications Of Colour Models In The Food Processing Industry: A Systematic Review -- Palarch's Journal Of Archaeology Of Egypt/Egyptology 17(9). ISSN 1567-214x

Keywords: Computer Vision; Colour Models; RGB Model; CMYK Model; HSV Model

ABSTRACT

Computer vision is an area that explores how machines can be rendered to obtain comprehension from visual videos or images. It is used widely in the field of food processing for quality grading and classification of food products. The acceptability of a food product by a consumer depends highly on its physical appearance. Colour, among other factors, is an important attribute that helps determine the quality of any food product. A colour model refers to an abstract mathematical model explaining how colours can be interpreted as number tuples, usually three or four values or colour components. This paper aims at reviewing the existing state of the literature on the applications of colour models in the food processing industry

1. Introduction

The quest for understanding the essence and working of colour is one that has been happening for centuries. This search has given rise to several systems, each of which has attempted to explain colour mathematically. Such a system is called a 'colour model'. A colour model is a system of mathematically expressing colours as ordered sets of numbers, typically three or four. When a 3-D coordinate system is taken to represent colours, with the amount of any three primary colours chosen on the three coordinate axes, then the range of colours which can be obtained through the various combinations of those three primaries in 3-dimensional space is called a 'colour space'. In such a coordinate system, each point in space represents one colour.

It is important to note that all scientific notions involved in colour models are based on the Human Visual System (HVS). In other words, all models will always relate to how humans perceive colour. Colour models are used to characterise colours according to characteristics such as lightness, chroma, hue, brightness, or saturation. They are also applied to match colours which is instrumental for professionals dealing with colour on any medium: print, video, or web. [1]

Types of Colour Models

There are broadly two types of colour models [2]. One is a **Physical-Technical Model**. Such a model uses three primary colours to generate other colours. There are many types of physical-technical models, and all of them vary from one another only in the three colours that are selected to be the primary colours. The RGB (Red Green Blue) and the CMYK (Cyan Magenta Yellow and Black) colour models are of this type. The other one is a **Perception – Oriented Colour Model.** Such a model employs parameters such as hue, saturation and brightness (or lightness) and is adapted to the observer's perception. The HSB (Hue-Saturation-Brightness) or HSL (Hue-Saturation-Lightness) and the LCH model come into this category.

2. Physical-Technical Models

RGB Model

The Red-Green-Blue colour model represents all colours as different combinations of red, green and blue. This is an additive colour model, which means that the three primary colours are mixed or 'added' to each other in varying proportions to obtain a new colour. In the RGB colour space, each of the three additive primaries can take on a value from 0 to 255. Therefore every possible colour that can be obtained in the colour space is represented as an RGB triplet (r,g,b), with unique r, g, and b values. When red, green and blue each have a value of 0, then the resultant colour obtained in the colour space is black. Likewise, if all three have a value of 255, then white is obtained.

The reason for using red, green and blue as the three primaries in this model stems from the theory of trichromatic vision by Young and Helmholtz. The human eye has three types of photoreceptors called cones. The ones sensitive to green and red are found in the fovea centralis (yellow spot). Of all the cones, 64% are red-sensitive, 32% senstive to green, and about 2% are blue-sensitive [3]. The “blue” cones have the highest sensitivity and are mostly found outside the yellow spot. Thus the brain interprets different colours based on the relative strength of signals received from the three different types of cones. The RGB colour model, therefore, was modelled after the way humans perceive colour. When these three primaries mix, they give rise to secondary colours, as shown in Figure 1.

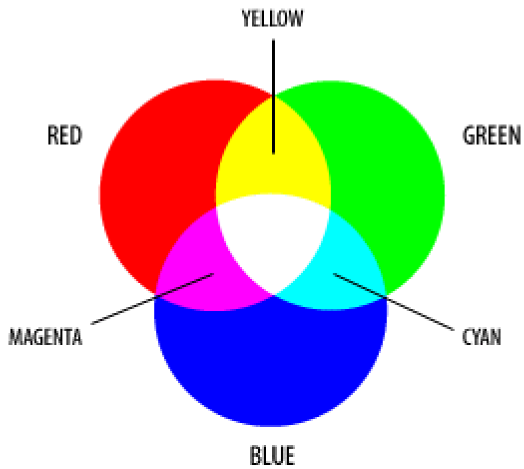


Figure 1. *Production of Secondary Colours from RGB [4]*

Colour T.V.s, video cameras, image scanners and digital cameras use the RGB colour model. Typical RGB output devices are LCD TVs, mobile phone screens, computers, video projectors, multi-colour LED displays, etc.

Advantages of the RGB Colour Model:

1. Image processing programs well support the RGB colour space. Some image formats like RAW and TIFF use the RGB colour system.
2. Graphic artists benefit significantly while working with RGB. During conversions from one colour space to another, the intensity of the colour of an image may be reduced. Some graphic artists prefer to do their colour modification work in the RGB mode before converting as it offers bright colours which aid visual artists in making accurate and precise corrections.
3. If an image is to be stored electronically, then it will be best stored in the RGB colour model. This is so as the colour intensity, saturation and brightness offered by RGB are much superior compared to that provided by CMYK. For printing, it can be converted to the CMYK model.
4. The RGB colour gamut is more significant than CMYK. [5]

Disadvantages of the RGB Colour Model:

1. RGB is a device-dependent colour model. This means that a particular RGB triplet, for example (245, 129, 100), may vary from one device to another. This is so as the colour elements (such as phosphors or dyes) employed by different manufacturers may differ in their response to the individual R, G, and B levels. Therefore, an RGB value does not represent the same colour across devices.[6]

2. RGB is not an intuitive colour model as it defines colours about the additive primaries. What this means is that for the untrained eye, it is difficult to know how to what quantities of the principals is to be mixed to produce a specific colour.

CMYK Model

In this model, the primaries are cyan, magenta and yellow. The fourth component, black, is included to improve both the density range and the available colour gamut. The "K" in CMYK stands for the key. Cyan, magenta, and yellow printing plates are consciously keyed or matched with the key of the black key plate.

Like RGB, this model too is device-dependent and is used in printers. An essential feature of this model is that it is a subtractive colour model. It means that cyan, magenta yellow, and black pigments or inks are transferred to a white surface to subtract any colour from the surface to create the final colour. Subtracting all colours by combining CMY at full saturation should theoretically render black. Impurities in CMY inks make full and equal saturation extremely difficult—consequently, some RGB light filters through not black but muddy brown colour. Therefore, the black ink is added to CMY. [7]

Advantages of the CMYK model

1. CMYK printing has a feature called halftoning. In this, the dots of each primary colour are printed in a pattern that is so small that human beings perceive a solid colour. This allows for the production of a full continuous range of colours. If this feature were not there, then CMYK printers would have been able to produce only seven solid colours, namely the three subtractive primaries (cyan, magenta, and yellow), black and red, green and blue.
2. The benefit of a black plate is that equivalent amounts of cyan, magenta and yellow can be transferred to the black plate. This reduces the likelihood of over-inking while providing greater control over the shadows and tone in an image.

Disadvantages of the CMYK model

1. Its colour gamut or range of reproducible colours is smaller than that of the RGB colour model. From the picture shown, it is evident that a problem will arise in conversion from RGB to CMYK when colours present outside the CMYK gamut but inside the RGB Gamut are used. The colours in the RGB range that are outside the CMYK gamut must be compressed or in other words mapped to space within the CMYK gamut. This always results in a loss of quality.
2. When a picture in RGB format is displayed on the monitor, It can produce bright colours that can't be duplicated in any CMYK press. The image on paper may be duller than the screen image.
3. The CMYK gamut largely depends on the printing conditions. The use of good quality inks and paper would give good results.
4. CMYK file sizes are more significant than RGB counterparts.

HSV Model

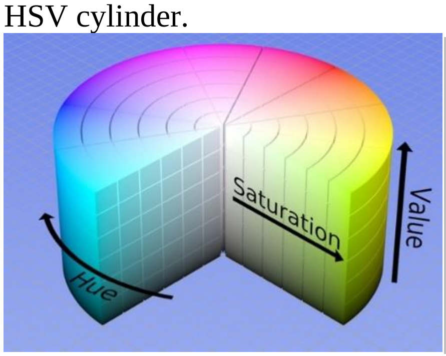
This model has three components, namely Hue, Saturation and Value. Value is sometimes replaced by 'brightness', then called HSB. It resembles the human colour perception more than the additive and the subtractive colour models.

HSL (Hue, Saturation and Lightness) and HSV are used today in colour pickers and image editing software. HSV is sometimes also called HSB, i.e. Hue, Saturation and Brightness.

The technical definitions of Hue, Saturation and Brightness are given in the CIECAM02 model as follows. CIECAM02 is the CIE's (International Commission on Illumination) latest colour appearance pattern, and the successor of CIECAM97.

1. *Hue* – It is the extent to which a stimulus can be identified as identical or distinct from stimuli described as red, green, blue, and yellow (the special hues).
2. *Intensity* – It is the total light passing via a specific region.
3. *Brightness* – It is the feature of a visual sensation that tends to generate more or less light.
4. *Lightness, value* - The "brightness compared to a similarly illuminated white".
5. *Colourfulness* - The "attribute of a visual sensation according to which the perceived colour of an area appears to be more or less chromatic". Colourfulness is the degree of difference between a colour and gray.
6. *Saturation* - The "colourfulness of a stimulus relative to its brightness".

HSL and HSV are the two most common cylindrical-coordinated point representations in an RGB colour model. Figure 2 (a) and (b) illustrate the HSV cylinder.



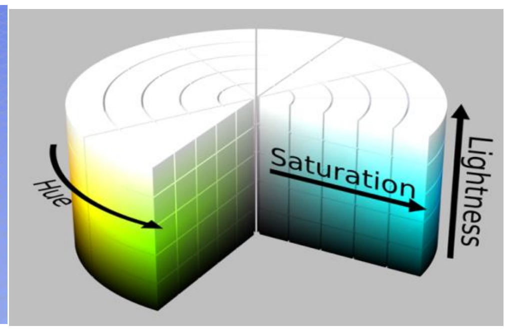


***Figure 2** (a). The HSV Cylinder [8] (b). The HSV Cylinder [9]*

The three components (Hue, Saturation and Value) are integrated into the geometry of a cylinder in the following manner:

***Table 1.** Angles around the vertical axis in hue*

Angle (°)	Colour
0-60	Red
60-120	Yellow
120-180	Green
180-240	Cyan
240-300	Blue

1. The *angle around the vertical axis* passing through the centre of the cylinder is a measure of hue.
2. The *distance of colour from the central vertical axis* corresponds to saturation. A 100% or one saturation indicates a bright, saturated colour. When the percentage falls to 0, the more colour becomes a neutral gray.
3. The difference along the central axis is brightness, value, or lightness. When the value is ‘0’, the colour space becomes blank. Any increase in the value brightens the colour space and reflects different colours.

If both Saturation and Value are 100%, then a pure colour is seen. If saturation is 0 and value is 100%, then pure white is seen. The cylindrical model had many shortcomings. For example, as the value was lowered, it became difficult to distinguish between Saturation and Hue. That was one of the reasons why the conical HSL model became more popular. Figure 4 shows the conical structure of the HSV Model. However, the accuracy of the cylindrical model is higher in theory.

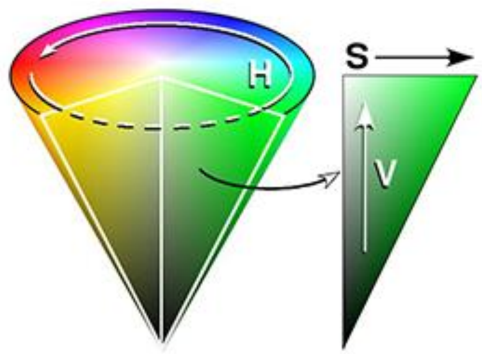


Figure 4. *The HSV Cone [11]*

Advantages of the HSV/HSL models:

1. Models like RGB and CMYK organise and define colours about the primaries. However, selecting a colour based on how the three primaries are mixed in that colour is not an intuitive process. The HSV/HSL models overcome this by organising colours in such a way that they agree with human perception and intuition of colour.

Disadvantages of the HSV/ HSL models:

2. Hue is a revolving quantity, represented numerically with 360° discontinuity. Therefore, it is challenging to use in mathematical computations or statistical comparisons: research involves circular statistics.
3. Charles Poynton, a digital video specialist, believes that HSB and HLS were developed to define numerical Saturation, Hue and Brightness in an era where users had to determine colours numerically. HSB and HLS’ standard formulations are flawed with colour vision properties. Now that consumers can select colours visually, or select colours linked to other platforms (such as PANTONE), or use perceptual-based programs such as HSB, LAB, and HLS will be discontinued.

CIE L*a*b*, HUNTER L*a*b* and L*u*v*

CIE 1931 XYZ is among the first mathematically described colour spaces. The Commission Internationale de l'éclairage (CIE) produced this in 1931.

Also called CIELAB colour model, CIE L*a*b is one of the colour spaces derived from CIE XYZ space in 1976. The L*a*b * colour model determines colour in 3D colour space based on its location. It defined all observable colours to the human eye and was designed to act as a device-independent guide.

It is based on the Opponent – Colours Theory according to which, the cones in the human retina perceive colours like variations of the following pair of opposites:

1. Light and Dark shades of colour
2. Red and Green
3. Yellow and Blue.

Hunter L*a*b* is also a colour model like the CIE L*a*b* and has similar parameters. The two are, however, calculated differently. The formulas for the Hunter system are square roots using the CIE XYZ where the CIE L*a*b is calculated using cube roots of the XYZ. [10]

The parameters used in the Hunter and the CIE L*a*b* models are as follows:

1. The lightness of colour represented as L*. An L* value of 0 yields black whereas an L* value of 100 indicates diffuse white.
2. Chroma/ position of a colour between red/magenta and green represented as a*. Negative a* values indicate green while positive values indicate magenta.
3. Position of a colour between yellow and blue, shown as b*. Negative values indicate blue and positive values indicate yellow.

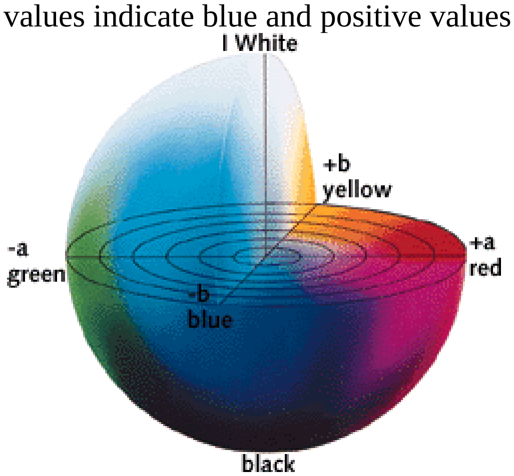


Figure 5. *The CIE L*a*b* Model [10]*

Likewise, the CIE L*u*v* is an easy-to-compute transformation of the 1931 CIE XYZ colour space, but attempting perceptual uniformity. It is used in applications such as coloured lights in computer graphics.

Advantages of the CIE L*a*b* and Hunter L*a*b* models:

1. It is device-independent. Therefore there will not be any discrepancies in LAB models on different devices, unlike the CMYK system and the RGB systems.
2. The Luminosity/lightness component resonates closely with human perception of lightness. It can be used to adjust the color balance appropriately.
3. The CIELAB colour gamut is much larger than those of the RGB and the CMYK models and includes the gamuts of the latter two models as well.

4. This model's colour gamut is so broad that it includes colours which cannot be perceived by the human eye. In other words, it includes imaginary colours as well. However, colour management software, such as built-in image processing programs, would pick the closest colour present in the spectrum of colours visible to humans by adjusting chroma, lightness, and occasionally hue.

Disadvantages of the CIE L*a*b* and Hunter L*a*b* models:

1. They are not entirely uniform by perception. Perceptual colour uniformity in space means one unit difference between two colours appears to be visually different by the same amount whether the colour is blue, purple, orange or red. Although the CIELAB scale was supposed to be perceptually standardised, in the yellow area, it is slightly over-expanded. Hunter L, a, b scale contracts in the colour space yellow region and extends in the blue region.

3. Applications of Colour Models in the Food Processing Industry

Computer vision is an area that involves methods to collect, store, interpret and comprehend real-world images and high-dimensional data to generate numerical or symbolic information [12]. Computer vision and Machine learning has been used in assessing relationships such as body mass index, age, tobacco smoking, alcohol intake, and diastolic/systolic blood pressure [13].

An essential application of computer vision is computers or robots that can perceive the world around them. Machine Vision (MV) is closely related to computer vision. Machine Vision (MV) is the technology used to provide image-based automated inspection and interpretation for applications like process control and industrial robot guidance [13=14]. Computer vision is associated with machine vision which execute several operations, including image acquisition, visualization and analysis [15].

Machine vision includes gathering knowledge to assist a production operation. It is widely used in quality control, where finished products are automatically inspected for inadequacies. A particular subject of this paper is the use of MV in the agri-food processing industry. Rapid development and cut-throat rivalry within business organizations demand greater competitiveness and performance [16]. Colour, among many other factors, is an important attribute that determines the quality of any food product. The acceptability of a food product by the consumer depends highly on its physical appearance. In the case of fruits and vegetables, colour is indicative of the stage of ripening, nutritive value and flavour. Prior to release into the market, fruits and vegetables have to be inspected. Human visual inspection is tedious, highly subjective, time-consuming and may not be thorough. This is where MV comes into play. Since the quality of a fruit or a vegetable is dependent on its appearance, it is vital to choose an appropriate colour model to detect changes in the products' colour post-harvest. Modern performance metrics are not newly developed; however, their cost-based performance measurement systems need to be replaced by those that truly drive the production process, as performance measures can also dictate behaviour [17]. [18] developed a cost-effective computer vision system to estimate the kernel size of different grades of Cashew.

The colour models frequently used in MV are the CIE L*a*b* and Hunter models. This is so as the two are device-independent models that provide consistent colour regardless of a change in input or output devices.

In this section, the applications of colour models in the food processing industry will be discussed with regards to different fruits, vegetables and other food products. Rational architecture and scalable solutions allow an embedded framework with numerous features and wider implementations [19]. In an attempt to quantify the standard colour of food products (like fruits and vegetables), a computer vision system (CVS) was implemented using colour models like RGB, HSV and L*a*b*. Based on their suitability for colour quantification in curved surfaces, the three colour spaces were compared. Results showed that the sRGB standard (linear signals) was effective in defining the mapping between the CCD camera's R'G'B' (no-linear signals) and a device-independent system such as CIE XYZ. CVS displayed modifications in the orientation of the sample, resolution, and zoom. CIE L*a*b* scheme was proposed as the best colour space to measure foods with curved surfaces. [20]

Mango

In the paper '*Colour vision system evaluation of bicolour fruit: A case study with 'B74' mango*' by S. P. Kang, A. R. East, and F. J. Trujillo, the authors explore the validity and use of a digital colour evaluation system to obtain hue angle and chroma values in the CIE LAB a*b* plane of a heterogeneously coloured fruit. The ripening of mangoes during the post-harvest period can be seen as a change in the background colour from green to yellow. In the CIE L*a*b* model, this is described as a change in hue angle. Captured images and histograms of the colour change showed that at the beginning of storage, the hue angle ranged from 95° to 120° (shades of green) and at the end of ripening the hue angle values ranged from 60° to 95° range (orange to yellow). This showed how colour model parameters could provide valuable information on colour changes in fruit. [21]

Apples

One of the major problems faced by apple sorting systems is separating an apple's stem-end/calyx from a true defect. In a single-camera NIR (near-infrared) approach, one of the general errors is that an apple's stem-end/calyx is usually confused with true faults. Consequently, incorrect sorting occurs. Cheng et al. developed a dual Near-Infrared (NIR) and mid-infrared (MIR) camera to solve this obstacle. The MIR camera is capable of recognising only the fruit's stem-end/calyx parts. In contrast, the NIR camera can identify not only the stem-end and calyx portions but also the apple's true defects. A dual-camera captured images were processed and analysed using an algorithm. A 100% recognition rate for good apples and a 92% recognition rate for defective apples was observed using this method. [22]

In another scenario, the 'non-enzymatic' browining phenomenon was studied in Golden Delicious and Amasya type of apple juice concentrates. They were at 65, 70, 75°Bx of Golden Delicious variety, stored at 5, 20, 37°C and Amasya series, stored at 37, 50, 65°C. CIE-L*a*b* and browning index (A420) were used to measure and compare colour development. Browning of all apple juice concentrate increased by a kinetic zero-order reaction kinetic. [23]

Barberries

Machine vision is used to identify foreign materials in barberries. Barberries are red fruits of shrubs grown in the low-water, salty fields of Iran. The quality of barberries is dependent on the percentage of foreign visual materials like peduncles, leaves and blight products present in them. These foreign materials vary from the barberries in shape and colour and separating them from the primary produce manually is a tedious and time-consuming task. Alireza Pourreza, Hamidreza Pourreza, Mohammad Hossein-Aghkhani created a new approach to detect these foreign visual materials automatically. A segmentation algorithm was developed for images of barberries in which the colour red was removed. In this method, the YCbCr colour space was used. Then YCbCr colour spaces' Cr plane was utilised to detect the mage target area. The barberry's bright cortex shine culminated in several pixels having a similar colour as the target portions in the Cr plane. A simple equation using binary image statistical parameters was used to find the compatible thresholds to detect target regions in each image. This algorithm allowed acceptably identifying foreign materials compared to manually segmented images. This method is very effective when the image contains many unwanted, partially large regions with the same colour as target areas. This method has a dual benefit. It improves the accuracy of visual foreign material detection and reduces the labour cost involved in the manual discovery of foreign material. [24]

In a study done in 2010, image processing algorithms were used to determine the apparent quality of barberries. Using an 8-megapixel camera in the RGB mode, images of high-quality barberries were taken. After a careful study of different colour models like CMY, HSB and RGB, it was found that the component 'M' (Magenta) of the colour mode CMY was very efficient in differentiating the colour features of high-quality barberries from that of low-quality or unripe barberries. The impurities like barberry spine, leaves, grits and unripe barberries had different colour limits from the main product and could, therefore, be distinguished. [25]

Dates

A study in 2009 was done to increase the speed of the process of inspecting date fruits and simultaneously maintain consistency and uniformity. A prototype of a computer-based date-grading and sorting system was developed. A set of external quality attributes was established as benchmarks. This mechanism had two subsystems: computer vision and fruit handling mechanism. The part of fruit handling had an electromechanical fruit handler that can position a fruit on a conveyor belt to take the fruit through an image processing system and finally to the sorting bins. The computer vision program had an image processing module and a pattern recognition module. The image processing system used a RGB colour space to capture date-fruit images. This was then transmitted to the processor, which extracted dates' external quality characteristics and presented them to the pattern identifier. The recogniser was the part that compares dates' external quality features to set standards. It categorised the underlying fruit into pre-specified quality categories and directed the sorter to the appropriate bin. Test results showed the mechanism could correctly sort 80 per cent of the dates. [26]

Research by Moustafa A. Fadel, Kurmestegy L, Rashed M, and Rashed Z, allows for the categorisation of Lolo, Khalas, Berhi, Fard, and Bomaan types of dates found in UAE. Images of various varieties were captured using a digital camera and fragmented into Red, Green and Blue (R, G, B). Image processing software was used to measure the image colour distribution frequency of pixels. The comparison of the varieties was done based on the calculated mean values. The results revealed that all three RGB components and colour luminosity could differentiate Lolo and Bomaan. However, only the blue component should be used to distinguish between Berhi and Bomaan and Berhi and Khalas. A chromatography was utilised to assess each variety's fructose, glucose, and sucrose content. A prediction equation of sugar content based on colour intensity was established for each date variety. [27]

Grape Fruit

A study by Dae Gwan Kim, Thomas F. Burks, Jianwei Qin and Duke M. Bulanon intended to explore the potential of using colour texture features to detect citrus peel diseases. A colour imaging system was developed to obtain grapefruit RGB images. Six different conditions — one normal and five diseased peel conditions (i.e. cancer, copper burning, greasy spot, melanose, and wind scar), were considered. A total of 39 image texture characteristics from transformed hue (H), saturation (S), and intensity (I) region-of-interest images were calculated using the colour co-occurrence method for each fruit sample. Algorithms for selecting useful texture characteristics were developed based on a gradually discriminating analysis, selecting 14, 9, and 11 texture characteristics for three colour combinations of HSI, HS, and I, respectively. Classification models were developed using reduced texture characteristic sets through a discriminant function based on generalised square distance measurement.

The result suggested using a reduced hue, saturation, and texture intensity feature set to distinguish between citrus peel diseases would be better. The model is reliable, due to its high classification precision, to identify new fruit samples according to their peel conditions. [28]

Banana

F. Mendoza et al. introduced a computer vision program to predict banana ripening. Mean value and variance of each image's histogram intensity were extracted and analysed using colour spaces RGB, HSV, and CIE L*a*b *. The output of colour space in classification was compared using discriminant analysis as selection criteria : (1) using colour information obtained from the entire image of bananas; (2) colour data from the background of spot-free bananas; and (3) combining colour information retrieved separately from the background free of spots and brown spots of bananas. Results show that the three analysed sets were able to correctly predict banana ripening stages as qualified visual perception with more than 94%. [29]

Persimmon

Persimmon is an edible fruit of several species of trees in the genus Diospyros. A problem which is faced in the processing and the sale of this fruit is that a large quantity of persimmon is rejected for fresh consumption. One of the methods which are extensively used for their preservation is the addition of sulphites. However, these compounds have adverse effects on asthmatic persons. As a result, their application is limited. One of the alternatives to prevent the large wastage of this fruit could be drying. Citric acid, combined with sufficient storage temperature may be an effective alternative. J.A. Cárcel, J.V. García-Pérez, N. Sanjuán and A. Mulet performed a 409-day dried persimmon slice experiment that was processed at four temperatures (2, 10, 18 and 28°C). Until drying, one sample group was pre-treated for 15 minutes in a potassium meta-bisulphite solution (3% w/w). The other two groups were pre-treated in a citric acid solution (3% w/w) for 15 and 35 minutes respectively, and the last group (control) was untreated. During storage, the CIE-Lab coordinates were calculated, and colour shift, ΔE, was estimated. Pre-treatment with citric acid turned out to be an interesting alternative to SO_2 as its effect was more effective at temperatures below 18°C. There were no significant variations between the two citric acid pre-treatments. [30]

Tomatoes

New Zealand's antioxidant content, operation, and colour of two commercially produced tomatoes (Lycopersicon esculentum L. var. Excell and Aranca) were examined. Excell tomatoes were harvested and individually stored, while Aranca variety was stored in groups of eight. Both tomato cultivars were stored at 15 ° C in the dark for four days, simulating typical pre-purchase storage conditions. The CIE LAB colour model was used after two days to record colour values of 2 varieties cut surfaces. Although the colours were identical, raw tomatoes' antioxidant content after four days of storage differed. In a subsequent experiment, the two tomato cultivars were sliced and soaked separately in a mixture of olive oil and white vinegar for 20 minutes. Two cultivars' CIE colour values showed no difference after processing. However, separate cultivar oil and vinegar treatments together reduced the red colour component. This was expressed as CIE colour values. [31]

Bell Pepper

Colour models in machine vision can also determine the moisture content of vegetables and fruits. G. Romano, D. Argyropoulos, M. Nagle, M. T. Khan and J. Müller investigated how digital images and laser light could predict the moisture content of bell pepper while drying. Hot-air convective drying is widely used for the preparation of spices. A matter of prime importance in the food processing industry is the continuous monitoring of the moisture content during the drying process to prevent over-drying and reduce losses. The imaging technology was used to obtain the colour of pixels in RGB, and these values were converted to the CIELAB model. At drying temperatures of 60°C and 80°C, the yellow pepper samples showed high L* (Lightness of colour) values when compared to the red and green pepper samples. However, as the drying process continued, all three showed low L* values. As the drying process became more severe, the samples lost more moisture, thereby becoming darker. Resultantly the L* values of the samples became low. The values of the green and yellow bell pepper samples increased during the drying from 60°C to 80°C. This implied that the colours moved towards the red end and away from the green end of the scale. This was explained by Rocha et al. (1993) as a breakdown of green coloured chlorophyll to brown coloured pheophyhn. The red samples showed a slight decrease in* values after 6 hours of drying due to heat degradation of carotenoids. The b* values remained stable for the green samples throughout drying. In contrast, the yellow samples showed a gradual increase in b* values and the red sample showed an initial increase, followed by a decrease in b* values. The colour of peppers thus tended towards the yellow end of the blue-yellow scale on drying. Therefore the CIELAB was used to monitor the dying process of bell peppers. [32]

Brocolli and Green beans

Many types of heat treatment applied to vegetables, including blanching. As a result, the green colour of vegetables differs considerably. Green beans from two nations, growing seasons and broccoli stems and florets were heat-treated from 40 to 96°C. Using the CIE-Lab model, all colour changes in specimens were tracked. Expressing the green colour in the L*a*b* colour model proved to reduce the observed variance in measuring samples substantially. Two consecutive reactions were modelled by a simplified kinetic mechanism: one that enhances colour, one that degrades colour. Second, non-linear regression was used to analyse all the data sets. The percentage variance obtained (R^2_{adj}) ranged from 75.7% to 90.8%. Allowing different initial conditions but similar kinetic parameters, data of the same vegetable type (green beans and broccoli separately) could be pooled and analysed together (R^2_{adj}=87.4% and 77.2% respectively). The kinetic parameters acquired were so identical that even green beans and broccoli together could be evaluated wholly pooled and generic. This experiment's results helped validate the process of visible colour formation and degradation in vegetables. The two methods are related to pigments in vegetables (such as chlorophyll and chlorophilides) and regardless of the vegetables under analysis. [33]

Eggs

A 2010 research was to develop an algorithm focused on image processing to detect internal blood spots and the extent of eggshell dirt by analysing photographs of eggs acquired under various illuminations. M. H. Dehrouyeh, M. Omid, Ahmadi, S. S. Mohtasebi and M. Jamzad developed an algorithm in HSI colour space to extract useful information from machine-captured egg images. The hue histogram was used to identify bloodstains, and maximum values of two ends of histogram were chosen as defect detection criteria. Eggshell dirt was detected using a connected area detection approach. Experimental tests showed that the blood spot distinction algorithm was 90.66 per cent accurate in defected eggs and 91.33 per cent accurate in intact eggs.

The dirt detection algorithm was 86% correct in fresh eggs, 83% accurate in low dirt eggs, and 88% accurate in high dirt eggs. [34]

Two critical parameters which determine the freshness of egg are yolk index and air room height. Qiaohua Wang, Xiaoyan Deng, YiLin Ren, Youchun Ding, Lirong Xiong, ZhouPing,

Youxian Wen and Shucai Wang investigated an image-based egg freshness detection method. The first step in this involved capturing the image of the egg using computer vision. Next, the air room region and the yolk region were separated from the captured image by image processing. The calculations performed on the processed image involved computing pixel areas and lengths of the yolk region and air room regions. The relative ratios of the pixel length and area of characteristic parts (yolk and air room regions) to that of the whole egg region were selected as characteristic parameters. A detailed analysis of the parameters showed that egg freshness reduced as the relative ratios increased. [35]

Potato Chips

Franco Pedreschi et al., reviewed the colour production in pre-dried sliced potatoes while frying and acrylamide formation in final potato chips. A cheap computer vision technique was used to capture chip RGB images and convert RGB values into L*a*b * units. Before frying, the potato slices were blanched for 3.5 minutes in hot water at 85 °C, considering unblanched slices as control. The blanched slices were then air-dried until 60% of moisture was obtained. The air-dried potato slices were fried at 120 °C, 140 °C, 160 °C and 180 °C until the moisture content was 1.8%. The concentration of Acrylamide was measured only in final fried chips at 120 °C, 150 °C and 180 °C and compared to that of two Chilean brands of commercial chips (Moms and Frito Lay). During frying at the four specified temperatures, colour values were reported in L*a*b * units using the total colour difference parameter (D.E.). It was observed that pre-drying did not significantly affect the colour of potato chips relative to blanched chips; however, when fried at 180 °C, pre-dried potato chips provide 44%, 22%, 44% lower acrylamide content than control chips, Moms and Frito Lay, respectively. [36]

Pizzas

Cheng-Jin Du and Da-Wen Sun developed a framework that automatically categorises pizza sauce spread using support vector machine (SVM) and colour vision. A sequence of image processing algorithms was developed to represent pizza sauce spread with low-dimensional colour. The transformation from red, green, and blue (RGB) to hue, saturation, and value (HSV) colour space was accompanied by background image segmentation. A vector quantifier was then designed to quantify the H.S. (hue and saturation) space to 256-dimension, and colour histogram represented the quantified colour characteristics of pizza sauce spread. Finally, principal component analysis (PCA) was used to reduce 256-dimensional vectors to 30-dimensional vectors. With the 30-dimensional vectors as data, SVM classifiers were used to classify pizza sauce spread. The polynomial SVM classifiers were found to result in best classification accuracy with 96.67 per cent on the research experiments. [37]

4. Conclusion

This paper provides detailed exploration of the existing state of the literature on the applications of colour models in the food processing industry. An attempt has been made to show how different Colour Models are suited for various purposes in Computer Vision. The discussion in the paper has shown how their readings help in understanding the quality of a food product. It also aids in the classification of food products based on quality standards. Comparisons between different classification techniques and their accuracy levels help in determining the most suitable method for use. For a particular purpose, selection of the appropriate colour model will help in describing a change most efficiently, effectively, and in the most humanely intuitive manner as possible.

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